

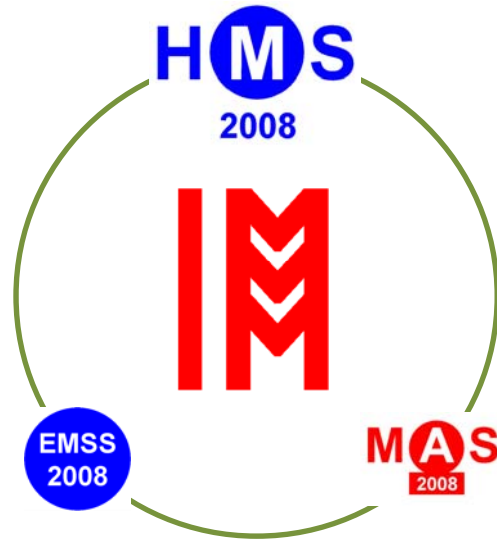
# 11<sup>TH</sup> INTERNATIONAL WORKSHOP ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELING & SIMULATION

CALABRIA



SEPTEMBER 17 - 19 2008  
CAMPORA S. GIOVANNI  
ITALY

## INTERNATIONAL MEDITERRANEAN AND LATIN AMERICAN MODELING MULTICONFERENCE



**MECHANICAL DEPARTMENT UNIVERSITY OF CALABRIA**



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# THE 11<sup>TH</sup> INTERNATIONAL WORKSHOP ON HARBOR MARITIME MULTIMODAL LOGISTICS MODELING & SIMULATION

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CAMPORA S. GIOVANNI (AMANTEA), ITALY

SEPTEMBER 17-19, 2008

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### *WELCOME TO HMS 2008*



The International Workshop on Harbor, Maritime & Multimodal Logistics Modeling and Simulation (HMS) continues a long tradition as the premier event in the field, anticipated in preliminary edition 1996 (Genoa) and 1998 (Riga) and officially established since fall 1999. So HMS2008 reaches this year its 10<sup>th</sup> Edition as confirmation of the value of this thematic workshop

concentrated in very specific, but very high quality contribution on a sharp subject.

It is evident that HMS Workshop plays a critical role in bringing researchers, teachers, vendors, and practitioners from worldwide together to discuss of the most advanced initiatives on Maritime, Harbor and Logistics Simulation arising in the world.

HMS2008 has a very high-quality program and represents one of the most successful editions in term of contributions; the event is organized into sessions spotlighting simulation applications in logistics and maritime modeling.

We are very grateful for all the efforts provided by many people from Authors to International Program Committee Members and Program Organizers; HMS requires contributions from many dedicated volunteers whose efforts during almost one year of planning and preparation are fundamental.

Each member of the HMS organization has done an exemplary job in organizing, publicizing, and running a successful conference.

The wonderful location of HMS2008 in South Italy provides further opportunities for attendees: Calabria area, is one of the reasons of 2008 edition success not only for the splendid framework of the South Italian Coast but also for the great efforts provided by Local Organizers.

Calabria stands in a splendid position facing the Straits of Messina and it is located in the centre of the Mediterranean: its origins are very antique (the early Italic civilization, the Magna Graecia, etc), it is for this reason that Calabria is a unique land, a region of ancient history in which Mediterranean and European civilizations are so deeply rooted.

Based on such consideration, as the essence of the conference being to facilitate dialogue, we hope that by gathering together a geographically and academically diverse group of researchers, all of whom are interested in specific topics, the process of knowledge transfer from to country can be facilitated and enhanced.

We thank all the attendees for their participation. We hope you enjoy a productive and rewarding HMS2008 Workshop and invite you to stay actively involved with HMS and I3M in the future.

Next year the event will be held in Tenerife, Canary Island, and we look forward to an even large event. However, we are glad to welcome you in HMS2008 within the wonderful framework of South Italy.

**AGOSTINO G. BRUZZONE**, MISS-DIPTM, UNIVERSITY OF GENOA

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## ACKNOWLEDGEMENTS

The HMS 2008 International Program Committee selected the papers for the Conference among many submissions and we expected a very successful event based on their efforts; so we would like to thank all the authors as well as the IPCs and reviewers for their review process.

A special thank to the organizations, institutions and societies that are supporting and technically sponsoring the event: Mechanical Department of University of Calabria, Modeling & Simulation Center - Laboratory of Enterprise Solutions (MSC-LES), DIPTEM - University of Genoa, Liophant Simulation, Autonomous University of Barcelona, McLeod Institute of Simulation Science (MISS), McLeod Modeling & Simulation Network (M&SNet), Institute of Electrical and Electronics Engineers (IEEE), Society for Computer Simulation International (SCS), International Mediterranean & Latin American Council of Simulation (IMCS), the Management and Advanced Solutions and Technologies (MAST), the Tonno Callipo, the Liquirizia Amarelli, the Giulio Barca Prodotti in Pelle. Finally, we would like to thank all the Workshop Organization Supporters.

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## Index

### Logistics and Manufacturing

SIMULATION-BASED ANALYSIS OF A CONCRETE ARMOUR UNITS MANUFACTURING PLANT FOR THE CONSTRUCTION OF A RUBBLE MOUND BREAKWATER, <i>David del Rio Vilas, Diego Crespo Pereira, Adolfo Lamas Rodriguez, Alejandro Garcia del Valle</i>	1
IDENTITY-BASED, ITEM-CENTRIC TRACKING PLATFORM FOR LOGISTICS APPLICATIONS, <i>Elisabeth Ilie-Zudor, Marcell Szatmári, Zsolt Kemény, Dávid Karnok, László Monostori</i>	10
BUSINESS SIMULATION GAME FOR TEACHING MULTI-ECHELON SUPPLY CHAIN MANAGEMENT, <i>Yuri Merkurjev, Jonas Hatem, Galina Merkurjeva, Jana Bikovska</i>	20
EXPERIENCES FROM THE APPLICATION OF HLA-BASED DISTRIBUTED SIMULATIONS IN THE PRODUCTION OF VEHICLES, <i>Michael Raab, Thomas Schulze, Steffen Straßburger</i>	29
MOST AND MTM FOR WORK METHODS OPTIMIZATION: A REAL CASE STUDY BASED ON MODELING & SIMULATION, <i>Antonio Cimino, Francesco Longo, Giovanni Mirabelli, Enrico Papoff</i>	35
SUPPLY CHAIN DESIGN: A CASE STUDY ON THE ADDITION OF NEW POTENTIAL CUSTOMERS, <i>Duilio Curcio, Francesco Longo, Giovanni Mirabelli, Enrico Papoff</i>	42
TOTAL PROCESS SIMULATION IN SHIPBUILDING: SIMULATION AIDED HULL ASSEMBLY PLANNING, <i>Jeroen Kaarsemaker, Ubald Nienhuis</i>	49
ALTERNATIVE LINE DELIVERY STRATEGIES SUPPORT A FORKLIFT FREE TRANSITION IN A HIGH PRODUCT VARIETY ENVIRONMENT, <i>Johannes Cottyn, Tim Govaert, Hendrik Van Landeghem</i>	55
WAREHOUSE LOGISTICS REVISITED: A CRITICAL ANALYSIS, <i>Istvan Molnar, Gyorgy Lipovszki</i>	61

### Automation Effects and Advanced Container Handling Technologies at Seaport Container Terminals

OPTIMISING ADVANCED CONTAINER HANDLING TECHNOLOGIES VIA DISTRIBUTED SIMULATION/EMULATION, <i>Horst-Dieter Kassl, Tobias Puchert, Holger Schütt</i>	67
LAYOUT OPTIMIZATION OF CONTAINER TERMINALS USING MATHEMATICAL PROGRAMMING AND SIMULATION, <i>Jörg Wiese, Natalia Kliewer, Leena Suhl</i>	72
DEGREE OF COOPERATIVENESS OF TERMINALS AND THE EFFECT ON THE BARGE HANDLING PROCESS, <i>A.M. Douma, P.C. Schuur, R.G.M. Jagerman</i>	81
THE CORRIDOR METHOD - A GENERAL SOLUTION CONCEPT WITH APPLICATION TO THE BLOCKS RELOCATION PROBLEM, <i>Marco Caserta, Stefan Voß, Moshe Sniedovich</i>	89
DECISIVE INCREASE OF CAPACITY AND THROUGHPUT BY USING ADVANCED PLANNING AND REAL-TIME OPTIMIZATION ALGORITHMS, <i>Udo Niessen, Eva Savelsberg, Ulrich Dorndorf</i>	94

# Modeling and Simulation in Logistics, Traffic and Transportation

ROUTING AND SCHEDULING OF PARCEL TANKERS: A NOVEL SOLUTION APPROACH, <i>Hong Choon Oh, Iftekhar A. Karimi</i>	98
MARITIME CHEMICAL LOGISTICS: IMPORTANCE OF OPTIMIZATION MODELING AND RESEARCH OPPORTUNITIES, <i>Hong Choon Oh, Iftekhar A. Karimi</i>	104
FRAMEWORK FOR SIMULATING LNG PORTS, <i>Piero Silva, Adrien Leleu, Edwin Valentin</i>	110
CAPACITY PLANNING ANALYSIS FOR SERVICE STEEL PRODUCTS HARBOUR, <i>Cristiana Gonçalves Borges, José Almeida Simões, Luiz Augusto Franzese, Daniel Pablo Paz</i>	118
LOGISTICS AND TRANSPORTATION WITHIN THE RETAIL SECTOR: SENSITIVITY ANALYSIS ON THE DISTRIBUTION SYSTEMS, <i>Antonio Cimino, Duilio Curcio, Francesco Longo, Giovanni Mirabelli</i>	123
EVALUATION OF OPERATION COST IN LINER SHIPPING: A DISCRETE-EVENT SIMULATION APPROACH, <i>Aldo McLean, William Biles</i>	129
MULTI-SCENARIO POLICIES FOR MARITIME REPOSITIONING PROBLEMS UNDER DATA SHORTAGE, <i>Theodor Gabriel Crainic, Massimo Di Francesco, Paola Zuddas</i>	134
AN OBJECT-ORIENTED PROGRAMMING APPROACH FOR A GIS DATA-DRIVEN SIMULATION MODEL OF TRAFFIC ON THE PANAMA CANAL, <i>Daniel Sasso, William Biles</i>	139
SCATTER SEARCH OPTIMIZATION OF AN INLAND WATERWAY TRANSPORTATION SYSTEM, <i>Nicholas Anderson, Gerald Evans</i>	146
REENGINEERING PORT PROCESSES THROUGH SIMULATION SUPPORT, <i>Francesco Ciliberti, Giuseppe Sciannameo, Barbara Scozzi</i>	150
COGNITIVE MIMO SONAR BASED ROBUST TARGET DETECTION FOR HARBOUR AND MARITIME SURVEILLANCE APPLICATIONS, <i>Albert Ortiz, Wenhua Li, Genshe Chen, Xiaokun Li, Mo Wei, Li Bai</i>	160
MARINE TRAFFIC: DESIGNING A COLLABORATIVE INTERACTIVE VESSEL TRAFFIC INFORMATION SYSTEM, <i>Dimitrios Lekkas, Spyros Vosinakis, Charalambos Alifieris, John Darzentas</i>	167
INTELLIGENTS AGENTS IN LOGISTICS: SOME TRENDS AND SOLUTIONS, <i>Janis Grundspenkis</i>	174

## Intermodal Terminals Optimization and Simulation

SEQUENTIAL ORDERING PROBLEMS FOR CRANE SCHEDULING IN PORT TERMINALS, <i>Roberto Montemanni, Andrea Rizzoli, Derek Smith, Luca Maria Gambardella</i>	180
INTEGRATED DESIGN PROCESS OF MARITIME TERMINALS ASSISTED BY SIMULATION MODELS, <i>Cristiano Marinacci, Andrea Quattrini, Stefano Ricci</i>	190
ADVANCED HANDLING OF STEEL PRODUCTS IN SEAPORTS USING MAGNET SYSTEMS, <i>Bernd Scholz-Reiter, Uwe Hinrichs, Jan Topi Tervo</i>	202
THE SHIP STOWAGE PLANNING PROBLEM, <i>M. Flavia Monaco, Marcello Sammarra</i>	208

ASSIGNMENT AND DEPLOYMENT OF QUAY CRANES AT A MARITIME CONTAINER TERMINAL,  
*Pasquale Legato, Daniel Gulli, Roberto Trunfio* 214

## Logistics Modeling and Simulation

RFID FOR AUTOMATING ACCOUNTING PROCESSES IN LOG CABIN CONSTRUCTION, *Valdis  
Porniaks, Egils Ginters, Gunars Grundstoks* 221

INVESTIGATION OF ACCIDENT AND NOISE INTENSITY ON LATVIAN ROADS USING SCAN  
STATISTICS, *Vladimirs Jansons, Vitalijs Jurenoks, Konstantins Didenko* 225

NONLINEAR MODELS FOR CRUDE OIL SCHEDULING ON PORTS, *Fabio Fagundez, João Lauro  
Facó, Adilson Xavier* 230

A QUANTITATIVE FRAMEWORK TO ASSESS CAPABILITY TRADEOFFS OF THE  
TRANSFORMABLE-CRAFT WITHIN THE SEABASING CONCEPT, *Stefanos Koullias, Janel Nixon,  
Dimitri Mavris* 236

## Multimodal transports: Hinterland Terminals

CONROCAPS- MODELLING INTERMODAL TERMINALS TO CALCULATE THEIR CAPACITY,  
*Susanne Ficke, Holger Schütt* 246

A RISK ASSESSMENT APPROACH FOR INLAND CONTAINER TERMINALS,  
*Manfred Gronalt, Hans Häuslmayer, Werner Jammerneegg, Edith Schindlbacher, Monika Weishäupl* 251

SHIP-TO-SHORE GANTRY CRANE SIMULATOR DESIGN: CRANE OPERATOR PERFORMANCE  
ANALYSIS AND ASSESSMENT TOOL OF CAGLIARI UNIVERSITY, *Agostino Bruzzone, Paolo  
Fadda, Gianfranco Fancello, Enrico Bocca, Giammarco D'Errico, Alberto Tremori* 257

ASSESSING PERFORMANCE INDICATORS FOR INLAND TERMINALS, *Manfred Gronalt, Martin  
Posset, Thouraya Benna* 268

## Container Terminals

LOAD CARRIER MANAGEMENT ON RO-RO TERMINALS, *Bernd Scholz-Reiter, Felix Böse,  
Michael Teucke, Anne Virnich* 274

CONTRIBUTION TO A FULLY AUTOMATIC CONTAINER TERMINAL AS PART OF THE  
LOGISTICS FACTORY OF THE FUTURE, *Wolfgang Echelmeyer, Alice Kirchheim* 280

OPTIMIZING YARD ASSIGNMENT AT AN AUTOMOTIVE TRANSSHIPMENT TERMINAL,  
*Luigi Moccia, Gregorio Sorrentino* 284

A DECISION SUPPORT SYSTEM FOR PLANNING MAINTENANCE PROCESSES IN A  
TRANSHIPMENT CONTAINER TERMINAL, *Gianfranco Fancello, Marco Naseddu, Andrea Ferrari,  
Paolo Fadda* 288

HUMAN RESOURCES DAILY ALLOCATION IN A TRANSHIPMENT CONTAINER TERMINAL, *Paolo  
Fadda, Gianfranco Fancello, Marco Pisano, Paola Zuddas* 296

**Author's Index** 301

# SIMULATION-BASED ANALYSIS OF A CONCRETE ARMOUR UNITS MANUFACTURING PLANT FOR THE CONSTRUCTION OF A RUBBLE MOUND BREAKWATER

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## ABSTRACT

New port facilities at Punta Langosteira, on the north-west coast of Spain, involve the construction of a large rubble mound breakwater that requires thousands of concrete armour units that will have to be supplied as the construction project progresses. For that reason, a provisory plant has been built in situ where the concrete blocks are cast, transported and stacked. Due to the implementation of a DGPS system, the blocks life cycle can be traced and an assessment of strategies for minimizing the number of blocks moves became plausible. In this paper, we describe the operational analysis for the determination of a comprehensive and simple set of rules which may result in a cost-effective operation of the concrete blocks plant whilst meeting the procedural constraints. To do so, a simulation-based approach was adopted both using the commercial tool Delmia QUEST and developing our own ad hoc Java simulator.

Keywords: simulation, optimization, supply chain modelling, manufacturing, stacking yard

## 1. INTRODUCTION

The project of the New Port Facilities in Punta Langosteira on the northwest coast of Spain is one of the most important building projects under construction in Europe, not only due to its size and complexity but also to its impact on the whole economy of the region. It has an initial budget of more than €429 million partly financed by EU Cohesion funds and by the European Investment Bank. A Joint Venture made up of the Spanish companies Dragados, Sato, Copasa and DRACE was chosen to accomplish this work, which started in April 2005 and is expected to finish by September 2011, although the outer main breakwater will have to be finished by the end of 2009. When finished, the main breakwater will have a total length of 3.4 km and a maximum height of 65m. (Autoridad Portuaria A Coruna 2008).

Prosermar Ingeniería S.L. is the firm that has supplied the DGPS system for tracing the concrete blocks' life cycle and responsible for determining a set of operational policies that may lead to an enhanced plant operation. It is in the framework of this job that the work reported here has been carried out.

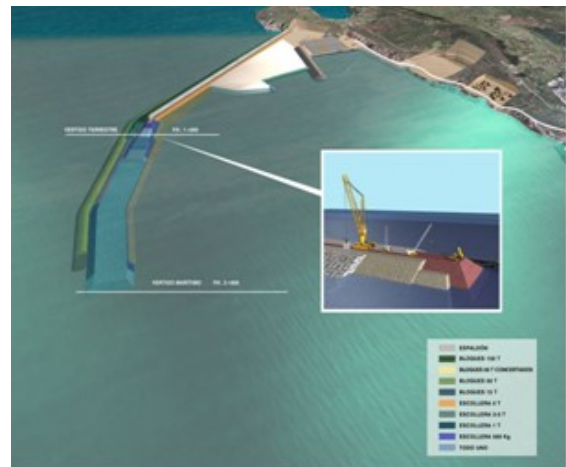


Figure 1: A Schematic General View of the Rubble Mound Breakwater. Layers of Concrete Blocks are shown.

## 2. THE PLANT

A plant has been built in situ to supply the amount and type of concrete blocks that the construction project requires. Blocks of 15, 50, 70 and 150 ton are manufactured and stacked by Rail Mounted Gantry Cranes in their corresponding yards. As a matter of fact, more than twenty three thousand 150 ton blocks, with a cost nearly €5,000 each will have to be created, transported and stored in this plant.

The plant is divided into two main areas dedicated to the production and stocking processes respectively. There are two stacking yards, one devoted to the 15 ton blocks. This yard is divided into two areas by the casting zone where blocks are cast by means of a continuous pouring system operating around the clock six days a week.

There are six pouring lines in the casting yard on which twenty moulds are moved by a crane following a predefined pouring sequence. Concrete is poured into the shuttering and after six hours it can be removed and moved to the next position. Blocks have to stay ten more hours until they have hardened enough so they can be lifted and transported in pairs by the cranes to their corresponding slots, where they will continue to harden.



Figure 2: A General View of the Plant during its Construction.

Concrete blocks have to meet quality standards related to their curing progression that define their life cycle, as shown in Figure 3. Due to the stochastic nature of this process, they cannot be directly delivered to their final destination in the breakwater and consequently have to be stored. Accordingly, three states are possible for a block, i.e. accepted for final delivery (“Green” Blocks), rejected (“Red” Blocks) and those not yet defined as green or red (“Yellow” Blocks). Besides, the prevailing adverse weather conditions during the winter months make it impossible to carry out maritime operations so that a stock is generated (Stock Phase), whereas during the rest of the year, production and delivery of blocks happen simultaneously (Input-Output Phase).

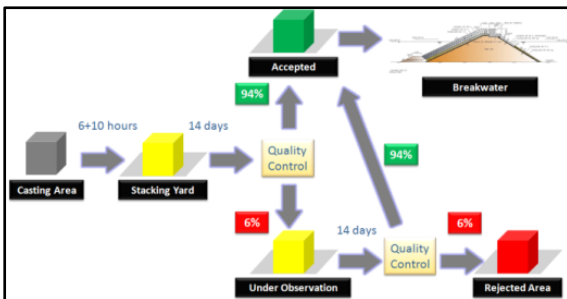


Figure 3: Blocks Life Cycle.

Yard Cranes displacements are monitored and managed by means of a DGPS system so position, identity and state of cranes and blocks can be known. In addition, historical records relative to a previous constructive experience in the nearby port of Ferrol have shown that only 0.36% of the total amount of blocks will not pass the quality tests and consequently will have to be removed. These two key aspects are the foundations on which we have developed our models.

### 3. THE PROBLEM

Every time a crane has to pick up or drop off a pair of blocks a decision has to be made. In the case of the 15 ton blocks, there are more than 760 candidate slots in the yard where to place them. Besides, they can be stacked on top of each other up to five levels. This case

is the most exacting since these blocks present the highest turnover. Consequently we decided to focus our analysis on it. The aim is to minimize the total distance travelled by the cranes while meeting both productive rates and operation constraints.

From a mathematical point of view, this real problem is similar to that of the Stacker Crane Problem (SCP). In the SCP a collection of source-destination pairs  $(s_i, d_i)$  is given where for each pair the crane must pick up an object at location  $s_i$  and deliver it to location  $d_i$ . The goal is to arrange these tasks so as to minimize the time spent by the crane going between tasks, i.e. moving from the destination of one pair to the source of the next one. This can be viewed as an Asymmetric Traveling Salesman Problem (ATSP) in which city  $c_i$  corresponds to the pair  $(s_i, d_i)$  and the distance from  $c_i$  to  $c_j$  is the metric distance between  $d_i$  and  $s_j$ . In our specific case, neither sources nor destinations are fixed so the complexity of the problem increases. Additionally, this would be a random dynamic 760-node instance. Even though it were studied as a fixed static case, it would be much larger than most of the instances that still remain unsolved (Gutin 2002). Further research in dynamic routing problems is proposed (Larsen 2000).

Considering this complexity as well as the need of obtaining real solutions, we finally decided to adopt a simulation-based approach by means of which we could evaluate the performance of our proposals and check their operational feasibility. The role of simulation to evaluate alternative management policies is fundamental, especially when the policies are computer generated and the human decision-makers do not have a complete understanding of all their details (Gambardella 2000). Simulation has been employed for supporting decision making processes in manufacturing-oriented supply chain applications (Qiao 2004) as well as in container terminals management. The location problem of containers in port container terminals has been broadly addressed following different approaches using both heuristics and metaheuristics for improving construction methods, but all of them based on specific process peculiarities (Günther 2005).

### 4. THE SIMULATION

Being aware of the logistic nature of the processes to be modelled, we have used the Delmia QUEST simulator, which allows a good implementation of push-pull policies, queuing logics, and transportation systems while offering an excellent 3D graphical simulation environment on which complex processes can be seen and understood in a very intuitive and practical manner. In fact, one of the most important implications of its utilization has been the possibility for project engineers to visualize the real operation in advance and to anticipate both problems and opportunities. QUEST has been employed to gain more knowledge about the real plant and preliminary information that was used later in the development of our simulator.

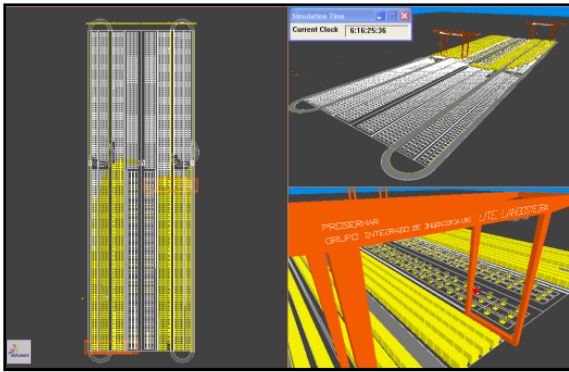


Figure 4: The QUEST Model of the 15ton Yard

We first studied the blocks management in the Stock Phase and then in the Input-Output Phase. The cinematic analogy was achieved by introducing all the geometrical and cinematic data relative to the real elements, i.e. crane dimensions and speeds, blocks dimensions, distance between slots, etc. Models started from CAD information about the real yard. Sources elements represent the cast process by generating three types of parts according to their proportions and following the predetermined sequence. A 760-stack point buffer represents the yard, connected to the sources by means of a Crane AGV System that have been used for modelling the gantry cranes and the logics and points where decisions have to be made. Crane's logics had to be coded in SCL, –a proprietary Simulation Control Language of Delmia– for modelling their kinematics and in order to implement decision rules. Crane movement has been modelled according to a so called “German” operative rather than an “American” one. This means that gantry, cross travel and hoist do not move simultaneously, representing a conservative but safer and more reliable operation from the maintenance point of view.

Connections between elements are required, combining push and pull processes. For example, incoming vehicles for blocks' delivery are modelled by sinks generating pull requests, as well as the buffers for stacking red blocks. Hence, the operational analogy is obtained, and as the simulation can be visualized, the model verification is easier and faster.

An especial effort was made in automating all the processes related to data input and output as well as model geometric definition. This flexibility was obtained by programming BCL scripts –Batch Control Language– with geometric information and characteristic operational parameters rather than using the QUEST GUI. As will be described later, the same intention guided the design of our simulator.

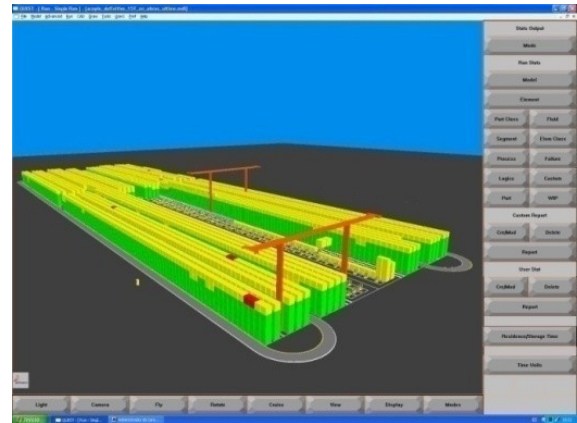


Figure 5: The Yard at the end of the Stocking Phase

Simulation of preliminary models of the Stock Phase was focused on testing a FIFO priority versus a Nearest Neighbour (NN) one when serving sources. Both of them are classical approaches in facing this kind of dynamic problems (Larsen 2000). A basic covering sequence based on maintaining parallelism between sources and stack points visited by the crane was initially proposed. While piling on the region of the yard parallel to the cast area results in an optimum crane performance, results become far from good whenever this parallelism is lost. One solution is to predetermine the maximum distance the crane may travel according to yard's geometry by dedicating farther slots to farther sources and so on. This policy, although simple, has proved to be as good as the NN one for the Stock Phase operation. Even more, we have determined the optimum value for the Stock Ratio in the Stacking Phase – assuming a FIFO pattern when serving sources– by means of the implementation in our simulator of a set of optimal rules. These are basically focused on avoiding those slots that have a lower y-coordinate than the source under consideration whenever a Source-Slot movement has to be done. A value of 86.80 m/block was obtained, which involves only an improvement of 0.3% respect the result derived from the NN procedure.

A Nearest Neighbour rule based on a Euclidean metric was finally adopted when deciding which stack to go to. In Table 1 results relative to different metrics are shown. The yard crane should select the available block corresponding to the pouring order, i.e. should act according to a FIFO policy. The reason is that it only represents less than 2% decrease in performance when compared to the NN operation while it enhances Quality Control and Traceability since it follows the actual cast process. Besides, it has a simpler as well as more robust implementation, in case of a software blackout for instance. But above all, it is less sensitive to the possibility of collapse in the cast area, that is to say, the possibility of overlapping two consecutive pouring processes in the same point. Due to the yard geometry, the NN operation tends to “abandon” the blocks that have been cast in the beginning of the lines, forcing to slow production rate.

Table 1: Stock Ratio (m/block) and Decision Rule in Sources for the NN Policy for Slot Decision in the Stocking Phase.

	FIFO	NN
Euclidean	87.06	85.54
Gantry Distance	87.30	85.93
Manhattan	87.30	85.92
Tchebychev	87.91	87.75

The Rejection Area location for red blocks was also determined. Traditionally, red blocks are piled on an extreme area of the yard so that they do not interfere with other operations. Since the generation of red blocks follows a random pattern, the simulations in QUEST of the stocking phase were first executed to find out whether a centroidal location for red block stacks would be more suitable than the traditional policy. Preliminary results seemed to indicate that both ways are equivalent in terms of distance. Further experimentation in our simulator confirmed this thesis, as will be explained later

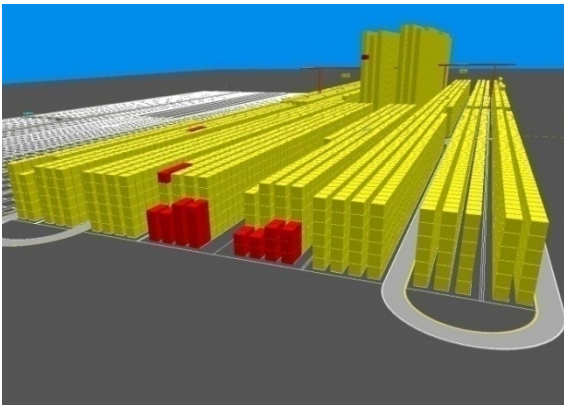


Figure 6: Head Location for Red Blocks. Collapse has happened in Sources

In order to acquire more knowledge and control of the simulation process we developed a Java application, by means of which once we first validated the results obtained in QUEST we could manage simulations in a much faster and detailed way. We could then run long term simulations of 144 working days of the Input-Output model in just a few seconds. Despite the fact of QUEST was extensively used for analyzing the Stock Phase, we could not run the Input-Output QUEST models for more than 20 days of simulation time.

#### 4.1. SIMPA

Our simulator SIMPA - in Spanish, standing for *Simulador de Patios de Apilamiento* - makes use of a combined event-activity oriented simulation approach. The system time evolution consists of an iterative process based on the increment of a time counter by steps corresponding to crane moves. In turn, elements - blocks and sources - are checked for state changes on each step relative to their curing process and the next crane move

is decided depending on the rules under consideration. Thus, simulation is event oriented in the sense that crane activities are modelled by starting-ending events. However, blocks casting and curing processes simulation is activity oriented since starting-ending conditions are checked at moments given by crane moves, not by their own activity events.

The underlying software architecture consists of two main modules corresponding to two java packages. One is the system's model module, which contains classes that represent its elements (crane, sources, stacking points and others). The other one is the simulation core module, which contains the main simulation loop and functionality related to the time management of the system and monitoring.

The elements that constitute the model are the following:

1. Crane. The crane is modelled by its position in Cartesian's coordinates and its cinematic properties - gantry, cross travel and hoist speeds - as well as its height.
2. Source. Sources are defined by their position in the ground (given x-y coordinates), casting state (empty, casting or waiting for the block to be moved to the yard), counter of time elapsed since the last casting initiated and properties common to every source (static declared properties) height of the blocks and cycle operational time.
3. Stacking Point. Stacking points are defined by their x-y coordinates, the number of blocks stacked, the list of time counters of the blocks (time passed since the casting of the block), the list of block's states (green, yellow or red) and the general properties to all of them, i.e. time of first and second quality tests and probability of passing them. The stacking point class also defines methods for adding and removing blocks.
4. Delivery Point. It represents a point to deliver a block that has finished its cycle in the yard and is sent to the breakwater (green) or removed (red). Hence, it is used to model the vehicles and the rejection area.
5. Pull Delivery Point. This class is an extension of Delivery Point that models a delivery point which requests a block to be served at constant time intervals. Specifically, it is used to model the vehicles incoming process along the Input-Output phase.
6. Crane Movements. The different types of movements the crane is able to complete are inherited from a super class called *Movement*, making it easier to manage the different actions that can be executed by the crane. The particular types of movements inherited are:
  - (a) Source to Stack Point movement. This class is defined for transporting blocks



that have already been cast and need to be stacked in the yard.

- (b) Stack Point to Delivery Point movement. This class is defined for the transportation of green or red blocks that have to be delivered.
- (c) Stack Point to Stack Point movement. This class is defined for reallocation movements.
- (d) Empty movement. This class is defined to relocate the crane after transporting a block.

The simulation core module contains only one class, called SimCore. Its properties are the time counter of the simulation run, the ending time of simulation and the names of files to monitor the state of the system during simulation. There is a main method that runs the simulation which executes the simulation loop as follows:

1. Initialize time counter to zero.
2. Determine next crane action according to policies.
3. Obtain list of necessary moves to make selected action  $\{mi\}$ .
4. For each move:
  - (a) Calculate move duration.
  - (b) Update time counter.
  - (c) If it is a transportation block move, then:
    - (i) Remove the block from its departing position.
    - (ii) Update transported block time counters.
  - (d) For each source:
    - (i) Update time counters as given by move duration.
    - (ii) If state should change, then update.
  - (e) For each block on each stacking point:
    - (i) Update time counters as given by move duration.
    - (ii) If state should change, then update.
  - (f) If it is a transportation block move, then deliver the block.
5. Save system state into a file.
6. If time counter  $>$  time limit, then finish the simulation. Else return to step 2.

Other methods perform certain parts of that loop. The state of every block, the number of green, yellow and red blocks and the distances travelled by the crane are saved into several files at each step.

Results have been measured by defining performance ratios for every process under consideration. Hence, the distance travelled by the gantry per block transported has been the main relative value on which the comparison of policy goodness relied on. This value has been calculated both for the Source-Slot moves – Stock Ratio– and for the Slot-Delivery ones –Delivery Ratio–. Other important values obtained have been the

total distance travelled by each crane, the number of reshuffles (movements required when trying to pick up a green block which is under a yellow one), and the maximum set up times for the loading/unloading operations without production collapse, among others.

#### 4.2. The Input-Output Phase Simulation

During the Input-Output Phase, yards A and B alternate in serving vehicles meaning that whenever a yard is receiving blocks from sources the other one is issuing blocks to the breakwater and vice versa. This sequential operation is a simple but effective and inexpensive way of traffic control that field engineers are used to employ. In our work, this procedure was adopted following the real process guidelines. In addition, we proposed that vehicles should always go to the location where the crane has finished its last move. Taking into account the important difference in speed between the crane -2.4 km/hour- and the vehicles -30 km/hour- we think that this is a reasonable proposal.

Three different approaches have been analyzed for this phase. A so called *Spreading Nearest Neighbour* policy (SNN) was first proposed as it implements a conservative criterion based on balancing the yard's occupancy level whilst avoiding reshuffling. The SNN is a modified NN in the sense that it follows a NN pattern but prioritizing the occupancy of empty slots. The closest free slot is chosen as a first option. If this is not possible then the closest pile with a yellow block on top is chosen. Otherwise the closest pile with a green block on top would be selected.

When delivering a pair of blocks to vehicles the yard crane selects the closest pile with a green block on top in that moment. In case the whole top level is yellow, the closest pile with highest green block is chosen. As reallocations become necessary and the spreading idea is kept, yellow blocks are placed on free slots if possible. Then again, blocks are left on top of the closest yellow block whenever the first option is not possible. Red blocks are picked up and delivered to their area at the head of the yard only when the crane is idle during the stocking sequence as they naturally come out from piles.

A *Greedy* algorithm was also studied. In the Greedy algorithm blocks coming from the cast area are placed on top of the closest possible pile regardless future consequences. However, decisions regarding the Slot-Delivery moves and the Red Blocks moves maintain the SNN approach. We also implemented a modified Greedy algorithm named *Greedy No Green* (GNG). The only difference lies on avoiding stacking on top of green blocks when a slot has to be chosen in a source-slot movement.

First, simulations of the Input-Output Phase were executed to confirm the head location for the rejected blocks' area. This was an extra validating group of simulations for the SIMPA that we could compare with QUEST results so that an SNN policy was adopted.

As shown in Table 2, although the central option seems to lead to a better performance, there is not a sig-

nificant difference between these two options, so it is not interesting a change in the traditional management of red blocks.

Table 2: Stock Ratio Results relative to Head and Central Location for Red Blocks under an SNN Policy (5 vehicles, set up = 0.5 min, 100 simulations per case)

Location	Mean(m/block)
Head	82.46
Center	82.56

Less intensive experiments with the other policies under consideration lead to the same conclusion.

This previous validating scenario led to two series of simulation experiments. The first has been designed for determining the cranes' performance with regard to the policy under consideration, the number of vehicles and the set up time. Results of the stock ratio in meters per block are shown in Figures 7 and 8. Simulations consisted of a series of 100 experiments for every combination of algorithm, number of vehicles and set up time (Table 3). We call set up time a delay that we have introduced before every single loading and unloading move aimed at determining the influence of the crane's acceleration and set up times over global yard performance. According to Project Engineers, it is quite unlikely for a crane to take thirty seconds in fixing/unfixing its hoist on a block in normal operation. This is the reason why this value of time was taken into account in guiding the simulation process.

Table 3: Average Stock Ratio and Success Rate (100 simulations per case).

Policy	Vehicles	Set up	Success	Stock Ratio
GNG	3	0	100%	56.19
	3	0.5	0%	0.00
	4	0	100%	44.28
	4	0.5	100%	34.27
	5	0	100%	21.20
	5	0.5	100%	13.21
	6	0	100%	10.86
	6	0.5	100%	14.22

Policy	Vehicles	Set up	Success	Stock Ratio
Greedy	3	0	100%	55.43
	3	0.5	0%	0.00
	4	0	100%	46.91
	4	0.5	96%	35.39
	5	0	100%	20.74
	5	0.5	100%	12.27
	6	0	100%	10.30
	6	0.5	100%	11.04

Policy	Vehicles	Set up	Success	Stock Ratio
SNN	3	0	100%	93.85
	3	0.5	0%	0.00
	4	0	100%	86.84
	4	0.5	100%	82.18
	5	0	100%	80.77
	5	0.5	100%	81.41
	6	0	100%	83.32
	6	0.5	100%	82.88

One important result is that three vehicles are not enough to cope with such a production rate when set up times are nearly half a minute regardless the policy imposed. Moreover, the larger the number of vehicles to be dispatched by the crane, the better the performance of the Greedy and the GNG rules. An even more interesting result is that there is a certain improvement tendency when the set up time increases.

Both Greedy and GNG policies behave in an almost identical manner confirming that the rule of not stacking on top of green blocks does not provide any significant advantage. On the other hand, and even more stable the SNN policy results in stock ratio values more than four times higher than the Greedy and GNG ones.

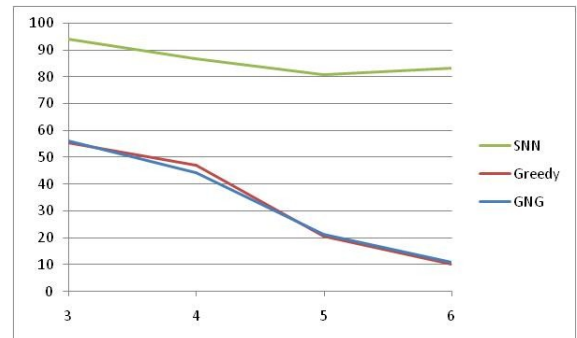


Figure 7: Stock Rate Dependence with Number of Vehicles for each Policy (set up time = 0)

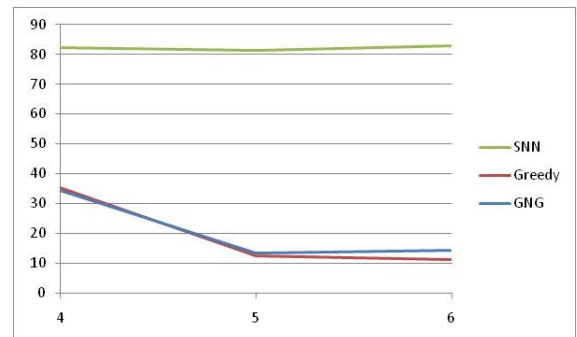


Figure 8: Stock Rate Dependence with Number of Vehicles for each Policy (set up time = 0.5)

Attending to crane performance, a validating operational scenario was proposed (Figure 9) confirming the agreement between production capacity and operational

crane capacity. The Greedy policy was simulated for a null set up time and four vehicles model.

Crane capacities correspond to the average results from the capacity test previously described. The crane can cope with the maximum production rate of 114 blocks/day presenting a surplus of 15 blocks/day. This difference justifies the fact that reallocations have to be performed during the stocking sequence. Besides, the crane operates at its maximum capacity during the delivery sequences, reaching its operational ceiling of 153 blocks/day. This is a very important conclusion since more vehicles do not mean a higher degree of progress of the construction project. However, as previously explained, five vehicles would be more desirable than four as the investment in an additional vehicle is lower than the savings in the crane's operational costs.

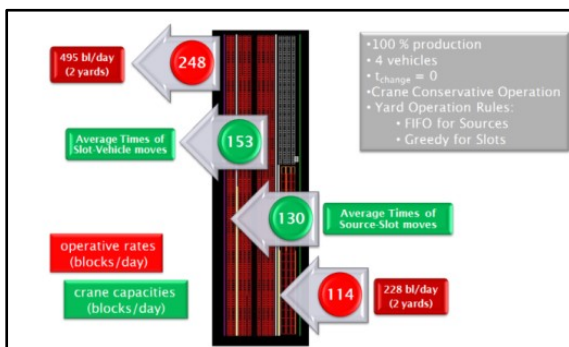


Figure 9: Logistic Input-Output Model: Rates and Capacities.

Results related to this model are presented in the next figures. In Figure 10, the distance travelled by the gantry for a 144 day season is depicted. Simulations showed that a total distance of 700 km is quite likely. The initial slope is higher because the crane has to operate in farther areas of the yard until the steady state is reached.

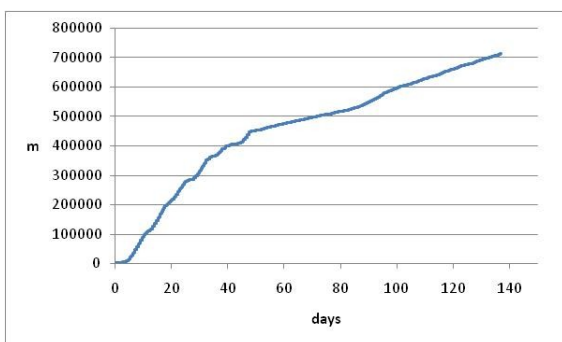


Figure 10: Evolution of Gantry Crane Distance Travelled (6 months, Greedy, 4 vehicles, set up = 0).

The resulting evolution of the Stock Ratio is shown in Figure 11. Then again, the Stock Ratio presents a region of high values as long as the stock generated during the winter months is not delivered. The total number of reallocations and its evolution during a 144 day simulation is presented in Figure 12. Reallocations only appeared after day 80 when the stock is finished. Were

the total number of reallocations the criterion on which the selection of policies would rely on, an SNN policy would be definitely chosen since the Greedy one is almost six times higher. The Yard's state evolution can be seen in Figure 13 relative to the number and type of blocks in the yard.

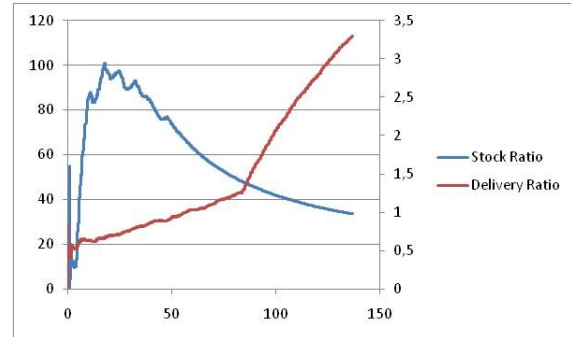


Figure 11: The Stock and Delivery Ratios Evolution (6 months, Greedy, 4 vehicles, set up = 0).

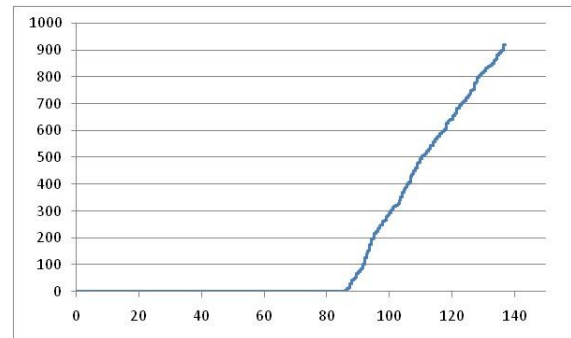


Figure 12: Number of Reallocations (Greedy, 4 vehicles, set up = 0).

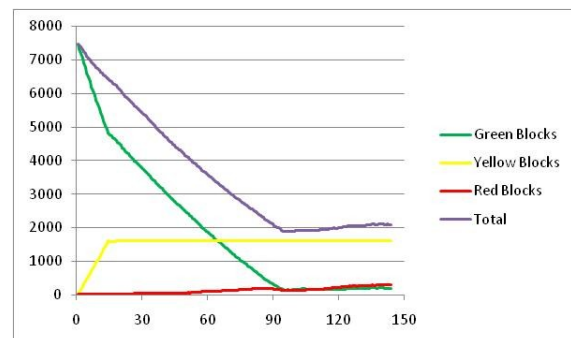


Figure 13: Yard State Evolution for a 6 Month Simulation (Greedy, 4 vehicles, set up = 0).

In order to test the robustness of the Greedy policy a set of 50 simulations was run (Figure 14). The improvement tendency relative to the increment in the set up times is now clearly depicted. For a 6 vehicles operation under a Greedy approach, there is a plateau between 0.4 and 0.9 minutes where the Stock Ratio presents excellent values. These results are not only stable but robust as it is necessary to impose a 1.2 minutes set up time for reducing the success rate from 100% to

90%. Then again, a ratio of 12 m/block is obtained under a Greedy policy operating with 5 vehicles and assuming a set up time of about 36 seconds. An effort in determining real set up times should be done so this value could be optimally adjusted together with appropriate reductions in global crane speed. This would imply an enhanced crane operation both from maintenance and distance minimization approaches. This is a non intuitive or predictable conclusion almost possible to attain by other means but simulation.

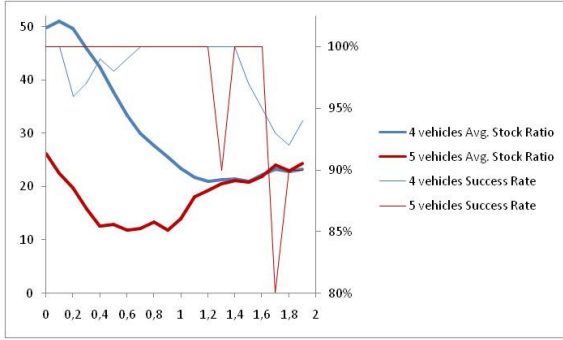


Figure 14: Robustness Test: Stock Ratio and Success Rate for Set Up Times between 0 and 2 minutes (Greedy, 50 simulations per case).

The Greedy proposal has been also analyzed under a very pessimistic value of rejection rate. At present, the actual rejection rate of 6% is being held. However, the typical initial starting up problems in these production environments usually imply a transient state when variables are out of control so it is recommendable to determine whether the actual operation should be maintained or a specific one should be selected and applied during that stage. Moreover, changes during the project related to concrete manufacturing equipment or concrete components –proportions of additives, cement, sand, etc. – may lead to the same situation.

Thus, we decided to test our Greedy algorithm under an increment of 100% in the individual rejection rate value. The proportion of Red Blocks was then fixed to 12% resulting in a total level of 1.44%. This final value involves a 200% increment in the expected number of Red blocks.

Table 4: Average Stock Ratio and Success Rate for 100 simulations per case.

Policy	Vehicles	Set up	Success	Stock Ratio
Greedy	4	0.5	100%	35.12
	5	0.5	100%	12.52

The average Stock Ratio of a series of 100 simulations with a set up time of 0.5 minutes and 4 vehicles was 35.12 m/block. For 5 vehicles, the value was 12.52 m/block. This behaviour is almost coincident to the results obtained for the 0.36% rejection rate. In addition, in both cases the success rate is 100%. Even though the concrete manufacturing process failed, the Greedy policy could cope with such amount of rejected blocks.

Finally, the proposed rules were compared to those previously applied in the construction of a similar breakwater in the Outer Port of Ferrol (traditional operation) and to a random strategy. In Ferrol, it was not possible to follow a strategy based on selecting optimal positions due to the absence of a GPS system. Moreover, at that moment there was not a clear estimation of the blocks' rejection rate, so a conservative stacking operation was adopted. To ensure the traceability of the block's life cycle it was necessary to assign predetermined positions in such a way that piles of blocks were filled sequentially. A pile was not initiated until the previous one was completely filled to prevent red blocks from scattering. This policy is far from optimal. Furthermore, it leads to a poor distance rate because with just a parallel assignment between sources and destinations the rate would be better.

The random policy consists of randomly selecting the next move for the crane at any stage. This way, an efficiency rate measurement of a completely non-controlled system was obtained.

Simulations of the traditional policy were run for a complete Stacking Phase (since we did not have detailed information about the Input-Output phase). Because of the time independent approach proposed by this policy, the purpose of simulation is only to ensure that collapse does not occur. The resulting average distance rate per block was 110.54 m/block. Were this traditional operation assumed, it would imply a 25% increase in the total distance travelled by the crane.

Table 5: Traditional and Random Operation. Average Stock Ratio (100 simulations per case).

Policy	Mean(m/block)
Traditional	110.54
Random	112.80

The random policy was tested for the Stacking Phase resulting very similar to the traditional operation. The obtained average rate was 112.80 m/block. This implies that traditional policy is equivalent to not following any, under a total distance minimization effort.

## 5. CONCLUSIONS

A simulation-based analysis of the concrete armour units manufacturing plant at Punta Langosteira has been described. Simulation has proved to be especially effective for the analysis of large and complex systems as is this case. It has also allowed an enhanced dynamic project management, highly valued by the engineering team.

We have employed a commercial tool -Delmia QUEST- as well as our own java developed discrete event simulator SIMPA. A group of policies have been simulated under different scenarios leading to a simple set of rules according to its easy implementation and low cost.

A Greedy algorithm is proposed as well as the indication of employing 5 vehicles for the transportation of

blocks. Besides, a reduction in the crane operational speed would lead to a more profitable crane's utilization. This Greedy rule has proven to be a robust operation faced with variations in set up times and with a doubled rejection rate.

Simulations indicate that our model may result in a 20% reduction in the total distance travelled by the crane in comparison with traditional operation. Even though this is a very conservative guess since it only takes into account the Stocking Phase, it has an immediate and proportional effect in reducing the plant operational cost.

#### **ACKNOWLEDGMENTS**

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#### **REFERENCES**

- Autoridad Portuaria de A Coruña, 2008. Available from: <http://www.puertodelatlantico.com> [accessed 4 May 2008].
- Gambardella, L.M., Rizzoli, A.E., 2000. *The Role of Simulation and Optimization in Intermodal Container Terminals*. Istituto Dalle Molle di Studi sull'Intelligenza Artificiale. Available from: <http://www.idsia.ch/luca/abstracts/papers/ess2000.pdf> [accessed 4 May 2008]
- Günther, H.O., Kim, K.H. (Eds.), 2005. *Container Terminals and Automated Transport Systems*. New York: Springer.
- Gutin, G.; Punnen, A.P. (Eds.), 2002. *The Travelling Salesman Problem and its Variations*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Larsen, A., 2000. *The Dynamic Vehicle Routing Problem*. Thesis (PhD). Technical University of Denmark.
- Qiao, G., Riddick, F., 2004. Modeling information for manufacturing-oriented supply-chain simulations. *Proceedings of the 36th Conference on Winter Simulation*, pp. 1184-1188. December 5-8, Washington D.C. (USA).

# IDENTITY-BASED, ITEM-CENTRIC TRACKING PLATFORM FOR LOGISTICS APPLICATIONS

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## ABSTRACT

Recent trends in industrial production are marked by rapid changes in structures of collaboration or competition, as well as the spreading of customized production and more intricate customer demands regarding quality and visibility of delivery processes. All this calls for efficient means of tracking and tracing beyond company borders—a technological step which is, in principle, available, yet, it is de facto restricted to isolated proprietary solutions excluding countless small and medium-sized enterprises from their application. The EU-funded project TraSer (Identity-Based Tracking and Web-Services for SMEs) was started with the goal of overcoming these obstacles by providing a free, open-source tracking and tracing solution platform which would allow SMEs to set up and maintain tracking and tracing services across company borders requiring low costs of initial investment and operation. The paper presents main goals and envisaged results of the project, as well as state-of-the-art of related topics.

Keywords: AutoID, track-and-trace, open-source, cross-company interoperability

## 1. IDENTIFIERS AND IDENTIFICATION FEATURES

### 1.1. Why are IDs needed?

The most fundamental requirement to be met before establishing tracking is the agreement upon a common identification system, consisting of:

- one or more standard types of physical ID carrier, and
- one or more ID allocation scheme which all users can interpret.

The presence of an identifier can trigger ID-specific actions, and together with proper location information, time stamp of detection etc., it can provide input to make tracking services work and keep them up-to-date.

### 1.2. Properties of identifiers used

Various means of identification offer different functionality levels which may be exploited in operations based on unique identifiers. Below, the main

groups of these features are listed. In (Ilie-Zudor et al. 2006), a similar grouping is presented with corresponding application examples specific for the case of RFID.

*Unique identifier.* This is the ability to provide an identifier which makes it possible to unambiguously mark a given item and set it apart from others within the range of the whole identifier-based system. This is the key property which is most needed when identity based services or operations are performed, and as it can be seen, all groups of physical or electronic carriers examined offer this feature.

*Location and time information.* Associating a location and time information with a given identifier can be carried out in two possible ways: i) Recognizing an item with a reader of a specified physical location at a given point in time allows us to imply that the recognized item (at least, the identification carrier meant to identify it) was physically present at the specified place and time (e. g., an item passes through a gate reader of fixed location which reports its occurrence automatically). ii) Knowing that a given item is attached to a kind of carrier whose location at certain points of time is known (e. g., a vehicle transporting the items, or a directory containing several documents), it is not necessary to identify the items during the transfer since it can be assumed that all originally contained items (e. g., articles locked into a vehicle) change their place together. Here, it is sufficient to report the progress of the carrier only (optionally, along with the identifiers of the items carried) without any repeated identification of the items taking place.

*Transfer of further data, read-only.* In some cases, not only an identity is extracted from the physical carrier but also auxiliary data are read which would be difficult, impractical or too costly to obtain from a remote or pre-recorded database. In these cases, the physical carrier of the identifier works, in essence, as an additional read-only data carrier as well.

*Transfer of further data, read and write access.* A further group of cases makes refreshing the aforementioned additional data necessary, which would call for a physical carrier functioning as a read-write data carrier as well. While this is no problem with re-

writable RFID tags or purely electronic identifiers, other carriers (e. g., bar code) can only offer the workaround of re-labeling.

*Transfer of further data, in-situ update.* Although relatively rare, it may be needed that additional data attached to identifiers change their contents autonomously and allow, e. g., the automatic recording of changes in the state of the item in question. Such a case may occur if chemical containers need to be equipped with RFID tags which can transmit the current temperature etc. to the reader, or if special tags are used for quick diagnostics of livestock etc. Of course, pre-printed physical carriers with fixed contents (e. g., barcode) cannot support the realization of this functionality.

*Changing the identifier.* In some cases, items need to discard their old identity and take on a new one (e. g., assignment of an item to a new responsible entity). This is seamlessly supported by re-writable RFID tags and purely electronic identifiers while other kinds of physical carriers (e. g., barcodes, non-rewritable RFID) would need a workaround by relabeling.

Table 1 summarizes the above properties with respect to their availability with various physical ID carriers, while Table 2 lists which properties are needed for different levels of functionality which rely on item identification.

Table 1: Possible support of various identifier properties

Property used	RFID	Barcode etc.	Human-readable	Electronic ID
ID	+	+	+	+
Location/time	+	+	+	+
Further data, R	+	+	+	+
Further data, R/W	+	W	W	+
In-situ update	+	-	-	+
Change of ID	+	W	W	+

+ supported  
 - not supported  
 W workaround (re-labeling) needed

Table 2: Required and possibly exploitable properties for various functionality levels

Functionality level	ID	Location/time	Further data, R	Further data, R/W	In-situ update	Change of ID
Identifier-based operations	+	-	*	*	*	*
Tracking-based operations	+	+	*	*	*	*
Advanced item-level services	+	+	*	*	*	*

+ required  
 - not needed  
 \* may be exploited

### 1.3. Application of identification architectures

Although the mere presence of a technical background for item-level identification forms a separate layer of functionality, it is hardly used alone. This is, in the first line, due to the fact that item-level identification in itself is rarely sufficient for desired functionalities and investing in ID carriers and readers alone makes only sense in some specific cases which are a rare exception to the above rule. This occurs when the reader (or a dedicated device coupled to the reader but having no connection to a database or a comparable repository) is able to decide on the spot what action has to be taken upon a given item's detection.

One of the most common examples mentioned in literature are RFID-based anti-theft solutions (Modern Purchasing 1993) where readers may react on a given subset of identifiers only (which are not even required to be unique)-these, of course, do not necessarily need to be obtained from a common repository and may reside pre-loaded in the hardware accompanying the readers.

Although only fiction now, many other uses are envisaged for the future. Recipe parameters (e. g., baking time) could be automatically read and forwarded to the appropriate device (Almirall et al. 2003), another interesting application is envisaged for washing machines where read-write RFID tags in clothes also record how many times the given piece has been washed and select the proper washing program to adapt to aging of the fabric (RFID Journal 2006).

One of the most unusual examples is the graphical tablet (Graphire pen functionality 2006) used as an input device for computers. Here, the identifier may prevent the stylus or mouse from being swapped or accidentally read by neighboring readers or may define the type of the input instrument, while additional measurement data (such as stylus tip pressure or a list of buttons pressed) can be transmitted to the reader in addition. The reader is implemented in a special form which can determine the exact spatial position of the input instrument within the borders of the tablet-this is rarely the case for commonly used readers; comparable plans are only found in the proposed idea of a triangulation-based location system using direction-selective long-range RFID readers for finding golf balls lost on a golf course (Transponder News 2005).

### 1.4. Application cases of ID-based operations

Identifier-based operations have a longer tradition in asset management than in supply chain management. The most simple cases of identifier-based asset management tend to be so rudimentary that it becomes difficult to draw a distinct border between the local use of identifier architecture (Figure 1) and actual identifier-based operations (Figure 2) supported by a facility-level data repository.

Common to all of these is the lock functionality, focusing on the binary question of a given individual (or a member of a given class) being inside/outside, or entering/leaving the given facility, (e. g., whether a

given tool is inside the storage room) often in conjunction with a go/no-go type authorization of further operations (e. g., personal RFID cards widely used in access control of buildings, restricted use of computers or other tools etc.). The key question setting actual identifier-based asset management operations apart from a mere local use of identifiers is whether or not there is a facility-level information architecture informing the reader of possible actions to be taken locally (e. g., granting access) and, optionally, gathering data about entities transferred through the reader-equipped locks at the facility borders (potentially resulting in binary information about a given entity being in the facility).

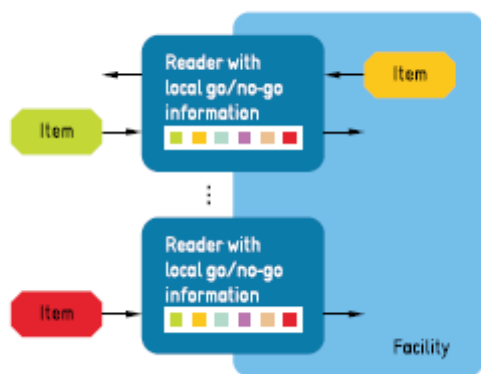


Figure 1: Local use of identifiers in asset management

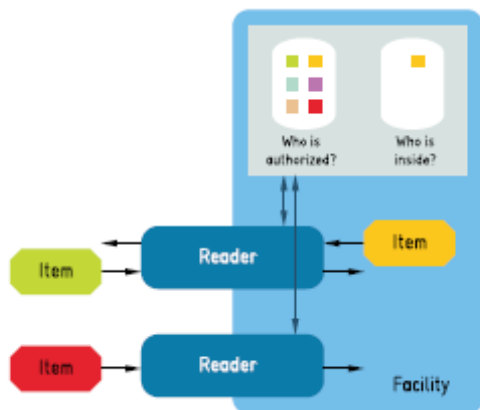


Figure 2: Identifier-based operations in asset management

Therefore, the most simple identifier-based anti-theft systems would rather qualify for the local use of identifiers while more elaborate access control (even a multilevel example for organizing a conference in China (Furness et al. 2005) and contemplation of RFID-aided house arrest supervision (Transponder News 2005) are known) would already require a central piece of hardware supervising the readers and thus belong to the class of ID-based asset management operations.

One of the most elaborate and interesting examples for ID-based asset management-personnel management, to be more exact-is used by the shipping company TNT

at the Helsinki Airport (RFID Lab Finland 2005). Here, security guards are required to patrol the facilities along a specified route to ensure the security of the logistics center of the company as well as other personnel. In order to control the work performance of the guards, each of them has to operate a portable RFID reader to detect tags placed along the required path. Each reader stores a list of the checkpoints passed, and the list can be acquired from the mobile readers at a given point of time (e. g., end of shift, end of one patrol etc.), and stored in the central records. In this arrangement, the mobility and connectivity of individuals and readers is "turned inside out" compared to the common arrangement, and instead of network connections, the mobile readers and the staff themselves convey the data.

Other examples of ID-based asset management are aviation service provider Nordam's more reliable tool collection system (AMT 17/3), and the improved access authorization procedure at the Californian harbors (Innovate Forum 2006). In the agriculture, farm animals can be identified using RFID tags, and a retrieval service for lost pets also relies on RFID implants as the means of identification ('Home Again' pet retrieval service (Home Again 2005), although in the latter case, the presence of location information and a widely accessible database may rather resemble the next level of functionality, i. e., tracking-based operations).

In supply chain management, most ID-based operations-keeping original organizational structures-are grouped around inventory changes or updates, related to what entities enter, reside in, or leave the inventory. In most cases, this calls for a more elaborate database than in the case of asset management with binary go/no-go or presence indicators, as in account-based stock keeping, several items of the same class are grouped and each of such classes may have its own supply level information, handling instructions etc.

A typical example of RFID-aided inventory management on the facility level is the RFID test case introduced at the Dutch book store Selexyz. The books headed to the pilot store were equipped with passive RFID tags before packing at the distribution center of a third-party-logistics service provider specialized in books. The tagging allowed the automation of the receiving of books at the store, which previously relied on manual bar-code reading. Now, the boxes containing the books can pass unopened through an RFID reader port, thus reducing the time needed to register which items entered the store upon a given delivery. The second major area of improvement is the inventory counting, which can be performed with portable RFID readers in a few hours instead of closing the store for a day. Due to these improvements, the need for staff in the book store has dropped from 22 to 15, and Selexyz has decided to expand the system to other stores (Trebilcock 2006).

Other examples for similar ID-based support for receiving and inventory counting operations can be found at the clothing stores Kaufhof (Roberti 2006), Marks & Spencer (Frontline Solutions 2005) and Levi's



(Frontline Solutions 2005b). Receiving is accelerated using RFID technology at Wal-Mart (Chain Store Age 2005) and Metro (Hoffman 2006). Manufacturing processes with a flow-through of material can benefit from identifier application as well, facilitating such solutions as automatic retooling of work-cells for the given item, and fail-safe identification of samples for quality control (Schreiner's LogiData control system applied by Auto5000 GmbH, a supplier of Volkswagen (RFID International 2005)); RFID-based administration of quality control at Ford's Essex engine plant in Windsor, Ontario (Furness et al. 2005); RFID-based identification of material test samples at the MTR Corporation of Hong Kong which builds and operates urban railways (Furness et al. 2005)). Closely related are also the DoD standards for product vendors (DoD 2004) which allow an identification of origin and also facilitate the in-transit tracking of goods which will be the focus of the next section. Generic value chains form a special application group, with such examples as architectural construction processes (Skanska Finland applies Enterprixe's 4D production model solution).

## 2. TRACKING-BASED OPERATIONS

### 2.1. Functionality

Tracking-based operations are primarily focusing on the movement of material within a network of various locations. In this context, the point of view of identifier-based operations concentrating on inventory changes of a given facility is, in some way, representing a dual to the attitude of tracking-based operations where the materials themselves form the main subject of observation and location information is represented as a property of the given individual. This change of perspective is necessary because this level of functionality requires the individual items (or batches of items which have their own identity) to be recognized and tracked as such across a series of locations—plain account-based material management is not suitable for the realization of this level of control (Rönkkö 2006).

### 2.2. Requirements

The realization of tracking-based operations requires the following preliminaries:

- Identifiers unique to instances or batches which can be successfully read at all locations and times in concern;
- Infrastructure and common methods/protocols of acquiring and forwarding the time/place information associated with reading an ID;
- A database of central role above the facility level (note that physically, it may be of a distributed form) where subsequent location/time marks associated with the given ID can be aggregated and are available for surveillance and further processing.

### 2.3. Advantages

The primary advantage of performing tracking on the level of items or batches (instances, in general; as opposed to class cardinality with account-based operations) is that the path or the presence of material can be tracked with higher accuracy than that of conventional structures. As a consequence of aggregation over all locations involved, detailed material-related information can be acquired and processed more efficiently, which in turn facilitates better decisions in material management and related issues, ranging from more efficient logistics in supply-chain management to optimized usage of material in asset management.

In the current material handling scene, account-based solutions still prevail, yet the direct or implied advantages of item-level tracking are clearly effecting its gradual spreading in cases where these advanced functionalities are worth the investment.

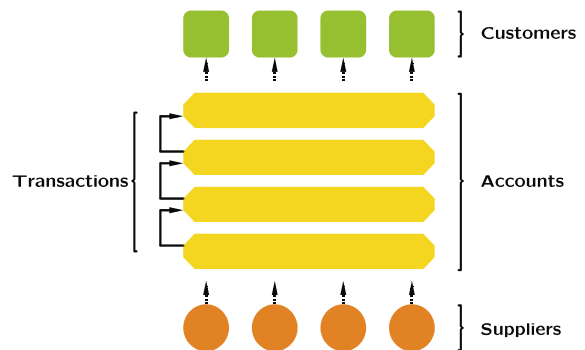


Figure 3: Account-based material management

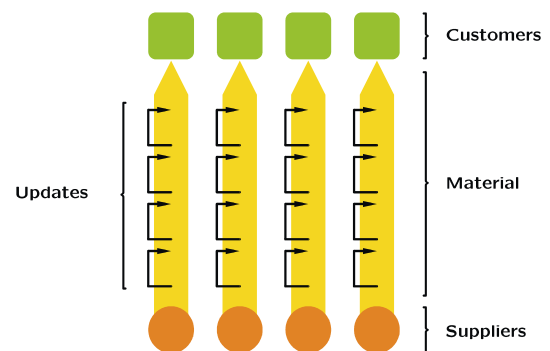


Figure 4: Item-centric material management

## 3. ADVANCED ITEM-CENTRIC SERVICES

### 3.1. Functionality

The next step in achieving higher-level functionalities is the integration of tracking and related services transcending either organizational borders (typical for supply chains) or functional borders within the same organization (typical for closed-circuit asset management), as shown in Figure 5.

This extended transparency (and not less the fact that groups which have to do with the same item in different ways—e. g., manufacturers, forwarders,

retailers, users-can access information about the item) gives the opportunity to establish advanced services on the item level (referred to as item-centric services) which go beyond the usual functionalities of pure tracking. As far as their access rights allow, various user groups can then either update (e. g., notification about the item passing through production stages) or read (e. g., inquiry about availability or delivery status) item-related information. Currently, a significant part of these elements is already in use in various branches of industrial production, yet they are kept from unfolding their full potential because only partial solutions are present, isolated from each other by organizational or functional borders which can be-if feasible at all-transcended by manual intervention only.

### 3.2. Requirements

As it can be expected, the additional requirements for integrated item-centric services revolve around establishing transparency through organizational or functional borders:

- Infrastructural requirements for transparency, such as interfaces and protocols in simple cases, and higher-level standards of mutual agreement, such as common ontologies if complex operations are required;
- Differentiated access control for user groups with various levels of authorization, requiring authentication, authorization and protection of communicated information (including identifiers).

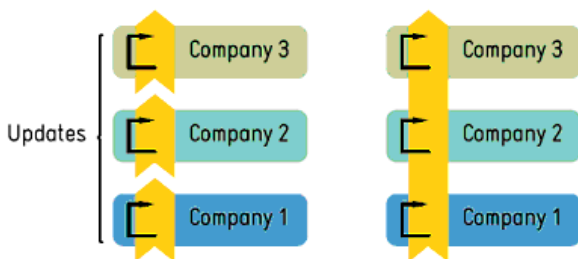


Figure 5: Tracking of material (yellow) interrupted at organizational borders (left) vs. integrated services transcending borders (right)

### 3.3. Advantages

Transparency transcending organizational or functional borders has received much attention in recent literature, as it is essential for improving efficiency in processes which, even if not tracked directly, do pass through these borders anyway. The successful control of such processes depends on decision makers or controlling mechanisms having a proper overview over events or processes concerning the subject of the transactions (observability, in a control engineering perspective (Dejonckheere et al. 2003)). Once this is provided, better decisions can be met for planning such processes as

- assignment of work and assets depending on limited resources;
- transfer or allocation of assets to meet current and future demands for closed-circuit asset management,
- order and work forecasts;
- optimization of transportation processes;
- processing of customized orders;
- quality feedback;
- "fault-tolerant" composition of products and production steps for supply chain management.

It is also worth examining the interfaces needed for transparency. In the most simple use cases, a web interface is sufficient (occasional use, such as checking order status by customers), while a long-lasting business-to-business relationship can exploit the benefits of closer system integration and thus relieve the involved parties of the drawbacks of manually controlled operations (time lags, human errors).

A company extending tracking services to its customers is able to provide the service only from the parts of the supply chain which are connected to the same tracking system, using the same notations and databases. Therefore, the most beneficial services can be built when the handling parties in the supply chain agree to share an integrated tracking system or one company is vertically integrated over a large part of the supply chain (see Figure 5).

## 4. AN IDENTITY-BASED, ITEM-CENTRIC TRACKING SOLUTION IN SUPPLY-CHAIN MANAGEMENT

### 4.1. Concept overview

This section details an approach under development of an open source platform which is created in order to support SMEs in the adoption and development of tracking-based logistics applications combining mass customization and mass collaboration features.

There are benefits for all types of economic actors if the technological problem of tracking in changing networks is solved. Smaller corporations could participate in temporary networks more easily, while large corporations could introduce advanced operations on a wider scale, and start to benefit, for example from Vendor Managed Inventory (VMI), and provide after sales services to more customers.

The solution focuses on forwarder independent product individual, shipment or product-data tracking. The forwarder independent tracking solution consists of two types of easily installable software components: checkpoint clients and server components. The checkpoint clients are used to register the movements of material and inventory status in a supply network, and the server components (i.e. the middleware) receive information from the clients and pass it to business applications.

For tracking-based logistics service solutions to be effective and valuable in temporary and changing participant networks is required that:

- The applications are product centric, rather than provider specific. The reason is that product centric applications facilitate solutions that can be used at different stages of the product life cycle and by actors that are not needed to be specified in advance.
- Service providers develop capabilities for efficiently setting-up identity checkpoints for product centric applications and for interacting with this novel type of applications.

The key point that takes the proposed research beyond the state-of-the art is illustrated in Figure 6 for logistics services. The unique address-code attached to the physical product, and the checkpoint client available for download on the Internet makes set-up and integration extremely cost efficient.

This solution is more portable than trying to communicate directly with the Application Programming Interfaces (APIs) of different ERP systems. If such communication is necessary in some application (e.g. real-time applications where very rapid reaction by the ERP on incoming events is required), then that can be provided by an application-specific 'agent' that registers with the platform for receiving such messages.

The approach taken in the solutions targeted, builds around the so-called 'product-centric' concept. This concept signifies that information about any individual product item (including product types) can be accessed over a network connection if the product item is identified properly. The approach is not limited to tangible objects; it could also be applied to documents (e.g.: CAD drawings).

In order to make this possible, globally unique item identification becomes necessary. In the solutions proposed the ID@URI approach (Furness et al. 2005) is adopted and further developed. In this notation the ID stands for an identity code of the consignment, and URI stands for the Internet address of the computer to which the information should be sent. This ensures that the system can be used with several partners and, also, that the uniqueness of tracking codes can be managed. When using URLs (Uniform Resource Locator) as URI (Uniform Resource Identifier), the network address where the information can be accessed is directly indicated. Since a URL must be globally unique by definition, it then becomes sufficient to use a unique ID for that URL to make the identifier globally unique.

The development of the concept proposed is being done as part of an international project, titled Identity-Based Tracking and Web-Services for SMEs (<http://www.traser-project.eu>).

The main scientific research objective of TraSer is: Gaining insight into possible ways of motivating prospective partners to participate in network-wide

information sharing (such as through scientifically founded guarantees for safe and efficient operation).

The technological objectives are:

- Assessing possibilities of integrating item-centric concepts into an existing transaction-processing scheme;
- Providing scalable and flexible access control while complying with industrial security requirements;
- Exploring and applying best practices for realizing network-level services in heterogeneous and changing environments.

#### 4.2. Overall platform description

A TraSer network consists of TraSer nodes (i.e., servers in charge of maintaining item-related information in their database) and TraSer clients (which provide interfaces for querying and updating of item-related information by human operators or other hardware/software components). The requirements listed below determine the architecture proposed for the TraSer network.

TraSer focuses on items which are unambiguously marked with an identifier. The latter can be entered into TraSer through a reader unit which is either a specific piece of hardware (RFID/barcode reader, alphanumeric terminal etc.) or software (in the case of product data management). Identifiers are static, they cannot be altered by the system. Data migration from one identifier to another is supported by the system, but the method of re-labeling is out of scope of TraSer.

Data associated with an item (having a given identifier) can be updated or queried through one given node in charge. An administrator is responsible for configuring and maintaining the TraSer node. Although the TraSer project will specify and implement one given software solution for TraSer nodes, other pieces of software may be TraSer-compliant as well, as long as they provide the same services, data and communication interfaces. This is important as some potential industrial customers have already pronounced their preference of re-implementing TraSer components with their own software tools.

TraSer Clients are entities which do not permanently store item-related data and provide no services related to given items but can contact TraSer nodes to use their data and services. The primary purpose of clients is communication with a user who can be either a human operator or a piece of hardware/software. Although we may specify a given range of possible TraSer clients, there are, theoretically, no constraints concerning the innards of a potential client, as it is only the communication behavior which determines its validity as a TraSer client.

It is a general principle that only TraSer nodes and TraSer clients can be directly connected to TraSer nodes. Other components, such as already existing ERP

systems, can be linked to TraSer nodes through special clients acting as adapters.

Figure 6 shows possible interactions between the entities listed above-note that the interfaces marked with dotted lines may not necessarily belong to the core specification of TraSer.

### 4.3. User characteristics

There are two base classes of users of the system, clients and data owners. Servers are only used by data owners, and only through the configuration interface. Clients of the system communicate with the client applications and put a significantly greater load on the system.

Clients are further divided into three sub-classes: checkpoints, partners and analysts. Servers can send and receive messages from other servers, in situations like this they are treated as partners.

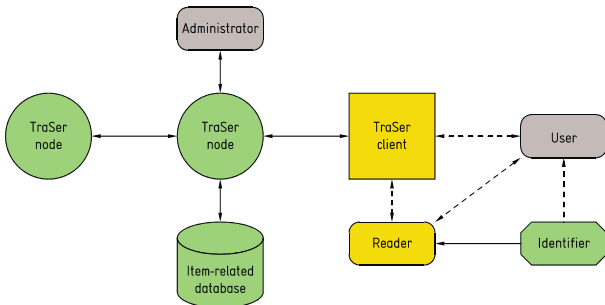


Figure 6: Components and interactions within TraSer

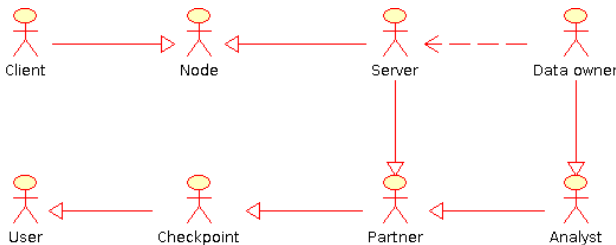


Figure 7: Hierarchy of actors

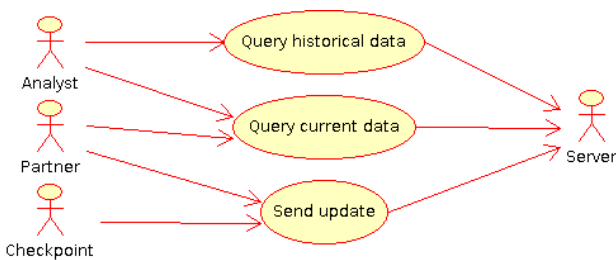


Figure 8: Everyday communication use cases

Checkpoints send update messages, but do not access the information stored. Typical checkpoints comprise logistics providers. Partners both update and query data, but the set of queries typically does not contain complex computations or retrieval of large historical data-sets. Analysts on the other hand have greater access and either use the system as a decision support tool, or want to extract rather old information for tracing purposes.

The TraSer library maintains a catalogue of partners' data. This catalogue is used for creating a secure communication channel over the internet and to know what is the communication and network related capability of remote parties. This catalogue can be used by any implementation using the TraSer library. Server configuration includes the management of authorization rules, supported message types, lifecycle, entity mapping and relaying services. Entity mapping is implemented via numbering scheme translation.

Numbering scheme mapping can be offered as a service on the server. If the server operator (i.e. the data-owner) decides to make the mapping rules available to others, it can be accessed by everyone, most importantly checkpoints that due to the lack of prior knowledge of entities to be handled, have limited possibilities in defining the mapping rules locally. Another service that can be offered by the server is the publishing of change of certain aspects of data regarding specific items, in other words client can subscribe to changes of information. In this case, after the client registers this fact, which is approved by the server, the server sends a notification message every time the data in question changes.

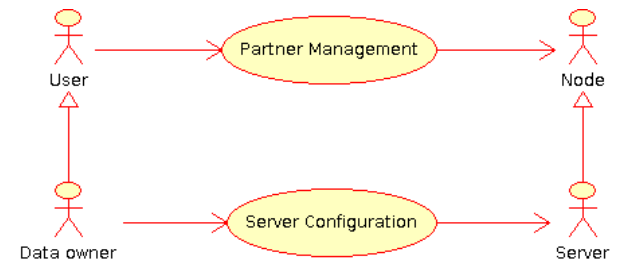


Figure 9: Node management use cases

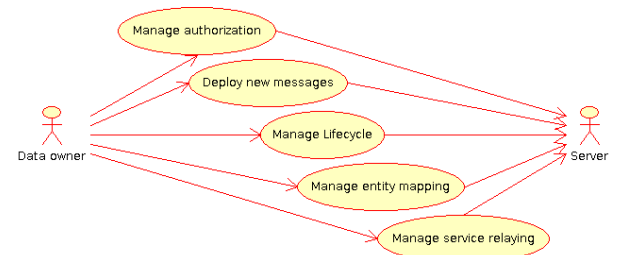


Figure 10: Server management use cases

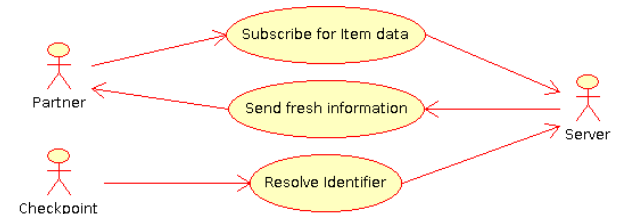


Figure 11: Publish / Subscribe & Identity resolving use cases

### 4.4. Partner management

In the TraSer platform there are partners and service addresses. Each partner that needs secure communication (i.e. wants to communicate over the internet) possesses a private-public key-pair. This key-

pair is used to secure and validate messages if sent over a possibly compromised channel like the internet.

Servers may offer their services using more than one communication channel, where different channels may have different settings. An example would be whether non-secured messages are accepted via a channel or not.

Security keys are in zero-or-one-to-one (0...1-1) correspondence with partners, meaning that partners can only have one security key and exactly one partner is associated with a security key. Service addresses and partners on the other hand are in many-to-one correspondence.

In TraSer users can export the contact detail of a local user that can be later imported into the partner catalogue of other parties. The user can select which service addresses he wants to include in the exported contact details. Of course it is possible to add partners to the catalogue by hand, and users can later modify already added or imported contact details as well as the details of the local user.

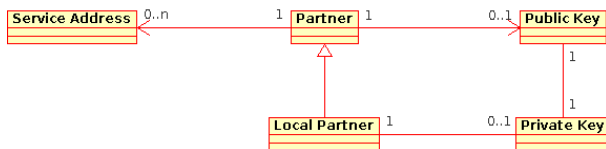


Figure 12: Partner data, class diagram snippet

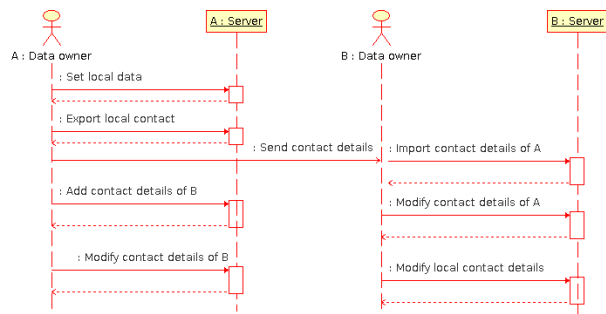


Figure 13: Partner management, sequence diagram

#### 4.5. Interoperation with non-TraSer environments

As not all industrial users obey TraSer principles, an Item identification scheme may be different from ID@URI. E.g. the identification may be represented as a Serial Shipping Container Code (SSCC) instead. In such case a translation must be made to the ID@URI.

For such cases the TraSer architecture offers three options:

- Upload clients may store information on all non TraSer items in a default server with a fixed URI
- Based on certain parameters (e.g. the SSCC prefix or the ISO 15963 allocation class), stored in local client settings, a URI may be chosen by the upload client
- The upload client may access a look-up service, that responds with an URI based on the existing ID plus possible extra characteristics (such as the Item Type)

TraSer will support protocols to use ID@URI look-up services. The URI stored in a client or looked-up through a service needs not be the final URI where the Item information is stored. The update and query traffic may further be redirected based on criteria at the Server node. Such redirection however should be invisible for the clients.

Another special case is when multiple (but different) ID@URIs are affixed to the item, or when an Item label is replaced with one with a different ID@URI. This may be needed when the IDs are pre-allocated to or pre-printed on the label. In this case all URIs should ultimately point or redirect to the URI where the Item information is stored.

#### 4.6. Confidentiality and transfer of information custody

Not everyone is entitled to upload or query information of Items. Each information category of each Item has an owner. The owner decides who may query and who may upload parts of the information belonging to that category. The TraSer concept is however based on an open environment and is jeopardized if upload restrictions are too strict. It should for instance not be necessary for a carrier to register with each of the information owners in order to scan the Items he carries.

Updates of information ownership and user rights are registered as a special kind of event.

Change of information ownership may imply that storage services are transferred to a new Server node. The new owner of the information is also responsible for rendering these services and he may decide to employ another service. It is also possible that the former owner is not authorized any longer to retrieve certain Item related information. Wholesalers for instance sometimes do not wish manufacturers to know who the final customers are. Yet the URI of the first information owner in the chain may be affixed to the Item as a barcode or in an RFID tag.

TraSer therefore includes a redirect mechanism. In case information storage is transferred to a new server, a link will be established on the old server. Information upload and retrieval is not performed directly, first the server is interrogated whether he still holds the applicable information. This mechanism is illustrated in Figure 14. Principles are:

- The identity of clients and nodes should be verified by means of signatures and certificates
- The Uploader is agnostic about information confidentiality requirements, the protocol must always be the same.
- URI transfers may be cached: the second upload or query is directed to the right node immediately
- The types of information should be coded (technical, logistic, usage)
- TraSer does not support:

- The case when downstream parties (e.g. customers) should not know the identity of the URI holder
- The case when manufacturers refuse to transfer ownership (or have bad or illegal intentions)

When a party in the chain drops out without redirecting its URI or without updating the redirects upstream, the chain is broken and information on the Item cannot be retrieved or updated any longer. This problem can not be resolved technically, but should be covered contractually.

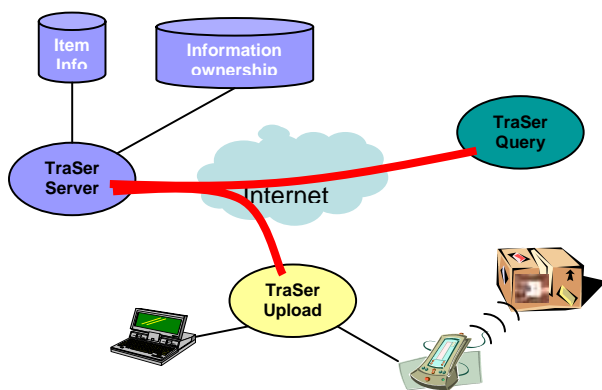


Figure 14: Information Confidentiality

## 5. CONCLUSIONS

Recent development of industrial production presents an ever-growing demand for tracking and tracing of work pieces, documents etc., more and more often beyond company or organizational borders. While identity-based tracking and tracing is already applied in industry, several-mostly cost-related-drawbacks confine it to isolated proprietary solutions applied at large companies, while SMEs venture the step of investing in present-day ID-based tracking usually due to the pressure of their larger customers only. The EU-sponsored project "Identity-Based Tracking and Web Services for SMEs" (TraSer, see <http://www.traser-project.eu>) is aimed at overcoming this obstacle by providing an easy-to-maintain open-source solution platform for tracking and tracing applications.

Given the findings about common use and placement of AutoID middleware in the enterprise IT infrastructure, a superficial first look at a TraSer node through clients attached to it may lead to the conclusion that TraSer is middleware in itself, in view of its capabilities of receiving reader input and communicating with already existing higher-level enterprise IT components. However, a closer look at TraSer nodes reveals properties which were, until now, not covered by AutoID middleware, especially i) long-term, organized storage of item-related data and the processing of queries regarding their access, and ii) communication of item-related messages within or across organizational borders. TraSer is, therefore, not meant to be yet another product to compete with today's

middleware solutions. Instead, TraSer clients can very well rely on existing middleware, especially when it comes to the aggregated collection of item-related data from autonomous sensor/reader clusters. In later phases of the project, the adoption of solutions like those found in Singularity (Singularity 2005), Blue Vector Systems (Blue Vector Systems 2005) or RFID Anywhere (RFID Anywhere 2006) can be considered for trial implementation. Nevertheless, it has to be carefully assessed whether the practical realization of such experiments should be carried out within the framework of the project or left to the open-source community.

## 6. ACKNOWLEDGEMENT

Work for this paper was supported by the 6th FW EU project "Identity-Based Tracking and Web-Services for SMEs" under grant No. 033512 and the Hungarian Scientific Research Fund (OTKA) under grant No. T73376 "Production Structures as Complex Adaptive Systems".

## REFERENCES

- Almirall, E.; Brito, I.; Silisque, A.; Cortés, U., 2003. *From Supply Chains to Demand Networks*. Technical report Report LSI-03-41-R, Technical University of Catalonia, Barcelona.
- Blue Vector Systems, 2005. *Blue Vector Systems corporate website*. Available from: <http://www.bluevectorsystems.com/>
- Chain Store Age, 2005. Research Confirms Wal-Mart's RFID Benefit, *Chain Store Age*, 81(12):80.
- Dejonckheere, J., Disney, S. M., Lambrecht, M. R., Towill, D. R., 2003. Measuring and Avoiding the Bullwhip Effect: A Control Theoretic Approach, *European Journal of Operational Research*, 147(3):567–590.
- Frontline Solutions, 2005. Marks & Spencer Expands RFID Trial. *Frontline Solutions*, 6(3):11–12.
- Frontline Solutions, 2005. Levi Strauss tries RFID on for Size. *Frontline Solutions*, 6(6):10.
- Furness, A.; Smith, I. G. (Eds.), 2004. *RFID Compendium & Buyers' Guide 2004–2005*. Available from: <http://www.aimuk.org/pdfs/RFIDcomp04.pdf>.
- Hoffman, W., 2006. Metro moves on RFID. *Traffic World*, 270(4):18.
- Home Again, 2006. *Home Again Pet Retrieval Service*. Available from: <http://www.homeagainid.com/>
- Ilie-Zudor, E.; Kemény, Zs.; Egri, P.; Monostori, L., 2006. The RFID Technology and its Current Applications, *Proc. of MITIP 2006*, pp. 29–36, 11–12 September 2006, Budapest, Hungary
- Innovate Forum, 2006. *Wherenet Active RFID Technology Chosen to Enhance Security at Major California Ports*. Available from: <http://www.innovateforum.com/innovate/article/articleDetail.jsp?id=282826>, 2006.
- Modern Purchasing, 1993. Anti-theft tags battle retail pilferage, *Modern Purchasing*, 35(10):15.
- RFID Anywhere, 2006. *RFID Anywhere product information page*. Available from:

- <http://www.sybase.com/products/rfidsoftware/rfidanywhere>
- RFID International, 2006. *RFID International web site*. Available from: <http://www.rfidinternational.com>
- RFID Journal, 2006. *RFID Consumer Applications and Benefits*. Available from: <http://www.rfidjournal.com/article/articleview/1332/2/129/>
- RFID Lab Finland, 2005. *TNT Suomi Oy-case description*. Available from: <http://www.rfidlab.fi/default.asp?1;2;100;0;:&file=7>
- Roberti, M., 2006. RFID is Fit to Track Clothes. *Chain Store Age*, 82(5):158.
- Rönkkö, M., 2006. *A model for item centric material control in manufacturing*. M. Sc. thesis, Helsinki University of Technology.
- Singularity, 2005. *Singularity Open Source Initiative, official web page*. Available from: <http://singularity.firstopen.org/>
- Transponder News, 2006. *Future trends in transponder systems*. Available from: <http://transpondernews.com/trendfut.html>
- Trebilcock, B., 2006. The book on item-level RFID tagging, *Modern Materials Handling*, 61(6):43–45.
- United States Department of Defense, 2005. *United States Department of Defense Suppliers' Passive RFID Information Guide, V6.0*. Available from: <http://www.ndia.org/Content/ContentGroups/Divisions1/Logistics/7DoD-Passive-RFID-Information-Guide-v6.0.pdf>
- WACOM, 2006. *Functionality of the Graphire Pen, WACOM Corporate site*. Available from: [ftp://ftp.wacom-europe.com/pub/white\\_papers/tech\\_g3\\_en.pdf](ftp://ftp.wacom-europe.com/pub/white_papers/tech_g3_en.pdf)

# BUSINESS SIMULATION GAME FOR TEACHING MULTI-ECHELON SUPPLY CHAIN MANAGEMENT

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## ABSTRACT

The objective of this paper is to present a new educational tool developed in the form of a business game for helping to understand concepts developed in the ECLIPS project, supported by the European Commission. The game provides an insight into different aspects of supply chain management, i.e. general supply chain mechanisms, as well as non-cyclic and cyclic inventory replenishment policies. This allows for people that have no deep notion in this area to better understand the project concepts and evaluate their efficiency in practice. Demonstrating concepts in a playful way is considered as more powerful and effective than purely explaining the underlying theory. The paper describes the rules of the game, playing process and provides results of the game test sessions.

Keywords: multi-echelon supply chain, supply chain management, simulation business game, education.

## 1. INTRODUCTION

Introducing of a new approach to supply chain management usually causes a necessity for its exhaustive explanation and illustration. For this purpose a new business game was developed that aims at providing an *educational tool* for helping in understanding concepts developed within the ECLIPS (Extended Collaborative Integrated Life Cycle Supply Chain Planning System) project. It specially targets creating awareness among supply chain key persons, managers of small and medium size enterprises (SME), students and decision makers that have a supply chain management background. The ECLIPS project objectives and developed approaches are discussed in Merkurjev et al. (2007, 2008).

The game focuses on multi-echelon supply chain networks. According to Chopra and Meindl (2007), a multi-echelon system can be defined as a series of two or more different facilities, where any change in the policy parameters in one facility affects the other facilities. A typical multi-echelon system (see Fig.1) is

one involving factory (1st echelon), central warehouse (2nd echelon), regional depot (3rd echelon) and retail outlets (4th echelon). There may be more than one facility at each echelon. A typical managerial problem in a multi-echelon system is to decrease total costs by coordinating orders across the supply chain, while providing a certain service level.

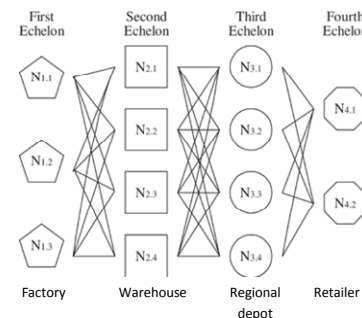


Figure 1: Multi-echelon Supply Chain Network

The game helps to understand how a multi-echelon supply chain based on cyclic planning is organised and functioning.

This game would not have been developed without the inspiration and experience drawn from other business games played and analysed by the authors. Some sources of inspiration include:

- MIT: beer game (Simchi-Levi et al., 2003);
- MÖBIUS: S&OP Game (Möbius);
- Involvation: Supply Chain Game (Involvation);
- EHSAL: ECOMAN business game (EHSAL).
- Gent University: ORSIAM Int. (Muller(-Malek), 1999);

## 2. DESCRIPTION OF THE GAME

The general process and playing rules by which the game is played is outlined in this sub-chapter. The different variations on the game, together with their



educational benefits are explained, as well as a short overview of the props used during the game and examples of possible networks are given here.

## 2.1. Playing process

The playing usually consists of playing a number of rounds (or periods) in the game. Each round consists of the following steps (which are executed from the end-customer to raw material supplier, echelon by echelon):

1. Tossing the demand dice(s) that determines end customer(s) demand;
2. Delivery of the demand by each retailer (if possible);
3. Filling in the “customer demand” and “delivery” columns in the respective transaction form;
4. Echelon by echelon delivery by transport;
5. For each retailer: decision if orders should be sent out to the nearest upstream warehouse;
6. Delivery of the demand by respective warehouse (if possible);
7. Echelon by echelon delivery by transport;
8. Decision if orders should be sent out to the nearest upstream warehouse. If an upstream warehouse is absent, production can be triggered;
9. Filling in the “customer demand” and “delivery” columns in the respective transaction form;
10. The raw material & production echelon has an alternating function each period: one period it can be triggered for new production, next period it moves its production one echelon ahead in the chain;
11. Filling in the “customer demand” and “delivery” columns in the respective transaction form.

### 2.1.1. Number of rounds to play

Ideally, more than three complete cycles have to be played to make conclusions. The required minimum number of periods in a game can be calculated with a following formula:  $play\_periods = echelons * 3$ .

The total number of playing rounds is not communicated to the players to avoid endgames. To avoid players guessing the number of periods, the scoring sheets contain entries for more periods than the number that will be played.

### 2.1.2. Playing with more than one player

If the game is played with more than one player, players are assigned to one or more inventory points. A possible further area of research is to assign different performance targets to the different players.

### 2.1.3. Performance metrics and scoring

At the end of the game, summary statistics are calculated based on performance metrics recorded during the game (see Tab. 2 and 3).

Following four performance metrics have been identified as being useful:

1. Demand: the sum of the demand at every retailer that is equal to the sum of the dices thrown.
2. Delivered products: the sum of the items delivered by retailers that is equal to the sum of the products that are placed in the trolleys.
3. Orders: how many orders have been issued during that round? An order is issued when a warehouse ships goods (by land, air, sea). Orders can be sent out by warehouses or retailers.
4. New production: the sum of the newly requested production at raw material & production units.

Calculation of the summary statistics is done by:

1. summing the four columns described above at the bottom of the sheets;
2. calculating the “inventory in the supply chain” at the end of the game by subtracting “start inventory” by “the sum of delivered” and adding “the sum of new production”;
3. estimating the “Service Level” at the end of the game is by dividing “delivered” by “demand”;
4. calculating the “total cost of the play” by summing up following components:
  - i. “inventory in the supply chain” \* “inventory carrying cost”;
  - ii. “sum of orders” \* “order cost”;
  - iii. “sum of New Production” \* “New Production cost”;
  - iv. Eventually: negative penalty for “sum of demand – sum of delivered” \* “lost sales cost”.

As a side remark, it should be noted that ideally, scoring should not take in account the part of the game where players “discover” the game mechanics. This can be done by scoring only over the number of periods minus the number of supply chain stages in the game.

A second side remark is that assembly games require a different scoring table. Each inventory-point has to be taken in account. Multi-sourcing games do not suffer from this drawback.

## 2.2. Different game modes to be played

Four ways of playing the game are provided.

1. Supply Chain Discovery: This play mode is suitable as a first introduction into multi-echelon supply chain inventory management. Player objectives are to attain a 95% service level at the lowest cost. Concepts that are suitable for identification are: general mechanisms of supply chains, bullwhip effect, introduction to ordering policies.
2. Ordering policies: Different ordering policies are played during the game and they are non-cyclic, cyclic non-synchronised and cyclic synchronised. Concepts that are suitable for identification are:

detailed workings of different ordering policies and their best practices.




3. **Supply chain design:** After playing with an existing supply chain, capacity constraints are introduced, the network is altered. The effects of changing the supply chain network become visible. Concepts that are suitable for identification are: mechanics of supply chain management and supply chain design.
4. **Risk Management:** Some assembly network is set up. Customer demand is kept as constant. Once the network and playing policies are stabilised, one of the suppliers is removed. Then the demand has to be satisfied by the remaining suppliers. Concepts that are suitable for identification are: supply chain risk management and risk mitigation strategies.

### 2.3. Symbols used during the game

Different supply chains can be modelled by using placemats with different symbols. They are described in the Appendix.

Only one product is used in the game. Because product large quantities can traverse the supply chain, colour codes are used to designate different quantities (see Tab.1).

Table 1: Colour Codes for Different Product Quantities

Products	Explication
	<u>One</u> unit of product
	<u>Five</u> units of product
	<u>Twenty-five</u> units of product

Demand occurs at a “retailer” and is generated by tossing either a:

- octahedron dice with sides 0,1,1,2,2,2,3,13 or
- cube dice with sides 0,1,1,2,2,9 or 0,1,1,2,3,11

For some games, demand can be constant or variable being read from a table each period.

Fulfilled demand is put in the “trolley” symbol. Unfulfilled demand is lost. No backlogging is allowed during the game. Depending on the game, a penalty for lost sales might be given.

### 2.4. Networks used during plays

The authors have tested different networks during the development phase. They felt some networks were more appropriate to illustrate some specific problems than others.

#### 2.4.1. Linear Supply Chain

Linear supply chain is represented in Fig.2. It can be used in the Discovery mode of the game. Each warehouse starts with an inventory of 20 products and retailer starts with an inventory of 30 products. Demand is dynamic and stochastic. The chain should be played for at least 30 periods.

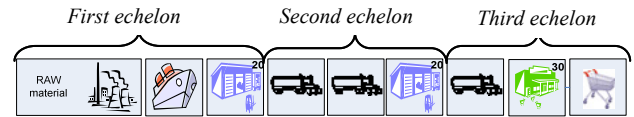


Figure 2: Three-echelon Supply Chain

#### 2.4.2. Distribution Chain (Paint Production Network)

Paint production network can be used in the ECLIPS mode. It consists of two subsequent distribution steps (see Fig.3). The black lines in figure indicate the possible ways to supply products to three end-customers (labelled from one to three). The initial stock of products is placed on the respective card; it is indicated in the figure below with numbers. Demand is dynamic and stochastic. The network should be played for at least 30 periods.

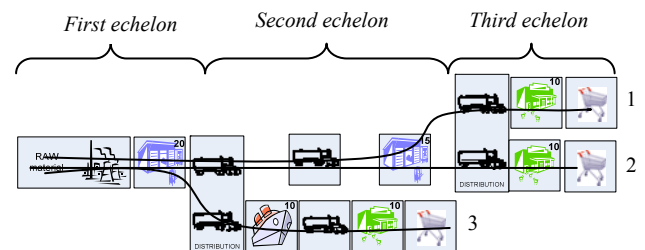


Figure 3: Three-echelon Distribution Network

#### 2.4.3. Small Assembly Chain

Small assembly chain consists of one assembly step which is intertwined with long transports and only one customer (see Fig.4).

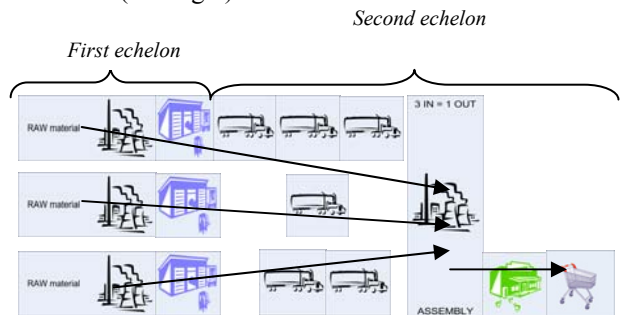


Figure 4: Small Assembly Chain

#### 2.4.4. Large Assembly Chain

Large assembly chain consists of three subsequent assembly steps which are intertwined with long transports and only one customer (see Fig.5). If a risk management game is played, the assembly step in the 2<sup>nd</sup> echelon could be replaced with a multi-sourcing.

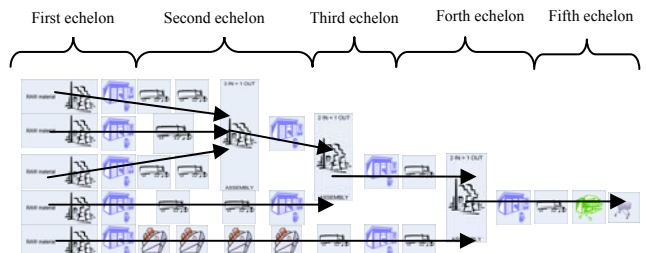


Figure 5: Large Assembly Chain

### 3. GAME TESTING RESULTS

The business game tests were performed by MÖBIUS and Riga Technical University (RTU) in January - February, 2008. This chapter describes the results of the game first plays and demonstrates what has been learned by the game players.

In the business game tests at MÖBIUS 8 players from the company participated and 5 concept tests were performed. At RTU the game tests were held within the course 'Supply Chain Management', where participated 18 Master students and 3 members from the department staff.

The following educational scheme and agenda of the day were proposed for the game plays at RTU:

1. Introducing the game –general rules (20’);
2. Playing the Discovery mode as an introduction into multi-echelon supply chain management (40’);
3. Analysing the results of the Discovery mode (10’);
4. Playing the ECLIPS mode as getting insight into following replenishment policies and their best practices (40’):
  - a. Non-cyclic, or continuous review policy (ROP);
  - b. Cyclic, or periodic review policy (POR):
    - Cyclic non-synchronised,
    - Cyclic synchronised;
5. Analysing the results of the ECLIPS mode (10’);
6. Making general conclusions (10’).

#### 3.1. General guidelines

The following are general guidelines of the game plays at RTU.

1. Supply chain networks are physically simulated in the game.
2. For each game mode a specific multi-echelon supply chain network is designed, i.e. a distribution network with 3 echelons and 5 nodes (see Fig.3) for the Discovery mode, and a three-echelon 3 nodes linear chain (see Fig.2) for the ECLIPS mode. Each element of the supply chain is represented by a card. The meanings of cards are explained in the Appendix.
3. Possible roles of players are defined as:
  - i. Retailer (R),
  - ii. Distribution Centre (DC),
  - iii. Factory Warehouse (FW),
4. Players' objective is defined as follows: to attain a 95% service level at the lowest cost.
5. The following costs are considered:
  - i. inventory holding cost that is equal to 1 EUR per period per unit,
  - ii. fixed order cost that is equal to 10 EUR per order,
  - iii. production cost that is equal to 3 EUR per unit.

6. Customer demand is dynamic and stochastic.
7. Only one product is used in the game.
8. Production can be triggered every 2 weeks in the Discovery mode, and it is instantaneous in the ECLIPS mode, so the manufacturer can produce when needed.
9. Information about the end customer demand, inventories at each stock point and placed orders in the network is visible for all players.
10. The number of periods in the game play is defined by 15 periods for the Discovery mode and by so called "long run", i.e. 100 periods, for the ECLIPS mode. Here, 1 period corresponds to 1 week of a real life.

#### 3.2. Gameplay

The recommended number of players for each supply chain network is defined by 3 in each team. Several teams supported by game moderators could play simultaneously.

Each player is assigned to a particular inventory point(s); e.g., in the Discovery mode:

- Player 1: R1, R2, R3 (retailers Nr. 1, 2, 3);
- Player 2: DC (distribution centre);
- Player 3: FW (production site with an inventory point).

Cards are placed on the table for a specific supply chain network layout defined in section 2.4.

Special forms developed for each player role, i.e. R, DC and FW in the network (see Tables 2, 3) were used by players in order to fix all transactions made during the game sessions.

Table 2: Transaction Form for R and DC

Inventory Carrying Cost		Order Cost					
1		10					
Period	Stock at the beginning of period	Customer Demand	Delivered	Stock at the end of period	Order	Service Level	Costs
1							
2							
3							
4							
...							
...							
14							
15							

Table 3: Transaction Form for FW

Inventory Carrying Cost		Order Cost		Production Cost			
1		10		3			
Period	Stock at the beginning of period	Customer Demand	Delivered	Stock at the end of period	New production	Service Level	Costs
1							
2							
3							
4							
...							
...							
14							
15							

To generate end-customer demand, a cube dice with sides 0-1-1-2-2-9 was used (see Fig.6). If respective

network contains more than one end customer, a dice is tossed several times to simulate demand for each end customer.



Figure 6: A Dice for the Game

At the end of each game mode, the following tasks are performed by the game moderator (in the Discovery mode) or by participants (in the ECLIPS mode):

1. Making cost calculation, i.e. total costs for each echelon and for the whole company (for this purpose special Excel templates of transaction forms are provided).
2. Drawing the following graphics based on processing data in Excel transaction forms to analyse:
  - a. company service level;
  - b. company inventory level;
  - c. company total costs;
  - d. demand variation through the network (only for the Discovery mode);
3. Explaining a decision strategy (only for the Discovery mode).

### 3.3. Results of the game

#### 3.3.1. Discovery mode

In the Discovery mode, 15 playing rounds were performed. As defined in the general guidelines, players' objective is defined as follows: minimising the company total costs while attaining a service level of 95%.

Let's note that lead times in the network are set at 1 period between retailer 1, retailer 2 and distribution centre as well as between distribution centre and factory warehouse, and at 3 periods between retailer 3 and factory warehouse (see Fig.3). Initial inventories are set at 10 pieces for retailers, 15 pieces for distribution centre and 20 pieces for factory warehouse as well as 10 pieces are in transit between factory warehouse and retailer 3.

Table 4: Example of Completed Transaction Form

Period	Stock at the beginning of period	Customer Demand	Delivered	Stock at the end of period	Order	Service Level	Costs
1	10	2	2	8	0	100,0%	8
2	8	9	8	0	1	90,9%	10
3	0	0	0	0	0	90,9%	0
4	12	1	1	11	0	91,7%	11
5	11	2	2	9	0	92,9%	9
6	9	1	1	8	0	93,3%	8
7	8	1	1	7	0	93,8%	7
8	7	1	1	6	0	94,1%	6
9	6	1	1	5	1	94,4%	15
10	5	9	5	0	1	81,5%	10
11	5	1	1	4	0	82,1%	4
12	9	0	0	9	0	82,1%	9
13	9	9	9	0	1	86,5%	10
14	0	2	0	0	0	82,1%	0
15	5	1	1	4	0	82,5%	4

Example of completed transaction form by DC player is presented in Tab.4. All data recorded by the game players in transaction forms are summarised in the Excel template sheet "Summary results" and used by the game moderator to calculate "Debriefing" results presented in Tab.5. These results include company performance metrics such as total costs, service level, new production, etc.

In the debriefing session the analysis of the company service level, inventory level, total costs and demand variation (see Fig. 7, 8, 9, and 10) leads to the following main conclusions.

As it follows from Fig.7, the game objective was not fully met. After the period T9 the service level dropped below 95%.

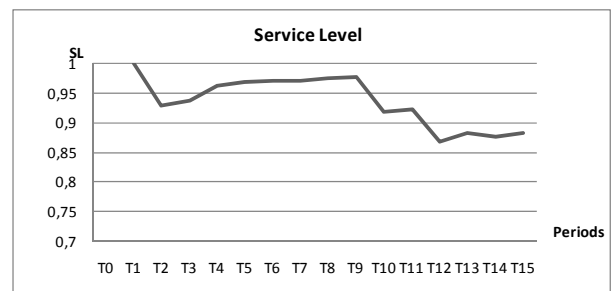


Figure 7: Company Service Level

Table 5: Results of the Discovery Mode

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	Sum	Average	FR
WIP	75	77	67	95	84	94	91	90	85	82	67	77	71	66	56	52		76,9	
SL		100,0%	92,9%	93,8%	96,3%	96,8%	97,1%	97,1%	97,5%	97,7%	91,9%	92,3%	86,8%	88,4%	87,8%	88,2%			88,2%
Cost pp		112	97	205	94	166	111	90	85	102	87	136	81	121	66	52		107,0	
Customer Demand		3	11	2	11	4	3	1	5	3	19	3	11	10	12	4	102	6,8	
Delivered		3	10	2	11	4	3	1	5	3	15	3	6	10	10	4	90	6,0	
Orders		2	3	2	1	3	2	0	0	2	2	2	1	4	1	0	25	1,7	
New Production		5	0	30	0	14	0	0	0	0	0	13	0	5	0	0	67	4,5	

Inventory initially raised then dropped below starting levels (see Fig.8). This could be explained by a company decision to decrease a safety stock level in order to minimise the company total costs. Due to this reason, as follows from Fig.9, costs were reduced after period T6.

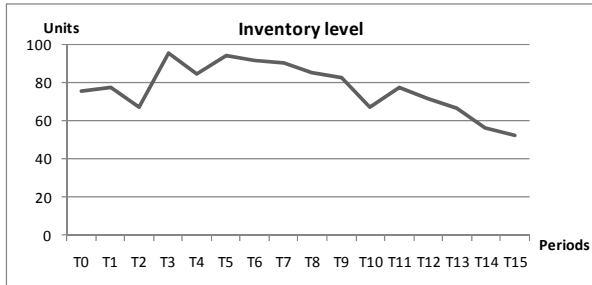


Figure 8: Company Inventory Level

However, since the decisions were made intuitively, it caused the decrease of the service level already after two periods (see Fig.7). This is due to the lead time of 2 periods between stock points. This result could have been partially expected, because the time to travel completely through the network is 8 periods and players did not have enough time to overpass arisen problem. Moreover, as follows from Fig.10 the demand variation increases in the network upstream echelons.

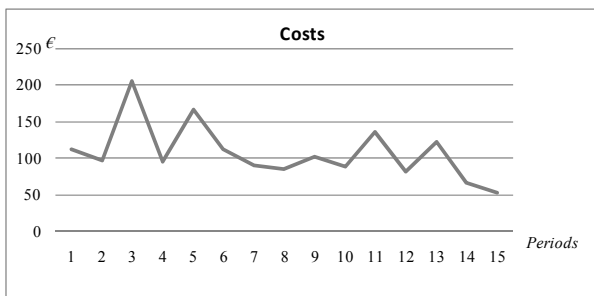


Figure 9: Company Costs

As a result, the company's strategy was not successful and it is necessary to introduce some inventory management techniques that could help to calculate a safety stock level that ensures service level of 95% and avoid so called bullwhip effect problem.

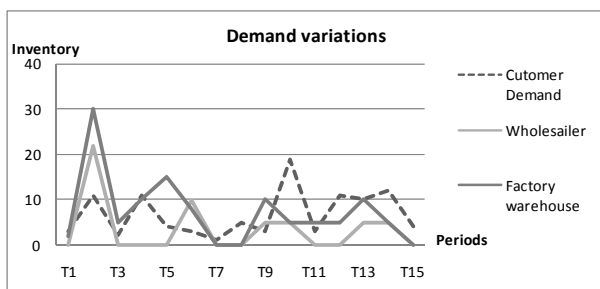


Figure 10: Demand Variations

The results of the Discovery mode were discussed in debriefing and acknowledged the material to be learned in the next game session.

### 3.3.2. ECLIPS mode

The ECLIPS mode of the game practically demonstrates the theoretical aspects of using different reordering policies. A non-cyclic (reorder point driven referred to as ROP) policy is compared with a cyclic policy (referred to as POR). The ECLIPS research has indicated hard and soft benefits of using the latter.

The hard benefit is an inventory reduction that can be witnessed during the game (see Fig. 11). As the most evident soft benefit, easy decision implementation and control can be mentioned.

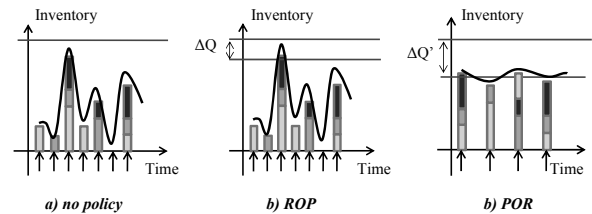


Figure 11: Inventory reduction potential

For testing purposes, a “long run” of 110 periods was performed for each of the three replenishment policies:

- non-cyclic,
- cyclic non-synchronised,
- cyclic synchronised.

For regular plays, only 30 playing rounds have to be performed. As defined in the general guidelines, players' follow the objective defined in the Discovery mode.

Let's note that lead times in the network are set at 1 period between retailer and distribution centre, 2 periods between other stock points and 1 period between raw material & production and nearest downstream warehouse (see Fig.2). Initial inventories are set at 30 pieces for retailer and 20 pieces for distribution centre and factory warehouse. The following policies are played in the game:

- non-cyclic policy with lot size =7 and reorder point equal to 8, 14 and 22 for retailer, distributor and factory warehouse, respectively;
- cyclic non-synchronised policy with cycles of 3 days and order-up levels of 21, 25, 25 for retailer, distributor and factory warehouse, respectively, that order at the same time;
- cyclic synchronised with cycles of 3 days and order-up levels of 21, 25, 25 for retailer, distributor and factory warehouse, respectively, that order when the previous stage has been supplied. All calculations are made according to respective formulas described in Simchi-Levi et al. (2003).

While testing, all results from transaction forms completed by players were aggregated and processed by the game moderator in the Excel template sheet

“Summary results” and used to calculate and analysed “Debriefing” results presented in Tab.6 and Fig. 12, 13, 14, and 15. These results include company performance indicators such as average inventory level and average costs, etc. For regular playing, players calculated the company performance indicators and draw graphics by their own.

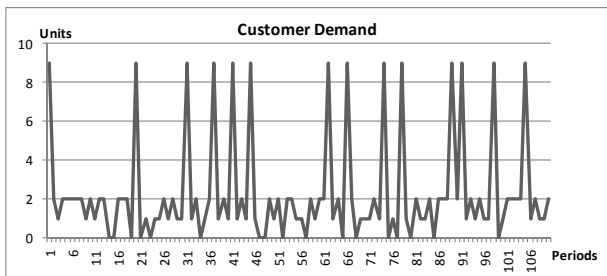


Figure 12: Customer Demand

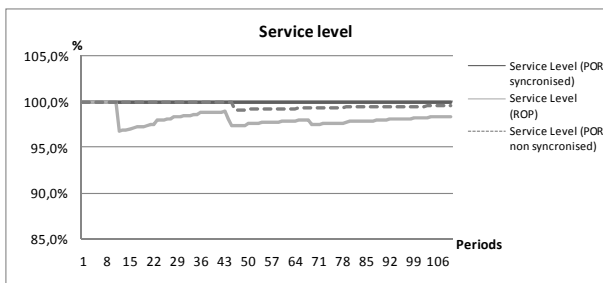


Figure 13: Service Level

Customer demand is shown in Fig.12. As follows from Fig.13, all replenishment policies allow keeping service level up to 95%.

Table 6: Results of Different Replenishment Strategies

	Non-cyclic	Cyclic non-synchronised	Cyclic synchronised
Average Costs	86,47	85,41	81,03
Average Inventory	71,15	68,74	64,46

However, by comparing average costs (see Tab.6), we can conclude that implementation of cyclic policy reduced the company average costs and average inventory level, in comparison with non-cyclic policy (see Fig. 14 and 15). Moreover, implementing synchronised cyclic policy can improve the results even more.

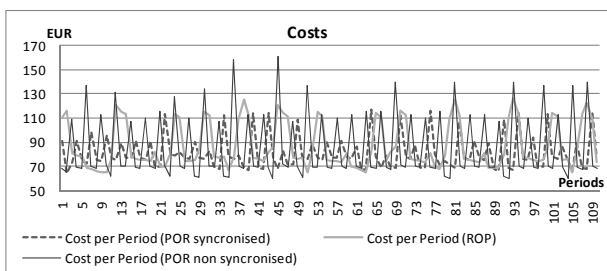


Figure 14: Total Costs

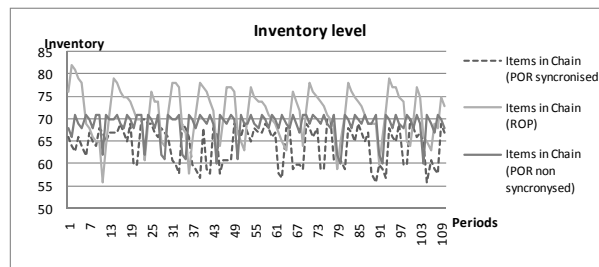


Figure 15: Inventory Level

Finally, we could conclude that trough playing the game participants could learn about the problems that arise in supply chain inventory management and what benefits the company could gain by implementing the cyclic replenishment policies.

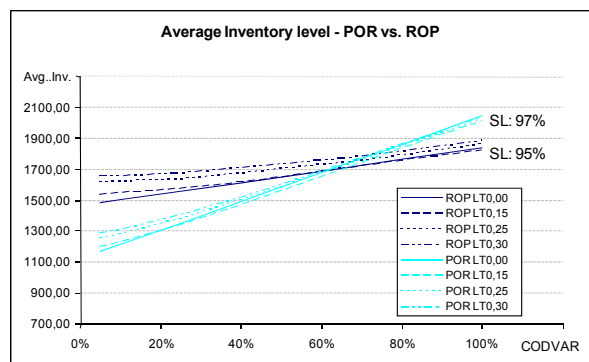


Figure 16: Industry case

Within the ECLIPS project a real industry case was investigated. The first results obtained from simulation indicate that the theory developed during the project can be proved (see Fig. 16). A real life implementation is scheduled at the end of the ECLIPS project. This implementation will be done for an even more complex case than those used in the simulations (= a “complex” generic network with 3 product branches in it resulting in 42 end products and 33 intermediary products).

#### 4. CONCLUSIONS

A business game for bringing over the ECLIPS concepts of Multi-Echelon Cyclic Planning (MECP) has been developed. Performed tests demonstrated ability of the game to help in understanding general mechanisms of supply chain management concepts, has been developed within the ECLIPS project. In particular, the game was used in order to introduce ordering policies aimed to improve supply chain performance, proving their efficiency and demonstrating benefits of their implementation. Performed experiments allows practically demonstrate to the game participants the theoretical aspects of investigated theory.








This business game can be used, for instance, at: large companies (early during a MECP deployment track); small and Medium companies (to propagate knowledge and concepts, and during a MECP deployment track); educational institutions and seminars (to bring over the ECLIPS concepts).



The discussed experiences approve the statement that demonstration of different events and decisions in supply chain in a playful way is a powerful and effective way to bring them over to a public. It is a worthy alternative to classic ex-cathedra explaining of the considered theory.

### ACKNOWLEDGEMENT

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### APPENDIX. SELECTION OF SYMBOLS USED IN THE GAME

Card	Explication
	<p><b>Raw Material &amp; Production</b> Production takes two periods to complete.</p> <ul style="list-style-type: none"> <li>• During the first period raw materials are ordered and processing starts.</li> <li>• During the second period the produce becomes available and can be moved to the next placemat (probably a warehouse).</li> </ul> <p>The difference between this symbol and the “production unit” is that this symbol is the first echelon of the network, whereas the “production unit” is placed in the middle of the network.</p>
	<p><b>Production Unit</b> A product can be transformed at a production unit. Production is pushed to the next placemat on the next period.</p>
	<p><b>Warehouse</b> Products can be stored at a warehouse. They only move if an order is received from either a production unit or a retailer.</p>
	<p><b>Transport by ship</b> Takes 1 period to complete. Unlimited capacity.</p>
	<p><b>Transport by truck</b> Takes 1 period to complete. Unlimited capacity, unless otherwise indicated.</p>
	<p><b>Retailer</b> Depicts a place where end-customers go shopping. A retailer (or a shop) is always succeeded by a shopping trolley.</p>
	<p><b>Trolley</b> End customer demand is placed in the shopping trolley. If the retailer has not enough inventories, only the fulfilled demand is put in the trolley.</p>

  DISTRIBUTION	<p><b>Distribution</b> These placemats indicate a distribution step. The examples on the left indicate two and three way distribution. Products are placed on the truck that goes to a specific sub-chain of the network. Once goods are put on a specific truck, they cannot be moved to another sub-network anymore.</p>
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### REFERENCES

Chopra, S, Meindl, P, 2007. *Supply Chain Management: Strategy, Planning, and Operation*. New Jersey, Prentice Hall.

EHSAL Management school. *Business game ECOMAN*. Available from: <http://www.ehsal.be/EMS/ecoman.asp> [accessed 28.04.2008].

Involvation. *Learning - Doing & Thinking*. Available from: <http://www.involvation.com> [accessed 28.04.2008].

Merkuryev Y., Merkuryeva G., Desmet B., Jacquet-Lagreze E., 2007. Integrating Analytical and Simulation Techniques in Multi-Echelon Cyclic Planning. *Proceedings. First Asia International Conference on Modelling and Simulation. AMS 2007. Asia Modelling Symposium 2007. 27-30 March 2007. Prince of Songkla University, Phuket, Thailand*. Editors David Al-Dabass, Richard Zobel, Ajith Abraham, Steve Turner. IEEE, 2007. P. 460-464. IEEE Computer Society

Merkuryev Y., Merkuryeva G., Hatem J., Desmet B., 2008. Supply Chain Simulation in the ECLIPS Project. *Proceedings. Second Asia International Conference on Modelling and Simulation, AMS 2008 (13-15 May 2008, Kuala Lumpur, Malaysia)*. Edited by David Al-Dabass, Steve Turner, Gary Tan, Ajith Abraham. IEEE, 2008. P. 684-690. IEEE Computer Society

Möbius. Added value of the S&OP Business game. Available from: <http://www.mobius.eu/cms/doi/pid/77> [accessed 28.04.2008].

Muller (-Malek) H., 1999. Value Assesment of a Take-Over Bid for a Competitor’s logistics Operations. In: Henri Mullerr (-Malek), Yuri Merkuryev, Irena Silinevicha, Gert Zulch, ed. *Cases in Industrial Logistics Management*. Shaker Verlag. Pages 215-222.

Simchi-Levi, D., Kaminski, P., Simchi-Levi, E, 2003. *Designing & Managing the Supply Chain*. New York, McGraw-Hill.

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# EXPERIENCES FROM THE APPLICATION OF HLA-BASED DISTRIBUTED SIMULATIONS IN THE PRODUCTION OF VEHICLES

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## ABSTRACT

This article discusses the application of distributed simulation in the context of vehicle production planning. The experiences are derived from a real industrial project which aimed at connecting up to seven individually developed simulation models. The article reports on lessons learned which include the need for efficient ways to manage and control HLA-based distributed federations, to maintain a single code base for the models as well as lookahead considerations for synchronization.

Keywords: distributed simulation, production planning, vehicle production

## 1. INTRODUCTION

Distributed Simulation refers in general to the concurrent execution of several simulation models on one or multiple processors (Fujimoto 2000). Resulting benefits are possibilities to reuse existing simulation models in an expanded context as well as to couple simulations models of different software manufacturers.

In factory design and furthermore in factory operation simulation models of different factory sub sections are often developed independently and with differences in level of detail and utilization focus. These models are usually well suited to analyze the respective factory sub sections. To model the interdependencies between the several sub sections, a complex model is needed. Dependencies of sub sections are mostly influenced by existing connection modules like storages or transport operations.

How can such a complex model be created? The classical approach would be the development of a new monolithic overall model, often with a level of detail which is lesser than the one provided by existing sub models. A different possibility (which is suggested in this contribution) is the coupling of the pre-existing simulation models establishing a complex distributed model while keeping the achieved level of detail. This approach has the following advantages yielding mainly from the reuse of the existing simulation models (Strassburger et al. 2006, Rabe und Jäkel 2001):

- Saving model development time in respect to the development of a new monolithic overall model
- Assuring the obtained level of detail
- Ensuring consistence between sub models and distributed overall model

The paper describes authors' experiences from an industrial project targeting HLA-based distributed simulation in the utility vehicle sector production. The following chapter explains very shortly basic tasks of distributed simulation and characterizes the usability of distributed simulation in industrial applications. Subsequently the starting position for this project and the derived requirements will be explained. Some implementation details are commented in the following chapter. Calculated results from the complex distributed simulation model are presented in the subsequent chapter. An outlook finishes the paper.

## 2. BASIC TASK INSIDE DISTRIBUTED SIMULATION

To achieve the needed interoperability between the pre-existing simulation models, there are three main tasks derived from the distributed simulation paradigm which must be fulfilled (Fujimoto 2000). At first an agreement on common objects of interest inside all simulation models has to be created. All participants have to use the same interpretation of sent and received data. This agreement has to consider the semantic interoperability between all components of the distributed model. The second task is to exchange data based on common objects which are defined in the agreement. Typically publish and subscribe mechanisms are applied. Synchronization of simulation time inside components is the third main task. In general every component has its own simulation clock and has to react to external events from other components.

The existing approaches can be divided into two categories. The first category includes solutions which couple only homogenous simulation models from one simulation model family. In this style, different models within one simulator (e.g. Plant Simulation) can be coupled based on internal features of that simulator.

This is a rather inflexible solution as it is bound to the proprietary capabilities of that simulator.

More flexibility is provided by solutions from the second category. These solutions are independent from a single simulation software manufacturer and are based on a framework or standard providing interoperability between the models. They are not bounded on proprietary interfaces. Known approaches are for example FAMAS (Boer 2005) and HLA (IEEE 1516-2000). The HLA-approach is a world-wide used and standardized architecture for distributed simulation, which allows to couple simulation and non-simulation components with different time advance mechanisms. Based on rather good user-acceptance, high flexibility and our own experiences with HLA we decided to use HLA for an industrial application.

### 3. STARTING POSITION

Within design and construction of a vehicle production factory, independent simulation models were developed to simulate the behaviour of seven interrelated assembly and paint sections. These models are used after the design phase to support ongoing factory operations. The material flow inside the factory is presented in figure 1. The aim of our industrial project was to connect the pre-existing sub section models of a factory and to integrate them into a complex distributed simulation model. This complex model should be used to investigate the interrelationships between the different sub sections. Therefore the dimensioning of buffers between sections and the coordination of production schedules were investigated in order to assess bottlenecks in the complex system. In our experience this scenario of having to couple different independently developed simulation models represents a typical use case in industrial applications.

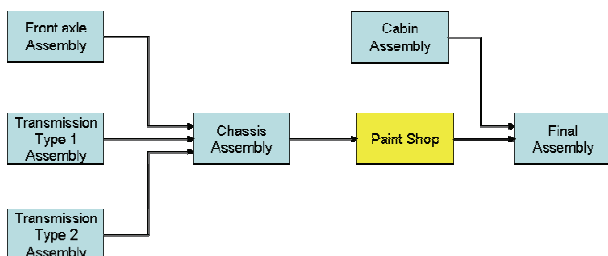


Figure 1: Schematic View on the Production System

Differences which typically need to be solved concern the implementation of the simulation models in varying simulation software, levels of detail in the models, time advance mechanisms and time dependencies. Our models can be divided into two application categories: assembly and paint shop models. Each category uses its own generic SLX simulation model, which is used in combination with an appropriate configuration file to generate an executable SLX simulation model suitable for one production area. Due to existence of a generic HLA interface for the SLX simulator, HLA with RTI 1.3NG was selected to

perform as middleware for distributed simulation (Straßburger 2001).

### 4. REQUIEREMENTS

To use a complex distributed model in this context following requirements need to be fulfilled:

- Unique model version both monolithic and distributed for using legacy simulation models,
- Simple management of distributed simulation tasks,
- Presentation of additional results related to the context of distributes simulation and
- Observance of simulation run-time.

An important requirement within the presented industrial project was the need to maintain a single code base for the monolithic and the distributed model versions of the models. This was a mandate to keep the models consistent as they are used in daily operations. The configuration of the models had to allow the flexibility to run a model either in stand-alone mode or connected to other models. The distributed model version has to contain additional features which allow for example reactions on external events, synchronisation with other distributed models and modelling of transport to the successor model. These additional features have to be hidden.

The HLA-runtime environment offers services of a very low level for managing basic tasks. For example, a distributed simulation model has to be started, has to join and resign the federation, and has to be finished in well defined way. Within our project scope it was advisable to develop a dedicated user interface that coordinates the necessary services for these tasks and hides them from the user.

One of the main project goals was to obtain new insights from the distributed complex model, which can't be obtained from single monolithic models. New features for collecting information and statistics between the models and their presentation in user-friendly environment had to be developed.

The run-time of distributed simulation models is strongly influenced by size of lookahead and used synchronisation methods. 100 days is a typically value for simulation run inside this industrial application area. Monolithic simulation models based on SLX execute these simulations in some seconds of run-time. The project has to guarantee run-times for distributed simulation which are in acceptable time slots.

### 5. IMPLEMENTATION

From the set of necessary implementation tasks, the customization of the generic models, the modelling of the material flow, the influence of the lookahead and the development of a user interface were chosen to be explained in more detail.

### 5.1. Customization of legacy generic simulation models

There were two different types of monolithic legacy generic simulation models. One for simulation of assembly processes and the other for simulation of painting processes. Both monolithic model types differ in modelling approaches; they are specialized for their application area. But they are unique in their implementation language SLX and generic concept. The generic models starts and will be adapted by using configuration files to a specific simulation model. Both legacy generic simulation models have to be extended through:

- HLA-services for joining and resigning a federation as soon as sending and receiving of object attributes and interactions,
- Integration of external events into their local event list and responding on this external events and
- Modelling of part movement between coupled models.

The requirement was the customization of the pre-existing generic monolithic simulation models to be able to participate in the distributed simulation. A basis condition was to avoid the development of different model versions for monolithic and distributed applications. The generic model should be able to generate both a monolithic and a distributed version of the simulation model to ensure the consistency between both models. The simulation language SLX offers the possibility to extend the source code during compilation. By using this SLX feature different model versions can be generated smartly. Figure 2 shows the approach to customize the pre-existing generic models.

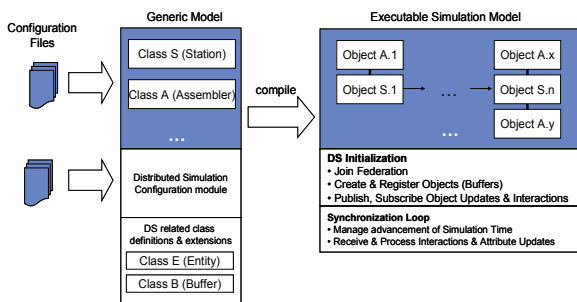


Figure 2: Customizing pre-existing generic simulation models for use in distributed simulations

Monolithic simulation models usually destroy their flowing material parts when they reach the end of the modeled process chain. In a distributed simulation it becomes necessary to hand over subsets of these parts to successive models. The transfer conditions of our industrial pilot project include the transfer of material to a bounded buffer of a successive model. In the distributed version the same simulation model has to pass the material part to next model. Enhancements to the simulation code had to be made to allow this behaviour.

Regarding their interoperability requirements our distributed simulation models are therefore compliant with a Type A.2 Interoperability Reference Model. The classification used here is derived from the Draft Standard for Commercial-Off-The-Shelf Simulation Package Interoperability Reference Models (Taylor, S. 2007) The A.2 reference model type describes the synchronized transfer of entities into a buffer with limited capacity. In our solution implementing this transfer and its conditions, we use an HLA interaction for the entity transfer and HLA attribute updates to communicate the current buffer content of the respective input buffers. Figure 3 shows a principle view and some important data structures.

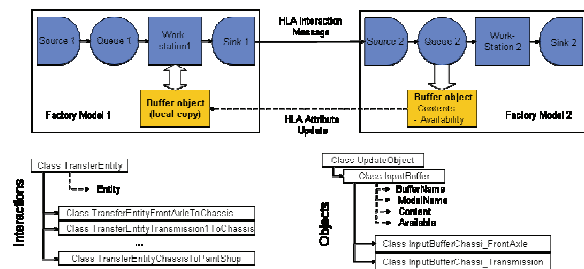


Figure 3: Modelling the Material and Information Flow beyond the Borders

For allowing the operation in a distributed simulation certain data about local objects and its attributes (which are of interest to the other models) has to be communicated regularly to other simulation models.

The Factory Model 1 in Figure 3 has to know the availability of the input buffer (Queue 2) in Factory Model2. Only if this buffer is available Factory Model 1 can transfer a part to Factory Model 2. The buffer object is published to all other models with the attributes Contents and Availability. Factory Model 2 publishes all changes of the attributes to other simulation models. A local copy of the buffer from Factory Model 2 is used inside Factory Model 1. If an attribute update from the original buffer is sent then the local copy will be updated automatically. So consistency between original and copy is ensured and Factory Model 1 decides about part transfer depending on the local copy of the buffer in Factory Model 2. For the publication and subscription as well as the sending and receiving of such data certain HLA functionalities have to be used. This behaviour has to be implemented, in the best case in a manner transparent to the end user.

### 5.2. Influence of lookahead

In distributed simulation the lookahead describes a period of time in which a sub model will not create external events for other sub models. Using a lookahead greater zero conservative synchronisation methods can calculate a time limit for other sub models. In general an increasing lookahead enforces parallelism of sub model execution and leads to decreasing execution time of distributed simulation models. Results of

experiments with different sizes of lookahead are shown in Figure 4.

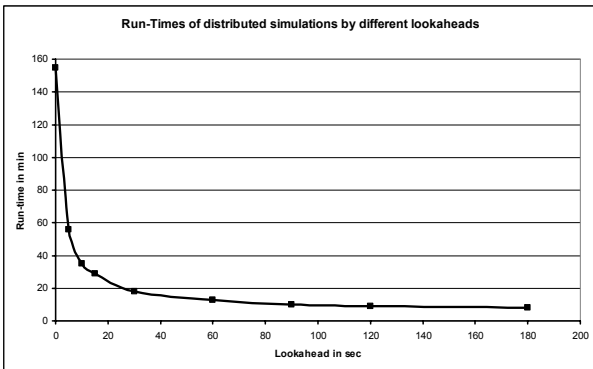


Figure 4: Run-Times of Distributed Simulations by Different Lookaheads

To use a large lookahead is useful from the point of performance. But a lookahead  $> 0$  is influencing the logic inside execution of events. This is shown using one example (Compare Figure 3). Factory Model 1 can not deliver parts if the buffer of Factory Model 2 is not available. Assume that the buffer attribute Availability has been updated inside Factory Model 2 at time  $t_1$ . The other models will be notified about the new value will at a timestamp  $t_2 = t_1 + \text{lookahead}$ . The value of the local copy of the buffer object inside Factory Model 1 will therefore not be updated until time  $t_2$ . As a result the logic inside Factory Model 2 uses an incorrect value about availability until time  $t_2$ . This can lead to undesired reactions inside Factory Model 2. For example, if the buffer is not available and the Factory Model 2 doesn't know this fact and then factory Model 2 could send a part into the full (not available) input buffer.

None general solutions for this problem have been found inside this project. Special application-depending approaches were used to avoid such problems.

### 5.3. User-Interface

For real industrial usage of distributed simulation it is necessary to support the end user in his operational work with the distributed simulation. The existing features and user interfaces of commercial simulators do not support the work with models in distributed environments. During the implementation of the industrial pilot project (which included up to seven individual models) it became very soon clear that the existing manual control features for starting, closing and controlling the distributed simulation were insufficient. For this reason the development of a user-interface (called commander) was initiated.

The version of the user-interface (called commander) currently developed provides the following services:

- Encapsulation of RTI-Services against the user
- Supporting the user in creating the composition of the complex model

- Creation of model visualization and calculation of simulation statistic
- Starting, controlling and closing down entire executions of the distributed simulation

The commander provides the opportunity to compose and manage distributed simulation models on an abstract layer without having the need to access the HLA API. Such a layer is mandatory to achieve high acceptance of distributed simulation in operational environments. The commander was implemented in C++ to be able to access the RTI-services provided by the HLA API. To store the commander configuration, an XML-file is used. Figure 5 shows an example of the Commander user interface.

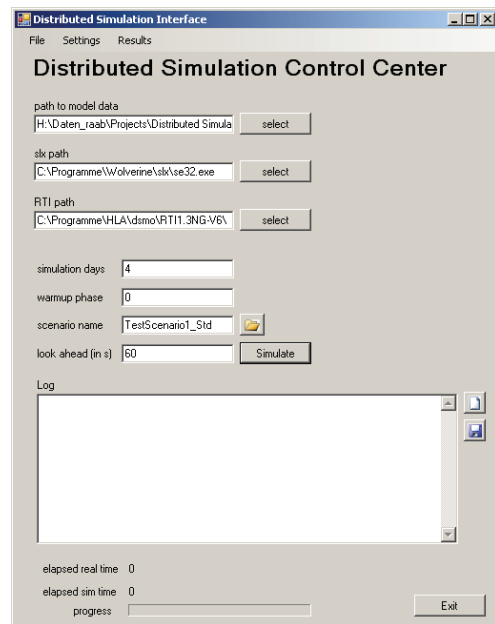


Figure 5: Form for the User-Interface

## 6. RESULTS

Besides the standard numerical result preparation within the pre-existing monolithic models, an "Observer-Federate" was used to collect data regarding the distributed simulation including the flow of material between the connected models and the history of buffer content changes. These data can be collected from the regular communication traffic between the models. For further characterization of dependencies between the different factory sections, each model collects additional statistics on waiting times due to full buffers and waiting times due to missing materials. This information relieves the search for bottlenecks in the complex system.

Table 1 shows results from model M4 for waiting times. Models M1, M2, M3 and M4 deliver parts to model M4. The production in model M4 has to stop, if needed parts from provider models are not available. Statistic for the duration of this models state is gathered.

Delays due missing incoming sub-models			
Model	Provider Models		
M4	M1	M2	M3
# of delays	0	10	4
Minimum delay	0s	30m	4m
Average delay	0s	3h 30m	45m
Maximum delay	0s	7h 34m	2h23m
Sum delay	0s	17h 30m	4h34m

Table 1: Delay Times for Model M4 Due Missing Incoming Parts from Provider Models

Figure 6 shows an example about demand and simulated production output of a sub model. The sub model depends on other sub models which deliver parts. The production output, depending on the behaviour of provider models can be calculated only in a complex model.

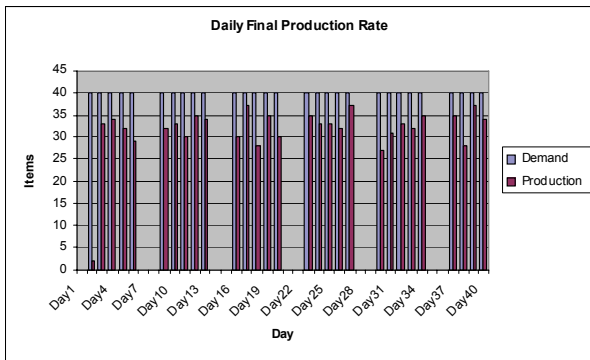


Figure 6: Daily Demand and Simulated Production Output for a sub model

For each of the monolithic simulation models in our industrial project an individual visualization model had been created. These models were inappropriate for the visualization of the distributed simulation, as for this use case only the material flow and the buffer fill levels *between* the individual models were of interest (i.e., the internal actions *within* a model were not to be visualized). Therefore a new visualization including statistic features for the interesting outputs had to be created (compare Figure 7).

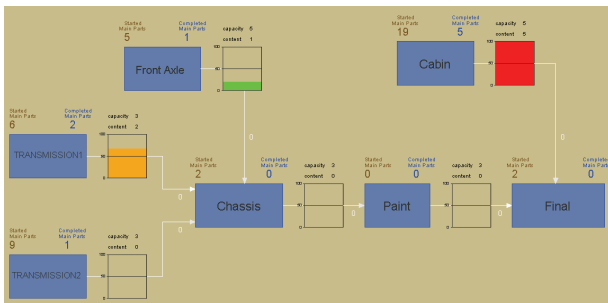


Figure 7: Visualisation of Material Flow and Buffer Contents

## 7. FUTURE WORK

The goal of this industrial project to use legacy monolithic simulation models in a distributed

simulation models has been achieved. The results that have been derived from the complex distributed model are relevant for project members. This project shows that distributed simulation in industrial fields is necessary, possible and manageable.

Additional work will be done in two directions: The development of more general solutions for the lookahead problem and the improvement of management services for more simply use an application of distributed simulation models.

## REFERENCES

- Boer, C. (2005). Distributed Simulation in Industry. Doctoral Thesis Erasmus University Rotterdam
- Fujimoto, R. (2000). Parallel and Distributed Simulation Systems. Wiley-Interscience
- IEEE 1516-2000 (2000) IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Framework and Rules.
- Rabe, M.; Jäkel, F.-W. (2001). Non military use of HLA within distributed manufacturing scenarios. In Schulze, T, Schlechtweg, S., Hinz, V.. (eds) *Proceedings der Tagung Simulation und Visualisierung 2001*. S.141-150. SCS Europe, 2001
- Straßburger, S. (2001). Distributed Simulation based on the High Level Architecture in Civilian Application Domains. Doctoral Thesis, University of Magdeburg, Germany.
- Strassburger, S., Schulze, T., Lemessi, M. (2006). Applying CSPI Reference Models for Factory Planning. In: *Proceedings of the 2007 Winter Simulation Conference*, eds. S. G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, pp. 603-609. December 9-12, 2007. Washington, D.C., USA.
- Taylor, S.J.E., Mustafee, N., Strassburger, S., Turner, S.J., Low, M.Y.H., Ladbroke, J. (2007). The SISO CSPI PDG standard for commercial off-the-shelf simulation package interoperability reference models. In: *Proceedings of the 2007 Winter Simulation Conference*. S. G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, eds., pp 594-602

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# MOST AND MTM FOR WORK METHODS OPTIMIZATION: A REAL CASE STUDY BASED ON MODELING & SIMULATION

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## ABSTRACT

The starting point of the research work is the actual configuration of a workstation (Pressure test workstation) belonging to a manufacturing system operating in the field of hydraulic hoses production. The objective of the paper is twofold. From one side it aims at comparing four different work methods for optimizing the workstation productivity. Note that the comparison is accomplished according to the work methods process time. From the other side the authors aim at comparing two different work measurement methods trying to establish the more efficient one. Note that the work measurement methods are used for calculating the work methods process time. Moreover, the authors adopt a Modeling & Simulation (M&S) based approach for implementing a three dimensional environment capable of recreating the Pressure test workstation with satisfactory accuracy. It allows the researchers to conduct the simulation study without disturbing the real system.

Keywords: Manufacturing system, time measurement & work method, MOST, MTM, Simulation

## 1. INTRODUCTION

Today manufacturing systems are forced to continually increase their efficiency and productivity in order to ensure their competitiveness and survival. There are many alternatives available for improving productivity. Clearly the effective design of work methods is one of the most important aspects of increased productive output. In this regards, Methods Engineering is a systematic technique for the design and the improvement of work methods, for the introduction of those methods into the workplace, and for ensuring their solid adoption (Zandin 2001). Motion and time study is at the heart of methods engineering (Ben-Gal and Bukchin 2002). As reported in Lawrence (2000) the motion study is determining the best way to perform a job and the time study is measuring the time required for a job to be completed using the best method.

Current research, which is related to methods engineering and workstation design, concerns the development of methodology set to apply the emerging technologies in design applications.

Several attempts have been made to apply computer technology to methods engineering and workstation design.

Braun et al. (1996) present an example of computer aided planning of a manual assembly workstation using a system called EMMA. The system is based on AutoCad and consists of a database of workstation elements and anthropometric data combined with an MTM analysis module.

Arzi (1997) suggests the integration of more advanced technology in the design process. Technology capable of effectively simulating human movement and rapid generating workstation prototypes. In this regards the author presents a framework for Rapid Prototyping (RP) based system.

Gilad and Karny (1999) present a considerably different approach. In effect, they develop an expert system suited for professional ergonomists as well as novices. The system, called ERGOEX, receives various data about the worker and the working environment, and generates quantitative and qualitative recommendations based on ergonomic knowledge bases.

The main contribution of this paper to the state of the art is to present an integration between M&S and work measurement tools for optimizing work methods. In particular Rhinoceros and eMWorkplace have been used for recreating in the virtual environment the system under consideration. MTM and MOST methods have been applied for the work measurement. Moreover, note that the research work allows to compare the work measurement tools trying to establish the more efficient one.

Before getting into details of the study let us give a brief overview of each section of the paper. Section 2 describes the manufacturing process and the pressure test workstation. Section 3 provides a brief description of the MTM and MOST methods. Section 4 gives specific details on the simulation model implementation. Section 5 presents a detailed analysis of the simulation results and shows the optimal work method. The last section reports the conclusions that summarize the scientific contribution of the work.

## 2. THE MANUFACTURING PROCESS AND THE PRESSURE TEST WORKSTATION

The Pressure test workstation belongs to a manufacturing system devoted to produce high pressure hydraulic hoses. The manufacturing plant, AlfaTechnology s.r.l., is located in the South of Italy (Calabria) and covers a surface of about 13.000 square meters. The plant layout is subdivided in two different operative areas. The first one, the Mechanical area, produces fittings and ring-nuts (and some other components usually used for hydraulic hoses assembly). The second one, the Assembly area, assembles rubber hoses with fittings and ring-nuts in order to obtain the final product. The Assembly area consists of 8 different workstations each one performing a specific operation of the hydraulic hoses assembly process. The operations performed in each workstation are described as follows.

- 1) *Preparation workstation*: according to the S.Os information, the operator takes the main components from the raw materials warehouse shelves and defines the length of the rubber hose;
- 2) *Seal Press workstation*: the operator prints on ring-nuts and fittings the quality and traceability identifying numbers by using the seal press machine and places the components inside apposite boxes;
- 3) *Cutting workstation*: the operators take rubber hose rolls from the raw materials warehouse shelves and cut the rolls according to the S.Os requirements (by using an automated or manual machine);
- 4) *Skinning workstation*: the operators eliminate a part of rubber at the ends of each hose in order to guarantee a good junction with the fittings;
- 5) *Assembly workstation*: the operators manually assemble the rubber hoses with fittings and ring-nuts;
- 6) *Stapling workstation*: the operators tighten the ring-nuts on the hoses by using the stapling machine;
- 7) *Pressure Test workstation*: the operators test the hydraulic hoses by using a pressure machine (setting a pressure value higher than the nominal value);
- 8) *Check and packaging workstation*: the operators compare the S.Os requirements and the hoses characteristics (quality controls), put the hydraulic hoses in the shipping cases.

Consider now the Pressure test workstation. The operations performed in this workstation have been subdivided in 6 different groups (each group has to be regarded as a macro-activity), described as follows.

- *Macro-activity 1* – the operator sets the workstation for starting the testing operations;
- *Macro-activity 2* – the operator prepares the hydraulic hoses to be tested;

- *Macro-activity 3* – the operator moves the hoses from the work table to the testing machine;
- *Macro-activity 4* – the operator connects the hydraulic hoses to the testing machines, performs the security procedures and starts the testing phase;
- *Macro-activity 5* – the operator puts away from the machine the hydraulic hoses, performs the visual checks and moves the hoses on the work table;
- *Macro-activity 6* – the operator completes the Shop Order.

Let us introduce the four different work methods. The authors focalize on operator's work methods in terms of hydraulic hoses simultaneously tested in the pressure machine: one single hydraulic hose (work method 1) two hydraulic hoses (work method 2), three hydraulic hoses (work method 3) and four hydraulic hoses (work method 4). Obviously the work method affects the workstation productivity in terms of Shop Orders completion. In fact, the higher is the number of hydraulic hoses to be simultaneously tested, the higher is the time for connecting the hydraulic hoses to the testing machines as well as the time required for their test and the lower is the operations frequency (i.e. the number of tests to be accomplished for a Shop Order completion).

On the other hand, the lower is the number of hydraulic hoses to be simultaneously tested, the lower is the time for connecting the hydraulic hoses to the testing machine as well as the time for their test and the higher is the operations frequency.

In this regards, the authors calculate the process time related to each work method applying the work measurements methodology (MTM and MOST) by means of simulation model (the simulation model is reported in the section 4) capable of reproducing with satisfactory accuracy the Pressure test workstation. Note that, this research approach allows to not disturb the real system until the simulation study is completed.

## 3. WORK MEASUREMENTS METHODOLOGIES

In this paragraph the Method Time Measurement (MTM) and the Maynard Operation Sequence Technique (MOST) are presented. MTM and MOST are predetermined time systems and provide information about manual work cycles in terms of basic human motions and time to them related. Sections 3.1 and 3.2 provide a brief description of such methodologies.

### 3.1. MTM

The Method Time Measurement is the most widely used system of predetermined times (Rice 1977).

The MTM is a procedure for analyzing any manual operation or method by breaking out the basic motions required to perform it and assigning to each a predetermined standard time based on its nature and the



conditions under which it is made (Karger and Bayh 1987). The total time for the manual operation is then calculated as sum of the time of each basic motion it is made by. Reach is the most common or basic MTM motion. Other motions include the following:

- *Move*: the predominant purpose is to transport an object to a destination;
- *Turn*: the hand is turned or rotated about the long axis of the forearm;
- *Position*: motion is employed to align, orient, and/or engage one object with another;
- *Grasp*: the main purpose is to secure sufficient control of one or more objects with the fingers or the hand;
- *Release*: the operator relinquishes control of an object;
- *Disengage*: contact between two objects is broken;
- *Eye times*: the eyes direct hand or body motions;
- *Body motions*: motions are made by the entire body, not just the hands, fingers or arms.

### 3.2. MOST

MOST concentrates on the movement of objects (Zandin and Kjell 1990). The primary work units are no longer basic motions, but fundamental activities (collection of basic motions) dealing with moving objects. These activities are described in terms of sub activities fixed in sequence. In other words, to move an object, a standard sequence of events occurs.

Objects can be moved in only one of two ways: either they are picked up and moved freely through space or they are moved and maintain contact with another surface. The use of tools is analyzed through a separate activity sequence model.

Consequently, only three activity sequences are needed for describing manual work. Summarizing the MOST technique is made up of the following basic sequence models:

- The *general move sequence* for the spatial movement of an object freely through the air. The activity sequence is made up of four different sub activities: action distance (A), body motion (B), gain control (G) and place (P);
- The *controlled move sequence* for the movement of an object when it remains in contact with a surface or is following a controlled path during the movement. In addition to the A, B and G parameters from the general move sequence, the sequence model for controlled move contains the following sub activities: moved controlled (M), process time (X), align (I);
- The *tool use sequence* for the use of common hand tools. The tools use sequence model is a

combination of general move and controlled move activities.

## 4. SIMULATION MODEL DEVELOPMENT VALIDATION PROCESS

As before mentioned, a simulation model has been used to compare four different work methods for optimizing the workstation productivity. The simulation model has been developed by means of the CAD software Rhinoceros and the simulation software EMWorkplace.

The CAD software has been used to model workstation equipments and final product components

The simulation software has been used for recreating in the virtual environment the Pressure test workstation. In fact, all the objects modeled by means of Rhinoceros have been imported and located in the right position (the same position the real objects take place in the real workstation) in the virtual environment provided by EMWorkplace.

The modeling phase has required a specific input data collection in order to recreate three dimensional objects with high level of detail. In this regards data about dimensions (length, width and height) and weights of all the objects being modeled were collected. Table 1 reports data for the geometric model implementation.

Table 1: data collection for geometric models implementation

Object Description	Object Type	Weight (Kg)	Dimensions (cm) L x W x H
Ring	Component	0.168	Depending on S.O.
Fitting	Component	0.336	Depending on S.O.
Marking die	Component	1.800	Depending on S.O.
Workstation stamp	Component	0.100	Depending on S.O.
Scanner	Component	0.400	12 x 7 x 18
Empty bin	Component	0.300	30 x 20 x 15
Rubber hose	Component	1.020	Depending on S.O.
Manual operated Dolly	Equipment	35.300	100 x 120 x 76
Rings bin	Equipment	0.300	30 x 20 x 15
Work table	Equipment	100.800	240 x 220 x 95
Pressure test machine	Machine	1020.040	368 x 90 x 150

Figure 1 and figure 2 shows respectively the work table and the pressure test machine three dimensional models. Finally figure 3 shows a panoramic view of the virtual layout of the Pressure test workstation.

After workstation layout recreation, next step was to insert and to train human models capable of reproducing in the virtual environment the real work methods. Human models have been selected from eM-Workplace libraries.

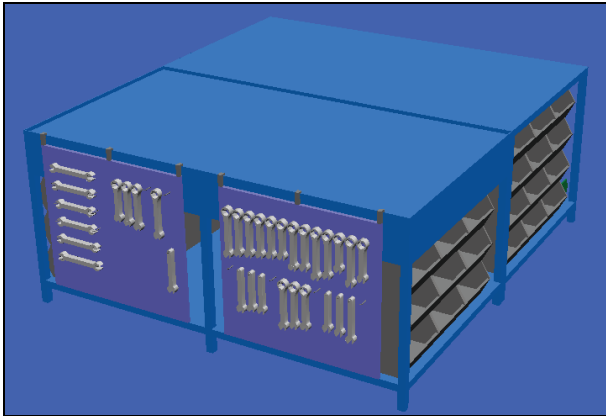


Figure 1: Work table three dimensional model.

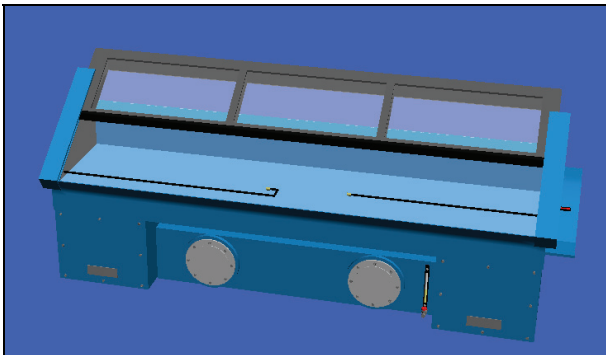


Figure 2: Pressure test machine three dimensional model.

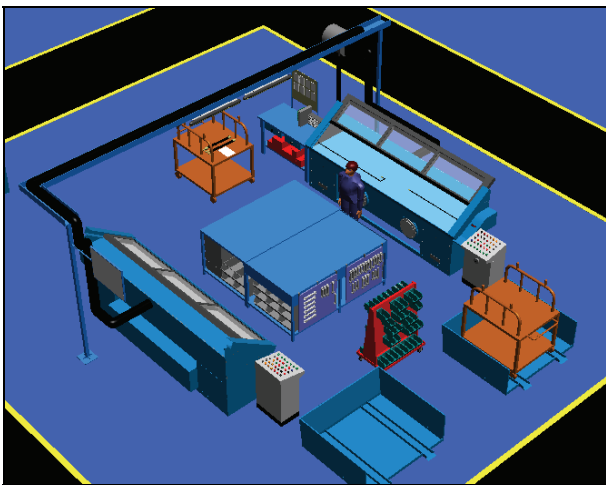


Figure 3: Panoramic view of the virtual layout of the Pressure test workstation.

The selection process has been carried out taking into account the characteristics of the real operators (age, gender, height, weight and physical condition) with the aim of importing in the virtual environment human models as much as similar to the real workers. Naturally each human model needs to be trained in order to perform the manufacturing operations. To this end, eM-Workplace provides the user with a programming language for teaching the basic motions of each operation. Figure 4 shows several programming code lines written for teaching the human model.

```
R 3
%VIEW 734.53 114.66 -1080.08 61.18
WALK vaicarrello1>vaicarrello2 (ARMFIX BODYFIX 850
%VIEW 1387.70 -1431.71 1055.31 43.56
CP RHAND 79.42 0.02 -12.75 0.00 -0.00 90.00
GET DXFIMPORT_0094 /POSE=afferrafoglio /RHAND=affe
CP RHAND 79.42 0.02 -12.75 0.00 0.00 90.00
MV /POSE=alzafoglio /RHAND=alzafoglio /AMR=0 /MTM
MV /POSE=avvicinafoglio /MTM1=(,M)
%VIEW -54.78 -1965.30 1168.56 52.18
WALK CURR>vaitavolocolaudo (ARMFIX BODYMOVE 850 W
PT 2.0 /D=0.07
MV /POSE=GUARDAfoglio
D 2
```

Figure 4: An example of programming code lines

After the simulation model implementation, determining if the simulation model is an accurate representation of the real system under consideration is a mandatory step for considerably increasing the success of the simulation study. In this context the simulation model has been analyzed and discussed with workers and employees of the manufacturing system. All the basic motions of the human models have been checked with workers' help and some errors concerning the work methods (wrong working postures, wrong motions or redundant motions) have been corrected. At the end of the validation, it was concluded that the simulation model is capable of recreating the real Pressure test workstation with satisfactory accuracy.

#### 4. SIMULATION RESULTS

The different work methods previously described ( see section 2) have been analyzed by means of a simulation model and using the Methods Time Measurement (MTM) and Maynard Operation Sequence Technique (MOST) for evaluating the time of each single macro-activity (see section 2). Note that, the authors take into consideration a typical Shop Order that requires the production of 12 medium section hydraulic hoses.

The macro activities 1 and 6 (workstation set-up and Shop Order completion) are made by preparation operations and so performed just once for the Shop Order completion. On the other hand the macro activities 3, 4 and 5 consist of cyclic operations and so cyclically performed for each hydraulic hoses. Obviously the frequency of such macro-activities depends on the work method performed by the operator (one, two, three, four hydraulic hoses to be simultaneously test by means of the pressure machine).

In addition, the macro-activity 2 is cyclically performed but the time of the macro-activity 2 affects the Shop Order total completion time just once (in other words it is cyclically repeated during the macro-activity 4).

Table 2 and table 3 reports respectively the MTM and MOST time values for each work method and for each macro activity as well as the total time for completing the Shop Order under consideration.

The work method 3 (three hydraulic hoses simultaneously tested) is characterized by the minimum Shop Order completion time according both the MTM and MOST methods.

Table 2: MTM results for the Pressure test workstation

	Macro-Activity 1 (sec.)	Macro-Activity 2 (sec.)	Macro-Activity 6 (sec.)	Total preparation time (sec.)
wm1	4.6	27.8	20.9	52.3
wm2	6.2	35.8	24.3	66.3
wm3	8	51.4	26.3	85.7
wm4	9.2	69	27.2	105.4
	Macro-Activity 3 (sec.)	Macro-Activity 4 (sec.)	Macro-Activity 5 (sec.)	Total working time (sec.)
wm1	189.3	349.6	373.6	912.5
wm2	87.6	235.3	274.1	597
wm3	54	219.1	243.4	516.5
wm4	44	224.5	243.6	512.1
Total time for completing the Shop Order (sec.)				
wm1	965.8			
wm2	663.3			
wm3	602.2			
wm4	617.5			

Table 3: MOST results for the Pressure test workstation

	Macro-Activity 1 (sec.)	Macro-Activity 2 (sec.)	Macro-Activity 6 (sec.)	Total preparation time (sec.)
wm1	4.8	28.5	22.6	55.9
wm2	5.7	36.4	24.5	66.6
wm3	7.1	52.1	27.1	86.3
wm4	8.3	69.7	27.6	105.6
	Macro-Activity 3 (sec.)	Macro-Activity 4 (sec.)	Macro-Activity 5 (sec.)	Total working time (sec.)
wm1	192.5	342.1	376.9	911.5
wm2	90.4	230.3	276.2	595.9
wm3	55.1	217.1	245.6	517.2
wm4	45.1	221	246.6	512.7
Total time for completing the Shop Order (sec.)				
wm1	967.4			
wm2	662.5			
wm3	604.1			
wm4	618.3			

Considering the MTM method, the total time is 602.2 seconds (about 10 minutes and 2 seconds). Note that the completion time improvement is about 38% respect to the first scenario, 9% respect to the second scenario and 2.5% respect to the fourth scenario.

Considering the MOST method, the total time is 604.1 seconds (about 10 minutes and 4 seconds). In this case the completion time improvement is about 37.5% respect to the first scenario, 9% respect to the second scenario and 2% respect to the fourth scenario.

Let us make a comparison between MTM and MOST methods. Such methodologies, for each work method, provide the user with very similar total time values. For instance, note that the MTM and MOST time values for the Shop Order completion, considering the work method 1, are respectively 965.8 and 967.4 seconds. Moreover 662.5 and 663.3 seconds are the time values the methods evaluate considering the work method 2. It can be concluded that MTM and MOST outputs differ one another of few percentage points. In this regards, they conduct the user to the same final

considerations (in this research work the choice of the optimal work method). Consider now, for such methodologies, the procedure for calculating the operation time. As previously stated (see section 3), the MTM method breaks out the basic motions required to perform an operation and assign to each a predetermined standard time. The operation time is the sum of time of the basic motions it consists of. On the other hand the MOST considers fundamental activities (collection of basic motions) dealing with moving objects. These activities are described in terms of sub activities (parameters) fixed in sequence. An index value is assigned to each parameter. Finally the time calculation is performed as follows:

1. Add all index values for the parameters;
2. Convert the total to Time Measurement Unit (TMU) by multiplying by 10.

Note that 1 TMU is 0.036 seconds.

In order to better understand the methods differences let report an application example. Consider the following operation: the worker walks three steps to pick up the Shop Orders sheet, reads the information he/she needs and puts it back. Note that such operation represents the macro activity 1.

Let consider the MOST method. A fully indexed Sequence Model might appear as follows:

$$A_6 B_0 G_1 \quad A_1 B_0 P_0 \quad T_3 \quad A_1 B_0 P_1 \quad A_0$$

where,

- A<sub>6</sub> = Walk three steps to object location;
- B<sub>0</sub> = No body motion;
- G<sub>1</sub> = Gain control of Shop Order Sheet;
- A<sub>1</sub> = Bring part within reach;
- B<sub>0</sub> = No body motion;
- P<sub>0</sub> = No placement;
- T<sub>3</sub> = Read the Shop Order information;
- A<sub>1</sub> = Bring part within reach;
- B<sub>0</sub> = No body Motion;
- P<sub>1</sub> = Release the Shop Order sheet.

For instance consider the code A<sub>6</sub>: the letter “A” represents the parameter and the number “6” is the index value. The sum of all the index values is:

$$6 + 0 + 1 + 1 + 0 + 0 + 3 + 1 + 0 + 1 + 0 = 13$$

Finally the operation time is calculated as follows:

$$13 \times 10 = 130 \text{ TMU} = 4.8 \text{ seconds}$$

Note that the parameters with index value “0” are here reported only for a clearer explanation of the method. In effect they do not add any time value to the final operation time (in the example under consideration only six parameters have to be considered).

Let consider the MTM method. Figure 4 reports the MTM analysis sheet.

The operation time is 135.80 TMU or rather 4.6 seconds considering the conversion factor (1 TMU is 0.036 seconds).


 <b>MTM Analysis Sheet</b>						Status:	
						Project nr:	
						Product description:	
Nr.	Description:	Code	L	TMU	R	Code	Description:
1			0,00	39,00	0,00	W3P	Walk three steps to object location
2			2,50	10,00	10,00	M49B0	Move the right hand a distance within reach
3			0,00	6,40	6,40	R50B	Reach the Shop Order sheet
4			0,00	2,00	2,00	G1A	Grasp the Shop Order sheet
5			0,00	10,00	10,00	M49B0	Move the Shop Order sheet in a distance within reach
6			0,00	40,00	55,60	PT55.6	Read the Shop Order information
7			0,00	10,00	10,00	M49B0	Move the Shop Order sheet in a distance within reach
8			0,00	6,4	6,4	P5B	Put the Shop Order sheet on the work table
9			0,00	2,00	2,00	RL1	Release the Shop Order sheet
10			0,00	10,00	10,00	M49B0	Move the right hand a distance within reach
				135,80			

Figure 4: MTM analysis sheet

It has been calculated as sum of the 10 basic motions the MTM method identified. In this regards a first difference between MTM and MOST methods is represented by the number of basic motions/parameters affecting the final operation time. Obviously the number of basic motions is higher than the number of parameters. In effects, as previously stated, a parameter represents a basic motions collection. Moreover, in addition to the MOST method, the MTM distinguishes between operations performed with the right hand and operations performed with the left hand. However, note that in the application example the operator does not use the left hand for performing basic motions.

Another relevant difference regards the methodologies codes. The MTM codes are more complex than the MOST codes. In effect the first ones are alphanumeric sequences (more letters and more numbers) longer than the second ones (one letter and one index).

After these brief considerations, we can conclude that the MTM method is a very exact system, but also very slow to apply. In effect basic motions distances must be accurately measured in inches or centimeters and correctly classified. Moreover, it can be used for conducting very detailed and accurate analysis. In this context, it provides the analysts with a complete list of basic motions; all of them can be checked and some errors concerning the work methods (wrong working postures, wrong motions or redundant motions) can be corrected. In conclusion the MTM can be also used as tool for analyzing and improving the work methods.

As concerns the MOST method is a simpler system, but still able to provide high level of accuracy and consistency (in effect, in this research work MOST and MTM time values are very similar). On the other hand, it can be used for conducting studies that do not require a high level of details in terms of basic motions analysis.

## 5. CONCLUSIONS

The starting point of the research work is the actual configuration of a workstation belonging to a manufacturing system operating in the field of idraulic hoses production. The main objective of the paper is to compare both four different work methods for optimizing the workstation productivity and two different work measurement methods (MTM and MOST) trying to establish the more efficient one. The work methods have been compared in terms of process time. The process time has been calculated by the MTM and MOST methods.

An approach based on Modeling & Simulation has been adopted.

The authors started the research work by modeling the actual configuration of Pressure test workstation. The simulation model has been developed by using the CAD software Rhinoceros and the simulation software eM-Workplace. By means of the simulation model and of the work measurement methods the different work methods have been analyzed compared.

The best work method in terms of hydraulic hoses to be simultaneously tested has been selected.

Moreover the MTM and MOST main differences have been identified and several considerations about the methods applications have been accomplished.

Further researches are still on going for analyzing the remaining workstations of the manufacturing plant.

## REFERENCE

- Arzi, Y., 1997. Methods engineering: using rapid prototype and virtual reality techniques. *Human Factors and Ergonomics in Manufacturing*, 7, 79-95.
- Ben-Gal, I., Bukchin, J., 2002. The ergonomic design of workstations using virtual manufacturing and response surface methodology. *IIE Transaction*, 34, 375-391.
- Bocca, E., Longo, F., 2008. *Simulation Tools, Ergonomics Principles and Work Measurement Techniques for Workstations Design*. Proceedings

of Summer Computer Simulation Conference, 15-18 June, Edinburgh (UK).

- Braun, W.J., Rebollar, R., Schiller, E.F., 1996. Computer aided planning and design of manual assembly systems. *International Journal of Production Research*, 34, 2317-2333.
- De Sensi, G., Longo, F., Mirabelli, G., 2007-a. *Modeling & Simulation Based Approach for Optimizing Seal Press Workstation in a Manufacturing System*, Proceedings of Business and Industry Symposium, March 25-29, USA.
- De Sensi, G., Longo, F., Mirabelli, G., 2007-b. *Ergonomic work methods optimization in a three dimensional environment*, Proceedings of Summer Computer Simulation Conference, July 15-18, San Diego, California, USA
- Gilad, I., Karni, R., 1999. Architecture of an expert system for ergonomics analysis and design. *International Journal of Industrial Ergonomics*, 23, 205-221.
- Karger, O., Bayh, F., 1987. *Engineered Work Measurement*, New York: Industrial Press.
- Lawrence, S.A., 2000. *Work Measurement & Methods Improvement*, New York: John Wiley & Sons.
- Longo, F., Mirabelli, G., Papoff, E., 2005. *Tecniche di analisi avanzate per la progettazione efficiente delle postazioni di assemblaggio manuale*, SdA – Soluzioni di Assemblaggio, VNU Business Publications Italia.
- Longo, F., Mirabelli, G., Papoff, E., 2006-a. *Material Flow Analysis and Plant Lay-Out Optimization of a Manufacturing System*, *International Journal of Computing*, 5(1), 107-116.
- Longo, F., Mirabelli, G., Papoff, E., 2006-b. *Effective Design of an Assembly Line Using Modeling & Simulation*, Proceedings of the Winter Simulation Conference, December 3<sup>rd</sup> – 6<sup>th</sup>, Monterey, California, USA
- Rice, R.S., 1977. Survey of Work Measurement and Wage Incentives. *International Journal of Industrial Engineering*.
- Zandin K.B., 2001. *Maynard's Industrial Engineering Handbook*, 5th ed. New York: McGraw-Hill.
- Zandin, Kjell, 1990. *MOST<sup>®</sup> Work Measurement Systems*. 2d ed. New York: Marcel Dekker.

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# SUPPLY CHAIN DESIGN: A CASE STUDY ON THE ADDITION OF NEW POTENTIAL CUSTOMERS

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## ABSTRACT

The work presents the results of a research work developed in cooperation with a third part logistics company operating in Calabria (South Italy) in the field of the beverage distribution. The paper focuses on a supply chain design problem; the main objective is to select new supply chain customers trying to minimize the impact on the service level provided to the actual customers. In particular the authors take into consideration three different routes within the actual distribution scenario (a route has to be regarded as a multi-drop mission performed by a single vector and serving multiple customers), testing for each route the potential addition of a certain number of new customers and observing the effects on the service level.

Keywords: third part logistics, supply chain design, distribution systems, modeling, simulation

## 1. INTRODUCTION

The main goal of a logistics and distribution system is to deliver the right quantity of items, at the right place and at the right time, trying to reduce transportation costs without affecting the service level provided to customers.

The globalization effects requires to each company operating in the supply chain to increase competitiveness and the value added of the business strategies. In this case optimal logistics and transportation increases customers' satisfaction, thereby guaranteeing better competitiveness and business survival in increasingly competitive markets.

There are many examples in which inadequate supplies and communications caused the decrease of business market shares associated to revenues reduction and lower quality of services to customers. Consider the case of the Nokia and Ericsson mobile phones and the case of the Land Rover Discovery (refer to “Creating a Resilient Supply Chains: A Practical Guide”, 2003).

At the beginning of 2000, the Philips was the sole suppliers of mobile phones components for both Nokia and Ericsson. A problem to the power lines caused a fire that destroyed one of the most important Philips plants. As consequence Philips stopped production and

distribution of mobile phones components caused economic damage to both Nokia and Ericsson (even if the economic impact on Ericsson was more severe, about 400 millions of dollars, because the Ericsson top management trusted Philips and did not react to the problem by searching additional suppliers). A similar situation was experienced by Land Rover when UPF-Thomson stopped deliveries, the economic impact was severe as well as the effect on the service level provided to final customers.

Among the various tools at present available for planning, analysing and managing logistics and distribution systems, simulation plays a critical role. Logistics simulation models are used for planning and analysing supplies and information flows and to test different possible scenarios such as changes in transportation modes (by rail, ship etc. or multi-pick and multi-drop strategies), supply management policies, products demand fluctuations, inventory control policies as well as addition of potential new final customers.

The present work considers the supply chain design problem in terms of addition of new customers. The authors believe that additional customers should be selected trying to reduce as much as possible the impact on the service level provided to the actual customers. The case proposed in the paper regards the distribution system of a third part logistics company. The logistic platform – located in Calabria, South Italy and served by the third part logistics company – is made up of 50 customers and two distribution centers. Connections among distribution centers and customers are assured by road transportation. The reach the main goal of the research work (understanding the impact of the addition of new customers on the service level), the authors use Modeling & Simulation and advanced statistic methods as decision support tool.

Before getting into details, a brief overview of the paper is reported. Section 2 presents the actual supply chain configuration reporting information on the distribution system and deliveries. Section 3 describes the implementation of the simulation model. Section 4 presents the supply chain design problem analysis and the results of the approach proposed by authors. Finally

the last section highlights the scientific contribution of the research work and reports the research activities still on going.

## 2. ACTUAL SUPPLY CHAIN CONFIGURATION

The research work has been developed in cooperation with a third part logistics company operating in the distribution of beverages. In the sequel is reported an accurate description of the supply chain actual configuration.

Items deliveries from suppliers to distribution centers are performed by using one vector (a truck) for each supplier. In effect, each supplier has its own distribution system. Inside each distribution center, items are subdivided and successively mixed in order to create the items assortment required by each customer. The deliveries from distribution centers to final customers are performed by means of multi-drop missions in which, a specific group of customers is served by the nearest distribution center and by one vector in order to reduce distribution and transportation costs. In effect the final customers are grouped in five different geographical areas, let  $C_{ij}$  be the  $j$ -th customer belonging to the  $i$ -th geographical area and let  $DC_1$  and  $DC_2$  be the two distribution centers.

Table 1: Geographical Areas and number of final customers for each area

Geographical Areas	Identifying Code	Number of Customers
South Calabria	GA <sub>1</sub>	11
North Calabria	GA <sub>2</sub>	10
Middle Calabria	GA <sub>3</sub>	9
Middle-West Calabria	GA <sub>4</sub>	8
North-West Calabria	GA <sub>5</sub>	12

The Figure 1 shows the actual configuration of the supply chain, from suppliers to final customers. Note that, as mentioned into the introduction, the third part logistics company being considered in this paper takes care of logistics and transportation between distribution centers and final customers.

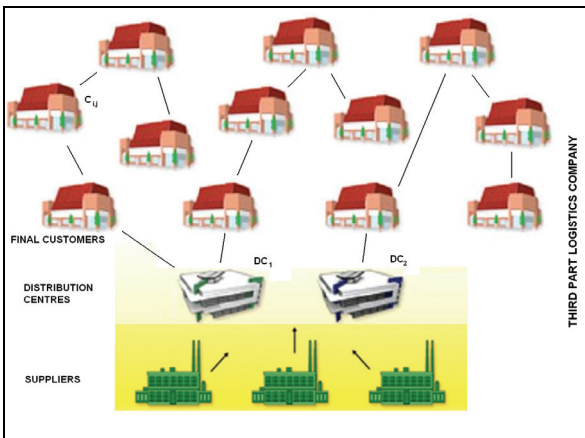


Figure 1: Supply Chain Actual Configuration

Customers' purchase orders are based on demand forecasts and emitted once per day 6:00 pm. Deliveries from distribution centers begins at 8:00 am of the morning ahead. Purchase orders are sent to the nearest distribution center that organizes and gets ready the requested items for shipment. Inventory management of and items re-order at distribution centers are based on re-order level policies and demand forecasts. Delivery missions from distribution centers to final customers (performed by the third part logistics company) are organized as follows. Trucks arrive at distribution center at 04:30 am. The trucks loading schedule depends on the truck tour total length (expressed in kilometers): the greater is the total length the higher is the priority of that truck.

Note that the main objective of the third part logistics service is to guarantee the right product in the right place, in the shortest time. Customer satisfaction level strongly depends on the delivery times: shorter delivery times mean higher customers' satisfaction level. Among performance indexes a key role is consequently played by the mean service level provided to customers. In effect this index measures customer satisfaction and it's defined as function of the delivery time.

In particular the service level is equal to one (maximum customer satisfaction) if the delivery is before 09:30 am, the service level decreases, (as well as the customer satisfaction), with the increase of the delivery time. Equation 1 expresses the service level of the  $i$ -th customer belonging to the  $j$ -th area ( $SL_{i,j}$ ), as function of time  $t$ .

$$SL_{i,j} = sl^{-t} \quad (1)$$

The parameter  $sl$  defines the decrease degree of the service level as the time goes by (expressed in minutes starting from 09:30 am). The value of such parameter is determined by empirical data considering the lost revenues due to the delay in the deliveries after 09:30 am.

## 3. SUPPLY CHAIN SIMULATION MODEL: IMPLEMENTATION, VERIFICATION AND VALIDATION

Supply chain design problems require the understanding of complex interactions between many stochastic factors and variables (i.e. demand forecast, stochastic lead time, demand intensity and variability, transportation alternatives, etc.). Modeling & Simulation (M&S) has to be regarded as the most suitable approach for recreating the complexity of the supply chain and for testing alternative supply chain configurations trying to achieve the minimization or maximization of a certain performance measure or acceptable trade-offs between conflicting objectives.

The simulation model, developed by using the discrete event simulation software eM-Plant, recreates each supply chain actor (supplier, distribution center, customers, third part logistics company, etc.) by using ad-hoc modeled classes. Each class has been developed

by using the Simple++ simulation language and is then instantiated in the simulation model main frame in order to recreate the supply chain actual configuration.

During the simulation runs all the supply chain activities are performed at run-time: i.e. by entering the object class of a customer it is possible to visualize purchase orders emission and items unloading operations, while by entering the object class of a distribution center, it is possible to visualize purchase orders management and trucks loading operations. The Figure 2 shows a table reporting mission information for the Middle-West Calabria area: for each final customer information on customer identifying code, city travel time, unloading time, delivery time and service level are displayed.

Tour	Customer	City	Travel Time	Unloading Time	Delivey time	Service Level
Middle-West Calabria	GA41	Cs (Carrefour)	16.9758	6.1970	7:20:42.5962	1.00
	GA42	Carnigliatello	31.2714	7.1998	7:59:22.3345	1.00
	GA43	Longobucco	53.7303	7.5414	9:00:14.3572	1.00
	GA44	Longobucco	1.8092	8.5051	9:10:46.0199	1.00
	GA45	Bocchigliero	1:10.5785	7.1777	10:28:31.3896	0.86
	GA46	Campana	27.1037	6.6474	11:02:16.4565	0.79
	GA47	Savelli	29.4834	8.2515	11:40:00.5516	0.72
	GA48	Loica	53.8006	6.6770	12:40:29.2097	0.62

Figure 2: Simulator table reporting missions information

Before using the simulation model for testing alternative supply chain configurations in terms of addition of new customers, the authors carried out the Verification and Validation of the simulation model. The process of determining that the simulation model implementation accurately represents the initial conceptual model has been carried out by using the debugging technique (simulation model verification). In effect this step is strictly related to model translation and the debugging technique (Dunn, 1987) helps in finding and correcting all the errors in the programming code.

Concerning the Validation phase, note that the system under consideration is a *terminating system*, (Banks, 1998); the length of each simulation run (24 hours) is fixed and is a consequence of the model and its assumptions. In this system the only checkable factor is the number of replications. The correct number of replications has to guarantee a simulated confidence interval of the performance measure being considered (the service level provided to customers) similar to the confidence interval of the real system. Such confidence interval can be expressed in terms of mean squares error. Considering the stochastic distributions implemented in the simulation model we can assert that the model is subjected to experimental error with normal distribution,  $N(0, \sigma^2)$ . The best estimator of  $\sigma^2$  is the mean squares error that can be evaluated by using equation 2:

$$SL_{mse}(t) = \sum_{h=1}^n \frac{(SL_h(t) - \overline{SL}(t))^2}{n-1} \quad (2)$$

where  $SL_h(t)$  is the value of the Service Level at instant of time  $t$  during the replication  $h$  and  $h=1, \dots, n$  is the number of replications. The number of replications chosen is 8; such number of replication assures a negligible mean squares error for the service level provided to customers.

#### 4. ALTERNATIVE SUPPLY CHAIN CONFIGURATION: ADDITION OF NEW FINAL CUSTOMERS

The supply chain design problem requires the analysis of the impact on the service level generated by the addition of new customers on two geographical areas. The areas being considered by the analysis are the South Calabria (GA<sub>1</sub>) area and the Middle Calabria (GA<sub>3</sub>) area: the analysis aims at considering 8 additional customers for the GA<sub>1</sub> area and 4 additional customers for the GA<sub>3</sub> area.

The effect of the addition of the customers in each area, has been investigated by using the factorial experimental design, in which each factor is an additional customer characterized by two possible levels: *Present (P)* and *Absent (A)*. Note that two different factorial experimental designs have been carried out: in effect the addition of new customers in the GA<sub>1</sub> area does not affect the service level of the customers of the GA<sub>3</sub> area and vice-versa (the multi-drop missions in each geographical area are performed by two different trucks).

Check of all possible combinations of the factors levels requires  $2^p$  simulation runs (p, number of factors). In the case of the GA<sub>1</sub> area,  $p=8$ , then there are 256 possible combinations requiring 256 simulation runs. Each run has to be replicated 8 times as mentioned in the previous section, ( $256 \times 8 = 2048$  replications). Carrying out 2048 replications, it's possible to evaluate the impact on the service level of all the effects (1<sup>st</sup> order effects, two-factor interactions, three-factor interactions, four-factor interactions and so on until the sole eight-factor interaction). However, in many real situations the system is dominated by the main effects and by the low order interactions. The high order interactions are negligible. Consequently it is possible to obtain useful information about the system decreasing the total number of replications. In general a  $2^p$  factorial experimental design may be run in a  $1/2^l$  design called a  $2^{p-l}$  fractional factorial design. Considering the high order interactions negligible, the system can be analyzed with a  $2^{8-3}$  fractional factorial design, carrying out only 32 simulation runs against 256 simulation runs required by a complete design. At the same time only 16 simulation runs can be used to run a complete design relative to the GA<sub>3</sub> area (in effect  $2^4 = 16$  simulation runs).

Table 2 reports the design of experiments matrix and the simulation results for the GA<sub>1</sub> area (similar results have been obtained for the GA<sub>3</sub> area) in terms of mean service level. Note that for each factors level combination, 8 different replications are reported.



Table 2: Experimental Design Matrix and simulation results of the GA<sub>1</sub>

GA <sub>1,12</sub>	GA <sub>1,13</sub>	GA <sub>1,14</sub>	GA <sub>1,15</sub>	GA <sub>1,16</sub>	GA <sub>1,17</sub>	GA <sub>1,18</sub>	GA <sub>1,19</sub>	Simulation Results (Service Level)							
A	A	A	A	A	A	A	P	0.836	0.837	0.835	0.836	0.834	0.838	0.839	0.835
P	A	A	A	A	P	P	P	0.801	0.786	0.790	0.793	0.788	0.782	0.796	0.790
A	P	A	A	A	P	P	A	0.810	0.806	0.801	0.805	0.808	0.809	0.802	0.801
P	P	A	A	A	A	A	A	0.830	0.830	0.842	0.840	0.833	0.828	0.830	0.831
A	A	P	A	A	P	A	A	0.826	0.820	0.829	0.819	0.821	0.830	0.822	0.820
P	A	P	A	A	A	P	A	0.818	0.821	0.819	0.823	0.814	0.817	0.813	0.805
A	P	P	A	A	A	P	P	0.800	0.790	0.792	0.798	0.781	0.787	0.793	0.786
P	P	P	A	A	P	A	P	0.788	0.791	0.789	0.780	0.780	0.789	0.787	0.774
A	A	A	P	A	A	P	A	0.820	0.810	0.815	0.813	0.821	0.823	0.819	0.821
P	A	A	P	A	P	A	A	0.812	0.811	0.818	0.820	0.822	0.814	0.818	0.810
A	P	A	P	A	P	A	P	0.797	0.782	0.798	0.802	0.804	0.781	0.803	0.790
P	P	A	P	A	A	P	P	0.780	0.781	0.792	0.780	0.776	0.782	0.779	0.776
A	A	P	P	A	P	P	P	0.772	0.769	0.791	0.792	0.767	0.781	0.773	0.770
P	A	P	P	A	A	A	A	0.789	0.801	0.783	0.791	0.799	0.786	0.801	0.789
A	P	P	P	A	A	A	A	0.813	0.821	0.823	0.818	0.810	0.808	0.818	0.819
P	P	P	P	A	P	P	A	0.781	0.779	0.787	0.792	0.784	0.777	0.773	0.781
A	A	A	A	P	A	A	A	0.839	0.841	0.838	0.835	0.840	0.846	0.845	0.843
P	A	A	A	P	P	P	A	0.810	0.803	0.810	0.819	0.799	0.801	0.796	0.803
A	P	A	A	P	P	P	P	0.785	0.777	0.785	0.771	0.772	0.771	0.788	0.789
P	P	A	A	P	A	A	P	0.809	0.796	0.810	0.819	0.802	0.799	0.808	0.800
A	A	P	A	P	P	A	P	0.790	0.782	0.803	0.791	0.799	0.806	0.808	0.799
P	A	P	A	P	A	P	P	0.785	0.788	0.791	0.779	0.776	0.777	0.784	0.791
A	P	P	A	P	A	P	A	0.794	0.801	0.806	0.811	0.787	0.801	0.799	0.795
P	P	P	A	P	P	A	A	0.806	0.791	0.808	0.799	0.794	0.784	0.805	0.802
A	A	A	P	P	A	P	P	0.782	0.789	0.806	0.791	0.789	0.785	0.798	0.781
P	A	A	P	P	P	A	P	0.784	0.788	0.779	0.785	0.772	0.776	0.781	0.789
A	P	A	P	P	P	A	A	0.791	0.792	0.808	0.809	0.801	0.798	0.806	0.791
P	P	A	P	P	A	P	A	0.798	0.792	0.803	0.784	0.786	0.786	0.798	0.793
A	A	P	P	P	P	P	A	0.783	0.791	0.798	0.786	0.782	0.781	0.783	0.782
P	A	P	P	P	A	A	A	0.804	0.803	0.799	0.811	0.796	0.802	0.812	0.810
A	P	P	P	P	A	A	P	0.782	0.777	0.782	0.789	0.781	0.779	0.773	0.780
P	P	P	P	P	P	P	P	0.743	0.741	0.752	0.758	0.750	0.743	0.751	0.740

#### 4.1. Supply chain design problem: simulation results analysis

The simulation results in output from the fractional factorial design have been studied by using the Analysis of Variance (ANOVA). As reported in Montgomery (2003), the ANOVA expresses the total variability of the performance measure being considered (the mean service level provided to customers) as sum of different terms. Each term is the variability of a factor. The greater is the variability of that factor the higher is the impact on the performance measure. In effect, by using a Fisher statistics the ANOVA checks for each factor two different hypotheses: (i) the factor has no impact on the mean service level (usually called H<sub>0</sub> hypothesis); (ii) the factor has an impact on the mean service level (usually called H<sub>1</sub> hypothesis).

The ANOVA also allows to define an analytical model (called meta-model of the simulation model) that expresses the mean service level as function of the factors being considered. Let  $SL_i$  be the mean service level for the  $i$ -th geographical area and let GA<sub>*i,j*</sub> the factors. Note that each factor can take only two values:  $A$  and  $P$ . The analytical model requires to use for each factor numerical values. To this end, let us introduce the following correspondence:  $A$  (-1) and  $P$  (1). Finally let  $\beta_{ij}$  the coefficients of the meta-model. The equation 3 expresses the  $SL$  in terms of the factors GA<sub>*i,j*</sub>.

$$SL_i = \beta_{i,0} + \sum_{j=1}^{j=k} \beta_{i,j} GA_{i,j} + \sum_{j < k} \sum_{j < k} \beta_{i,jk} GA_{i,j} * GA_{i,k} + \dots + \sum_{j < k} \sum_{j < k} \sum_{j < k} \beta_{i,jkl} GA_{i,j} * GA_{i,k} * GA_{i,l} + \epsilon \quad (3)$$

- $i = 1,3$  – identifying index of the geographical area;
- $j = 12, \dots, 19$  or  $j = 10, \dots, 13$  – identifying index respectively for the South Calabria new customers and Middle Calabria new customers

Note that equation 3 is not a continuous function; in effect  $A$  and  $P$  respectively mean new customer absent (no addition of the new customer to the multi-drop delivery mission) and new customer present (addition of the new customer to the multi-drop delivery mission). Consequently equation 3 can be used only for evaluating the value of the mean service level when the factors take the values “-1” or “+1”. Obviously the evaluation of the service level (by using equation 3) when the factors take the value “0” has no sense.

#### 4.2. Analysis of Variance for the GA<sub>1</sub> area

Table 3 reports the results of the Analysis of Variance for the GA<sub>1</sub> area. As well known from the theory of ANOVA the non negligible effects are characterized by the  $P$ -Value lower than 0.05 ( $\alpha = 0.05$ , confidence level used in the analysis of variance). For further

information on the Analysis of Variance please refer to Montgomery (2003). The predominant effects – that is the effects generating a non negligible variation of the mean service level – are the first order effects and some effects of the second order.

Table 3: Analysis of Variance for the GA<sub>1</sub> area

Term	Effect	Coef	SE Coef	T	P
Constant		0.79839	0.000404	1977.56	0.00
GA <sub>1,12</sub>	-0.00748	-0.00374	0.000404	-9.27	0.00
GA <sub>1,13</sub>	-0.01055	-0.00527	0.000404	-13.06	0.00
GA <sub>1,14</sub>	-0.01184	-0.00592	0.000404	-14.67	0.00
GA <sub>1,15</sub>	-0.01455	-0.00727	0.000404	-18.02	0.00
GA <sub>1,16</sub>	-0.01028	-0.00514	0.000404	-12.73	0.00
GA <sub>1,17</sub>	-0.01328	-0.00664	0.000404	-16.45	0.00
GA <sub>1,18</sub>	-0.0163	-0.00815	0.000404	-20.18	0.00
GA <sub>1,19</sub>	-0.02016	-0.01008	0.000404	-24.96	0.00
GA <sub>1,12</sub> *GA <sub>1,13</sub>	0.00225	0.00112	0.000404	2.79	0.01
GA <sub>1,12</sub> *GA <sub>1,14</sub>	-0.00008	-0.00004	0.000404	-0.10	0.92
GA <sub>1,12</sub> *GA <sub>1,15</sub>	-0.00059	-0.0003	0.000404	-0.74	0.46
GA <sub>1,12</sub> *GA <sub>1,16</sub>	0.00077	0.00038	0.000404	0.95	0.34
GA <sub>1,12</sub> *GA <sub>1,17</sub>	0.00039	0.0002	0.000404	0.48	0.63
GA <sub>1,12</sub> *GA <sub>1,18</sub>	0.00156	0.00078	0.000404	1.94	0.05
GA <sub>1,12</sub> *GA <sub>1,19</sub>	-0.00242	-0.00121	0.000404	-3.00	0.00
GA <sub>1,13</sub> *GA <sub>1,16</sub>	-0.0003	-0.00015	0.000404	-0.37	0.71
GA <sub>1,13</sub> *GA <sub>1,19</sub>	-0.00014	-0.00007	0.000404	-0.17	0.86
GA <sub>1,14</sub> *GA <sub>1,15</sub>	0.00092	0.00046	0.000404	1.14	0.26
GA <sub>1,14</sub> *GA <sub>1,16</sub>	-0.00041	-0.0002	0.000404	-0.50	0.62
GA <sub>1,14</sub> *GA <sub>1,18</sub>	0.00183	0.00091	0.000404	2.26	0.03
GA <sub>1,14</sub> *GA <sub>1,19</sub>	-0.00137	-0.00069	0.000404	-1.70	0.09
GA <sub>1,15</sub> *GA <sub>1,16</sub>	-0.00148	-0.00074	0.000404	-1.84	0.07
GA <sub>1,15</sub> *GA <sub>1,19</sub>	-0.00105	-0.00052	0.000404	-1.30	0.20
GA <sub>1,16</sub> *GA <sub>1,17</sub>	0.00053	0.00027	0.000404	0.66	0.51
GA <sub>1,16</sub> *GA <sub>1,18</sub>	0.0007	0.00035	0.000404	0.87	0.39
GA <sub>1,16</sub> *GA <sub>1,19</sub>	0.00009	0.00005	0.000404	0.12	0.91
GA <sub>1,17</sub> *GA <sub>1,19</sub>	-0.00009	-0.00005	0.000404	-0.12	0.91
GA <sub>1,18</sub> *GA <sub>1,19</sub>	-0.00027	-0.00013	0.000404	-0.33	0.74
GA <sub>1,12</sub> *GA <sub>1,13</sub> *GA <sub>1,16</sub>	0.00069	0.00034	0.000404	0.85	0.40
GA <sub>1,12</sub> *GA <sub>1,13</sub> *GA <sub>1,19</sub>	0.00078	0.00039	0.000404	0.97	0.33
GA <sub>1,12</sub> *GA <sub>1,14</sub> *GA <sub>1,15</sub>	-0.00016	-0.00008	0.000404	-0.19	0.85

Note that all the first order effects have an impact on the mean service level provided to customers. It means that each additional customer considerably affects the service level. The customers to be added to the supply chain should be selected trying to minimize the effect on the service level. To this end the authors use the analytical model provided by equation 3. In order to find out the coefficients of the analytical model, the Analysis of Variance has been repeated for the GA<sub>1</sub>, deleting insignificant factors (those factors characterized by *P-Value* > 0.05). Table 4 reports the coefficients of the analytical model for those factors affecting the service level.

Equation 3 can be used for plotting the variation of the service level in case of addition of a new customer. Figure 3 shows the effect on the service level when a new customer is added. Note that some customers, as for instance GA<sub>1,12</sub> and GA<sub>1,13</sub>, have a lower impact on the service level than other customers, such as GA<sub>1,18</sub> and GA<sub>1,19</sub>. Equation 3 and Figure 3 can be used for selecting the best customers to be added to the supply chain.

Table 4: Coefficients of the input-output analytical model for the GA<sub>1</sub> area

Term	Coef
Constant	0.798391
GA <sub>1,12</sub>	-0.00374
GA <sub>1,13</sub>	-0.00527
GA <sub>1,14</sub>	-0.00592
GA <sub>1,15</sub>	-0.00727
GA <sub>1,16</sub>	-0.00514
GA <sub>1,17</sub>	-0.00664
GA <sub>1,18</sub>	-0.00815
GA <sub>1,19</sub>	-0.01008
GA <sub>1,12</sub> *GA <sub>1,13</sub>	0.001125
GA <sub>1,12</sub> *GA <sub>1,18</sub>	0.000781
GA <sub>1,12</sub> *GA <sub>1,19</sub>	-0.00121
GA <sub>1,14</sub> *GA <sub>1,18</sub>	0.000914
GA <sub>1,14</sub> *GA <sub>1,19</sub>	-6.88E-04
GA <sub>1,15</sub> *GA <sub>1,16</sub>	-7.42E-04

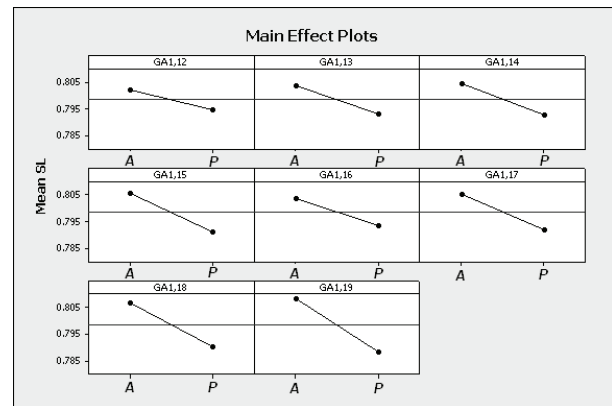


Figure 3: Main effects plots, SL versus addition of new potential customers in the GA<sub>1</sub> area

### 4.3. Analysis of Variance for the GA<sub>3</sub>

As in the previous case, the results obtained by using the supply chain simulator in combination with the factorial experimental design and the Analysis of Variance are extremely interesting, because they allow to correctly select the best new customers of the supply chain. The analysis for the GA<sub>3</sub> area points out that localities such as GA<sub>3,12</sub> and GA<sub>3,13</sub> generate a remarkable reduction of the mean service level (see Figure 4) in comparison to GA<sub>3,10</sub> and GA<sub>3,11</sub>. The addition of such customers has a negligible effect on the mean service level provided to all the customers of the same multi-drop mission. Furthermore the accurate selection of the supply chain final customers – on the basis of the impact on the mean service level and in relation to the demand forecasts in terms of purchase orders – helps in keeping under control the transportations costs and to guarantee efficient logistics and transportation processes.

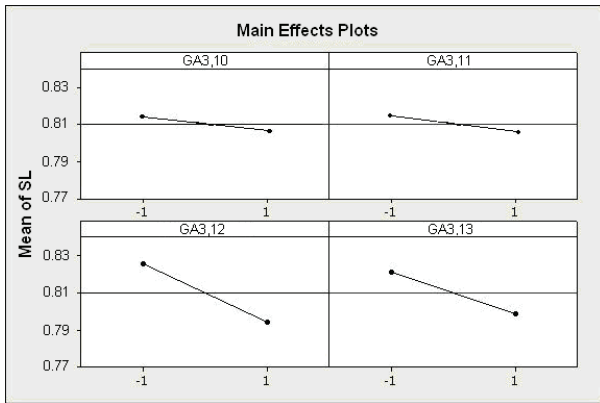


Figure 4: Main effects plots, SL versus addition of new potential customers in the  $GA_3$  area

## 5. CONCLUSIONS

The research work proposed in this paper has been developed in cooperation with a third part logistics company operating in South Italy (Calabria) in the field of beverage distribution. The main goal was the selection of new potential customers trying to minimize the effect on the mean service level. To this end the authors decided to implement a supply chain simulator and use the simulator in combination with design of experiment and analysis of variance. In particular specific analysis have been carried out considering two different geographical areas and investigating, for each area, the effects on service level generated by the addition of respectively 8 and 5 new customers.

The approach based on Analysis of Variance allows to evaluate (for each area considered) the variation of the service level when a customer is added to the multi-drop delivery mission. The best customers have to be selected among those generating the smallest variation of the service levels. The addition of new final customers that have a negligible impact on the mean service level helps in maintaining high efficiency of the logistics and transportation processes.

Further researches are still on going using the same simulator for optimizing the distribution strategies from suppliers to distribution centers.

## REFERENCES

- Banks J., 1998. *Handbook of simulation*. New york: Wiley Interscience.
- Beamon, B. M., 1998. Supply chain design and analysis: models and methods, *International Journal of Production Economics*, 55 (3), 281-294.
- Broekmeulen, R. A. C. M., 2001. Modelling the management of distribution centers. In: *Food Process Modeling*, edited by Tijssens, L. M. M., Hertog, M. L. A. T. M., Nocolai, B. M. Cambridge: Woodhead Publishing Ltd.
- Bruzzone, A.G., Bocca, E., Longo, F., Massei, M., 2007. Logistics Node Design and Control over the Whole Life Cycle based on Web Based Simulation. *International Journal of Internet Manufacturing and Services*, 1(1), pp. 32-50.
- Buzzzone, A.G., Longo, F., Massei, M., Saetta, S., 2006. The Vulnerability of Supply Chains As Key Factor in Supply Chain Management. *Proceedings of Summer Computer Simulation Conference*, July 30<sup>th</sup> – August 03<sup>rd</sup>, Calgary Canada.
- Chan, F.T.S., Chan, H.K., 2005. Simulation modeling for comparative evaluation of supply chain management strategies, *Journal of Advanced Manufacturing Technology* 25, 998–1006.
- Creating a Resilient Supply Chains: A Practical Guide, 2003. Report produced by the *Center for Logistics and Supply Chain Management*, Cranfield school of Management.
- Curcio, D., Longo, F., Mirabelli, G., Papoff, E., 2007. Pharmaceutical Routes Optimization using Artificial Intelligence, *Proceedings of Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications*, September 6-8, Dortmund, Germany.
- De Sensi, G., Longo, F., Mirabelli, G., 2007. Inventory policies analysis under demand patterns and lead times constraints in a real supply chain. *International Journal of Production Research*, 99999:1, 1 – 20, doi:10.1080/00207540701528776
- De Sensi, G., Longo, F., Mirabelli, G., Papoff, E., 2006. Ants Colony System for Supply Chain Routes Optimization. *Proceedings of Harbour, Maritime & Multimodal Logistics Modeling and Simulation*, October 4<sup>th</sup> – 6<sup>th</sup>, Barcelona, Spain.
- De Sensi, G., Longo, F., Mirabelli, G., Papoff, E., 2006. Spreadsheets Based Tool for Supporting Demand Forecasting in Distribution Centers, *Proceedings of the International Workshop on Modeling and Applied Simulation*, October 13<sup>th</sup> – 15<sup>th</sup>, Savona, Italy.
- Dunn, R.H., 1987. The quest for software reliability. In: *Handbook of software quality assurance*, edited by G.G. Schulmeyer and J.I. McManus, 342 – 384, New York: Van Nostrand Reynold.
- Farahani, R. Z., Elahipanah, M., 2008. A genetic algorithm to optimize the total cost and service level for just-in-time distribution in a supply chain. *International Journal of Production Economics*, 111, 229–243.
- Ingalls, R. G., 1998. The value of simulation in modeling supply chain. *Proceedings of the Winter Simulation Conference*, pp.1371-1375 Washington D.C.
- Longo, F., Mirabelli, G., 2008. An Advanced Supply Chain Management Tool Based on Modeling & Simulation. *Computer and Industrial Engineering*, 54(3), 570-588.
- Mentzer, J.T., Konrad, B.P., 1991. An efficiency/effectiveness approach to logistics performance analysis. *Journal of Business Logistics*, 21(1), 33–62.

- Montgomery, D.C., Runger, G.C., 2003. *Applied statistics and probability for engineers*. Third Edition.
- Persson, F., Olhager, J., 2002. Performance simulation of supply chain designs, *International Journal of Production Economics*, 77, 231-245.
- Sabri, E. H., Beamon, B. M., 2000. A multi-objective approach to simultaneously strategic and operational planning in supply chain design. *Omega*, 28, 581-598.

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# TOTAL PROCESS SIMULATION IN SHIPBUILDING: SIMULATION AIDED HULL ASSEMBLY PLANNING

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## ABSTRACT

Shipbuilding processes in Western Europe are primarily characterized by its result: unique ships built on customer-specification. This character pushes the limits of conventional planning and control methodology. The application of simulation aided production planning as a means to improve process control of multifaceted shipyard processes is therefore subject of research. In general the capacity limiting resource of a production system requires the best control and the production flow of the adjacent processes should be brought in balance with this bottleneck. For shipbuilding, this is the erection site (slipway, dock), at which the hull assembly takes place. Improving shipbuilding process control by simulation starts therefore at modelling this resource. The paper presents the status of an ongoing research effort showing that hull assembly and total shipbuilding processes can be modelled and that simulation in this context is a powerful means to improve process control within the maritime industries.

Keywords: production simulation, assembly planning, ship production, virtual manufacturing

## 1. INTRODUCTION

The shipbuilding industry is a labour intensive industry which is operating in a global and extremely competitive market. The shipbuilding process involves numerous production steps of many parts and their assemblies, far-reaching interactions with suppliers and a large volume of manhours to design and construct the large and complex structures. The price of these structures is determined by the laws of supply and demand, compromising between the level at which a shipyard is prepared to accept a contract and the level the customer is prepared to pay. The resulting price however is subject to many influences and is not very transparent in the market because of the small series size typical for shipbuilding. The necessary margin for shareholder's satisfaction and company's continuity must be obtained by having an acceptable cost level. As material cost is essentially fixed by the requirements of the ship's specification, significant reduction in construction cost can only result from improvement in production efficiency, both at the yard as well as at the

subcontractors. Thus, the shipbuilders' financial situation depends on the achieved production efficiency. To meet this, improvement of process control is a requisite.

However, the complicated character of the shipbuilding process, especially in the case of one-off ships, pushes the limits of conventional planning and control methodology. Due to this, it is a challenge for all partners (shipyards and suppliers) within the total ship production process to make a feasible planning that is as optimal as possible and by which a suitable utilization of resources is achieved.

A means to improve process control is the application of simulation. This technique enables to manually investigate alternative production scenarios for the total shipbuilding process in advance. With this, products and processes can mutually be brought in balance and processes can be geared to one another resulting in smooth logistics of materials and components and properly levelled utilization of workstations as a consequence.

The study reported in this paper is aimed at enabling simulation of ship assembly processes on the hull erection site, with the goal to improve the corresponding process control. The paper presents the preliminary results of an ongoing research programme showing that multifaceted total shipbuilding processes can be modelled and that simulation in this context is a powerful means to improve process control within the maritime industries. The paper starts with a brief overview of ship production and hull assembly processes including the most important dependencies and details of process and product. Next, shipbuilding process control and the need for simulation is presented. This is followed by a description of the current simulation developments and applications in shipbuilding. It continues with the status of the development of the hull assembly simulation model. An application of simulation in planning is included in the results section. The paper ends with conclusions relative to the applicability of simulation in shipbuilding processes.

## 2. INTRODCUTION IN SHIPBUILDING

### 2.1. Physical decomposition of ships

Every ship can be considered as an autonomous system that offers the capability to fulfil the tasks required for its mission. On the one hand, every ship has to have the capability to float, sail and manoeuvre. On the other hand, a ship has functionalities that are integrated in the ship's standard systems, which are cargo or service related. Therefore, it can be said that every ship consists of a floating body subdivided into compartments that holds the systems, see Figure 1 for an example. These are all made up from elements classified as parts (steelwork) or components.

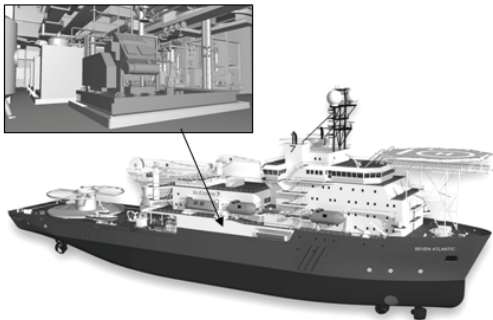


Figure 1: Yard number 713 with a typical compartment including volume and routing components

The hull, superstructures and deck houses are built up from steel parts, consisting of conserved structural steel material. The hull represents a steel assembly system of very many parts that provides the structural strength which makes it possible for the ship to fulfil its tasks. In general, every hull consists of three parts; the stern (aft), midship and stem. For hydrodynamic reasons, the first and the latter have curved forms, the rest of the hull is the widest part, almost prismatic, and quite voluminous.

Components cover the so called volume and routing components. Volume components include mechanical equipment, outfitting material, interior elements, and all other equipment necessary for ship operation. The routing components represent the infrastructure connecting with each other the power generation, consuming and/or processing volume components. These consist of piping, ducting, cabling and secondary steelwork to mount them to the ship structure. Currently, almost all systems and components are supplied to a shipyard and the integration, hook up and commissioning is arranged by the yard. This is not necessarily the case for the turn key supplies with full responsibility assigned to the supplier.

### 2.2. Work breakdown structure of ships

The presented physical decomposition and customized nature of ships make the shipbuilding process very complicated. Every ship taken in production represents a challenging planning and control task because the internal activities of a shipyard require the production of a large number of individual parts and their assembly in

a meaningful order. Beyond that, a large number of systems must be integrated in an order that matches the order of the internal yard activities. Therefore, proper organization and a convenient product taxonomy play a very important role in shipbuilding.

In spite of the one-off character of shipbuilding, shipyards have adopted group technology (Storch 1988) for the organization of their current steelwork practices, which are considered to be leading during the production of a ship. By focussing on methods to improve the organization of work, "one-off" production can be structured such as to reap the advantages offered by mass production (Kihara and Yamamoto 1968). This can be arranged through standardisation of the production processes by means of employing many different kinds of constructions subdivided in a number of similar subassemblies (group production). The advantage of this is that it is possible to employ a repetitive process for the production for every group in a "few" successive simple activities which are subdivided in work steps. This subdivision of work and specialisation in production allows efficient organisation and work simplification (steeper learning curves) and provides the parallel with mass production.

With regard to the hull assembly process, only the upper two levels of the work breakdown structure (WBS) of ships need to be introduced. Figure 2 presents the upper level as the ship and the second level as the section level. This means for the hull assembly process, with regard to the steelwork, that the ship is erected by subsequently placing and connecting sections. Because of the application of the group technology philosophy, the section dimensions, weight, and assembly time of every section are in harmony with the other sections.

The presented WBS is shipyard specific, ship dimensions and yard setup can be reasons for an extra assembly stage where sections are combined into blocks that are then integrated to form a ship. The main advantage for these shipyards is that this shortens the lead time of the ship on the assembly site, providing a better allocation of the most expensive resource(s) on a shipyard. The lower levels of the WBS exist of subassemblies and parts.

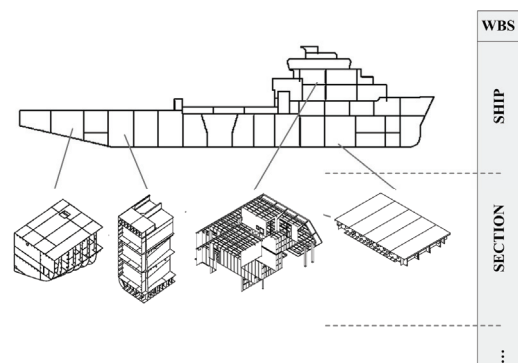


Figure 2: Upper two levels of the WBS of ships

### 2.3. The hull assembly process

The highest level of the WBS hierarchy presents the product ship that is erected during the process called

hull assembly, which is described in this section. Material inputs for the process are pre-outfitted sections, small parts like brackets to mount the sections to each other, and outfitting material.

After welding and grinding, sections are pre-outfitted with prefabricated routing components and secondary steelwork. On-section (pre-)outfitting is done because of better accessibility and shorter transport lines to allow greater efficiency compared to on-board outfitting. Furthermore, it is of advantage when the onboard activities are minimized as much as possible, because many parallel processes involving many parties take place on the ship normally. An accurate assembly of sections is therefore a prerequisite, because that precludes rework during hull erection.

The hull assembly process starts with the milestone event “lay keel” (Figure 3). This event implies the first section to be laid on the hull erection site. Before this event can happen, the erection site must be emptied and cleaned. This site preparation for erection happens immediately after the launch of the predecessor ship. During the erection of the predecessor, the assembly of the sections of the next ship is well under way. Therefore, it is possible to build up a small section stock which enables shortening the lead time of the ship on the erection site, resulting in a better allocation of the capacity limiting resource(s) on a shipyard.



Figure 3: Keel lay event (left) and erected bottom sections during outfitting (right)

After the first section is laid on the erection site, the planned subsequent sections can be mounted to this first section. Special attention is paid to the accurate alignment of sections. Once a section has been welded to the ship in formation, another section can be attached to this section. The first section is a midship bottom section, followed by other bottom sections to create a complete deck area (Figure 3) as soon as possible, which simplifies possible outfitting processes that can only be done when such a deck area is complete. Before this deck is closed off by mounting the next layer of sections, all components which are planned to be positioned on this deck and which cannot or are difficult to be carried onboard later, are placed in the right compartment (Figure 4).



Figure 4: Main engines (left) and big equipment positioned during hull assembly (right)

When two sections are welded to each other, routing components can be connected with the help of fitting pieces. After positioning of equipment, these can be connected to the piping infrastructure by mounting measure pipes in between. Pulling of electrical cables, followed by the connection to equipment, is done after the ship in formation has reached a certain progress where it is worth starting pulling full cable lengths over long distances.

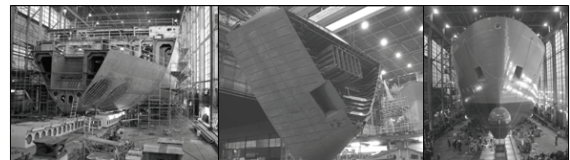


Figure 5: Ship during erection with scaffolding (left), transport of section to the ship in assembly (centre) and fully erected ship just before launch (right)

Figure 5 shows that the accessibility of the ship decreases with its progress, outfitting processes require therefore relatively more and more time as the erection process progresses. Scaffolding and gangways are applied on the inner and outer side of the ship to keep its accessibility as good as possible. Sometimes, it is required to cut extra holes in bulkheads to guarantee safe and practical work conditions.

If all processes involving heat are completed on the bulkheads and decks adjacent to a tank, pressurising of this tank can start. When this is completed for a compartment and all grinding processes are done, this compartment can be conserved. Distortion of an existing paint system should be precluded, but this is not always possible.

The output of the hull assembly process is the erected ship that thereupon can be launched when the hull is painted and all under water components like thrusters and rudders have been installed. After the launch, the ship is brought to the so called outfitting quay and all assembly processes from now on fall under the completion stage.

#### 2.4. Process control

As far as their assembly processes are concerned, a shipyard is in a subordinate position vis-à-vis its suppliers, because it heavily relies on their performance in terms of efficiency and reliability. A well prepared plan, which takes into account all facets of the complex product and a limited amount of resources, to meet the project goals and to keep to this planning during production, is therefore, a prerequisite for a well-executed project.

This plan consists in general of several schedules which are drawn up during different stages of the project. The master schedule offered to a shipowner within the budget proposal can be seen as part of strategic scheduling as it contains estimations of the lead time of the main activities (based on an available slot on the erection site) and the delivery of the main components.

Based on the offered budget proposals, the “future” shipowner defines a short list with most competitive shipyards that are requested to provide a detailed proposal. This includes a detail planning that can be seen as a plan on tactical level, which brings the many shipbuilding process steps in the right temporal and spatial order. As already mentioned, the erection site (dock, slipway) is the most expensive resource which needs to be allocated as efficiently as possible. The available slot on the erection site is therefore part of the master schedule, but it is also the starting point for determining the detail planning. In general the process starts by tracing the erection relations between sections and big components which cannot or are difficult to be carried onboard. The corresponding hull assembly schedule then forms the basis for deriving all other production and delivery schedules. On operational level, the detail plan is fine tuned with the actual progress and available transport possibilities.

Hengst (1999) emphasizes the importance of the erection schedule as follows. When a shipyard has one erection site, the shortest possible delivery time of subsequent ships is amongst others determined by the launch date of the ship in formation on that site. Its allocation partly determines the delivery time and inherently the shipyard’s competitiveness. Every shipyard strives therefore to shorten the erection time, which is a “bottleneck” where all ships needs to get through.

It is a real challenge for all partners (shipyard and suppliers) within the total ship production process to make a feasible and “optimal” planning in which a suitable utilization of resources is achieved. Because the erection schedule forms the basis for deriving this integrated planning, obtaining an “optimal” erection schedule is a prerequisite. The application of simulation can be used to achieve this, because this technique enables to investigate alternative production scenarios for the total shipbuilding process in advance, both on the strategic as well as the tactical level. On the operational level, it can be applied to aid in fine tuning of the tactical plan to actual production situations. With this, products and processes can mutually be brought in balance and processes can be geared to one another with smooth logistics of materials and components and properly levelled utilization of workstations as a consequence.

### 3. HULL ASSEMBLY SIMULATION

#### 3.1. Simulation in shipbuilding

Simulation to control shipbuilding processes has in recent years been applied with success in the steel building area, prefabrication and sub construction assembly processes. The main result of this experience is the universally applicable Simulation Toolkit for Shipbuilding (STS) of the Flensburger Schiffbau-Gesellschaft (FSG). FSG and DUT are co-founders of *Simulation Cooperation in the Maritime Industries* ([www.SimCoMar.com](http://www.SimCoMar.com)), a bundling of efforts in the

area of simulation in ship production. Goals of this cooperation are the further development of the STS, knowledge exchange in applying simulation and joint research. The actual cooperation partners are DUT, FSG, Shipyard Nordseewerke, the Technical University of Hamburg-Harburg, the Center of Maritime Technologies (all three in Germany), and the University of Liege – ANAST (Belgium).

The shipyard independent STS is a class library developed in eM-Plant of Siemens-UGS-Tecnomatix, a simulation package based on the discrete event simulation principles. The STS contains a wide variety of simulation functions needed for modelling the production processes of companies in the maritime industries. The tools can easily be implemented in all kinds of simulation models and they can be adapted to certain tasks and specifics by adjusting their parameters (Steinhauer 2005). The development of the STS is part of SimCoMar’s goals to be able to simulate the total ship production process. At Delft University of Technology (DUT), several simulation projects at Dutch shipyards have been executed based on the STS, see for example Kaarsemaker (2006) or Kaarsemaker (2007).

Experiences from all involved shipyards show that the steel building processes, from pre-manufacturing up to hull erection, are suitably applications of process simulation. But at this time, there is still a lack of simulation applications in the area of the more complex shipbuilding processes such as erection, outfitting and supply chain processes.

#### 3.2. Strength of simulation in shipbuilding

The strength of simulation, especially in shipbuilding, has been shown in various projects. In spite of that, proving its direct financial advantage is often beyond the bounds of the possible because a shipbuilding project is never the same and consequently it is not possible to run the same project with and without the use of simulation. The gained experience within SimCoMar shows that the main benefit from applying simulation is the possibility to accurately test, evaluate and communicate (an almost unlimited amount of) future production scenarios in the computer before they become reality. This relates to the set-up of new production facilities as well as the normal day-to-day building of new ships in existing facilities.

#### 3.3. Requisites for simulation

In theory, it is very easy to state that it is reasonable to run through the total production process of a ship in a computer simulation. It’s also true that model development and maintenance is speed up by the STS, but a disposal simulation model can be created very quickly. A good simulation tool and programmers are of course main requisites for simulation, but the correctness of input and output data is at least as important.

Important influences on the success of a simulation project are; an extended analysis of the “is”-state, clear



objectives and a good preparation. A simulation model is as good as its preparation and its results are in accordance with the quality and form of the input data. A consistent data-infrastructure that is continually kept up-to-date is needed, but unfortunately, data-readiness for simulation is still a rarity.

The main benefit from applying simulation is doing “unlimited” scenario research to reach an “optimal” plan. Therefore, product data needs to be available in an early stadium. This is in general a problem in current ship production practice, because detail engineering information gets out at a very late stage (concurrent engineering). A product data-generator to assess the missing data to enable simulation at an early stage is therefore a requirement.

Careful model validation takes a lot of time, but this is needed to achieve a valuable simulation model. In spite of a well-validated model, a right interpretation of simulation results is required. The results of a simulation are statistical values of a random check, all constraints and simplifications of the model have to be considered. Thereby, simulation can’t guarantee an optimal solution.

### 3.4. Simulation of hull assembly processes

The current status of the development of the simulation aided hull assembly planning tool is that the extended analysis of the “is”-state and the collection of validation data is in progress. As already mentioned in the last section, these are the most time-consuming activities concerning the creation of a simulation model.

Analysis of the “is”-state implies the introduction to the production processes and facilities of the process under study. In other words, the collection of material flow diagrams, process parameters, dimensions of production facilities, but also the collection of necessary product, process and project data. As written before, product data needs to be available in an early stadium. This is for the hull assembly process not a problem, as best estimates for these data are already made during budget proposal (before the ship is sold).

Collection of validation data implies in first instance that the process parameters (capacities of resources) are checked for correctness. This can be done by timing activities and work steps, but also by verifying registered working hours and production progress. With these data, the simulation model can be calibrated. After that, the calibrated simulation model can be run in parallel to reality to improve its veracity.

### 3.5. Result

A basic hull assembly model of the FSG erection site has been made available to the SimCoMar community. This model, presented in Figure 6, is structured with the STS. It can therefore easily be adapted to be a basic for the creation of a specific model for another shipyard, for example the IHC Merwede shipyard in Hardinxveld-Giessendam.

Figure 6 presents besides the top view of the hull erection model, the layout of a simulation model

modelled with the STS. This object library enables to model truly the facility (site and crane) and (sub-) product (sections and ship in assembly). In the figure are marked furthermore the methods which take care of starting actions and control the elements in the model. The general tools are shown in the upper left corner, these take care of:

- coordination and synchronization of the events
- administration of the model
- the operating calendar and shift times
- personnel definition and administration
- periodical summarization of statistics
- managing means of transport and the transports

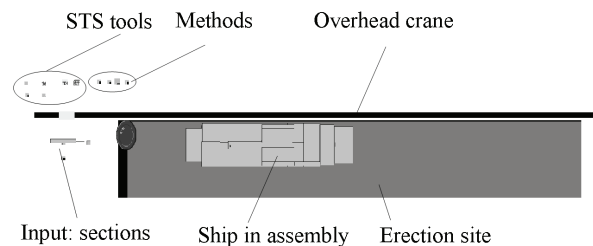


Figure 6: Top view snapshot of the basic SimCoMar hull erection model during a simulation run

Not shown in this figure is the statistics object that arranges the periodical summarization of resource statistics and the aggregated representation in work load diagrams. This is enabled by the STS tools which automatically tape all events (process steps, requests, transports, etc.) into tables. Based on these data, it is possible to visualise the results and then to evaluate them. The possibilities of a simulation model like this can be illustrated with an example regarding the workforce. Its composition (without suppliers) is simplified as given in Table 1.

Table 1: Composition workforce

Designation	Site	Shifts	Numb.
Constructing	...	...	...
Welding method 1	...	...	...
Welding method 2	...	...	...
Scaffolding	...	...	...
Quality checking	...	...	...
Grinding	...	...	...
Tank pressurizing	...	...	...
Painting	...	...	...
Aligning / Transport	...	...	...
Total			+/-100

This table can be explained as follows. During certain shifts, the workforce exists of approximately 100 employees of whom a certain number have certain designations who work at certain locations. The simulation model takes into account that when an activity requires two employees with the designation constructing during a dayshift, that the activity won’t be

executed when there is only one available and vice versa of course.

Via the statistics object, the workload diagrams as presented in Figure 7 can be created. This possibility to visualise results enables evaluating the balance between the production and employee schedules, with other words: resource levelling. Besides, representing progress or stage of assembly, or which section and components are worked on is possible as well. This knowledge combined with a view as in Figure 7, enables verifying what is going on at that moment in the simulation model.

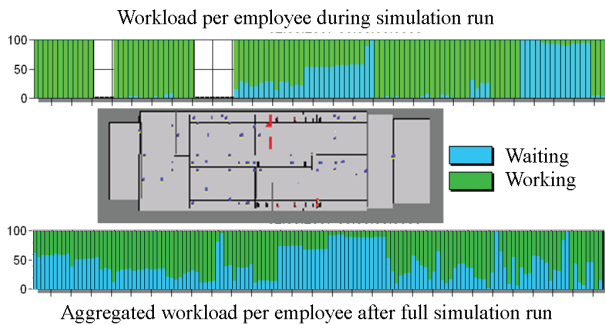


Figure 7: Workload per employee, also represented in the top view of the model, during and after simulation run

The combination of resource performances, comparison of planning with a simulated production realisation and the possibility to trace every part in the simulated production enables searching for reasons for delays and disturbances, which normally are not obvious because of all dependencies in the process. From these, conclusions can be drawn regarding improvements to production planning and resource management (Kaarsemaker (2006)).

#### 4. CONCLUSIONS

Presented is the status of an ongoing development of a simulation aided hull assembly planning tool. Currently, the extended analysis of the “is”-state and the collection of validation data is in progress, these are the most time-consuming activities concerning the creation of a simulation model.

Presented is a basic simulation model of an erection site, which comprises the whole production process concerning steelwork. After adjustment, this model can be used for the erection site (Hardinxveld-Giessendam) under research. Furthermore, the functionality of the model needs to be extended to include the big components that are part of the erection process. With the output that is possible to generate, it is assumed that the model could be fully validated, verified, and synchronised with reality, all extremely important for the success of the model.

The coming half year is reserved to continue the development of the simulation aided hull assembly planning tool. Conversely, because of the results up to now and the experience gained from other simulation projects, it can already be concluded that it is feasible to

model hull erection processes on a high level of detail in the form of a simulation tool and that this techniques can be of benefit for the improvement of production control at any shipyard.

#### ACKNOWLEDGEMENTS

Some phrases from Section 3.1 to 3.3 were also presented in Kaarsemaker (2007).

#### REFERENCES

- Hengst S., 1999. *Scheepsbouw Deel 1*, 1st ed. Delft: Delft University Press.
- Kaarsemaker J. et al, 2006. Simulation of a maritime pre-fabrication process. *Proceedings of International Conference on Computer Applications and Information Technology in the Maritime Industries*. May 8-10, Oegstgeest (the Netherlands).
- Kaarsemaker J. et al, 2007. Section building model embedded in a total process simulation environment. *Proceedings of International Conference on Computer Applications in Shipbuilding*. September 18-20, Portsmouth (UK).
- Kihara H., Yamamoto N., 1968. Recent Developments in Management and Production Methods in Japanese Shipyards, *Proceedings of SNAME Diamond Jubilee meeting*, pp. 3.1-3.16. . June 18-21, New York (USA).
- Steinhauer D., 2005. SAPP – Simulation aided production planning at Flensburger. *Proceedings of International Conference on Computer Applications and Information Technology in the Maritime Industries*,. May 8-11, Hamburg (Germany).
- Storch R. et al, 1988. *Ship Production*, 1st ed. Centreville, Maryland: Cornell Maritime Press.

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# ALTERNATIVE LINE DELIVERY STRATEGIES SUPPORT A FORKLIFT FREE TRANSITION IN A HIGH PRODUCT VARIETY ENVIRONMENT

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## ABSTRACT

Forklift transport fails when it comes to efficiency. As a result, more and more attention is going to alternative transport systems that automate or further structure the material flow; such as line deliveries by train and conveyor technology. Only substituting the transport system itself is not cost-effective. The resulting improvements are rather low compared to the high investment cost. Therefore, in this paper alternative material flow and line delivery strategies are taken into consideration. Within a high product variety environment a combination of materials kitting and line stocking is proposed. This approach has some important benefits on top of the pure forklift free transition. A basic model is constructed to calculate the kitting area and transport system requirements. A truck assembly company is used as case study. A feasibility study is carried out, to give a rough indication of the cost-effectiveness of the model.

Keywords: Materials kitting, line assembly, forklift free

## 1. INTRODUCTION

What drives the research on and implementation of forklift free (also referred to as 'fork-free') factories? Forklifts have long been the undisputed standard for material handling within the factory walls. The main reason is undoubtedly their enormous flexibility. Forklifts can perform the complete internal logistic flow as long as two important conditions are satisfied: Appropriate forklift construction and sufficient transport and handling space. Mostly the number of forklifts is overdimensioned in order to cope with fluctuations of the material flow. That - in combination with the human factor - makes the internal transport system flexible because the transport duties can easily be adapted to a changing material flow or factory layout.

Nowadays, flexibility remains an important issue but with the emergence of lean concepts it can not longer be at the cost of the efficiency of the transport system. Considering the different forms of waste stated below, it is obvious that forklifts fail when it comes to efficiency.

1. **Overdimensioning:** From own experience we noted that the uncertainty about the cycle time for transport tasks is certainly an important factor that contributes to an excessive number of forklifts. Since roaming vehicles are difficult to monitor visually, idle time remains easily hidden. The flexibility of the forklift transport is exactly the result of an over dimensioned transport system.
2. **Waiting:** Another aspect is the manual character of the forklift. The human factor makes the transport system vulnerable to social disruptions.
3. **Defects:** Finally, there's also the safety issue. Forklifts are a constant threat to personnel and can cause serious material and infrastructure damage. Neumann et al. (2007) and Gecker (2004) even state the human loss and liability cost relative to forklift injuries as the number one driver for forklift free plant floors.

As a result, more and more attention is going to alternative transport systems that automate or further structure the material flow. That explains the growing research on and implementation of line deliveries by train (Manual and automatic) and conveyor technology (Electrified Monorail System, Chain conveyor, Power&Free). The design of a material handling system is commonly subdivided in two highly interrelated sub-problems: design of the material flow network that provides the resource inter-connections; and sizing of the transporters fleet and allocation of the intergroup moves to these transporters (Montoya-Torres (2006); Sly (2006)). Both topics are well documented in literature. Forklift transport is typically a one on one delivery of pallets of parts (BULK) between origin and destination points. Alternative transport systems benefit from modified delivery approaches. It is obvious that trains must deviate from the one on one transport to for example a milkrun system to be effective. Automated transport systems - such as Automated Guided Vehicles (AGV) and Electrified Monorail Systems (EMS) - require special pickup and dropoff stations.

Only substituting the transport system itself is not cost effective. The resulting improvements are rather low compared to the high investment cost. In addition, safety issues - such as forklift injuries - are difficult to quantify and therefore far from trivial to incorporate in an investment analysis. Therefore, in this paper alternative material flow and line delivery strategies are taken into consideration on top of the forklift free transition. Bozer and McGinnis (1992) compared the use of materials kitting for a Just In Time (JIT) delivery of parts for assembly to the line stocking approach of the bulk delivery. It is important to determine the contents of each kit. This assembly line feeding problem is discussed by De Souza et al. (2008). In addition, the use of the kits at the line can reduce the walking distance of the line operator. Within a high product variety environment a combination of both approaches is proposed: line stocking for common and materials kitting for variant parts. This approach has some important benefits on top of the pure forklift free transition: (1) reduction of the transport system requirements by restricting necessary dropoff stations; (2) reduction of walking distances for the line operator by presenting kits; (3) reduction of line stock by JIT delivery of parts; (4) centralizing the parts handling at the kitting area.

Section 2 presents a basic flow model to calculate the kitting area and transport system requirements. Different model configurations/strategies are made possible by a set of parameters. In Section 3 a truck assembly company is presented as case study. The feasibility study gives a rough indication of the cost-effectiveness of the extended forklift free transition. A Dupont model is constructed that uses the flow model output to obtain a first impression of the financial potential of this endeavour. Section 4 concludes and states further research possibilities.

## 2. FLOW MODEL

In order to make accurate model calculations regarding the different internal logistic flows, it is necessary to build a database based on the current situation ('AS IS'). The constantly changing layout and material flow of a real factory is too complex for the feasibility study. Therefore the current situation is frozen and a snapshot of the factory layout and material flow will be used. The feasibility at that specific time will then be determined. The following sections highlight the three important aspects in the model: (1) material flow; (2) transport system and (3) line delivery strategy.

There is no optimization integrated in the presented model. The transport system network, vehicle routing, kit composition, etc. are all based on average values of a small production period. The proposed logic should be sufficient however to determine the feasibility by roughly estimating the required investments and featured improvements.

### 2.1. Material flow

The current material flow is assumed to be in bulk. A

container (pallet, rack, box, ...) containing a certain number of the same parts is transported to the line and placed as stock. The line operator empties the batch and orders a new one timely. This method is called line stocking. Each combination (Part, Origin Point, Destination Point) is identified by a specific transport frequency  $N$  and an amount  $A$ . This means that  $N$  times per shift, a package of average  $A$  parts is transported. In addition the use frequency  $f$  of a part at the use point is calculated by (1) with  $Nb_{assembly}$  the number of products that are assembled during one shift on that use point.

$$f = \frac{N \cdot A}{Nb_{assembly}} \quad (1)$$

This value tells in how many final products the part is used. A value of 0.2 means that the part is used in 2 out of 10 products. The latter parameter is a significant one: it can fluctuate widely from  $f \geq 1$  (common part) to  $f \leq 0.001$  (an exotic option part) and it differentiates industries: the frequency range in automotive is less than in truck assembly, while the latter is smaller than in harvester equipment assembly. Within a high product variety environment line stocking results in an excessive inventory at the line (Fisher and Ittner 1999). Parts that are assembled in almost any product, are referred to as common parts. Variant parts reflect the various options that can be installed on a product at the same workstation. Materials kitting is the practice of putting together a kit of parts and/or subassemblies before delivery to the assembly line (Bozer and McGinnis 1992). A kit can combine materials for one final product at different use points (travelling kit) or materials for different final products at the same use point (stationary kit). Within the proposed model a mixture of line stocking and (travelling) materials kitting is integrated. The model parameter **Frequency Boundary**  $f_b$  makes the divide between both groups of parts. Parts with a higher (or equal) use frequency than  $f_b$  are brought in bulk. Parts with a use frequency less than  $f_b$  are collected in kits. For example, when  $f_b$  is 0.5 then all parts that are assembled in half or more final products are kept as inventory at the assembly line. The other parts are seen as variant parts and will be brought JIT in kits.

The flowchart in Figure 1 describes the composition strategy of the kits based on the average use frequency  $f$  of each part at each line station. The first step is filtering the parts list based on their use frequency. Those with  $f \geq f_b$  are left out. The remaining parts are grouped in kits considering the line direction and some restriction parameters:

$$(p_{kit} + p_{PN}) < p_{max} \quad (2)$$

$$(w_{kit} + w_{PN}) < \frac{w_{max}}{\delta_w} \quad (3)$$

$$(p_{kit} + p_{PN}) < \delta_p \cdot p_{max} \quad (4)$$

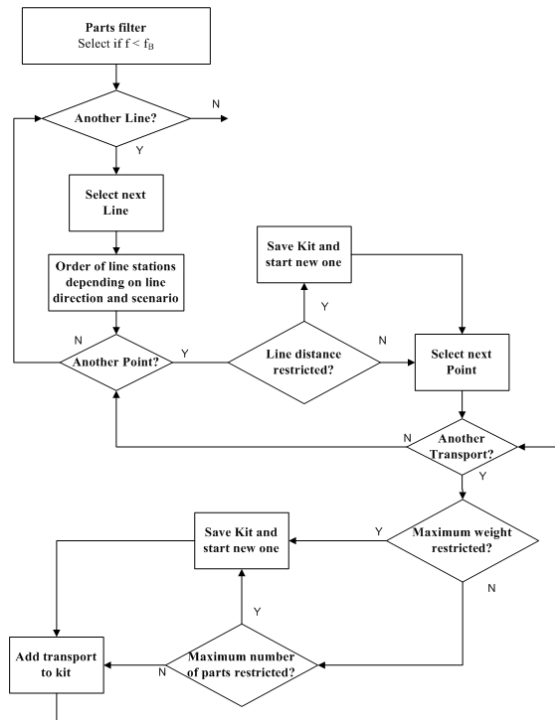


Figure 1: Flowchart of the Kit Composition Strategy in the Model

- **Maximum line distance  $\Delta_l$**  (line stations): The maximum line distance the kit can travel. This value is expressed in the number of line stations the kit passes through. This parameter is introduced to restrict the walking distances of the line operator emptying the kit. A value of  $\Delta_l = 3$  means that each kit can contain parts for one product assembly at no more than three different line stations.
- **Maximum weight  $w_{max}$**  (kg/kit): The carriers of each transport system have a maximum weight limit that can be transported. This parameter makes sure that this limit is not exceeded.
- **Maximum number of parts  $p_{max}$**  (parts/kit): This is a restriction on the number of parts that are put into the same kit. Restricting this amount, should ease the handling of the kit by the line operator. This restriction however is not binding, because otherwise the result would have kits that contain a large number of small parts. Therefore this restriction is coupled to a certain percentage of  $w_{max}$ . So, considering the parts restriction, part number PN can be added to the kit when (2) OR ((3) AND (4)) is satisfied. Expression (2) is the normal parts restriction. Expression ((3) AND (4)) eliminates kits with many small parts by making sure that the total weight is minimum the weight restriction divided by  $\delta_w$ . A value  $\delta_w = 5$  means that the kits must weigh at least 20% of  $w_{max}$ . Additionally there is an extra expression that restricts the number of parts again to maximum  $\delta_p$  times the normal parts

maximum. So, when all parts are small (low weight) than the used parts restriction can be  $\delta_p \times p_{max}$ . When  $\delta_p = 3$  then kits can contain three times more small parts.

The composition of the kits requires extra handling. Therefore a kitting area is introduced where all necessary kits are composed. Within the proposed model two extra parameters concerning the kitting process are introduced: **Overall Picking Productivity PP** and **Batch Size BS**. In order to calculate the amount of pickers required, a productivity has to be assigned, ex. 175 line picks per picker per hour. If the use frequency of a part is larger than 1, only 1 pick is counted to pick all the pieces. In real-life picking situations, often batch picking is used. This means that several kits are picked at the same time. BS = 4 means four kits will be picked at the same time. If a part is picked that occurs in 2 of the 4 kits, only 1 pick is counted because the picker can take the 2 pieces and drop them in the 2 different kits. He only has to walk once. In addition to the picking workforce a sufficient infrastructure is needed to support the kitting processes. If current warehouses don't satisfy the needs, new infrastructure or different methods must be introduced.

Optimal values should be obtained for the different model parameters. For example, an increasing value for the frequency boundary parameter  $f_b$  results in more kitting and more transport efforts. But more travelling kits at the line, decreases the handling efforts of the line operator. However, before this exercise can be made, the benefits of materials kitting at the production line must be quantified more precisely.

## 2.2. Transport System

Based on the selected alternative for the forklifts, the transport system requirements are calculated within the proposed model. Each transport technology has specific characteristics for the (1) **transport network** and (2) **carrier**. In current literature much research can be found on optimal solutions for network design (Wan (2006); Montoya-Torres (2006)) and vehicle routing (Le-Anh and Koster (2006); Chuah and Yingling (2005)). However, in this paper there is no need for an optimal solution. A simple calculation will do for the feasibility study of the complex material flow. Based on the total list of bulk and kit transports (see 2.1 *Material Flow*) a static simulation is performed. To reduce the complexity of the problem, the model doesn't incorporate the dynamic behaviour of the transport system. The possible transport systems are: (a) **Manual train** (Forklift-like pulling unit), (b) **Automatic train** (Automated Guided Vehicle) and (c) **Electrified Monorail System**. As an example the working method is illustrated for the EMS.

(c1) *EMS transport network* - At each use point (for bulk and kits) on the factory floor a dropoff point is drawn. An unidirectional network of tracks is constructed to interconnect all points. Everything is

done manually, so an optimal network is not the aim. The purpose is - based on an CAD drawing of the factory floor - to determine the distance between each two points in the network. The output is a number of dropoff stations, an amount of track in meters and some shifting tracks.

(c2) *EMS carrier* - Each carrier is independently driven and can transport a certain maximum volume  $V_{cmax}$  ( $m^3$ ) and maximum weight  $w_{cmax}$  (kg) over the transport network at an average speed of  $v_{cavg}$  (ms). Equation (5) summons all required carrier time (seconds) to route the material flow through the transport network. There are  $n$  transport combinations (part, origin, destination).  $d_i$  is the shortest path distance of transport  $i$  (meter) to go from origin to destination and complete the loop back to the origin in the EMS transport network. Based on the number of work hours during one shift  $t_{shift}$  the number of carriers can be calculated (6).

$$T_c = \sum_{i=1}^n \frac{d_i}{v_{cavg}} \quad (5)$$

$$n_c = \frac{T_c}{60.60.t_{shift}} \quad (6)$$

### 2.3. Line Delivery Strategy

The line delivery strategy determines what happens with the travelling kits when they are dropped off at the assembly line. Four different approaches are proposed:

1. **Further handling at the line** - The kit is simply placed at the dropoff point by the transport system. Further handling has to be done by the line operators. When the kit stays at a fixed position, it results in larger walking distances to fetch the parts. When the travelling kit is collected in some sort of cart, then the line operator has to take it with him during assembly causing him to do extra handling.
2. **Couple cart to the line** - The part numbers for both sides of the assembly line are combined in kits and placed on carts. When dropped off, the carts are coupled to the driving mechanism of the line. They run along with the product at line speed, resulting in smaller walking distances.
3. **Conveyor at both sides of the line** - Each side of the line has its track and dropoff stations. When dropped off, the kits are placed on (or coupled to) the (chain) conveyor. They run along with the product (at both sides) at line speed, resulting in smaller walking distances.
4. **Carrier runs along with the line** - This option is the most advanced one. Each side of the line has its track and dropoff stations. Here the kits are not really dropped off. The carrier leaves the main track and runs along the line

on a secondary track at line speed presenting the parts to the line operator, resulting in smaller walking distances. Figure 2 illustrates strategy (4) in the case of a truck assembly company.

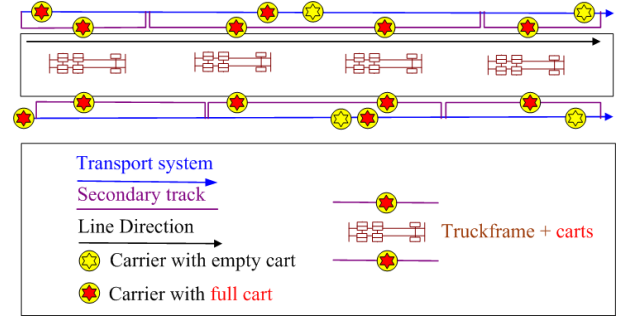


Figure 2: Dropoff Strategy 'Carrier Runs Along with the Line'

## 3. CASE STUDY – A TRUCK ASSEMBLY COMPANY

### 3.1. High Product Variety

The database contains the internal logistic flow from 33 days during the months April and May of the reference year. There are two main lines: one produces 72 trucks per shift in a two shift operation, the other produces 36 trucks in one shift. The average number of transports and the average transport amount of the parts from warehouses to lines and pre-assembly are calculated over 33 days. The origins of the material flow are a High Bay Automatic Warehouse, Small Box Warehouse, some conventional stores and 40 pre-assembly stations. The destination points are 149 line stations and 137 pre-assembly stations. The logistic points are drawn on top of an AutoCad file of the factory layout. The possible routings are added by connecting the logistic points through lines and network points (numbered points) to a complete logistic network. Figure 3 gives an excerpt of the current situation. There is a total of 4320 transport combinations (part, origin, destination). There are more different part numbers than there are packages transported during one shift (3317 against 2215). This reveals the complexity of this material flow. There are many parts that are only used in few trucks, referred to as variant parts. The use frequency of a part number at a specific line station gives an idea of the percentage of trucks the part is assembled into. A frequency of 0.2 means that the part is used in 2 out of 10 truck assemblies at that line station. Table 1 lists a few examples.

Table 1: A Delivery Overview of Some <Part Number, Line Station> Combinations

Part Number	Line Station	Weight (kg/part)	Frequency (parts/truck)
03176675	EL09	0,169	0,133
20478323	ER06	0,25	0,933
980464	CL10	0,006	9,073
208911	CR06	0,24	0,075
955399	AR03	0,41	3,779



materials kitting and the presentation of kits to the line operator. By using JIT supply, space utilization at the line is reduced. This also has a unquantified positive impact on production.

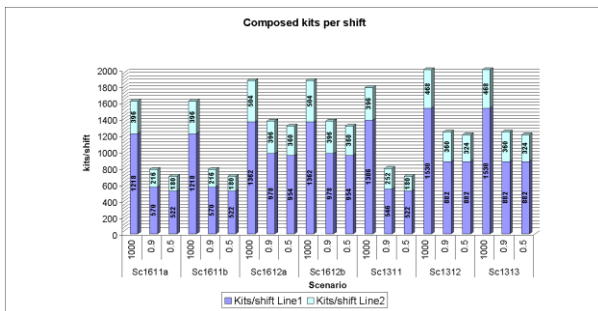


Figure 6: The Number of Kits Composed per Shift.

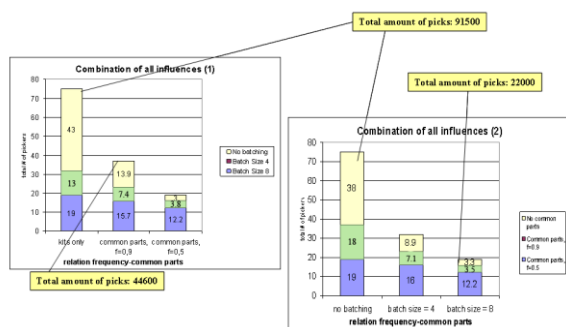


Figure 7: General Overview of the Number of Picking Operators Needed

This feasibility study is only a rough indication. The output is an early impression of featured challenges and expected costs and improvements. It points out which scenarios are open for further research. Based on detailed simulation and practical studies a more founded decision is possible. The detailed simulation will have to determine the number of carriers that will have to be added due to variability and failures, as well as indicate how big and where buffers are to be included in the transportation system. The technical issues regarding delivery to the hands of the operator by an automatic handling system will have to be studied by experimental setups.

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#### REFERENCES

Bozer, Y. A., and L. F. McGinnis. 1992. Kitting versus line stocking: A conceptual framework and a descriptive model. *International Journal of Production Economics* 28 (1). P.1-19.

Chuah, K. H., and J. C. Yingling. 2005. Routing for a just-in-time supply pickup and delivery system. *Transportation Science* 39 (3): 328–339.

De Souza, M. C., C. R. V. de Carvalho, and W. B. Brizon. 2008. Packing items to feed assembly

lines. *European Journal of Operational Research* 184. P.480-489.

Fisher, M. L., and C. D. Ittner. 1999, June. The impact of product variety on automobile assembly operations: Empirical evidence and simulation analysis. *Management Science* 45 (6). P.771-786.

Gecker, R. 2004, December. Materials handling strategies: A fork-free future. *Inbound Logistics* 24 (12). P.52-56.

Le-Anh, T., and M. D. Koster. 2006. A review of design and control of automated guided vehicle systems. *European Journal of Operational Research* 171:1–23.

Montoya-Torres, J. 2006, October. A literature survey on the design approaches and operational issues of automated wafer-transport systems for wafer fabs. *Production Planning & Control - The Management of Operations* 17 (7): 648–663.

Neumann, J., L. Tyler, and M. Urban. 2007, May. *Forklift free plants...considerations for success*. White paper, Kinetic Technologies inc. Available online (7 pages).

Sly, D. 2006, April. *Techniques for the evaluation, reduction and elimination of excess material flow within industrial facilities*. White paper, Proplanner. Available online (22 pages).

Wan, Y.-T. 2006, May. *Material transport system design in manufacturing*. Ph.D. dissertation, Industrial and Systems Engineering, Georgia Institute of Technology.

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# WAREHOUSE LOGISTICS REVISITED: - A CRITICAL ANALYSIS

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## ABSTRACT

The authors have undertaken a retrospective analysis of an industrial logistic project delivered to the Hungarian Post (HunPost). First, the paper briefly overviews the major generalized practical experiences related to warehouse logistics. Next, the assignment and problem definition are described, then the input data analysis, the design and implementation of the simulation model, the model results and the system-related conclusions. Finally, the paper discusses the lessons learned.

Keywords: warehouse logistics, postal logistics, simulation pitfalls, acceptance of simulation

## 1. INTRODUCTION

It is always a rare occasion when real projects can be retrospectively analyzed and conclusions for future works made. The authors have got the rare opportunity to retrospectively analyze a simulation project and found a series of pitfalls in the simulation modeling process also discussed in (Annino and Russell 1979) and (Law and McComas 1989). Unfortunately, related to pitfalls what regards manufacturing and logistic models and their usage, only less definitive statements can be made, as explained below. This paper discusses the authors' experiences and the lessons learned.

The authors revisited a contracted simulation project, which has been realized for HunPost in 2000. The project's aim has been to help the design process of a new warehouse and use the simulation model to get quantitative data about how the system works. The application can be considered therefore as a standard industrial application with a short delivery time of 10 weeks. There have been no overwhelming scientific challenges, there were no sophisticated technical problems to be solved; the simulation model which the designer can trust and build upon "just" needed to work and deliver data, since in case of mistakes, the design flaws could have caused not only additional costs but also credibility and reputation loss for the designer institution and its subcontractors.

From the long-term perspective, however, a series of additional concerns can be raised, which all are closely related to the simulation model. These concerns include, but are not restricted to the following:

- Do the simulation model and the related experiments constitute a "final solution" for the design phase or is there additional need for the use of advanced modeling technology for "real-time" analysis or on-line control?
- Is the simulation model implemented in a way that it is re-usable, extendable, open, etc?
- What is the overall economic efficiency of the company's approach?

By answering these questions, as a by-product, several additional questions might also be answered:

- Why simulation models are still not widely applied in industrial practice?
- What developers and educational institutions can do to improve the success rate and find the major success factors?
- Do better education, marketing and software (faster, more user-friendly etc.) help?

## 2. SIMULATION MODELING OF THE DISTRIBUTION WAREHOUSE

The phases of simulation modeling are presented as executed. The focus of the presentation however is on the exceptions, special cases. Steps and model features are presented in order to provide an inside of the model.

### 2.1. Assignment and Problem Definition

Contractual requirements and their consequences defined a series of major model characteristics:

- The model must be able to make predictions whether the logistics system is able to deliver the specified output quantities based on a given set of scheduled input quantities by using the known technological elements and time.
- It should demonstrate the characteristics of the working system (e.g., technological elements, their utilization factors and waiting times, incl. their distributions, furthermore, predefined events).

- The simulation model should be used to determine bottlenecks and to analyze alternative solutions.
- The simulation model must be able to communicate with MS Excel in order to receive input and deliver data.

## 2.2. Methodology and Data Sources

Based on the detailed technological plan, the layout, the definition of the model elements and their parameters have been established and the simulation model created. Then the simulation model has been used in the subsequent phase to determine the parameters and policies of the working system.

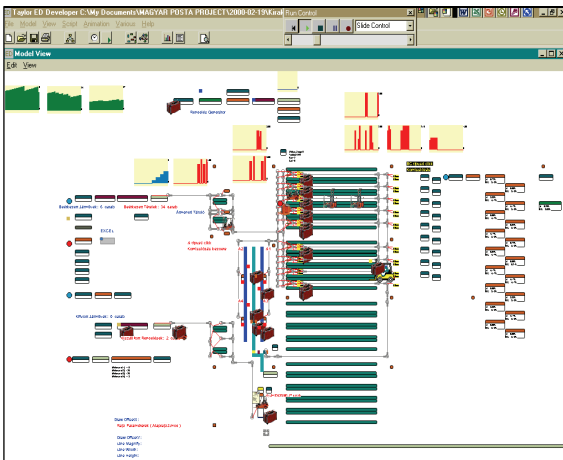


Figure 1: The (2D) block-diagram of the model

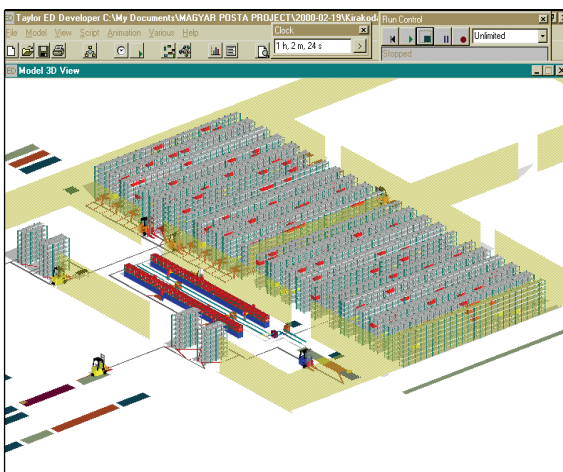


Figure 2: The (3D) block-diagram of the model

The following warehouse operations were modeled:

- Warehouse load-in operation (see Figure 3.)
- Disposition operation.
- Commissioning (A, BC) operation (see Figure 4.)
- Packing operation (see Figure 5.)
- Warehouse unload operation (see Figure 6.)

## 2.3. Simulation Model Implementation

The simulation model of the HunPost was implemented using Taylor Enterprise Dynamics, an object-oriented simulation model development environment, which is able to model and control different simulated processes. It is used widely and both the modeling and visual tools of the software were considered as flexible and capable enough to communicate with other Windows applications (incl. MS Office tools). The additional feature of zoom-in/zoom-out made it possible to implement models of large size or with large amount of detail.

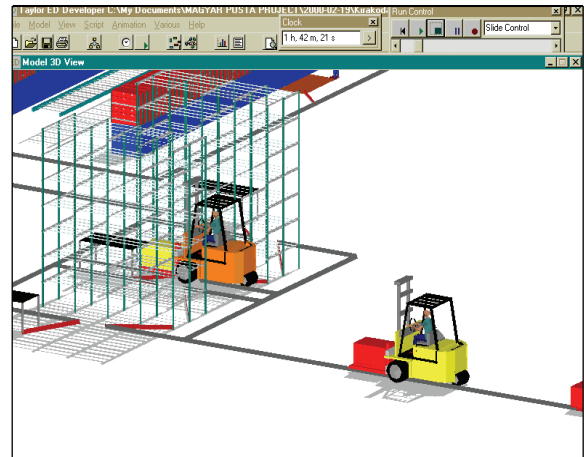


Figure 3: Load-in operation

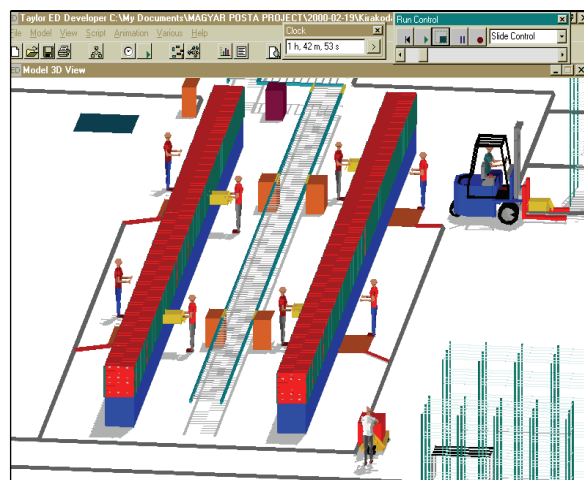


Figure 4: Commissioning (A) operation

## 2.4. Simulation Model Data

The model data related to model elements and their parameters, internal and external model variables, etc. can be defined using interactive GUI, and the simulation program as necessary. An example of GUI-based data input is presented in Figure 7.

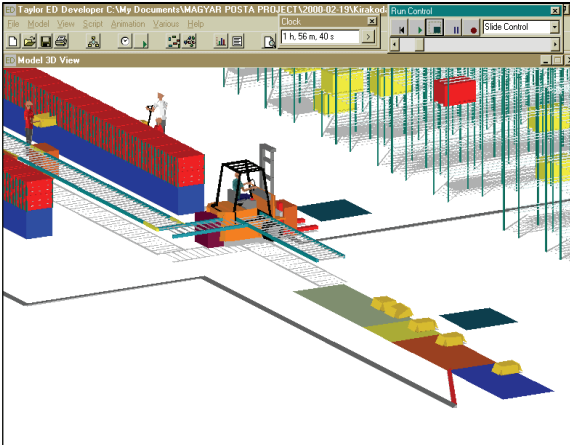


Figure 5: Packing operation

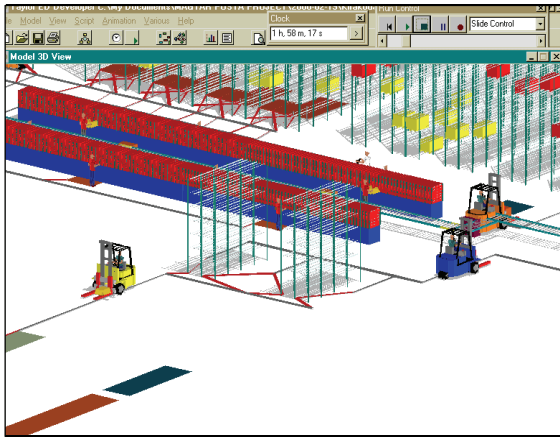


Figure 6: Unloading operation

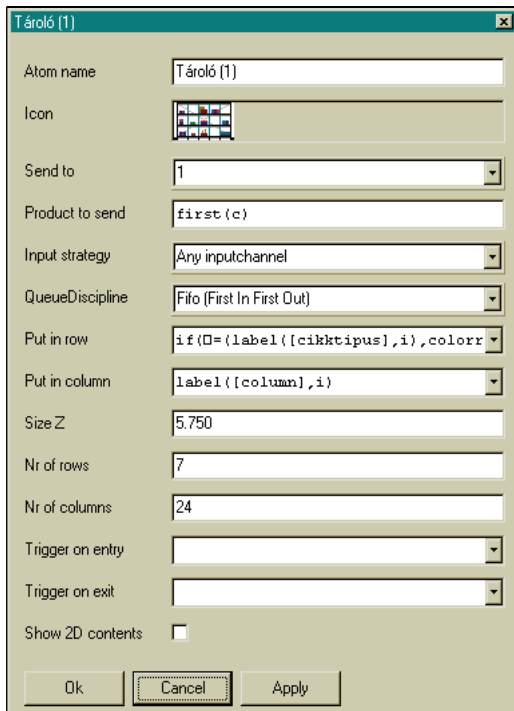


Figure 7: Data input using interactive GUI

Certain input data are provided for the simulation program by the MS Excel application (as requested),

which makes even larger amount of data easy to handle.

## 2.5. Simulation Model Results

- Commissioning operations can be studied in terms of quantities and behavior (changes over time), moreover also by type (type A., Type BC).
- The transportation machines (e.g., cranes or forklifts) can be observed while utilized (e.g., speeding up, slowing down).
- The content change of warehouse storages can be observed over time.
- Commission-related activities, actual storage content and the impact of different fill-up strategies over time can be observed in terms of numerical and graphical data.
- Simulation model characteristics and behavior can be observed (see Figure 8 and 9).

### 2.5.1. Evaluation of the Simulation Model Results

The simulation model fulfills all the contractual requirements defined at the beginning of the project and listed in 2.1. The model is able to predict the major quantitative and qualitative indicators of the working systems and can be used for determining the model parameters. In effect, the simulation model has been used for fine-tuning the working system parameters to achieve higher efficiency.

## 2.6. Simulation Experiments and Possible Model Improvements

Further model experiments are possible in order to

- determine the system behavior in case of new transportation routes,
- study the impact of changes in the number of transportation machines,
- utilize the data stored in the warehouse database,
- make further efforts to improve parameter fine tuning.

## 3. RETROSPECTIVE ANALYSIS: LESSONS LEARNED

### 3.1. Some Application Trends

According to Hlupic (2000), over 80% of the simulation applications in academia and over 55% in industry are applications of the fields of manufacturing and logistics. These results are also supported by Williams (1997), who states, “indeed, manufacturing is among the oldest and most frequent areas of simulation application” and list also further references to support his statement. Authors are aware that the growth of simulation applications has not slowed in the last decade. Improved

simulation interface, development of application-oriented simulators, new applied methodology (e.g., fuzzy modeling, agent-based modeling) increase the use of simulation, while animation provides credibility and a better understanding for model developers and customers, as well.

Logistics is a growing area of simulation use. Literature (e.g., Larsen (2003)) shows clearly that post agencies, carriers such as United States Postal Service (USPS), the Norwegian and Belgian Post must process large number of orders within a short time, in a series of operations involving transportation equipment (e.g., aircraft, train, trucks, assorted material-handling equipment), human resources (e.g., loading and unloading crews, drivers) and information (e.g., digital data, RFID). These corporations have used simulation to understand and to improve their operations. National and international competition forces also the HunPost to apply new methods and technology to solve logistical problems.

As a recent report PriceWaterhouseCoopers (2008) shows, a series of application field related software tools were embedded into a suite of simulators (Postal Simulators, Strategic Infrastructure Simulators, Plant/Facility and Product Stream Simulators), establishing a unique decision support system, which enables:

- Simulate and visualize alternative solutions.
- Analyze, quantify, verify and select the best solution.
- Predict consequences of a solution before implementation.

The leading industrial and government corporations went far in following the suggestions listed in Roth, Gass, and Lemoine 1978: (e.g., (i) established post-review panels that evaluate models, provide guidance to potential users, (ii) created “Government Modeling Research Centers”, which coordinate and direct some of the Government modeling research, develop software and establish standards, conduct training programs, organize databases. According to Swain (2007), the growth of simulation applications in industry and the military led to a growing demand for simulation professionals. Academic programs in modeling and simulation were introduced and standardization efforts undertaken, moreover new organizations (e.g., Alabama Modeling and Simulation Council) have been established to develop the different aspects of simulation.

### 3.2. Engineering vs. Management Issues

The application trends described in 3.1 however, cannot be observed (yet) in the Central-Eastern European countries. Authors ask the simple questions: - Why? What are the reasons?

In an effort to determine at least some of the reasons, we revisited the project presented above and

analyzed it according to the success factors listed in (Law and McComas 1989) and (Law and McComas 1991). We have realized that the professional rules were not violated, but we did not spend too much attention to some of the components listed in (Annino and Russell 1979; Law and McComas 1989; Law and McComas 1991; Law and Kelton 1991; and Williams 1997). The list of suspected errors is enumerated as follows. The project management:

1. Did not employ good project management techniques,
2. Did not communicate with management on a regular basis,
3. Contributed to the misuse of animation,
4. Was unable to help in constructing a support infrastructure within the company for simulation,
5. Was unable to help disseminating awareness of simulation and its benefits throughout the organization,
6. Was unable to help maintaining knowledge of and enthusiasm for simulation within the organization
7. Did not organize training classes and seminars in simulation,
8. Did not document the successful applications of simulation and the benefits accruing from them,
9. Did not support evaluation and choice of simulation consultants and model builders at the company.

Based on the list above, we must conclude that the management of the project has not been as strong as needed. Analyzed based on Ulgen’s list of criteria (Ulgen 1991), which defined the successful management of a simulation project, management showed clear deficiencies in not fulfilling the following points:

1. Client uses the results of the simulation project in the decision-making process.
2. Client saves money in using the results of the simulation project.
3. Client accepts simulation as a design and analysis tool within the company.
4. Client company representative earns visibility and recognition due to his/her involvement with the simulation project.
5. New and better solutions are generated as a result of using simulation.
6. Client company becomes interested in using other industrial engineering productivity tools

As a consequence, the “higher level” applications, described in Larsen (2003) were never developed:

- The project did not move ahead to use the model to handle the operational problems of

the real system.

- The project did not move ahead into strategic and value chain network directions; towards real-time, on-line control, supply chain management and integration into the working IT environment (e.g., ERP system).
- The three months project time frame has been entirely used to develop a quality solution and to deliver the product. The project did not fully utilize the intellectual factor of time (it is good because it is becoming “unusual” fast and competitive, but also bad in the same time, because it is not providing enough time to check out new solutions, hardware or software or methodology cannot be developed and certainly, the human factor will also be neglected).

The user behavior can be explained based on Sparkes and McHugh (1984): “... although an increasing number of companies appreciate the importance of forecasting, the methods used are predominantly naïve and few companies are taking steps to improve the situation through using alternative techniques or through computerizing established techniques.” The withheld enthusiasm of the management of the HunPost however was caused by missing education and training, as well as limited motivation and involvement. Under these circumstances, the application environment at the corporations cannot be very innovative; as a matter of fact, simulation models are developed abroad and solutions are delivered, (in best case, adaptations are permitted).

#### 4. CONCLUSIONS.

In this paper, authors present a warehouse logistics model and analyze its retrospective difficulties and pitfalls. The final conclusion of the analysis is very simple: it is not sufficient to fulfill the contract and deliver the simulation model to the customer, but efforts must also be focused on the long-term impact of the simulation model application. Important factors related to the project management must be taken into consideration and the project should establish mutually advantageous business relationship and improve the profession itself.

#### REFERENCES

- Annino, J.S., Russell, E. C., 1979, The Ten Most Frequent Causes of Simulation Analysis Failure-and How To Avoid Them! *SIMULATION*, Vol. 32, No. 6, 137-140.
- Axelrod, R., 2005, *Advancing the Art of Simulation in the Social Sciences*. Handbook of Research on Nature Inspired Computing for Economy and Management, J.P. Rennard (Ed.), Hersey, PA: Idea Group, 2005.

- Hlupic, V., 2000, Simulation Software: An Operational Research Society Survey of Academic and Industrial Users. *Proceedings of the 2000 Winter Simulation Conference* (Eds. J.A. Joines, R.R. Barton, K.Kang, and P.A. Fischwick), 1676-1683.
- Larsen, N.E., 2003, Simulation - A Key Tool to Accelerate and Add Confidence to Postal Network Configuration. *Proceedings of the 2003 Winter Simulation Conference* (Eds. S. Chicks, P.J. Sanchez, D. Ferrin, and D.J. Morrice), 1585-1592.
- Law, A.M., McComas, M. G., 1986, Pitfalls in the Simulation of Manufacturing Systems. *Proceedings of the 1986 Winter Simulation Conference* (Eds. J. Wilson, J. Henriksen, S. Roberts, P.), 539-542.
- Law, A.M., McComas, M. G., 1991, Secrets of Successful Simulation Studies. *Proceedings of the 1991 Winter Simulation Conference* (Eds. B.L. Nelson, D. Kelton, G. M. Clark), 21-27.
- Law, A. M., Kelton, W. D., 1991, *Simulation Modeling & Analysis*. International Edition Industrial Engineering Series, McGraw-Hill.
- PriceWaterhouseCoopers, 2008, *Postal Logistics & Systems Simulators: A hierarchy of postal simulation systems*. Available from: [http://www.arenasimulation.com/pdf/post\\_x.pdf](http://www.arenasimulation.com/pdf/post_x.pdf) , [Accessed: 5/1/2008].
- Roth, P. F., Gass, S. I., Lemoine, A. J., 1978, Some Considerations for Improving Federal Modeling. *Winter Simulation Conference, Proceedings of the 10th conference on Winter Simulation - Volume 1*. 1978, Miami Beach, FL, 213 – 218.
- Sparkes, J.R., McHugh, A. K., 1984, Awareness and Use. of. Forecasting Techniques in British Industry, *Journal of Forecasting*, Vol. 3, 37-42.
- Swain, J. J., 2007, Biennial survey of discrete-event simulation software tools. *New Frontiers in Simulation, Simulation Software Survey, OR/MS Today* , October 2007.
- Ulgen, O. M., 1991, Proper Management Techniques Are Keys to A Successful Simulation Project. *Industrial Engineering Magazine*, August 1991, 37-41.
- Williams, A. G., 1997, How Simulation Gains Acceptance as a Manufacturing Productivity Improvement Tool. *11th European Simulation Multiconference ESM97, SCS Europe*, (eds.: A. R. Kaylan, A. Verbraeck).

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# OPTIMISING ADVANCED CONTAINER HANDLING TECHNOLOGIES VIA DISTRIBUTED SIMULATION/EMULATION

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## ABSTRACT

Simulation technology is state of the art in planning new terminals and reorganising existing ones. Typically the systems used for simulation are working offline and all information have to be entered into the model before running the scenarios. This effort can be reduced by combining the terminal operation system (TOS) with the simulation model using the parameters which are stored within the TOS. In this combination the material flow as well as the control system including all strategies has to be rebuild within the simulation. In a next step not only some defining parameters but the strategies theirselves are used in the simulation by coupling the whole TOS to the simulation. This kind of simulation, where only the material flow is build in, is called emulation. Splitting the whole simulation into different modules (the TOS and the device emulators) is the base for the distributed system. Typical emulation systems are often developed for just one application and therefore use very restricted communication protocolls. The DeCoNet framework is the base for an open distributed emulation network where each module may be realised using its own development environment and operation systems.

Keywords: Test Bed, Emulation, Container Terminal, Terminal Operation System (TOS), Distributed

## 1. INTRODUCTION

The rapid growth in worldwide container handling will continue in the near future, as predicted by several forecasting organisations. The terminals have to reorganise to enhance productivity. But: the more complex and automated the operation at the container terminal becomes, the more rises the importance of a high sophisticated IT-system to cope with the new demands.

The system "container terminal" is relatively complex. It is characterised by numerous parameters and interactions between technical, operational and economical components. Furtheron some of the influencing quantities have a random character as e.g. arrival times, daily no. of boxes, loading and discharging times of vessels, container movement time of a crane etc.

With the aid of simulation technology it is possible to reproduce the system "container terminal" as a virtual

system in order to analyse an existing or planned terminal in detail. As a simulation model is a computer-based system the real system "container terminal" has to be represented in such a way that an equivalent mathematical model can be constructed which then reproduces the processes - including fortuitous events - in a realistic way.

Thus a simulation system is a powerful tool with the help of which the user can "play through" and subsequently analyse the processes of a terminal in order to get a transparent basis for the decision-making process. Special simulation models have been developed for each planning level because there are different problems resulting in different requirements.

Additionally to these systems, which are mainly used for strategic planning tasks simulation nowadays is also used to support the day to day operation. The basic principle for this is the emulation of the terminal equipment. Emulation is defined as "a model that accepts the same inputs and produces the same outputs as a given system." (IEEE 1989). The emulation is directly coupled to the TOS. With this structure emulation can be used among others for:

- Evaluation and optimisation of strategies used in the TOS
- Testbed for the real TOS
- Visualisation of new Terminals
- Testbed for acceptance tests of external equipment (figure 1)

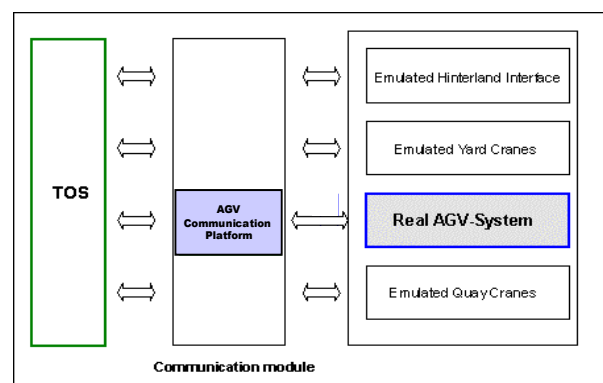


Figure 1: Using Emulation for Acceptance Test of External Equipment

One of the first projects considering all these topics has been realised at the Container Terminal Altenwerder (CTA, Hamburg, Germany). Till this day these emulators are in use to verify new releases of the TOS before installing it at the real terminal. Hartmann and Schütt (2000) describes the whole project beginning with the feasibility check up to an emulation system (IEEE 1989).

Emulation technology is found also in other parts of logistics. Burges et al. describe an application in the automotive branch, Ha (2007) describes approaches of different levels to combine the terminal operation system (TOS) with simulation/emulation modules.

## 2. FROM SIMULATION TO EMULATION

With the aid of simulation models it is possible to support resp. investigate the planning and design of new container terminals as well as the optimisation of long term strategies of existing ones. The evaluation of the simulated container terminal operation is carried out with regard to economic and technical aspects. The target variables which are output, measured against each other and interpreted are the costs incurred and the handling volumes achieved.

### 2.1. Terminal simulation

Simulation systems may be classified into low-term, medium-term and very detailed types. The low level system does not reproduce the terminal operation at all, but limits to global processes (e.g. berthing, quay productivity). Detailed systems do reproduce the single process in detail (e.g. equipments acceleration, container tracking within the terminal). Medium-term level tools for the decision-making process for the strategic planning and design level cover the expansion or re-organisation of existing terminals and changes in organisational structures that extend beyond short-term deployment planning (operational level). This kind of model does not simulate the individual containers in isolation but the behaviour of the whole system "container terminal".

With the aid of a medium-term model it is possible to determine

- the bottlenecks of a system
  - terminal layout and/or operation strategies
- the productivity of a system
  - service time for different vessel types/external truck operation/railway operation
  - the required number of transport/stacking equipment and STS cranes
- the performance of equipment used (operation, waiting-, idle-, cycle-time)
  - extensive cost evaluation

Figure 2 shows the structure of an example of a medium-term level simulation system (SCUSY-Simulation of Container Unit Handling Systems)

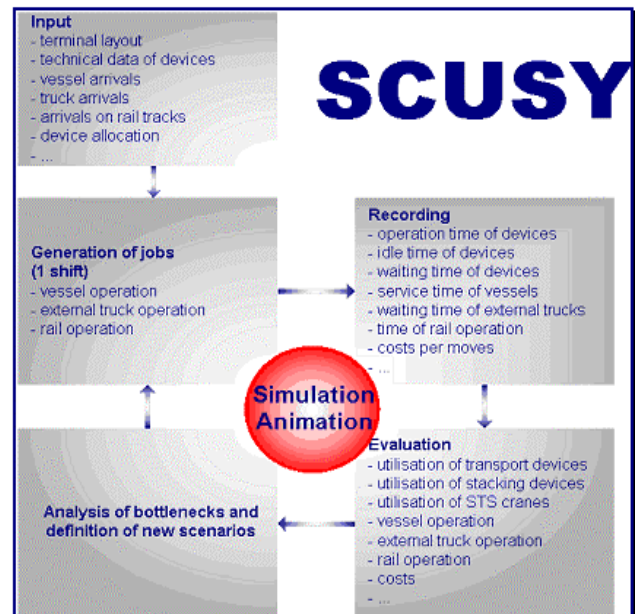


Figure 2: Structure of a Medium-Term Level Simulation System

The output shows e. g.:

- operation time for the individual vessel services
- the performance of STS cranes (moves/hr, operation time, waiting time and idle time)
- service time for external trucks and railway operation
- capacity utilisation of all container stacks
- utilisation of equipment (straddle carriers, terminal chassis, fork lift trucks, RMG, RTG)
- operation time, idle time and
- waiting time for other equipment (e. g. RTG for chassis, or chassis for RTG)

With the results of the simulation it is possible to calculate the operation costs for each terminal operation system. At the end a technical and economical evaluation of all analysed terminal systems will be executed.

### 2.2. Coupling TOS and simulation

Using standard "offline" simulation systems forces the user to enter all input data into the simulator. A first step to reduce the input effort needed may be done by using defined interfaces between the terminal operating system (TOS) and the simulator. As shown in Figure 3 data concerning layout information, technical data of the devices used and some parameters defining the strategies are transferred to the simulation.



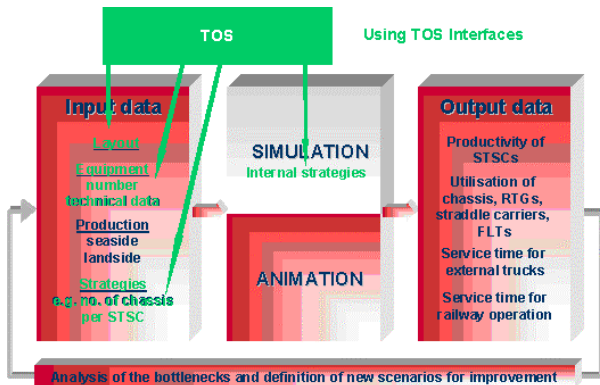


Figure 3: Coupling the TOS with the Input Module of the Simulation

The coupling may be realised via flat ASCII files, which are written by the TOS and is read by the simulator. If the data needed is stored within a (SQL) database, the simulator may get the information directly out of this database.

Besides the reduced input effort this method provides another benefit: Parameter changes made in the TOS are used automatically in the next simulation run.

### 2.3. Terminal emulation

While in phase 2 (see 2.2) all processes are controlled via the SCUSY strategies (resource scheduling, stack allocation, ...), in this phase the simulation –now called emulation- will only model the container flow, while strategies are directly taken from the TOS via the coupling. (see figure 4)

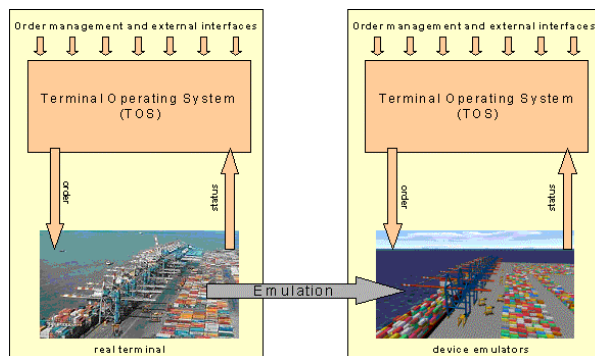


Figure 4: Switching between Real Terminal and Emulation System

Using the emulators of STS cranes, horizontal transport equipment (AGV, terminal truck, straddle carrier, ...) and stacking equipment (RMG, RTG, Fork lift trucks, reachstacker, ...) the real TOS can be used for the control of all terminal operations. In this way the following tasks may be performed:

- Testing new releases of the TOS  
New software versions of the TOS may be tested without any side effects to the real terminal operation.

- Fine tuning of TOS strategy parameters  
Internal parameters of the TOS may be adjusted to the specific terminal operation using actual throughput data of prior shifts. The implemented strategies of the TOS are used for controlling terminal processes without disturbing the real terminal operation.
- Evaluating new strategies to be used at the terminal

New strategies for resource scheduling, allocating stacking blocks and stacking strategies within one block may be tested before implementation at the real terminal. The proper comparison of different strategies may be done under exactly the same conditions. In real operation it is normally not possible to re-adjust exactly identical conditions

But using emulation will not only provide a test bed for the TOS, but furthermore will allow the terminal operator to fine-tune the strategies by finding the optimal parameter combination for the specific terminal. Moreover historical data may be imported and using them scenarios may be recalculated via the emulation to train the operator to cope with problems better next time.

The approach described is able to split up the material flow into small pieces (device emulators), which can be operated in a distributed simulation using a communication framework (see [3]). This does not only lead to higher performance and therefore to the opportunity to run scenarios in multiple real time. Moreover it is possible to combine emulators implemented using various simulation tools, based on various operation systems and hardware platforms, if they are solely able to dock to the communication framework (see figure 5).

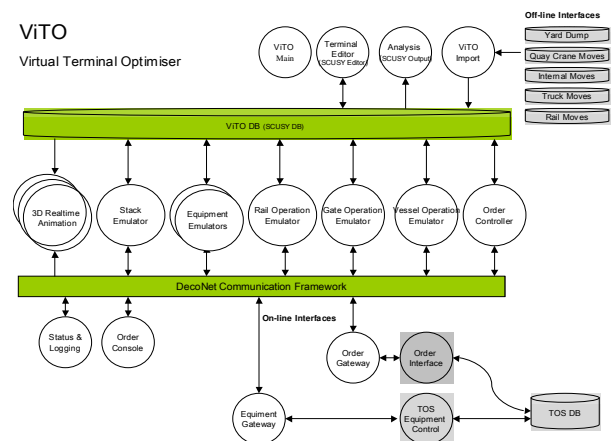


Figure 5: Structure of Distributed Terminal Emulation

As a last step the same segmentation made within the material flow may be done in the information flow, i.e. in the TOS. This is a precondition for using this approach in the field of “the port of the future” where new container handling technologies will be evaluated. E.g. it is not possible to test and optimise an AGV-

system using a TOS created for straddle carriers – due to the coupled handover of the container.

Based on this modularly built TOS and the distributed emulation, the testing and optimisation of advanced container handling technologies may be done in advance for existing terminals without building new simulation models and with regard to the existing TOS with only small changes where necessary. Moreover enhanced TOS functionalities may be fine tuned to optimise new technologies productivity.

### 3. DISTRIBUTED EMULATION VIA DECONET

The biggest challenge in designing software based emulations is to handle the complexity of corresponding real systems. In most circumstances a real system representation results in a single and highly specialized software implementation. In many times badly maintainable and hardly expandable software applications are resulting. Even simple changes leads in expansible, time-wasting redevelopments for necessary adjustments.

The idea to improve flexibility and efficiency of emulation systems is the use of distributed software techniques. Each part of a real system should also be realized as a separate software module. Each module represents an independent and specialized system which is assigned to exact one task. Possible modules are device emulators (e.g. crane-emulator), reporting systems or also a tool for 3D-visualisation of an emulated environment.

With this modular design principle a simple reusability of each module is warranted and this causes in long-term reduction of development efforts and costs. To achieve this objective a centralized network is needed which manages data and control flows between different emulation modules. This network has to implement the whole functionality which is needed to realize a time-controlled, event-driven emulation environment.

The solution of these requirements results in the Device-emulator Communication Network (DeCoNet). The DeCoNet is designed as a star layout network with client/server architecture based on Microsoft .NET framework techniques for service oriented distributed software-development. These .NET techniques are known under the name of Windows Communication Foundation (WCF) (Justin 2007).

The distributing centre bases on the DeCoNet service application which runs on each .NET 3.0 compatible PC. Each DeCoNet compatible client can connect to this service and is able to use the whole operational environment.

Neither the used development platform nor the target operating system for the implementation of individual DeCoNet clients is predetermined. In additional also the most important communication technologies are implemented to realize the connection between client and service. Every combination is possible. Heterogeneity is in the DeCoNet environment the most important keyword.

The following chart illustrates the fundamental communication techniques provided by DeCoNet

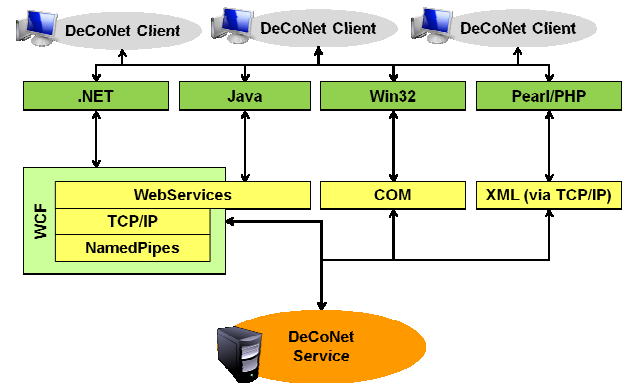


Figure 6: DeCoNet's Communication Techniques

#### 3.1. DeCoNet functionality

In summary DeCoNet emulation systems are made up by separated software modules. Each module is realized as a DeCoNet client and each client is connected to the DeCoNet service. The DeCoNet service provides a lot of features to ensure a smoothly interaction between this modules. An integrated event manager, a free configurable emulated time environment and a complex status management are only some features of the DeCoNet. Each client can define its behavior in miscellaneous ways.

The most important capability represents the communication between separate software modules. To achieve this goal the DeCoNet uses two different communication techniques, the push and the pull principle.

The push principle is realized by the DeCoNet message-system. Each client can register a new message-type which is defined by a unique name and a specified data type (e.g. XML-Documents, floating points). Such registered message-types can be used by every client for sending a message through the DeCoNet system. A client has three possible ways to handle with message-types. First and by default a client cannot process any message types. To enable processing capabilities a client has to specify this behavior explicit. A client can establish a message-type connection and in special cases it can additionally subscribe to it.

A message-type connection permits the direct sending capability. In this case the sending client specifies one or more receiving clients who are connected to the used message-type. This message is transferred to the DeCoNet service which forwards it to each specified client.

Message-type subscriptions are enabling an outstanding feature. Subscriptions are offering the possibility for indirect sending, a very flexible way of message forwarding. The sending client does not have to specify any receiving clients. Instead of it the DeCoNet service looks up to the whole list of registered clients and sends the incoming message to each client with an active subscription to the specified message-type.

The pull principle is implemented by the DeCoNet property-system. Each property is assigned to an individual client but it is globally stored on the running system of the DeCoNet service. The maximum amount of registered properties is unlimited and each property stores data of a predefined type. Properties are equipped with configurable behaviors, like permission management to define its read and/or write capabilities.

Property-subscriptions standing for the special feature of passive data transfer. Each client can register a subscription containing one or more properties. The behavior of a property-subscription is configurable in miscellaneous ways. Possible settings are for example the minimal time-interval of delivery or to trigger only when a value has changed. A reporting system which will log the current positions of each device-emulator on every second, but only if an involved property has changed, would be a thinkable usage.

In conclusion, the DeCoNet stands for an innovative and complex communication framework to realize software based emulations within distributed and heterogeneous system environments.

#### 4. CONCLUSIONS AND OUTLOOK

Emulation technology may be used for testing terminal's control system as well as for fine-tuning its parameters. The splitting into small modules allows the usage of a distributed network.

With the implementation of the DeCoNet framework these modules can be realised in different development environments using standard communication procedures. In this way an open system is created, where modules of different developers may be combined. E.g. the AGV-emulator may be developed by the AGV-supplier, while the crane emulator is developed by terminal's IT department.

If the TOS itself is build up in a module based architecture, the emulation system may use these small modules and via the DeCoNet framework new strategies may be implemented in the emulator and tested before the are implemented in the real TOS.

#### REFERENCES

- Burges, U., Mayer, G. 2006 Virtuelle Inbetriebnahme von Produktionssystemen in der Automobilindustrie mittels Emulation (german). *Proceedings of Simulation in Produktion und Logistik 2006, asim*, pp 541-550. SCS Publishing House,
- Daniluk, D. 2007 *Emulation mit der High Level Architecture* (german). Saarbrücken, germany:VDM Verlag Dr. Müller.
- Ha, Byung-Hyun 2007 Development of a Simulator of Interacting with terminal Operating Systems *Proceedings of the International Joint Symposium on Logistics Information Technologies*. November 27-28, Pusan National University, Busan, Korea
- Hartmann, S., Schütt, H. 2000 Simulation in Planung, Realisierung und Betrieb am Beispiel des Container-Terminals Altenwerder (german). In:

Möller, D.P.F., eds. *Frontiers in Simulation - Simulationstechnik*. Ghent, Belgium: SCS, pp 425-430

IEEE 1989 Std 610.3-1989, *IEEE Standard Glossary of Modeling and Simulation Terminology*

Smith, Justin 2007 *Inside Windows Communication Foundation*, Redmont, Washington, USA: Microsoft Press.

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# LAYOUT OPTIMIZATION OF CONTAINER TERMINALS USING MATHEMATICAL PROGRAMMING AND SIMULATION

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## ABSTRACT

Container terminal operators are under pressure to handle the increasing amount of container transfer in the global transportation network. To manage the growth, new container terminals are built or the capacity of existing ones is expanded using modern container handling technologies as well as automatic equipment. An efficient layout of the container terminal is crucial to obtain the maximum capacity.

In this paper we present an approach based on a mixed integer linear model to find promising layout configurations for container terminals. Means of simulation are used to validate and evaluate the attained layout configuration. In addition the adequacy of the mixed integer linear model for planning layouts of container terminals is evaluated using the developed simulation model.

Keywords: container terminal, layout optimization, simulation

## 1. INTRODUCTION

The layout of a container terminal is vital for an efficient operation of the terminal. The task of designing the layout is a strategic planning task arising when new terminals are built or existing ones are redesigned. Due to the continuing increase in the worldwide container turnover many container terminal providers have to extend their capacities to manage this growth. As a consequence new terminals like the Jade Weser Port in Germany are built and existing ones are expanded.

Planning the layout of a manufacturing facility is a well studied problem in the literature. Koopmans and Beckmann (1957) developed a quadratic assignment model which is the first model used to plan facility layouts. Until now the planning of facilities is an interesting field of research due to the complex combinatorial problem structure.

Current mixed integer formulations for the facility layout problem (Meller, Chen, and Sherali 2007; Xie and Sahinidis 2008) adopt the sequence pair concept introduced by Murata et al. (1996) for the related problem of the VSLI system design. An actual survey on the facility layout problem can be found in Drira,

Pierreval and Hajri-Gabouj (2007) or Singh and Sharma (2006).

In comparison to the facility layout problem the design of container terminal layout is a less studied field. Mainly simulation studies have been carried out to compare different scenarios of possible terminal layout configurations.

Liu et al. (2004) evaluate the performance of two different layouts for the use of Automated Guided Vehicles. The results demonstrate that a higher performance can be gained using automated vehicles, and in addition that the yard layout has an impact on the number of vehicles needed as well as the terminal performance.

Yang, Choi, and Ha (2004) compare the performance of Automated Container Terminals using either AGV (Automated Guided Vehicles) or ALV (Automated Lifting Vehicles). Therefore they develop a simulation model considering a perpendicular yard layout. The simulation study shows that ALV configuration is superior to AGV configuration.

Yun and Choi (1999) develop a simulation model for a typical container terminal configuration with yard cranes and yard trucks. An object oriented simulation model for the terminal configuration is developed consisting of the subsystems gate, container yard and berth. Experiments are done considering a reduced configuration of a real container terminal in Pusan, Korea.

Brinkmann (2005) describes a simulation study in order to investigate the optimal capacities of a new container terminal for given expected container turnover. In consecutive simulation studies they determine the optimal number of quay cranes and the storage capacities needed.

Kim, Park, and Jin (2007) suggest a method for designing the layout of container yards regarding a configuration where terminal trucks are used as internal transport mean. They determine an optimal yard configuration using formulas to calculate the expected travel costs of trucks and the number of relocations for a container to pick up.

Steenken, Voß, and Stahlbock (2004) and Stahlbock and Voß (2008) give an extensive survey on different optimization methods for container terminal logistics.

## 2. LAYOUT PLANNING FOR CONTAINER TERMINALS

In terms of facility layout design the problem is to find an efficient arrangement of objects in a given area knowing the material flow between these objects. In general, the aim is to minimize the cost for transporting material. Transferring this concept to container terminal layout planning we have items to arrange on a container terminal and a flow of container among these items.

Items of a container terminal are quay cranes which are organized at berthing places, the storage blocks for intermediate storage of containers and additional buildings. Furthermore, depending on the regional characteristics, tracks might exist on the terminal. Trucks enter the container terminal through a gate to collect import or to deliver export containers. Besides these items driving lanes for transport equipment have to be considered on determining a feasible layout.

Regarding the list of items just mentioned we have to consider that not all of them have full flexibility to be positioned on the terminal area: The quay cranes are bound to the quay and, furthermore, they are moveable during daily operation. In addition the land side connections to external roads and train tracks necessitate that the gate and tracks are restricted to subsections of the available terminal area. As a result a model for container terminal layout design needs the ability to restrict elements to a subset of possible positions.

The most important remaining flexible items are storage blocks. Addressing storage blocks several observations can be made in the context of layout design. We assume that the storage capacity of the terminal for different types of container such as empty and reefer container is predetermined. Depending on the terminal equipment used, the dimensions of the blocks can be considered either as constant or as variable. For example when using yard cranes the width of a block is restricted to the given width of the used yard cranes. This is in contrast to a straddle carrier system where the width can be assumed to be flexible at least in a given range. In addition the length of a block is not restricted by any of the described equipment. To sum up we can make two observations: First, the used terminal equipment influences the design of the blocks, thus having an impact on the terminal layout. Second, the storage blocks can be variable in their dimensions. Despite these observations we assume in the following that the terminal equipment is given for each scenario and that the block dimensions are fixed due to the inherent complexity of the problem when considering variable dimensions.

As mentioned before different types of containers are handled on a container terminal. With respect to the storage of these container types different conditions have to be considered. The most frequent containers are regular twenty- or forty-foot containers for which no special attributes addressing storage conditions have to be considered. On the contrary, for reefer containers,

containers for hazardous goods and empty containers special storage conditions exist: Empty containers are normally stored separately and can be stacked higher than normal containers. Containers for hazardous goods have to be stored in sections of the yard which are specially prepared. Moreover a minimal distance between this type of containers and other types is defined by law. Reefer containers need a power supply and thus cannot be stored in a section for regular containers. As layout design is considered, these conditions have to be considered on building blocks and in particular on defining a container-flow among items. For instance, considering a block that solely stores reefer containers, a less intensive flow of containers to this block can be assumed compared to a block storing regular containers.

For the horizontal means of transport like yard trucks or straddle carriers driving lanes need to be considered on planning a terminal layout. In order to regard them we introduce minimal distances among blocks and among all other items.

For the model introduced in the present work we make the following assumptions:

- The number of quay cranes is given, each with a fixed position at the quay.
- The area of the container terminal is rectangular and its dimensions are given.
- The needed storage capacity is given and the number as well as each dimension of a storage block is predetermined.
- The gate can be positioned at a predetermined border of the terminal area.
- The container flow between the items is given and considers the ratio of container types.

To consider non-rectangular areas in the model it is possible to introduce virtual items with a fixed position on the non-useable segments of the area. Quay cranes operate flexibly on the quay and thus their position changes during daily operation. For the strategic decision on the layout we spread the quay cranes equally along the quay given each crane a fixed position.

### 2.1. Model Formulation

Based on these assumptions we are able to formulate a mixed integer model. To reduce the model complexity we use the sequence pair representation. Meller, Chen, and Sherali (2007) and Xie and Sahinidis (2008) successfully adopted this representation used in VLSI design for the facility layout problem. For sake of brevity we only describe our used variable representation and refer for a more detail description to the above mentioned publications. We introduce binary variables  $n_{ij}^a$  and  $n_{ij}^b$  to define a relationship of item  $i$  to item  $j$  with respect to their relative location in the layout:

- If  $n_{ij}^a = 1$  and  $n_{ij}^b = 1$ , then item  $i$  must follow item  $j$  in the x-direction.
- If  $n_{ij}^a = 0$  and  $n_{ij}^b = 0$ , then item  $j$  must follow item  $i$  in the x-direction.
- If  $n_{ij}^a = 0$  and  $n_{ij}^b = 1$ , then item  $i$  must follow item  $j$  in the y-direction.
- If  $n_{ij}^a = 1$  and  $n_{ij}^b = 0$ , then item  $j$  must follow item  $i$  in the y-direction.

Using this representation we formulate a mixed integer model to find a layout for a container terminal considering minimal distances between items and a set of quay cranes each having a fixed positions.

*Parameters:*

$s$	direction indices ( $s = \{x, y\}$ )
$v$	sequence pair variable indices ( $v = \{a, b\}$ )
$w_i$	width of item $i$
$l_i$	length of item $i$
$lb_i^s$	lower bound of $s$ -position of item $i$
$ub_i^s$	upper bound of $s$ -position of item $i$
$L^s$	length of container terminal in $s$ -direction
$pos_i^s$	$s$ -position of item $i$
$a_{ij}^s$	minimum distance in $s$ -direction between items $i$ and $j$
$f_{ij}$	container flow between $i$ and $j$
$I$	set of all items
$Q$	set of quay cranes ( $Q \subset I$ )

*Variables:*

$d_{ij}^s$	Manhattan distance in $s$ -direction between item $i$ and item $j$
$x_i$	x-coordinate of upper left corner of item $i$
$y_i$	y-coordinate of upper left corner of item $i$
$p_i$	binary variable for the orientation of item $i$
$n_{ij}^v$	binary variable denotes the relative location to each other of item $i$ and item $j$

Using the described variables and parameters we define the following model, which we refer to as CTLE:

$$z = \min \sum_{i,j \in I, i \neq j} (d_{ij}^x + d_{ij}^y) f_{ij} \quad (1)$$

s.t.

$$x_i \geq x_j + p_j l_j + (1 - p_j) w_j + a_{ij}^x - L^x (2 - n_{ij}^a - n_{ij}^b) \quad \forall i, j \in I \ i \neq j \quad (2)$$

$$y_i \geq y_j + (1 - p_j) l_j + p_j w_j + a_{ij}^y - L^y (1 + n_{ij}^a - n_{ij}^b) \quad \forall i, j \in I \ i \neq j \quad (3)$$

$$L^x \geq x_i + p_i l_i + (1 - p_i) w_i \quad \forall i \in I \quad (4)$$

$$L^y \geq y_i + (1 - p_i) l_i + p_i w_i \quad \forall i \in I \quad (5)$$

$$y_i = pos_i^y, x_i = pos_i^x \quad \forall i \in Q \quad (6)$$

$$p_i = 0 \quad \forall i \in Q \quad (7)$$

$$1 = n_{ij}^v + n_{ji}^v \quad \forall i, j \in I, i < j, \forall v \quad (8)$$

$$n_{ik}^v \geq n_{ij}^v + n_{jk}^v - 1 \quad \forall i, j, k \in I, i \neq j \neq k, \forall v \quad (9)$$

$$d_{ij}^x \geq \left( x_i + p_i \frac{l_i}{2} + (1 - p_i) \frac{w_i}{2} \right) - \left( x_j + p_j \frac{l_j}{2} + (1 - p_j) \frac{w_j}{2} \right) \quad \forall i, j \in I \ i \neq j \quad (10)$$

$$d_{ij}^x \geq \left( x_j + p_j \frac{l_j}{2} + (1 - p_j) \frac{w_j}{2} \right) - \left( x_i + p_i \frac{l_i}{2} + (1 - p_i) \frac{w_i}{2} \right) \quad \forall i, j \in I \ i \neq j \quad (11)$$

$$d_{ij}^y \geq \left( y_i + (1 - p_i) \frac{l_i}{2} + p_i \frac{w_i}{2} \right) - \left( y_j + (1 - p_j) \frac{l_j}{2} + p_j \frac{w_j}{2} \right) \quad \forall i, j \in I \ i \neq j \quad (12)$$

$$d_{ij}^y \geq \left( y_j + (1 - p_j) \frac{l_j}{2} + p_j \frac{w_j}{2} \right) - \left( y_i + (1 - p_i) \frac{l_i}{2} + p_i \frac{w_i}{2} \right) \quad \forall i, j \in I \ i \neq j \quad (13)$$

$$lb_i^x \leq x_i \leq ub_i^x \quad \forall i \in I \quad (14)$$

$$lb_i^y \leq y_i \leq ub_i^y \quad \forall i \in I \quad (15)$$

$$x_i, y_i \in \mathbb{R}^+ \quad \forall i \in I \quad (16)$$

$$p_i \in \{0, 1\} \quad \forall i \in I \quad (17)$$

$$n_{ij}^v \in \{0, 1\} \quad \forall i, j \in I, \forall v \quad (18)$$

The objective function (1) minimizes the travel distances needed to transport the given container flows. Constraints (2) and (3) in conjunction with constraints (8) and (9) prevent the overlapping of items and in addition force the existing of a minimum distance between items. Constraints (4) and (5) guarantee the limitation of item positions to the dimension of the terminal area ( $L^x \times L^y$ ). The quay cranes are fixed to a given positions with a fixed orientation ((6), (7)). Constraints (10)-(11) are used to calculate the rectangular distances between the items. Finally, constraints (14) and (15) define an upper and lower bound on the possible positions of the items upper left corner.

Additionally, we adopt valid inequalities presented in Meller, Chen, and Sherali (2007) to our formulation:

$$d_{ij}^x \geq \min \left( \frac{l_i}{2}, \frac{w_i}{2} \right) + \min \left( \frac{l_j}{2}, \frac{w_j}{2} \right) + a_{ij}^x - L^x (2 - n_{ij}^a - n_{ij}^b) \quad \forall i, j \in I \ i \neq j \quad (19)$$

$$d_{ij}^y \geq \min \left( \frac{l_i}{2}, \frac{w_i}{2} \right) + \min \left( \frac{l_j}{2}, \frac{w_j}{2} \right) + a_{ij}^y - L^y (1 + n_{ij}^a - n_{ij}^b) \quad \forall i, j \in I \ i \neq j \quad (20)$$

These valid inequalities force the distances between items  $i$  and  $j$  to be at least as great as the sum of the following values: the minimum of the half length and width of item  $i$ , the minimum of the half length and width of item  $j$  plus the minimum distance  $a_{ij}^s$  depending on the relative location denoted by the  $n_{ij}^v$  variables.

## 2.2. Distance Correction

To model the distances between two items we choose the rectangular distance also known as Manhattan distance. This measure of distance is suitable for use in a mixed integer formulation. Nevertheless, it is an approximation of the actual distance needed for means of horizontal transport to travel between two items, for example having two items  $i$  and  $j$  with  $x_i = x_j$ . In this case  $d_{ij}^x = 0$ , even if an item  $k$  exists with  $y_i < y_k < y_j \wedge x_j - p_k \frac{l_k}{2} + (1 - p_k) \frac{w_k}{2} < x_k < x_j$  (see Figure 1). We refer to item  $k$  as blocking item because in reality a horizontal mean of transport travel from item  $i$  to item  $j$  has to detour round the blocking item  $k$ .

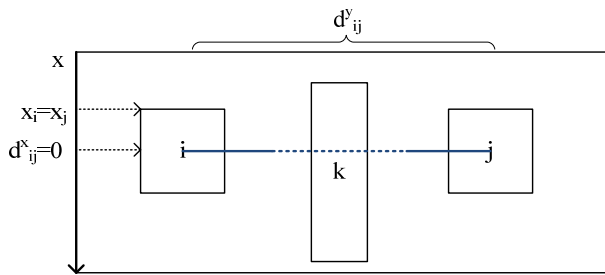


Figure 1: Manhattan Distance

To consider those detours we implement a procedure which takes solutions of the CTLE model and searches for pairs of elements for which the distance has to be corrected. For those pairs we update their distances and finally a new objective value  $z^c$  is calculated.

For the above constellation of items  $i$ ,  $j$  and  $k$   $d_{ij}^x$  is updated by adding:

$$d_{ij}^x += 2 * \min \left( \left| x_j + p_j \frac{l_j}{2} + (1 - p_j) \frac{w_j}{2} - x_k \right|, \left| x_j + p_j \frac{l_j}{2} + (1 - p_j) \frac{w_j}{2} - (x_k + p_k l_k + (1 - p_k) w_k) \right| \right) \quad (21)$$

Figure 2 illustrates the updated distance  $d_{ij}^x$ .

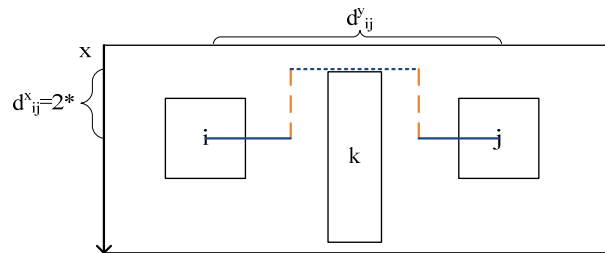


Figure 2: Corrected Distance

## 2.3. Problem Instances

We develop two scenarios based on typical yard and equipment configuration of container terminals. Based on these two scenarios we build instances of different size. We consider one terminal configuration using a straddle carrier system like the CT4 in Bremerhaven, Germany, and a terminal with yard trucks and yard cranes which is typical for an Asian container terminal like the HIT 9 in Hong Kong.

For the straddle carrier scenario we use the available data described in Brinkmann (2005) to build a realistic instance: The CT4 container terminal has a quay length of 1750 m with four berths and a terminal depth of 650 m. The containers are stored in 22 blocks in the yard. They are divided in 15 blocks for storing regular containers ( $l = 117$  m,  $w = 150$  m), 3 blocks for storing reefer containers ( $l = 76$  m,  $w = 175$  m), one storage block for container containing hazardous goods ( $l = 117$  m,  $w = 150$  m) and one block for empty containers ( $l = 139$  m,  $w = 117$  m). The external trucks enter the terminal through a gate ( $l = 30$  m,  $w = 30$  m) and are serviced in a truck service area ( $l = 30$  m,  $w = 79$  m). Tracks with a length of 1430 m and a width of 45 m exists for the service of trains, and 16 quay cranes are used to service vessels. Based on this instance with four berths we build smaller instances with 1, 2 and 3 berth(s). These instances are built by scaling the values respectively to the number of berths. For example the scenario regarding three berths consists of 12 quay cranes. To determine the correct number of storage blocks needed we do not scale directly the number of blocks but the storage capacity needed. Based on the storage capacity the actual number of blocks is calculated. In particular considering the block for storage of hazardous container we scale the dimensions to avoid an unrealistic high storage capacity for hazardous container (B\_14\_8:  $l = 59$  m,  $w = 122$  m; B\_12\_4:  $l = 59$  m,  $w = 122$  m). In Table 1 the instances are detailed.

Table 1: CT4 Instances

Instance	Reg.	Reef.	Haza.	Emp.	$L^x$	$L^y$	$l^{train}$
B25_16	15	3	1	3	1750	650	1430
B19_12	11	2	1	2	1470	600	1073
B14_8	8	1	1	1	980	600	715
B12_4	6	1	1	1	784	600	572

For the layout instances based on a yard crane system we build instances in orientation to the terminal HIT 9 in Hong Kong having two berths with an overall quay length of 700 m. Due to a lack of available data we assume the following values: we use a typical block length for blocks operated by rubber tired gantry cranes of 176 m (Kim, Park, and Jin 2007). We assume a width of a block for reefer and regular container of 24 m. The block width for empty container is set to 29 m. Storage of hazardous containers is not considered. The depth of the terminal is assumed to be 450 m. For the instance having two berths 8 quay cranes operate at the quay. In the container yard 22 blocks are used for the storage of containers. The landside connection consists of a gate with additional waiting slots for trucks with a length of 170 m and a width of 45 m. No railway connection exists. Based on this instance with two berths we build additional instances regarding one or three berth(s). The instances for the yard crane scenario are described in Table 2.

Table 2: HIT9 Instances

Instance	Reg.	Reef.	Emp.	L <sup>x</sup>	L <sup>y</sup>
A34_12	28	3	2	1050	450
A23_8	19	2	1	700	450
A12_4	9	1	1	350	450

## 2.4. Container Flow

In short term daily operation of a container terminal the decision of where to place an export container is an essential task. The occurrence of rehandles has to be avoided and in addition the aim is to have short distances to the berth where the designated vessel is expected to be moored. In addition the workload of the equipment in the yard should be balanced to avoid bottlenecks. The same thoughts can be made for import containers.

For the strategic layout design these operational planning tasks for the flow of containers can be neglected. Regarding two blocks storing the same type of containers and having the same dimensions it is of no relevance which of the blocks is next to a specific berth. Hence we model the flow for equal container types by equally distributing the containers among the blocks of the same size.

In contrast the flows of different container types have to be considered. That is, containers of special type can only be routed to storage blocks meant for this type. Thus one building the flow matrix we distinguish different container types. Based on the statistical occurrence of the special container type we weight the corresponding flow of containers.

To show the complexity of the CTLE model with a non-equally distributed flow matrix we introduce a second method. This method adopts the equally distribution and randomly intensifies or reduces the flow between blocks. To ensure a nearly same overall flow a decrease is only allowed when the sum of decreases is less than the sum of increases and vice versa. In addition a ratio  $r$  is given which bounds the maximal possible increase or decrease of the flow  $f_{ij}$  value to a value lower than  $r * f_{ij}$ . For each of the described instances in section 2.3 we model one flow equally distributed and one with a randomly adjustment using a ratio of  $r = 0.3$ .

## 2.5. Ordering of Items

As mentioned in the previous section it can be observed that pairs of identical items exists which have the same flow to all other items. With respect to a layout the positions of those items can be interchanged without a change of the solution value. To avoid the enumeration of identical solution we add a constraint to CTLE to order those items in advance. Let  $ID$  be the set of identical items pairs:

$$ID := \{(k, m) | f_{ki} = f_{mi} \wedge f_{ik} = f_{im} \wedge w_k = w_m \wedge l_k = l_m \forall i \in I, i \neq k, i \neq m, k < m\} \quad (22)$$

We add the following constraint to CTLE:

$$n_{km}^a = 1 \quad \forall (k, m) \in ID \quad (23)$$

This constraint forces item  $k$  to follow item  $m$  either in the x- or the y-direction.

## 2.6. Computational Results

The resulting mixed integer instances are solved using Cplex 11 (ILOG 2007) on an Intel Pentium 4 CPU 3.40GHz with 4 GB RAM. Table 3 shows results for the instances using the standard flow of containers. The described valid inequalities and constraint (23) are added to the CTLE model. The column #Nodes describes the number of nodes examined in the branch and bound process and Time depicts the time in minutes needed to solve the instances. We set a time limit of 12 hours to solve the instances. For instances with a higher gap than zero no optimal solution could be found due to restriction of time or memory. The column  $z^c$  shows the results by adjusting the distances as described in section 2.2. Values in columns  $z^c$  and  $z$  are given in kilometers. The last column Gap depicts the Gap between the current lower bound and the current best solution.

Table 3: Results with  $r = 0$ 

Instance	#Nodes	Time	$z$	$z^c$	Gap
B25_16	2989	721.4	7827.60	7911.21	25.4
B19_12	84389	378.8	4879.47	4995.13	12.6
B14_8	565711	76.7	2507.92	2533.11	0
B12_4	200645	11.0	1737.77	1749.97	0
A34_12	661	720.0	4284.83	4352.54	38.0
A23_8	49361	484.7	2062.01	2188.10	23.9
A12_4	58312	4.5	788.96	883.95	0
Sum	962068	2397.0	24088.56	24614.03	

Table 3 shows that about 40 hours are needed to solve all instances. The CT4 instances can be optimally solved until two berths. A higher proportion of berth to the number of blocks exists in HIT9 scenario. Just the one-berth-instance can be solved optimally for the HIT9 instances. Updating the distances by considering blocking elements increases the sum of the solution values by about 2.18%.

Table 4 shows results for the instances with a randomly adjusted flow using a ratio of  $r = 0.3$ .

Table 4: Results with  $r = 0.3$ 

Instance	#Nodes	Time	$z$	$z^c$	Gap
B25_16	2046	720.0	7359.27	7634.2	30.7
B19_12	61501	177.87	4828.72	5050.1	26.8
B14_8	1523117	720.0	2469.63	2527.6	23.2
B12_4	4263591	718.53	1691.8	1780.1	12.5
A34_12	16	720.0	3829.9	3928.2	37.9
A23_8	21595	720.0	2039.0	2155.1	31.2
A12_4	3676232	720.0	762.6	858.6	20.6
Sum	9548098	4496.42	23161.1	23933.9	

For those instances the constraint (23) is not relevant because of an empty set  $ID$ . The results show that none of the instances can be optimally solved when using a randomized flow matrix.



## 2.7. Discussion of Model

The assumption of fixed block dimensions restricts a possible important degree of freedom. The above results show that even without considering variable block dimensions the model is hard to solve. That is, why we first restrict this degree of freedom. The aim is to evaluate the adequacy of a layout model like the CTLE for planning container terminal layouts.

With respect to fixed block dimensions one can state that by knowing this information it is easily possible to construct manually an at least feasible solution. The main degrees of freedom remaining are:

- The placement of gate and tracks.
- The orientation of the blocks; either perpendicular or parallel to the quay.
- The placement of blocks considering different container types.

To evaluate the above discussed adequacy of the CTLE model for planning container terminal layouts we developed a simulation model. This simulation model is used to evaluate the resulting layouts in simulation studies. In addition to the layouts found by the CTLE model we manually constructs layout solutions that are additionally evaluated.

## 3. SIMULATION

A modular configurable discrete event-based simulation model has been designed in Plant Simulation 8.1 (UGS Tecnomatix 2007) to evaluate the performance of the layout configurations generated by the previous described solution method and to analyze the adequacy of the CTLE model.

As we have to cope with two different equipment scenarios we use a level of abstraction that gives us the ability to manage various scenarios. Moreover it is essential for evaluating the performance of a container terminal that the whole terminal operation is simulated.

### 3.1. Simulation Design

We structure our simulation model in modules for each vital part of the terminal. Beginning at the seaside the first module consists of a berthing place and a fixed number of assigned quay cranes. The quay cranes at one berth are all either in discharging mode or (when all containers are unloaded) in charging mode. The sequence of the containers to unload and load for a vessel is defined in advance. For transporting containers between the seaside and the storage blocks as well as between storage blocks and landside facilities we use an abstract class of horizontal means of transport. Depending on the ability of the horizontal means of transport to hoist a container the process of unloading a container from a vessel is decoupled from the availability of horizontal means of transport at the corresponding apron. The container can be temporary stored on the apron until a horizontal transport mean arrives that is able to hoist the container. The needed transport times are calculated based on distance matrix

gained from the results of the layout optimizing procedure.

The stacking module either consists of a yard crane system or in case of the straddle carrier system is just a memory of stored containers. To determine the time needed for storing a container in a block or for taking a container out of a block a distribution is used which depends on the length of the block.

The landside connections are modeled by a module for tracks using a defined number of stacking cranes to manage the loading and unloading operations of trains. As for the vessels the sequence of containers to discharge and charge is given. The operation of external trucks on the terminal is modeled similar to the horizontal means of transport using a distance matrix to calculate the needed travel times. In case of external trucks the gate is either start or destination for each move of an external truck on the yard. For the straddle carrier system truck service lanes exit, where straddle carriers load or unload arriving external trucks.

The operational assignment of ships to berthing places is managed by a First Come First Serve procedure. The choice of a block to temporarily stack a container is done randomly by considering that non regular containers have to be stored in designated blocks. Transport jobs are randomly assigned among the currently available horizontal means of transport.

### 3.2. Simulation Scenarios

For the generation of data we use a scenario generator based on the work of Hartmann (2004). The scenario generator computes information about vessel, truck and train arrivals. In addition the amount of containers delivered by each arriving carrier as well as the type of container is generated. Based on a dwell time distribution the containers are assigned to a carrier which picks it up. For a detailed description of the generation process and the configurable parameters we refer to Hartmann (2004).

For the scenario CT4 and HIT9 we assume a configuration with two berthing places. Thus the layout solutions for the instances B14\_8 and A23\_8 are relevant for the simulation. Arrival data is generated for a horizon of seven days with 6500 containers arriving by vessels, 4367 containers arriving by feeders, 225 containers arriving by truck and 490 containers arriving by train. The average dwell time of containers is 4.6 days. For the HIT9 scenario we assume the same values except that no containers arrive by train. The containers arriving by train are added to truck arrivals. Using different seed values we generate 10 datasets with different arrival data for each scenario. To achieve a relative high workload in the terminal for the last two days we let up to two vessels arrive on day two and the remaining three vessels on day six of the horizon. The collection of statistical data is started at the beginning of day six. For the HIT9 scenarios 20 trucks and for the CT4 scenario 22 straddle carriers are used as horizontal means of transport. Table 5 shows the average number of carriers arriving in the given horizon.

Table 5: Average Carrier Arrivals

Scenario	Trucks	Feeders	Vessels	Trains
CT4	651.5	39.4	4.6	8.5
HIT9	1564.8	39.4	4.6	0

For both scenarios CT4 and HIT9 we evaluate the adequacy of the CTLE model by simulating different layout solutions found during the branch and bound process and manually constructed layout solutions. In addition solutions with corrected distances are simulated. The manual layout solutions are constructed by positioning the blocks perpendicular to the quay considering minimal distances. The blocks for non regular containers are positioned in the back of the yard as well as the truck service area and the tracks.

The layout solutions simulated for the CT4 scenario are displayed in Table 6. The columns  $z$  depict the corresponding solution value and columns  $z/\max(z)$  the proportion of the solution value compared to the worst solution. B\_Man is a manually constructed solution. Using the distance correction method the solutions in the forth column are computed based on the corresponding solution in the first column.

Table 6: Simulated Layout Solutions for CT4

Lay. Sol.	$z$	$\frac{z}{\max(z)}$	Lay. Sol.	$z$	$\frac{z}{\max(z)}$
B_z1	2507.9	0.78	B_z1_C	2533.1	0.79
B_z2	2541.2	0.79	B_z2_C	2599.8	0.81
B_z3	2752.7	0.85	B_z3_C	2757.8	0.86
B_z4	3208.7	1.00	B_z4_C	3221.4	1.00
B_Man	2635.3	0.82	B_Man_C	2650.3	0.82

Table 7 shows the layout solutions for the HIT9 scenario. A\_Man and A\_Man2 are manually constructed solutions, whereat A\_Man2 has been constructed with the aim to get a worse solution. In total 12 layout solutions are simulated for the HIT9 scenario with a different of 16 % of the best solution value (A\_z1) compared to the worst solution value (A\_Man\_c2).

Table 7: Simulated Layout Solutions for HIT9

Lay. Sol.	$z$	$\frac{z}{\max(z)}$	Lay. Sol.	$z$	$\frac{z}{\max(z)}$
A_z1	2062.2	0.84	A_z1_C	2188.1	0.89
A_z2	2099.9	0.85	A_z2_C	2155.1	0.87
A_z3	2117.6	0.86	A_z3_C	2221.7	0.90
A_z4	2151.6	0.87	A_z4_C	2248.8	0.91
A_Man	2154.3	0.87	A_Man_C	2267.6	0.92
A_Man2	2431.7	0.98	A_Man2_C	2469.2	1.00

### 3.3. Simulation Results

To quantify the efficiency of the terminal layout we use the following performance measures:

- Average turnaround time (TAT) of trucks and trains.

- Average quay crane moves per hour when a ship is moored at the corresponding berth.
- Average of the sums of travel distances of horizontal means of transport.

The values displayed are scaled either by dividing the maximal average value or in case of the quay crane moves per hour by the minimal average value.

Figure 1 shows the results for the CT4 scenario simulating each layout solution in Table 6. The sum of distances traveled by the horizontal means of transport is the lowest for the optimal solution B\_z1 found by the CTLE model. The second best value of average travel distance is achieved by B\_z2. Sorting the solutions by the solution values  $z$  would result in the same hierarchy than sorting by the average travel distances. Focusing on the average quay crane moves per hour a maximal difference of 1.8% occurs between B\_Man and B\_z3. The best value of train TAT is achieved by B\_z2 and the best value of truck TAT by B\_z1.

Comparing the manual constructed solutions B\_Man with B\_z1 a slightly higher value of about 2.7% occurs for the average travel distances. This results in a 0.5% lower value of quay crane moves and a 1.6% higher value of truck turnaround time for the manual solution. However the B\_Man solution achieves a 2.7% better result for the turnaround time of trains.

The horizontal means of transport in the CT4 scenario service quay crane jobs with a higher priority than truck and train jobs. As the results show this leads to higher differences in the corresponding performance measures (Truck TAT and Train TAT) compared to the quay crane moves performance measure.

Figure 2 shows the simulation results for the HIT9 scenario simulating the layout solutions in Table 7. The maximal difference in the average travel distances about 11.4% exists between the solutions A\_z1 and A\_Man2\_C. Regarding the performance measures average quay crane moves per hour and turnaround time of trucks just slightly differences occur. The best value of quay crane moves per hour is about 2% increased and the best value of turnaround time of trucks is 1.6% decreased compared to the worst solution. The manual constructed solution has the highest value of average quay crane moves and just a 0.3% higher value of average turnaround time of trucks.

The results for the solution with corrected distances shows that compared to the corresponding solutions with no correction the travel distances are increased by values between 2.6% and 3.3%. This leads to an average decrease in quay crane moves per hour of about 0.8% and an average increase of truck turnaround times of about 0.6%.

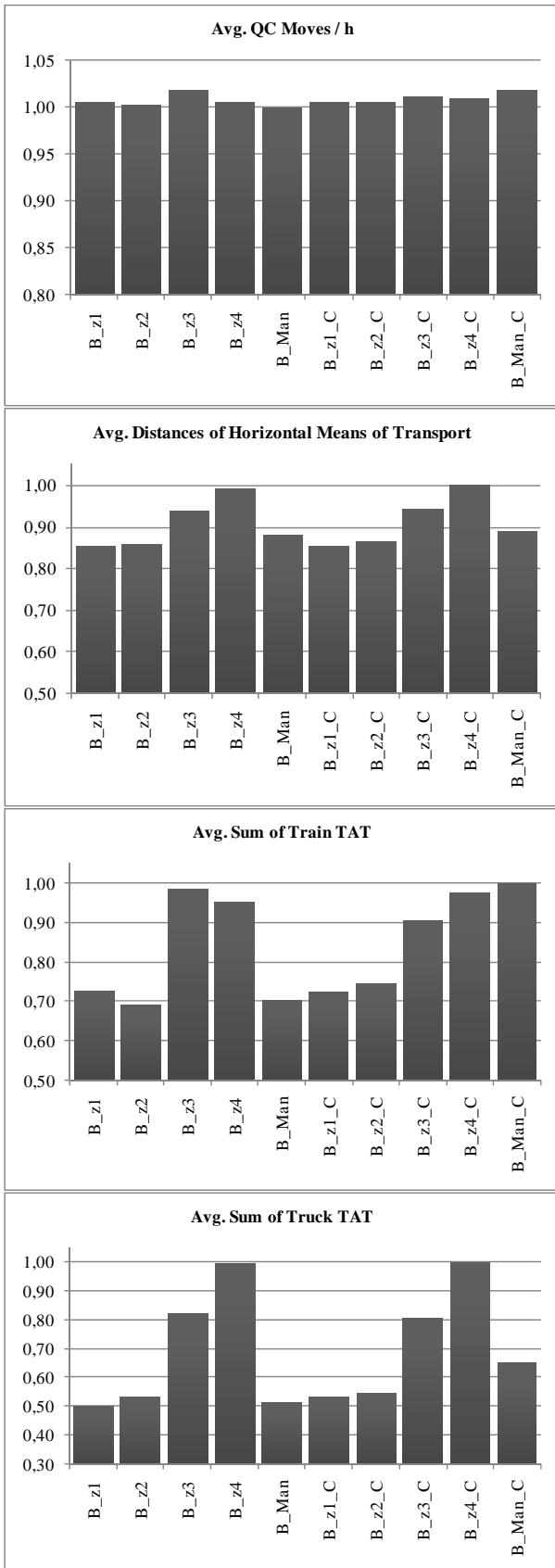


Figure 3: Simulation Results for CT4 Scenario

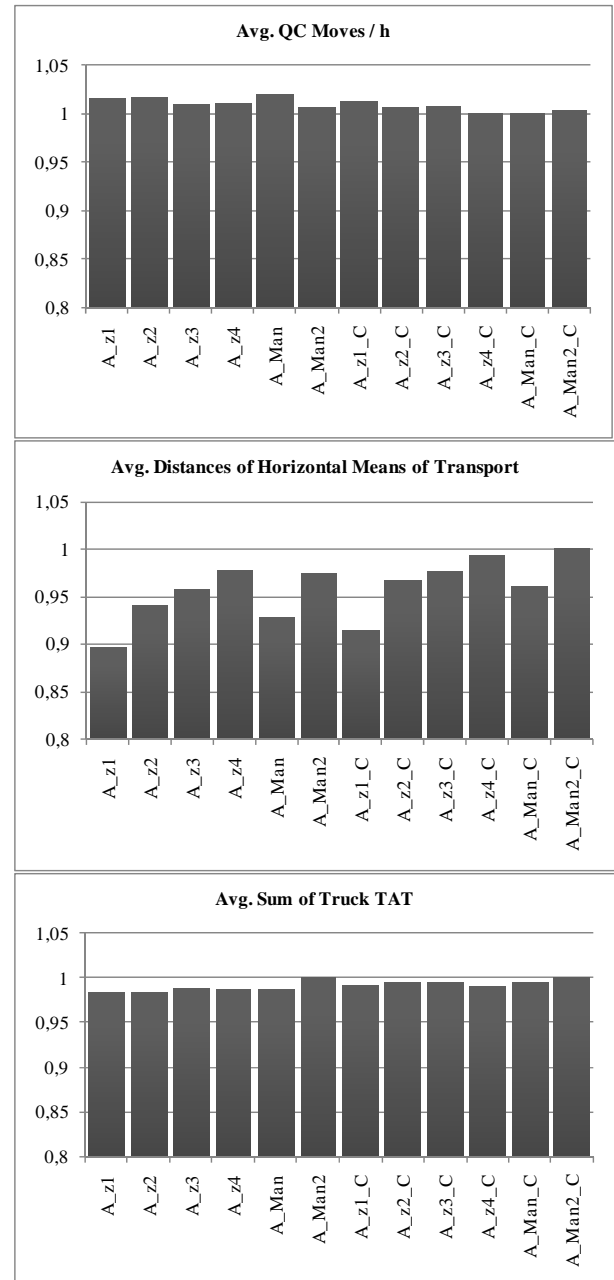


Figure 4: Simulation Results for HIT9 Scenario

#### 4. CONCLUSION AND OUTLOOK

We presented a mixed integer formulation for the layout planning of container terminals. Based on two scenarios we build different instances and present computational results. The results show that instances of practical size are hard to solve. To analyze the rectangle distance measure we use a distance correction method. Considering blocking elements increases the distances in average by about 3.6%.

In section 2.7 we discuss the adequacy of the presented model (CTLE) for planning container terminal layouts. To analyze the adequacy we carry out a simulation study for different layout solutions. The results show that a higher performance is gained for solutions found by the CTLE with a low gap compared to worse solutions. Nevertheless the manual constructed

solutions show no significance difference in the performance compared to the solutions found by the CTLE. Promising layout solutions are found by the CTLE but manual planning achieves quite competitive solutions. For example the solution value  $z$  for A\_Man differs by 3% from the best solution found by the CTLE. The simulation results show that a small improvement in the solution value  $z$  not results in significantly higher terminal performance.

For further research it would be interesting to extend the model to consider variable block dimensions. In addition the influence of different types of equipment on the layout could be studied. Furthermore, the simulation model should be extended by implementing more detailed operational decisions such as the dispatching of horizontal means of transport.

## REFERENCES

- Brinkmann, B., 2005. *Seehäfen*. Berlin: Springer.
- Drira, A., Pierreval, H. and Hajri-Gabouj, S., 2007. Facility layout problems: A survey. *Annual Reviews in Control*, 31: 255-267.
- Hartmann, S., 2004. Generating scenarios for simulation and optimization of container terminal logistics. *OR Spectrum*, 26: 171-192
- ILOG, 2007. *Cplex v11.0 User's manual*. Gentilly, France: ILOG.
- Kim, K., Park, Y. and Jin, M., 2007. An optimal layout of container yards. *OR Spectrum*, online available since November 2007.
- Koopmans, T. C. and Beckmann, M., 1957. Assignment Problems and the Location of Economic Activities. *Econometrica*, 25: 53-76.
- Liu, C., Jula, H., Vukadinovic, K. and Ioannou, P., 2004. Automated guided vehicle system for two container yard layouts. *Transportation Research Part C*, 12: 349-368
- Meller, R. D., Chen, W. and Sherali, H. D., 2007. Applying the sequence-pair representation to optimal facility layout designs. *Operations Research Letters*, 35: 651-659.
- Murata, H., Fujiyoshi, K., Nakatake, S. and Kajitani, Y., 1996. VLSI module placement based on rectangle-packing by the sequence-pair. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, 15: 1518-1524
- Singh, S. and Sharma, R., 2006. A review of different approaches to the facility layout problems, *The International Journal of Advanced Manufacturing Technology*, 30: 425-433.
- Stahlbock, R. and Voß, S., 2008. Operations research at container terminals: a literature update. *OR Spectrum*, 30: 1-52.
- Steenken, D., Voß, S. and Stahlbock, R., 2004. Container terminal operation and operations research - a classification and literature review. *OR Spectrum*, 26: 3-49.
- UGS Tecnomatix, 2007. *Tecnomatix Plant Simulation 8.1 User Guide*.
- Xie, W. and Sahinidis, N. V., 2008. A branch-and-bound algorithm for the continuous facility layout problem. *Computers & Chemical Engineering*, 32: 1016-1028
- Yang, C., Choi, Y. and Ha, T., 2004. Simulation-based performance evaluation of transport vehicles at automated container terminals. *OR Spectrum*, 26: 149-170
- Yun, W. Y. and Choi, Y. S., 1999. A simulation model for container-terminal operation analysis using an object-oriented approach. *International Journal of Production Economics*, 59: 221-230

# DEGREE OF COOPERATIVENESS OF TERMINALS AND THE EFFECT ON THE BARGE HANDLING PROCESS

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## ABSTRACT

We consider the container barge rotation planning and quay scheduling problem in the Port of Rotterdam, introduced in Douma et al. (2008). The problem concerns the alignment of barge rotations (sequence of terminal visits) with the quay schedules of the terminals concerned. Douma et al. (2008) propose an agent based solution to meet the specific business constraints. Underlying assumption of their model is that terminals are fully cooperative, i.e., they make agreements with barges about guaranteed waiting times and provide insight in the terminal occupation during the day. In practice, however, terminals might behave more opportunistically. We compare different degrees of cooperativeness. Results indicate that fully cooperativeness results in the lowest average waiting time per barge and thus offers the best service to the barge. Providing less information or processing barges first-come first-served (FCFS) results in uncertain sojourn times for barges, uncertain arrival times at terminals, and increasing delays for barges. The insights we provide can help terminals to decide on the strategy they will adopt.

Keywords: cooperativeness, Multi-Agent System, quay scheduling, rotation planning

## 1. INTRODUCTION

We consider the container barge rotation planning and quay scheduling problem in the Port of Rotterdam. This problem was introduced by Douma et al. (2008) and concerns the alignment of barge rotations (a sequence of terminal visits) with the quay schedules of the terminals concerned. In this introductory paper an agent based solution was proposed to deal with the specific business constraints in the problem. A basic underlying assumption is that terminals are fully cooperative in the sense that they are willing to make guaranteed agreements with barges about maximum waiting times and that they give insight in their occupation during the day. However, in practice the attitude of terminals might be less cooperative, e.g., terminals might not keep the agreements with barges or give limited insight in their occupation. Aim of the present paper is to provide insight in the effect of the degree of cooperativeness of terminals on the barge handling process.

In Section 2 we describe the problem and problem setting. In Section 3 we discuss some related literature.

Section 4 describes briefly the multi agent based solution proposed by Douma et al. (2008). In Section 5 we discuss the different degrees of cooperativeness of terminals. Section 6 describes our simulation model and the experimental settings. In Section 7 we present the results of the simulations. Finally, in Section 8 we discuss our results and draw some conclusions.

## 2. PROBLEM AND PROBLEM SETTING

The container barge rotation planning and quay scheduling problem we consider in this paper is inspired by a real problem in the Port of Rotterdam. Barges are used as means to transport containers from the port to the hinterland and vice versa. In 2007 there were 31 container terminals in the Port of Rotterdam and about 75 barges visit the port daily, visiting about eight terminals each.

For both barges and terminals it is beneficial to align their operations. For barges this is important since they want to leave the port in time, i.e., in accordance with their sailing schedule. For terminals this is important to use their quays as efficiently as possible.

Complexities in the problem are the specific business constraints. In the past, several attempts have been made to establish a central party that coordinates the activities of both terminals and barges. However, it turned out that this solution was not acceptable for the actors involved for several reasons. First, terminal operators compete with each other (so do barge operators) and are therefore reluctant to share information that possibly undermines their competitive position. Second, no contractual relationships exist among barges and terminal operators. This means that barge operators and terminal operators cannot force each other contractually to deliver a certain service or charge each other for poor services. Third, both barge and terminal operators want to stay autonomous, i.e., in control of their own operations. Modeling the problem in a mathematical way is a hard task, since one has to deal with different actors having different interests, a highly dynamic environment (barges arrive over time, lot of events and disturbances), and a loosely structured and loosely coupled network of actors.

Today, barges and terminals communicate by means of telephone, fax, and E-mail, to make appointments. However, due to a poor alignment of activities, uncertainties during operations, and strategic

behavior of both terminals and barge operators, this leads to inefficient use of quays and long sojourn times of barges in the port.

### 3. RELATED LITERATURE

The container barge rotation planning and quay scheduling problem has been studied before in a few studies (see, e.g., Connekt 2003; Melis et al. 2003; Schut et al. 2004; Douma et al. 2008). Besides that the problem is related to several fields. We mention the berth allocation problem (Cordeau et al. 2005; Stahlbock and Voss 2008), the ship routing and scheduling problem (Christiansen et al. 2004), the attended home delivery problem (Campbell and Savelsbergh 2006), the hospital patient scheduling problem (Decker and Li 2000), and multi agent theory (Wooldridge and Jennings 1995). In Douma et al. (2008) we provide a discussion of each of these fields. For the role operations research methods play in the in the optimization of terminals operations we refer to an extensive literature study by Steenken et al. (2004) and Stahlbock et al. (2008).

A new element in the present paper is the concept of *degree of cooperativeness*. In the literature on Multi-Agent Systems the concept *cooperation* has been frequently discussed in different meanings. Cooperative agents are, e.g., considered as agents working together to achieve the same goal, in contrast to agents that are self-motivated and maximize their own benefits (Kraus 1997). Sandholm (1999) state that self-interested agents can be assumed to be cooperative, if they use the strategies imposed by the designer and not choose a strategy themselves. The latter might be more likely in problems with competing self-interested agents. In these situations the design of the communication protocol becomes important, to let the agents exhibit desired behavior (Sandholm 1999). The concept *cooperation* in Multi-Agent Systems is also strongly related to the field of (Cooperative) Game Theory. In a game (self-interested) players usually have a choice to adopt a cooperative attitude or not, and they make a decision based on expected pay-offs. This choice might be in favor of being cooperative, especially when players have long-term relationships and face each other in repeated games (see, e.g., Mailath 2006).

The long-term relationships between terminals and barges might influence the decisions both actors make and the service they are willing to offer. It turns out that in the problem we consider the behavior of terminals is hard to regulate within the system (see Section 5 for an explanation). However, if terminals offer better services to barges, it might improve their relationship in the long term. Services can be, e.g., guarantees on waiting times (Kumar 1997; Whitt 1999).

In this paper we give insight in the effect of different degrees of cooperativeness of terminals and the effect on the barge handling process. The results can

be used by terminal operators to decide which degree of cooperativeness they should adopt when implementing a Multi-Agent System.

### 4. MULTI AGENT BASED APPROACH

In Douma et al. (2008) we introduced a multi agent based solution for the problem. In this solution every barge and every terminal is equipped with a software agent acting in the best interest of its principal and it is assumed that every agent is opportunistic and makes the best decisions possible (in terms of the actor's objective) with the knowledge it has.

As a communication mechanism between barges and terminals we introduced an information exchange protocol based on waiting profiles. A waiting profile contains information about the maximum amount of time a barge has to wait until its processing is started after it has arrived. This information is provided for every possible arrival moment during a certain time horizon. A waiting profile is generated by a terminal on request of a barge as it enters the port and is barge specific. Waiting profiles are issued - only once per rotation - by all terminals the barge has to visit. The maximum waiting times determining the waiting profile are guaranteed maximum waiting times. This is a service to the barges such that they can accurately estimate the latest arrival time at the next terminal. The barge in turn needs to be at the terminal at the announced time, otherwise it has to make a new appointment and builds up a bad reputation which can be used by a terminal as input for the generation of future waiting profiles. The information in the waiting profiles can be used by a barge operator to determine the rotation with the smallest sojourn time in the port.

We define an *appointment* made between a barge and a terminal as an agreement from two sides. The barge promises the terminal to be present at the terminal before a certain time, i.e., the latest arrival time. The terminal in turn guarantees the barge a latest starting time, if the barge keeps its promise. If the barge does not keep its promise and arrives later than the announced time, it has to make a new appointment. In making appointments, the barge uses the guaranteed latest starting times at preceding terminals.

In Douma et al. (2008) we propose to add some slack  $s$  to the waiting profile. This means that we uniformly increase the maximum waiting times with a certain amount of time  $s$  in order to enhance the planning flexibility of terminals. In this way terminals have more possibilities to schedule barges dynamically, without violating appointments made with other barges.

To understand how waiting profiles can be generated we refer to Douma et al. (2008). For now we assume that terminals can issue waiting profiles and that a barge is able to determine a sequence of terminal

visits (a rotation) that minimizes its sojourn time in the port.

## 5. DEGREE OF COOPERATIVENESS

In this section we introduce the concept ‘degree of cooperativeness’ and we describe the different degrees.

### 5.1. Three degrees of cooperativeness

In the multi agent based model proposed in Douma et al. (2008) we assume the terminals to be ‘fully’ cooperative. What we mean is that terminals give barges first a waiting profile (expressing the maximum waiting times during a certain time horizon) and, second, make appointments which guarantee barges a maximum waiting time until the start of service. In the current situation, however, terminals have a dominant position in the port. For a terminal it is of little importance that a barge has to wait a few hours. Terminals can even benefit from long queues, since this reduces their risk of quay idle time. This is not in the interest of barges, but in the current situation they have no power base to force a terminal to behave differently. The terminals on the other hand can force barges to show desired behavior, by refusing their processing and let them wait some additional time to be processed. Currently, there are several initiatives (i.e., Approach I (Connekt 2003)) to seduce terminals to be more cooperative towards barges. It would be interesting to investigate to what extent increasing cooperativeness would influence the barge handling process.

In this paper we therefore consider the effect of the ‘degree of cooperativeness’ of the terminal on the performance of the terminals and barges. With degree of cooperativeness we mean the extent to which i) a terminal gives insight in its occupation during the day and ii) the extent to which a terminal is willing to keep an appointment. We consider three degrees of cooperativeness:

- i. Fully cooperative: a terminal issues waiting profiles and processes barges according to the appointments made
- ii. Partly cooperative: a terminal issues waiting profiles, but processes barges first-come first-served
- iii. Lowly cooperative: a terminal only gives insight in its current queue length, and processes barges first-come first served.

In i and ii we assume that waiting profiles are issued only once per rotation. In iii, however, the queue length is issued at any moment a barge asks for it, even repeatedly. One might argue that in case iii terminals are not that un-cooperative, since they provide information at any moment a barge asks for it. We still stick to the label ‘lowly cooperative’ for two reasons. First, the quality of information is low (only the current queue length). Second, this label can also be used in the case of absolute lack of terminal information, provided that barges are learning about queue lengths by other

means such as barge transponders, eye-sight or friendly colleagues.

We evaluate the effect of different degrees of cooperativeness by means of simulation. We give insight in the effects of the terminal behavior on the average waiting times at the terminal, and average tardiness of a barge. Note that we fix the capacity of terminals in our experiments, which means that the utilization of the terminal is depending on the number of arriving barges and not on the degree of cooperativeness of the terminal. The latter, however, can have an effect on the average waiting time of barges in the queue.

### 5.2. Terminal are fully cooperative

The fully cooperative case is extensively described in Douma et al. (2008). In Section 4 we give a brief description of the idea.

### 5.3. Terminals are partly cooperative

If a terminal is partly cooperative it issues a kind of waiting profile which can be used by barges to determine their best rotation. However, the waiting times expressed in the waiting profile are not guaranteed. On the contrary, barges are processed in the order they arrive at the terminal.

Barges plan their rotation on arrival in the port and use the waiting profiles to minimize their expected sojourn time in the port. Once they have determined their best rotation they announce their expected arrival time to the terminal, assuming that the waiting times in the waiting profile are valid maximum waiting times. However, during execution waiting times might be different from what is announced, since other barges might have arrived earlier. Waiting profiles are therefore not more than an indication of the busyness of the terminal during certain periods of the day. The announced expected arrival times of the barges are therefore also not more than an indication, subject to the waiting times at terminals during the rotation.

Barges do not update their rotation during execution, but visit the terminals in the sequence determined on arrival of the port.

### 5.4. Terminals are lowly cooperative

If terminals are lowly cooperative they give only insight in the current length of their queue, e.g., as the sum of the expected processing times of the queued barges.

Barges sail through the port from terminal to terminal and make a decision on so-called decision points they visit going from one terminal to another. Barges make decisions based on information about the actual state of the port, like queue lengths of terminals they have to visit.

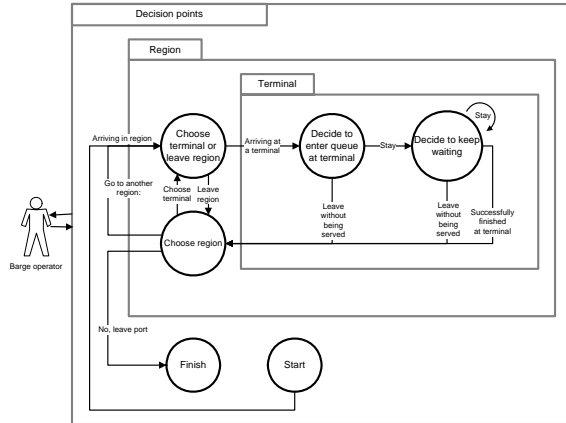


Figure 1 Decision moments for a barge operator agent in the lowly cooperative case

We define decision points at three levels, namely port level, region level, and terminal level (see Figure 1). We discuss the decision points successively. The first decision is made at node *start*, on arrival in the port. The barge operator agent first chooses which region (cluster of terminals) it wants to visit. On arrival in this region it either decides to pass the region or to visit a terminal (node *choose terminal or leave region*). If it decides to visit a terminal, the barge operator can decide, on arrival at the terminal, to enter the queue (node *decision to enter queue at terminal*). If it enters the queue it can reconsider from time to time whether it keeps on waiting at the current terminal or leave the queue to visit another terminal (node *decide to keep waiting*). After it has visited a terminal it can decide to go to another region or to stay in the current region (node *choose region*). If it decides to stay in the current region, the agent has to choose which terminal to visit or yet sail to another region. If it has decided to go to another region it sails there and on arrival in this region it again has to decide either to visit a terminal or to go to another region.

In our model we assume that barges in node *decision to enter queue at terminal* and *decide to keep waiting*, always decide to enter the queue and to keep waiting, respectively. At the node *final* the barge just decides to leave the port. At the other nodes we make a decision as denoted in Table 1. In future study we can refine the decision rules.

Note that the network of decision points is a virtual network. If we say that a barge heads to the region of the first planned terminal, this actually means that the barge first determines what the next region is. If this is the same region as it is in now, then it directly sails to the next planned terminal. If this region is different, then it will physically move to the other region and decide (on arrival in this region) which terminal to visit.

Typical for the lowly cooperative case is that barges determine (or update) their rotation during execution.

Table 1 Decision rules at different decision points

Decision node	Decision
Start	Solve a traveling salesman problem (minimizing the total sailing time) and head to the region of the first planned terminal
Choose terminal or leave region	Go to the terminal in this region with the lowest sum of the processing time of the waiting barges
Choose region	Go to the region of the first planned terminal, unless all terminals in the rotation are visited

## 6. SIMULATION MODEL AND EXPERIMENTAL SETTINGS

To evaluate the Multi-Agent System for different levels of information exchange, we consider different scenarios. To obtain insight in the functioning of the Multi-Agent System, we consider also other port configurations besides the Port of Rotterdam. In this section, we describe (briefly) the simulation model and the experimental settings. We use the same model and experimental settings as used in Douma et al. (2008).

### 6.1. Simulation model

For the simulator we apply an object oriented, discrete event simulation. The system we simulate comprises the terminals and barges. The course of the simulation is event based. This means that after an event the barge or terminal can perform an action resulting in a state transition, after which the state of the system remains unchanged until the next event. The state of the system can be described by the state of all the barges and terminals in the system. A barge can be in three states, namely sailing, waiting, or handling. A terminal can be in two states, namely handling a barge, or being idle. The state definitions might be augmented in the future with, e.g., handling sea vessels, closing of the terminal, et cetera. Events in our model are i) the arrival of a barge in the port, ii) the arrival of a barge at the terminal, iii) start handling, and iv) finish handling. Remark that these events only refer to a physical change in the system, arrival of information is not seen as an event. In the lowly cooperative case we have an additional event (related to the network of decision points), namely the arrival in a region. In the future also events (like a time trigger) related to the decision point *decide to keep waiting* might be introduced. On an event an action can be undertaken by a barge or a terminal. This requires a decision of either the barge operator or the terminal operator.



## 6.2. Experimental settings

This section describes the experimental settings. We assume that all handling and sailing times are deterministic. As time unit we use minutes in our experiments.

### 6.2.1. Scenarios

We have created 36 different scenarios varying along the dimensions presented in Table 2. Remark that the average utilization degree is input for the model, i.e., we generate the number of barges and terminal visits such that we obtain the desired utilization degree.

Table 2 Dimensions varied in the experiments

Variable	Value
Port layout	three variants (see Section 6.2.2)
Number of terminals per region	4 and 9
Number of quays per terminal	1
Utilization degree	50, 75, 90%
Time window barge	fixed, variable (see Section 6.2.4)

Every scenario is evaluated by means of simulations. For the waiting profile implementation, we also vary the value of the slack  $s$  (the additional flexibility in the waiting profile) for  $s \in \{0, 30, 60\}$ , with  $s$  in minutes.

All scenarios have a run length of 100 days. We apply a warm-up period of ten days (which proves to be sufficiently long) and a cool-down period of three days.

### 6.2.2. Network layouts

We consider three different port layouts (see Figure 2), which are inspired by the geographical structure of large ports around the world (Rotterdam (layout II), Antwerp (layout III), Hamburg (layout III), Singapore (layout II), and Shanghai (layout II)). We do not claim that our port layouts fit these ports exactly, but they are reasonable approximations. Layout I is added to evaluate the effect of regions on the performance of the system.

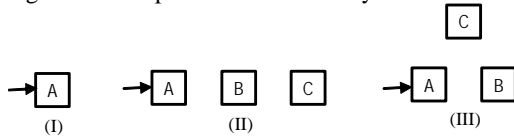


Figure 2 Three port layouts: one region, three regions in line, and three regions in a triangle. The arrows represent the port entrance and exit point.

We vary the number of terminals per region (either four or nine terminals). The sailing time between two terminals only depends on the regions each of the terminals belongs to, not on the Euclidian distance. In the port it is not possible to sail straight from one terminal to another, since there are only a few connecting water ways. We therefore assume that the

sailing time within a region is always equal (we choose it to be 20 minutes). Sailing through a region (without visiting a terminal) takes 40 minutes. Sailing times between terminals are given by Table 3 on a regional level. So, for instance, from Table 3 we can see that traveling from a terminal in region A to a terminal in region C takes 240 minutes in a line port configuration.

Table 3 Sailing times (in minutes) between terminals belonging to specific regions

From/to a terminal in region	Line			Triangular		
	A	B	C	A	B	C
Port entrance and exit point	20	140	260	20	140	140
Region A	20	120	240	20	120	120
Region B	120	20	120	120	20	120
Region C	240	120	20	120	120	20

### 6.2.3. Parameter settings and distributions

The number of barges that visit the port within the planning horizon is derived from the number of terminals in the port, the number of quays per terminal, the average utilization degree, and the average number of terminal visits in a rotation. The inter-arrival time between barges is exponentially distributed.

Table 4 Parameter settings

Parameter	Value
Time to load or unload a container	3 min.
Mooring time on arrival and departure	10 min.
Maximum number of terminal visits per rotation	15

The call size (sum of the containers to load and unload) at a terminal is drawn from a normal distribution with mean 30 containers and a standard deviation of 10 containers. The handling time of a barge is the sum of the time to load and discharge containers, and the mooring time on arrival and departure. We discretize the normal distribution by rounding to the nearest integer with a minimum value of one. The number of terminal visits (calls) in a rotation is triangularly distributed with a minimum  $a$ , maximum  $b$ , and mode  $c$ . The mode denotes the most frequent value in the distribution. The minimum  $a$  is equal to one. The maximum  $b$  is equal to the maximum number of calls in a rotation or the number of terminals in the port. Mode  $c$  is equal to  $(a+b)/2$ . Other parameters are given in Table 4. We point out that the distributions used for the call size and the number of terminals in a rotation are inspired by real data.

### 6.2.4. Time window of the barge

Most barges, sailing the river Rhine to Rotterdam, sail according to sailing schedules that are determined once a year. Generally, this means that the total time a barge is supposed to be in the port is fixed, irrespective of the number of calls in the port, i.e., the time windows of all barges have equal length. However, due to disturbances

and uncertain sojourn times in the port, one might argue that the sojourn times of barges in the port depend also on the number of terminal visits in the rotation. We therefore choose to consider both fixed and variable time windows.

Fixed time windows are determined as follows. We assume an average number of calls and an average call size per call. We assume that an average barge visits all regions in the port. Based on that, we can calculate the expected handling time (including mooring time) and sailing time. This is an estimate of the minimum time an average barge needs in the port to finish all its activities. To add slack for waiting at terminals, we multiply the sum of the handling and sailing time with some factor (1.8). This factor is chosen such that a reasonable number of barges can leave the port within their time window. The exact value of the factor is not very important in our experiments, more important is the fact that the time windows of all barges have the same length (in one single experiment). The size of the time window does not depend on the chosen average utilization degree.

The variable time windows are calculated as follows. For every barge, we calculate the sum of the handling time (including mooring time) and the expected sailing time. The result is increased with some fixed percentage of slack and a variable percentage depending on the number of terminals in the rotation. The slack per terminal is set to 4% and the fixed percentage depends on the utilization of the terminals and is for a utilization degree of 50, 75, and 90% equal to 10, 50, and 100%, respectively. So, for a barge that has to visit eight terminals in a port with a 50% utilization degree, this means that the time window is equal to total handling and sailing time in the rotation times  $1+10\%+8\cdot4\%=1.42$ .

## 7. RESULTS

In our experiments we assume that all terminals have the same degree of cooperativeness. In Section 7.1 we present the results of our simulation in case all terminals are fully cooperative. Section 7.2 gives these results in case all terminals are partly and lowly cooperative. In Section 7.3 we compare the performance of these three different degrees of cooperativeness.

### 7.1. The fully cooperative case

With respect to the results for the fully cooperative case we focus on an interesting relation between the *total waiting time* in a rotation and the *number of calls* (terminal visits) in a rotation, especially for utilization degrees of 75% and higher. In Figure 3 we depicted this relation based on ten replications of a scenario with port layout II, 9 terminals per region, and 90% utilization degree.

From the picture we can conclude the following. First, the waiting time reduces significantly if more

slack is added to the waiting profile. Second, the total waiting time in a rotation reduces if a barge visits more terminals in its rotation. More specifically, the sum of the waiting and sailing time seems to be more or less constant in the number of terminals a barge visits (Figure 4).

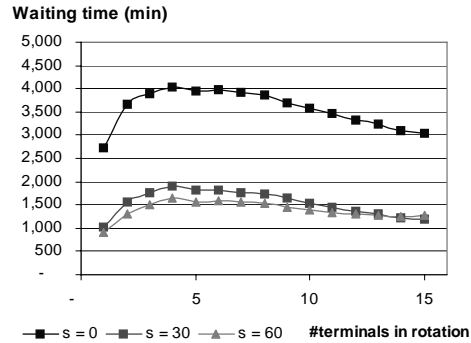


Figure 3 Average waiting times for different levels of slack and different rotation lengths in the fully cooperative case

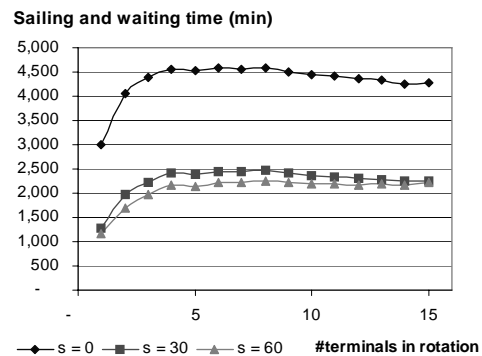


Figure 4 Average waiting and sailing times for different levels of slack and different rotation lengths in the fully cooperative case

This seems maybe counter intuitive. The explanation for this result is that barges, if they visit more terminals, use the waiting time at terminal A to visit another terminal B. Waiting time is then used partly for sailing, handling and waiting at terminal B. Especially when a barge visits more terminals, it has more options to minimize its waiting time in a rotation.

### 7.2. The partly and lowly cooperative case

If we consider the relation between the total waiting time and the number of calls in a rotation for the partly or lowly cooperative case (for utilization degrees of more than 75%), we find that the total waiting time increases linearly with the number of terminals a barge has to visit. In Figure 5 we show this relation for the partly cooperative case, for the same scenario as used in Figure 3 and 4. The graph for the lowly cooperative case is similar except for the scale of the lines.

The reason that the total waiting time increases linearly is because terminals process barges FCFS. On every arrival at a terminal a barge has to enter the queue and wait for its service until all earlier arrived barges are processed.

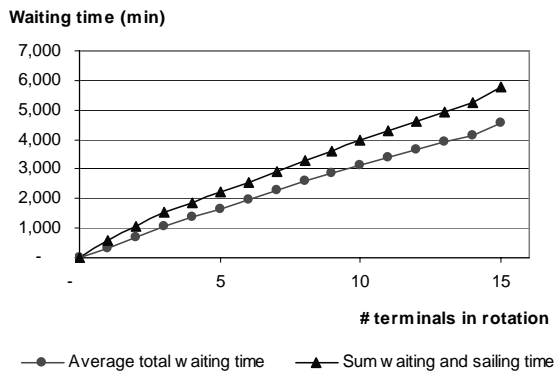


Figure 5 The waiting time, and the sum of the sailing and waiting time, if barges are processed FCFS

The difference in the partly and lowly cooperative case results mainly from the extent to which barges can use the information issued by terminals to reduce the average waiting time at a terminal, as can be seen in the next section.

### 7.3. Comparing the three degrees of cooperativeness

If we compare the average tardiness of barges for the different degrees of cooperativeness of terminals we find that being fully cooperative, with the use of waiting profiles including slack varying from 0-60 minutes, outperforms lower degrees of cooperativeness (see Figure 6 and 7).

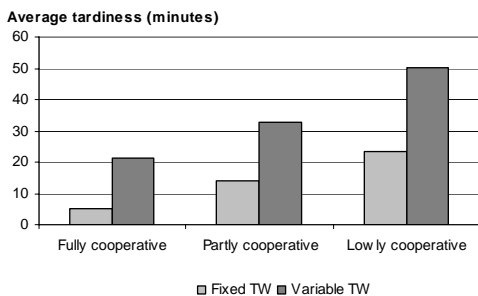


Figure 6 The average tardiness of barges averaged over all scenarios, specified for a 50% utilization degree and fixed and variable time windows

The reason why the partly cooperative situation performs worse for 90% utilization, is because barges determine a rotation (and announce the corresponding arrival times) based on the issued waiting profiles. This has some disadvantages. First, the waiting profiles might be outdated since barge arrivals can be significantly different from the announced arrival times. This effect is larger for higher utilization degrees.

Second, barges assume that in the waiting time of one terminal another terminal can be visited. However, the waiting time at every terminal turns out to be more or less equal.

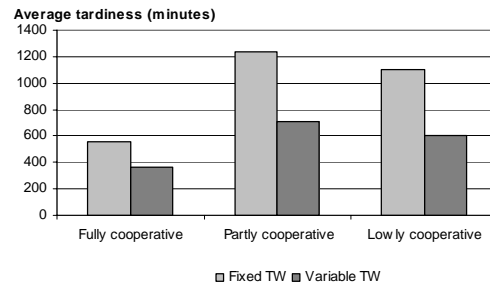


Figure 7 The average tardiness of barges averaged over all scenarios, specified for a 90% utilization degree and fixed and variable time windows

The fact that lowly cooperative outperforms partly cooperative – in case of a high utilization degree – is interesting from a barge perspective. This suggests that, if terminals are reluctant to provide any information to the barges, then barges will surely benefit from joining their forces and exchange information on a mutual basis.

Table 5 Average waiting time of a barge at terminal for different degrees of cooperativeness

Degree of cooperativeness	Avg. waiting time at terminal (min)
Fully	203
Partly	304
Lowly	294

If we consider the average waiting time of a barge at the terminal for the same scenario we used for Figure 3 and 4 (we averaged the results of all the terminals) we find the numbers presented in Table 5. The results of Table 5 compared with Figure 6 suggest that reduction of the average waiting time corresponds with a better performance in terms of average tardiness.

## 8. DISCUSSION AND CONCLUSIONS

Our simulation results suggest that the way terminals deal with barges influences to a large extent the performance of these barges. If terminals are fully cooperative there is more certainty about the barges that have to be processed, whereas in the lowly cooperative case terminals are not restricted by appointments and have more flexibility in their operations.

Although fully cooperative seems to be a good alternative, there is also a down-side for terminals. If terminals are fully cooperative, there is no real incentive for barges to reduce the number of terminals in a rotation. Reducing the number of terminal visits leads only to a small reduction of the port sojourn time. However, more terminal visits per barge means more dependencies between terminals, and on average

smaller call sizes per barge resulting in more idle time of the crane during mooring of the barges. FCFS processing gives barges a clear incentive to reduce the number of terminal visits and is more robust against disruptions. However FCFS leads also to several disadvantages during operations. First, terminals do not exactly know when a barge is processed and when containers need to be stacked at the quay. Second, barge operators need to stow their barges very flexibly to be able to visit terminals in a different order. This affects the utilization degree of the barges. If barges make appointments, there is more certainty about their rotation, which enables them to increase their ship utilization. Third, there is more uncertainty in sojourn times of barges in the port, which makes the sailing schedules offered to carriers less reliable.

It is subject to discussion which degree of cooperativeness is desirable from both a terminal and barge perspective. If terminals are fully cooperative we expect that the balancing of the total workload over all terminals can be done more effectively than when terminals are less cooperative. This will generally result in shorter waiting times for barges at terminals such that more barges can depart the port timely. If terminals are partly cooperative, the value of waiting profiles might deteriorate dramatically, since terminals process barges at the time they prefer, but also barges might decide to visit terminals in a different sequence. Waiting profiles might then become misleading, since barges and terminals can act upon this information making it less relevant. If terminals are lowly cooperative, on the contrary, we expect that especially the introduction of sea vessels and opening times at terminals makes it hard to decide which terminal to visit when. Especially, like in Rotterdam, when barges visit several regions twice and they have the option to go to a terminal either the first time a region is visited or the second time.

We can imagine that in practice also a mix of degrees of cooperativeness can be found among terminals, for instance, terminals that participate in the Multi-Agent System (and are fully cooperative) and terminals that are not willing to participate. The latter terminals will cause a lot of uncertainties about the time a barge needs to be processed at those terminals, which makes it harder to make appointments with fully cooperative terminals. In this hybrid setting it is essential for barges that they make appointments such, that they can visit the less cooperative terminals in between the appointments.

#### ACKNOWLEDGMENTS

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#### REFERENCES

- Campbell, A. M., and Savelsbergh, M. (2006). Incentive schemes for attended home deliveries. *Transportation Science*, 40(3), 327-341.
- Christiansen, M., Fagerholt, F., and Ronen, D. (2004). Ship Routing and Scheduling: Status and Perspectives. *Transportation Science*, 38(1), 1-18.
- Connex. (2003). *Eindrapport Approach*. Delft. Report is in Dutch: Connex.
- Cordeau, J. F., Laporte, G., Legato, P., and Moccia, L. (2005). Models and tabu search heuristics for the berth-allocation problem. *Transportation Science*, 39(4), 526-538.
- Decker, K., and Li, J. (2000). Coordinating Mutually Exclusive Resources using GPGP. *Autonomous Agents and Multi-Agent Systems*, 3(2), 133-157.
- Douma, A. M., Schutten, J. M. J., and Schuur, P. C. (2008). Waiting profiles: an efficient protocol for enabling distributed planning of barge rotations along terminals in the Port of Rotterdam. *To appear in Transportation Research Part C*.
- Kraus, S. (1997). Negotiation and cooperation in multi agent environments. *Artificial Intelligence*, 94, 79-97.
- Kumar, P., Kalwani, M.U., Dada, M. (1997). The impact of waiting time guarantees on customers' waiting experiences. *Marketing Science*, 16(4), 295-314.
- Mailath, G. J., Samuelson, L. (2006). *Repeated Games and Reputations: Long-Run Relationships*: Oxford University Press.
- Melis, M., Miller, I., Kentrop, M., van Eck, B., Leenaarts, M., Schut, M., et al. (2003). *Intelligent Logistics Concepts*.
- Sandholm, T. (1999). Distributed Rational Decision Making. In *Multiagent Systems, A Modern Approach to Distributed Artificial Intelligence* (1 ed., pp. 201-258): MIT press.
- Schut, M., Kentrop, M., Leenaarts, M., Melis, M., and Miller, I. (2004). APPROACH: Decentralised Rotation Planning for Container. *Proceedings of the 16th European Conference on Artificial Intelligence*.
- Stahlbock, R., and Voss, S. (2008). Operations Research at Container Terminals: a literature update. *OR Spectrum*, 30, 1-52.
- Steenken, D., Voß, S., and Stahlbock, R. (2004). Container terminal operation and operators research - a classification and literature review. *OR Spectrum*, 26, 3-49.
- Whitt, W. (1999). Improving Service by Informing Customers about Anticipated Delays. *Management science*, 45(2), 192-207.
- Wooldridge, M. J., and Jennings, N. R. (1995). Intelligent Agents: Theory and Practice. *The Knowledge Engineering Review*, 10(2), 115-152.

# THE CORRIDOR METHOD – A GENERAL SOLUTION CONCEPT WITH APPLICATION TO THE BLOCKS RELOCATION PROBLEM

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## ABSTRACT

The Corridor Method is a solution concept which may be characterized as a method-based metaheuristic. That is, based on a given algorithm which is meant to work well at least on small sized instances of a specific type of optimization problem, it defines one or more neighborhoods which seem to be well suited for the specific problem and the given algorithm. These neighborhoods may be viewed as corridors around given solutions. Experiments show that this type of approach is a successful hybridization between exact and metaheuristic methods. We show successful applications for the block relocation problem arising, e.g., at container terminals.

Keywords: corridor method, blocks relocation problem, container terminal

## 1. INTRODUCTION

In this paper we present a dynamic programming inspired metaheuristic called corridor method along with its application upon the blocks relocation problem in block stacking systems, as found, e.g., in the stacking of container terminals in a yard. It can be classified as a local search based metaheuristic in that the neighborhoods that it deploys are method-based. By this we mean that the search for a new candidate solution is carried out by a fully-fledged optimization method which generates an optimal solution over the neighborhood. The neighborhoods are thus constructed to be suitable domains for this optimization method. Typically these neighborhoods are obtained by the imposition of exogenous constraints on the decision space of the target problem and, therefore, must be compatible with the method used to search these neighborhoods. This is in sharp contrast to most traditional metaheuristics where neighborhoods are move-based, i.e., they are generated by subjecting the candidate solution to small changes called moves.

While conceptually the method-based paradigm applies to any optimization method, in practice it is best suited to support optimization methods, such as dynamic programming, where it is easy to control the size of a problem, hence the complexity of algorithms,

by means of exogenous constraints. The essential features of the method may be illustrated in the context of well-known combinatorial optimization problems where exponentially large dynamic programming inspired neighborhoods are searched by a linear time/space dynamic programming algorithm.

This paper has the following structure: Section 2 presents the blocks relocation problem along with a dynamic programming based formulation; Section 3 illustrates how the Corridor Method can be implemented to effectively tackle the problem at hand; Section 4 offers computational results and, finally, Section 5 concludes with some remarks.

## 2. THE BLOCKS RELOCATION PROBLEM

Increasing containerization and competition among seaport container terminals have become quite remarkable in worldwide international trade. Operations are nowadays unthinkable without effective and efficient IT use and appropriate optimization (management science and operations research) methods. Besides enabling efficient data interchange between supply chain partners, related information systems need to support terminal operators, shipping companies and even port authorities.

In container terminals, it is common practice to store outbound containers in the yard before loading them into a vessel. To be able to face competition among terminals and to guarantee a high level of service, operators must reduce unproductive time at the port; see, e.g., Stahlbock and Voß (2008) and the references given there for a comprehensive survey.

Relocation is one of the most important factors contributing to the productivity of operations at storage yards or warehouses (Yang and Kim, 2006). A common practice aimed at effectively using limited storage space is to stack blocks along the vertical direction, whether they be marine containers, pallets, boxes, or steel plates (Kim and Hong, 2006). Given a heap of blocks, relocation occurs every time a block in a lower tier must be retrieved before blocks placed above it. Since blocks in a stack can only be retrieved following a LIFO (Last In First Out) discipline, in order to retrieve the low-tier block, relocation of all blocks on top of it will be

necessary. Figure 1 illustrates how the block stacking technique is used at a bay. Each vertical heap is called stack. A stack is made up by a number of tiers, which define the height of the stack. A bay is the collection of stacks and the width of the bay is given by the number of stacks. In Figure 1 the order in which a block is to be retrieved is indicated by a progressive number. Consequently, in order to pickup block 1, blocks 5 and 4, in this order, must first be relocated to either stack 1 or 3.

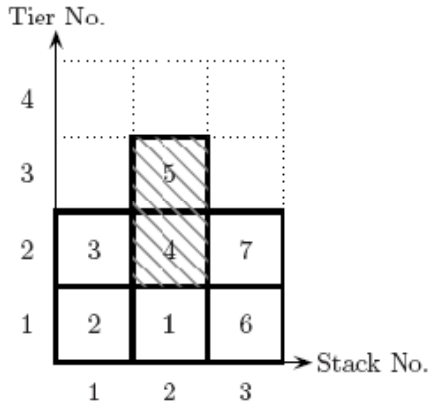


Figure 1: An example of a bay with  $m = 3$  stacks and  $n = 7$  blocks.

If the current configuration of the bay is taken as fixed, one might be interested in finding the sequence of moves that should be executed, while retrieving blocks according to a given sequence, in order to minimize the overall number of relocation moves. While in the shuffling problem containers are rearranged but not removed, in the on-line version of the problem, at each step, a container is removed from the bay, hence reducing the number of containers in the bay until all containers have been picked up from the bay. Exact as well as approximate algorithms have been proposed to minimize the number of relocations while retrieving blocks. For example, Watanabe (1991) proposed the use of an accessibility index to forecast the number of relocation movements. With a similar approach, Castillo and Daganzo (1993) and Kim (1997) proposed heuristic rules to estimate the number of relocations for inbound containers. A mathematical formulation and a branch and bound approach, along with an effective heuristic scheme for the blocks relocation problem are presented in Kim et al. (2000) and in Kim and Hong (2006).

In this paper, in a fashion similar to what is presented in Kim and Hong (2006), we consider the initial bay configuration as fixed and the sequential order of pickup as known in advance. Given this fixed initial arrangement, we are interested in finding the relocation pattern at each pickup operation in such a way that the total number of relocation moves within a bay is minimized.

The general idea of this paper is based upon the introduction of a dynamic programming scheme that captures all the possible states of the bay at any given time. Given an incumbent bay configuration and a

target block to retrieve, we distinguish between two cases: (i) the block to be retrieved is *free*, which is, no block is currently above it. In this case, the only acceptable decision is to retrieve the target block and place it into its final destination. On the other hand, (ii) if at least one block is currently placed upon the target block, we enumerate all the possible relocation strategies for the uppermost block and move this block to another stack, giving rise to a new bay configuration. This enumeration process is repeated until case (i) is reached, after which the current target block is retrieved and the next target block is addressed. The process terminates when the last block to be retrieved is freed up.

Let us consider the case of a bay with  $N$  blocks, indicated with  $\{1, \dots, N\}$ , in which the first  $n$  blocks must be retrieved, with  $n \leq N$ . Without loss of generality, we assume that not necessarily all the blocks must be retrieved. Let us indicate with  $i \in \{1, \dots, m\}$  a stack in the bay and with  $k \leq n$  the current block to be retrieved. Throughout this section, we will use the bay of Figure 1 as reference example.

We now introduce the following assumptions:

**H1:** As in Kim and Hong (2006), pickup precedences among blocks are known in advance. We indicate the pickup precedence with a number, where blocks with lower numbers have higher precedence than blocks with higher numbers (e.g., in Figure 1, the pickup precedences are  $1 < 2 < \dots < 7$ ).

**H2:** When retrieving a target block, we are allowed to relocate only blocks found above the target block in the same stack using a LIFO policy (e.g., in Figure 1, when picking up block 1, we are forced to relocate blocks 5 and 4, in this exact order).

**H3:** Relocation is allowed only to other stacks within the same bay (e.g., in Figure 1, when relocating blocks 5 and 4, they can only be moved to either stack 1 or 3).

**H4:** Relocated blocks can be put only on top of other stacks, i.e., no rearrangement of blocks within a stack is allowed (e.g., in Figure 1, when relocating blocks 5 and 4, these can only be placed on top of blocks 3 and 7).

In the following, let us define the basic elements of the dynamic programming (DP) model:

**State variable:** Let us indicate with  $s = (k, i, t, C)$  the state variable, where  $k \in \{1, \dots, n\}$  is the block to be retrieved,  $i \in \{1, \dots, m\}$  is the stack in which the target block is found,  $t$  is the list of blocks above the target block and  $C$  is the configuration of the remaining blocks (e.g., with respect to Figure 1, we have  $k = 1, i = 2, t = \{5, 4\}$ , and  $C = \{\{3, 2\}, \{7, 6\}\}$ ).

**Decision variable:** At each step, one of two different cases arises, namely (i) the target block has no other blocks placed above and can currently be retrieved and placed outside of the bay, i.e.,  $t = \emptyset$ . In this case, the only alternative is to retrieve the target block and to

place it into its final destination; (ii) the target block cannot be retrieved since at least one block is still above it, i.e.,  $t \neq \emptyset$ . Let us indicate with  $\tau$  the uppermost block in the sequence  $t$ , which is, the block that is currently on top in stack  $i$ . In this case, the decision is about identifying which stack block  $\tau$  should be relocated to. Let us indicate with  $x$  such a stack and with  $D(s)$  the set of all feasible values of  $x$  with respect to the current state  $s$  (e.g., in Figure 1, we have  $\tau = 5$  and  $D(s) = \{1, 3\}$ , that is, the next decision concerns where to relocate block 5 and the only feasible moves are either to move it to stack 1 or to stack 3).

**State transition function:** Let us indicate with  $s' = (k', i', t', C')$  the state obtained by applying decision  $x \in D(s)$  to the current state  $s$ , which is,  $s' = T(s, x)$ . Here  $T$  represents the state transition function. As previously mentioned, two different cases may arise: (i)  $t = \emptyset$ ; or (ii)  $t \neq \emptyset$ . In case (i), we have that  $k' = k + 1$ ,  $i'$  is the stack in which block  $k + 1$  is currently located,  $t'$  is a new list of blocks currently above the target block  $k + 1$  and, finally,  $C' = C$  is the configuration of the remaining blocks. On the other hand, in case (ii), it is easy to see that  $k' = k, i' = i, t' = t \setminus \{\tau\}$ , and  $C'$  depends on the application of move  $x$  to block  $\tau$  (e.g., in Figure 1, let us suppose that  $x = 1$ . In this case, the new state is  $s' = T(s, 1) = (1, 2, \{4\}, C')$ , where  $C' = \{\{5, 3, 2\}, \{7, 6\}\}$ ).

**Functional equation:** The DP “backward” functional equation is

$$f(s) = 1 + \min_{x \in D(s)} \{f(T(s, x))\} \quad (1)$$

where  $s = (k, i, t, C)$  indicates the current state, and  $T(s, x)$  is the state transition function that accounts for the application of decision  $x$  upon the current state  $s$ . We set  $f(s) = 1$ , for  $s = (n, i, \emptyset, C)$ , which is the cost of retrieving a block from the bay and moving it to its final destination. More formally, we can explicitly distinguish between the aforementioned cases (i) and (ii). Consequently, the functional equation can be rewritten, for  $k = n - 1, \dots, 1$ , as

$$f(k, i, t, C) = \begin{cases} 1 + f(k + 1, i', t', C), & t = \emptyset \\ 1 + \min_{x \in D(s)} \{f(k, i, t \setminus \{\tau\}, C')\}, & t \neq \emptyset \end{cases} \quad (2)$$

with  $f(n, i, \emptyset, C) = 1$ .

It is easy to see that one of the major drawbacks of the proposed dynamic programming scheme lies in the exponentially large number of entries in the dynamic programming evaluation table. Consequently, the size of the evaluation table can become very large after only a few steps of the dynamic programming algorithm. In the next section we illustrate how this major obstacle can be overcome.

### 3. THE CORRIDOR METHOD FOR THE BLOCKS RELOCATION PROBLEM

The Corridor Method (CM) has been presented by Sniedovich and Voß (2006) as a hybrid metaheuristic, linking together mathematical programming techniques with heuristic schemes. The basic idea of the CM relies on the use of an exact method over restricted portions of the solution space of a given problem. Given an optimization problem  $P$ , the basic ingredients of the method are a very large feasible space  $X$  and an exact method  $M$  that could easily solve problem  $P$  if the feasible space were not too large. However, since, in order to be of interest, in general the size of the solution space grows exponentially with respect to the input size, the direct application of method  $M$  to solve  $P$  becomes unpractical when dealing with real-world instances, which is, when  $X$  becomes larger.

Let us now consider how the CM can be applied to the blocks relocation problem. As mentioned in Section 2, the main drawback of the proposed method is the exponential growth of the number of reachable states. We define a “two-dimensional” corridor around the current configuration, in such a way that the number of states generated from the current configuration is limited. Given a current bay configuration  $s$ , the number of new configurations that can be generated starting from  $s$  is equal to  $|D(s)|$ . Consequently, in order to reduce the number of generated states, one can apply exogenous constraints that impose horizontal as well as vertical limits upon the bay. For example, horizontal limits could be introduced by reducing the number of stacks to which blocks can be relocated, as well as vertical limits, by establishing a maximum height, in terms of number of blocks in the same stack.

Let us now formally define the “constrained” neighborhood induced by the application of the CM upon a given configuration. Let us indicate with  $s = (k, i, t, C)$  the current bay configuration, where  $C = \{c_1, \dots, c_m\} \setminus \{c_i\}$  indicates all the stacks of the bay excluding stack  $i$ . Let us indicate with  $|c_i|$  the number of blocks currently on stack  $i$ . Given two parameters  $\delta$  and  $\lambda$ , we define the set of restricted admissible decisions as

$$D(s, \delta, \lambda) = \{x \in \{1, \dots, m\} \setminus \{i\} : i - \delta \leq x \leq i + \delta, |c_x| \leq \lambda\}. \quad (3)$$

Finally, we define the restricted neighborhood of the current configuration  $s$ , i.e., the set of “feasible” bay configurations that can be created from  $s$  as

$$N(s) = \{s' : s' = T(s, x), x \in D(s, \delta, \lambda)\}. \quad (4)$$

Consequently, the size of the neighborhood can be made arbitrarily small by changing the values of  $\delta$  and  $\lambda$ . For this reason, we can say that the “corridor” around the incumbent bay configuration is defined by imposing *exogenous constraints* on the solution space of the problem via calibration of parameters  $\delta$  and  $\lambda$ .

#### 4. COMPUTATIONAL RESULTS

In this section we present computational results on randomly generated instances. All tests presented in this section have been carried out on a Pentium IV Linux Workstation with 512Mb of RAM. The algorithm has been coded in C++ and compiled with the GNU C++ compiler using the -O option.

We designed an experiment that resembles that of Kim and Hong (2006). We divided our computational tests in two parts: (i) tests on small-medium size instances, for which an exact solution can be computed using the dynamic programming scheme. For these instances, we present a comparison of our algorithm with respect to the optimal solution as well as with respect to the solution found by the algorithm of Kim and Hong (2006), running the code provided by the authors on our randomly generated instances; and (ii) tests on large scale instances, for which the optimal solution is unknown. In order to measure the solution quality of our algorithm, we compare our results with those obtained running the algorithm of Kim and Hong (2006) on the same set of instances.

The random generation process takes as input two parameters, the number of stacks  $m$  and the number of tiers  $h$ , and randomly generates a rectangular bay configuration of size  $n = h \times m$ , where  $n$  indicates the total number of blocks in the bay. For each combination of  $m$  and  $h$  we generated 40 different instances.

In Table 1 we compare the results of the proposed scheme with those obtained running the code of Kim and Hong (2006) on the same set of instances. It is worth noting that all values reported in the table are *average* values, computed over 40 different instances of the same class. This helps in offsetting instance specific biases in the reported results. In addition, we fixed a maximum computational time for the CM of 60 seconds, after which the algorithm was stopped. Clearly, since the CM is based on a dynamic programming scheme, whenever the algorithm is truncated, no solution is returned.

In Table 1 and Table 2, the first and second columns define the size of problem instances, in terms of number of tiers and number of stacks. The third and fourth columns report average number of moves and computational time of the algorithm of Kim and Hong (2006) (called KH for short). Columns five and six report the same information, average number of moves and average computational time, for the proposed CM. Column seven reports the gap between the solution of the CM and the optimal solution obtained by using the dynamic programming scheme (omitted in Table 2 because instances were too large to be solved via dynamic programming). The gap is computed as:

$$\gamma = \frac{z^{CM} - z^*}{z^*} \quad (5)$$

where  $z^*$  is the optimal solution found by the dynamic programming scheme and  $z^{CM}$  is the average best solution found by the proposed CM scheme. Finally, the

last two columns provide a measure of the corridor, in terms of width ( $\delta$ ) and height ( $\lambda$ ). We solved each instance with different combinations of  $\delta \in \{1, 2, \dots, m/2\}$  and  $\lambda \in \{h+1, h+2, \dots, 1.5h\}$ . We report the values used to obtain the best solution in the shortest computational time. It is worth noting that, for the sake of consistency with the results reported in Kim and Hong (2006), all results reported in this section with respect to the number of moves (No.) only count the number of relocations and do not take into account the final retrieval of the target blocks to their final destinations.

In addition, in order to further reduce the stochastic effects of the algorithm, we run the algorithm with the same set of parameters  $\delta$  and  $\lambda$  five times on the same instance. Consequently, given an instance class  $h \times m$ , we solved each one of the 40 instances  $5 \times |\Lambda| \times |\Delta|$  times. In the table we report the average values over all the runs of a given instance class.

Table 1: Computational Results on Small Size Instances.

Bay Size		KH		CM			Corridor	
h	m	No.	Time <sup>†</sup>	No.	Time <sup>†</sup>	$\gamma$	$\delta$	$\lambda$
3	3	7.1	0.1	5.4	0.10	0.00	1	4
3	4	10.7	0.1	6.5	0.10	0.00	1	4
3	5	14.5	0.1	7.3	0.10	0.00	1	4
3	6	18.1	0.1	7.9	0.15	0.00	2	4
3	7	20.1	0.1	8.6	0.10	0.01	2	4
3	8	26.0	0.1	10.5	0.20	0.01	2	4
4	4	16.0	0.1	9.9	0.20	0.02	2	5
4	5	23.4	0.1	16.5	0.50	0.01	2	5
4	6	26.2	0.1	19.8	0.50	0.03	2	5
4	7	32.2	0.1	21.5	0.50	0.03	2	5

<sup>†</sup> : CPU seconds on a Pentium-IV 512Mb RAM.

In Table 1, the “smaller” instances in the upper part of the table, i.e.,  $3 \times 3$  to  $3 \times 6$ , are solved to optimality by the CM. Consequently, a first observation of our results is related to the effectiveness of the CM in solving small instances to optimality in a very short computational time. For all the other instances, the algorithm compares favorably with the Kim and Hong (2006) algorithm, especially when dealing with large scale instances. In order to provide a further indication of the robustness of the algorithm, in Figure 2 we graphically present the variability of the results on the largest instances. As shown in Figure 2, the algorithm is quite robust with respect to the parameter values  $\delta$  and  $\lambda$  as well as with respect to the initial configuration of the bay.



Table 2: Computational Results on Medium Size Instances.

Bay Size		KH		CM		Corridor	
h	m	No.	Time <sup>†</sup>	No.	Time <sup>†</sup>	$\delta$	$\lambda$
5	4	23.7	0.1	16.6	0.5	2	6
5	5	37.5	0.1	18.8	0.8	2	6
5	6	45.5	0.1	22.1	0.8	2	6
5	7	52.3	0.1	25.8	1.43	1	7
5	8	61.8	0.1	30.1	1.46	1	6
5	9	72.4	0.1	33.1	1.41	1	6
5	10	80.9	0.1	36.4	1.87	1	6

<sup>†</sup> : CPU seconds on a Pentium-IV 512Mb RAM.

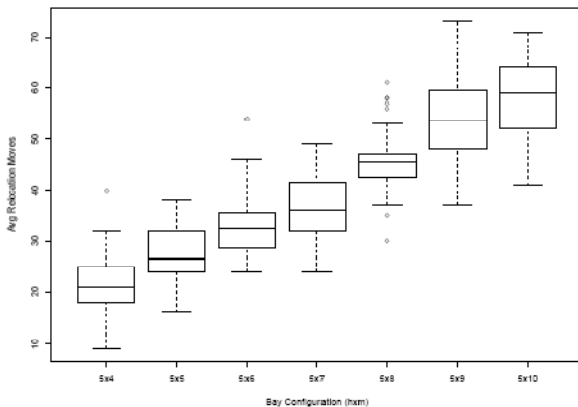


Figure 2: Variability results.

## 5. CONCLUSION

In this paper we have presented a metaheuristic-based algorithm for the Blocks Relocation Problem, in which one is given a sequence of blocks to be retrieved from a bay according to a fixed set of precedences. The objective is to find the blocks relocation pattern that minimizes the total number of movements required to comply with the retrieving sequence. This problem finds applications in a wide spectrum of real-world situations, where stacking techniques are used to reduce space usage, e.g., at a container terminal yard. We have first proposed a dynamic programming algorithm that can be used to find the optimal solution to the problem. However, since the size of the search space grows exponentially with respect to the input size, the dynamic programming approach cannot be used in real time when dealing with medium and large scale instances. For this reason, we tackled the problem by designing a Corridor Method inspired algorithm, in which a two-dimensional “corridor” is build around the incumbent yard configuration. The imposition of exogenous constraints on the target problem sensibly reduces the size of the solution space, making the use of the “constrained” dynamic programming scheme practical even on very large instances.

## REFERENCES

- Castilho, B. and Daganzo, C. (1993). Handling strategies for import containers at marine terminals. *Transportation Research B*, 27(2):151–66.
- Kim, K. H. (1997). Evaluation of the number of rehandles in container yards. *Computers & Industrial Engineering*, 32(4):701–711.
- Kim, K.H., Hong, G.P., 2006. A heuristic rule for relocating blocks. *Computers & Operations Research*, 33, 940 - 954.
- Kim, K. H., Park, Y. M., and Ryu, K. R. (2000). Deriving decision rules to locate export containers in container yards. *European Journal of Operational Research*, 124:89–101.
- Sniedovich, M., Voß, S., 2006. The corridor method: A dynamic programming inspired metaheuristic. *Control and Cybernetics* 35, 551 - 578.
- Stahlbock, R., Voß, S., 2008, Operations research at container terminals – A literature update. *OR Spectrum* 30, 1 - 52.
- Watanabe, I. (1991). Characteristics and analysis method of efficiencies of container terminal: an approach to the optimal loading/unloading method. *Container Age*, 3:36–47.
- Yang, J. H. and Kim, K. H. (2006). A grouped storage method for minimizing relocations in block stacking systems. *Journal of Intelligent Manufacturing*, 17:453–463.

# DECISIVE INCREASE OF CAPACITY AND THROUGHPUT BY USING ADVANCED PLANNING AND REAL-TIME OPTIMIZATION ALGORITHMS

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## ABSTRACT

Automation of terminals with integrated optimization approaches is a big topic. But at most only a few companies worldwide really have the knowledge to base their approaches on highly sophisticated mathematical algorithms and heuristics to improve equipment and yard utilization. INFORM combines in unique manner the advantages of *planning* ahead by assigning slots and equipment over a *longer time period* and the necessities of making *optimized decisions* in *real time*. Based upon this knowledge as well as the consulting experience of HPC the new brand TERMINALSTAR was established in 2006. In cooperation INFORM and HPC are offering a TOS for sea ports and various standardized and customized optimization packages. The challenging CTB project proves the expectations to be justified.

employees have to be and -even more ambitious- have to feel themselves supported by a new IT-system during their daily business.

For almost 10 years, INFORM has developed a modular terminal logistics operating and optimization system that is today used for handling tens of thousands of containers at maritime and inland ports as well as road/rail terminals. Together with HPC the new brand TERMINALSTAR was established in 2006 offering a TOS for sea ports and various standardized and customized state of the art optimization packages (Niessen 2007, Niessen 2008a, 2008b). These packages build upon the extensive research results on optimizing container terminals with the help of advanced mathematical models and methods developed in the field of Operations Research. A recent survey (Stahlbock and Voß 2008) lists over 200 references for these topics.

Keywords: advanced-optimization, CTB, TERMINALSTAR, planning-and-control-combination

## 1. INTRODUCTION

Sea ports are the engines of our economy. Their possibility to cope with the continuously increasing maritime trade is essential for the health of our economies. Innovative technologies help to increase capacities and throughput of new and already existing terminals (Niessen 2007, Niessen 2008a, 2008b). Especially advanced IT technologies prevent those economical junctions from becoming fatal logistic bottlenecks (Savelsberg 2008).

What are the main challenges for ports which can be supported by innovative IT applications?

Generally, the main objective at a container terminal is to minimize vessel turnaround times, corresponding to the maximization of quay crane throughput. Furthermore, the demand for increasing density by stacking higher leads to the necessity to implement optimization tools to avoid extensive reshuffling. And last but not least all involved

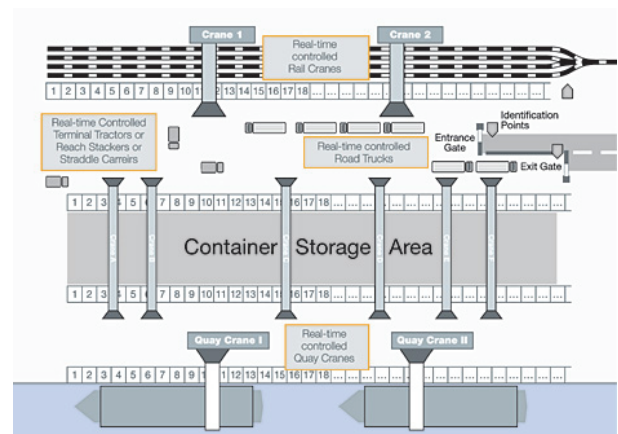


Figure 1: General Transportation flow through a port container terminal. Source: INFORM

## 2. THE CONTAINER TERMINAL BURCHARDKAI (CTB)

## 2.1. The “Implementation-Framework”

The CTB project is a good example for the challenges today’s software and software design have to face.

Regarding this terminal the overall goal is to almost double the throughput over the next couple of years (2.6 Million TEU to 5.2 Million TEU). A combination of new and already existing transport technologies (fully automated RMG, conventional VC, rail cranes ...) and storage facilities shall be in use (RMG-Blocks, VC-Blocks, Empty Facilities). Software from different companies for different purposes will be implemented and parts of the old software system will be kept.

TERMINALSTAR is in charge of the storage and stacking logistics, the transport optimization, the loading and unloading of vessels as well as the information management and the GUIs for the control centre. Since CTB operates at its capacity limits, down times for implementation have to be reduced to some minutes. Time for testing has to be used very efficiently.



Figure 2: Progress in terminal operations: The Burchardkai, Hamburg, in 1968; straddle carrier based operation in 2005; and the future layout in 2014 with automated six-high storage blocks served by triple rail mounted gantry cranes (in red). Source: INFORM

## 2.2. Software modules of TERMINALSTAR implemented at the Burchardkai Hamburg

The following modules of TERMINALSTAR will be implemented in Hamburg.

The first module, called *Yard Control*, includes algorithms taking care of smart stacking which will be explained in more detail in the next chapter, the preplanning of Empties and the possibilities to exchange same empty containers against each other. Furthermore it helps to avoid idle times of equipment by smart Housekeeping rules. Finally it takes care of the whole IMO and Reefer management.

The module *Process Control* optimizes all workflows. This module is a kind of centre module since all manual and automated transport demands are governed here. Furthermore the Process Control takes care of the truck schedule. Hence, according to specific rules the most favorable order to load and unload

container at certain areas of the terminal is determined within this module.

Most of the decision intelligence is located in the *Equipment Control* module. Optimization tools offer a medium term planning, e.g. scheduling of the upcoming transport demands, as well as an online control optimization, e.g. when a container has to be moved on short notice and hence all orders close to this point in time have to be rescheduled – again in a smart way keeping in mind directions and distances which have to be covered. All different kinds of equipment can be organized. The software is partly customized according to the special conditions which have to be kept in mind for each specific terminal.

The *Vessel Manager* takes care of the sequences in which the containers arrive beneath the quay cranes.

The *Hinterland Manager* is in charge of the loading and unloading procedures and all optimization aspects regarding the rail interface.



Figure 3: Softwaremodules of TERMINALSTAR implemented at the Burchardkai Hamburg

The final module to be presented here is the *Control Center*. GUIs to supply information and to give support for decisions have to be developed closely according to the mental models of the users. Hence, a thorough procedure of development including regular user reviews and adjustments to their needs was carried out during this project.

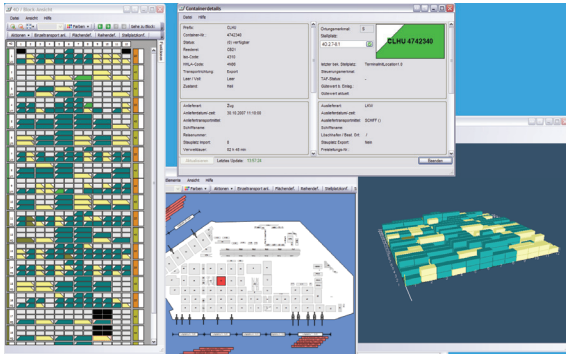


Figure 4: Examples of GUIs developed during the CTB project

This year in summer the first modules of TERMINALSTAR will be implemented at the Burchardkai Hamburg.

### 2.3. TERMINALSTAR's contribution to meet the overall goal

The overall goal of the CTB project is to increase capacity, to push the throughput, reduce the costs per box while using the same space. Hence, this demands higher and smarter stacking as well as faster and more efficient handling.

In the following some examples will be pointed out to explain the input advanced optimization can offer regarding this challenges (Dorndorf et al. 2007).

Two of the main differences regarding *planning and control* applications at terminals are that uncertainty is higher in planning than in control, and that reaction time is much shorter in control, which generally has to be done "online." Hence, computation in planning is not a very strict constraint and uncertainty models and calculi can be used. By contrast, in control computations have to be very fast, which can either be achieved by very fast algorithms or by only modifying planning results according to realizations (wait-and-see approach).

To maximize the throughput of the system, unproductive moves should be avoided by using advanced storage and stacking approaches.

The *stacking problem* consists of finding an optimal location for each incoming container. The container is characterized by a set of attributes (geometrical, operational and logistical). It is good practice to place containers with similar attributes one on top of the other. In this way, each container in a stack can be considered equivalent, avoiding rehandles. One of the most used stacking strategies involves placing export containers with the same departing ship and same destination on top of each other. Alternatively, it is possible to stack according to the estimated time of departure so that containers with an earlier departure time will be placed on top of others that will be picked up later.

In automated storage blocks, automatic re-stacking during times where the handling equipment would otherwise be idle, can be used to re-optimize the storage

area, resulting in a reduction of one-tenth of container loading operations.

In the vast majority of cases, information is uncertain at the moment of the decision. Often it changes over time (for example, time of departure). The fast turnover of containers implies that the available time window for each decision is usually very limited (order of seconds). For these reasons, the stacking problem can be classified as a real-time optimization problem. This means that, in practical applications, one of the most employed optimization techniques are heuristics, mainly rule-based systems or ranking systems.

Other alternative approaches are based on the use of the "soft computing" area of research. A key element of the system is an inference engine formed by a set of rules "if... then..." that operates on fuzzy variables. The use of fuzzy technology allows to model uncertain and qualitative data through the use of linguistic variables, simplifying the mathematical model and reducing the number of variables. The resulting inferential engine uses its tolerance towards imprecision and uncertainty to represent adequately the complex relationships between the variables of the system, making it more understandable and transparent to the user.

In many cases, different algorithms or mathematical models are evaluated and validated through simulation tools.

*Transport optimization* deals with the horizontal transportation of containers. An import container is initially transported from the quay side to the storage area, most frequently by straddle carriers or internal trucks and on some modern facilities by automated guided vehicles. This leads to challenging online vehicle routing optimization problems. At CTB, for example, 104 straddle carriers are controlled. Compared to current practice, the efficiency can often be improved by pooling vehicles. Similar vehicle routing problems arise on the land side, where containers are transported between the storage blocks and the railhead and where external trucks must be scheduled and routed through the terminal.

The intermediate storage area is organized in rectangular blocks that are either served directly by the straddle carriers, which can stack containers up to three or sometimes four high, or by rubber tired or rail mounted gantry cranes (RTMG and RMG) that can typically stack up to five or six high. For example, an RMG block at the CTB can hold more than 2,000 standard containers. At newer facilities the operation of the RMG cranes is fully automatic with two or even three cranes per storage block. Crane scheduling is concerned with the online optimization of the stacking cranes. The objective is to minimize the travel times of the cranes and delays and waiting times at the interfaces of the storage blocks. Online crane scheduling is also needed at the rail interface to unload and load rail cars.

## 2.4. List of References

- Dorndorf, U., Herbers, J., Panascia, E., Zimmermann, H.-J., 2007, *Ports o' Call for O.R. Problems, From stacking containers in seaports to staff planning at airports, optimization opportunities abound*, OR/MS Today
- Niessen, U., Daniels, S., 2007, *Hamburg Burcharkai – Project Update, Open Heart Surgery, The Intelligence Behind*, Lecture TOC Hongkong
- Niessen, U., 2008a, *Next generation container terminal*, Lecture TOC Shanghai
- Niessen, U., 2008b, *The Intelligence Behind - the Benefits to Earn: Decisive Increase of Throughput by Using Innovative Software*, Lecture TOC Amsterdam
- Savelsberg, E., 2008. *Innovation in European Freight Transportation*, Springer-Verlag Berlin Heidelberg.
- Stahlbock, R., Voß, S., 2008. *Operations Research at container terminals: a literature update*, OR Spectrum 30 (1).

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**Udo Niessen** After completing his studies in engineering and economy Mr. Udo Niessen worked as sales engineer at the wagon factory Talbot in Aachen, Germany. Here he learned about rail technology and companies involved. The majority of Mr. Niessen's experience has been built up during a 16-years employment with INFORM GmbH (Institute for Operations Research and Management), Aachen. From 1992 to 1993 he was employed as System Consultant and Customer Adviser. In 1994 he became head of the sales department and in 1997 Director of the Logistics Systems Division. Since 2000, Mr. Niessen has been Vice-President of INFORM GmbH. During the last years, he and his team have been involved in the planning and installation of various implementations of the Logistics Optimisation System SyncroTESS in different application areas. He was member of the central logistics planning team for the new Container Terminal in Altenwerder (CTA) for one and a half years. After the design phase SyncroTESS was installed at CTA for the rail connection and the truck dispatch within the terminal. Currently Mr. Niessen is heading the Inform team delivering the new control software for the CTB project.

Mr Niessen was also involved as the general project manager for the implementation of the Logistics Optimisation System SyncroTESS in the three new parcel centres of the Swiss Post. Each parcel centre is connected to the national railways.

Since 2003, Mr Niessen has been one of the four shareholders of INFORM GmbH.

For several years, **Eva Savelsberg** was head of a research group on national and international large-

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**Ulrich Dorndorf** is the Chief Technical Officer of INFORM. After receiving his Master in Engineering from the Technical University of Darmstadt, he joined INFORM in 1992. As project manager and head of software development he has been involved in the development and introduction of large scale decision support systems mainly for transport, terminal and airport logistics. As Chief Technical officer, he now manages the company's Research and Development efforts with focus on optimization, decision support and simulation technologies. He holds a PhD in Economics and Operations Research from the University of Darmstadt and has published more than 40 papers on optimization models and methods.

# ROUTING AND SCHEDULING OF PARCEL TANKERS: A NOVEL SOLUTION APPROACH

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## ABSTRACT

For more than half a century, tanker routing and scheduling problems have also attracted extensive interest from researchers. To date, only one existing tanker routing and scheduling model explicitly accounts for the cargo stowage constraints faced by tanker owners. But the originators of the latter model fail to offer efficient solution methodology that can meet the practical needs of industry practitioners. This paper aims to bridge the research gap in the domain of tanker routing and scheduling in two major ways. First, it introduces a novel solution methodology that can (1) efficiently solve tanker routing and scheduling problem with all key operating constraints, and (2) meet the practical needs of industry practitioners. In addition to highlighting the pros and cons of our tool relative to existing tools, this paper also discusses research opportunities that remain available in this field.

Keywords: parcel tanker, routing and scheduling, optimization, stowage

## 1. INTRODUCTION

For many years, the US\$2.2 trillion global chemical industry has been a key driver of the global economic growth. The global chemical trade which hit more than US\$1.24 trillion in 2006 has achieved an impressive 14% average annualized growth between 2000 and 2006 (World Trade Organization, 2007). To support this growing chemical trade, new parcel tankers which primarily ship cargos between chemical processing facilities and manufacturers worldwide have been built in record numbers (Shaw, 2003).

Essentially, a parcel tanker distinguishes itself from other maritime bulk carriers by its multiple independent cargo tanks which enable it to carry multiple liquid cargos simultaneously. To ensure there is no contact between different cargoes, each tank usually has its own cargo handling system which consists of pump and associated piping. Moreover, these pumps and pipes are constructed using materials that are compatible with the cargoes to be handled so that their qualities will not be compromised as a result of their passage through the pumps and pipes. In practice, each cargo handling

system is designed to handle a variety of products from light to heavy end products so as to enhance the cargo carrying versatility of the tankers. Clearly, the pipe work associated with these tanks for cargo loading and discharging as well as the cargo loading and discharging arrangement are complex. Thus, all procedures that entail handling of cargoes have to be carried out with great care and precision to both avoid cargo contamination and ensure that cargoes owned by different shippers are kept separated. To ensure incompatible chemical cargoes do not come into contact with each other, parcel tankers are usually constructed with cofferdam (i.e. a space between two tank walls) between adjacent tanks. In addition, cargo tanks of parcel tankers must also be cleaned prior to loading of cargoes to (1) uphold the chemical cargo quality and (2) avoid unwanted chemical reactions that may pose safety hazards.

Due to safety concerns, parcel tanker operators have to contend with two regulatory constraints that are sanctioned by International Maritime Organization (IMO). First, the cargo tanks of parcel tankers must be lined with appropriate coatings that are compatible with the cargoes that they are carrying in accordance with either Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (BCH code) for ships constructed before 1 July 1986 or International Bulk Chemical Code (IBC Code) for those built after 1 July 1986. This is to protect (1) the inner surfaces of cargo tanks from the corrosive properties of chemical cargoes and (2) the cargoes from contamination that arises due to corrosion and accumulated scale on uncoated tank surfaces. Typical coatings in use include epoxy, phenolic resins, zinc silicate, polyurethane and rubber. However, majority of these coatings are not compatible with all chemical cargoes. For example, epoxy coating is compatible with alkalis, glycols, vegetable oils but not with aromatics like benzene and toluene. On the other hand, zinc silicate is compatible with aromatics but not with acids, alkalis and vegetable oils. As such, parcel tankers usually have their cargo tanks lined with a number of different coatings so that they can carry as wide a range of chemical cargoes as possible.

Second, dangerous chemical cargoes that might cause a chemical reaction by mixing must be not be loaded into adjoining tanks as stipulated in the IBC Code and BHC Code. This regulatory stowage restriction is summarized in the U.S. Coast Guard Compatibility Chart that is found in Code of Federal Regulations (CFR) Title 46 Part 150 and many in the shipping community are using it as a guide to identify the incompatible chemical cargoes that cannot be loaded into adjacent tanks. A copy of the compatibility chart is shown in Figure 1 where a box with “X” indicates the possible reaction of the corresponding chemical cargoes and they cannot be carried in adjacent tanks.

Cargo Group	REACTIVE GROUPS																							
	1. NON-OXIDIZING MINERAL ACIDS	2. SULFURIC ACID	3. INORGANIC ACID	4. ORGANIC ACID	5. CARBONIC ACID	6. ALIPHATIC AMINES	7. AROMATIC AMINES	8. AMIDES	9. ORGANIC AMIDES	10. ORGANIC AMIDES	11. ORGANIC AMIDES	12. ORGANIC AMIDES	13. VINYL ACETATE	14. ACRYLATES	15. SUBSTITUTED ALLYL	16. ALLYLENE OXIDE	17. EPIHALOHYDRIN	18. EPOXIDES	19. ALDENES	20. ALCOHOLS, GLYCOLS	21. PHENOLS, CREOSOLS	22. CAPROLACTAM SOLUTION		
1. NON-OXIDIZING MINERAL ACIDS	X																							
2. SULFURIC ACID		X																						
3. INORGANIC ACID			X																					
4. ORGANIC ACID				X																				
5. CARBONIC ACID					X																			
6. ALIPHATIC AMINES						X																		
7. AROMATIC AMINES							X																	
8. AMIDES								X																
9. ORGANIC AMIDES									X															
10. ORGANIC AMIDES										X														
11. ORGANIC AMIDES											X													
12. ORGANIC AMIDES												X												
13. VINYL ACETATE													X											
14. ACRYLATES														X										
15. SUBSTITUTED ALLYL															X									
16. ALLYLENE OXIDE																X								
17. EPIHALOHYDRIN																	X							
18. EPOXIDES																		X						
19. ALDENES																			X					
20. ALCOHOLS, GLYCOLS																				X				
21. PHENOLS, CREOSOLS																					X			
22. CAPROLACTAM SOLUTION																						X		
30. OLEFINS																								
31. PARAFFINS																								
32. AROMATIC HYDROCARBONS																								
33. HALOGENATED HYDROCARBON MIXTURES																								
34. ESTERS																								
35. VINYL HALIDES																								
36. HALOGENATED HYDROCARBONS																								
37. NITRILES																								
38. CARBON DIOXIDE																								
39. SULFURANE																								
40. GLYCOL ETHERS																								
41. ETHERS																								
42. HYDROCARBON OXIDES																								
43. HALOGENATED WATER SOLUTIONS																								

Figure 1: Cargo Compatibility Chart from 46 CFR Part 150

Parcel tankers are capital-intensive and their operating cost runs in ten thousands of dollars a day per ship. In an industry which is notoriously cyclical by nature, efficient cargo assignment, routing and scheduling of parcel tankers is crucial to the financial success of a tanker company. Unfortunately, an optimal assignment of cargos, routes and schedules to a fleet of ships requires solving an inherently complex combinatorial problem. This complexity is further accentuated in the tanker sector primarily due to the need to comply the aforementioned two safety regulations (i.e. cargo-tank and cargo-cargo restrictions) imposed on cargo stowage conditions by IMO.

## 2. LITERATURE REVIEW

Tanker routing and scheduling problems (TRSPs) have also attracted extensive interest from researchers for more than half a century. Recently, Oh and Karimi (2007) highlighted that distinction can be made among these problems in terms of their characteristics. The latter define the problem scope and business operations practice which tend to differ among tanker companies. Problem characteristics in turn contribute to the

variations in the types of operating constraints considered in these problems as well as the solution methodologies that have evolved to address them. Generally, there are six basic characteristics that define a TRSP. They include the number of cargo types carried by each tanker, number of vessel types in a fleet, cargo delivery arrangement, time chartering option, demand nature and problem objective. . In some problems such as those of Flood (1954) and Brown et al. (1987), each tanker can only carry single cargo type per voyage, as opposed to multiple cargo types in other works. In addition, the former addressed a homogenous fleet problem where all vessels are of the same type (i.e. single vessel type) with the same cargo carrying capacity. Together with Rao and Zions (1968) and Sherali et al. (1999), their problems also entail direct shipment of each cargo from its origin to its destination without the tanker visiting other ports for loading or discharging of other cargos. The option of time chartering other tankers to fulfill shipment orders is another characteristic that differentiates TRSPs. Some of the existing models such as those of Rao & Zions (1968), Brown et al. (1987), Bausch et al. (1998), Sherali et al. (1999) and Brønmo et al. (2007) account for this option while others omit this option. The last two distinguishing problem characteristics are related and they are associated with the nature of shipment orders and problem objective. Most of the earlier models address TRSPs with a set of given shipment orders and with the objective of fulfilling all these orders at minimum costs. In contrast, recently developed models like those of Jetlund and Karimi (2004), Neo et al. (2006) and Brønmo et al. (2007) considered a problem where there are decisions pertinent to selection of shipment orders that are to be fulfilled with the objective of profit maximization. See Table 1 for an overview of differences in problem characteristics among the selected models.

Essentially, there are two approaches of solving TRSPs. One employs pure optimization techniques to determine optimal solutions of problems concerned. Examples of such approach can be found in Appelgren (1971), Brown et al (1987), Bausch et al. (1998), etc. But application of their solution methods in the industry is limited primarily due to excessive computational times needed to solve problems of industrial scale. Due to enormous complexity of TRSPs, the solution time needed to solve them to optimality increases exponentially with problem size. In addition, the application of these methods also tends to be inhibited by specific characteristics of their respective problems. Recall from Table 1 that both Appelgren (1971) and Brown et al (1987) address problems which only have direct shipment of cargos while the problem in Bausch et al. (1998) has a predetermined set of shipment orders.

Table 1: Key Problem Characteristics and Operating Constraints

Authors	Paper Code (P/C)		Problem Characteristics					Operating Constraints			
			No. of cargo types	No. of vessel types	Direct shipment	Orders to fulfill	Ship time charter option	Problem objective	Cargo-Cargo restrictions	Cargo-Tank restrictions	Ship stability
Flood (1954)	a	S	S	Y	F	N	1	N	N	N	N
Rao & Zions (1968)	b	M	M	Y	F	Y	1	N	N	N	N
Appelgren (1971)	c	M	M	Y	D	N	2	N	N	N	Y
Mckay & Harley (1974)	d	M	M	N	F	N	1	N	N	N	Y
Brown et al. (1987)	e	S	S	Y	F	Y	1	N	N	N	Y
Scott (1995)	f	M	M	Y	F	N	1	N	N	N	N
Bausch et al. (1995)	g	M	M	N	F	Y	1	N	Y	Y	Y
Sherali et al. (1999)	h	M	M	Y	F	Y	1	N	N	N	Y
Jetlund & Karimi (2004)	i	M	M	N	D	N	2	N	N	N	Y
Neo et al. (2006)	j	M	M	N	D	N	2	Y	Y	Y	Y
Brønmo et al. (2007)	k	M	M	N	D	Y	2	N	Y	N	Y

**Notations:** S = Single, M = Multiple, Y = Yes, N = No, F = Fixed, D = Decision Variables, 1 = Cost Minimization, 2 = Profit Maximization

In contrast, the second approach of addressing TRSPs uses heuristics that usually have the capability to derive good solutions of large scale problems in much lesser computational times than the first approach. These heuristics can be found in McKay and Harley (1974), Sherali et al. (1999), Jetlund and Karimi (2004), and Brønmo et al. (2007) and they tend to meet the basic operational need of tanker companies which typically require short turnaround times to generate good routes and schedules for their fleets. Generally, these heuristics are able to determine good solutions efficiently by (1) novel mathematical formulation that makes problem more tractable (e.g. Sherali et al., 1999 and Jetlund & Karimi, 2004) than other conventional approaches, (2) leveraging the prowess of intelligence-based search algorithms as in McKay and Harley (1974) and Brønmo et al., 2007). See Table 2 for details of solution approaches of all selected models.

Table 2: Solution Methods (SM) of Selected Models

PC	SM*	Remarks
a	POM	Applies transportation theory which employs simplex method
b	POM	Employs column generation scheme that involves solving out-of-kilter subproblems
c	POM	Applies branch and bound algorithm with Dantzig-Wolfe decomposition technique
d	H	2 step approach: (1) generates a set of possible schedules and then (2) determines the best one by employing an iterative scheme that solves a linear programming (LP) model
e	POM	2 step approach: (1) generates all possible schedules and then (2) determines the optimal one by solving a SP model
f	POM	Uses Lagrangian relaxation to generate a set of feasible schedules (which include the optimal one) and use a modified Benders' decomposition to determine the optimal one
g	POM	2 step approach: (1) generates all possible schedules and then (2) determines the optimal one by solving a SP model
h	H	Uses a specialized rolling horizon heuristic to solve practical sized problems that are represented by aggregated model
i	H	Uses the slot-based modeling approach and a decomposition-based algorithm
j	POM	Uses commercial solver (CPLEX)
k	H	Uses multi-start local search approach

\* POM = Pure Optimization Method; H = Heuristic

Evidently, many solution techniques that cater to different types of TRSPs have evolved over the years. Nevertheless, majority of them have limited application potential in tanker business world due to omission of key operating constraints faced by tanker owners. To the best of the authors' knowledge, no tanker routing and scheduling models account for the aforementioned

two stowage constraints explicitly and concurrently till the publication of Neo et al. (2006). But the latter fail to offer efficient solution methodology that can meet the practical needs of industry practitioners. For example, it took more than five hours to solve their model for a simple single tanker problem. Clearly, this model alone cannot meet the industry needs since tanker owners usually require a much shorter solution time to address a larger scale problem which involves multiple vessels.

In our effort to bridge this application gap, this paper introduces a novel solution methodology that can (1) efficiently solve TRSP with all key operating constraints, and (2) meet the practical needs of industry practitioners. To illustrate effectiveness of our proposed approach, we apply our new solution approach to solve a realistic TRSP of industrial scale. In addition to highlighting the pros and cons of our tool relative to existing tools, this paper also discuss research opportunities that remain available in this field.

### 3. PROBLEM STATEMENT

Essentially, the TRSP that we are addressing in this paper is similar as the multi-ship problem described in Jetlund and Karimi (2004) and underlying assumptions in both problems are also similar. The key difference in these two problems lies in the account of cargo-tank and cargo-cargo restrictions which are omitted in the model formulation of Jetlund and Karimi (2004). In our effort to make this paper complete and self-explanatory, we describe our TSRP and its assumptions as follows.

We consider a fleet of  $S$  tankers ( $s = 1, 2, \dots, S$ ) where the following information is known for each tanker  $s$  at the start of planning horizon: (1) its current location, (2) the set  $\mathbf{L}_s$  (loaded) of cargos on board the tanker  $s$ , (3) cargo stowage plan of these loaded cargoes, (4) the route (i.e. sequence of port visit) and schedule of  $s$ , and (5) the cargo  $j$  ( $j \in \mathbf{L}_s$ ) to be unloaded at each port, (6) its total volumetric and weight carrying capacities, (7) its total number of cargo tanks and capacity of each of these tanks. In addition, there is also a set  $\mathbf{U}$  (unloaded) of potential cargos that is available for pick up by any tanker in the fleet. Critical information pertinent to each of these potential cargos  $j$  ( $j \in \mathbf{U}$ ) are available and they include its pickup port, discharge port, and size in volume and weight. There is also a time window of pickup for each of these potential cargos  $j$  ( $j \in \mathbf{U}$ ) which is denoted as  $(EPT_j, LPT_j)$ , where  $EPT_j$  is the earliest pickup time and  $LPT_j$  the latest pickup time. In the planning horizon which is 4 week long or so, a tanker  $s$  may serve some or all of the set  $\mathbf{U}$  of potential cargos in addition to those in  $\mathbf{L}_s$ .  $\mathbf{U}$  also includes the transshipment cargos with assigned time windows for pickup by small ships. A tanker  $s$  can possibly visit  $P$  ports ( $i = 1, 2, \dots, P$ ) which consist of all the pickup and discharge ports of cargoes in  $\mathbf{L}_s$  and discharge ports of cargoes in  $\mathbf{U}$ . Whenever a tanker  $s$  visits a port  $i$ , it pays a fixed port charge of  $PC_{is}$  which depends mainly on the size/capacity (dwt) of  $s$  and the number of berths that it visits. Typically, a ship anchors after arrival at a port and waits for a free berth to load



and/or discharge cargos. Before it can berth and before it can leave a port, it must go through inspections. We assume a fixed total inspection time,  $T_{adm}$  at any port for all the tankers.

The objective of our TRSP is to maximize the expected total profit of the tanker company over the planning horizon by (1) selecting the cargos that the fleet should serve subject to all relevant constraints, and (2) deriving the cargo stowage plan as well as the route and schedule of every tanker in the fleet. The total profit is revenue arising from the service of cargos minus the port costs, time charter cost, tank changeover costs and fuel costs of all tankers. We also make the following assumptions to simplify the problem or to estimate some parameters:

- (1) Each tanker capacity is constrained only by its total volume or deadweight in tonnes.
- (2) Every tanker belongs to a certain class based on its deadweight capacity. We estimate port cost as the average cost of approaching a port for the ships of the respective class.
- (3) Speeds of each tanker  $s$  in ballast and laden voyages are constant at  $v_s^B$  and  $v_s^L$  nautical mile per hour (nm/h) respectively.
- (4) There are four main fuel oil consumption rates to consider for each tanker  $s$  and they are linear functions of time spent at sea, time spent at port during cargo loading, time spent at port due to cargo unloading, time spent on tank cleaning respectively. At ports where there are both cargo loading and unloading activities, the fuel consumption rate is assumed to be average of the consumption rates at port during cargo loading and loading.
- (5) Loading and discharge times are given by the total cargo volume or weight transferred divided by the relevant pump rates. The resulting service time is a conservative measure, as a carrier sometimes would be able to load and/or discharge multiple cargos at the same time. In other words, we do not model the actual port operations in detail. This is also reasonable for a planning model and also because as a ship may spend as much as 40% of its total time waiting at ports rather than in actual port operations.
- (6) Inspection time before berthing and that before leaving the port are both  $0.5T_{adm}$  for every tanker.
- (7) Once a tanker loads a cargo, it must deliver that cargo. It cannot transship that cargo to another vessel.
- (8) Cargo deliveries have no due-dates.
- (9) Any vessel instability that arises due to cargo stowage can be adequately rectified by filling the ballast tanks to their respective appropriate levels.

To this end, it is important to highlight three key features of our TRSP which not only distinguish it from other problems but also make it more computationally challenging to solve. First, our problem accounts for

different voyage speeds for each tanker based on whether the latter is in laden or ballast voyage. This reflects more realistically of the industry practice where the ballast speed is usually higher than the laden speed (i.e.  $v_s^B > v_s^L$ ). Second, our TRSP also represents the fuel consumption of vessels more realistically by having consumption rates which differ according the vessel activities. In contrast, all existing TRSPs in literature do not have such detailed representation of fuel consumption rates. A more realistic representation of the fuel consumption is clearly crucial in the current business environment where bunker fuel constitutes 40-90% of a vessel daily operating costs and fuel prices have risen by almost 300% over the last three years. Third, our TRSP does not restrict the number of visits by each tanker to any port over a given planning horizon. In the TRSPs of Jetlund and Karimi (2004) and Neo et al. (2006), the authors limit the number of visit to any port by a vessel to a maximum of one.

#### 4. NOVEL SOLUTION FRAMEWORK

Due to confidentiality reasons, we cannot disclose the technical details of our new solution framework to any external party. As such, we will not present or describe any details of the algorithmic steps involved in our solution framework in this paper. Instead, we only highlight the key features of our new novel solution approach which allow it to solve TRSPs of industrial scale efficiently and meet the practical needs of industry practitioners.

Essentially, our new methodology entails an implicit enumeration algorithm that aims to generate good cargo-tanker combinations, and their corresponding routes and schedules, feasible cargo stowage plans. It also involves one final step of solving a set-partitioning model who aims determine the best (in terms of overall profit) cargo-tanker combinations, and the corresponding cargo stowage plan, route and schedule of each tanker of each tanker. The novelty of our new solution approach stems primarily from the ability of a heuristic to determine a good cargo stowage plan, a good route of and schedule of a tanker by enumerating only a fraction of all possible permutations.

Through our experimental studies that were based on industrially realistic data, we are able to demonstrate that the aforementioned heuristic can (1) derive optimal route and schedule of a tanker in more than 98% of randomly generated problems, and (2) derive a feasible cargo stowage plan that satisfies the cargo-cargo, cargo-tank restrictions and meets the business needs of tanker owners. More importantly, this heuristic is also able to arrive at a solution to a given TRSP using minimal time which is in terms of seconds on a desktop PC.

Leveraging on the heuristic's ability to determine good route and scheduling, cargo stowage plan of a tanker efficiently, we strategically employ it in our new solution framework to iteratively generate good cargo-tanker combinations with the corresponding stowage plans, routes and schedules of tankers. With this set of

cargo-tanker combinations and their respective stowage plans, routes and schedules of tankers, our solution framework will then proceed to solve a set partitioning (SP) model which has the objective of maximizing the total profit of the fleet of tankers over the given planning horizon. Essentially, the SP model has two constraints. One ensures that each of the pending cargos ( $j \in U$ ) can only be assigned to at most one tanker while the other ensures that each tanker  $s$  is assigned to only one route and schedule.

### 5. CASE STUDY

To illustrate effectiveness of our proposed approach, we apply our new solution approach to solve a realistic TRSP of industrial scale. Basically, the problem is similar to the one described in Jetlund and Karimi (2004) where it consists of 10 tankers (5,800-11,000dwt, 10-12 cargo tanks), 42 pending cargos to be picked up by tankers, 37 onboard cargos at time zero and 42 ports. However, our TRSP is more complex primarily due to two main reasons. First, it includes cargo stowage decisions with account of cargo-cargo and cargo-tank restrictions. Second, our TRSP accounts for tank cleaning time requirements which are dependent on the order of cargo changeovers. In contrast, the TRSP in Jetlund and Karimi (2004) does not include these decisions, restrictions and requirements. As such, we randomly generate additional data to account for cargo-cargo and cargo-tank restrictions, as well as tank cleaning time requirements. Due to the sheer size of this extra data set, we are unable to present them all fully in tabular formats. The readers may obtain the full data for this problem by contacting the corresponding author.

We code our new solution methodology in Visual C++ and then use it solve the aforementioned problem. We ran our program on a Windows XP desktop PC with Pentium 4 (2.4 GHz) processor and 256MB RAM. In less than 20 minutes, the program is able to determine the cargo-tanker combinations, cargo stowage plans, routes and schedules of all tankers which offer good total profit to the tanker company over the given planning horizon. Table 3 presents the solution overview which includes the number of route/schedule/stowage (r/s/s) plans generated, profit of r/s/s plan selected by solving the aforementioned SP model, onboard cargos (at time zero) and new cargos (based on selected r/s/s plan) of every tanker in the problem. Figure 2 also shows the routes and schedules of all tankers in the problem based on the solution derived by our new solution methodology. For illustration purpose, we also present the cargo stowage plan of tanker S1 based on its selected r/s/s in Table 4. For example, cargo C6 (which is loaded and unloaded by S1 during its fourth and tenth port of visit) is stowed in tank T11 and T12 in parcels of 851.4m<sup>3</sup> and 859.1m<sup>3</sup> respectively.

From the above discussion, it is clear that our new solution methodology offers a practical and efficient approach to address TRSP in two major ways. First, the

proposed approach does not require advanced computing hardware to execute the underlying algorithmic procedure. Moreover, it requires minimal time to determine a good and feasible solution which satisfies all key operational constraints faced by tanker operators.

Table 3: Solution Overview of Case Study

Tanker ID	Number of r/s/s generated	Profit of selected r/s/s (\$)	Onboard cargos (time zero)	New cargos
S1	267	93,222.7	C43,C44,C45,C46, C47,C48,C49,C50, C51,C52	C6,C10,C30,C31,C33,C34,C35
S2	97	102,053.0	C53,C54,C55	C36
S3	122	61,985.9	C56	-
S4	169	120,203.0	C57	C1,C2,C4,C17
S5	12	44,986.8	C58,C59,C60,C61	C41
S6	83	70,770.6	C62	-
S7	107	103,308.0	C63,C64,C65,C66, C67	-
S8	61	-40,892.0	-	-
S9	71	163,033.0	C68,C69,C70,C71, C72,C73,C74	C12,C12,C13, C14
S10	115	108,997.0	C75,C76,C77,C78, C79	-
	<b>Total</b>	827,668.0		

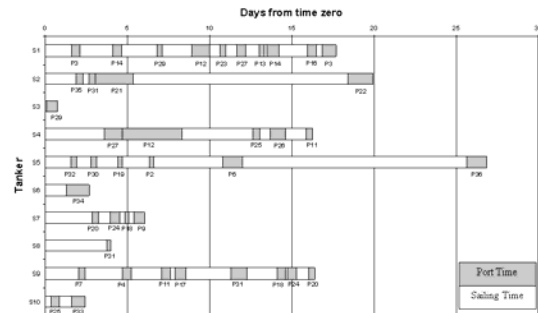


Figure 2: Routes and Schedules of Tankers

Table 4: Cargo Stowage Plan of Tanker S1 in Case Study

Tank ID	Cargo																	
	C1	C18	C38	C31	C33	C14	C35	C43	C44	C45	C46	C47	C48	C39	C31	C32		
T1	0.0	0.0	0.0	0.0	0.0	480.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	316.9	0.0	0.0
T2	0.0	0.0	0.0	0.0	0.0	0.0	119.2	0.0	0.0	0.0	0.0	0.0	251.2	0.0	0.0	0.0	0.0	0.0
T3	0.0	0.0	578.0	0.0	0.0	0.0	0.0	191.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	176.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T5	0.0	0.0	0.0	668.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	137.2
T6	0.0	527.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	122.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T7	0.0	0.0	0.0	0.0	253.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	119.0
T8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.1	0.0	0.0
T9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T11	851.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	985.5	0.0	0.0	0.0	0.0	0.0
T12	859.1	0.0	0.0	0.0	0.0	0.0	0.0	201.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PN*	4	4	4	4	6	3	3	0	0	0	0	0	0	0	0	0	0	0
DN*	10	5	9	9	7	10	10	1	1	1	1	2	6	6	6	3	3	

\* PN and DN denote the pickup and discharge port numbers of a cargo respectively. They represent the order of the port in a port visit sequence when the cargo is loaded and unloaded respectively. Cargos which are onboard at time zero will have pickup port numbers equal to zero.

### 6. CONCLUSION

This paper makes some primal and significant contributions towards research on tanker routing and

scheduling primarily via the introduction of a novel solution framework that can address TRSP of industrial scale and with account of key operational constraints faced by tanker owners. These constraints include those pertinent to cargo pickup time windows, cargo stowage conditions and tank cleaning requirements. It is also important to highlight the proposed algorithmic procedure can be conveniently modified for evaluation purposes or to accommodate to preferences of tanker owners. For example, tanker owners may want to evaluate the impact of assigning specific cargos ( $j \in \mathbf{U}$ ) to specific tankers on their bottom-lines. Or they may have preferences on the available tonnage supply at specific regions at specific time intervals of the future so that their tanker companies will be in a better position to capitalize on the potential spot chartering opportunities that have been identified. In both such incidents, the need or preference of the decision-makers can be easily accommodated with only minor modifications of few algorithmic steps in our proposed solution methodology. To the best of the authors' knowledge, a solution methodology with all the abovementioned features for routing and scheduling of tankers does not exist in the literature.

Nevertheless, improvement opportunity remains available in this field, particularly in the area of solution methodology development. Clearly, there are other extensions of the TRSP addressed in this paper which are relevant to the tanker industry and which need to be addressed. Some of these industrially relevant problem extensions include (1) addition of bunking decisions, (2) encompassing ballast water allocation decisions to manage ship stability, and (3) treatment of vessel speeds as decision variables, which are based on laden weight of a voyage to manage fuel consumption. Inevitably, these extensions complicate the problem drastically and require the development of new solution approaches which may differ from our proposed solution framework. However, these extensions do offer exciting research opportunities which can significantly enhance decision-making processes of tanker companies in their tasks of routing of scheduling of tankers.

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#### REFERENCES

Appelgren, L., 1971. Integer Programming Methods for a Vessel Scheduling Problem. *Transportation Science*, 5, 64-78.

- Bausch, D., Brown, G., Ronen, D., 1998. Scheduling short-term marine transport of bulk products. *Maritime Policy and Management*, 25(4), 335-348.
- Brown, G., Graves, G., Ronen, D., 1987. Scheduling Ocean Transportation of Crude Oil. *Management Science*, 33(3), 335-346.
- Brønmo, G., Christiansen, M., Fagerholt, K., Nygreen, B., 2007. A multi-start local search heuristic for ship scheduling- a computational study. *Computers and Operations Research*, 34, 900-917.
- Flood, M., 1954. Application of transportation theory to scheduling a military tanker fleet. *Operations Research*, 2, 150-162.
- Jetlund, A. S., Karimi, I. A., 2004. Improving the logistics of multi-compartment chemical tankers. *Computers & Chemical Engineering*, 28, 1267-1283.
- McKay, M., Hartley, H., 1974. Computerized Scheduling of Seagoing Tankers. *Naval Research Logistics Quarterly*, 21, 255-264.
- Neo, K-H, Oh, H-C, Karimi, I. A., 2006. Routing and Cargo Allocation Planning of Parcel Tanker. Presented at 16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering, July 9-13 2006. Garmisch-Partenkirchen, Germany.
- Oh, H-C, Karimi, I. A., Routing and Scheduling of Parcel Tankers: State of the Art and Opportunities. Presented at 2nd International Maritime-Port Technology and Development Conference, 26 to 28 September 2007. Singapore.
- Rao, M., Zions, S., 1968. Allocation of Transportation Units to Alternative Trips – A Column Generation Scheme with Out-of-Kilter Subproblems. *Operations Research*, 16, 52-63.
- Shaw, J., 2003. Forty-Five Years of Parcel Tanker History. *Harbour & Shipping*, November, 16-17.
- Scott, J., 1995. A transportation model, its development and application to a ship scheduling problem. *Asia-Pacific Journal of Operational Research*, 12, 111-128.
- Sherali, H., Al-Yakoob, S., Hassan, M., 1999. Fleet management models and algorithms for an oil tanker routing and scheduling problem. *IIE Transactions*, 31, 395-406.
- World Trade Organization, 2007. International Trade Statistics 2007. Available from: [http://www.wto.org/english/res\\_e/statis\\_e/its2007\\_e/its2007\\_e.pdf](http://www.wto.org/english/res_e/statis_e/its2007_e/its2007_e.pdf). [accessed 1 April 2008]

# MARITIME CHEMICAL LOGISTICS: IMPORTANCE OF OPTIMIZATION MODELING AND RESEARCH OPPORTUNITIES

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## ABSTRACT

Despite the prevalence of optimization models in academic literature that address a wide variety of maritime transportation planning problems and the significant cost saving opportunities that these models can offer, their applications in maritime chemical logistics remain few and far between. In this paper, we aim to address the overlook of optimization models by industry practitioners in two ways. First, we present several models developed by our group that can address realistic problems in maritime chemical logistics. Second, we identify and describe future research opportunities in this field. On the whole, several opportunities remain available for improving the decision-making processes in maritime chemical logistics via optimization modeling, and for addressing the practical needs of various stakeholders which include port operators, shipping and chemical companies.

Keywords: maritime chemical logistics, optimization models, research,

## 1. INTRODUCTION

Since the industrial revolution in the late 18th and early 19th century, the contribution of chemical industry to global economic growth is increasingly significant. The global chemical trade which hit more than US\$1.24 trillion in 2006 has achieved an impressive 14% average annualized growth between 2000 and 2006 (World Trade Organization, 2007). Correspondingly, the demand for maritime transport and logistics for the chemical industry has also increased over the years. Heideloff et al. (2005) stated that the capacity of ships (300 gross tons and over) that primarily support the global chemical industry and comprise oil, chemical, and liquid gas tankers, grew 3% annually between 2001 and 2005 to reach 368.4 million deadweight ton (dwt) at the beginning of 2005. In addition, the world has also been witnessing a flurry of expansion in chemical terminaling and storage facilities that include the bulk liquid terminals as reported by Markarian (2000) to accommodate the rise in the global demand of chemical

products and seaborne chemical trade. Recently, Royal Vopak (2008) have decided to continue the Phase 4 capacity expansion project of their Banyan terminal which is expected to be completed in June 2009. The terminal will then have a total capacity of 1,245,000m<sup>3</sup>. After officially opened a new tank farm of 380,000m<sup>3</sup> at the Fujairah terminal in February 2008, Royal Vopak are now evaluating the feasibility of expanding it by another 1,200,000m<sup>3</sup> with construction of new jetties that have four to six docking spaces. Evidently, the growth in the fleet of ships and the expansion of port facilities supporting the chemical industry that take place in tandem with the growth of global chemical industry highlight the importance of maritime transport in global chemical logistics.

Efficient and cost-effective management of maritime chemical logistics is clearly crucial to the financial success of global chemical supply chains, since the logistics costs can be as high as 20% or more of purchasing costs (Karimi et al., 2002). Maritime transportation planning problems in general have attracted the interest of academic researchers since the 1950s. Many of existing optimization models in the literature can address a variety of problems in maritime chemical logistics and they include ship routing and scheduling, fleet sizing and allocation, logistics network design, port or terminal operation planning, etc. Nevertheless, their applications in the industry remain limited. This phenomenon could be attributed to two key reasons. First, many of the industry practitioners are not aware of the availability of such optimization models that can support their decision-making processes. Second, there are practitioners who are aware of their availability but are somehow either intimidated by the underlying mathematical complexity of these models or doubtful of their ability to address their planning problems. Though it is true that majority of existing optimization models are mathematically complex, that should not deter industry practitioners from applying them as end-users, especially if extensive experimental studies have proven problem solving ability of these models. Moreover, given the increasingly complex and competitive business

environment in maritime chemical logistics, it is important that major stakeholders like port operators, ship owners, and chemical companies learn the science, not just the art, of running their businesses so that critical decisions can be made systematically and objectively. Clearly, one effective means of making systematic and objective decisions can be accomplished via the application of optimization models.

This paper aims to address the underutilization of optimization models in maritime chemical logistics in two ways. First, we describe planning problems in maritime chemical logistics, and introduce optimizations models developed by our group that address these problems. Second, we identify and describe future research opportunities in each of these problems which will improve the application of optimization models in the industry. On the whole, several opportunities remain available for improving the decision-making processes in maritime chemical logistics via optimization modeling, and for addressing the practical needs of various stakeholders which include port operators, shipping and chemical companies

## **2. ACADEMIC RESEARCH**

This section aims to offer readers a brief overview of major research works done by our group that use optimization-based models to address six important transportation planning problems in the realm of maritime chemical logistics. We divide our review into six parts and for each part, we (1) introduce the problem background, (2) describe our optimization-based approach to address the problem, and (3) identify opportunities for further research.

### **2.1. Product Pooling Location-Allocation**

In practice, producers of liquid chemicals do not share their storage facilities even when their products are similar in terms of quality and storage requirements. These producers usually store their products individually in dedicated storage tanks before they are discharged into chemical tankers for delivery to their respective destination ports. Similarly, these ports are also equipped with storage tanks to receive the cargos from the chemical tankers. The storage tanks at a destination port belong either to an industrial customer who needs the cargos as feedstock for its manufacturing processes or to a third party logistics (3PL) company which manages the storage activities of cargos on behalf of its industrial clients. Even when the storage tanks are owned by 3PL companies, each of them will be dedicated to only one client and not be shared among different clients.

With collaborative logistics being a buzzword in the business world today, the current storage arrangement of liquid chemicals described above has ample room for improvement. Clearly, producers of liquid chemicals with same commercial grades can harness significant cost savings if they share the storage facilities of their products before they are distributed to

their respective customers via short and frequent milk runs. This is both technically and financially feasible, especially when (1) these chemicals are manufactured using mature and stable production technologies and (2) their storage requirements are similar, and (3) customers of these producers are in the same vicinity. Such arrangement of pooling chemicals from multiple producers at shared storage facilities prior to their delivery to their respective customers is an excellent example of collaborative logistics. By collaborating with each other in the storage and transportation of chemicals, chemical companies can achieve the economies of scale in storage and distribution costs that cannot be attained individually.

To help potential pooling companies make strategic logistics design decisions for product pooling arrangement, Tong (2003) and Tong et al. (2006) developed a solution strategy which entails a multi-period mixed-integer linear programming (MILP) model and a heuristic. The model serves to determine the optimal product pooling locations, and capacities of terminals while the heuristic generates routes of milk runs that serve the suppliers and customers. The authors also applied their solution approach on a realistic problem of industrial scale which entails determination of methanol pooling location in the Asia Pacific region.

Several extensions of this problem are possible, which would address some practical features. Specifically, one needs to consider multiple products and transport via parcel tankers. This will require a faster and integrated methodology to address routing and location problems. Finally, uncertainty always exists in business data such as demand and freight rates, and models are needed for addressing these.

### **2.2. Routing and Scheduling of Chemical Tankers**

World-scale chemical processing facilities in major production centers in the US, Europe and Middle East export a wide range of chemical and petrochemical products to downstream manufacturers worldwide. Earnings of major operators engaged in shipping of bulk liquid chemicals are mainly derived from this deep-sea trade, where fleets of multi-compartment chemical tankers shuttle between major production ports and manufacturers worldwide.

Ships are capital-intensive and their operating cost can run in ten thousands of dollars a day per ship. Whether it is a chemical company that owns and manages a fleet of ships, or a shipping company that manages the fleet and is hired by a chemical company via a third 3PL provider, the ultimate cost of logistics directly affects the cost effectiveness of global chemical supply chains. Efficient routing and scheduling of multi-parcel chemical tankers is therefore a key challenge for both chemical and shipping industries. An optimal assignment of cargos and schedules to a fleet of carriers is a complex combinatorial problem. Nevertheless, many shipping companies still route and schedule their ships manually. Hence, the potential for

improving the scheduling process in maritime transportation is considerable. Computer-based decision support systems (DSS) with optimization routines can be valuable to fleet operators in achieving efficient fleet operation, which would eventually benefit the global chemical industry.

To improve the decision-making processes in management of parcel tankers, Jetlund and Karimi (2004) used the slot-based modeling approach (Karimi and McDonald, 1997) to develop a profit maximization MILP model for routing and scheduling parcel tankers engaged in the shipping of bulk liquid chemicals with cargo pickup time-windows. They proposed a heuristic decomposition algorithm that obtains the fleet schedule by repeatedly solving the base formulation for a single ship. Their solution approach is generally applicable to all kinds of carriers engaged in the transportation of multiple commodities, and to transportation systems where frequent schedule updates or a short-term planning horizon is required.

To the best of the authors' knowledge, none of the existing models that address routing and scheduling of chemical tankers account for the operational constraints pertinent ship stability and cargo stowage till the recent publication of our work. Neo et al. (2006) introduced a new routing and scheduling model that accounts explicitly the unique operational limitations of chemical tankers. Essentially their new model which is an extension of single-ship model of Jetlund and Karimi (2004) involves deciding which ports should the ship visit and in which sequence, which cargoes it should pickup and unload, and when, which tanks should each cargo be assigned and when over the entire trip so as to maximize the profit for the ship.

Though many of the existing ship routing and scheduling models have been developed for maritime chemical logistics, they possess some shortcomings that adversely affect their application in the industry. First, no existing ship routing and scheduling model comprehensively accounts for all key operating constraints. Practically all existing models account for only some of these constraints and ignore the rest. As such, this limits their application potential in maritime chemical logistics. Second, none of the existing models account for uncertainty in parameters. One reason could be that even the deterministic forms for these models are NP hard problems. However, shipping companies must routinely contend with a wide variety of uncertainties due to weather-induced voyage delays and mechanical problems of vessels, and accounting for these uncertainties is definitely crucial from an industrial standpoint. Thus, a stochastic model with a reasonably practical algorithm, which comprehensively addresses uncertainties will be of significant practical value to most shipping companies. Finally, cargo compatibility and ship stability are also important considerations in maritime chemical logistics and have not been addressed satisfactorily by the existing models.

### **2.3. Scheduling Trans-shipment Operations in Maritime Chemical Transportation**

Shipment of chemical cargos can be broadly classified into two main types, namely deep-sea and short-sea shipping. Deep-sea shipping entails transportation of cargos between continents in deep seawater, where large multi-compartment tankers move large volumes of cargos between major ports and manufacturers. In contrast, short-sea shipping focuses transportation of cargos with regional areas. It normally involves smaller multi-compartment vessels that travel relatively short distances between regional ports. When deep-sea carriers arrive at major ports, they not only unload some cargos, but they also directly (ship-to-ship) transfer some cargos to short-sea carriers for further delivery to regional ports. This reduces transport costs, because the fuel and time-charter costs of deep-sea carriers are far greater than those of short-sea carriers. Furthermore, deep-sea carriers often cannot enter shallow destination ports, because of draft limitations. Then, the only way to deliver cargos to regional destinations is by transferring them to the smaller carriers that can access regional ports. The operation of transferring cargos directly (ship-to-ship) from intercontinental deep-sea to regional short-sea carriers or, generally, from one vessel to another is called trans-shipment.

Over the years, the increase in deep-sea and short-sea shipping activities globally and the myriad of mergers, acquisitions, and collaboration are increasing the demand for trans-shipment operations. The main feature that distinguishes the trans-shipment of chemicals from that of other goods is that the transfer must be direct via a hose, making it necessary for both the donor and recipient ships to be engaged in the operation simultaneously. Unlike most other goods or containers that can simply be stored at a port for a period before another ship collects them, a donor ship cannot simply dump a non-containerized chemical cargo at a port and leave, and let the recipient ship collect it some time later. Most ports do not have facilities for such temporary storage. Such a delayed transfer would normally require a 3PL facility and would incur significant additional costs. Moreover, when multiple ships are involved in trans-shipment, multiple trans-shipment operations may overlap in time, queues of ships may develop and congestion may occur. This congestion may lead to delays and subsequent costs, if one does not synchronize and schedule the various requests optimally. Clearly, a careful scheduling is crucial and extremely important under such circumstances for the shipping companies, because ships are highly capital-intensive assets with operating costs. In addition, port costs also increase with the time that a ship spends at a port and can be substantial. Sometimes, even the demurrage of tankers may be important and this can be several thousand U.S. dollars per day. Therefore, there is a tremendous need for systematic scheduling procedures that minimize the total cost of trans-shipment operations.

No optimization model has been developed to address such trans-shipment scheduling problem till recently when Huang and Karimi (2006a) introduced a MILP scheduling model for a general trans-shipment scenario for regional distribution, where multiple large donor-carriers trans-ship bulk liquid cargos to multiple small recipient-carriers at a trans-shipment location. Their model aims to determine the sequence in, the sides (larboard or starboard) from, and the times at which, each recipient ship should receive cargos to minimize the total time-charter costs of all ships. They also presented and compared several alternative formulations of their model. To address large problems, the authors introduced a novel approach which simplifies their rigorous model heuristically using a cargo aggregation assumption. This approach reduces the formulation size tremendously and decreases model solution times by around 2 orders of magnitude, yet gives near-optimal solutions. This heuristic model promises to be very effective for solving large problems of practical interest. Compared to the manual procedures used in practice for such problems, their MILP models promise to reduce the total operation cost by up to 6.32%.

Essentially, further research opportunities in this field are similar to those described in previous section. One entails comprehensive account of realistic operating constraints so as to improve application potential of optimization models. The other one concerns the account of uncertainty induced by weather and mechanical problems of vessels, and development of efficient solution methodologies to address problems with uncertainty.

#### **2.4. Scheduling Tanker-Lightening Operations in Crude Oil Transportation**

In marine transportation of crude oil, fully loaded large crude oil tankers such as Very large crude carrier (VLCC) and Ultra Large Crude Carrier (ULCC) usually cannot pass through shallow channels or dock at shallow ports due to shallow drafts, narrow entrances, or small berths. Under such circumstances, small vessels are employed to unload a part of the crude oil from the tanker at offshore deep sea in order to reduce its draft and enable its entry into a shallow channel or port. Subsequently, both the tanker and the small vessels travel to the refinery port to deliver the crude oil. The direct ship-to-ship transfer of crude oil from large tankers to small vessels in order to lighten the tankers is called tanker lightening. The large tankers that require lightening are called ship-to-be-lightened (STBL). The small vessels that unload crude oil from an STBL and deliver to the destination ports are called service ships (SS). Apparently, tanker lightening scheduling problem is a special case of the general transshipment problem described in the previous section. However, the former has one distinguishing characteristic that differs from that of the general transshipment problem. While the latter normally involves small vessels making single voyages and then

all carriers (large and small) continuing to their next destinations, the tanker lightening operation may involve multiple voyages of the SSs within the planning horizon. Therefore, the travel times of SSs between refineries and lightening locations, the discharge operations of SSs at the refinery ports outside the lightening locations, etc. are important considerations in the problem.

Though a lightening operation incurs additional cost, it offers two advantages to a refinery. First, tanker lightening helps reduce the time-charter costs or demurrage of large tankers (STBL), which can be of the order of US\$100,000 per day, by reducing their waiting times for unloading. It also helps reduce inventory costs at the refineries by ensuring on-time delivery of crude oils. Second, tanker lightening gives flexibility to crude supplies. For instance, SSs enable faster delivery, as multiple vessels can simultaneously discharge crude to different tanks, and deliver parts of the crudes to the refineries that need them urgently, before an STBL reaches them. During congestion, tankers may easily spend days awaiting lightening service and demurrage costs may pile up rapidly. Because of such extremely high economic stakes, effective scheduling of lightening operation is crucial for minimizing logistics costs by reducing the waiting times of STBLs and increasing the utilization of SSs.

Unlike other existing models, Huang and Karimi (2006b) developed two new, continuous-time, slot-based MILP models that addressed a general and realistic form of the tanker-lightening scheduling problem with several realistic and practical features ignored by previous work. These features include possibility of multi-compartment service vessels picking up different crude parcels during one voyage and making multiple visits to different STBLs during one voyage, options of selecting crudes to lighten, accounting for the impact of crude densities, demurrage and time-charter costs, etc. Based on their numerical evaluation using literature examples in Lin et al. (2003), the authors noted that their reduced slot-based continuous-time formulation appears to be tighter, simpler, and faster than an existing event-based formulation by Lin et al. (2003) for a slightly different version of the tanker-lightening problem. To reduce solution time required to solve large problem, the authors simplified their rigorous model slightly by means of some intuitive heuristic simplifications. A study was also carried out by the authors to demonstrate the significant reduction of solution time that can be achieved by the simplified model.

Several significant issues remain unaddressed and they offer opportunities for future work on tanker-lightening scheduling problem. First, existing models addressed only a static version of the problem, where all parameters and data are fixed and known. In real life, operational disruptions do occur unexpectedly. As such, it is crucial that models can be enhanced in terms of industry realism by considering the inherent

uncertainties in estimated travel times. Second, practically all existing tanker-lightering scheduling models assumed stationary lightering, i.e. the STBLs do not move, while being lightered. Mobile tanker-lightering operation is also used in practice, where both SSs and STBLs travel at a slow speed during the lightering, which would also be a useful variation of the problem addressed by existing models.

### **2.5. Scheduling Tank Container Movements for Chemical Logistics**

When chemical companies seek to transport their liquid products in quantities much smaller than the parcel sizes of chemical tankers, they usually turn to container ships. For this, the chemical producers have to store or pack their liquid cargos into tank containers prior to their loading onto container ships. In essence, a tank container is a cylindrical tank set inside a frame of the standard dry container which comes in two standard sizes, namely 20x8.5x8 ft and 40x8.5x8 ft. A major challenge that the companies using tank containers face arises from the imbalance of product supply and demand which results in an imbalance in the container flows across different regions. There are major flows of loaded containers from the production centers toward the various demand centers globally. However, equivalent flows of products from the demand centers, which can enable the return of the emptied containers to the production centers, often do not exist. As a result, empty containers accumulate at the demand centers, which must be repositioned to the production centers. As a result, there are major flows of loaded containers from the production centers toward the various demand centers globally. This container imbalance problem is further exacerbated by the need to clean the tank containers at various globally distributed cleaning depots before reuse and with the depots often located far away from the production centers. Clearly, significant cost savings can be derived from a systematic study and optimization of multiproduct tank container movements and related activities (such as cleaning) so that there are (1) timely supplies of empty containers to production sites, (2) systematic transfer of used containers to cleaning depots after service, and (3) optimal repositioning of clean and empty containers to suitable places in anticipation of product orders.

Karimi et al. (2005) were among the first to undertake a comprehensive study of this important short-term tank container management problem. They used an innovative, event-based, “pull” approach to develop a novel linear programming formulation for the minimum-cost or maximum-profit scheduling of the transport and cleaning of multiproduct tank containers (loaded and empty) given a set of projected shipment orders in the short-term. The authors also illustrated the application potential of their models by using it to solve large and industrially relevant problems with key practical considerations such as alternate ship schedules, delivery time windows, and intermodal transport routes.

Ample research opportunities do exist in this area. One key extension is to address uncertainty in container demand orders and a solution methodology for the stochastic model. This is important, because most requests for quotes on containers must be confirmed or agreed to weeks in advance with competitive rates and changes and cancellations can occur easily.

### **2.6. Contract Selection and Tank Allocation in a Terminaling and Storage Facilities**

Due to the need to reduce their capital expenditure associated with the logistics facilities and to focus on the core competency of chemical manufacturing, chemical companies are increasingly outsourcing a variety of their logistics activities to 3PL firms in recent years. One key service provided by the 3PL firms to chemical companies is short-term to long-term storage of petrochemical and chemical products. Typically, these 3PL firms own tank storage facilities or tank storage terminals that are located at strategic ports such as Singapore, Rotterdam, etc., where clusters of chemical companies operate in the vicinity. A typical third-party storage terminal may have more than a hundred tanks with a total storage capacity of 150,000 m<sup>3</sup> storing a variety of chemicals with varying storage specifications. The tanks in a storage terminal normally have different sizes and characteristics to cater to the variety of storage requirements. Together with the variety of contract orders raised by the chemical clients, which are likely to differ based on storage requirements and time spans, it is clear that the optimal allocation of tanks to contract orders is a complex combinatorial issue.

No model has addressed this problem until recently, when Tay et al. (2005) presented three multi-period MILP models for selecting contracts and allocating tanks to contracts in a typical storage terminal with the objective of profit maximization. For managing larger facilities, the authors proposed two heuristics. They also illustrated their models and algorithms with a case study of industrial scale where the heuristics give comparable solutions that are roughly 8-9% lower than the optimum solution. On one hand, they show the advantage of rigorous optimization, while on the other, they show that even these heuristics could represent significant savings compared to the manual procedures used in the chemical logistics industry.

Like previous problem, the research in this field is still in its infancy and several opportunities exist from revenue management to facility design. One of them, as highlighted by Tay et al. (2005), entails the representation of a more realistic tank allocation problem via an account of tank maintenance requirements. Another research opportunity may also be in the form of accounting for uncertainty in business parameters such as forecasted contract orders for storage tank space. This is especially crucial when the problem involves a relatively long planning horizon and a stochastic programming approach would be more appropriate to determine the optimal tank allocation decisions.



### 3. CONCLUSION

In the modern economic era, it is crucial for all chemical companies, ship and port owners to have sound strategic, tactical, and operational business plans that give them a competitive edge to survive in such turbulent business environment. However, the formulation of good business plans can no longer rely solely on the experience of individuals, especially in the complex marketplace of shipping and chemical industry. Together with the wide variety of complex operating constraints in maritime chemical logistics, good business decisions are no longer intuitive, and ad hoc, myopic, or simplistic decision-making processes can be imprudent. In such a complex business environment, it is important that chemical companies, ship owners, and port owners learn the science, not just the art, of running their businesses so that decisions can be made systematically and objectively. One scientific way of running business can be accomplished by employment of optimization models in critical decision-making processes. With the prevalence of optimization models that can support and improve these processes, it is critical that business operators which include chemical companies, ship and port owners are truly aware of these models and understand the benefits of applying them in their organizations. To achieve that, we have described in this paper several practical problems in the maritime chemical logistics which can be addressed using optimization techniques developed by our group and have also identified several opportunities for improving the decision-making processes in maritime chemical logistics with their unique operating characteristics and constraints in mind. We have also used realistic case studies to illustrate the merits of our optimization-based solution approaches which have potential of benefiting major stakeholders of maritime chemical logistics significantly.

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### REFERENCES

- Heideloff, C., Monden, R., Stockmann, D., 2005. Tanker fleet development. *ISL Shipping Statistics and Market Review*, 25. Available at: [http://www.isl.org/products\\_services/publications/pdf/COMM\\_3-2005-short.pdf](http://www.isl.org/products_services/publications/pdf/COMM_3-2005-short.pdf). [accessed 1 April 2008]
- Huang, C., Karimi, I. A., 2006a. Scheduling Transshipment Operations in Maritime Chemical Transportation. *Industrial and Engineering Chemistry Research*, 45, 1955-1973.
- Huang, C.; Karimi, I. A., 2006b. Scheduling tanker-lightering operations in crude oil Transportation. *Industrial and Engineering Chemistry Research*, In Press.
- Jetlund, A. S., Karimi, I. A., 2004. Improving the logistics of multi-compartment chemical tankers. *Computers & Chemical Engineering*, 28, 1267-1283.
- Karimi, I. A., McDonald, C. M., 1997. Planning and Scheduling of Parallel Semicontinuous Processes. 2. Short-Term Scheduling. *Industrial and Engineering Chemistry Research*, 36(7), 2701-2714.
- Karimi, I. A., Srinivasan R., Por, L-H, 2002. Unlock supply chain improvements through effective logistics. *Chemical Engineering Progress*, 98(5), 32-38.
- Karimi, I. A., Sharafali, M., Mahalingam, H. 2005. Scheduling Tank Container Movements for Chemical Logistics. *AIChE Journal*, 51(1), 178-197.
- Lin, X., Chajakis, E. D., Floudas, C. A., 2003. Scheduling of tanker lightering via a novel continuous-time optimization framework. *Industrial and Engineering Chemistry Research*, 42, 4441-4451.
- Markarian, J., 2000. Bulk Liquid Terminals Market in Expansionary Mode. *Chemical Market Reporter*, 258(21), FR16.
- Neo, K-H, Oh, H-C, Karimi, I. A., 2006. Routing and Cargo Allocation Planning of Parcel Tanker. Presented at 16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering, July 9-13 2006. Garmisch-Partenkirchen, Germany.
- Royal Vopak, 2008. Vopak Matters. Available from: [http://www.vopak.com/media/pdf/Vopak\\_Matter\\_issue\\_1\\_February\\_2008\\_FINAL\\_LowRes.pdf](http://www.vopak.com/media/pdf/Vopak_Matter_issue_1_February_2008_FINAL_LowRes.pdf). [accessed 1 April 2008]
- Tay, H-L, Karimi, I. A., Peck, C-K, Peh, X-L, 2005. Contract Selection and Tank Allocation in a Terminaling and Storage Facility. *Industrial and Engineering Chemistry Research*, 44, 7435-7450.
- Tong, K-L (2003). *Integration of Logistics for Base Petrochemicals in Asia*. Thesis (M.Sc.). The Logistics Institute – Asia Pacific, National University of Singapore.
- Tong, K-L, Oh, H-C, Karimi I. A., 2006. Optimal Break-bulk Location and Storage Design in Maritime Chemical Distribution. Presented at INFORMS International, June 25-28 2006. Hong Kong.
- United Nations Conference on Trade and Development, 2005. Review of Maritime Transport 2005. Available from: [http://www.unctad.org/en/docs/rmt2005\\_en.pdf](http://www.unctad.org/en/docs/rmt2005_en.pdf). [accessed 1 April 2008]
- World Trade Organization, 2007. International Trade Statistics 2007. Available from: [http://www.wto.org/english/res\\_e/statis\\_e/its2007\\_e/its2007\\_e.pdf](http://www.wto.org/english/res_e/statis_e/its2007_e/its2007_e.pdf). [accessed 1 April 2008]

# FRAMEWORK FOR SIMULATING LNG PORTS

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## ABSTRACT

LNG ports are often located at very remote locations and have a dedicated function of exporting product to markets worldwide. Vessels are dedicated to routes between ports and often are part of the investment. These are just a couple of the characteristics of a LNG exporting port. Due to these specific characteristics the design and simulation of such a port is different from a normal maritime port. In this paper we identify a set of attention points that need to be considered and help to perform a simulation study for a LNG port. We have applied these attention points to a new LNG port in Yemen and describe the results and the advantages of following these additional processes in an early stage of the simulation study..

Keywords: port design, LNG vessels, discrete event simulation

## 1. INTRODUCTION

With the cost of oil increasing, it becomes more worthwhile to invest in alternative sources of energy. LNG is one of the fuels rapidly gaining interest, but LNG is only available at very remote locations. Further LNG is expensive and hazardous to transport from these remote locations to ports that can handle and have storage facilities. With the requirements for LNG products in the Western world, three types of investments can be spotted in news papers more often:

- Port Authorities preparing their port for the import of the product
- Vessels being build and put to use
- New LNG train production facilities with ports for exporting

In this paper we discuss the complexity and the special elements in design studies for the third point of the list above. Compared to a normal export terminal the following things appear to be of great importance in a design study for LNG port operation:

- The locations of LNG ports are remote, most often due to the difficult wind and wave conditions

- LNG vessels require large safety distances from other vessels
- LNG vessels can not be loaded partially, but due to the bad weather the loading process could be interrupted
- Production of the LNG is a continuous process, stopping the process due to lack of storage space is unacceptable
- Production and throughput flows must not be stopped due to financial requirements

Several researchers have described how ports and marine traffic should be simulated (Kidston and Kunz 2008, Thiers 1998, Fu and Fang 1998). Some have even developed generic toolsets for the modeling of maritime traffic in a port, for example POSEIDON (Carbone et al 1998). Over the years the generic work has specialized for container terminals (Mayer et al 2004, Nam et al 2002), but no work has been done specifically for LNG terminals to the knowledge of the authors.

We believe that the items which are crucial in LNG port design also have crucial effects to the way a simulation study for a LNG port must be executed. The specific elements should be included in the simulation model and put in the correct perspective in performing the scenarios for design evaluations. This paper describes a list of attention points with common options that are specific in a simulation model for LNG terminal design.

The second section describes in more detail the consequences and background of the LNG specific requirements. The third section describes the attention points for development of the simulation model for LNG ports. We applied these attention points successfully for LNG operations at a port in Yemen and Russia, which we describe in section 4. We end this paper with some remarks and conclusions for further improvement of the framework.

## 2. SPECIFIC IN LNG SIMULATION STUDY

Vessels that come to a LNG port to be loaded are often dedicated vessels making a round trip to a market and back to the port. These vessels will arrive according to a schedule that is reasonable well adjusted to the nominal production of the facility. However, the exact arrival

cannot be predicted and is influenced by other events the vessel has encountered, for example the waiting time in the port of unloading or weather conditions at the ocean. The majority of the vessels will arrive, but a minor set of vessels will arrive between 24 and 56 hours later than desired based on the levels in the storage.

Once the vessel is arriving, it cannot just go to the berth. Several conditions need to be met for the vessel, of which the weather conditions are probably the most fluctuating. LNG is found at remote areas such as Middle East, the Pacific or the North pole. At all these places the weather can be terrible, resulting in high waves coming from different directions. The design of the berth layout can reduce the effect of the wave conditions, but still quite some disturbance can be encountered by vessels during connection to the berth, loading or departure to open sea. Correct representation of these events either requires a historical data file of the weather, wind and waves in the region or information from meteocean models.

Additional complexity in the process of vessel handling is that once a vessel starts with a process, it cannot stop. The vessel needs to be able to travel without interruptions to the berth, the vessel cannot leave the berth half way the loading process and vessel travel cannot be interrupted during the travel to open sea.

While the vessel movements are very variable, the production of the LNG trains is not. It is a constant flow of product into LNG tanks. The only interferences are the scheduled maintenance period or breakdowns somewhere in the train. The maintenance schedule for LNG trains is a long cycle of up to 5 to 7 years.

### 3. FRAMEWORK WHAT SHOULD MODEL CONTAIN

The processes in the simulation model for LNG can be separated into two parts:

- Production of LNG
- Vessel operation

The simulation model need to contain the items that are specific for LNG port operations, further specified to the actual port or production facilities. We identify attention points that should be incorporated into the simulation model. These attention points combined result in the framework for LNG port simulation models.

The production of the LNG might seem simple, because it is a constant flow of product into tanks, but it is affected by three major items:

- Availability of storage space in a tank
- Maintenance cycle
- Breakdown occurrences

Availability of storage space in a tank means that the production will stop if no space is available. It also means that the LNG production trains have to evaluate

from a set of tanks which tank to fill. The selection mechanism will evaluate the tanks that are available for storage and based on the correct state of the tank. For example, if two tanks are available, the mechanism will select the largest tank or the tank with the most available space still to be filled. Once the LNG production has filled a tank, a new tank needs to be selected and this process needs to be triggered.

**Attention point 1: Selection mechanism for a tank to fill be evaluated every time that a tank is filled.**

The production process needs to be stopped when all tanks are full. A restart of the production facilities, even if the stoppage is only half an hour, requires a couple of hours before the restart of the production reaches full speed. The effect of a stoppage of production is thus larger than just the hours until a vessel starts to empty the tanks. For example if a vessel is only 1 hour too late, then the stoppage of production easily takes 10 hours. Unnecessary long stoppages can be avoided by reducing the rate of production at the moment that the storage capacity is nearly fully utilized. A reduction of the production rates for as little as 1 hour can avoid a complete stoppage of the LNG production facilities.

**Attention point 2: Production rate might change when tanks are about to be full.**

In simulation is a rule of thumb that the length of a simulation replication is approximately three times as long as the longest effective cycle. The longest cycle in the LNG production facilities is the scheduled maintenance cycle of 5 to 7 years. As a result, the cycle for a simulation should be around 15 to 21 years. If we also consider the need for multiple replications, then we might have a total run time of several centuries for valid results. A trade off might be to focus only on the months with the maintenance or months with specific weather to reduce the run time.

**Attention point 3: Trade off to handle maintenance of production facilities in short separate simulation experiments.**

A final point of attention in the shipping study is to consider the effect of breakdowns to the overall system. Murphy's law claims that breakdowns occur when you least want them, but in a simulation model for shipping it is much worse if the breakdowns do not occur at all. The effect of a breakdown is that the storage gets less filled than would occur given a normal production. Therefore, a breakdown of production units might cause that less storage capacity is required and that less stoppages occur due to overloading the available tanks. Thus a trade off needs to be made whether it is worthwhile to consider breakdowns of production trains in the simulation model.

**Attention point 4: Trade off to include the effect of**

#### breakdowns of the production trains.

The vessel operation is a more complex process that consists of items shown in the process flow underneath: Vessel arrival at port can be triggered by different processes. Vessels are part of a network serving mechanism and the network is designed in such a way that the vessels should arrive when sufficient product is in the storage. In normal maritime simulation projects the vessels that arrive are highly random in number, size and type. A LNG port does not have this randomness, only LNG vessels will arrive and the size of LNG vessels is almost always the same type. There are different ways to handle the lack of randomness. One option is to include the complete network of the vessel and allow vessels to move from the port where the vessel is loaded to the market port and back. This requires some more data collection, but has the advantage of also providing insight in the requirements for vessels. Vessels can also be generated new into the system at the moment that they are expected. A schedule could be defined ahead of the simulation experiment to define exactly when a vessel is expected to come based on a constant production or put some sensors in the tanks that evaluate and trigger a new vessel to arrive at the moment that sufficient product is in stock.

#### Attention point 5: Select a mechanism to handle arrival of vessels.

Once a vessel arrives near the terminal it is not allowed directly to go to berth and get loaded. Depending on the port one or more checks need to be performed before a vessel is granted permission. The most common permissions for LNG vessels are the following:

- Capacity in storage - sufficient product should be available in the storage tanks before the LNG vessel can move to the berth
- Berth - the berth is available for the LNG vessel
- Wave height - the wave height is not above a threshold for berthing operations
- Predicted wave height - the predicted wave height to be expected for the duration of the loading operation is not exceeding the threshold for vessels being located at berth
- Channel - the channel to be used to travel to the berth is available
- Tugs - tugs to support the vessel to move to the berth are available
- Pilots - pilots to support the vessel to navigate to the berth are available
- Time period - the vessel arrival applies to time periods that need to be considered

In addition to the wave height it might also be required to consider the direction of the waves. For example, waves coming from the South have hardly any effect to a vessel, due to the position of the berth and thus the

waves of the South have a higher threshold than waves coming from the East. The same applies for the future wave height resulting in thresholds during the loading process.

#### Attention point 6: Decide which conditions need to be met before a vessel is allowed to travel to the berth of the port.

The LNG vessel that is allowed to move to the berth and is ready to perform the operational steps will first require one or more resources for traveling to the berth. These resources can be the tugs and pilots, but also might be the channel and reservations in the future to have access over crossing points with other waterways. The conditions mentioned in attention point 6 are all matched, but still the physical claim to the resources in the port need to be performed.

#### Attention point 7: Claim physical resources required for traveling to the berth

The LNG vessel at the berth will be subject to one or more processes before the actual loading can start. These processes are connection to the loading arms, verifying custom papers etcetera. The actual loading process will consume LNG from one or more storage tanks. The LNG vessel will perform comparable decisions as have been made by the selection for a tank to fill from the production trains. The correct tank needs to be allocated and available to be emptied. When the selected tank is emptied into a vessel another tank is selected, until the vessel is loaded ready to leave or until some kind of disturbance occurs. In some designs of storage tanks and pipes is decided to empty several tanks simultaneously to fill a vessel. This includes additional complexity to the selection mechanism and to the decisions made to design the number of tanks and options to consume LNG from a tank to load a vessel.

#### Attention point 8: Selection mechanism for a tank to be emptied to load the LNG vessel

Loading operation of a vessel is vulnerable for disturbances that occur in reality. The most common disturbances are:

- Breakdown of one or more loading arms
- Waves above threshold that require stoppage of loading
- Insufficient product in storage tanks to continue loading

In the simulation model these disturbances should be included and also handled. For example, a breakdown can result in a slower loading rate or it can stop the loading completely. The high waves can enforce loading to be temporarily stopped, but it can also mean that a vessel needs to leave the berth completely and reconnect to the berth in a later stage.

Attention point 9: Evaluate the applicable disturbances to the loading process with their effects.

Finally, when the loading is completed, the full LNG vessel can be prepared to depart to open sea. Again a range of permissions needs to be verified for applicability to the specific LNG port. The most common permissions for LNG vessels leaving the berth are the following:

- Wave height - the wave height is not above a threshold for berthing operations
- Channel - the channel to be used to travel to the berth is available
- Tugs - tugs to support the vessel to move to the berth are available
- Pilots - pilots to support the vessel to navigate to the berth are available
- Time period - the vessel arrival applies to time periods that need to be considered

Attention point 10: Decide which conditions need to be met before a vessel is allowed to leave the berth to travel to open sea

The LNG vessel that is allowed to leave the berth will first require most likely the same resources as it required to get to the berth for attention point 7.

Attention point 11: Claim physical resources required for traveling from the berth to open sea

#### 4. EVALUATION OF APPLICABILITY FRAMEWORK

The applicability of the framework and attention points are underneath demonstrated using two different simulation studies performed by Sogreah and Systems Navigator for Total. The first simulation study is a LNG terminal for a LNG production of 32 million ton annual in Yemen, the second simulation is a LNG terminal for production growing from 39 million ton to 117 million ton annual in Russia. The two simulation studies followed the same process steps as described underneath:

- Define the requirements of the simulation model based on the attention points mentioned in section 3
- Develop the simulation model in Arena 11.0
- Interface the simulation model using Scenario Navigator
- Perform convergence tests for the base design with weather data from historical files using different number of replications
- Perform sensitivity scenarios for different constraints and designs
- Report on outcome of sensitivities with overview reports and detailed reports of individual vessel movements and events in production process

#### 4.1. LNG Terminal in Yemen

Total is developing a new terminal in Yemen in which 2 LNG production trains will feed 2 tanks. The LNG will be exported via vessels at one berth. The berth will not contain break waters, thus different thresholds apply to the berthing, loading process and forced departures. In the region especially in June, July and August high waves affect the vessel movements due to the monsoon.

##### 4.1.1. Attention points in Yemen

Attention point 1: Selection mechanism for a tank to fill be evaluated every time that a tank is filled.

Both tanks are filled simultaneously

Attention point 2: Production rate might change when tanks are about to be full.

Sensitivity studies are performed with reducing the production rate if the tank is above a certain level. In other sensitivity scenarios the production is completely reduced during the monsoon period to reduce the risk of overloading the tank storage.

Attention point 3: Trade off to handle maintenance of production facilities in short separate simulation experiments.

Long maintenance is considered in a planning for 7 years with large maintenance of 30 days and short maintenance of 7 years.

Attention point 4: Trade off to include the effect of breakdowns of the production trains.

Short breakdowns for the production trains are excluded of the simulation.

Attention point 5: Select a mechanism to handle arrival of vessels.

A vessel will be triggered to arrive if the level in the tank is more than 180.000 tons in both tanks. After this trigger there is a 5% chance that the vessel is more up to 12 hours late and a 1% chance that a vessel is 12 to 48 hours later than the moment of the trigger.

If a vessel is at the berth loading and the tank contains more than 180.000 tons, then a new vessel will only be triggered if the total quantity in the tanks is sufficient for both vessels.

Attention point 6: Decide which conditions need to be met before a vessel is allowed to travel to the berth of the port.

The conditions that need to be met are varied in the simulation experiments. The base case scenario contains the following checks:

- Berth is available
- No berthing threshold while traveling to the berth
- No forced departure threshold while loading. The full loading period will be evaluated, including extra time for repair to loading arms or delays due to loading thresholds.
- During the monsoon period vessels only move to the berth between 6 and 12 in the morning

In some scenarios the vessels were allowed to move directly to the berth without considering the possibility of a departure threshold. In these scenarios the number of forced departures was higher than in the base case.

In some other scenarios the forecasting has been adjusted with extra strong thresholds or thresholds that were different for the coming 24 hours and the period after this.

**Attention point 7: Claim physical resources required for traveling to the berth**

The terminal has only one berth and thus only one vessel at the time needs to be handled. Therefore, restrictions such as a channel or tugs have not been considered. The only restriction is the availability of the berth.

**Attention point 8: Selection mechanism for a tank to be emptied to load the LNG vessel**

The two tanks will simultaneously fill the vessel. Thanks to the simultaneous loading and the simultaneous filling will the level in tank 1 always be the same as in tank 2.

**Attention point 9: Evaluate the applicable disturbances to the loading process with their effects.**

The vessels encounter 2 disturbances during the loading process. The first disturbance is the weather. If the waves from a certain direction are above a threshold level the vessels should stop loading or even leave the berth temporarily to return to the berth once the level of waves is safe again. The second disturbance that applies to the vessel is the state of loading arms. The loading arms have irregular breakdowns in small percentage of times that the loading is performed. In some very rare situations even both loading arms are broken down, stopping the filling of the vessels completely. If only one of the loading arms has a breakdown, then the production rate drops from 10 t/hr to 5 t/hr.

**Attention point 10: Decide which conditions need to be met before a vessel is allowed to leave the berth to travel to open sea**

Vessels are allowed to move to open sea once they are 100% loaded. The vessel does not encounter any physical issues while leaving.

**Attention point 11: Claim physical resources required for traveling from the berth to open sea**

This is similar as attention point 7: the physical resources are not a restriction.

#### 4.1.2. Simulation model of Yemen

The figure underneath shows the animation of the simulation model in Yemen with the two active LNG production trains, the LNG tank storage and the level of LNG already loaded into the vessel.

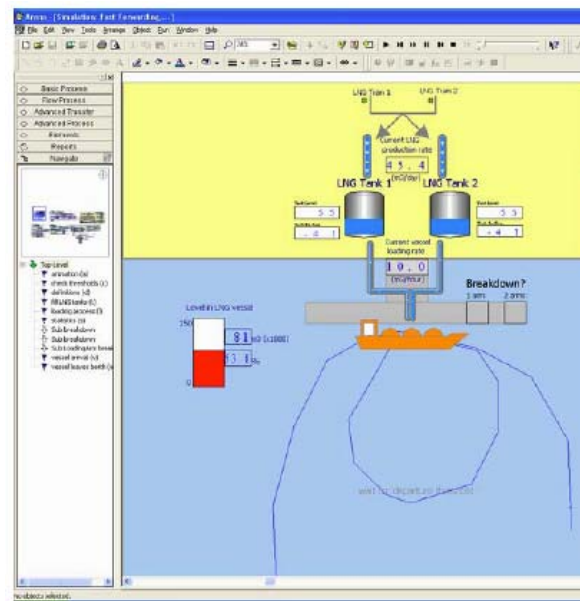


Figure 1: Simulation MODEL in YEMEN

#### 4.1.3. Project conclusions Yemen

The graph underneath shows the waiting time of vessels in different sensitivity studies and allows easy comparison of the best configuration and the effects of different scenarios and tests.

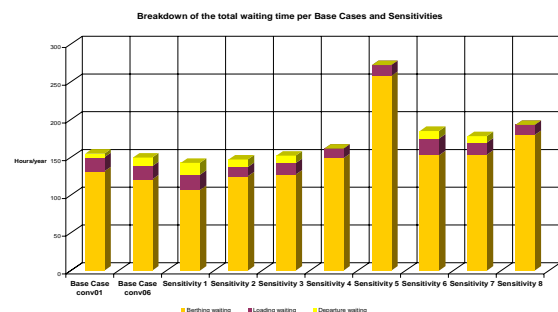


Figure 2: Waiting time of vessels

The graph is only one of the many performance indicators that have been (graphically) represented and provided to the future port operator. Every individual scenario provided almost 700 pages of structured

documentation enabling detailed analysis of each aspect of the scenario.

#### 4.2. LNG Terminal in Russia

The Russian authorities have allowed Total and GazProm to exploit the LNG field 300 kms North of Murmansk (the Shtokman fields). A first port design has resulted into 3 different layouts that should physically be possible to export the LNG production in phases. The first phase is two berths for handling export of LNG produced by 1 LNG train. The second phase will double the production capacity and at the end of the third phase 3 berths will be available with 6 tanks and 4 LNG production trains.

Depending on the layout the berth will be protected by break waters or natural reefs, thus different thresholds apply to the berthing, loading process and forced departures. Especially from October to April the weather in this region is bad due to the cold.

##### 4.2.1. Attention points in Russia

Attention point 1: Selection mechanism for a tank to fill be evaluated every time that a tank is filled.

All tanks available in a phase are filled simultaneously

Attention point 2: Production rate might change when tanks are about to be full.

Sensitivity studies are performed with reducing the production rate if the tank level is above the nominal level, but did not reach the geometrical level of the tank yet.

Attention point 3: Trade off to handle maintenance of production facilities in short separate simulation experiments.

Long maintenance is considered yearly for 32 days. This maintenance included the required time for restating the facilities after a stoppage. The LNG trains schedule their maintenance from the first of the month May, June, July or August.

Attention point 4: Trade off to include the effect of breakdowns of the production trains.

Short breakdowns for the production trains are excluded of the simulation.

Attention point 5: Select a mechanism to handle arrival of vessels.

The LNG production will be exported by two types of vessels, Membrane or Spherical vessels. The type of vessel that arrive next depends on a random chance of 90% or 50% in some sensitivities. A vessel will be triggered to arrive if the level in all the tanks is more

than the quantity required to load the vessel. This includes reservations for liquid by vessels that are already loading at one of the other available vessels. Thanks to the storage capacity and the ability to handle several vessels simultaneously it is possible in this port to have one or more vessels waiting outside in open sea for access to a berth.

After the trigger that sufficient product is in a tank for the vessel a delay applies for late arrivals of vessels. There is a 5% chance that the vessel is more up to 12 hours late and a 1% chance that a vessel is 12 to 48 hours later than the moment of the trigger.

Attention point 6: Decide which conditions need to be met before a vessel is allowed to travel to the berth of the port.

The conditions that need to be met are varied in the simulation experiments. The base case scenario contains the following checks:

- Berth is available
- No berthing threshold while traveling to the berth
- No forced departure threshold while loading. The full loading period will be evaluated, including extra time for repair to loading arms or delays due to loading thresholds.
- Tugs are available
- No other vessel is traveling through the channel

In some scenarios the vessels were allowed to move directly to the berth without considering the possibility of a departure threshold. In these scenarios the number of forced departures was higher than in the base case.

In some other scenarios the forecasting has been adjusted with extra strong thresholds or thresholds that were different for the coming 24 hours and the period after this, either the full year, or only in the winter period.

Attention point 7: Claim physical resources required for traveling to the berth

The terminal has in phase one only one berth and thus only one vessel at the time needs to be handled. In phase 2 and 3 the number of berths used by LNG vessels will be increased, thus the tugs and the channel availability becomes a limitation.

Attention point 8: Selection mechanism for a tank to be emptied to load the LNG vessel

All the tanks will simultaneously fill the vessel. Thanks to the simultaneous loading and the simultaneous filling will the level in tank 1 always be the same as the level in the other tanks.

Attention point 9: Evaluate the applicable disturbances to the loading process with their effects.

The vessels encounter only disturbances due to the weather. If the waves from a certain direction are above a threshold level the vessels should stop loading or even leave the berth temporarily to return to the berth once the level of waves is safe again.

Attention point 10: Decide which conditions need to be met before a vessel is allowed to leave the berth to travel to open sea

Vessels are allowed to move to open sea once they are 100% loaded, the tugs are available and the channel is not occupied by an other vessel.

Attention point 11: Claim physical resources required for traveling from the berth to open sea

This is similar as attention point 7: the physical resources are restricted for tugs and the channel.

#### 4.2.2. Simulation model of Yemen

The figure underneath shows the animation of the simulation model in Russia with 3 LNG trains, 4 tanks and 2 loading berths. The purple vessel is a membrane vessel ready to leave and the orange vessel is a spherical vessel arriving to be loaded at berth 2.

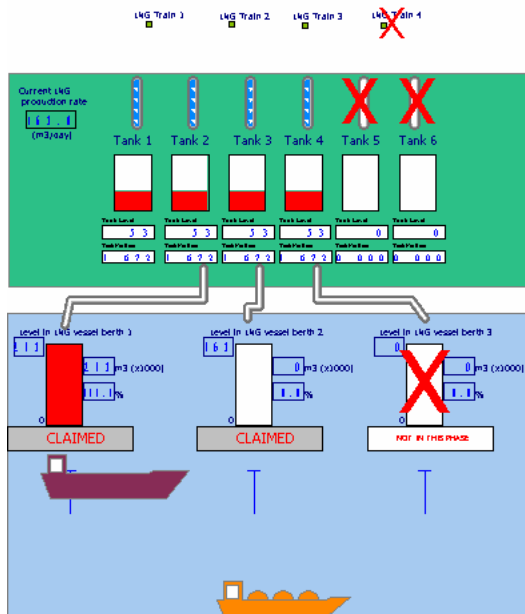


Figure 3: Simulation MODEL in RUSSIA

#### 4.2.3. Project conclusions Russia

The graph underneath shows the waiting time of vessels in different sensitivity studies and allows easy comparison of the best configuration and the effects of different scenarios and tests.

The graph is only one of the many performance indicators that have been (graphically) represented and provided to the future port operator. Every individual scenario provided almost 700 pages of structured documentation enabling detailed analysis of each aspect of the scenario.

## 5. CONCLUSIONS AND FURTHER RESEARCH

The main use of the framework has been in discussing with the customers the need for modeling their LNG operation and explain them why certain information is needed. We found out that the list of possible conditions to verify permissions require extension. It turned out, mainly in the simulation study of the LNG operations in Yemen, that the time periods that apply are different over the periods of time in the year.

Further we noticed during the model development and the first analysis, that it would have been very useful to also specify a framework for reporting and types of reports to be gained from the simulation model. Early discussion about the content of the reports would have enhanced the understanding and reduced the rework that has been done in final stages.

The framework has helped in the specification for the simulation model, we foresee further research whether we could make dedicated simulation building blocks for the maritime shipping studies like these LNG ports to enable more rapidly implementation of the simulation model.

## REFERENCES

- Carbone, CA, Bruzzone, BA, Giribone, GP, 1998, Harbour Services and Lay-Out Re-Engineering by Using Simulation, *Proc. of 1st Workshop on Modelling & Simulation within a Maritime Environment*, Riga.
- Kidston, KD, Kunz, KT, 2008, Using Simulation to Evaluate Traffic Engineering Management Services in Maritime Networks, *Proceedings of Military Modelling and Simulation Symposium*.
- Mayer, MA, Bockstael-Blok, BW, Valentin, VE, 2004, Containers a Drift: Visualization-simulation of an inland container terminal design, *Simulation and Gaming, Volume 35, Issue 1, pp. 29-52*
- Nam, NK, Kwak, KK, Yu, YM, 2002 Simulation Study of Container Terminal Performance, *Journal of Waterway, Port, Coastal, and Ocean Engineering, Volume 128, Issue 3, page 126-132*
- Thiers, TA, 1998, A Port Simulation Model as a Permanent Decision Instrument In: *Simulation, Volume 71, Issue 2, page 117-125*
- Wu F, WF, Fang, FX, 1998, Maritime Traffic Simulation Based on Origin-Destination Model, *Journal of Dalian Maritime University, Volume 24 Issue 4, page 10-14*

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# CAPACITY PLANNING ANALYSIS FOR SERVICE STEEL PRODUCTS HARBOR

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## ABSTRACT

The problem of calculating future capacity of a projected port involves several uncertainties, which means that it is not possible to find a single formula that considers the interaction of the different variables affecting the port's operational performance, particularly considering that many of these variables are related to stochastic distributions and restrictions in shared resources. Only a simulation model can consider all the variables and produce a reliable projection of the port's future behavior. It is very important to precisely estimate the figures because the demurrage costs grows exponentially as the port's occupancy moves toward 100%, which directly affects the project's feasibility.

Keywords: harbour, simulation, steel, investments

## 1. INTRODUCTION

### 1.1. Objectives

The objective of this project is to be able to compare different investment options for the projected port –yet to be built– at ArcelorMittal Tubarao, a port that will receive coal and dispatch steel products. The project is focused in evaluating the capacity of different possible combinations of equipment and facilities in order to reach the desired operating capacity with the minimum investment, considering different market scenarios.

As Silva (1999) stated, the port must be able to seamlessly organize and maintain continuous flows, becoming more efficient while processing bigger flows of merchandize in less time, lowering the costs where possible. In order to move the high volume loads required, modern ports have implemented computers and automatic systems to select the best transporting strategies –beyond overhead crane managing–, which, followed by only one person, can attain the results of hundreds of cargo loaders, diminishing drastically the cost of services, and quickening the operations.

Besides this analysis, it should be taken into account that the Brazilian ports suffer the indifference of the responsible parts towards the expansion of the exporting market, the modernization of ports, the (unnecessary

high) costs of cabotage or their lack of interest in the naval industry, as mentioned by Oliveira (2000)

Another important limitation are the inefficiencies and high operational costs created by applying traditional but outdated costing and evaluation techniques, which embroil the predictions about the system. Thus very important decisions are the result of outdated estimative policies which results in improper cost estimation, which severely modify the project apparent feasibility.

This work attempts to develop a method to optimize the investment decisions, taking into account the scenario limitations, aiming for the critical processes involved. Making use of model simulation techniques is possible to validate different scenarios and alternatives in order to be able to detect the highest operational effectiveness while reducing the needed investment and minimizing the operational costs. This method solves the problem of locating the berths, cranes, overhead cranes, conveyor belts and other high cost critical equipment.

### 1.2. Problem Definition

According to Guan and Cheung (2004) the problem of allocating berths for the ships to arrive will be considered as a resource allocating problem.

As Moon (2000) defined, the problem consists in determine the location and berthing time of each arriving ship. Therefore the planning consists in assigning each free berth to one arriving ship before its effective arrival to the berth itself.

According to Brown, Cormican e Lawphongpanich (1997), requests of berth changing, delays and advanced arrivals routinely happen and should be taken into account, since they will cause frequent revisions of the approved plan.

Due to this high frequency of occurrence, a careful berthing allocation plan is necessary in order to avoid incurring in penalties miscalculations and delays (BROWN et al., 1994).

A typical port, constituted by berths, must be able to host multiple ships at the same moment (GUAN; CHEUNG, 2004). When there are no berths available,

the ship must wait its turn behind the docking bar. The port entering can only be made through the only channel access which can only be used by a ship at a time (either to arrive or depart). The priority is given to loaded arriving ships.

Guan e Cheung (2004) name the sum of waiting time and processing time (servicing time) of a ship as its “flowing time”

According to Moon (2000), each ship needs a specific area and time at the berth in order to unload and load the corresponding cargo. During this process, different variables must be taken into account, such as the ship type and its particular waiting time, the amount of the products to be loaded or unloaded, and the delay that any product may have.

Since the moment of arrival of any ship can be perfectly considered a random variable, it is not necessary to predict the precise arrival of each ship. IN the practice it is impossible to planify the precise time for each ship arrival.

At the beginning of each month , the system generates a number of ships corresponding to month’s shipping program; then a UNIFORM(0, 30) days delay is assigned to each ship.. Dividing the month in regular periods will not produce a realistic pattern; the selected approach generates a Poisson distribution for time between ships arrivals, which is reasonable considering the multiple factors affecting ships traveling time.

The second most important random factor of the port model is the servicing time, the time that the ship has to stay berthed. It is very important due to the long time it involves and the high variance it possesses. Factors such as equipment malfunction or availability, production delays, weather, truck availability, entrance channel availability and other random factors create a complex problem that can be easily implemented into the simulation model but that is impossible to predict from a plain pre-made formula.

Therefore this factor will also affect with its own randomness the waiting time of the arriving ships, creating a highly random port behavior. It is notable that due to these very same factors the randomness of the system increases dramatically when the port occupation approaches to the 100%

### 1.3. Modeling

This model was developed using the software ARENA 11.0. It includes operations of coal reception and handling –by conveyors– and steel products retrieval, loading and dispatching.

The model considers the possibility of operating with different configurations of unloading equipment, cranes, berths, and conveyors, as well as the ability to vary the capacities of each and every resource in order to be able to contrast diverse available situations.

Different types of ships where defined varying the capacities, load compositions and resources needed to unload. Different demand scenarios can be modeled modifying the arrival frequencies of the types of ships and the desired dispatching schedule.

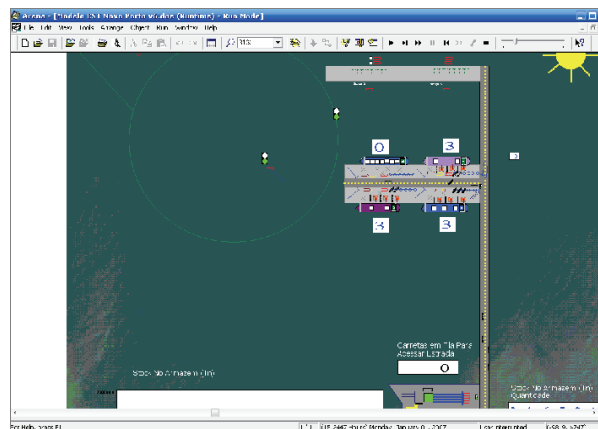


Figure 1: Screenshot of the model while running

### 1.4. Systems description

This system is composed by two sub-systems almost independent: The Coal System, and The Products System.

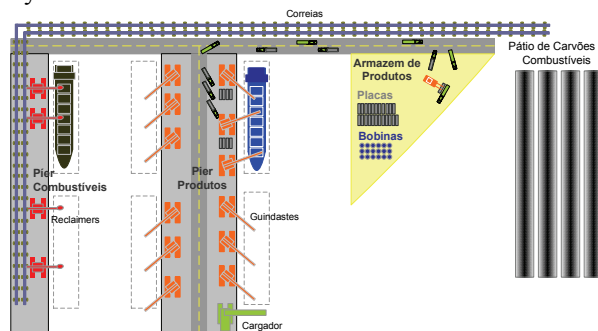


Figure 2: Harbor Layout

#### 1.4.1. The Coal System

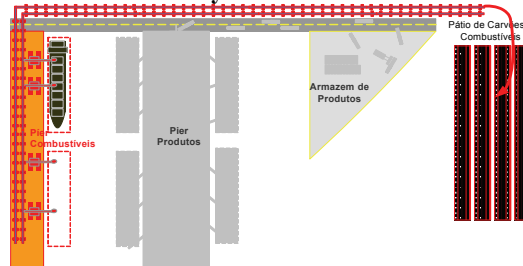


Figure 3: Coal System Layout

The project defines a harbors dedicated to receiving coal. These harbors can only be configured with one or two berths.

Unloading equipment will extract the coal from the ship and discharge it on a system of conveyors that will move away it into the storing area. Special restrictions exist in order to avoid mixing different kinds of coal, since they will be sharing conveyors.

Up to three unloading equipments may attend a single ship, but if needed, unloading equipment may simultaneously attend two ships at the time.

### 1.4.2. The Products System

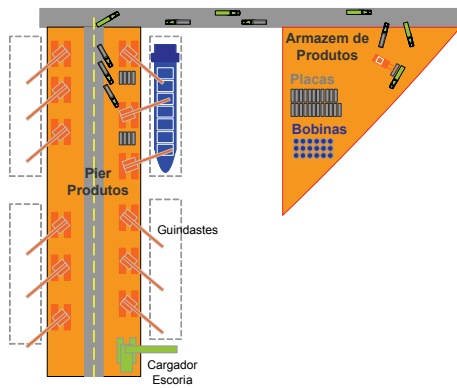


Figure 4: Layout of Products System

This system is composed by two connected harbors and a two-way route to the land. The number of berths may be easily set to one, two, three or four, while any number of cranes may be assigned.

Several kinds of products will be loaded by cranes: slabs, coils, and other steel products. Cranes can move slabs in groups of two or three, but have to move individually each coil.

Products will be transported by trucks from the storage area to the corresponding berth so the crane loads the ship with its cargo.

Cranes also have to carefully situate each product in the ship, demanding time. Each truck will have to wait until a proper crane is available, generating a queue for each berth.

Up to three cranes may simultaneously attend a single ship, if available. Cranes may be shared by different ships, since each crane can move to another ship as soon as it finishes its last task (which may or may not finish the ship's task queue).

It is critical to verify the interferences among the different trucks moving both ways, avoiding collisions and checking if the road's capacity is enough.

## 2. CASE STUDY

Since CST shares its port with other companies, as the port occupancy grows, the operational costs will increase exponentially, turning port operations extremely expensive. As CST is involved in an ambitious expansion plan, this will require the construction of a completely new port, which will operate at the required volume while maintaining competitive costs.

### 2.1. Scenario Definitions

Possible future scenarios were defined varying the frequency of each type of ship and balancing the steel products outcome with the coal that the new scenario involves.

			Jan	Feb	Mar
Product Ships					
Ship Type	Product Type	Shipment (Tn)			
P1	Slabs	55000	1	1	
P2	Slabs	40000	3	3	
P3	Coil	20000	5	5	
P4	Coil	10000	19	20	
P5	Various	18000	2	2	
P6	Slag	50000	1	1	
Coal Ships					
Ship Type	Variety of Coals	Shipment (Tn)			
C1	1	30000	1	0	
C2	1	55000	1	1	
C3	1	75000	1	2	
C4	2	75000	2	2	
C5	3	75000	1	1	
C6	4	75000	0	0	

Figure 5: Definition of Demand Scenario

Demand was defined on a monthly basis, considering variations of production level during the year. The arrival frequency of each type of ship was created generating a number of ships corresponding to each month, and assigning to each ship a random delay time of UNIFORM (0,30) days; resulting in a Poisson pattern of arrivals.

### 2.2. Investment Alternatives Definitions

Several variables, involving mayor investments, were used to define alternatives, each one requires a different level of investment, as well as different combinations of assets may be performed using the same budget.

#### Coal system

- Number of berths
- Number of Stacker Equipment
- Type and capacity of Stacker Equipment
- Conveyors capacity

#### Products System

- Number of berths
- Number of cranes
- Capacity of cranes
- Space available for trucks waiting at harbor
- Time to relocate crane in other berth
- Time to load truck at warehouse
- Number of trucks available

It was difficult to calculate the best combination of assets to reach the required capacity, due to multiple and dynamic bottlenecks in the system.

Different combination of assets will result in bottlenecks at different points in different moments. Only the simulation can find the expected performance under each combination of assets and considering different scenarios

Each alternative involves a different combination of assets, that is, more of one type of asset and less of the other type. For Instance: We can build a bigger channel allowing two ships circulating at the same time, and build less berths. Total ship time in harbor (time in berth + time waiting)

	Scen. 1	Scen. 2	Scen. N
Capacity of Access Channel	1	2	2
Number of Berths	6	4	2
Number of Cranes	4	6	3
Capacity of Cranes (ton/h)	1200	1000	1500
Crane Equipments Reliability	95%	95%	97%
Number of Stacker Equipment	1	2	3
Capacity of Unload Eq. (n/h)	1000	1500	2500
Number of Conveyors	1	2	2
Capacity of Conveyors (ton/h)	1800	900	2000

Several combinations may sum the same level of investment, but may differ in their expected performance.

By linear calculations of capacity balance it is impossible to reach results in terms of Demurrage costs, etc.

Testing about 20 scenarios, it was possible to find many scenarios acceptable in terms of: Reaching Operational Capacity, reduced costs of Demurrage, acceptable Supply Reliability and acceptable Service level to Client's Ships.

More important, we could test the design under different demand scenarios and select those (about 4) showing a robust behavior under a wide range of situations, and select those that allow us to minimize the investment.

### 3. CONCLUSIONS

Investments alternatives may vary by at ranges of US\$ millions, according to the decision of acquiring more equipments or cranes, or the amount of berths to be built, etc.

The model may be possible to reach the same capacity, involving substantially different amount of investments; that means it was possible to optimize the required investment.

Additionally, alternatives apparently good in certain scenarios may be inadequate to other common scenarios.

The model allowed CST to find the investments alternatives that reach the expected capacity, while maintaining demurrage costs limited in all scenarios, and minimizing the required investment as well.

#### 3.1. Profit Analysis

The usage of the model may save CST unnecessary equipment investments and prevent choosing an

alternative which may generate excessive demurrage costs in certain scenarios.

### 4. LITERATURE REVIEW

As previously said, most of the studies focus on strategic and tactical problems related to container operations, while avoiding researches about specific problems of berth allocation.

Kim e Moon (2003) use integer linear programming (ILP) in order to solve the problem using LINDO®. The computational time it took to solve each situation increased noticeably while considering more than 7 berths and the planning horizon was beyond 72 hours. Thus the conclusion that it was impossible to solve the problem through integer lineal programming was reached, and a Simulated Annealing algorithm was suggested to solve berth assignments optimization problems.

Lim (1998) modeled the problem as a restricted version of a bi-dimensional storing problem, shown succinctly trough a graph. In his solution proposal, he considered a fix berthing time, managing the ship berthing locations. At the Park and Kim (2003) research, a crane and berth managing program is proposed.

Imai, Nishimura e Papadimitriou (2001) considered the problem of berth allocation for commercial ports. In first place, it considers the problem as a static berth allocation problem (SBAP), which can be formulated as a integer three-dimensional attribution, assuming that every ship is already waiting at the port while the berthing plan is defined. Afterwards, attempts to consider the problem as a dynamic berth allocation problem (DBAP), which assumes that it is known when each ship arrives, and they only approach the port when the corresponding berth is available.

Imai, Nagaiwa and Tat (1994) suggested an algorithm that minimizes the sum of the waiting times of the ships at the port, also minimizing the insatisfaction in terms of berthing order. The berth allocation problem initially defined as a nonlinear multicriterial integer problem is redefined as a simple attributions problem. One of the latest works of Imai, Nishimura e Papadimitriou (2005) uses some assumptions taken from Imai, Nishimura e Papadimitriou (2001), considering that the manipulation time of the ship depends on where it is berthed.

### ACKNOWLEDGMENTS

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### REFERENCES

- SILVA, G.. COCCO, G. 1999 Cidade e portos: *os espaços da globalização*. DP&A: Rio de Janeiro,  
 OLIVEIRA, C. T. 2.000 Modernização dos portos. 3. ed. Aduaneira: São Paulo,.

- GUAN, Y.; CHEUNG, R. K. 2004. *The berth allocation problem: models and solution methods*. OR Sprectrum, v.26: p. 75 - 92 ,
- MOON, K.C. A 2000. *Mathematical model and a heuristic algorithm for berth planning*. PhD thesis, Pusan National University ,
- NISHIMURA, IMAI e PAPADIMITRIOU 2001 *The dynamic berth allocation problem for a container port*. *Transportation Research-B* 35 (4), p. 401-417,.
- NISHIMURA, IMAI e PAPADIMITRIOU. 2001. Berth allocation planning in the public berth system by genetic algorithms
- KIM, K. H., K. C. Moon. 2003. Berth scheduling by simulated annealing. *Transportation Res*
- LIM, A. 1998. The berth planning problem. *Oper. Res. Lett.*
- ANDRADE, E. L. 1.985 *Introdução à Pesquisa Operacional*. 2. ed. LTC: Rio de Janeiro, 2.000.
- BRONSON, R.. *Pesquisa Operacional*. McGraw-Hill do Brasil: São Paulo,.
- OLIVEIRA, C. T. 2.000. *Modernização dos portos*. 3. ed. Aduaneira: São Paulo

# LOGISTICS AND TRANSPORTATION WITHIN THE RETAIL SECTOR: SENSITIVITY ANALYSIS ON THE DISTRIBUTION SYSTEMS

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## ABSTRACT

In the following paper the effect of some critical parameters on the efficiency of a logistics & transportation system operating within the supply chain supporting the large scale retail sector is presented. In particular a three stages supply chain made up by 5 suppliers, 3 distribution centres and 120 stores, is considered. A Modelling & Simulation based approach is used for investigating the relationship between the mean service level provided to customers and the organization of the unloading and loading operations at the distribution centres. To this end two critical parameters (the trucks arrival time and the trucks waiting time at the distribution centres) are considered.

Keywords: Logistics & Transportation, Distribution systems, Modelling, Simulation,

## 1. INTRODUCTION

Efficient logistics and transportation processes should have as priority objective the complete fulfilment of customers' need, guarantying the right products at the right time, complying with delivery schedules, respecting required conditions and minimizing logistics and transportation costs.

An efficient logistics & transportation system within the retail sector is characterized by a number of critical points: huge number of supply chain actors located in different regions (suppliers, distribution centres and stores), thousands of items type, different alternatives for transportations; furthermore in the case of the fresh food (i.e. fish or meat) additional critical aspects regards stocking rules, items deterioration and food quality preservation.

Note that the interactions among the logistic flows that take place inside the distribution centres can strongly affect the service level provided to final stores. In effect within each distribution centre suppliers' deliveries need to be divided, mixed (for creating the assortment required by each store), loaded on trucks and finally shipped to each store. The capability to optimize the trucks loading scheduling plays an important role and impacts the system efficiency. Each truck loading

operation should be scheduled trying to fill the stores orders in terms of ordered quantity.

There are many examples in which inadequate supplies and communications caused the decrease of business market shares associated to revenues reduction and lower quality of services to customers. Among the various tools at present available for planning, analysing and managing logistics and distribution systems, simulation plays a critical role. Logistics simulation models are used for planning and analysing the supplies and communications chains and to test different possible scenarios such as changes in transportation modes (by rail, ship etc. or multi-pick and multi-drop strategies), supply management policies as well as products demand fluctuations.

The present work focuses on the distribution system within a supply chain devoted to support the large scale retail sector. In particular the main goal of the research work is to investigate the effects of trucks arrival time and trucks waiting time at the distribution centres on the mean service level provided to final stores.

Before getting into the details of the paper let us give a brief summary of the paper. Section 2 describes processes and activities that take place within the supply chain. Section 3 presents the experiments carried out by using the simulation model and section 4 the results analysis. Finally the conclusions that summarize the main results achieved by the research work and the research activities still on going.

## 2. THE SUPPLY CHAIN AND THE DISTRIBUTION PROCESS

The figure 1 shows the flows of products and information within the supply chain. We focalize on logistics and transportation of fresh products (the supply chain considered operates in the south part of Italy, Calabria). Final stores emit purchase orders in the morning before 9.00 am. The deliveries related to such orders reach the stores the morning after. Purchase orders are sent to the distribution centres that according to items availability, sent new orders to suppliers (suppliers selection is made according to pre-defined percentages or according to suppliers prices).

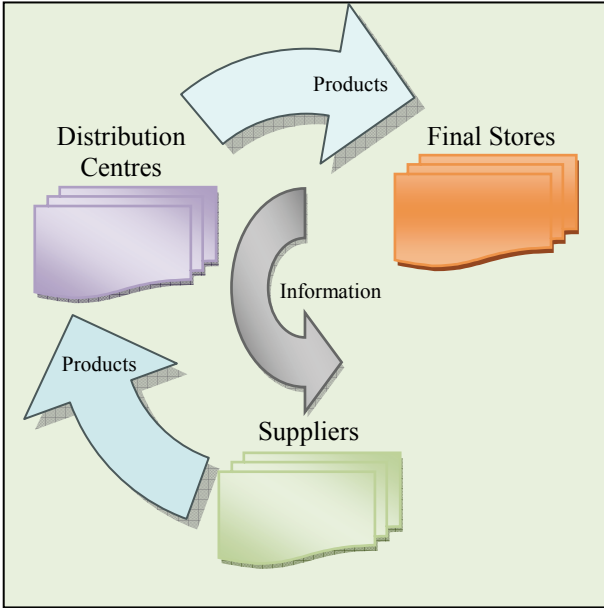


Figure 1 – Supply Chain actors, flow of products and flow of information

As before mentioned the purchase orders regard fresh products, so each supplier informs the distribution centres about its products delivery schedule, based on the number of orders received. Such information is sent before the 12.00. According to the suppliers' products delivery schedule, the distribution centres organize and schedule the delivery missions to stores.

Note that a truck should leave the distribution centre for delivering mission only when all the items required by the stores are available. Let us use the following notation:

- $I_{ij}$  : quantity of the item  $i$ -th required by customer  $j$ -th
- $I_{ia}$  : quantity of the item  $i$ -th delivered by the supplier  $a$
- $I_{ib}$  : quantity of the item  $i$ -th delivered by the supplier  $b$
- $Q_{ic}$  : quantity of the item  $i$ -th delivered by the supplier  $c$
- $t_a$  : Supplier  $a$  delivery schedule
- $t_b$  : Supplier  $b$  delivery schedule
- $t_c$  : Supplier  $c$  delivery schedule

Consider the logic used by the distribution centres for missions planning. Let us consider the case of a single item (the item  $i$ -th). The total quantity of the item  $i$ -th increases as the time goes by (in correspondence of each supplier's delivery). The quantity  $I_{ij}$  of the item  $i$ -th required by store  $j$ -th is available at the distribution centre by the time  $t_c$ .

By generalising to  $n$  items, trucks arrivals at the distribution centre should be scheduled by the time  $t_k$  in order to provide the store with the required quantity of items (or to minimize the lost quantity). Note that the grater is the time  $t_k$  for truck arrival at the distribution centre, the higher could be the probability to completely

fill the store order. To this end the trucks arrival at the distribution centre is usually scheduled by adding to the time  $t_k$  an additional time called  $t_{ad}$ .

The historical data analysis shows that the fill rate provided by suppliers to distribution centres is lower than one; in other words, it can happen that the quantity produced and shipped by suppliers is lower than the quantity ordered by the distribution centres. For each suppliers and distribution centre, we were able to identify the probability to have quantity produced and shipped equals to quantity ordered and the probability that the quantity produced and ordered takes a value between zero and the quantity ordered (i.e. this happens in the case of transportation or production problems).

Due to the problems above mentioned, the distribution centres can receive items quantity lower than the required quantity and they have to perform items distribution to stores according to stores importance (usually defined by a priority number) and to trucks waiting time at the distribution centres.

Trucks organisation in the distribution centre is scheduled as follows: the truck reaches the distribution centre at a given time as estimated in the evaluation phase. If the quantity of items ordered by the overriding store is already available, the truck is loaded and it leaves the distribution centre to supply the products.

In case the amount of products in the warehouse is not enough to fill the order of the overriding store, the operators check whether further deliveries from suppliers are scheduled. In case other deliveries are expected, the truck is put on hold for a certain time interval; otherwise, available products are loaded and the truck leaves the distribution centre to deliver such products to the store. In case no products are available, the truck leaves the distribution centre if and only if returns must be collected at the store.

Note that the time interval during which trucks wait at the distribution centres for suppliers' deliveries (let us indicate this time with  $t_w$ ) has an impact on the fill rate provided to customers. Moreover, in case after the  $t_w$  time interval, no additional supplies are delivered, the truck is loaded with available items and leaves the distribution centre to deliver them and/or to collect returns. In addition another parameter affecting the fill rate provided to stores is the time  $t_{ad}$  added to the estimated trucks arrival time at the distribution centre.

The objective of the analysis being proposed in the paper is to understand the effect of the  $t_w$  and  $t_{ad}$  on the fill rate provided to stores. Let  $I_{r,i,j}$  be the quantity of the item  $i$ -th received by the store  $j$ -th, let  $I_{i,j}$  be the total quantity if the item  $i$ -th required by the store  $j$ -th, the fill rate  $F_r$  is defined as follows.

$$F_r = \frac{\sum_{i=1}^n I_{r,i,j}}{\sum_{i=1}^n I_{i,j}} \quad (1)$$

Different measures of the fill rate can be evaluated by using equation 1 in correspondence of different



instant of time: i.e. the fill rate can be evaluated early in the morning (before trucks departure from the distribution centres) and at 10:00 am for those trucks/stores waiting for additional deliveries from suppliers.

In order to carry out the analysis before mentioned, we implemented a discrete event simulation model of the supply chain. The main modelling steps are include the supplier, distribution centre and store classes implementation, the integration of the supply chain actors within a cooperating network (flow of items and information). Within each class specific activities were implemented: orders out, pallets unloading, control of incoming items, returns loading trucks (stores); customers' order acceptance, suppliers' selection, suppliers trucks unloading, items mixing, pallets and trucks loading for stores deliveries (stores); orders acceptance, production, items loading on pallets and on trucks (suppliers).

From a Modelling & Simulation point of view the system under consideration is a terminating system since simulation duration is a natural consequence of the model and of its assumptions. In this type of system the results accuracy only depends on the number of replications evaluated so as to ensure a confidence interval of 95% concerning the fill rate. By replicating 5 times each simulation runs we found out that the simulated fill rate confidence interval is similar to the real system fill rate confidence interval.

The simulation model was implemented to carry out the analysis of sensitivity on the trucks waiting time at the distribution centre,  $t_w$  and on the additional time,  $t_{ad}$ , in order to evaluate their impact on the fill rate provided to stores.

Let  $h$  be the number of final stores, the mean fill rate in output from the generic simulation run  $k$  is defined as follows:

$$\overline{F}_{r,k} = \frac{\sum_{k=1}^5 F_{r,h,k}}{5} \quad (2)$$

### 3. EXPERIMENTAL DESIGN AND SENSITIVITY ANALYSIS

The validity of the simulation results obviously depends on how experiments are carried out. Due to this reason, in the present work simulation runs were carried out by using the Design of Experiment (DOE).

The sensitivity analysis concerning the effect of  $t_w$  and  $t_{add}$  (factors) on the fill rate  $F_r$  provided to stores (performance measure) has been carried out by using the factorial experimental design. In a factorial experimental design, simulation runs are made for all possible level combinations of the factors taken into account. Simulation results obtained according to the factorial experimental design have been then analyzed by using the Analysis of Variance. For each factor five different levels have been considered, as reported in table 1. TAC and FS are fixed factors, in fact the aim of the analysis is not to draw conclusions on the entire

population of factors levels, but to focus only on the values selected for experiments shown in Table 1.

**Table 1** – Five different levels for each factor

	$t_w$	$t_{ad}$
<b>Level 1</b>	0	0
<b>Level 2</b>	30 min	30 min
<b>Level 3</b>	60 min	60 min
<b>Level 4</b>	90 min	90 min
<b>Level 5</b>	120 min	120 min

Table 2 shows experiments results in correspondence of each different combination of the factor level, in terms of mean fill rate provided to final stores. Note that for each scenario 5 different replications are reported.

#### 3.1 Sensitivity analysis

The aim of the sensitivity analysis is twofold: (i) identify the effect of  $t_w$  and  $t_{add}$  on the mean fill rate provided to stores; to this end we aim at evaluating an analytical model (usually called meta-models of the simulation models) capable of expressing the performance measure (the mean fill rate) as function of the critical parameters being considered (also conducting a sensitivity analysis devoted to eliminate insignificant effects); (ii) identify the optimal trucks organization at the distribution centre both in terms of trucks waiting time and trucks arrival time at the distribution centres. The input output analytical model should be as follows.

$$\overline{F}_{r,ijk} = \mu + t_{wi} + t_{adj} + (t_w * t_{ad})_{ij} + \varepsilon_{ijk} \quad (3)$$

$i = 1, \dots, 5$ ; number of levels of factor  $t_w$ ;  
 $j = 1, \dots, 5$ ; number of levels of factor  $t_{ad}$ ;  
 $k = 1, \dots, 5$ ; number of replications.

In equation (3),  $\mu$  is the global average of the simulation results,  $t_{wi}$  is the main effect on  $F_{rijk}$  of the  $i$ -th level of  $t_w$ ,  $t_{adj}$  is the main effect on  $F_{rijk}$  of the  $j$ -th level of  $t_{ad}$ ,  $(t_w * t_{ad})_{ij}$  is the effect on  $F_{rijk}$  of the interaction between the  $i$ -th level of  $t_w$  and the  $j$ -th level of the  $t_{ad}$ , while  $\varepsilon_{ijk}$  is a component of casual error normally distributed with zero mean and variance  $\sigma^2$ .

The sensitivity analysis allows to understand the importance of the main effects  $t_w$  and  $t_{ad}$  as well as the importance of the interaction effects  $t_w * t_{ad}$ . To this end an effect can be neglected when by changing the level of the factor there is no effect on the mean fill rate. On the contrary, the effect has to be considered when the levels of the factor have an impact on the average value of the fill rate. It is common knowledge that a sensitivity analysis can be carried out by using the Analysis of Variance (ANOVA). In effect the ANOVA factorises the total variability of detected data in different components and compares the different components by using a Fisher statistics.

Table 2 – Simulation results

$t_w$	$t_{ad}$	$F_{rijk}$				
0	0	0.87	0.90	0.87	0.88	0.85
0	30	0.83	0.84	0.91	0.85	0.89
0	60	0.88	0.89	0.84	0.89	0.80
0	90	0.83	0.87	0.83	0.87	0.89
0	120	0.85	0.88	0.80	0.86	0.88
30	0	0.87	0.90	0.85	0.88	0.85
30	30	0.84	0.85	0.90	0.85	0.89
30	60	0.90	0.85	0.80	0.87	0.77
30	90	0.84	0.88	0.82	0.89	0.90
30	120	0.84	0.90	0.79	0.86	0.90
60	0	0.85	0.84	0.84	0.84	0.83
60	30	0.80	0.83	0.89	0.80	0.87
60	60	0.89	0.85	0.79	0.85	0.76
60	90	0.80	0.82	0.81	0.87	0.87
60	120	0.83	0.88	0.78	0.84	0.88
90	0	0.85	0.84	0.84	0.84	0.83
90	30	0.80	0.81	0.89	0.80	0.87
90	60	0.89	0.85	0.79	0.85	0.76
90	90	0.80	0.82	0.81	0.87	0.87
90	120	0.83	0.88	0.78	0.84	0.88
120	0	0.85	0.84	0.84	0.84	0.83
120	30	0.80	0.81	0.89	0.80	0.87
120	60	0.89	0.85	0.79	0.85	0.76
120	90	0.80	0.82	0.81	0.87	0.87
120	120	0.83	0.88	0.78	0.84	0.88

Let  $MS$  and  $DOF$  and  $\alpha$  respectively be the mean squares of the factors being considered, the degree of freedom and the confidence level and let  $f$  be the Fisher Statistics; the comparison between the different components of the total variability is expressed by equation 4 for the components of the variability related to the truck waiting time  $t_w$ .

$$F_0 = \frac{MS(t_w)}{MS_E} > f_{\alpha, DOF(t_w), DOF(\varepsilon)} \quad (4)$$

The effect cannot be neglected (it has an impact on the fill rate) when – at a confidence level  $\alpha$  (in this specific case  $\alpha=0.05$ ) – the ratio  $F_0$  is higher than the value  $f$  of the Fisher statistics that depends on  $\alpha$  and on the degrees of freedom. The effect importance can also be estimated by comparing the probability that the value  $f$  is higher than  $F_0$  with a level of confidence  $\alpha$ . In this case the effect has an impact on the fill rate when this probability is equal to, or lower than the selected confidence level.

Table 5 reports the results of the analysis of variance, the last column indicated the probability value ( $P$ ) that  $f$  is higher than  $F_0$ .

The results of the analysis of variance show that both the main effects of  $t_w$  and  $t_{ad}$  have an impact on the mean fill rate. On the contrary the interaction effect can be neglected.

Figure 4 shows, respectively, the trend of the mean fill rate when factors  $t_w$  and  $t_{ad}$  change. Note that by increasing the trucks waiting time at the distribution centre, the mean fill rate provided to stores decreases from 0.87 to 0.84. A different behaviour can be found in the mean fill rate versus  $t_{ad}$  graph: the higher is the additional time the lower is the mean fill rate provided to store (if  $0 \text{ min} < t_{ad} < 60 \text{ min}$ ); for  $t_{ad} > 60 \text{ min}$  the mean fill rate increases again.

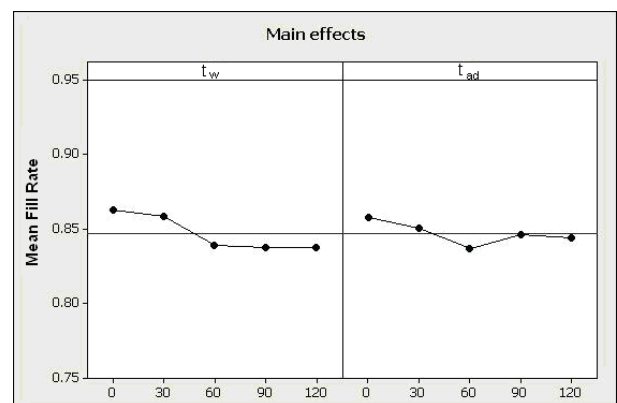


Figure 2. Main effects of  $t_w$  and  $t_{ad}$  on the mean fill rate provided to stores

The figure 5 shows the mean fill rate by contemporarily changing  $t_w$  and  $t_{ad}$ . Such graph can be used for understanding the best combination of the factors levels (the combination guarantying the highest mean fill rate). The highest mean fill rate is obtained when  $t_w = 30 \text{ min}$  and  $t_{ad} = 0 \text{ min}$ .

Note that the starting hypotheses of the analysis of variance assume that the observations are normally and independently distributed, with the same variance for any combination of levels of factors. These assumptions are usually verified by using the residuals analysis. A residual is the difference between an observation in terms of fill rate and the corresponding average value calculated on the 5 simulation replication.

Table 3. Analysis of Variance for LS

Source of variation	Sum of squares	DOF	Mean Square	$F_0$	$P$
$t_w$ treatments	0.030044	4	0.007511	5.63	0.000
$t_a$ treatments	0.011800	4	0.002950	2.21	0.069
$t_w * t_{ad}$ interaction	0.002016	16	0.000126	0.09	1.000
Error	0.299980	225	0.001333		
Total	0.343840	249			

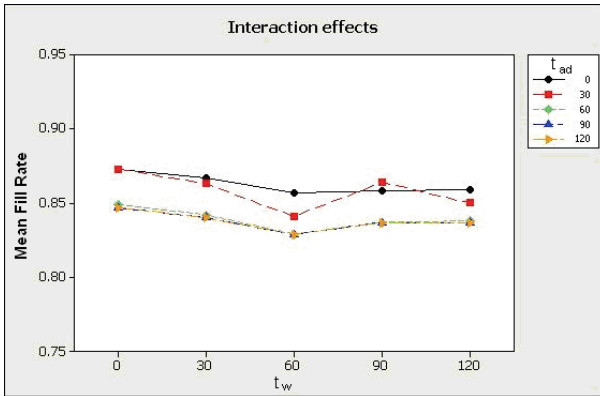


Figure 3. Interaction effects of  $t_w$  and  $t_{ad}$  on the mean fill rate provided to stores

### 3.2 The residuals analysis

As before mentioned the validity of the analysis of variance results can be tested by using the residuals analysis.

The assumption of normality can be tested by building a normal probability plot of residuals. If residuals approximately fall on a straight line passing from the centre of the graph, the assumption of normality can be accepted. In Figure 4 we can observe that, in the case being analyzed, the deviation from normality is not severe.

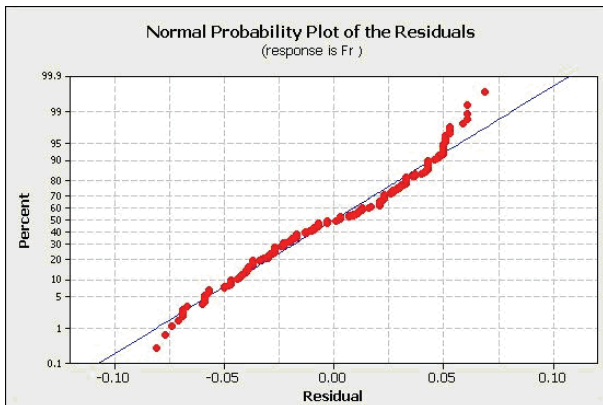


Figure 4. Normal Probability plot of residuals for testing the assumption of normality.

The assumption of equal variance can be tested by plotting residuals against the levels of factors or against the level of the average fill rate: residuals variability must anyhow not depend on the level of factors or on the mean fill rate. Figure 5 and 6, respectively, show residuals versus  $t_w$  and versus the mean fill rate and do not show any particular trend; therefore, the equal variance hypothesis can be accepted.

Finally, the assumption of independence can be tested by plotting residuals against the implementation order of the simulation runs. A sequence of positive or negative residuals could indicate that observations are not independent among themselves. Figure 7 shows that the hypothesis of independence of observations can be accepted.

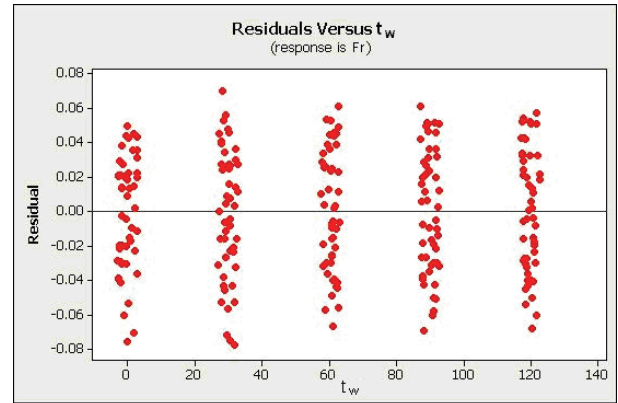


Figure 5. Residuals versus the trucks waiting time,  $t_w$

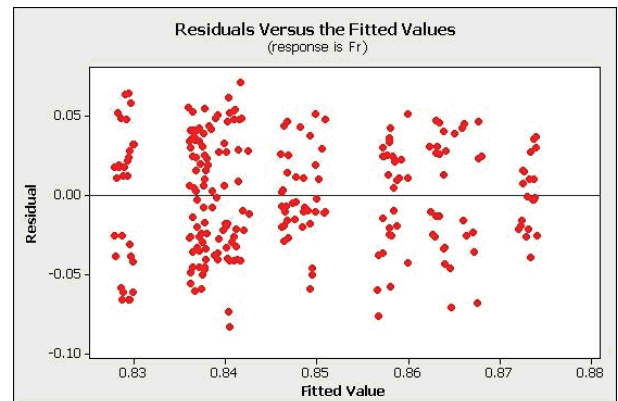


Figure 6. Residuals versus the fill rate values

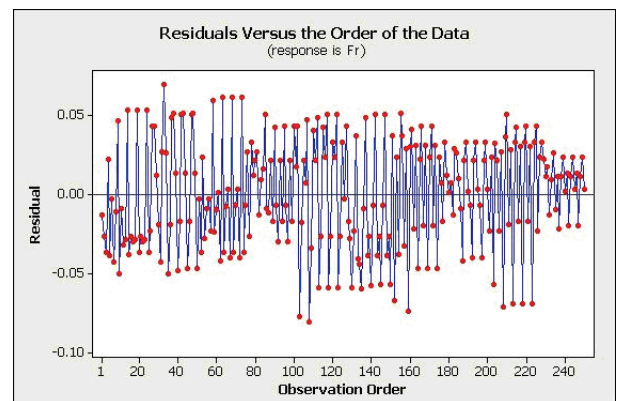


Figure 7. Residuals versus order of the data

## 4. CONCLUSIONS

The paper investigates the effect of some critical parameters on the efficiency of a logistics & transportation system operating within the supply chain supporting the large scale retail sector. In particular the attention is focused on trucks loading and unloading operations at the distribution centres. The results analysis shows that the trucks estimated waiting time and the distribution centre and the additional time on the estimated trucks arrival time can strongly affect the service level provided to final stores.

## REFERENCES

- Ballou R., 2003. *Business Logistics/Supply Chain Management*. Prentice Hall, Readings.
- Banks, J., 1998. *Handbook of Simulation*. New York: Wiley Interscience.
- Birkin, M., Clarke, G., Clarke, M.P., 2002. *Retail Intelligence and Network Planning*. New York: J.Wiley.
- Blackwell, R.D., 1997. *From Mind to Market*. New York: Harper-Collins Publisher.
- Bruzzone A.G., Simone S., Bocca E., 2004. Intelligent Management of a Logistics Platform for Fresh Goods. *Proceedings of SCI2004, Orlando, July*.
- Bruzzone A.G., Mosca R., Briano C., Brandolini M. 2000. Models for Supporting Customer Satisfaction in Retail Chains. *Proceedings of HMS, Portofino, October 5-7*.
- Curcio, D., Longo, F., Mirabelli, G., 2007. Inventory policies comparison in a manufacturing process using modeling & simulation. *Proceedings of the International Mediterranean Modelling Multiconference*, pp. 237 – 242. October 04 – 06, Bergeggi (Italy).
- De Sensi, G. , Longo, F., Mirabelli, G., 2007. Inventory policies analysis under demand patterns and lead times constraints in a real supply chain. *International Journal of Production Research*, doi: 10.1080/00207540701528776
- Longo, F., Mirabelli, G., Papoff, E., 2006. Material Flow Analysis and Plant Lay-Out Optimization of a Manufacturing System. *International Journal of Computing*, 5(1), 107-116.
- Longo, F., Mirabelli, G., 2008. An Advanced Supply Chain Management Tool Based on Modeling & Simulation, *Computer and Industrial Engineering*, Vol 54(3), 570-588.
- Longo, F., Mirabelli, G., Papoff, E., Modeling Analysis and Simulation of a supply chain devoted to support pharmaceutical business retail, *Proceedings of the 18<sup>th</sup> International Conference on Production Research, July 31 – August 4 , Salerno, Italy*.
- Monks, J.G., 1996. *Operations Management*, New York: McGraw Hill.
- Montgomery, D.C. and Runger, G.C., 2003. *Applied statistics and probability for engineers*. 3<sup>rd</sup> ed. London: McGraw-Hill.
- O'Leary, D.E., 2000. *Enterprise Resource Planning Systems: Systems, Life Cycle, Electronic Commerce, and Risk*. Cambridge University Press.
- Roberson, J.F, 1994. *Logistics Handbook*. Free Press.
- Seifert, D., Marzian, R., McLaughlin, J., 2003. *Collaborative Planning, Forecasting, and Replenishment: How to Create a Supply Chain Advantage*. Amacom
- Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E. *Designing and Managing the Supply Chain*. McGraw-Hill.

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# EVALUATION OF OPERATION COST IN LINER SHIPPING: A DISCRETE-EVENT SIMULATION APPROACH

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## ABSTRACT

An evaluation of the operation costs of a liner shipping network is presented in this study. The approach defines a discrete-event simulation model designed to mimic the dynamic operation and schedule structure of a liner service network of four service routes, 25 container ships, 18 container ports, and 36 port calls a week. Three months planning analysis is considered. The proposed approach includes evaluations of costs related to the operation liners at container ports and at sea. The expected operational results are reported for the overall network and the individual contribution of service routes, ports, and container ships to the network. The results allow for assessing the operation of service routes and defining the set of ports, container ships fleet, and schedules that are performing below and above the expected network level.

Keywords: Liner shipping, simulation, service routes, logistic performance

## 1. INTRODUCTION

Transportation of goods in containers and the container shipping industry have rather recent histories. Containerization was born to offset the disadvantages of the break-bulk shipping method used by general cargo vessels, providing an effective method to control increasing labor cost and handling time while damage, pilferage, and accidents were minimized. The development of the global trade and, consequently, growing demand for liner services, presented new challenges to the shipping of goods. An increasing number of ports, service reliability concerns, fuel costs, and imbalances in trade markets are some of the obstacles to the profitability of modern liner services.

A liner shipping network is formed by a number of service routes, which are a collection of container ports, container ship, and calling schedules. In a network, a container can move through service routes from an origin to a predefined destination. Schedules allow these containers to reach their destinations in a direct mode if only one service route is used and indirectly if more than one service route is required. Therefore, the configuration and structure of this network is essential to the performance of shipping activities. All these elements impact and contribute to the operational cost

and level of operation of the shipping process during a planning period.

The productivity of a liner shipping network is associated with the number of transported entities through the network. Its effectiveness can be related to the ability to satisfy the demand for service and comply with specific performance requirements. The level of cost in liner shipping determines the operational characteristics of the network. Evaluating these service routes, where conditions mimic reality, presents opportunities to determine operation costs, productivity, and performance at various levels of operation in the shipping network and its individual components.

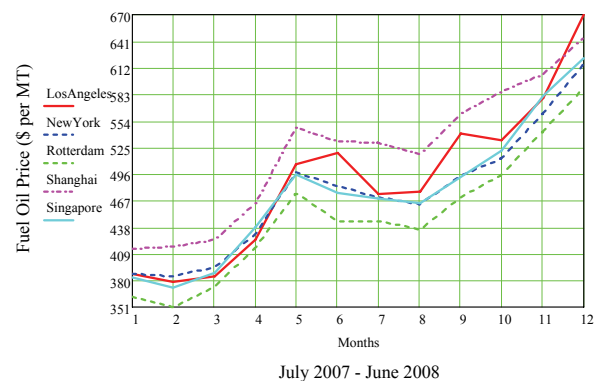


Figure 1. Fuel oil average prices at major ports.

Given the growing demand for liner services and increasing costs of modern operations, liner operators face new challenges. Despite of the improvement in the design and propulsion of container ships, the instability of prices for marine fuel oil, maintenance and other service costs are major concerns in the industry. Current prices for fuel oil oscillate between \$500.00 and \$650.00 per metric ton (pmt). Recent studies reported the design of service routes under \$170.00 and \$330.00 pmt price levels. Figure 1 shows the tendency of prices for IFO380 fuel oil in the last 12 months at some of the major container ports. In addition to the price for fuel oil itself, its unstable behavior and its future projections are discouraging as well. Assessing the effect of price factors toward the operational performance of service routes and their relative contribution to a network is

critical not only during the design stages but also during regular operation of the system.

This paper presents the evaluation of the operation cost and performance in a liner shipping network where four service routes and an offer of container cargo at ports are modeled. The object of this paper is to use a simulation model to mimic the dynamic behavior service schedules, container fleet, port activities, and container cargo to evaluate the expected operations in a system.

## 2. LITERATURE REVIEW

Measuring the operation cost in shipping is paramount to a profitable and efficient shipping process. Research in this area is diverse in the application of cost models. Lane, Heaver, and Uyeno (1987) proposed a set of cost functions to determine the cost-efficient fleet on defined trade routes. An operational cost estimation model was presented in Perakis and Jaramillo (1991) for ship deployment purposes. Baird (2002) defined a cost model for transshipment process evaluations.

Other studies had integrated service route analysis and its relationship to the cargo transported. Song, Zhang, Carter, and Field (2005) measure the cost-efficiency of trade routes based upon the assignment of container cargo. Bendall and Stent (1999) evaluated trade routes for container ships to avoid reducing load factors.

Some authors suggest that fuel cost is a minor input for liner shippers because operations rely on delivery speed. Specific algorithms to evaluate fuel consumption in a container ship are presented in Cullinane and Khanna (1998). Shintani, Imai, Nishimura, and Papadimitriou (2007) present an approach using the specific fuel consumption rate for an individual container ship to evaluate the operation cost in route. At the current price levels, the effect of fuel oil on the operation cost in shipping is a major concern to firms. The approach in Eljard (2006) includes a set of equations that account for the individual specification of a container ship to forecast the actual fuel consumption in the vessel at a given sailing speed.

Simulation modeling is defined in Law and Kelton (2000) as an analysis method where computers are used to evaluate a model numerically and gather data in order to estimate the desired true characteristics of the model. Liner shipping operations have been previously studied through simulation. In the study presented in Van Rensburg, He, and Kleywegth (2005) a discrete-event simulation approach was applied to evaluate voyage costs, fuel cost, and capital cost in liner shipping. Research exclusively dedicated to the analysis of service route costs and liner performance is increasing. Lai, Lam, and Chan (1995) develop a simulation model of liner shipping operations in the Europe-Middle East-Far East routes to evaluate policies for container allocations. Ryan (1998) uses simulation to demonstrate advantages in fast ship operations to the service frequency and output.

## 3. EVALUATION METHOD

A simulation model is used to evaluate the operation cost and logistics performance of a liner shipping network. The model replicates the operation of liners in an end-to-end weekly service schedule structure through a predefined planning period. The model allows for the evaluation of individual operation cost components during shipping activities. Possible delays in sailing segments and port operations are considered.

The arrival time, size, and status of intermodal containers are represented in realistic levels at ports. Two types of intermodal containers are modeled: 20- and 40-foot. Each container is assigned a destination port that can be reached with the current design of the network. Therefore, significant container traffic is generated in service routes as each container ship moves its assigned cargo from port to port within the network.

The liner shipping network under evaluation is composed of four service routes, 24 containers ships, 18 ports, 28 port calls, and four canal transits a week. Table 1 shows the sequence of port calls for each service route evaluated including canal transits. A weekly schedule structure is assumed for all routes and port calls. Service routes are modeled for the Transpacific, Atlantic, and Asia to Europe trade lanes. The Transatlantic route (R1) serves 8,541 nautical miles (nm) in four weeks using four container ships of 4,895 TEU. The Pacific service route (R2) totals 13,155 nm round trip using five 9,600 TEU container ships. The Asia-Europe Service (R3) requires eight 8,200 TEU to service 21,646 nm round trip including transit through the Suez Canal. The Asia to East Cost North America service (R4) requires eight 4,738 Panamax to serve 23,229 nm in 56 days, round trip.

Table 1. Service Routes and Port Calls Sequence

R1	R2	R3	R4
Rotterdam	Yantian	Bremerhaven	Ningbo
Bremerhaven	Hong Kong	Suez W	Shanghai
Le Havre	Los Angeles	Ningbo	Yantian
Felixstowe	Oakland	Xiamen	Hong Kong
New York	Pusan	Hong Kong	Panama S
Norfolk	Ningbo	Yantian	New York
Charleston	Xiamen	Tanjung P.	Norfolk
-	-	Suez E	Savannah
-	-	Algeciras	Panama N
-	-	Rotterdam	-

The services schedule and routes presented in Table 1 were obtained from service proformas and published schedules submitted by supporting shipping operators. The model logic assigns predefined routing sequences to each individual container based upon its destination port. One or more service routes may be required to transport a container from its origin to destination port. Therefore, the model allows for transshipment of cargo through ports and considers transit storage and handling activities. The level of containers at each port and in container ships is

measured for logistics analysis. Storage and handling of containers generate operation costs to the system.

### 3.1. Cost Model

Frankel (2002) estimates that the operational cost in a mega mainline container ship of 2000-3000 TEU was \$2,000/hour at sea and \$1,200/hour in port. This estimation includes ship fuel and maintenance cost. It allows for the evaluation of the operation cost in a round trip and service route once the number of container ships is defined. Therefore, the structure of the cost model can greatly influence operation practices and operation decision.

The simulation model is designed to evaluate the cost associated to the individual operations of container ships, port, and service routes. Consequently, cost components are computed in terms of the overall network and individual service routes. Fees and operation charges are fed into the system for each container ship, port activity, and routing point. The model used proposes three main groups for the evaluation of operation cost:

1. Container Ship Related Cost (SC)
2. Port Related Cost (PC)
3. Canal Transit Cost (CC)

Container Ship Related Costs include all aspects associated with operating and maintaining a container ship whether at sea or at port. Fuel oil, diesel, and lubricant costs are grouped under this group. The fuel oil cost is evaluated from the container ship's fuel consumption rate, distance served, and contracted fuel price. The consumption rate is provided by the shipbuilder. Stopford (1996) proposes that the operation of the vessel at lower speeds results in fuel savings because of the reduced water resistance modeled by the *cube rule*. This relationship shows that the level of fuel consumed is very sensitive to speed:

$$F = F^* \left( \frac{S}{S^*} \right)^a \quad (1)$$

In the cube rule, F and F\* are the actual and designed fuel consumption in tons/day respectively. The exponent *a* has a value of about three for diesel engines. The S and S\* represent the actual and designed sailing speed of the container ship in knots, respectively.

Lubricant cost is computed as a 5% of the fuel oil consumption rate per hour of operation multiplied by lubricant price. Lubricant and fuel oil costs are added and reported as fuel oil for simplicity of the reports. Diesel cost is evaluated for auxiliary generator while the ships undergo service at container ports.

Other SC costs are related to capital investment, hull insurance, crew manning, operation auxiliary expenses, and ship maintenance and repair and are regarded as Fixed Cost. These costs depend mostly

upon physical characteristics of individual container ships. The capital cost was estimated for all ships at a 2007 chartering rate of \$12.00 per 14-ton slot per day. Meanwhile, the hull insurance and maintenance and repair cost were estimated upon 10% and 5% per day of the capital cost respectively. Crew and auxiliary costs are allowances for manning and living support onboard. For simplicity it was decided to charge a fixed rate of \$500 and \$50 per crew member per day of operation crew and auxiliary cost respectively.

Port Related Costs are costs incurred while servicing a container ship at port, including ship dockage charges, stevedoring charges, and intermodal container storage charges. Charges and fees are specified per individual port. An approach using a standard berthing fee per hour for the first 150m LOA and an extended berthing fee per hour for additional meter of LOA is used. A penalty is charged for a ship overstaying outside the scheduled service time at ports. Overstaying was charged at a rate per meter LOA for every 15 minutes or fraction. Stevedoring and storage charges are related to the size of containers and handling port. Stevedoring rates change upon container port, status of the container (e.g. full or empty), and size. Rates are given for full 40- and 20-foot containers and determined for empty containers at 40% of its rate full (e.g. \$80 for full and \$55 for empty 40 foot containers). Storage charges are given in TEU per hour units. Storage charges were defined by container port and classified in two categories that include storage during first departure (CPT) and storage during transshipment (CTT1).

Canal Transit Costs include fees related to transiting the Panama and Suez Canals. For the Panama Canal, an approximation of \$54 per ship's registered TEU capacity was used, while for the Suez Canal an approximation of \$80, \$56, and \$50 per registered TEU capacity and ship type considering feeders, panamax, and post-panamax, respectively (ACP 2005). These fees are assigned to each Canal per service route.

### 3.2. Logistic Model

Surveys among shippers show that quality of service aspects, such as transit time and frequency of service (Gwulliam, 1993) are very important criteria for carrier selection due to effects on inventory carrying costs of shippers and receivers. Shippers and customers have different criteria for which logistics metrics should be used to assess shipping performance. Evaluating the performance of the shipping process and its relationship to the operation cost suggests opportunities for improved services for shippers and savings for carriers.

It was determined that representative indicators of the level of operation in the network were the operation cost, vehicle-miles traveled, and TEU Delivered. However, the Operation Cost per TEU Transported and the Network Cost per Hour of Operation are indicators of the level of productivity of the system. Other important indicators evaluated by the model include the storage time of container, utilization of the stowage

capacity in container ship and storage at port, and throughput per service routes.

### 3.3. Simulation Model

The main component of the simulation model is the Port Module Structure. The main purpose of a Port Module is to evaluate cost and performance during shipping operations. Therefore, a port module is divided in four activity areas: arrival, berthing, service, and departure. A total of eighteen port modules were designed for the model and configured to mimic basic characteristics in current container ports. These configurable parameters include physical aspects including access channel length, number of berths, container storage capacity, lift off-lift on procedures, number and performance of quay cranes, and departure procedures. The costs related to activities at port are part of the network setup parameter that includes storage cost per TEU per hour, stevedoring charges, and container ship docking charges. These activities are evaluated and their statistics collected at these modules for individual container ships, ports, and service routes. Several tables created in Microsoft Access database were used to store, update, and feed these initial parameters into the simulation model. Evaluation of time performance for shipping events and logistic results are also tasks of these port structures.

The Canal Modules are also important structures in the simulation model. Canal Modules manage the transit schedules for container ships to enter the Panama and Suez Canals, measuring the distance traveled, transit cost, and time performance while waiting and transiting the channels. There are two canal modules in the model and the transit are measured at a service speed of 5 knots for container ships. Ports and routing points are interconnected in the network and distances between origin-destination pairs are defined in a Distance Matrix.

In the simulation, the sailing time between ports is determined by the service speed of container ships and distance in a voyage within consecutive port calls. These parameters are feed to the simulation through in Segment Speed and Distance Tables. However, a provision for delays in voyages due to weather and sea conditions is included in the model. This event is modeled through a uniform distributed variate on the interval between 0 and 1% of the sailing or voyage distance. The voyage time summary of service proformas and the model animation were used to verify and validate the representation of the model to a real shipping system.

### 4. NETWORK RESULTS

The results for three months' analysis of the operation of the liner shipping network evaluated show operation costs, transit time, and container ship utilization levels consistent with quarterly reports in liner shipping industry. The initial setting parameters were constant for all port and container ships through the simulation experiment. The main parameters are presented as follow:

Berthing fee = \$150.00 per hour  
 Additional fee = \$4.00 per hour  
 Overstaying penalty = \$4.00 per 15 minute units  
 Fuel oil price = \$350.00 pmt  
 Diesel price = \$560.00 pmt  
 Lubricant price = \$1,000 pmt  
 Consumption rate for 4,700; 4,895; 8,200 TEUs (including 9,600 TEU) = 133; 156; and 248 mt per day at maximum cruising speed.

The analysis of the operation yields an average Network Operation Cost of \$419.581 million in three months of operations. The largest contribution to the operation cost is given by Fixed Cost, \$258.243 million, representing 62%. The second largest cost is the Network Fuel Oil Cost at \$78.661 million, or 19% of Cost. The summary for the network also reveals 10% for Stevedore Cost. Canal transits reached 5% of the operation cost at \$20.073 million. Storage cost was 4% or \$15.442 million, driven by the cost of retaining containers before their first departure (e.g. CPT) at \$15.111 million and storage during transshipment procedures or CTT1 at \$0.330 million. These results are shown Table 2:

Table 2. Operation Cost results from Model Run.

Cost Item	Average	Half width	H-Observed	Share
Fuel Oil	\$ 78,661,436.31	10,774.71	\$ 78,686,379.46	19%
Diesel Oil	\$ 2,405,583.47	1,118.82	\$ 2,408,449.37	1%
Dockage	\$ 4,877,440.89	2,012.87	\$ 4,880,861.36	1%
Canal	\$ 20,073,960.00	0.00	\$ 20,073,960.00	5%
Stevedor	\$ 40,207,830.80	41,999.26	\$ 40,317,186.00	10%
Storage	\$ 15,442,176.36	388,290.14	\$ 16,173,004.50	4%
CPT	\$ 15,111,737.88	389,081.57	\$ 15,840,205.94	-
CTT1	\$ 330,438.49	4,860.45	\$ 341,545.53	-
CTT2	\$ -	0.00	\$ -	-
Fixed	\$ 258,243,757.70	2,111.69	\$ 258,247,733.00	62%
Total Operations	\$ 419,581,747.05	374,798.44	\$ 420,302,456.37	-

In terms of operations, R1 produced 22% of cargo throughput consuming only 11% of the cost in the system. Route 2 was the most productive service route with 33% of throughput and 25% of the total operation cost. The high productivity of route R3 was offset by its cost of 39% of operations in the network. A required transit through the Suez Canal imposes schedule limitations and high transit charges on this route. The lowest operation level was found in R4. An average of 429,196 TEU were delivered during the analysis.

In terms of productivity, the Operation Cost per TEU was reported for R1, R2, R3 and R4 at \$517, \$712, \$1,275 and \$1,598 respectively. Throughput on these routes reached levels of 92, 143, 125, and 67 thousand TEU delivered. Meanwhile, the Operation Cost per Hour per Ship was reported for R1, R4, R3 and R2 in \$5,397, \$8,832, \$9,029, and \$9,325 respectively. These values are average with half-width lower than 1%. Improving the current network operation cost was possible based upon changes to the service speed in service routes, improving service route R3 yield to \$414.00 million in operation costs for the network, 2% lower than previously measured in the initial network.



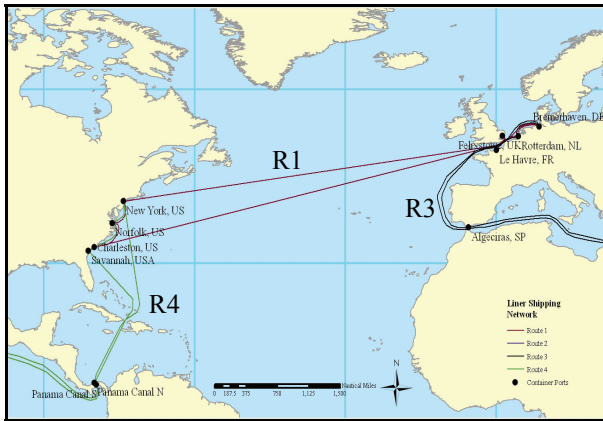


Figure 2. Service Routes, North Atlantic Operations

## 5. CONCLUSIONS

The results obtained from the simulation study to this particular liner shipping network support the idea that highest share in the operation cost for both the network and service routes is the Fixed Cost of operation. These results support the decision of to purchase over chartering large container ships to reduce fixed cost without considering initial capital investment and shipyard delivery time.

A comparison between the operation cost per TEU obtained and the average market freight rates per TEU for trade routes reported in UNCTAD and Containerization International annual reports would show opportunities and drawbacks to operators from using this network during the planning period. The model estimated an average cost of \$1,275.96 per TEU transported between Europe and Asia, whereas freight rate reports, for the first quarter of 2007, \$755 per TEU from Europe to Asia and \$1,549 in the opposite direction. If these rates were maintained for the last quarter of 2007 a net profit of \$273.00 per TEU could be expected from shipments from Asia to Europe and losses of \$520.00 per TEU for shipments in the other direction.

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## REFERENCES

- Autoridad del Canal de Panamá, ACP., 2005. *Suez Canal Pricing Forecast 2005-2025*. New York: Johns & Associates Inc.
- Bendal, H. B., & Stent, A. F., 1999. Longhaul feeder services in an era of changing technology: An Asia-Pacific perspective. *Maritime Policy & Management*, 26(2).
- Cullinane, K. and Khanna, M., 1998. Economics of Scale in Large Container Ships. *Journal of Transport Economics and Policy*, 33(2).
- Eljardt, G., 2006. Development of a fuel oil consumption monitor system. Thesis (PhD). Technische Universitat Hamburg-Harburg.

- Frankel, E.G., 2000. The Challenge of Container Transshipment in the Caribbean. *IAME Panama 2002 Conference Proceedings*. November 13-15, International Association of Maritime Economics.
- Gwilliam, K.M., 1993. *Current issues in Maritime Economics*. Boston: Kluwer Academic Publishers.
- Lai, K. K., Lam, K., & Chan, W. K., 1995. Shipping containers logistics and allocation. *Journal of the Operational Research Society*, 46, 687-697.
- Lane, D.E., Heaver, T.D., and Uyeno, D., 1987. Planning and scheduling for efficiency in liner shipping. *Maritime Policy and Management*, 14(2), 109-125.
- Law, A. M., & Kelton, W. D., 2000. *Simulation Modeling and Analysis*. Boston: McGraw-Hill.
- Perakis, A.N., and Jaramillo, D.I., 1991. Fleet deployment optimization for liner shipping part 1: Background, problem formulation and solution approaches. *Maritime Policy and Management*, 18(3), 183-200.
- Ryan, N., 1998. The Future of Maritime Facility Design and Operation. *Proceedings of the Winter Simulation Conferences*, pp. 1223-1227.
- Shintani, K., Imai, A., Nishimura, E., and Papadimitriou, S., 2007. The container shipping network design problem with empty container reposition. *Transportation Research Part E*, 43.
- Stopford, M., 1997. *Maritime Economics*. Chesham, Buckinghamshire: Pointing-Green Publishing.
- Van Rensburg, J. J., He, J., and Kleywegt, A. J., 2005. A computer simulation model of container movement by Sea. *Proceedings of the 2005 Winter Simulation Conference*, 1559-1566.

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# MULTI-SCENARIO POLICIES FOR MARITIME REPOSITIONING PROBLEMS UNDER DATA SHORTAGE

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## ABSTRACT

Due to the global trade imbalance, some ports tend to accumulate unnecessary empty containers, while others face container shortages. As a consequence, shipping companies must properly reposition their empty containers between ports. A major difficulty in this activity consists in the many sources of uncertainty. Sometimes historical data are useless for estimating uncertain parameters, because they are inadequate, insufficient or they do not consider future changes in the operational environment. In these cases, point forecasts and uncertain parameter distributions can be generated by shipping companies' opinions. They can be incorporated in standard deterministic optimization models and multi-scenario formulations linked by non-anticipativity conditions. In this study, we explain the importance of multi-scenario policies.

Keywords: empty container repositioning, optimization under uncertainty.

## 1. INTRODUCTION

The need to perform the maritime repositioning of empty containers occurs because directional imbalances in freight flows lead to the accumulation of empty containers in import-dominant ports and to shortages in export-dominant ones. Since empty containers only generate costs for shipping companies, they must be repositioned so as to minimize inventory, transportation and handling costs, while at the same time meeting demand and supply requirements in every port. The maritime repositioning of empty containers represents a crucial activity for shipping companies. According to their strategies, the demand for empty containers at ports must be met, in order to take advantage of future transportation opportunities and to reduce the risk of competitors providing containers as requested (Di Francesco 2007).

Many parameters are typically uncertain at the time repositioning decisions must be made. For example, information on the number of empty containers required in each port is usually imprecise,

because unexpected transportation demands may arise. Moreover the number of empty containers available in ports is uncertain, because shipping companies do not know precisely when they will be returned by import customers.

Sometimes shipping companies do not have adequate statistics based on historical data, to estimate uncertain parameters. Statistical information may be insufficient or it could be necessary to take into account information not derived from historical data. As a consequence, the future evolution may exhibit no probabilistic dependence on the past and historical data may be useless for decision-making processes.

In order to solve empty container repositioning problems, both deterministic and stochastic optimization models have been proposed (Crainic 2003). Deterministic formulations assume that all data are precisely known. They might yield low-quality repositioning plans for the needs of shipping companies, in fact, since they allocate empty containers according to expected values, they can provide an insufficient number of empty containers, when larger demands or lower supply values will be eventually observed. Stochastic programming approaches take into account the influence of data uncertainty on the solution of optimization models. However, they require a good knowledge of the distributions of uncertain data. Moreover in many cases it is difficult to specify reliably these distributions.

The contribution of this paper is to introduce a new methodology of modelling to deal with uncertainty and data shortage. Since historical data may be unavailable or unreliable, expert-based opinions are used to build subjective distributions of uncertain parameters and to generate several possible futures or scenarios. They are collected in a multi-scenario optimization model and are linked by non-anticipativity constraints, so that current decisions cannot take advantage of information not yet available.

We compare the multi-scenario formulation to a single-scenario deterministic model, where uncertain parameters are replaced by the expected values derived

from the subjective distributions. Our results emphasize the opportunity of adopting multi-scenario policies instead of standard deterministic ones. Multi-scenario policies exhibit higher demand fulfilment percentages, because they can over-allocate the flows of empty containers with respect to point forecasts and meet a larger number of potential requests.

## 2. PROBLEM DESCRIPTION

In this section we describe a general maritime network over which empty container repositioning is performed. The backbone of maritime repositioning systems is represented by ports, which serve as transit facilities for empty containers in order to meet potential transportation requests arising in the landside. Shipping companies must make decisions on the number of empty containers to be stored in ports.

To introduce transportation decisions, we need to define the demand and the supply of empty containers at ports. In import-dominant ports we refer to the empty container supply, which represents the number of empty containers available in a given port at any given time, due to past inventory, trucks and trains arriving from the landside. In export dominant ports, we consider empty container demand, that represents the number of empty containers requested in a given port at any given time. The demand for empty containers must be met using the supply available in other ports, that is, empty containers must be repositioned. This activity is performed by vessels sailing well-established routes according to tight schedules. Shipping companies must decide how many containers must be repositioned by vessels.

The time-dependency of transportation decisions also characterizes the relationship between shipping companies and ports. Shipping companies must decide how many empty containers will be loaded and unloaded in ports one day before the arrival of vessels, so that the ports can organize their internal activity on time and all terminal operations can be performed as requested.

Several parameters are uncertain, when these decisions must be made. The uncertain parameters we consider are future supplies and demands at ports, transportation capacities for empty containers and maximum number of empty containers that can be loaded and unloaded. Uncertainty as to supply depends on returning times of empty containers in ports. Customers can hold containers for several days. It is not simple to estimate when they will be returned and how much time is needed to move them to ports. Uncertainty on empty container demand at ports is associated with unexpected transportation opportunities arising in the landside. Moreover, unexpected transportation requests result in loaded containers modifying both the transportation capacity for empty containers and the maximum number of empties that can be loaded and unloaded. While a part of these parameters is known, others offer less precise information, especially towards the end of the planning horizon.

## 3. RELATED LITERATURE

In recent years some shipping companies have adopted decision support systems based on deterministic optimization models, to reposition empty containers. This is a consequence of the intensive research developed over past years in this issue.

Dejax and Crainic (1987) reviewed past papers in the management of empty flows. They mentioned few authors addressing the problem of allocating empty containers in a dynamic environment by deterministic optimization models.

Lai *et al.* (1995) evaluated several allocation policies in the maritime reposition issue to prevent the shortage of empty containers when the demand for them is uncertain. They exploited probability distributions derived from historical data to estimate uncertain parameters, whereas in many cases reliable statistics are not available.

Shen and Khoong (1995), focusing on the business perspective of the shipping industry, developed a deterministic optimization model for repositioning empty containers to minimize repositioning costs.

Cheung and Chen (1998) applied a two-stage stochastic network model to the dynamic allocation of empty containers. They relied on available probability distributions to estimate uncertain parameters.

Choong *et al.* (2002) addressed the end-of-horizon issue to manage a fleet of empty containers in the context of an inland distribution system. They proposed a time-extended deterministic optimization model. To deal with uncertain parameters, decisions were implemented in a rolling horizon fashion.

Leung and Wu (2004) developed a dynamic optimization model for repositioning empty containers, to generate solutions insensitive to the realization of uncertain parameters. They assumed customer demands as a single source of uncertainty and exploited the reliability of available data to estimate uncertain parameters.

Ereza *et al.* (2005) proposed a time-extended optimization model to manage loaded and empty tank containers simultaneously. However, their formulation is deterministic and recourse actions are performed implementing decisions in a rolling horizon fashion.

Olivo *et al.* (2005) proposed a time-extended optimization model for the centralized control of empty container repositioning in the context of multimodal networks. However, their formulation is still deterministic and uncertain parameters are taken into account by implementing decisions in a rolling horizon fashion.

To our knowledge, there is currently no optimization model aimed at the repositioning of empty containers, when historical data are inappropriate for estimating uncertain data. To address this problem, in this paper we propose a multi-scenario optimization model, where scenarios are generated by expert-based opinions.

#### 4. DETERMINISTIC AND MULTI-SCENARIO OPTIMIZATION MODELS

In this section we present a deterministic single-scenario model and a multi-scenario formulation to solve the previous problem. To facilitate the understanding of the modeling process, first we introduce to the deterministic model, then the multi-scenario formulation is presented.

As for the deterministic model, let  $G = (N, A)$  be a time-expanded network, where nodes represent ports replicated in every period of the planning horizon and vessels in the periods when they arrive at ports. We consider several types of arcs, representing different types of decisions. Arcs from a given port in a period to the same port in the next period represent the number of empty containers to be kept in stock. Arcs from a given vessel in a period to the same vessel berthing in another port in another period represent the number of empty containers to be repositioned. Arcs from ports to vessels represent the number of empty containers to be loaded, whereas arcs from vessels to ports represent the number of empty containers to be unloaded.

We minimize the cost of loading, unloading, repositioning and storing empty containers over maritime networks. Mass balance constraints must be satisfied for every node in every period. Constraints ensure an upper capacity on the number of empty containers that can be loaded and unloaded from vessels arriving in every port. Moreover the stock level of empty containers in ports must not exceed storage capacities. Finally, the volume of empty containers repositioned between ports cannot be larger than the space available on vessels.

Regarding notation, a compact form is provided for the deterministic single-scenario formulation, which assumes perfect knowledge of what information is going to arrive in the future. Let us denote by  $s$  the scenario representing the expected system future. The deterministic model can be expressed as follows:

$$\min cx_s \quad (1)$$

s.t.

$$Ax_s = b_s \quad (2)$$

where the decision variable  $x_s$  must be non-negative and integer.

The cost vector  $c$  in the objective function (1) includes loading, unloading, storage and transportation costs. The matrix  $A$  in constraint set (2) represents the coefficient matrix. We indicate the equality in constraint set (2), because capacity constraints can be expressed in terms of equality constraints by adding slack variables.

To take specifically into account the uncertain nature of supplies, demands, transportation and loading-unloading capacities, we consider a set  $S$  of scenarios. They are assumed to be identical up to a given period

$\theta$ , because more precise information is available in the first part of the planning horizon. We collect all scenarios in an overall mathematical model, linked by non-anticipativity constraints. They guarantee that decisions are identical up to period  $\theta$  for every scenario, so that we do not take advantage of information not yet available. We denote by  $w_s$  the weight associated with every scenario  $s \in S$ , to characterize its relative importance. We also denote by  $x_{ts}$  the set of decision variables to be implemented at time  $t \in T$  in scenario  $s \in S$ . The multi-scenario formulation can be expressed in a compact form as follows:

$$\min \sum_{s \in S} w_s cx_s \quad (3)$$

s.t.

$$Ax_s = b_s \quad \forall s \in S \quad (4)$$

$$x_{ts} = x_{tg} \quad \forall t \in \{1 \dots \theta\}, \forall s, g \in S \quad (5)$$

where (5) represents non-anticipativity constraints. According to (4), constraint systems (2) are replicated for every scenario. Since the uncertain parameters we consider are future supplies, demands, transportation and loading/unloading capacities, the index  $s$  denotes the RHS vector, as well as decision variables.

#### 5. EXPERIMENTATION

In this section we apply the previous formulations to a time-extended network made up with five ports and five periods. We simulate the behavior of this system over a number of periods and compare multi-scenario policies with deterministic ones. In this simulation empty container supplies and demands are supposed to be the only sources of uncertainty.

First, we solve the multi-scenario model and the deterministic one in the first period. Next, we assume which values are taken by uncertain parameters, when they are observed. Since many joint realizations of uncertain parameters may become true in the next period, we limit our analysis to two significant cases:

- The expected values of these uncertain parameters will become true.
- The worst-case realization of these uncertain parameters will be observed (i.e. the largest values of demand and the lowest values of supply).

Then we add a new period at the end of the planning horizon, we run both models once again, we implement decisions, we evaluate policies and so on. We perform this simulation for five periods.

Expert-based opinions are used to estimate uncertain demands and supplies. Shipping company suggestions indicate the minimum, the most plausible and the maximum values for each uncertain parameter. Such information is collected in triangular distributions. Then, we consider three values of demand and supply for each port in each period: the mode, the minimum and the maximum, we build one scenario for each joint realization and we link all scenarios by non-anticipativity conditions. We also assume that every joint realization of uncertain parameters is independent one from the other, so the weight of scenarios can be calculated by multiplying probabilities derived from triangular distributions.

Taking into account shipping companies' needs, we compute demand fulfillment percentages and total repositioning costs (storage, transportation, loading and unloading costs) to evaluate deterministic and multi-scenario policies.

According to this simulation, if expected values are observed, the multi-scenario solution results in a larger number of empty containers loaded on vessels. As a result, shipping companies are put in position of satisfying unexpected demands in future periods, whereas this is not possible when the deterministic formulation is adopted.

When the worst combination of uncertain parameters occurs, the deterministic solution is particularly inappropriate, because usually there is no container to meet extra demands. As a result, at the end of the simulation we are not able to meet a number of requests for empty containers. When we adopt the multi-scenario one, the number of unfulfilled requests is significantly lower. In Figure 1, we show demand fulfillment percentages over the simulation periods, when the worst-case values are observed.

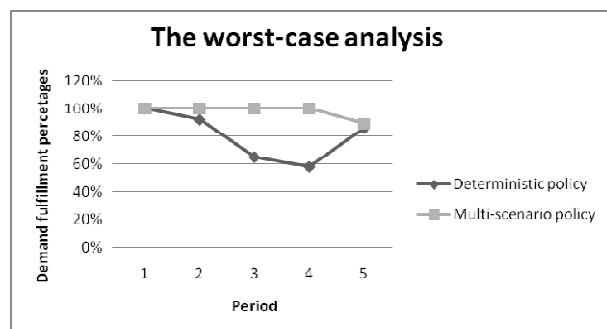


Figure 1: Demand fulfillment comparison between deterministic and multi-scenario solution in the worst-case

Due to the expensive loading and unloading costs, multi-scenario policies yield larger operating costs than the deterministic ones. The difference between these costs represents what shipping companies should pay to ensure high-quality decisions, whose effectiveness is immune to the influence of uncertain parameters.

Failing to satisfy empty container demand results in significant loss for shipping companies. Therefore, we add the expected possible loss associated with

unfulfilled demands to repositioning costs. Our simulation shows that this sum is considerably lower when multi-scenarios policies are adopted. To conclude, they are by far better than the deterministic ones.

## 6. CONCLUSIONS

The contribution of this paper has been to introduce a new modelling process to address empty container repositioning under uncertainty and data shortage. This formulation has retained the advantage of a set of scenarios generated by expert-based opinions, to determine decisions which are not based on inadequate historical data.

We have illustrated that multi-scenario policies make for insight compared to deterministic ones, which provide high-quality repositioning plans only if expected values are observed. The multi-scenario formulation allows shipping companies to better satisfy empty container demands for the different values that may be taken by uncertain parameters, even though it yields slightly higher repositioning costs.

## REFERENCES

- Cheung, R.K., and Chen, C.Y., 1998. A Two-Stage Stochastic Network Model and Solutions Methods for the Dynamic Empty Container Allocation Problem. *Transportation Science*, 32(2), 142-162.
- Choong, S.T., Cole, M.H., and Kutanoglu, E., 2002. Empty container management for intermodal transportation networks. *Transportation Research Part E*, 38(6), 423-438.
- Crainic, T.G., 2003. Long-haul Freight transportation. In: R.W. Hall, ed. *Handbook of Transportation Science*, Kluwer Academic Publishers, Norwell, MA, 451-516.
- Dejax, P.J., and Crainic, T.G., 1987. A Review of Empty Flows and Fleet Management Models in Freight Transportation. *Transportation Science*, 21(4), 227-247.
- Di Francesco, M., 2007. *New Optimization Models for Empty Container Management*. Thesis (PhD). Cagliari University.
- Erera, A.L., Morales, J.C., and Savelsbergh, M.W.P., 2005. Global intermodal tank container management for the chemical industry. *Transportation Research Part E*, 41, 551-566.
- Leung, S.C.H., and Wu, Y., 2004. A Robust Optimization Model for Dynamic Empty Container Allocation Problems in an Uncertain Environment. *International Journal of Operations and Quantitative Management*, 10(4), 1-20.
- Lai, K.K., Lam, K., and Chan, W.K., 1995. Shipping Container Logistics and Allocation. *Journal of the Operational Research Society*, 46, 687-697.
- Oliivo, A., Zuddas, P., Di Francesco, M. and Manca, A. 2005. An Operational Model for Empty Container Management. *Maritime Economics & Logistics*, 7(3), 199-222.

Shen, W.S., and Khoong, C.M., 1995. A DSS for empty container distribution planning. *Decision Support Systems*, 15(1), 75-82.

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# AN OBJECT-ORIENTED PROGRAMMING APPROACH FOR A GIS DATA-DRIVEN SIMULATION MODEL OF TRAFFIC ON THE PANAMA CANAL

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## ABSTRACT

This paper proposes the integration of a Geographic Information System (GIS) with the Arena Simulation software to model the transit of ocean-going vessels through the Panama Canal. The purpose of this integration is to initialize the simulation model with the vessels that are currently transiting the system and the ones ready to begin their transit taking into account waiting time in queue, booking status, navigation restrictions and their times through the locks.

The interface process consists of gathering vessel location and attribute data, which is loaded in database format in the GIS where it is analyzed and displayed in a map containing the location of the locks, anchorage areas, tie-up stations and the transit route. Once analyzed, Arena reads the GIS data from the database and proceeds with the simulation considering navigation transit time, locks transit and lockage times.

Keywords: Geographic Information Systems, object-oriented programming, simulation initialization, Panama Canal

## 1. INTRODUCTION

Geographic Information Systems (GIS) have become a worldwide application that can integrate and relate any data with a spatial component in order to support the decision making criteria in many organizations. This research demonstrates how the GIS technology can be integrated with a simulation software as an interface to model the transit of ocean-going vessels through the Panama Canal. The data analysis and integration is accomplished through object-oriented programming modules embedded in the GIS and simulation software utilized for the implementation.

The Panama Canal provides an ideal opportunity to demonstrate the potential of such application in an inland waterway with the capability to input real-time or customized data, based on critical information from the Canal. The Panama Canal is a 50-mile long waterway that joins the Atlantic and Pacific Oceans through the Isthmus of Panama with an average of 12,000 vessel transits per year influencing world trade patterns and economic expansion in many remote areas of the world.

## 2. METHODOLOGY

There are three main tools that were key to this implementation: GIS, object-oriented programming, and Arena-based simulation.

### 2.1 The Geographic Information System (GIS)

The methodology involved with the GIS consisted of a series of steps that provided an accurate representation of the Panama Canal by capturing geographic data (coordinates), storing it in a database, querying specific features based on location or attribute values to analyze and manage it, displaying the vessels on the map and providing an interface for the simulation model. The mapping scheme that the software uses consists of organizing spatial data as a collection of thematic layers linked by geography (Murad-al-shaikh, Page, Stewart, and Taggart 2003). The initial set of layers focused on the political data layer, which contains the country's shape and boundaries and on top of the political data layer came the lakes and rivers layers that constitute Panama's hydrography. The next components of the map were the navigation channels and the Canal locks. There are five navigation channels that were modeled with the East and West lanes. The channels are the following: Pacific Entrance, Miraflores Lake, Gaillard Cut, Gatun Lake, and the Atlantic Entrance. There are three sets of locks: Miraflores Locks, Pedro Miguel Locks, and Gatun Locks, and these were also modeled with the East and West lanes and their corresponding chambers. The coordinates for the navigation channels and transit route were gathered using a Garmin GPS (Global Positioning System) in a transit throughout the Canal. The geographic data that was captured was integrated to generate the map of the Panama Canal in Figure 1.



Figure 1: Panama Canal Map

## 2.2 Object-oriented Programming

A valuable advantage of the GIS software utilized (ArcGIS Desktop 9.0) is that it comes with Visual Basic for Applications (VBA) embedded. This option provides an integrated programming environment. These applications have Visual Basic Editor (VBE) which enables an interface to write a Visual Basic (VB) macro and integrate VB's functionality with the extensive object library embedded in the software. Object-oriented programming is a structure or design for computer programming languages in which the user works with objects that have properties and behaviors that can carry out specific instructions (Burke 2003). ArcObjects is the object-oriented programming development platform for the ArcGIS applications used in this research. It provides the framework that enables data management and map presentation functions common to GIS applications. The object models implemented in this model are the following:

1. ArcMap Object Model
2. Map Layer Object Model
3. Geometry Object Model
4. GeoDatabase Object Model 1

The vessels currently in the system are generated by randomly sampling coordinates in the transit route layers. The first step into generating these vessels is initiating the programming sequence with the ArcMap Object Model by defining the current document which is the working map. The object navigation continues

until accessing the Map Layer Object Model which contains the East and West lane transit route layers. Figure 2 from Burke (2003), represents the map layer object model with all the different types of layers and highlighted in yellow the corresponding path to selecting the layers needed.

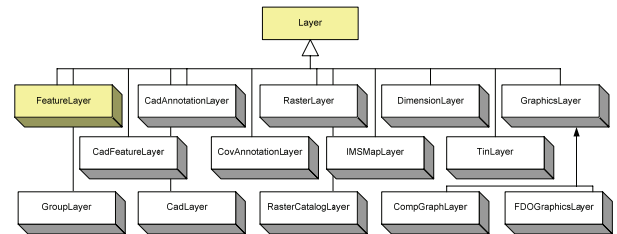


Figure 2: Map Layer Object Model

Once the layers were selected, since the vessels in the system are represented by points in the map, it was necessary to navigate towards the Geometry Object Model. The logic behind this sequence is to define a geometry element which is going to be part of the map, and the type of element, in this case, a point. Figure 3 from Burke (2003), depicts the different types of geometry elements that can be utilized in different applications, also highlighting in yellow the path to the element implemented in this application.

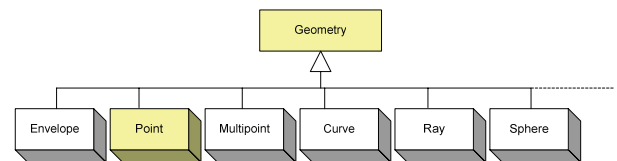


Figure 3: Geometry Object Model

The number of points or vessels is selected through a graphical user interface (GUI) as seen on Figure 4 which allows the definition of other vessel attributes such as: direction (North or South), lane (East or West) and vessel mix based on vessel types. Each vessel type has a specific dimension attribute represented in Table 1 from Panama Canal Authority (2003), and is color coded in the GUI as a visual aid to identify the type of vessel once plotted in the working map.

Table 1: Vessel Types

Type	Size Category
1	Beam < 70
2	70 ≤ Beam < 80
3	80 ≤ Beam < 90, Draft < 36
4	80 ≤ Beam < 90, Draft ≥ 36
5	90 ≤ Beam < 100, Draft < 30
6	90 ≤ Beam < 100, 30 ≤ Draft < 36
7	90 ≤ Beam < 100, Draft ≥ 36
8	Beam ≥ 100, Draft < 30
9	Beam ≥ 100, 30 ≤ Draft < 36
10	Beam ≥ 100, 36 ≤ Draft < 38
11	Beam ≥ 100, Draft ≥ 38, 6/12
12	Beam ≥ 100, Draft ≥ 38, 8/16



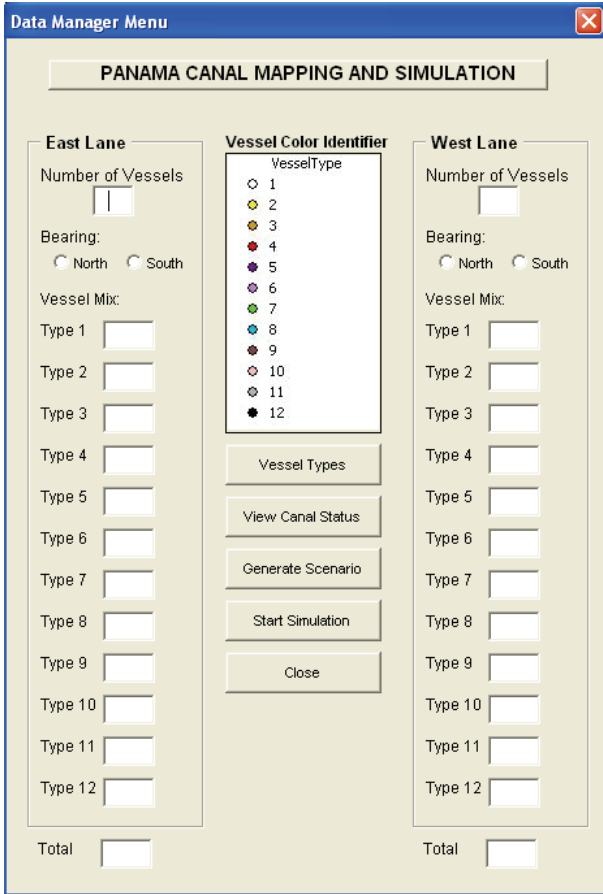


Figure 4: Graphical User Interface

At the time the number of vessels in the system is entered, a random coordinate sampling algorithm is executed generating coordinate locations along the East and West lanes inside the Canal. The algorithm specific to this function is detailed below.

Let :

$$\text{Random Vessel Location} = P(x,y)_{i,j} \quad (1)$$

Where:

$x$  = Longitude

$y$  = Latitude

$i$  = Number of random vessel locations along the route

$j$  = Number of replications for the simulation

As the algorithm runs through the iterations, the generated data is placed in a geodatabase which stores spatial features (points, line and area data) and their attributes in a relational database management system (RDBMS) table (Access, Oracle, DB2, and SQL Server), it is a native data format for all ArcGIS applications (Murad-al-shaikh, Page, Stewart, and Taggart 2003). The geodatabase is in Microsoft Access database format which will be the interface between ArcGIS and Arena. Figure 5 from Burke (2003), represents the Geodatabase Object Model 1 that is accessed in order to build the database.

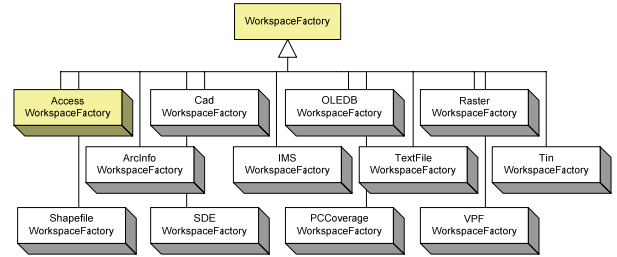


Figure 5: Geodatabase Object Model 1

As all the vessel location points are generated, the next phase was to calculate the remaining transit distance in the waterway subject to direction, whether it is North or South. This is accomplished through the Map Layer Object Model. The navigation segments are separated by points which will be the location reference to calculate the distance. Figure 6 depicts the navigation segments for both, East and West lanes. The yellow points separate the navigation segments on the East lane and the red points separate the navigation segments on the West lane.

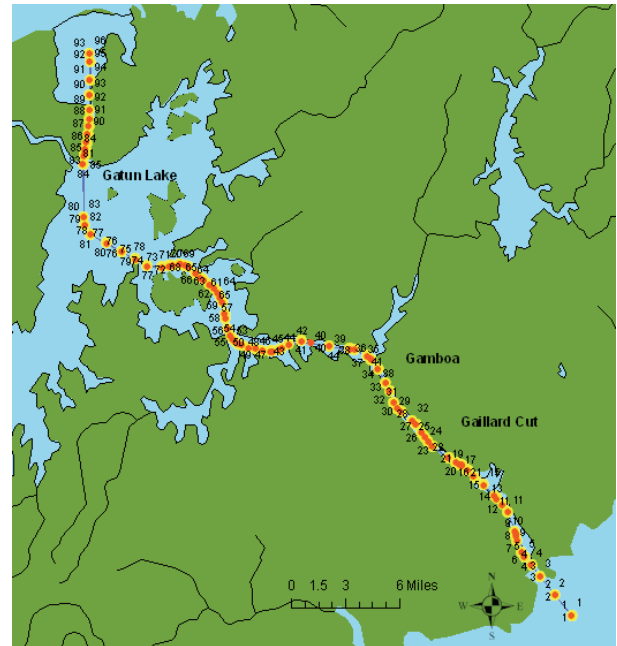


Figure 6: Transit Route with Segment Markers

The distance matrix  $k \times m$  was developed for this purpose and the algorithm is as follows:

Let:

$$D(P_k, P_m) = \text{abs}[P_k(x,y) - P_m(x,y)] \quad (2)$$

Where:

$D$  = Distance in miles

$k$  = Number of vessels in the system

$m$  = Number of navigation segments

$P_k(x,y)$  = Vessel coordinates

$P_m(x,y)$  = Navigation segment coordinates

In every iteration, for a specific segment and specific vessel the algorithm would return the straight line distance between the two points. Table 2 represents a section of the distance matrix for the East lane highlighting in yellow the distance in miles between vessel 5 and navigation segments 11, 12, 13 and 14 as seen on the route section in Figure 7.

Table 2: Distance Route Section for the East Lane

Vessel #	Segment (miles)					
	1	11	12	13	14	15
1	38.74	32.14	31.63	31.18	30.98	30.11
2	26.00	19.59	19.10	18.66	18.46	17.61
3	17.72	11.00	10.48	10.04	9.83	8.96
4	33.67	27.36	26.88	26.45	26.24	25.40
5	6.88	0.08	0.44	0.88	1.09	1.96
6	40.21	33.55	33.04	32.59	32.38	31.51

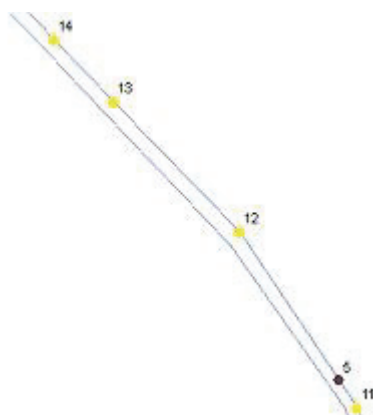


Figure 7: East Lane Route Section

The last step into finalizing the GIS module was defining two more attributes for the vessels in the system, identifying in which navigation channel (Pacific Entrance, Miraflores Lake, Gaillard Cut, Gatun Lake or Atlantic Entrance) the vessel is in and the remaining transit distance to the next point where an activity takes place based on the distance matrix and vessel direction. This was accomplished through another algorithm that was incorporated into the distance matrix, which would create a binary matrix with the same  $k \times m$  definition. Following the same scheme it populates a matrix with a '0' or a '1', identifying navigation segments that are ahead of the vessel in the route with a '1' and navigation segments that are behind the vessel with a '0'. On each vessel iteration with all the navigation segments, the first time when a value of '1' was generated it meant that all the next navigation channels including the current iteration were located ahead of the vessel and it triggered a function to verify the vessel's longitude to determine the current navigation channel based on a set range of coordinates for each specific navigation channel. Table 3 is a binary matrix section for the same vessel location analysis shown in Figure 7.

Table 3: Binary Route Section for the East Lane

Vessel #	Segment					
	1	11	12	13	14	15
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	1	1	1	1	1
6	0	0	0	0	0	0

Finally, the geodatabase is updated with the following vessel attributes previously discussed: latitude, longitude, vessel type, direction, transit lane, navigation channel, distance to next activity point, replication number, and vessel ID. Attributes from the geodatabase will be the engine to initializing the simulation model described in the next section.

### 2.3 Simulation Model

The software that provides the flexibility and the tools to interact with the GIS module in order to perform the data analysis is Arena. The capability of Arena is demonstrated with the integration Microsoft Access, Microsoft Excel, VBA, and SIMAN blocks through object-oriented programming triggered by the GIS application. "For specialized needs, like complex decision algorithms or accessing data from an external application, you can write pieces of your model in a procedural language like Visual Basic or C/C++." (Kelton, Sadowski, and Sturrock 2004). There three components to the simulation model:

1. Model initialization
2. Navigation channels
3. Canal Locks

As an aid to understand the following sections, below is Figure 8 with a basic sketch of the Canal components and their sequence according to the transit direction.

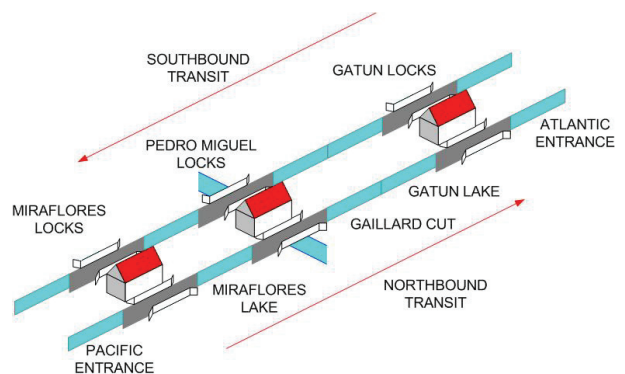


Figure 8: Panama Canal Components

#### 2.3.1. Model Initialization

Arena has VBA built-in events which center around the simulation run as shown in Figure 9 from Kelton, Sadowski, and Sturrock (2004).

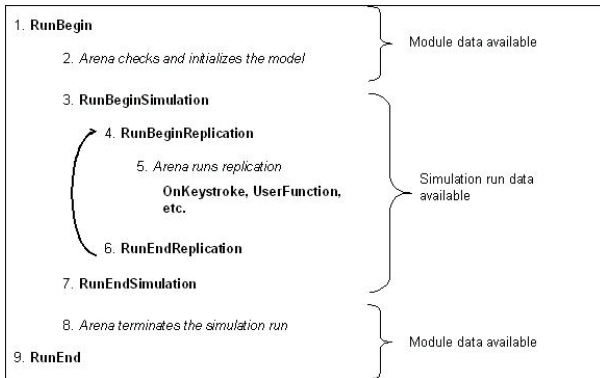


Figure 9: Arena Simulation-run VBA Events

The RunBeginReplication event is where the simulation initialization takes place. From the GIS module previously described, the geodatabase contains two tables, one with the vessels in the system on the East lane and another table with the vessels in the system on the West lane. One of the many attributes in the table was a replication number. As the simulation run begins, the coding on this event generates a replication table through SQL (Structured Query Language) instructions. The replication table contains only those vessels and corresponding attributes for the specific replication. The SQL instruction validates the replication number through a SIMAN variable that contains this data and is updated on every replication. In the same manner the replication table is updated with the corresponding data. Since the number of vessels vary based on the GIS GUI input, it not possible to have an Arena create module with a set number of entities. Within this event there is also a coding scheme that counts the number of records in the replication table and assigns it to a variable called VesselCount. This variable was introduced into the create module through object-oriented programming in the entities per arrival field along with a batch number of one in max arrivals. This implies that all vessels will arrive at the same time, which is at time equal zero. The logic behind this decision is that the vessels are already in the system and do not require any arrival distribution.

When the simulation run begins, vessels in the system are generated in the create module at time equal zero and proceed through a series of decide modules which will re-direct them to the corresponding navigation channel based on the navigation channel attribute created in the GIS model. As the navigation channels are selected, an assign module calculates the remaining travel time dividing the remaining navigation channel travel distance by the allowed travel speed and adds a time travel attribute to the vessel entity. The vessel is then connected to the navigation channel through a route module.

The Panama Canal has three scenarios that can be modeled:

1. Traffic heading northbound and southbound simultaneously in both transit lanes.

2. Traffic heading northbound in both transit lanes
3. Traffic heading southbound in both transit lanes

The scope of this research focuses on the simulation model initialization. Banks, Carson, Nelson, and Nicol (2001), suggest several methods of reducing the initialization bias in a steady-state simulation in order to avoid any artificial and unrealistic initial conditions in this type of simulation. If it is an existing system, the approach would be to collect data and use it to specify more typical initial conditions. "It is recommended that simulation analysts use any available data on existing systems to help initialize the simulation, as this will usually be better than assuming the system is to be completely stocked, empty and idle, or brand new at time 0" (Banks, Carson, Nelson, and Nicol 2001). In order to proceed with this method vessel data was generated based on existing historical mix. Moving forward, it was necessary to establish a single overall output performance measure that was entered into the statistic module of Arena in order to compute the total work in process (WIP) of all vessels combined. The history of this variable was tracked by plotting the curve versus time during the simulation in order to have a visual approximation on when the curve appears to have stabilized in order to specify a reasonable warm-up period. On all three scenarios the curve was plotted for the initialized and non-initialized system and it was demonstrated how the non-initialized system would require a warm-up period in order to gather un-biased statistical data versus the initialized system which allows collecting statistical data without a warm-up period.

### 2.3.2. Navigation Channels

As previously mentioned, there are five navigation channels: Pacific Entrance, Miraflores Lake, Gaillard Cut, Gatun Lake, and Atlantic Entrance. The entrances need to be modeled differently from the others because these need to have a module to create vessels transiting northbound or southbound. The entrance starts with a create module to generate vessels followed by an assign module which will give the originating vessel the same attributes as described for the initialization vessels except for the distance. This attribute is not needed because these are starting from the beginning and will transit all the navigation channels in the waterway. As there are two transit lanes the channels need to take into consideration the East and West lane as well as the direction which could be northbound or southbound. There are two decide modules which will direct the vessel based on its attributes. If the vessel is traveling northbound from the Pacific Ocean, the module will direct the vessel towards the Miraflores Locks, and if the vessel is traveling southbound, it will direct the vessel towards the Pacific Ocean. The other navigation channels are basically the same except for the module to

generate the vessels and modeling an exit to any of the two Oceans.

### 2.3.3. Canal Locks

The locks' modules vary in modeling complexity based on the number of chambers. The Pedro Miguel locks only have one chamber on each side, one for the East lane and one for the West lane, therefore, it only needs a process module per chamber. Following the same logic as the navigation channels it needs to consider the vessel direction, in this case if the vessel is heading northbound the next modeling section will be the Gaillard Cut, and if it is traveling southbound the next modeling section will be the Miraflores Lake.

The highest complexity increases when modeling the Gatun Locks. These locks have three chambers per lane and determining the modeling logic for vessels heading northbound or southbound is more challenging. Every chamber requires a decide module because from each module there are two options based the heading attribute. A vessel in chamber 1 can be directed to chamber 2 or to the Gatun Lake, consequently, a vessel in chamber 2 can be directed to chamber 1 or chamber 3, and finally a vessel in chamber 3 can be directed to chamber 2 or to the Atlantic entrance.

All the processing times in the locks were determined by distribution utilizing the Input Analyzer from Arena. Processing times are based on vessel categories and historical times gathered the Panama Canal Authority (2003).

## 3 RESULTS

In this paper, the results for scenario 1 will be demonstrated. Figure 10 shows a graph with the behavior of the WIP curve with 5 replications superimposed on the graph.

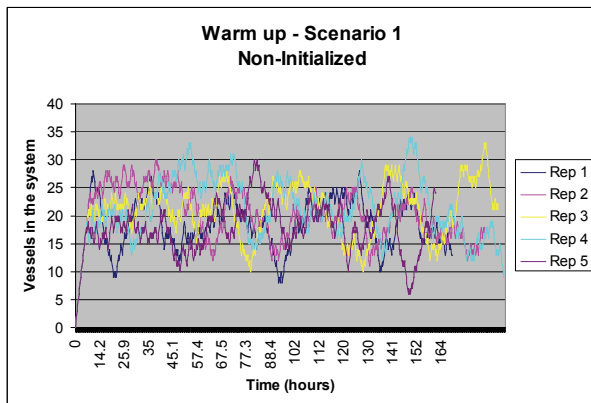


Figure 10: Scenario 1 Non-Initialized

The system starts stabilizing between 14 and 15 hours, a reasonable warm-up period would at about twenty four hours before gathering statistical data. With this setting, the average WIP was of 18.950 at a 95% confidence interval with 60 replications.

Figure 11 is a graph of the WIP curve with 5 replications superimposed, demonstrating the system being initialized with 15 vessels at time equal zero.

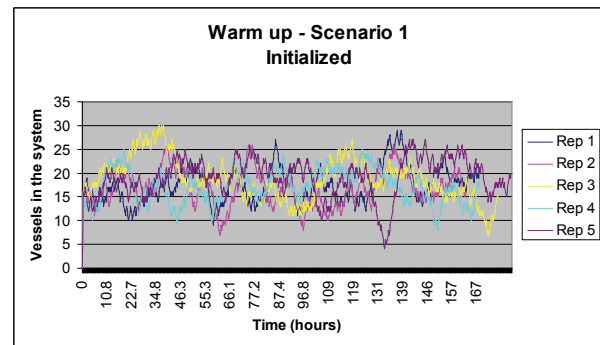


Figure 11: Scenario 1 Initialized

There were no warm-up period considerations for this simulation run. The warm-up period at Arena's replication parameters was set to 0. With this approach, the average WIP was of 19.316 at a 95% confidence interval with 60 replications.

From the results of the non-initialized system, it can be inferred that 15 vessels in the system utilized for the initialized system might not have been the correct number of vessels to have at time equal zero. A number closer to 18.950 based on the simulation results may have been a better approach. The number of 15 vessels was more to emulate choosing vessels at a real-time scenario of the Canal, which could still be the case.

The results presented in this paper demonstrate the logic behind the GIS/Arena integration and how the results are gathered in order to demonstrate its functionality. The initialized and non-initialized work in process graphs demonstrate the effect of starting the simulation empty and idle versus starting the simulation with vessels already in the system. It is obvious from the graphs, that the non-initialized system will require a warm-up period in order to have the capability to gather statistics within a certain confidence level without being biased. The modeling approach developed by Franzese, Abdenur, Starks, Botter, and Cano (2004), consisted of three inputs components: vessel arrival mix, traffic rules, and vessel pre-sequencing. The time between arrivals was based on historical or forecasted demand assigning the vessel type attributes to establish the transit rules. The model developed in this research incorporates vessel arrival mix based on historical data taking into account vessel types as attributes in order to establish the navigation rules. The input consists of an initialization interface that allows the placement of vessels currently in the system at the beginning of the simulation. This application provides the flexibility to model different scenarios inside the Canal. It is a new method for generating replications based on a simulation map.

#### 4 SUMMARY AND CONCLUSIONS

In summary, the modeling approach implemented in this research demonstrated two new techniques in simulation:

1. Model initialization. It introduces vessels in the system at the start of the simulation rather than having to warm-up the model in order to gather un-biased statistical data. It provides the flexibility to model different scenarios inside the Canal by varying the vessel mix based on historical data or real-time vessel selection.
2. Simulation replications. It introduces a new method for generating replications in simulation runs. As the vessels are initially placed in the system at the start of simulation based on specific coordinate locations, these same types of vessels are randomly relocated at different coordinate locations at the beginning of each simulation replication for the length of the simulation run.

#### REFERENCES

- Banks, J., Carson II, J.S., Nelson, B.L., and Nicol, D.M., 2001. *Discrete-Event System Simulation*. 3rd ed., Upper Saddle River, NJ: Prentice Hall.
- Burke, R., 2003. *Getting to Know ArcObjects: Programming ArcGIS with VBA*, Redlands, CA: ESRI Press.
- Franzese, L.A.G., Abdenur, L.O., Starks, D., Botter, R.C. and Cano, A., 2004. Simulating the Panama Canal: Present and Future. *Proceedings of the 2004 Winter Simulation Conference*, 1835-1838.
- Kelton, W. D., Sadowski, R.P., and Sturrock, D.T., 2004. *Simulation With Arena*. 3rd ed., Boston, MA: McGraw-Hill.
- Murad-al-shaikh, M., Page, K., Stewart, M., and Taggart, M., 2003. *Introduction to ArcGIS I (for ArcView 8, ArcEditor 8, and ArcInfo 8) Course Lectures and Exercises*. Redlands, CA: ESRI Press.
- Panama Canal Authority, 2003. *Simulation Model of Panama Canal Transit Operations - Request for Proposals No. CDO-150552*. Panama: Panama Canal Authority.

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# SCATTER SEARCH OPTIMIZATION OF AN INLAND WATERWAY TRANSPORTATION SYSTEM

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## ABSTRACT

This paper presents an optimization-simulation model for determining inventory operating policies for an inland waterway transportation system involving petroleum delivery. The overall process involves the use of a criterion model, represented as a decision maker's utility function, and an optimization procedure which employs scatter search. Variance reduction techniques are also employed in order to improve the accuracy of the estimates of the performance measures associated with the system. The main purpose of the system is to determine values for inventory policy variables such as the reorder points and reorder quantities at various network locations.

Keywords: Logistics, Simulation, Optimization, Inventory Modeling

## 1. INTRODUCTION

This paper describes a simulation-based decision support system for determining operating policies for a barge transportation system on an inland river system. In addition to a simulation model, the system relies on the input of a decision maker's utility function over conflicting performance measures, the use of standard variance reduction techniques, and an optimization procedure based on the heuristic optimization procedure, scatter search (Glover and Laguna 2000).

The next section of this paper gives a brief description of the system under study and the associated simulation model. The third section of the paper gives an overview of the decision support system, including a discussion of the utility function, the optimization methodology, and the variance reduction techniques employed. The fourth section of the paper provides an illustrative example of the use of the system. Finally, the fifth section of the paper provides a summary and conclusions.

## 2. DESCRIPTION OF THE TRANSPORTATION SYSTEM AND MODEL

The application was developed to aid a decision maker in a complex, stochastic environment. The Arena software package (Kelton, Sadowski, and Sturrock 2007) was chosen as a base for the DSS. The flexibility of Arena is demonstrated in this research as the DSS includes Arena modules, SIMAN blocks, imbedded Visual Basic for Applications, and is manipulated by external Visual Basic code.

The objective of this study was to determine the best values for reorder points and reorder quantities for fuel deliveries in an inland waterway system. The fuels are delivered to six locations on the river system. All trips begin and end at a supply location, Location 6. Locations 1 through 5 are upriver of Location 6, while Location 7 is downriver. The fuels are delivered by a tow system. Each tow consists of four barges; a barge is made up of ten tanks. A barge can be loaded with either all diesel or all non-diesel fuel, i.e., diesel and non-diesel cannot be mixed within a barge. However, diesel and non-diesel can be mixed within a tow. The system operated according to a reorder point, order –up-to quantity. That is, the main control variables associated with the inventory policy were the reorder point and the maximum capacity for each storage tank (i.e., demand point).

There is one supply location in the system, and it is assumed that this supply point never runs out of fuel. Barges are loaded at a rate of 5000 barrels per hour, and unloaded at a rate of 2800 barrels per hour.

The simulation model employs respective variables to represent the fuel levels of various types at each location in the system. Each day an entity is created for each fuel at each location. This entity decrements the level of the variable representing the level of that fuel type for that particular location. If the level of the on-hand inventory is below a set reorder point, a check is made to determine if there is a stockout situation. If there is a stockout, a counter is incremented and a mechanism is invoked to record the amount of time associated with the stockout.

The entity can now be thought of as an order to replenish inventory.

Depending on the destination of the fuel, the tow will travel through one or more set(s) of locks. The stochastic nature of the locking process is accounted for in the simulation model. Based on historical data, the locking times are assumed to follow a triangular distribution with a minimum of one hour, a maximum of three hours, and a mode of two hours.

Upon arriving at the lock, the tow attempts to seize a resource representing the lock. If this resource is busy, the tow waits in queue for passage through the lock. The locking time, or time required to traverse the lock, is a source of uncertainty in the model. The tow travels to its destination, seizing and delaying at locks as required. In this way, the tow is delayed for the appropriate travel time to and from its destination. When the tow arrives at its destination, each entity is then routed to the appropriate storage based on its attributes, where it decrements the total number of orders in the system and increments the level of inventory.

### 3. SCATTER SEARCH OPTIMIZATION, UTILITY FUNCTION, AND VARIANCE REDUCTION

The decision support system consists of several components, including the simulation model, an optimization procedure based on scatter search, a utility function to represent the tradeoffs that the manager is willing to make between the various performance measure associated with the system, and a procedure to allow for variance reduction with respect to the estimates of these performance measure values. The basic simulation model was described in the previous section of the paper. This section will describe the optimization algorithm, the utility function, and the variance reduction techniques employed.

The optimization algorithm used for this application was scatter search. As noted by Glover, Kelly, and Laguna (1999), "Scatter search focuses on generating relevant outcomes without losing the ability to produce diverse solutions, due to the way the generation process is implemented." For example, newly generated points are not convex combinations of the initial points. These new points are extrapolations, containing information not contained in the initial reference points.

Scatter search employs two concepts to guide its search: quality and diversity. The quality of a solution refers to the value of the objective function, while the diversity of a solution set refers to the differences between pairs of solutions in the reference set. Requiring a specified level of diversity helps to assure that the procedure will not get trapped at a local optimum. The basic scatter search design can be described as follows.

The diversification generation method is employed to "generate a starting set of solutions to guarantee a critical

level of diversity" (Laguna and Marti 2003). For the purpose of the diversification generation method, the application divides the range of each decision variable value into four subranges of equal size. A solution is then constructed in two steps; a subrange is randomly selected, and then a value is randomly generated from the selected subrange. The diversification generation method focuses on the diversity of the solutions and not the quality. Each solution is then passed to the improvement method.

The improvement method is used to improve the set of diverse solutions, thereby producing a set, denoted by  $R$ . The improvement method used for this application is Nelder and Mead's (1965) simplex method. This method is a classical numerical search technique for unconstrained nonlinear optimization problems. The improvement first constructs the current simplex for each diverse solution. The construction of the initial current simplex requires an initial point and a step factor, or distance between two vertices. The initial point is generated by the diversification generation method, while the step factor is input by the decision maker.

The improvement of diverse solutions is repeated until the set  $R$  contains the number of unique members specified by the decision maker. The reference set is typically small, made up of no more than 20 solutions. The Reference Set Update Method is then invoked.

The Reference Set Update Method is used to designate a reference set of the best solutions. The best solutions are not based solely on objective function value. A solution may be added to the reference set if it improves the diversity of the set even when the objective function value of the solution is inferior. In this way the reference set includes both high quality and high diversity members from the improved solutions.

The decision maker specifies the size of the reference set,  $b$ , at the start of the procedure. The Reference Set Update Method forms two mutually exclusive subsets,  $b_1$  and  $b_2$  such that  $b_1 \cup b_2 = b$ , so  $|b_1| + |b_2| = |b|$ , where  $b_1$  represents the subset of high quality solutions and  $b_2$  represents the subset of high diversity solutions. The reference set,  $RefSet$ , is formed as follows: The set  $R$  of improved diverse solutions is sorted in ascending order based on objective function value. The top  $|b_1|$  solutions are added to  $RefSet$  and removed from  $R$ . The remaining  $|b_2|$  members of  $RefSet$  are added based on a maximum value of minimum Euclidean distance as follows: For each remaining member of  $R$ , we calculate its Euclidean distance from each member of  $RefSet$ . The minimum Euclidean distance for each member of  $R$  is stored. The member of the set  $R$  with the maximum minimum Euclidean distance metric is removed from  $R$  and added to  $RefSet$ . We then calculate the Euclidean distance for each remaining member of  $R$  to each member of  $RefSet$  and

repeat the process until the size of *RefSet* is that specified by the decision maker.

The Subset Generation Method consists of generating subsets from the reference set that will be used for creating new solutions. The subsets generated in the Subset Generation Method consist of all two element pairs. The number of this type of subset is  $(|b|^2 - |b|)/2$ . These subsets are then combined using the Solution Combination Method. The Solution Combination Method is used to develop new solutions based on structured combinations of the subsets generated in the Subset Generation Method. These combinations are structured to create points “both inside and outside the convex regions spanned by the reference solutions” (Laguna and Marti 2003).

The individual subset solutions formed by the Solution Combination Method are then improved using the Improvement Method as previously described.

The reference set is then updated as previously described and the stopping criteria are checked. The improved solutions are sent to the Reference Set Update Method and the process iterates until the stopping criteria are met.

The stopping criteria can be based on the decision maker’s preferences in terms of the membership of the reference set, the number of iterations, or the elapsed time. For example, when the reference set is updated, it is checked for new members. If all members or a specified number of members are new, the process is repeated. If no new members have been added, the process stops. The decision maker can alternatively specify the number of iterations after which the best solution found thus far will be selected. Finally, the decision maker can specify a time limit on the search. For the purposes of the applications described in this paper, the decision maker is asked to specify a number of iterations as the stopping criteria.

The objective used to guide the scatter search optimization procedure is the maximization of expected utility. This is a single attribute utility function, in which the attribute is the overall cost, as a function of the reorder point and reorder quantity settings. The costs considered include the total penalty cost (TPC), variable transportation cost (VTC), and the total inventory holding cost (IHCTotal).

The total penalty cost (TPC) is the sum of the product of the number of backorders (BO) and the backorder cost (BOC) and the product of the penalty cost (PC) and the number of days with zero inventory (Penalty) as shown in below.

$$TPC = (BO * BOC) + (PC * Penalty) \quad (1)$$

After decrementing the inventory, the entity checks the level of the inventory versus the reorder point. If the inventory is below the reorder point, the entity then checks

whether or not the inventory is negative. If the inventory is negative the entity increments the value of the variable BO by one. The values of BOC and PC are set and do not change during the simulation run.

The Variable Transportation Cost (VTC) is the product of a per mile transportation cost (PMTc) and the distance traveled (DT) as follows:

$$VTC = PMTC * DT \quad (2)$$

The value of PMTC is set and does not change during the simulation run.

The Inventory Holding Cost (IHCTotal) is the sum of the individual inventory holding costs for each of the six fuel types at each of the six locations. The individual IHC’s are calculated as the product of three terms: the average level of inventory for a specific fuel at a specific location in units of barrels, a constant  $h$  (a holding charge in units of \$/barrel/day), and  $D$  (the number of days simulated). The average level of inventory of fuel could be a negative number; therefore the individual holding cost for fuel type  $i$  at location  $j$  is calculated as shown below.

$$IHC_{ij} = \max(\text{DAVG}(\text{fuel}_i \text{ at location}_j) * h * D, 0) \quad (3)$$

IHCTotal is then simply the sum of the individual inventory holding costs over all fuel types and locations. Finally, the total solution cost (TSC) is calculated as the sum of TPC, VTC, and IHCTotal. The output from the simulation model is a single value describing the cost for a specific vector of reorder point settings.

Each evaluation performed as part of the optimization procedure discussed above involves the employment of the simulation model. Several replications are made at each design point in order to obtain an estimate of the expected utility for that design point. In order to improve the accuracy of the estimates (i.e., reduce the variances), two common variance reduction techniques are employed.

The variance reduction techniques (VRTs) used in this application are common random numbers and antithetic variates. Common random numbers (CRN) is perhaps the most widely used VRT. Janssens, Deceuninck, and Van Breedam (1995) explain that the CRN methodology is usually used to estimate the difference between the expected performance measures of multiple systems. The CRN method uses the same underlying uniform random numbers to drive the simulation and to make sure that these random numbers are used at exactly the same place for each system. The basic idea is that the random noise will be the same for both systems; therefore the observed differences between the systems will be due to their differences, not random noise.

The concept of antithetic variates (AV) resembles CRN. L’Ecuyer (1994) explains that the idea is that very unlucky events in the first simulation should be



compensated by “antithetic” very lucky events in the second one and vice versa, thus reducing the variance on average. So, we run the model using a sequence of underlying IID uniform deviates,  $U$ 's, to drive the simulation for computing the unbiased estimate of the mean, for example, then we drive the simulation using the antithetic sequence,  $(1 - U)$ 's, to compute another unbiased estimate of the mean. The average of these two then becomes our new estimate for the mean, which should have a smaller variance.

#### 4. AN ILLUSTRATIVE APPLICATION

Various runs were made for three types of utility functions, involving a “decision maker” who was either risk averse, risk prone, or risk neutral. Note that a risk neutral decision maker is the same as one who wishes to minimize total expected cost.

The decision maker initializes the start of the operation associated with the decision support system by setting values for a series of parameters, including the initial inventory levels and lower and upper bounds for all tanks, the capacities associated with the barge-tow configurations, and the parameter for the scatter search and Nelder and Mead simplex search schemes.

The simulation is set up for a one-year run in real time. For the risk averse case, a total of 142,238 replications at various design points, and expected utility was improved from an initial value of .915 to a final value of .973 through the search process.

#### 5. SUMMARY

This paper has illustrated how various modeling techniques, including heuristic optimization procedures such as scatter search, simulation modeling, variance reduction methods, and utility functions can be merged to solve a complex problem in logistics.

#### ACKNOWLEDGMENTS

This paper is based on the first author's PhD dissertation (Anderson 2004).

#### REFERENCES

- Anderson, N.P., Simulation optimization of logistics systems through the use of criterion models, Ph.D. Dissertation. 2004. Department of Industrial Engineering, University of Louisville, Louisville, Kentucky.
- Glover, F., J.P. Kelly, and M. Laguna. 1999. New advances for wedding optimization and simulation. In *Proceedings of the 1999 Winter Simulation Conference*, The Association for Computing Machinery, 255-260, New York, NY.
- Glover, F. and M. Laguna. 2000. Fundamentals of scatter search and path relinking. *Con. and Cyb.* **39** (3), 653-684.
- Janssens, G. K., W. Deceuninck, and A. Van Breedam. 1995. Opportunities of robust regression for variance

- reduction in discrete event simulation, *Journal of Computational and Applied Mathematics*, Vol. 64, No. 1-2, 163-176.
- Kelton, W. D., R.P. Sadowski, and D.T. Sturrock. 2007. *Simulation With Arena*, 4<sup>th</sup> Edition, McGraw-Hill, Boston, MA.
- Laguna, M., and R. Marti. 2003. *Scatter Search Methodology and Implementations in C*. Kluwer Academic Publishers., Boston, MA.
- L'Ecuyer, P. 1994. Efficiency improvement and variance reduction, 1994 *Winter Simulation Conference Proceedings*, The Association for Computing Machinery, 122-132, New York, NY.
- McGeoch, C. 1992. Analyzing algorithms by simulation: variance reduction techniques and simulation speedups, *ACM Computing Surveys*, Vol. 24, No. 2, 195-212.
- Nelder, J.A. and R. Mead. 1965. A simplex method for function minimization. *Computer Journal* **7**, 308-313.

#### AUTHORS BIOGRAPHY

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# REENGINEERING PORT PROCESSES THROUGH SIMULATION SUPPORT

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## ABSTRACT

In the last decades the management of ports has become ever more difficult. The goal of port management is to let ports evolve from logistic distribution centres into transport solution providers. Such evolution can be achieved through Business Process Reengineering (BPR), often jointly to the implementation of Information Technology (IT) solutions. Such approach does not always give the expected results. It is thus very important to use the most suitable tools. In this paper we propose an example of the path followed to study the processes related to four European ports (Taranto, Kavala, Thessaloniki, Igoumenitsa) and show the methodology for the first steps of BPR (as-is process representation and analysis). In our research we studied 10 processes and applied our methodology for their representation and analysis. As an example, focusing on one process, we show how to implement such methodology and how to use a simulation software for the as-is process analysis.

*Keywords:* Business Process Reengineering, Port, Simulation

## 1. INTRODUCTION

In the last decades we have assisted to a radical change in the way ports are considered. Indeed, the ports are evolving from logistics distribution centres (the so called third generation) into transport solution providers (namely the fourth generation), thus becoming 'lean' ports (UNCTAD 1999).

The challenge for a lean port is to quickly move cargo and smoothly deliver a service in alignment with the market demand while eliminating all types of waste in the physical and documentary/information processes (Marlow and Paixao 2003). This evolution is based on the concepts of leanness, flexibility, just-in-time and BPR techniques (Marlow and Paixao 2003).

Processes reengineering is a crucial issue to ensure that the port system is efficient. The drivers of port efficiency do not only consist of infrastructure variables, but also of management and/or policy variables. As stated by Clark et al. (2002), the greater the efficiency at the port

level, the lower the transport costs, consequently the higher is the ship turnaround. Port efficiency is an important determinant of handling costs too. As a consequence, BPR is necessary for many ports that want to increase their competitiveness.

BPR is offered as an enabler of organizational transformation (Davidson 1993, Venkatraman 1994). Organizations usually adopt a BPR approach when they believe that a radical improvement can be achieved by marrying business processes, organizational structure, and IT change (Stoddard and Jarvenpaa 1995). In the past the use of BPR for organizational transformation in the public sector has largely been neglected. However the trend has changed in the last years and several studies on BPR in Public Administration have been published. For example, in a report entitled "Reengineering through Information Technology" (1993), the US government identified a strategy with several major initiatives to reengineer government services in order to meet the demand for better performance.

While lessons drawn from studies using private-sector organizations might be useful, these findings are not always applicable to public sector organizations since such organizations usually face different sets of issues, problems, and challenges (Swiss 1991).

According to this general approach, many ports have proceeded to reengineer their processes as a consequence of a joint IT introduction. The cases of Asian ports, such as Singapore and Hong Kong, which currently are the most competitive on a global context, are emblematic. The port of Singapore is a very large transshipment hub, serves everyday about 60 container vessels and moves about 45,000 containers (Port of Singapore Annual Report 2006). The key of its success is the rethinking of its processes focused on IT introduction. Such introduction allowed to fasten the information exchange not only inside the port, but also with customers, suppliers, etc. and to fully manage every issue related to administration and planning activities, and all the port operations (Gordon et al. 2005, Lee-Partridge et al. 2000, Tongzon 1995).

BPR does not always give the expected results. It is thus very important to use the most suitable tools. In this paper we propose an example of the path followed to

study the processes related to four European ports (Taranto, Kavala, Thessaloniki, Igoumenitsa). The study is part of a larger project, co-financed by the European Regional Development Fund (ERDF) through the INTERREG IIIB ARCHIMED Programme, aimed to promote intermodal transport, increase accessibility and connections with marginal internal areas, and take advantage of the potentialities of TEN-T (Trans-European Transport Network) Egnatia road axis. In particular we expose some results related to the activities focused on the development of an IT platform to support ports and stakeholders in managing administrative and organizational processes and accessing to information. More in detail, we describe in the paper the process analysis that was preparatory to the development of the platform. In particular, we deal with the first phase of BPR, namely the 'diagnose', as defined by Kettinger et al. (1997).

The paper is organized as follows. First we expose the research methodology used, identify the critical processes for each port involved in the research, and provide an overall representation of the port operations. Then we apply the methodology on one process, namely the Management of the Bill of Lading, and simulate such process to analyze the related performance. Finally we give the results of the simulation of all the critical processes (which we did not describe more in detail in the paper due to length's limits) and sum up several conclusions and insights for future research.

## 2. RESEARCH METHODOLOGY

The BPR literature proposes many methodologies for its implementation although the differences among them are little. To perform our task we followed the approach suggested by the coordination theory (Crowston 1997, Malone and Crowston 1994). Coordination theory perspective suggests identifying the variety of dependencies that arise in a process and the coordination mechanisms being used to manage them.

First of all we performed an extensive study of the literature that permitted us to better understand who are the ports actors and what is the role played by each of them. Moreover we identified the actors for every port involved in the project.

A port community involves many actors that need to exchange and handle many documents. There is a real difficulty in managing different organizations with different ways of thinking (and often languages) while at the same time respecting the international rules and laws.

One of the findings of our research has been that the port environment is composed by different actors so that the processes involved in such network are very often inter-organizational. Ports are complex and multi-part organizations in which institutions and functions often intersect at various levels (Bichou and Gray 2004).

The main protagonists that are typically involved in a port community are:

- Administrative Institutions (namely Port Authority, Harbour Office, Maritime Health Office, Pilots, Towboats, Mooring Personnel);
- Police Institutions (namely Financial Police, Custom House);
- Traders (namely Ship-owners, Shipping-companies, Receivers, Charterer);
- Intermediate (namely Port agents, Forwarding houses, Terminal);
- Financial institution (namely Banks, Chambers of Commerce).

The output of this phase is showed in Figure 1.

To collect data on the processes carried within the ports we conducted direct interviews with different port actors (Shipping Agency managers, Port Authorities directors and clerks). Two members of the research group went to Greece to interview the actors operating in the Greek ports involved in the project.

From the literature review and the direct interviews, we were able to report a list of the processes carried out within a port.

We also defined a questionnaire to be submitted to the Port Authorities involved in the project in order to identify the critical processes carried out in their own ports. The questionnaire reported a list of the main processes carried out within a port and the main activities carried out within the mentioned processes. When submitted to the interviewed persons, the questionnaire was used as a reference during the interview. Once the critical processes were identified by using the questionnaire, the interview was focused on the collection of data about such processes. The questionnaire was not submitted only to the interviewed persons but was also submitted to the main actors in the ports involved in the project.

By the analysis of the interviews and the responses to the questionnaire submitted to different ports actors, we were able to identify the critical processes for each port involved in the project. The list of the critical processes is reported in

Table 1.

After the identification of the critical processes we represented and analyzed them. For the representation we created, for each process:

- the root definition (i.e. the identification of CATWOE, namely Customers, Actors, Transformation, Worldview, Owner, Environment);
- the tree diagram;
- a tabular representation (for each activity we identified inputs, outputs, resources, and duration); and
- the reticular representation.

Table 1: Critical Processes

Port	Critical processes
Taranto	Releasing of the Health Practice
Igoumenitsa	Management of the Documentation for Waste Disposal
	Management of ship failures
	Management of the cargo loading
Kavala	Management of the Bill of Lading
	Bunkering management
	Management of containers in equipped areas
	Management of the International code for the Security of Ports and Ships (ISPS)
Thessaloniki	Integration between port and railway
	Management of works

Then with the support of a specific software (namely Simprocess®) we simulated and analyzed such processes. One of the problems in the process analysis has been the data gathering; indeed not ever the needed data were available or exhaustive. When we found a lack of data for a process, this process was simulated making reasonable hypotheses about the lacking data. Nevertheless we checked with the interviewed people that such data were coherent with the reality.

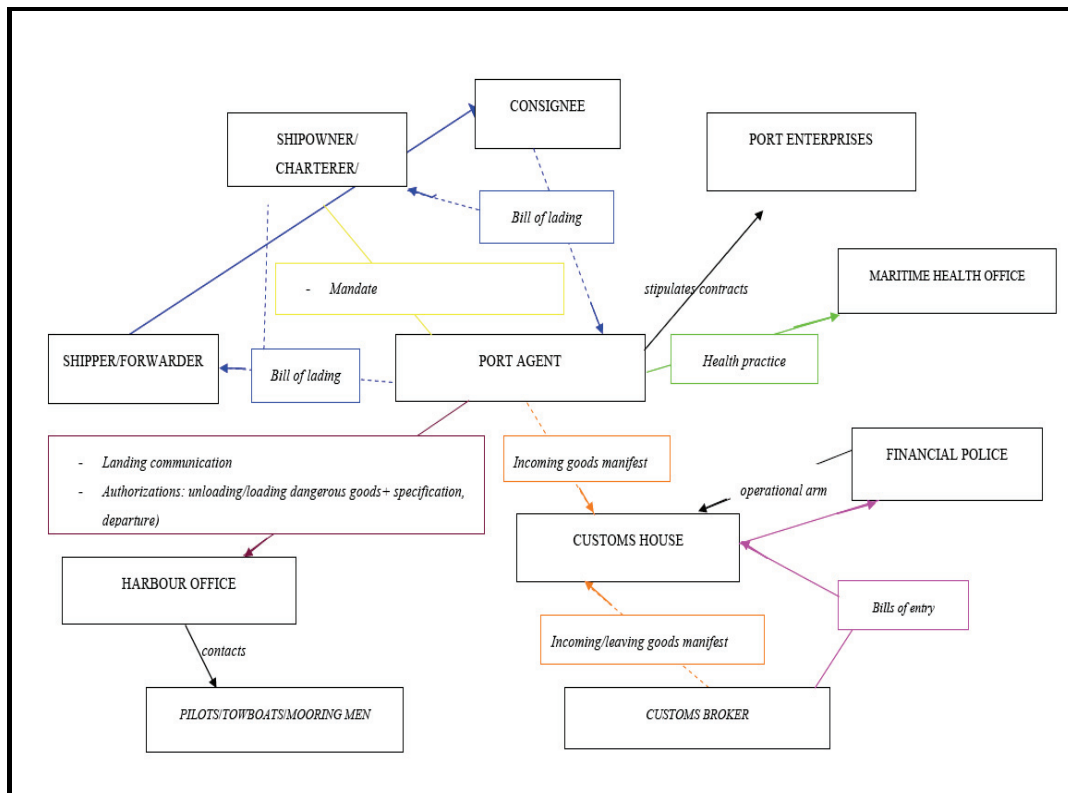


Figure 1: Flows among the Actors Involved in the Port Processes

Next we represent, simulate and analyze only one process as an example, namely the Management of the Bill of Lading. The remainder of the paper is articulated as follows: first we describe the process, then we represent it, and finally we simulate it and analyze the results.

### 3. PROCESS ANALYSIS AND REPRESENTATION

The 'Management of the Bill of Lading' process starts when the Shipper has to make a cargo shipment and needs the Bill of Lading. The process stops when the Bill of Lad-

ing is delivered to the Receiver that forwards it and receives the shipment.

The process customer is the Receiver that, by delivering the received Bill of Lading, qualifies as such and receives the shipment. The process actors are: Shipper, Ship's Master, Port Agent, Receiver, Chamber of Commerce, and Bank. The process transformation is:

Drawing up of the Bill of Lading → Bill of Lading in Receiver's hands

The process worldview is to let the Receiver qualify as such and pick up the cargo arrived at the destination port.

The process environments are the ship delays in arriving at the destination port.

The tree diagram (Figure 2) uses blocks to represent all the activities identified for the process, starting from an initial macro-block, i.e. the process itself, and then dividing it into the macro-activities that constitute the process. The decomposition of the activities is repeated until arriving to the single activities that constitute the process as it was characterized. Each activity represented within the diagram has a code that allows understanding to what macro-block the activity belongs. In the case of a two-way specialization (a situation in which two alternative routes are feasible), e.g. under the 1.2 block, the codes of the two lower level blocks are 1.2.a and 1.2.b.

The tabular representation (Table 2) summarizes each activity, with its code and its characteristics, i.e. descrip-

tion, inputs, outputs, actors, duration, costs, and technical and material resources. In the Duration column we highlighted in red the duration that has been hypothesized for the lack of data. Indeed, not ever it has been possible to gather accurate data from the actors. As stated above we verified with the actors that all the data hypothesized were coherent with reality.

Very useful for the software implementation is the reticular representation (

Figure 3) that graphically describes the activities so the entire path of the process from the initial event to the final event can be identified, along with the interdependencies among the activities. To identify the interdependencies, the inputs and outputs of each activity, as defined in the tabular representation, can be useful.

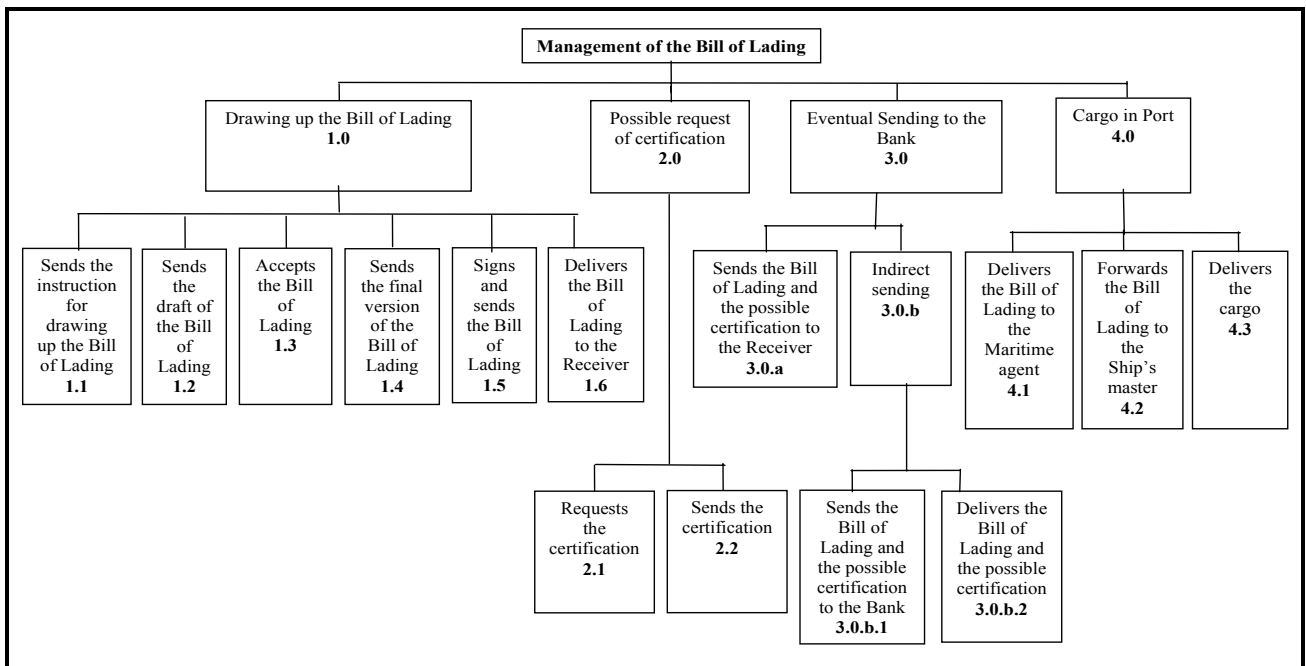


Figure 2: Management of the Bill of Lading (Tree Diagram)

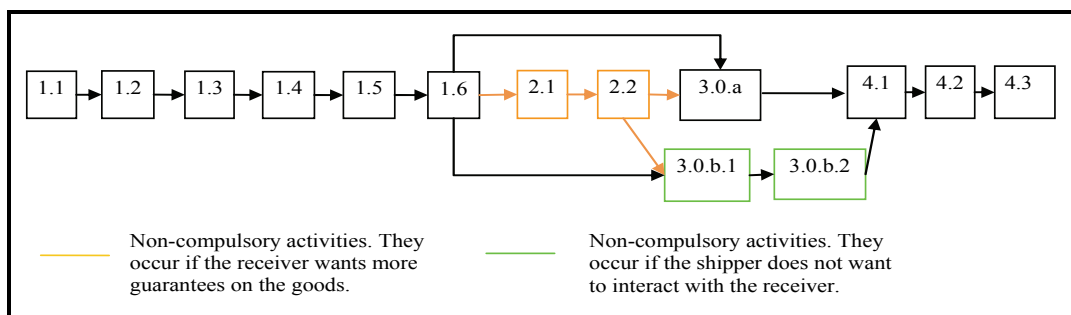


Figure 3: Management of the Bill of Lading (Reticular Representation)

Table 2: Management of the Bill of Lading (Tabular Representation)

Activity ID	Description	Actors	Input	Output	Duration			Communication tools
					Optimistic	Mean	Pessimistic	
1.1	Forwarding the instruction about drawing up the Bill of Lading	Shipper to Port Agent	Shipping of the goods	Instruction list	15 minutes	30 minutes	12 hours	Fax E-mail
1.2	Forwarding the draft of the Bill of Lading	Port Agent to Shipper	Instruction list	Draft of the Bill of Lading	15 minutes	30 minutes	12 hours	Fax E-mail
1.3	Acceptance of the Bill of Lading	Shipper to Port Agent	Bill of Lading draft	The latest version of the Bill of Lading		Immediate		Fax E-mail
1.4	Forwarding the final version of the Bill of Lading	Port Agent to Master	The latest version of the Bill of Lading	The latest version of the Bill of Lading		10 minutes		Face to face
1.5	Signing and forwarding the Bill of Lading	Master to Port Agent	The latest version of the Bill of Lading	Bill of Lading signed		10 minutes		Face to face
1.6	Delivering the Bill of Lading	Port Agent to Shipper	Bill of Lading signed	Bill of Lading signed		10 minutes		Face to face
2.1	Requesting the certification	Shipper to Chamber of Commerce	Bill of Lading signed	Forwarding of the request		1 hour		
2.2	Forwarding the certification	Chamber of Commerce to Shipper	Forwarding of the request	Certification		30 minutes		
3.0.a	Forwarding the certification and the Bill of Lading	Shipper to Receiver	Bill of Lading signed and certification	Certification and Bill of Lading signed		30 minutes		Courier
3.0.b.1.	Forwarding the possible certification and the Bill of Lading	Shipper to Bank	Bill of Lading signed and certification	Bill of Lading signed and certification		30 minutes		
3.0.b.2.	Delivering the Bill of Lading and the possible certification	Bank to Receiver	Bill of Lading signed and certification	Bill of Lading signed and certification		30 minutes		
4.1	Delivering the Bill of Lading	Receiver to Port of destination Agent	Bill of Lading signed	Bill of Lading signed		2 hour		Face to face
4.2	Forwarding the Bill of Lading	Port of destination Agent to Master	Bill of Lading signed	Bill of Lading signed		Immediate		Face to face
4.3	Delivering cargo	Port of destination Agent to Receiver	Bill of Lading signed	Picking up of goods		Immediate		Face to face

#### 4. PROCESS SIMULATION

Following we simulate the as-is model of the Managing the Bill of Lading. The simulation is the last step of ‘diagnose’ as defined by Kettinger et al. (1997). Indeed, with such step we can measure, through several indicators, the performance of the process. To carry out this task we utilize a specific software, namely Simprocess®. Simprocess® is an object-oriented process modelling and analysis tool that integrates process mapping, object-oriented simulation, and activity-based costing (ABC) into a single tool. Simprocess® allows representation of processes, people, and technology in a dynamic computer model. A model, when simulated, mimics the operations of the business. Because simulation software keeps track of statistics about model elements, performance metrics can be evaluated by analyzing the model output data (as in Figure 9).

In such model, in the first macro-activity, namely ‘Drawing up the Bill of Lading’, there is a deep information exchange among Shipper, Port Agent, and Ship’s Master. All these actors interact to produce the Bill of Lading.

On the basis of the information gathered through the interviews and considering the lacking of some data, we made the following assumptions for the simulation:

- The request of shipping the goods occurs once a day at 09:00 and for ten days, so we analyzed ten process occurrences;
- For all the simulation, the following actors are available: 20 Shippers, 20 Masters, 20 Receivers, 20 Banks, one Port Agent, and one Chamber of Commerce (the choice to insert a number of 20 actors for each role is aimed at not causing queues due to interferences between different process occurrences in the process simulation);
- The probability to request the possible certification is equal to 30%;
- The Shipper takes one hour to request the certification;
- The Chamber of Commerce takes half an hour to send the requested certification;

- The probability that sending the Bill of Lading and the possible certification to the Receiver happens in an indirect way is equal to 40%;
- The activity of sending the Bill of Lading and the possible certification to the Bank takes at least one hour, on average two hours and at most three hours;
- The delivery of the Bill of Lading from the Bank to the Receiver takes at least one hour, on average two hours and at most four hours;
- The delivery of the Bill of Lading to the Port agent takes two hours;
- The forwarding of the Bill of Lading to the Ship’s master and the delivery of goods to the Receiver occur only after the ship is arrived at the port, on average after another day since the Bill of Lading is delivered to the Port Agent;
- After forwarding the Bill of Lading to the Ship’s Master, it takes one hour before delivering the goods;
- The actors involved are available all the week days in the following hours:
  - Shipper and Chamber of Commerce: from 08:00 to 13:00 and from 15:00 to 20:00;
  - Port agent and Bank: from 08:00 to 13:00 and from 15:00 to 19:00;
  - Master and Receiver: from 08:00 to 20:00;

Some displays of the model created with the software are reported in the next Figures (4-8). Figure 4 shows the overall process, whereas Figures 5-8 show the activities included in the four blocks, namely ‘Drawing up the Bill of Lading’, ‘Possible request of Certification’, ‘Eventual sending to the Bank’ ‘Cargo in port’.

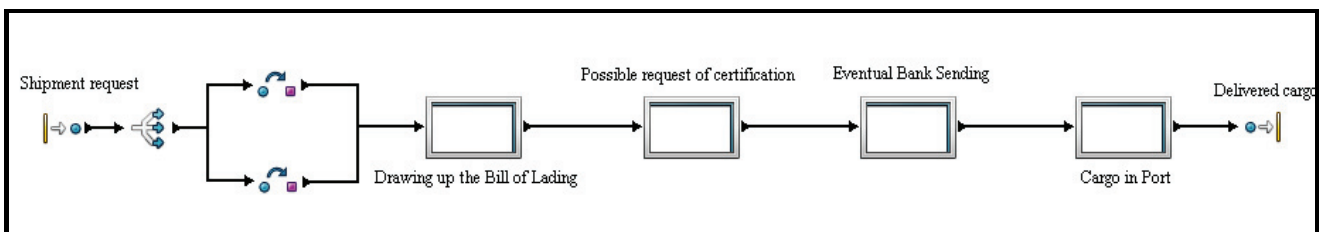


Figure 4: Bill of Lading: As-is Model (General View)

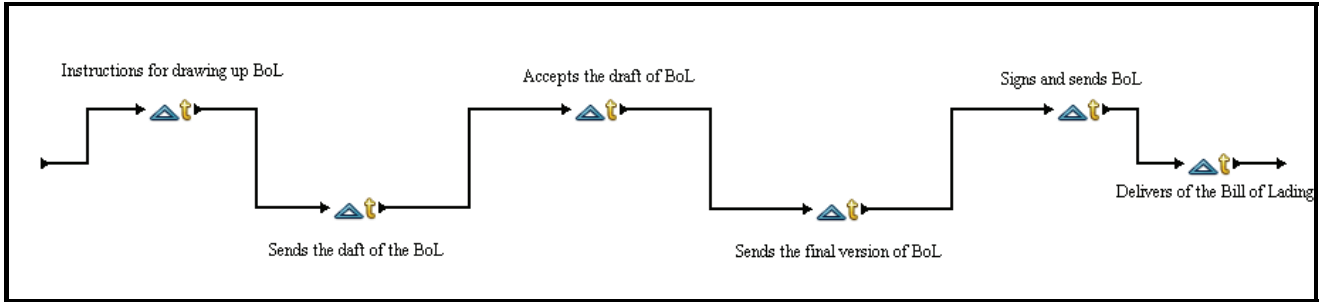


Figure 5: Drawing up the Bill of Lading (Macro-activity 1.0)

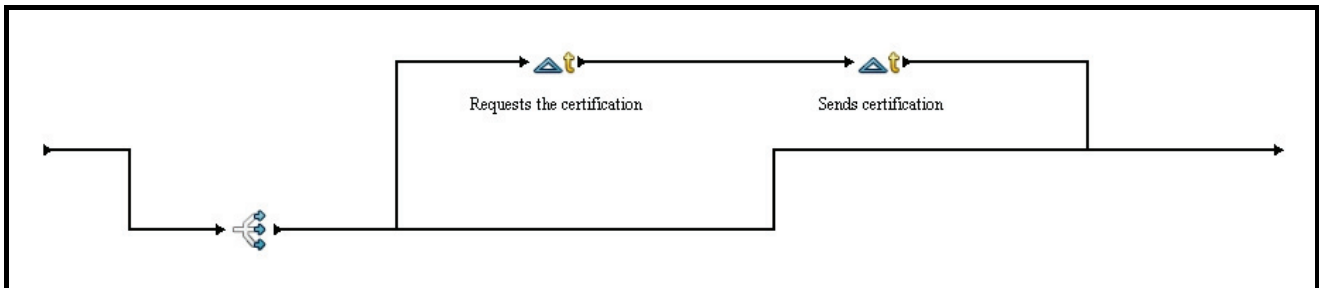


Figure 6: Possible Request of Certification (Macro-activity 2.0)

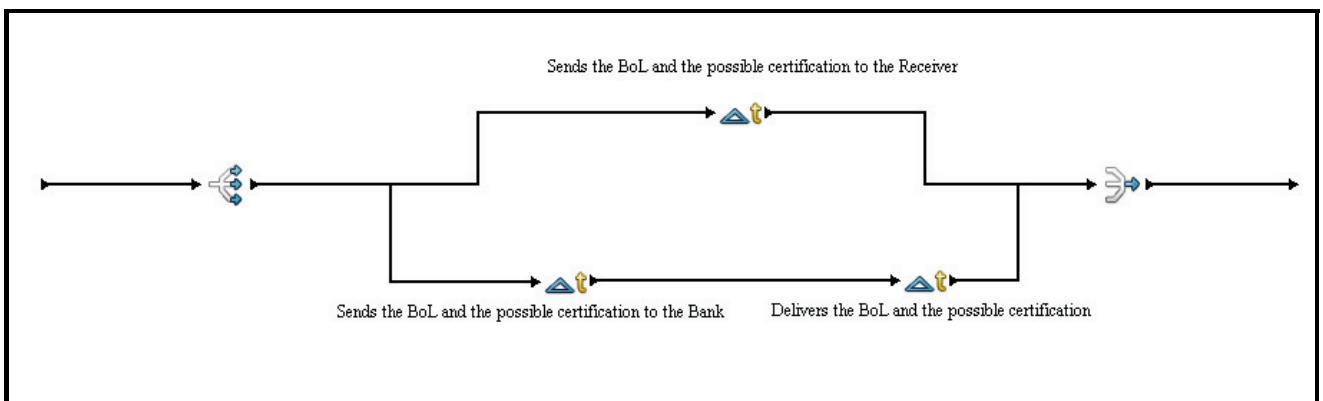


Figure 7: Eventual Sending to the Bank (Macro-activity 3.0)

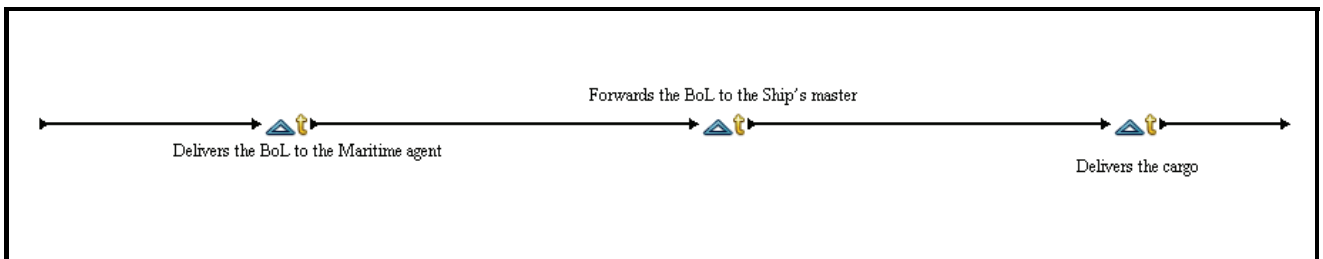


Figure 8: Cargo in Port (Macro-activity 4.0)



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SIMPROCESS Standard Report for Bill of Lading (as-is)
Simulation Run Duration 00:01:31.937
Actual Run Duration 184 days

Entity : Total Count - Observation Based : Replication 1
Entity Names      Total      Remaining  Total
                  Generated In System Processed
request + certific 59         0          59
shipment          184        0          184
simple request     125        2          123

Entity : Count By State - Time weighted : Replication 1
Entity Names      Total In System----- Processing----- wait For Resources-- Traveling-----
                  Average      Maximum      Average      Maximum      Average      Maximum      Average      Maximum
request + certific 0,926        3          0,191        2          0,241        2          0,494        3
shipment          0,000        1          0,000        0          0,000        0          0,000        1
simple request     1,912        5          0,356        3          0,514        4          1,042        5

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1
Entity Names      #Observed  Total In System----- Processing----- wait For Resources-- Traveling-----
                  Average      Maximum      Average      Maximum      Average      Maximum      Average      Maximum
request + certific 59         69,288      96,167      14,277      25,745      18,018      38,943      36,994      44,754
shipment          184        0,000       0,000       0,000       0,000       0,000       0,000       0,000       0,000
simple request     123        68,200     97,302     12,677     23,888     18,363     43,511     37,160     47,608

Resource : Number of Units By State - Timeweighted : Replication 1
Resource Names    Defined Capacity  Capacity  -----Idle----- -----Busy-----
                  Average      Maximum      Average      Maximum      Average      Maximum
Bank              20               20,000    19,337      20,000    0,038      2,000
Chamber of Commec 1               1,000     0,410       1,000     0,007      1,000
Master            20               20,000    19,493      20,000    0,007      2,000
Port Agent        1               1,000     0,253       1,000     0,182      1,000
Receiver          20               20,000    19,417      20,000    0,083      2,000
Shipper           20               20,000    19,186      20,000    0,231      3,000

```

Figure 9: Simulation Report (Partial View)

As emerging from the report generated by the software (Figure 9), during the whole simulation 184 requests of shipping goods were generated (one per day), but only 182 of them were completely processed, i.e. for these process occurrences the goods were shipped by the Port Agent. The remaining two requests did not complete their path because the simulation process was terminated. Moreover, 56 request of shipping with certifications are generated. The path followed by a shipping request to the final event interfered with the paths followed by the other shipping requests. At the most 5 shipping requests and 3 certifications were simultaneously processed. There were waiting times before performing activities because some actors were unavailable at that moment, since they were not working, due to the assumed working hours and the actors involved in performing other activities. The process lasts 68 hours on average for the simple request and 69 hours for the request with certification. 12.5 hours are for performing activities related to simple requests and 14 hours for requests with certification, almost 18 hours are for waiting due to the unavailability of the actors that perform the activities. The actors that work more within the process are the Shipper and the Port Agent. The activities that caused the entities to wait for being processed are:

- the sending of the certification by the Chamber of Commerce;

- the forwarding of the Bill of Lading by the Port Agent to the Master;
- the delivery of goods by the Port Agent;
- the sending of the draft of the Bill of Lading by the Port Agent; and
- the sending of the final version of the Bill of Lading by the Port Agent.

By analyzing the data by macro-activity, we noted that the entities (i.e. the Bills of Lading) spent almost 35.5 hours in 'Cargo in port' (4.0) almost 25.5 hours in 'Drawing up the Bill of Lading' (1.0), almost 0.5 hour in 'Possible request of Certification' (2.0) and almost 2.5 hours in 'Eventual sending to the Bank' (3.0). Considering that for 'Cargo in port', 24 hours are solely dedicated for physical operation (i.e. unloading goods, docking etc.), the real time spent for the administrative process is 11.5 hours on average. Consequently, the real bottleneck of the entire process is the 'Drawing up the Bill of Lading' macro-activity. In this macro-activity there is a heavy and redundant exchange of data that cause a great waste of time.

## 5. RESULTS OF THE ANALYSIS

Following the same methodologies utilized for the above example (root definition, tree diagram, reticular representation, tabular representation, and software simulation) we have analyzed all the processes indicated in

Table 1. For length's limits we do not show all the tables and figures related to such processes. We limit solely to sum up the results emerged by such study. In this manner we can have a wider comprehension of the port operation and its limits.

For the Management of the Health Practice at the port of Taranto there are no significant criticalities, since the overall duration of the activities aimed at releasing the Health Practice to the Ship's Master is much less than the time that is potentially available to release it. The ship thus has not to wait due to delays, once it is arrived.

As to the Bunkering management at the port of Kavala, there are no significant criticalities. Potential problems should be searched within the activities of communicating dates and hours of the ship arrival between the Port Agent and the Gas-oil company selected for bunkering. As emerging from the information gathered, the Port Agent, after an early communication concerning the ship arrival, does not get in touch with the selected company, although it would be important that the two actors involved in the process remain in contact.

As to the Management of containers in equipped areas at the port of Kavala, there were multiple requests of checking containers that interfered among them. A potential problem could thus be caused by the limited capacity of the container area in that port, which is still under construction. This area, since it does not allow to simultaneously work on a high number of containers, can cause delays in accepting requests.

As to the Management of works at the port of Thessaloniki, there was a work overload for the planning office.

As to the Management of Landing Communication at the port of Thessaloniki, the overall duration of the activities is much less than the waiting times for activities performed in parallel to be completed. This is an evidence of a complex process, which is open to enhancements through BPR techniques.

As to the Integration between Port and Railway at the port of Thessaloniki, there was a considerable difference between the overall time to perform the activities and the time needed to the train to arrive at the port. This confirms what emerged from the face to face interviews, i.e. the need to modernize the railway structure linked to the port of Thessaloniki.

During the literature review and the processes analysis we found that the processes can be divided into two categories: 'documental processes' and 'operational processes'. The former are characterized by heavy document flows (e.g. Releasing the Health Practice, Management of the Documentation for Waste Disposal, Management of the International code for the Security of Ports and Ships, Management of the Bill of Lading); as a consequence, the main criticalities derive from the management of the documental flow. In the latter (e.g. Integration between Port and Railway, Management of works, Management of containers in equipped areas, Management of ship failures,

Management of the cargo loading, Bunkering management) there is a predominant operative part. As a consequence, the main criticalities are influenced by the availability of facilities (e.g. docks, terminals), as well as of instruments and tools (e.g. cranes, trucks, ships). Consequently the 'documental processes' can be strongly influenced by BPR because the performance of such processes is mainly based on activity flow improvements, IT solutions, or bottleneck elimination. In the 'operational processes' the improvement of the performance should be obtained not only by BPR but mainly by increasing the resources (human or not) and the facilities. So the BPR effort must be mainly oriented toward the 'documental processes' to have real improvement.

## 6. CONCLUSIONS

In this paper we first highlighted the need for the ports to adapt their processes to the new global context through the BPR. Then we proposed a methodology based on graphic representation, tabular representation, and software simulation for the first step of BPR (i.e. 'diagnose'). As showed by the literature analysis and empirical evidence, ever more the ports need a rethinking of their processes. Very significant is the case of the port of Singapore. The BPR can be helpful to redesign the general operations of a port. The result of this effort is a radical improvement of the port performance. However the implementation of BPR is not simple, there are many ways of implementing it and many tools available. So it is very important to select the right path to follow.

In this paper we proposed the path followed to deal with BPR. The type of representation used for the process analysis (namely root definition, tree diagram, reticular representation, and tabular representation) was suitable for the next step, i.e. the implementation of the simulation software. Through the simulation support we highlighted the bottlenecks, the main workloads, and the inefficient activity flows.

Nevertheless it has to be noted that the main problem of the BPR implementation was the availability of relevant data. In this paper it is evident how the lack of some data reduces the precision of the analysis.

Finally, with this research we have started to create a repository of the most critical processes within the ports. Such repository could be very useful for all the actors involved in port activity. Indeed, not ever the actors know well who their partners in port processes are. Moreover such repository is useful for research and consulting scope; indeed the possibility to compare the same processes implemented by different ports can allow finding best practices.

Further research could be focused on gathering more available data to redesign the processes and simulate the to-be processes, in order to compare the as-is and to-be process performance, and to enhance the number of processes analyzed.

## REFERENCES

- Bichou, K., Gray, R., 2004. A logistics and supply chain management approach to port performance measurement. *Maritime Policy & Management*, 31(1), 47-67.
- Clark, X., Dollar, D., Micco, A., 2002. *Maritime Transport Costs and Port Efficiency. The World Bank Development Research Group Macroeconomics and Growth Policy Research*, working paper, 2781.
- Crowston, K., 1997. A coordination theory approach to organizational process design. *Organization Science*, 8(2), 157-175.
- Davidson, W.H., 1993. Beyond re-engineering: the three phases of business transformation. *IBM Systems Journal*, 32 (1), 65-79.
- Gordon, J.R.M., Lee, P.M., Lucas, H.C., 2005. A resource-based view of competitive advantage of the Port of Singapore. *Strategic Information System*, 14, 69-86.
- Kettinger, W.J., Teng, J.T.C., Guha, S., 1997. Business process change: A study of methodologies, techniques, and tool. *MIS Quarterly*, 21, 55-80.
- Lee-Partridge, J.E., Teo, T.S.H., Lim, V.K.G., 2000. Information technology management: The case of the Port of Singapore Authority. *Strategic Information System*, 9, 85-99.
- Malone, T.W., Crowston, K., 1994. The interdisciplinary study of coordination. *Computing Surveys*, 26 (1), 87-119.
- Marlow, P.B., Paixao, A.C., 2003. Measuring lean ports performance. *International Journal of Transport Management*, 1, 189-202.
- Port of Singapore Authority Annual Report, 2006.
- Stoddard, D.B., Jarvenpaa, S.L., 1995. Business process redesign: Tactics for managing radical change. *Journal of Management Information Systems*, 12 (1), 81-107
- Swiss, J.E., 1991. *Public Management System: Monitoring and Managing Government Performance*. Englewood Cliffs, NJ: Prentice Hall.
- UNCTAD, 1999. Technical note: Fourth generation port. *UNCTAD Ports Newsletter* 19, 9-12.
- Teo, H., Tan, B., Wei, K., 1997. Organizational transformation using electronic data interchange: The case of TradeNet in Singapore. *Journal of Management Information Systems*, 13 (4), 139-165.
- Tongzon, L.L., 1994. Determinants of port performance and efficiency. *Transportation Research A*, 29 (3), 245-252.
- The White House, Office of the US Vice-President, 1993. *Reengineering through Information Technology*. Washington, DC.
- Venkatraman, N., 1994. IT-enabled business transformation: automation to business scope redefinition. *Sloan Management Review*, 35 (2), 73-87.

## BIOGRAPHIES

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# COGNITIVE MIMO SONAR BASED ROBUST TARGET DETECTION FOR HARBOUR AND MARITIME SURVEILLANCE APPLICATIONS

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## ABSTRACT

Robust detection of various hostile threats is vital to protect Navy ships and other facilities under harbour and maritime environments. Traditional single-input single-output (SISO) sonar transmits single acoustic waveform by single projector, which has a few disadvantages including low target detection probability, low resolution, vulnerability of interception by the enemy, sensitivity to jamming, etc. Multi-input multi-output (MIMO) sonar is an emerging technology to overcome all these disadvantages. In this paper, cognitive monostatic/bistatic/multistatic MIMO sonar approaches are proposed. MIMO sonar transmits different orthogonal acoustic waveforms from multiple projectors with different spatial distribution. Through space-time-waveform diversity, MIMO sonar is able to apply coherent processing techniques over the received signals, and acquires more diversity gains. The cognition concept proposed in the literature for radar and wireless communication is applied to MIMO sonar to improve its robustness and adaptability. The advantages of proposed cognitive MIMO sonar will be demonstrated by Monte Carlo computer simulations.

Keywords: cognitive MIMO sonar, space-time-waveform adaptive processing (STWAP), target detection, monostatic/bistatic/multistatic, harbour and maritime surveillance

## 1. INTRODUCTION

There are many threats such as submarines, mines, unmanned underwater vehicles (UUVs), unmanned surface vehicles (USV), manned surface vehicles (MSV) to Navy ships and other important facilities under harbour and maritime environments. All-weather day-night robust detection of underwater and surface threat targets is very important for military applications in the presence of severe clutter, jamming, and some kinds of sonar measurement errors. Sonar has been widely investigated in the last few decades and exploited for target detection, tracking, classification and imaging. According to the numbers of transmitters and receivers, sonar mainly has four schemes: (1) single-input single output (SISO); (2) single-input multiple-output (SIMO); (3) multi-input single-output (MISO); (4) multi-input

multi-output (MIMO) (Akyildiz 2005, Li 2008, Coon 2008, Maiwald 2008, Guerci 2003).

SISO is the most traditional sonar working approach which transmits single acoustic waveform by single projector. It has a few disadvantages including low target detection probability, low resolution, vulnerability of interception by the enemy, sensitivity to jamming, etc. SIMO sonar transmits single acoustic waveform by single projector but the received acoustic waveforms are coherently processed by the multiple receivers. Multiple-input multiple-output (MIMO) radar and sonar has recently become a hot research area for its potential advantages (Xu 2007, Li 2007, Yang 2007, Lehmann 2006). MIMO sonar uses multiple antennas to simultaneously transmit several linearly independent acoustic waveforms and deploy multiple antennas to receive the reflected signals. The echoes from different targets can be linearly independent of each other.

According to the location of transmitters and receivers, sonar can be divided into three categories: (1) monostatic sonar whose transmitters and receivers are co-located; (2) bistatic/multistatic sonar whose transmitters and receivers are distributed in different places; (3) hybrid multistatic sonar in which part of the transmitters and receivers are co-located and others are located in different places. At present the most popular sonar in use is the monostatic sonar because it is easier to operate. However, there are some disadvantages of monostatic sonar. The first is its comparatively lower survivability because it is easy to be detected by the enemy when in operation. Its resolution is limited by the size of the sonar aperture. Bistatic sonar has some advantages over monostatic sonar such as covert receiver, higher survivability, and improved ECCM. Multistatic sonar is initially defined as netted configurations of bistatic sonars (Tsakalides 1999). Recently the multistatic sonar concept is generalized to consist of different kinds of netted sonars such as conventional SIMO monostatic sonars, SIMO bistatic sonars, multiple-input-single-output (MISO) monostatic sonars, MISO bistatic sonars, and most recently proposed monostatic/bistatic/sparse-aperture MIMO sonars. Multistatic sonar has many advantages over monostatic and bistatic sonars but with more complexity and communication capacity requirements. The illuminators installed on a high valued ISR

platform and those on each monostatic sonar can provide space-time-waveform diversity with the potential of improved SNR, wider coverage, anti-jamming, and higher detection rates and lower false alarm rates, and higher resolution because of much bigger sonar aperture.

There are important and challenging problems still needed to be solved, especially for monostatic/bistatic/multistatic sonar. In this paper, we try to improve the robustness of target detection by monostatic and bistatic MIMO sonars through artificial intelligence. Cognitive radar is a very newly proposed technique (Haykin 2006). Through cognition, the sensor working status and environment sensing such as jamming can be obtained. The sonar system bias, sonar element failure, and jamming information is integrated with the space-time-waveform adaptive processing module which can greatly improve the robustness performance of MIMO sonar based target detection.

The paper is organized as follows. Section 2 presents robust STAP for cognitive monostatic SIMO sonar. Cognitive monostatic and bistatic MIMO sonars are described in Section 3 and 4, respectively. Robust target detection by cognitive MIMO sonar is developed in Section 5. Monte Carlo computer simulation is presented in Section 6. Finally, the conclusions are provided in Section 7.

## 2. ROBUST STAP FOR COGNITIVE MONOSTATIC SIMO

Space-time adaptive processing (STAP) is an important module of the SIMO sonar. The output of the STAP module is input into the target detection module (discussed in Section 5). The basic structure of the second-order statistics based STAP beamformer is shown in Figure 1. Without loss of generality, we consider a uniform linear array (ULA) with  $N$ -element. A coherent processing interval (CPI) consists of  $M$  pulses with a fixed repetition interval (PRI)  $T$ . Many techniques can be easily extended to nonuniform linear array, rectangle array, circular array, and other array structures. For a  $N$ -element ULA, the steering vector of the  $i$ -th waveform ( $i = 1$  for SIMO sonar) is given by

$$\mathbf{s}_i = \mathbf{b}_i \otimes \mathbf{a}_i \quad (1)$$

where  $\otimes$  denotes the Kronecker product, and its  $N$ -dimensional spatial steering vector  $\mathbf{a}_i$  and  $M$ -dimensional Doppler steering vector  $\mathbf{b}_i$  are defined as

$$\mathbf{a}_i = \begin{bmatrix} 1 & e^{j2\pi d \cos \theta / \lambda_i} & \dots & e^{j2\pi(N-1)d \cos \theta / \lambda_i} \end{bmatrix}, \quad (2)$$

$$\mathbf{b}_i = \begin{bmatrix} 1 & e^{j2\pi T f_{d_i}} & e^{j2\pi T(2)f_{d_i}} & \dots & e^{j2\pi T(M-1)f_{d_i}} \end{bmatrix} \quad (3)$$

where  $\theta$  is the wavefront angle,  $f_{d_i}$  is the Doppler frequency for the  $i$ -th orthogonal waveform. The original statistics based STAP algorithm is given by

$$\min_{\mathbf{w}} \mathbf{w}_i^H \mathbf{R}_{n,i} \mathbf{w}_i \quad s.t. \quad \mathbf{w}_i^H \mathbf{s}_i = 1 \quad (4)$$

where  $\mathbf{R}_{n,i}$  is the positive-definite  $NM \times NM$  dimensional covariance matrix for the  $i$ -th waveform which is associated with the total interference (clutter plus jamming plus receiver noise) for the given range cell under test. The optimal weight and filter output  $y_i$  for the  $i$ -th waveform are given by

$$\hat{\mathbf{w}}_i = \left( \mathbf{R}_{n,i}^{-1} \mathbf{s}_i \right) / \left( \mathbf{s}_i^H \mathbf{R}_{n,i}^{-1} \mathbf{s}_i \right), \quad (5)$$

$$y_i = \hat{\mathbf{w}}_i^H \mathbf{x}_i. \quad (6)$$

The original second-order statistics based STAP algorithm given by equation (4) is not robust to steering vector error, array element failure, jamming, and clutter. It has been shown that prior knowledge can improve the performance of STAP radar detection effectively. Cognitive STAP is proposed here to robustly detect targets for sonars. Prior knowledge and online learning of environments are both utilized to improve the detection performance. Prior knowledge is used to help selecting the secondary data. Some constraints are also formed for STAP beamformer from prior knowledge. The steering error is calibrated by the sensor registration module. Sensor health monitoring module can detect the health of each array element. The failure element is not included in the STAP beamformer. The cognitive statistics based STAP beamformer is expressed as

$$\begin{aligned} \min_{\mathbf{w}} \mathbf{w}_i^H \mathbf{R}_{n,i} \mathbf{w}_i \quad s.t. \quad & \mathbf{w}_i^H \hat{\mathbf{s}}_i = 1, \\ & \mathbf{w}_i^H \mathbf{U}_c = 0, \quad \mathbf{w}_i^H \mathbf{U}_{jam} = 0, \quad \mathbf{w}_i^H \mathbf{w}_i \leq \varepsilon \end{aligned} \quad (7)$$

where  $\hat{\mathbf{s}}_i$  is the steering vector after calibration of the sensor system bias parameter  $\Delta\theta$ ,

$$\hat{\mathbf{a}}_i = \begin{bmatrix} 1 & e^{j2\pi d \cos(\theta - \Delta\theta) / \lambda_i} & \dots & e^{j2\pi(N-1)d \cos(\theta - \Delta\theta) / \lambda_i} \end{bmatrix} \quad (8)$$

$$\hat{\mathbf{s}}_i = \mathbf{b}_i \otimes \hat{\mathbf{a}}_i. \quad (9)$$

$\mathbf{U}_c$  is the prior knowledge of the dominant clutter subspace,  $\mathbf{U}_{jam}$  is the jamming subspace detected online by the spectrum sensing module. The failure array element detected by the sensor health monitoring has been excluded from the angle-Doppler steering

vector. The quadratic constraint expressed by equation (7) can improve the robustness of the STAP beamformer against channel mismatch and steering errors. The covariance matrix  $\mathbf{R}_{n,i}$  is estimated by

$$\hat{\mathbf{R}}_{n,i} = \sum_{k=1}^K \mathbf{x}_{k,i} \mathbf{x}_{k,i}^K \quad (10)$$

Prior knowledge (GIS, clutter model database, MIMO sonar waveform library) and online learning of environments (sonar system bias, sonar health monitoring, jamming) are used to adaptively select the secondary data.

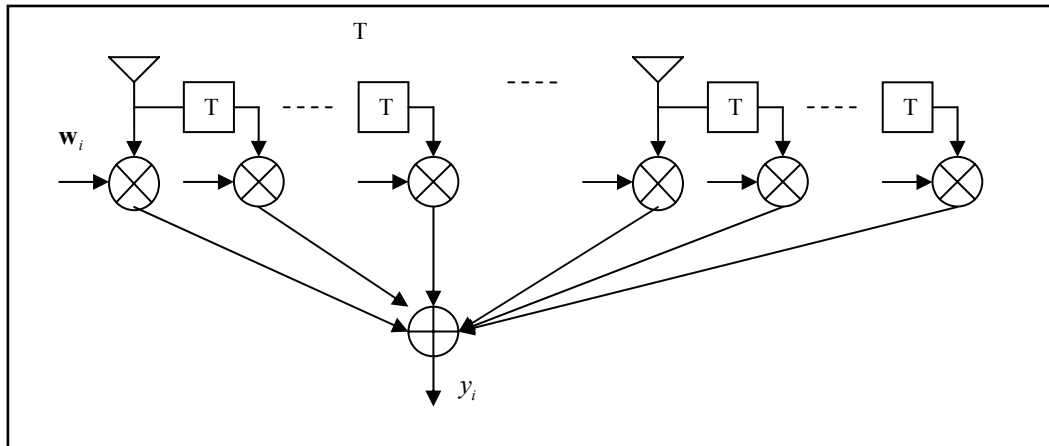


Figure 1: The Basic Structure Of The STAP Beamformer

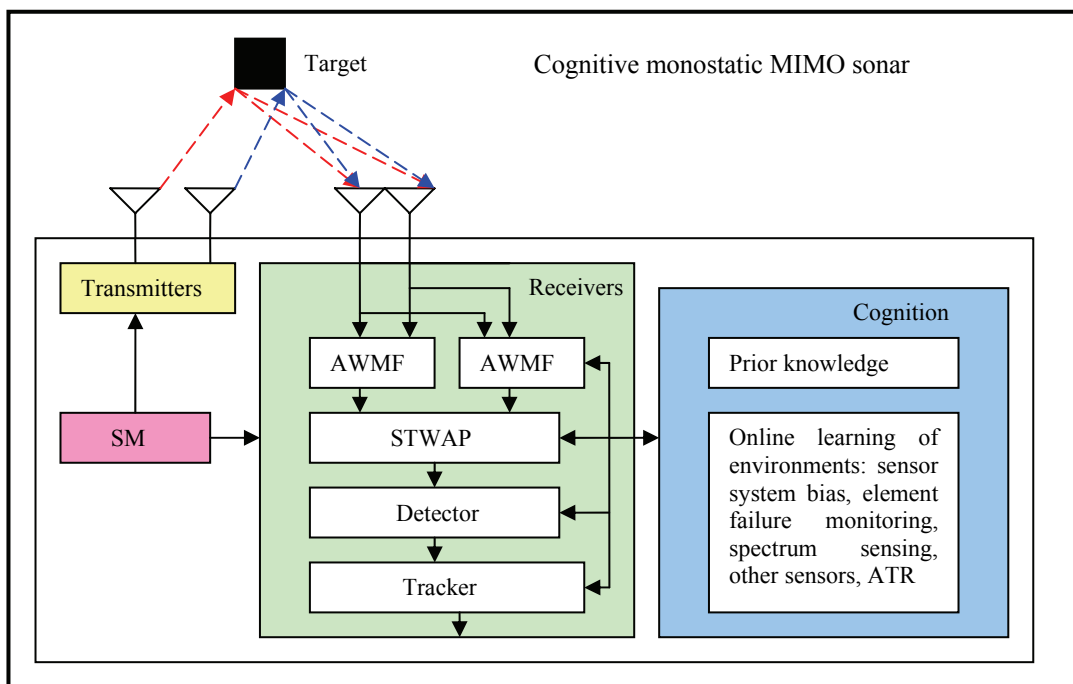


Figure 2: Block Diagram Of The Cognitive Monostatic MIMO Sonar

Many optimization algorithms proposed in the literature can be used to solve the STAP problems expressed as equations (4) and (7). Some popular methods are SMI, constrained LMS (CLMS), constrained RLS (CRLS), Generalized Sidelobe Canceller (GSC), and neural network based optimization methods. The criteria (4) and (7) optimize the output variance subject to constraints. It is not very

robust to non-Gaussian heavy-tailed clutter. A more robust STAP beamformer is based on lower order statistics such as fractional lower-order statistics (FLOS) or zero-order statistics (ZOS). The FLOS based STAP beamformer is defined as

$$\min_{\mathbf{w}} E \left\{ \left| \mathbf{w}_i^H \mathbf{x} \right|^p \right\} \quad s.t. \quad \mathbf{w}_i^H \hat{\mathbf{s}}_i = 1, \quad (11)$$

$$\mathbf{w}_i^H \mathbf{U}_c = 0, \quad \mathbf{w}_i^H \mathbf{U}_{jam} = 0, \quad \mathbf{w}_i^H \mathbf{w}_i \leq \varepsilon$$

$$\min_{\mathbf{w}} E \left\{ \log \left( \left| \mathbf{w}_i^H \mathbf{x} \right| \right) \right\} \quad s.t. \quad \mathbf{w}_i^H \hat{\mathbf{s}}_i = 1, \quad (12)$$

$$\mathbf{w}_i^H \mathbf{U}_c = 0, \quad \mathbf{w}_i^H \mathbf{U}_{jam} = 0, \quad \mathbf{w}_i^H \mathbf{w}_i \leq \varepsilon$$

where  $p$  is the fractional lower-order. When  $p = 2$ , FLOS based STAP becomes the second-order statistics based STAP in equation (7). The ZOS based STAP beamformer is defined by

There are no closed form solution to (11) and (12). A stochastic gradient method or Genetic Algorithms (GA) can be used with the results of (4) or (7) as its initialization.

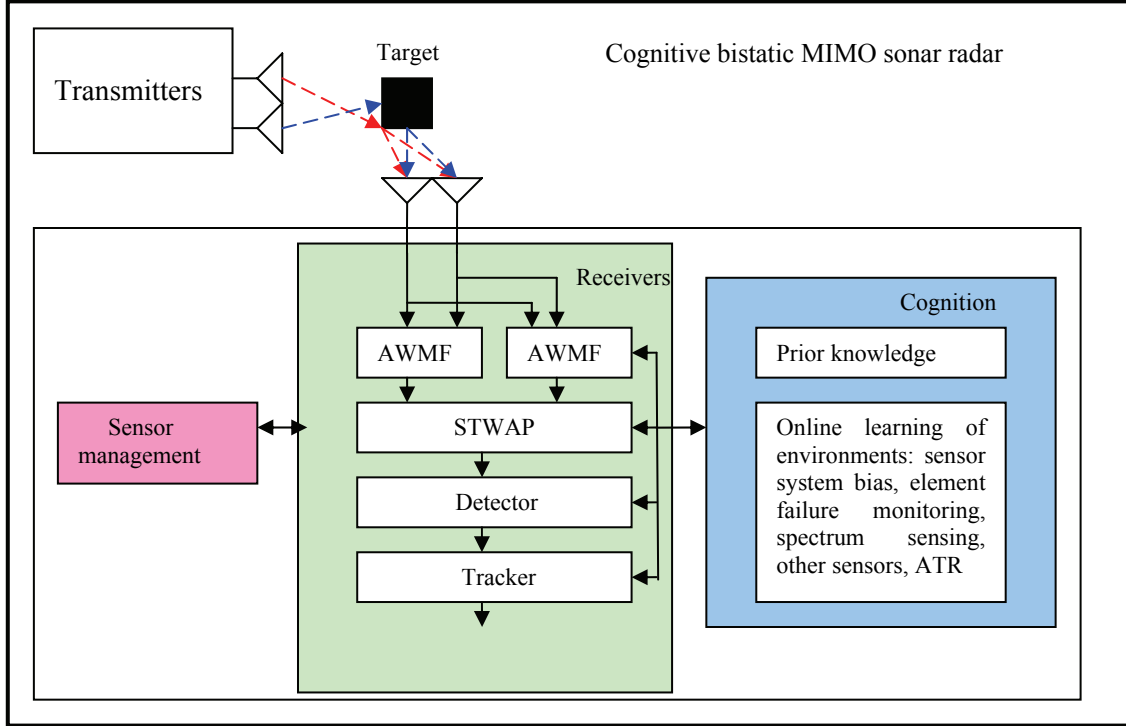


Figure 3: Block Diagram Of The Cognitive Bistatic MIMO Sonar

### 3. COGNITIVE MONOSTATIC MIMO SONAR

The block diagram of the cognitive monostatic MIMO sonar is shown in Figure 2. There are mainly four modules: (1) multiple transmitters; (2) co-located multiple receivers: acoustic waveform matching filter (AWMF), space-time-waveform adaptive processing (STWAP), target detector, and tracker; (3) cognition module: prior knowledge and online sensing of environments; (4) sensor management (SM). The STWAP is described in detail here.

Multiple transmitters and multiple receivers are co-located which can be two ULAs or the same ULA for both transmitting and receiving. Suppose that the element distances for the transmitter and receiver ULAs are  $d_T$  and  $d_R$ , respectively. Monostatic MIMO processes all waveforms together by a single STWAP instead of using one STAP for each waveform. Suppose there are  $L$  transmitters,  $N$  receivers, and  $M$  coherent pulses.  $T$  is the coherent pulse interval.  $(\theta, \phi)$  is the

wavefront angle of the target in 3D space to the ULA. Statistics based STWAP can be expressed as:

$$\min_{\mathbf{w}} \mathbf{w}^H \mathbf{R}_n \mathbf{w} \quad s.t. \quad \mathbf{w}^H \hat{\mathbf{s}} = 1, \quad (13)$$

$$\mathbf{w}^H \mathbf{U}_c = 0, \quad \mathbf{w}^H \mathbf{U}_{jam} = 0, \quad \mathbf{w}^H \mathbf{w} \leq \varepsilon$$

where

$$\mathbf{R}_n = E \left[ \mathbf{X} \mathbf{X}^H \right], \quad (14)$$

( $\mathbf{X}$  is the  $NML$ -dimensional baseband measurements.)

$$\mathbf{w} = [\mathbf{w}_1^T, \mathbf{w}_2^T, \dots, \mathbf{w}_L^T]^T \quad (\text{weight}), \quad (15)$$

$$\hat{\mathbf{s}} = [\hat{\mathbf{s}}_1^T, \hat{\mathbf{s}}_2^T, \dots, \hat{\mathbf{s}}_L^T]^T, \quad (16)$$

(steering vector after sensor calibration),

$$\hat{\mathbf{s}}_l = \mathbf{b}_l \otimes \hat{\mathbf{a}}_l \text{ (steering vector of } l\text{-th waveform),} \quad (17)$$

$$\mathbf{b}_l = \begin{bmatrix} 1 & e^{j2\pi T f_{d_l}} & e^{j2\pi T(2) f_{d_l}} & \dots & e^{j2\pi T(M-1) f_{d_l}} \end{bmatrix} \quad (18)$$

(Doppler steering vector of  $l$ -th waveform),

$$\mathbf{a}_l = \begin{bmatrix} 1 & \dots & e^{j2\pi(N-1)d_R \cos(\theta-\Delta\theta) \sin(\phi-\Delta\phi)/\lambda_l} \\ e^{j2\pi d_T(l-1) \cos(\theta-\Delta\theta) \sin(\phi-\Delta\phi)/\lambda_l} \end{bmatrix} \quad (19)$$

(spatial steering vector of  $l$ -th waveform),

$$f_{d_l} = \frac{2}{\lambda_l} \left[ (\mathbf{v}_t - \mathbf{v}_e)(\mathbf{P}_t - \mathbf{P}_e) / |\mathbf{P}_t - \mathbf{P}_e| \right] \quad (20)$$

(Doppler frequency of  $l$ -th waveform).

If  $L = 1$ , monostatic MIMO in equation (13) changes to SIMO in equation (4).

#### 4. COGNITIVE BISTATIC MIMO SONAR

The block diagram of the cognitive bistatic MIMO sonar is shown in Figure 3. Transmitters ULA and receivers ULA are located on two different platforms. There are mainly four modules: (1) multiple transmitters on one platform; (2) co-located multiple receivers on another platform: acoustic waveform matching filter (AWMF), space-time-waveform adaptive processing (STWAP), target detector, and tracker; (3) cognition module: prior knowledge and online sensing of environments; (4) sensor management (SM). The STWAP is described in detail in this section.

Suppose that the element distances for the transmitter and receiver ULAs are  $d_T$  and  $d_R$ , respectively.  $T$  is the coherent pulse interval. Suppose there are  $L$  transmitters,  $N$  receivers, and  $M$  coherent pulses.  $(\theta_t, \phi_t)$  and  $(\theta_r, \phi_r)$  are the wavefront angles of the target to the transmitter and receiver ULAs in 3D space. Statistics based bistatic MIMO STWAP can be expressed as the following optimization problem:

$$\begin{aligned} \min_{\mathbf{w}} \quad & \mathbf{w}^H \mathbf{R}_{2D,n} \mathbf{w} \quad s.t. \quad \mathbf{w}^H \hat{\mathbf{s}} = 1, \\ & \mathbf{w}^H \mathbf{U}_c = 0, \quad \mathbf{w}^H \mathbf{U}_{jam} = 0, \quad \mathbf{w}^H \mathbf{w} \leq \varepsilon \end{aligned} \quad (21)$$

where

$$\mathbf{R}_{2D,n} = E[\mathbf{X}_{2D} \mathbf{X}_{2D}^H], \quad (22)$$

$\mathbf{X}$  is the  $NML$ -dimensional baseband measurements after 2D Doppler compensation,

$$\mathbf{w} = [\mathbf{w}_1^T, \mathbf{w}_2^T, \dots, \mathbf{w}_L^T]^T \text{ (weight),} \quad (23)$$

$$\hat{\mathbf{s}} = [\hat{\mathbf{s}}_1^T, \hat{\mathbf{s}}_2^T, \dots, \hat{\mathbf{s}}_L^T]^T \text{ (steering vector),} \quad (24)$$

$$\hat{\mathbf{s}}_l = \mathbf{b}_l \otimes \hat{\mathbf{a}}_l \text{ (steering vector of } l\text{-th waveform),} \quad (25)$$

$$\mathbf{b}_l = \begin{bmatrix} 1 & e^{j2\pi T f_{d_l}} & e^{j2\pi T(2) f_{d_l}} & \dots & e^{j2\pi T(M-1) f_{d_l}} \end{bmatrix}, \quad (26)$$

(Doppler steering vector of  $l$ -th waveform),

$$\hat{\mathbf{a}}_l = \begin{bmatrix} 1 & \dots & e^{j2\pi(N-1)d_R \cos \bar{\theta}_R \sin \bar{\phi}_R / \lambda_l} \\ e^{j2\pi d_T(l-1) \cos \bar{\theta}_T \sin \bar{\phi}_T / \lambda_l} \end{bmatrix}, \quad (27)$$

( $l$ -th spatial steering vector),

$$f_{d_l} = \frac{1}{\lambda_l} \left[ \frac{(\mathbf{v}_t - \mathbf{v}_e)(\mathbf{P}_t - \mathbf{P}_e) / |\mathbf{P}_t - \mathbf{P}_e| + (\mathbf{v}_r - \mathbf{v}_t)(\mathbf{P}_r - \mathbf{P}_t) / |\mathbf{P}_r - \mathbf{P}_t|}{2} \right] \quad (28)$$

(Doppler frequency of  $l$ -th waveform).

Multistatic MIMO sonar can be set up with networked multiple monostatic and bistatic MIMO sonars. We will present our multistatic MIMO sonar in our future paper.

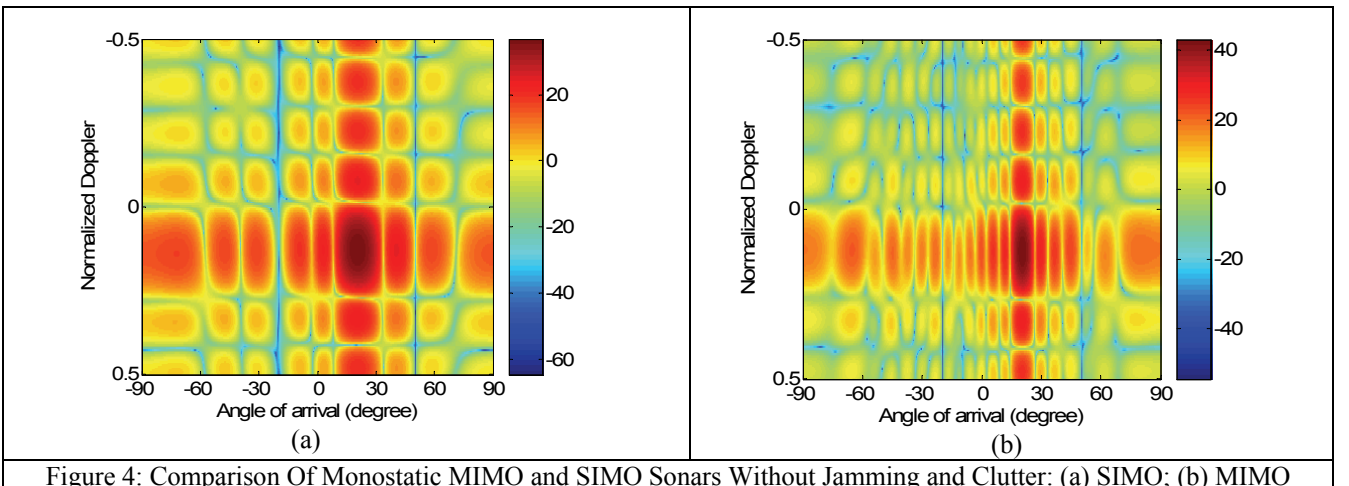


Figure 4: Comparison Of Monostatic MIMO and SIMO Sonars Without Jamming and Clutter: (a) SIMO; (b) MIMO



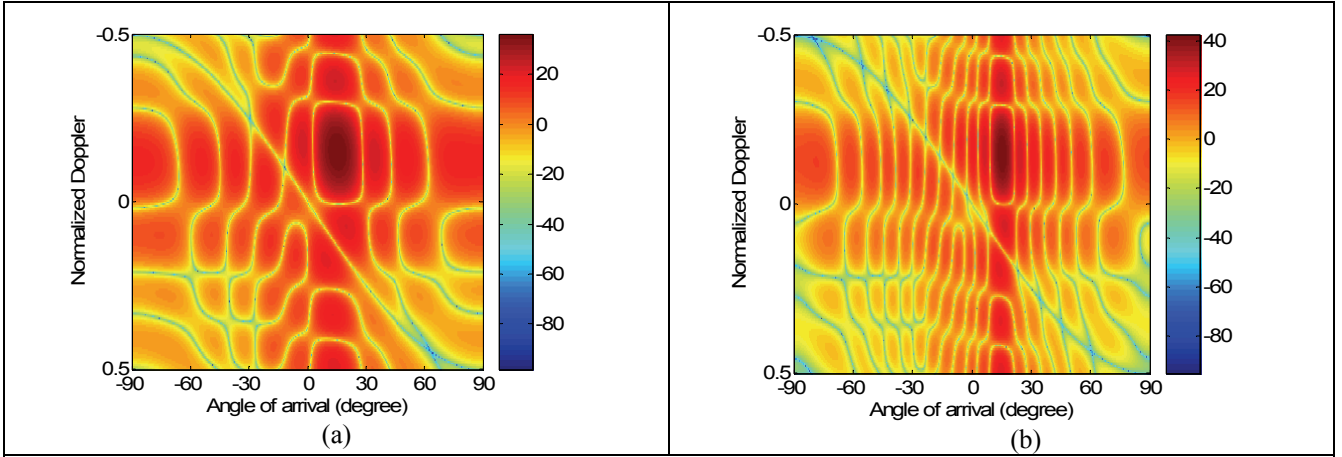


Figure 5: Comparison Of Monostatic MIMO and SIMO Sonars With Jamming and Clutter: (a) SIMO; (b) MIMO

## 5. ROBUST TARGET DETECTION BY COGNITIVE MIMO SONAR

Distributed detection is presented here for the multistatic sonar with a configuration of many monostatic and bistatic sonars. There are three steps: (1) Optimal weight estimation by STAP/STWAP for each tested range cell. (2) Local adaptive matched filter (AMF) constant false alarm rate (CFAR) detection using the estimated weight (Goldstein 1999). (3) Detection fusion in the Fusion Center by DS reasoning. The sonar detection for the  $k$ -th tested range cell and  $i$ -th STAP/STWAP can be expressed for each of the following two hypotheses,

$$\begin{aligned} H_0 : \mathbf{x}_i^k &= n_i^k, \\ H_1 : \mathbf{x}_i^k &= \mathbf{x}_i^k + n_i^k. \end{aligned} \quad (29)$$

The adaptive matched filter (AMF) CFAR test statistic  $\Lambda_i^k$  is then calculated by

$$\Lambda_i^k = \left\| (\hat{\mathbf{w}}_i^k)^H \mathbf{x}_i^k \right\|^2 \left[ (\hat{\mathbf{s}}_i^k)^H (\hat{\mathbf{R}}_i^k)^{-1} \hat{\mathbf{s}}_i^k \right]. \quad (30)$$

The local detection result is

$$D_i^k = \begin{cases} H_1 : \text{if } \Lambda_i^k \geq \eta_i^k, \\ H_0 : \text{if } \Lambda_i^k < \eta_i^k. \end{cases} \quad (31)$$

The local AMF CFAR detection results are finally fused by our DS fusion toolbox.

## 6. MONTE CARLO COMPUTER SIMULATIONS

The performance of cognitive MIMO sonar is evaluated and compared with conventional SIMO sonar under various environments. Linear sonar arrays are used for MIMO transmitter and receiver. The proposed method

can also be applied to other sonar arrays such as rectangular and three-dimensional sonar arrays.

Figure 4 compares the performance of SIMO and monostatic MIMO sonars without jamming and clutter (only random noise exists in the measurements). In Figure 4(a), there are 10-element for MO. In Figure 4(b), there are 2-element for MI and 10-element for MO. Figure 4 shows that through waveform diversity, the resolution of MIMO sonars is improved effectively. The resolution of 2-input 10-output sonar is 2 times higher than that of 1-input 10-output SIMO sonars.

Figure 5 compares the performance of cognitive SIMO and monostatic MIMO sonars with jamming and clutter. In Figure 5(a), there are 10-element for MO. In Figure 5(b), there are 2-element for MI and 10-element for MO. Through cognitive sensing of the environments, the covariance of the jammings and clutters are available and applied in the space-time-waveform adaptive processing algorithm. Figure 5 shows that through waveform diversity, the resolution of MIMO sonars is also improved effectively under jamming and clutter. Deep notches are formed to filter the jamming and clutter. As shown in Figure 4 and Figure 5, the output of the SIMO and MIMO sonars at the target 's position and Doppler has a peak. After STWAP, the target can be detected by CFAR.

## 7. CONCLUSIONS

Inspired by recent advances in MIMO radar and cognitive radar, we have developed a robust target detection based on cognitive monostatic and bistatic MIMO sonar for harbour and maritime surveillance applications. STWAP, target detector and cognition are three important modules in a MIMO sonar. It has been shown that through space-time-waveform diversity and cognition processing, MIMO sonar has many superior advantages over conventional SISO sonar such as higher target detection probability, higher resolution, much less vulnerability of interception by the enemy, more robustness to jamming and sonar system bias and sonar element failure. More complex networked

multistatic MIMO sonar is in investigation and the new results will be reported in another paper.

## REFERENCES

- Akyildiz, I. F., Pompili, D., and Melodia, T., 2005. Underwater acoustic sensor networks: research challenges. *Ad Hoc Networks*, 3, 257-279.
- Li, Y., Huang, H., Li, S., and Zhang, C., 2008. LPI Performance analysis of MIMO sonar detection. *UDT Europe 2008*.
- Coon, A. Hall, B., Kanyuck, B., and Skarda, G., 2008. Novel approaches to multistatic sonar processing and source deployment. *UDT Europe 2008*.
- Maiwald, D., Benen, S., Corsten, A., Rose, B., and Schmidt-Schierhorn, H., 2008. Modular multistatic sonar systems. *UDT Europe 2008*.
- Nicholas J. Willis, 2005. *Bistatic Radar*. Scitech Publishing, Inc.
- Guerci, J., 2003. *Space-Time Adaptive Processing for Radar*. Artech House.
- Goldstein, J. S., Reed, I., and Zulch, P., 1999. Multistage partially adaptive CFAR detection algorithm. *IEEE Trans. AES*, 35(2), 645-661.
- Tsakalides, P., and Nikias, L., 1999. Robust space-time adaptive processing (STAP) in non-Gaussian clutter environments. *IEE Proc. – Radar, Sonar Navig.*, 146(2), 84-93.
- Haykin, S., 2006. Cognitive radar: a way of the future, *IEEE Signal Processing Magazine*, 23(1), 30-40.
- Xu, L., and Li, L., 2007. Iterative generalized likelihood ratio test for MIMO radar. *IEEE Transactions on Signal Processing*, 55(6), 2375-2385.
- Li, J., and Stoica, P., 2007. MIMO radar with colocated antennas: review of some recent work. *IEEE Signal Processing Magazine*, 24(5), 106-114.
- Yang, Y., and Blum, R. S., 2007. Minimax robust MIMO radar waveform design. *IEEE Journal of Selected Topics in Signal Processing*, special issue on: *Adaptive Waveform Design for Agile Sensing and Communication*, 147-155.
- Lehmann, N., Haimovich, A., Blum, R., Chizhik, D., Cimini, L., and Valenzuela, R., 2006. High resolution MIMO-radar. *Proceedings of Asilomar Conference on Signals, Systems and Computers*, Pacific Grove, CA, November 2006.
- Haykin, S.. Cognitive radar network, [ieeexplore.ieee.org/iel5/11178/36018/01706227.pdf](http://ieeexplore.ieee.org/iel5/11178/36018/01706227.pdf)

# MARINETRAFFIC: DESIGNING A COLLABORATIVE INTERACTIVE VESSEL TRAFFIC INFORMATION SYSTEM

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## ABSTRACT

International legislation and current technology provide the tools for better vessel traffic surveillance. Land-based systems are able to collect and process the information transmitted by vessels through the 'Automatic Identification System'. These systems possess a valuable set of information that can be exploited in a variety of useful applications of public interest. The University of the Aegean implemented 'MarineTraffic' as a pilot Vessel Traffic Information System, facing several significant challenges, such as the radio-waves limitations, the establishment and coordination of a large number of stations and the cost-effective processing and storage of a huge amount of collected data. The system design adheres to a set of principles, such as the community efforts to build the stations network, the interactive interfaces and the publicly available information. A large number of interested parties adopted the application, since it exhibits its potential to support many applications, including message notifications, simulation of special scenarios, fleet management, environmental protection and observation of areas of special interest.

**Keywords:** Automatic Identification System, Vessel Traffic System, Information System, Design, Interaction, Collaboration

## 1. INTRODUCTION

In line with the European Directive 2002/59 and the regulations of the International Maritime Organization, vessels on the one side and countries on the other side, are requested to support better vessel traffic surveillance.

Aegean and Ionian Seas constitute a unique environment for implementing a large scale shore-based Vessel Traffic Information System (VTIS). A plethora of islands are distributed around the Greek seas, they usually have high mountains and therefore they are ideal for building a network of stations receiving and observing vessels positions. At the same time, millions of passengers are travelling each year around the islands using local ferries, while a very large number of commercial vessels are crossing the Aegean or are entering into the basic commercial ports.

The University of the Aegean is currently designing and implementing a pilot VTIS, initially

exploiting the university's own infrastructure, which is distributed on six distant islands in the Aegean Sea. The initial objective of the pilot implementation is to support the research activities of the department of Product and Systems Design Engineering. The public interface of the application is available at <http://www.marinetraffic.com/ais/>.

The system exploits the benefits of the Automatic Identification System (AIS) which is in fact an active long-range Radio-Frequency Identification (RFID) system. AIS transponders fitted on all vessels with gross tonnage (GT) of 300 tons or more, automatically broadcast information, such as their position, speed, and navigational status, at regular intervals via a VHF transmitter built into the transponder. The information originates from the ship's navigational sensors, typically its global navigation satellite system (GNSS) receiver and gyrocompass. Other information, such as the vessel name and VHF call sign, is programmed when installing the equipment and is also transmitted regularly. Some voyage-related information, such as destination port and Estimated Time of Arrival (ETA) are transmitted as well.

The signals are initially addressed to other vessels, as a supplementary navigation tool and a collision avoidance device, when combined with other means and of course with good seamanship. It is however obvious that land stations (Vessel Traffic Systems – VTS) may also receive and process these signals in order to extract very useful information about vessel traffic in the area. The collected information may be used in a variety of relevant applications, such as traffic simulation, accident or crisis scenarios, fleet management, info-kiosks and personal notifications, as discussed in the present paper.

## 2. BACKGROUND

### 2.1. Existing Technology and Limitations

In recognition of the requirement for reporting vessels positions, the AIS Technical Standards (ITU-R M.1371-1) describe the functional specifications for Ship-borne Mobile Equipment that performs the necessary functions. The AIS equipment is categorized in two different classes: Class A equipment complies with the

IMO AIS carriage requirement while the Class B provides capabilities for smaller vessels, not necessarily fully compliant with IMO requirements, but fully compliant with AIS technical standards.

The ITU-R Recommendation M.1371-1 describes the Class A AIS device as “Shipborne mobile equipment intended for vessels meeting the requirements of IMO AIS carriage requirement, and is described above”. Class B devices are based on the same technical principles. The main differences from Class A devices are that a) the position reporting rate is slower, b) navigational status is not transmitted, c) the informational fields transmitted are restricted. It is obvious that Class B transponders are designed for ‘less critical’ applications, giving priority to the information transmitted by larger vessels (Class A fitted).

Although AIS has the potential to greatly enhance Vessel Traffic operations, the system has several limitations or potential drawbacks. As a result, a VTS cannot rely solely on AIS data for critical applications related to the safety of navigation. However, this data have a great value for applications of informational nature or applications related to the protection of the environment, to fleet management, port operations, alerting, etc. Some significant limitations follow:

- A Vessel Traffic Information System based on AIS data provides a very ‘attractive’ picture of vessel traffic. An operator of the VTIS may solely rely on this picture, neglecting to observe additional sources, something that may lead to a dangerous situation. AIS provides only a partial picture of vessels positions, since not all vessels are equipped with AIS transponders or transmission may be weak or erroneous.
- AIS is subject to the problems of VHF-FM radio-wave transmission and propagation, such as interference, distortion and problems caused by physical obstacles in land areas.
- AIS transmission may reach its capacity limits in crowded areas, giving priority to the closest vessels. Again, a VTIS would only receive a partial picture of vessel positions and movements.

## 2.2. Legal Framework

The international standards and regulations related to vessel traffic surveillance were developed by cooperating international bodies such as IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities), IMO (International Maritime Organization) providing regulatory directions and ITU (International Telecommunications Union) providing technical standards. The practical implementation has been speed up by revision of SOLAS Convention in 2001, Copenhagen Declaration 2001, EU Directive 2002/59 and the EMSA (European Maritime Safety Agency).

Especially in the European Union, in addition to initiatives being taken at national level, EU Directive 2002/59 has been set in place, aiming at the establishment of a Community vessel traffic monitoring and information system. The purpose of this initiative is to ensure that ships in EU waters, and their cargoes, are monitored more effectively than in the past, and that there is a more consistent approach across all EU sea areas. The Directive requires Member States and the Commission to co-operate to establish computerized data exchange systems and to develop the necessary infrastructure. In this direction, data collected by VTIS on a national level, can be distributed in various formats to other interested parties. The combination of data will enable the long-range observation of seas and it will dramatically increase the surveillance capabilities of European countries.

Concerns have been expressed by the IMO in respect to publishing the vessels positions information through public web sites. The concern has to do with the possible consequences on the safety of vessels. It is clear however, that web-based applications are addressed to the public for informational and statistical purposes and they cannot be used for navigation purposes neither for critical safety applications.

Publishing personal or sensitive information is another issue to pay attention to. AIS data does not fall into this case. Vessel’s identity and position information are transmitted through open public frequencies and are addressed to anyone possessing a relevant receiver. Additionally, vessels equipped with Class A transponders belong to the public transportation (either commercial or passenger) and do not transmit any kind of personal information. Private vessels equipped with Class B transponders may switch off their device in case they wish to maintain their privacy. The captain of any vessel has also the right to switch off its AIS unit, in case the vessel is sailing in areas subject to piracy and other criminal actions.

## 3. SYSTEM DESIGN

### 3.1. Basic Principles

The system design is based on an innovative open and collaborative approach and it adheres to the following principles:

- *The growth of the station network is based on community efforts.* The coverage of large areas is based on terrestrial VHF stations. That means that a large number of stations are necessary to adequately have a good picture of vessel traffic. The community-based model is cost-effective, while it results in quick expansion and in a high level of coverage redundancy.
- *The user interface is highly interactive.* The information related to vessel identities and movements is given interactively to the end-user by means of visual, textual and acoustic

tools, supporting the accessibility through an open web-based application, without the need for additional software.

- *Data collected are convertible and sharable with various interested parties.* The information collected is of interest to port authorities, European agencies, research institutes, content providers, shipping companies and other interested parties. Data are shared toward various destinations, using persistent formats and protocols, such as XML and Web Services.
- *Information is publicly available and not commercially exploited.* The project uses the resources of the University, the contribution of the community and the financial support of sponsors, in order to design, deploy and support the necessary information and communication infrastructure.
- *Mutual data exchange with other Vessel Traffic Information Systems* must be supported in order to have a complete picture of marine traffic around European coasts. This objective can be fulfilled by supporting multiple data exchange protocols based on international

standards, such as XML, TCP/IP raw data transmission and Web Services.

A generic picture of the above design principles is given in Figure 1 below. Internet is the main communication medium for all involved parties, taking of course the necessary security measures whenever this is necessary. All involved parties are depicted here: The network of AIS receivers covering different or overlapping areas; the central premises hosting the database, the data collection software and the web applications; other VTS networks mutually exchanging data; other applications receiving data feed in various formats; and finally the end-users consuming the services through the web or through mobile devices.

Five core data flow directions are depicted in this topology:

1. Ship → Public radiofrequencies
2. AIS receiver → Central infrastructure
3. Central infrastructure → web & mobile end-users
4. Central infrastructure → Other specialized applications
5. Bi-directional data exchange with other VTS Networks

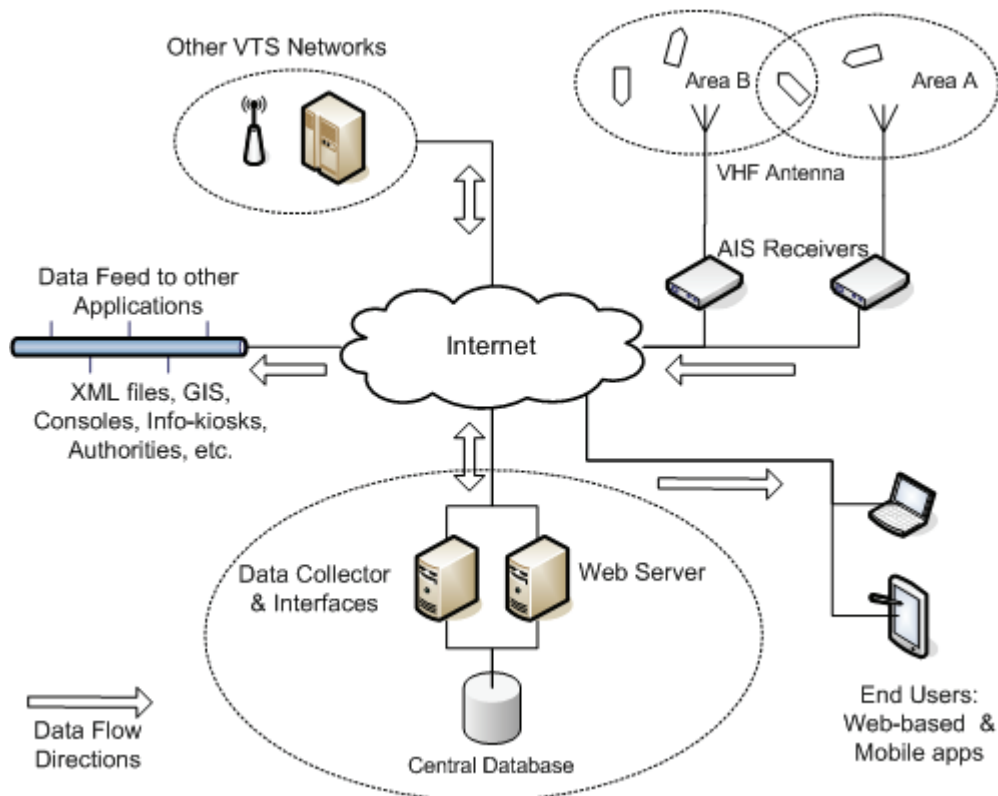


Figure 1: Generic Topology of VTMIS and peripheral equipment and applications

### 3.2. User Requirements

A brief list of generic user requirements follows, as collected by system designers, citizens, shipping professionals, national authorities, central system administration and other interested parties:

- *Openness and Availability:* Information must be open and available to the public, without constraints, in various visual and textual formats.
- *Data diversity and distribution:* Collected data must be accessible by different heterogeneous parties, in different standard formats, meeting the needs of a variety of applications.
- *Connectivity:* Network connectivity between central facilities and data collectors (receiving stations) must be IP-based in order to support the efforts of the community of individuals. Web services will be supported whenever a strict security policy applies.
- *Efficient processing and storage:* The amount of collected data is expected to grow enormously as the system expands to cover additional sea areas. Data collection, processing, storage and retrieval must be optimized at the best possible level, in order to support heavy vessel traffic, heavy application usage and long back-track of historical data.
- *Alerting:* One of the most useful features that will enhance the benefits of the system is the provision of alerts of various types (arrivals, ETAs, vessel appearance, points of interest and surveillance etc.), through various channels (voice gates, web, email, sms, etc.)
- *Interactive and friendly interfaces:* Interested parties must have a dynamic web-based or mobile environment in order to fully exploit the capabilities of the system. It is therefore necessary to implement multiple diversified levels of data representation and flexible customizable views.
- *Collaboration:* The nature of this system is collaborative. Data collection on the one side (installing remote distributed receiving stations) and data enrichment on the other side (additional information uploaded by users) are necessary to build such a network of stations. Even a vessel's crew is part of this community, since they enter several ship and voyage details into their AIS units, which are then transmitted and uploaded into the central database.

### 3.3. Challenges

A wide area VTIS which publishes the collected information through the web or through other channels, has to face several challenges, such as:

- *Morphology of Terrain.* Covering seas around island and continental areas, especially in Greece, poses several problems due to mountains and other obstacles.

- *AIS Limitations:* The AIS protocol is designed to use a minimal set of data, in order to support the communication of a large number of vessels using a very restricted bandwidth. Some details are missing, while the length of existing content is very restricted.
- *Coordination of a large network of stations:* Sufficient coverage of the Greek archipelago requires a large number of base station installations (>30). The number significantly increases when the coverage is to be expanded in other countries. For such a large network of devices, proper monitoring, alerting and supporting is necessary. Additionally, data may be received by different stations for the same overlapping areas, requiring proper filtering and synchronization.
- *Combination with other sources of data,* such as port details, shipping databases and scheduled itineraries. For example, in order to forecast port arrivals and other moves, it is necessary to combine data derived from scheduled itineraries databases, port geographical data and historical data of similar vessels moves.
- *Inconsistencies in transmitted data,* such as: Erroneous or obsolete content entered by crew, Errors in positioning details, Participation of boats (smaller boats or boats navigating in closed waters do not carry AIS transponders)
- *A cost-effective processing and storage of a large amount of data,* in order to preserve the history of vessels traffic for long periods.

## 4. IMPLEMENTATION

### 4.1. A Community-based system to build infrastructure and collect data

High cost in building base stations, in providing data lines and especially in supporting the infrastructure in remote isolated locations, pose significant difficulties in establishing a large network of stations. On the other hand a VTIS has no value unless vessels can be monitored in long-range itineraries. Additionally, base stations must cover overlapping areas, in order to provide the necessary redundancy.

Deploying and supporting tens or hundreds of base stations would require a substantial investment in money, time and human resources. MarineTraffic would never come alive, unless we kept the system open and we called any interested party to participate, by just installing an antenna and using any existing Internet connection. This approach shows great success until now. We recorded a very high interest from people wishing to support their area in vessel monitoring, from professionals, from authorities and from radio-amateurs just wishing to experiment with equipment, antennas and radio-frequency reception.

In return, the public site acknowledges the participation of third parties, while the participants feel the power of a large-scale social network, combining a huge amount of data. The system is also open to the public to upload additional information, such as vessels' and ports' photographs. The University of the Aegean hosts and supports the central facilities to collect process and publish the data and it provides technical support for the remote sites sharing their data.

#### 4.2. An Interactive web-based Interface

One of the major objectives of the project is to provide an attractive interactive and accessible web-based interface, supporting the usability for every interested party. The public website combines the Asynchronous JavaScript and XML (AJAX) technology and the server side scripting with a wide range of optical, textual and sound content. It exploits the dynamic map APIs, such as the one provided by Google at no cost for non-commercial applications.

The interactive environment has been designed so as to support a variety of usages, depending on the potential users and their needs. Local authorities may wish to monitor vessel traffic in a specific port in real time. Passengers usually want to have an estimation of the arrival time of a ship, or even better to be alerted when their ship is approaching the port. Furthermore, they may wish to observe the weather conditions during their trip, as well as the route that their ship will be

following. Finally, a ship owner company may be interested in tracking the exact position of their ships at any time and in observing their route.

In order to fulfill these user needs, the web-based interface provides layered, customizable information presentation and a number of functions that aim to assist users in navigating the map and viewing the required information. Concerning map navigation, the environment allows users to track the position of a specific ship by selecting it from a list of all ships that have been identified and inserted in the database, and to focus on a specific port from the list of all major ports in the Aegean Sea. Concerning information presentation, users can adjust the layers of information that they wish to be displayed on the map, such as specific vessel types, ports and vessel names. Furthermore, by selecting a specific vessel, users can view vessel details, such as name, flag, dimensions, etc. and they can also visualize its route on the map.

Besides the map visualizations, the system provides an additional number of useful services. For any given port, it presents a list of ships that have been recently arrived and of those that are expected to arrive along with their estimated time of arrival. It also provides statistical data on arrivals, departures and distribution of vessel types. Finally, it can generate sound alerts and send e-mails to the interested users concerning vessel arrivals and departures and estimated times.



Figure 2: The Interactive web-based environment

#### 4.3. Technical Solution

Each one of the base stations transmits the received raw AIS data directly to a central server, through any

Internet connection. No data processing takes place at the station side, in order to avoid extra overhead and software maintenance. The bandwidth requirements are very low. Even in areas crowded by vessels, the

bandwidth consumption is estimated at no more than 10 Kbits/second due to the intrinsic design of AIS data transmission protocol which has to support more than one thousand vessels in a restricted area, transmitting data within a very narrow time-span.

At the server side (Database) the collected raw data is decoded into structured information i.e. position, identity and voyage-related records. A data 'clean-up' is necessary at the first stage of the processing, since:

- Duplicate data may be received by different station in overlapping areas
- Amount of data is huge, since a moving vessel may transmit its position information several times a minute and hundreds of vessels may appear within the system's range at each time. The processing software ignores records received sooner than one minute for the same vessel. The one-minute interval is adequate for this application, since it is designed for informational and not for navigation safety reasons
- Erroneous data are often received, due to GPS glitches or, rarely, due to erroneous AIS data encoding and transmission. Detection of erroneous data is based on heuristic methods, i.e. based on logical checks and on the comparison with other existing information and previously recorded positions.

A second server (Listener) provides the connectivity and the interfaces to open networks, for both collecting and presenting previously stored data.

## 5. ADDITIONAL APPLICATIONS AND RESEARCH AREAS

### 5.1. Simulation

The massive collection of vessel position data can be analyzed and used as input in simulation models in order to conduct research concerning traffic and safety in the Aegean Sea. Mainly, we are planning to develop an interactive analysis and simulation environment, which will process past ship routes stored in the database and acquire critical information. The system is an early design stage and the expected functionality is the following:

- *Detection of dangerous waterways*: based on the traffic analysis of the recorded ship routes and the average weather conditions, the system may estimate places considered dangerous using a number of metrics, such as: high traffic, frequent storms, difficult to access, etc.
- *Detection of congestions and delays in ports*: being a country with high tourism, congestions and delays have been noticed in popular ports of Greece, especially during high-traffic seasons (July - August). The system may detect and perform statistical analysis of such

occurrences, in order to assist experts in proposing solutions.

- *Simulation of what-if scenarios*: using hypothetical scenarios, such as an oil leak or emergency evacuation of a ship, in user-defined position and time of the year in the Aegean Sea, the system may estimate the availability of nearby ships and the time needed to approach the emergency area.
- *Simulation of alternative ship routes*: the system may allow an interactive modification of ship routes in order to propose alternative scenarios aiming to minimize sea danger and to avoid port congestions..

### 5.2. Alerting

Several categories of alerts or notifications may be generated and distributed through various channels (e.g. email, visual and sound notification through web-pages, SMS to mobile devices, interactive TV, voice gates). The generated alerts fit into one of the following categories:

- *Position alerts*: Sent whenever a vessel arrives/departs in/from a port, whenever it reaches a specific waypoint or whenever it goes in or out of the range of the system.
- *Estimation alerts*: Sent periodically, whenever a prediction of the time of arrival at a specific port or waypoint, is possible.
- *Special situation alerts*: Sent whenever a special, application-specific situation occurs. A special situation may include but not limited to: A vessel attempting to anchor at an area with underwater cables; a candidate vessel which is possibly the origin of a detected pollution; moving vessels in a very close proximity.

### 5.3. Fleet Management

Fleet Management is an essential function which allows shipping companies to efficiently observe their vessels, to minimize costs by better coordinating port approaches, to organize bunkering, to ideally adjust vessel's speed and consumption, and to improve their overall productivity.

The services provided by MarineTraffic may be easily personalized in order to meet the special requirement of a shipping company, by providing surveillance of a specific subset of vessels. Current positions, routes, port reaches and estimated times of arrivals are valuable information for a shipping company wishing to better organize its fleet and to maximize its efficiency and cost-effectiveness. Personalization of services can be offered through the web-based application, giving the possibility to the operations department to have a full and accurate picture of the fleet, at any place and at any time, as an outsourced information service.



#### 5.4. Other application & research areas

We plan to investigate the added-value that the implemented system provides to a variety of research areas. Our future work will include:

- Study of radio-waves propagation. Hundreds of vessels around a base station, distributed in large areas, provide an ideal collection of transmitters that can be observed in terms of signal quality and propagation.
- Research models on the detection of the origin of a pollution or the observation of illegal fishing and other criminal actions
- Combination of vessels itineraries with weather conditions
- Observation of areas of special interest, such as underwater cables, places with archaeological interest or environmental-sensitive areas.
- Examination of the necessary assumptions and amendments that must be made in order to exploit the collected data in more safety-critical applications.

#### 6. CONCLUSIONS

A Vessel Traffic Information System collecting vessels data through the ‘Automatic Identification System’, which also combines this information with other sources, may become a very powerful tool for maritime surveillance and for other special applications.

A careful design of a pilot system, such as the ‘MarineTraffic’, has to face several challenges and has to respond to specific user requirements. An effective implementation must include a large number of base stations collecting data and to process a huge amount of information. As such, it would only come into operation if a considerable investment was made or if the community helped. The second option applies to our case, which proved to be rather successful and efficient.

The interface presenting the data is web-based and highly interactive, in order to attract all interested parties and to be able to respond to the needs of the shipping industry. By analyzing user needs, we conclude that there is a large number of useful application areas where the system may be used as a tool. There are significant potentials in evolving the pilot system to support important applications, such as Notification and Alerting, Simulation of special scenarios, Tracking the origin of a pollution, Fleet management, Study of radio-wave propagation and many others.

#### 7. REFERENCES

Dziewicki M. 2006. The role of AIS for small ships monitoring. *BalticMaster Workshop*, Gdynia.

European Union, 2002. EU Directive 2002/59, ‘Establishing a Community vessel traffic monitoring and information system and repealing Council Directive 93/75/EEC’

Filipowicz W, 2004. Vessel Traffic Control Problems. *The journal of Navigation*, 57, 15–24. The Royal Institute of Navigation.

Harre I, 2000. AIS Adding New Quality to VTS Systems. *Journal of Navigation*, 53, 527-539 Cambridge University Press.

Harralda J. R., Mazzuchia T. A., Spahna J., Van Dorpa R., Merricka J., Shrestha S. and Grabowski M. 1998. Using system simulation to model the impact of human error in a maritime system. *Safety Science* 30 (1-2) 235-247.

Hasegawa, K., 2001. Intelligent Marine Traffic simulator for congested waterways, in Proc. of 7th *IEEE International Conference on Methods and Models in Automation and Robotics*, 631-636

International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), 2003. *Guidelines on the Universal Automatic Identification System*, Vol.1 Part I, Operational issues.

Köse E., Basar E., Demirci E., Güneroglu A., Erkebay S., 2003. Simulation of marine traffic in Istanbul Strait. *Simulation Modelling Practice and Theory* 11(7-8) 597-608

Mavrakis D., Kontinakis N., 2004. A queueing model of maritime traffic in Bosphorus Straits, *Simulation Modelling Practice and Theory* 16(3), 315-328

Roberts C.M., 2006. Radio frequency identification (RFID). *Computers & Security*, 25 (1) 18-26.

# INTELLIGENT AGENTS IN LOGISTICS: SOME TRENDS AND SOLUTIONS

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## ABSTRACT

The paper gives an insight into trends and solutions based on intelligent agent paradigm in logistics domain. Three kinds of systems are described: single agents constituting multi-agent systems, holonic systems and multi-multi-agent systems. Single agents and multiagent systems are used in various applications, holons mainly are designed for transportation scheduling while multi-multi-agent systems are the most suitable for supply chain management. The prototype of simulation tool based on holonic agents has been developed and used to simulate four different types of auctions.

Keywords: logistics, intelligent agent, holon, simulation tool

## 1. INTRODUCTION

The logistics domain is complex, decentralized, dynamic (goals, organizations' capabilities and beliefs are continuously changing), and open because organizations may enter or leave the system at any time (Perugini et al. 2003). In this domain a great number of actors are operating. These actors compose supply chains, i.e. networks of suppliers, factories, warehouses, terminals, distribution centers, retailers and customers, as well as various means of transportation, such as trucks, trailers, vans, cargo boats, barges, planes, etc.

Analysis of the available publications reveals that regardless of the fact that traditional mathematical and simulation techniques still dominate for problem solving and optimisation of solutions new approaches start to expand, for example, Web-based, knowledge-based, and mobile systems appear in logistics domain. The paper has focus on agent-based technologies, multi-agent and multi-multi-agent systems which emerge only recently in connection with such relevant complex, and wherewith unsolved, problems as coordination in supply chain management, dispatching of transportation orders, management of, for example, a seaport or a container terminal, etc.

Intelligent agents model organizations' logistics functions, processes, expertise and communications with other organizations, or simulate users involved in traffic, transport units or elements of transport infrastructure (Zhu and Bos 1999, Henoch and Ulrich

2000). Agent technologies and, in particular, multi-agent systems become quite popular for supply chain management (Gerber, Vierke, and Zinnikus 2000; Yuan, Liang, and Zhang n.d.; Fox, Barbuceanu, and Teigen 2000; Zhengping, Low, and Kumar 2003) because they model distributed tasks. Multi-multi-agent systems, in their turn, appear as the next step – integration of multi-agent systems providing reliability of overall supply chain processes (Frey et al. 2003, Stockheim et al. 2004, Nimis and Stockheim 2004).

The objective of this paper is to give an insight into applications of agent-based technologies and to figure out trends in development of such systems for logistics domain. The paper is organized as follows. The next section gives an outline of plethora of intelligent agents already proposed for transportation and logistics systems. Holonic agents are discussed in Section 3. Section 4 is devoted to multi-multi-agent systems. The brief description of the developed prototype of simulation tool based on holonic agents is given in Section 5. Finally, in the last section conclusions are made and future work is outlined.

## 2. INTELLIGENT AGENTS FOR TRANSPORTATION AND LOGISTICS SYSTEMS

The analysis of different information sources allows to conclude that applications of agent-based technologies cover many transportation and logistics problems, for instance, traffic modelling, logistics management and planning, vehicle dispatching, transportation scheduling, and others (Graudina and Grundspenkis 2006). At the moment a plethora of various agents already exists, and many research activities and application projects are carried out. In fact the very nature of logistics domain determines that single agents should be integrated in different kinds of multi-agent systems (MAS).

Logistics management motivates introduction of two generic meta-types of agents, namely, management agents which pursue goals with respect to their environment and defined action space, and service agents which solve well specified tasks autonomously (Henoch and Ulrich 2000). In logistics management agents are software entities for meeting operational

goals. These agents to the certain extent are autonomous, proactive, goal directed, take goal responsibility, and make decisions. They act autonomously, but their actions are constrained by the provided information and models. A management agent needs the following information: a goal to pursue, its skills and behaviour, model of environment, its role in the agent community, e.g. a role of supervising and collaborating agent or sub-agent, communication and cooperation protocols. In a logistics domain where the coordination of joint actions plays the most important role, this agent exhibits the following properties: acts in a collaborating manner, applies various problem solving strategies, manifests communication abilities, uses methods for conflict solution among its sub-agents, and shows capabilities for goal and model building, which are used by its sub-agents.

One of the main functions of agents in logistics and transportation systems is collaboration support which is divided into subfunctions: collaborative information sharing, collaborative operation and collaborative configuration (Yuan, Liang, and Zhang n.d.). To provide collaborative support such agents as searching, scheduling, optimisation and negotiation agents are used.

A supply chain is the subarea where intelligent agents are intensively studied and implemented. The new software architecture for managing the supply chain at tactical and operational levels with the purpose to improve its overall quality has been worked out (Fox, Barbuceanu, and Teigen 2000). This architecture is composed from a set of intelligent software agents and actually represents a MAS. Each agent is responsible for one or more activities in a supply chain and is interacting with other agents in planning and executing their responsibilities. The typical set of agents includes six agents. An order acquisition agent is responsible for customers' orders and communication with a logistics agent in cases when orders are modified or cancelled. A logistics agent coordinates and manages movement of materials or products across the supply chain. A transportation agent is responsible for the assignment and scheduling of transportation resources. A scheduling agent is responsible for scheduling and rescheduling activities in the factory, and for resource assignment. A resource agent manages availability of resources. A dispatching agent performs the order release and real-time floor control functions.

A typical logistics scenario (Zhengping, Low, and Kumar 2003) includes a variety of logistics service providers, manufacturers, and suppliers whose actions must be coordinated. Four types of agents, namely, a distribution hub agent, a logistics coordinator agent, a manufacturer agent and a transporter agent represent generic roles in a typical supply chain. An architecture for agent-based logistics coordination has been designed based on the JADE agent platform (<http://jade.tilab.com/>). Each participant of a supply chain provides the agent platform with a set of agent instances. The agent platforms which include basic

management agents and application agents are linked via Internet. Basic management agents embody a registration agent, a communication agent and a directory agent while an application agent includes interface, activation controller, optimisation/planning modules, for example, a demand forecasting or a transportation planning modules, and a knowledge base.

The Distributed Intelligent Agents for Logistics (DIAL) project is an open systems architecture that allows existing models to interface and communicate in a distributed network environment to evaluate and develop logistics plans (Satapathy, Kumara, and Moore 1998). A customer's problem is decomposed and assigned to corresponding intelligent agents which working together generate a logistics plan. Intelligent software agents are built on the top of simulation models to communicate among themselves, and to generate or to assist in generating a correct course of actions. Of course, DIAL is only one example of MAS developed for logistics. Various MASs have been developed and applied due to the growing success of FIPA standardization (<http://www.fipa.org/>) for MAS, increasing availability of FIPA-compliant frameworks, such as JADE (<http://jade.cselt.it/>) and open service infrastructures, for instance, Agent Cities (<http://www.agentcities.org/>) (Stockheim et al. 2004, Nimis and Stockheim 2004). A large number of agent-oriented methodologies have been proposed in recent years, for example, Gaia and its extension SODA, PASSI, AUML, MaSE, Tropos, TAO, CoMoMAS, MAS-CommonKADS, PROMETHEUS, and many others, part of which are described and compared in (Padgham and Winikoff 2004).

Recently the agents' family is supplemented with a new kind of agents. Mobile agents not only can communicate and interact with other agents but also can move from one place to another, and find and process information, as well as can send back results to the users (Schoder and Eymann 2000). Mobile agents provide an innovative concept for distributed systems development. These agents have a great potential for transportation and logistics problem solving, and for supply chain management because global transportation networks and supply chains require distributed global planning of activities.

### **3. HOLONIC AGENTS FOR TRANSPORTATION AND LOGISTICS PROBLEM SOLVING**

Design of agent based systems for transport has created a new agent technology, so called holonic agent or a holon (Bürckert, Fischer, and Vierke 1999). A holon is composed from agents working together in order to reach a common goal. A holon interacts with its environment similarly as a single agent. In (Bürckert, Fischer, and Vierke 1998) three kinds of holonic structures are described. First, a holon may be organized as a federation of autonomous agents (Figure 1a). In fact, this structure is just another version of traditional MAS because all sub-holons are fully autonomous

agents. A super-holon (composition of subordinate agents) is realized exclusively through cooperation among sub-holons and in reality is just a new conceptual instantiation of the same agent architecture. Second, a holonic agent may be created as a union of all involved agents (Figure 1b), i.e., agents merge into one agent, and merged agents completely give up their autonomy. After termination of super-holon each agent may be reverted into its initial state. Third, a holon as a moderated group is a hybrid way of forming a holon because agents give up only part of their autonomy to a super-holon keeping their own plans, goals and communication facilities. A super-holon is one of agents which coordinates resource allocation within a holon and controls communication with the rest of agent society. Thus, a super-holon becomes a representative, or so called, head of the holon (Figure 1c).

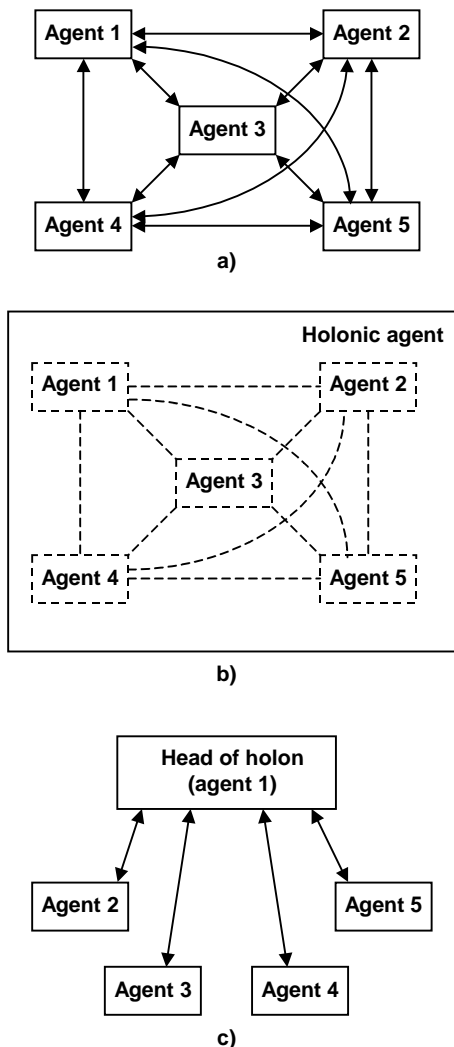


Figure 1: Three Kinds of Holonic Structure (adapted from (Bürckert, Fischer, and Vierke 1998))

The most important requirements for a holonic agent are the structure and cooperation, that is, a domain must be recursively decomposable and must

have sufficient cooperative elements between the distinguished problem solvers. It is quite obvious that the holonic approach is suitable for problem solving in transportation and logistics. This approach is successfully used in several projects for transportation scheduling, starting with MAS-MARS (Fischer and Kuhn 1993), followed by TELETRUCK (Bürckert, Fischer, and Vierke 1999; Bürckert, Fischer, and Vierke 1998), its extension TELETRUCK-CC (Bürckert and Vierke 1999) and PLATFORM (Gambardella, Rizzoli, and Funk n.d.). The agents of MAS-MARS represent homogenous trucks and negotiate on incoming orders optimising the distribution and execution of these orders. In contrast, the TELETRUCK system schedules orders using heterogeneous agents modelling different forms of vehicles. The main idea in the TELETRUCK system is to model basic transportation units (drivers, trucks, trailers, chassis, containers, etc.) of transportation domain explicitly by component agents that merge into a holon representing a vehicle for a transportation task. The agent society is implemented as a holonic agent system that acts in a corporate way. The TELETRUCK-CC allows several independent shipping companies to cooperatively optimise their fleet schedules. The PLATFORM architecture consists of the intermodal transport planner that manages planning of the whole intermodal transport chain, and the simulation system that simulates intermodal transport unit transportation process.

Another kind of holonic software agent is realized in the Casa ITN system (Gerber and Klusch 2002). Each member of participant group, namely, producers, buyers, retailers, and logistics companies is represented by an appropriate holonic agent. Holonic agents accomplish hierarchically decomposed tasks and resource allocation, coordinate and control activities and information flows of their sub-agents. There are known also other applications such as scheduling of work in a production plan and coordination of business processes in a virtual enterprise where the holonic agent approach has been successfully used.

To summarize, it is worth to stress, that holonic structures besides such characteristics as hierarchy, decomposability, communication and cooperation have the most important characteristic – an open architecture. This made the design of MAS much more easy because instead of monolith agents with all needed functionality the holonic architecture promotes the design of small units with limited functionality which may be added or deleted from the MAS without impact on the rest of the system. This very relevant characteristic determines that the holonic approach will be widely used in future not only in transportation and logistics but also in other intelligent agent applications.

#### 4. MULTI-MULTI-AGENT SYSTEMS FOR SUPPLY CHAIN MANAGEMENT

Multi-agent systems (MAS) support distributed task modelling for supply chains which involves many different independent tasks, i.e., planning, execution

and control of production, transportation and warehousing processes (Nimis and Stockheim 2004). Looking at MASs from the viewpoint of supply chain management design these systems depend on each others' input and output, and therefore need to be integrated in heterogeneous systems. Integration of MASs leads to the concept of multi-multi-agent systems (MMAS). The structure of MMAS is designed to inherently meet the requirements of distributed supply chains where information for integrated production planning and control is not available within a whole supply chain. Analysis, design and implementation of MMAS has resulted in the Agent.Enterprise system (Frey et al. 2003, Stockheim et al. 2004, Nimis and Stockheim 2004). The Agent.Enterprise methodology focuses on a distributed and weakly coupled development process. The results of the analysis and design phase are consolidated in functionally restricted prototypes which constitute a test bed for components of MMAS. The project substitutes their prototypes with so called gateway-agents in order to connect their applications to the common scenario. Details of MMAS development process are given in (Stockheim et al. 2004) In brief, the analysis phase includes the role definition and assignment step followed by the use case specification. At the design phase of Agent.Enterprise two central design decisions are united in the gateway-agent concept as it is shown in Figure 2.

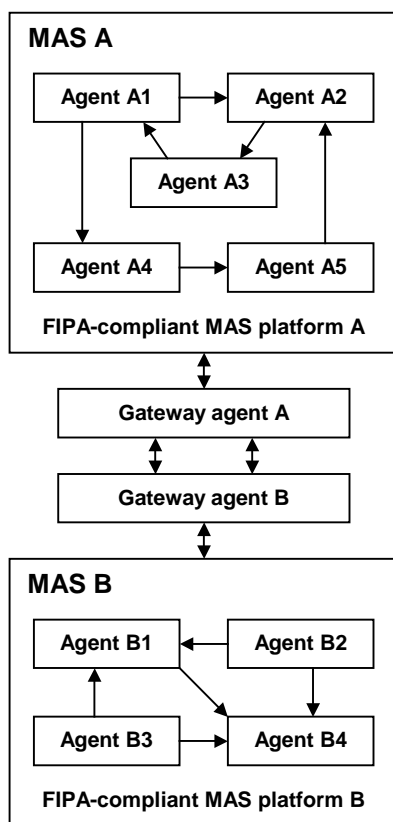


Figure 2: Multi-Multi-Agent Design Concept (adapted from (Nimis and Stockheim 2004))

The use of FIPA-compliant platforms avoids many of communication-related obstacles connected with heterogeneity of knowledge representation and semantics in individual MAS. The gateway-agent concept defines a virtual MAS where agents are scattered across a number of agent platforms such that an ontology can specify semantics of conversations, and ontology expressions are used as means of communication. At the design phase every individual MAS to be integrated should be represented by a single agent that comprises all roles of the corresponding MAS and provides them to the resulting MMAS. The implementation phase starts with the implementation of functionally restricted prototypes. There are some advantages of the gateway-agent concept. Developers can focus on a single agent and only gateway-agents must be available during operation. Moreover, the MMAS provides an integration of different agent platforms. On the other hand, the multi-multi-agent concept may be less flexible than the holonic agent approach because an individual MAS should be represented by a single agent with its full functionality.

The MMAS called the Agent.Enterprise covers services of supply chain scheduling, shop floor production planning and control, as well as pro-active tracking and tracing services. The MMAS provides reliability of overall supply chain processes (Stockheim et al. 2004).

## 5. SIMULATION TOOL BASED ON HOLONIC AGENTS

To gain experience of holonic agent design we have developed the prototype of simulation tool which in details is described in (Grundspenkis and Lavendelis 2006). The purpose of the prototype is to simulate delivery of goods from Asia to Europe using the following supply chain: Asian deep sea port (Shanghai, China) → deep sea shipping lines → deep sea port (Hamburg, Germany) → feeder shipping lines → Baltic and Mediterranean feeder ports (Greece, Finland, Lithuania, Latvia, Estonia) → trains → railway container terminals → customers in the EU and CIS countries. The multiagent system depicted in Figure 3 consists from clients' agent, logistics companies' agents and agents of each carrier. The system is built as follows: each client has his agent and each logistics company has its agent, too. Clients make deals with logistic companies using auctions. Each client is an auctioneer and logistics companies are bidders. A client's agent gets all necessary auction parameters from a client, e.g., a starting point and a destination, an auction type and a starting price per unit. Each logistics company's agent has knowledge base containing all carriers with whom his owner (logistics company) collaborates, and information about routes they operate. After receiving an offer to participate in an auction, a logistics company's agent must calculate its private evaluation. To do it, this agent must find all possible routes between a starting point and a destination. A transport network is modelled by a weighted graph

which nodes represent terminals and edges are possible routes. Weights of nodes correspond to costs for keeping units of goods (containers) in terminals, and weights of edges correspond to their transportation costs. After finding the route with minimal total costs (the widely known shortest path algorithm is used), the agent gets its private evaluation which is the sum of the minimal total costs and the minimal company's profit.

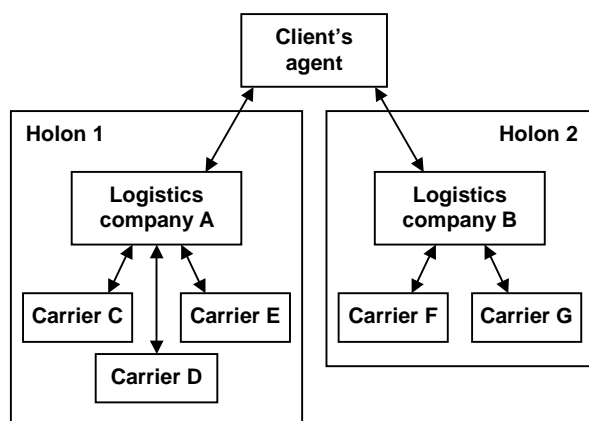


Figure 3: Example of Holonic System for Auction Simulation

The auctioneer starts an auction by sending all auction parameters to bidders. Four well known types of auctions, namely, English, Dutch, first-price sealed-bid and Vickrey auction (Wooldridge 2002) are implemented in the developed simulation tool. Each agent has its strategy for each type of auction captured in its knowledge base. Having its strategy and its private evaluation, an agent makes a decision to bid or not to bid. At the end of auction the auctioneer (the client) can make a deal with the winning agent. Automation of communication between a carrier agents and a logistics company agent can be done using auctions, too. In this case a holonic agent is used because for clients a logistics company and carriers with which it corporates is one whole object (holon) represented by one holonic agent. It is worth to point out that communication of carriers and ships, trains and/or trucks is not based on auctions because they are units of the same company. In fact, instead of deal making coordination is needed in this case (the developed prototype don't support coordination mechanisms).

The interface of the developed simulation tool consists from three main parts: 1) the auction parameters' input part, 2) the knowledge editing part and 3) the bid and winner information output part. The first part allows to input routes and auctions' parameters. The second part allows the user to edit agent lists, their attributes and knowledge bases. The third part consists of Europe's and China's maps where during an auction all terminals and routes are drawn. There is also the result table where information about the price, the route and the time is represented.

The developed simulation tool is used as a test bed to investigate influence of auction protocols on price, i.e. to find an answer to the question which auction gives the lowest price? In fact for risk-neutral bidders the chosen protocol is not important but for risk-averse bidders Dutch and first-price sealed-bid auctions are the best for auctioneers. However, risk-averse auctioneers do better with Vickrey and English auctions (Wooldridge 2002). Results of experiments carried out with the developed simulation tool shows that if both an auctioneer and bidders are risk-neutral there is not big difference which auction protocol is used (variations of the price are not more than 10% in any case). In real world it seems that small companies mainly are risk-averse while big companies may take a risk more willingly because their possible relative losses will not be so crucial for them.

At the moment the prototype can not support simulation of realistic situations because the simulation tool is implemented using Borland C++ Builder and MS Access database and is running on one computer without the Internet connection. A real system should have one server and many client's and logistic company's computers each having one agent. Actually it is only a matter of programming client-server applications to implement a simulation tool for real life situations, and it is one direction of future work.

## 6. CONCLUSIONS

This work is based on analysis of rather large number of information sources. This allows to conclude that in logistics domain there are three kinds of agent architectures. A plethora of single agents already have been developed which are integrated in multi-agent systems (MAS). Holonic systems have found their applications mainly in transportation problem solving, in particular, for scheduling tasks. In the supply chain management MASs and MMASs are widely used.

To get experience we have developed the prototype of simulation tool based on holonic agents. This tool allows to simulate one predefined supply chain for delivering goods from Asia to Europe. The prototype is used for investigation of influence of four different auction protocols on price.

The future work envisages continuation of analysis of existed approaches of applying agent technologies to automate the coordination and decision making in logistics, already proposed methodologies for single agent-based, MAS and MMAS development and the corresponding software. Another direction of future work is the development of holonic agent based simulation tool that is applicable for real life situations.

## REFERENCES

- Bürckert, H.-J., Fischer, K., Vierke, G., 1998. Transportation Scheduling with Holonic MAS – the TELETRUCK Approach. In: *Proceedings of the Third International Conference on Practical Application of Intelligent Agents and Multi-Agent*

- Technology (PAAM'98)*, (H.S. Nwama and D.T. Ndimu, eds.).
- Bürckert, H.-J., Fischer, K., Vierke, G., 1999. Holonic Fleet Scheduling with TELETRUCK. In: *Proceedings of the Second International Conference on Computing Anticipatory Systems (CASYS'98)*.
- Bürckert, H.-J., Vierke, G., 1999. Simulated Trading Mechanismen für Speditionsübergreifende Transportplanung. In: *Logistic Management – Intelligente I+K Technologien*, (H. Kopfer and C. Bierwirth, eds.), Springer-Verlag.
- Fischer, K., Kuhn, N.A., 1993. A DAI Approach to Modeling the Transportation Domain. Research Report RR-93-25, DFKI.
- Fox, M.S., Barbuceanu, M., Teigen, R., 2000. Agent-Oriented Supply-Chain Management. *International Journal of Flexible Manufacturing Systems*, (12), 165–188.
- Frey, D., et al., 2003. Integrated Multi-Agent-Based Supply Chain Management. In: *Proceedings of the 1<sup>st</sup> International Workshop on Agent-Based Computing for Enterprise Collaboration*.
- Gambardella, L.M., Rizzoli, E., Funk, P. Agent-Based Planning and Simulation of Combined Rail/Road Transport. Available from: <http://www.idsia.ch/~luca/simulation02.pdf>
- Gerber, A., Klusch, M., 2002. Agent-Based Integrated Services for Timber Production and Sales. *IEEE Intelligent Systems*, 17(1), 33–39.
- Gerber, A., Vierke, G., Zinnikus, I., 2000. Generic Modeling of Multi-Agent Solutions for Transportation Domains. In: *Proceedings of the ECAI 2000 Workshop 13 “Agent Technologies and their Application Scenarios in Logistics”* (I.J. Timm, et al., eds.), Berlin, 29–33.
- Graudina, V., Grundspenkis, J., 2006. Agent-Based Systems, their Architecture and Technologies from Logistics Perspective. In: *Scientific Proceedings of Riga Technical University, Computer Science, Applied Computer Systems*, 5<sup>th</sup> Series, Vol. 26, RTU Publishing, Riga, 159–173.
- Grundspenkis, J., Lavendelis, E., 2006. Multiagent Based Simulation Tool for Transportation and Logistics Decision Support. In: *Proceedings of the 3<sup>rd</sup> International Workshop on Computer Supported Activity Coordination CSAC 2006*, INSTICC Press, Portugal, 45–54.
- Henoch, J., Ulrich, H., 2000. Agent-Based Management Systems in Logistics. In: *14<sup>th</sup> European Conference on Artificial Intelligence Workshop Notes, Agent Technologies and their Application Scenarios in Logistics* (I.J. Timm, et al., eds.), 11–15.
- Nimis, J., Stockheim, T., 2004. The Agent.Enterprise Multi-Multi-Agent System. In: *Special Track on Agent Technology in Business Applications (ATeBA 04) at Multi-Conference on Business Information Systems (MKWI 2004)*.
- Padgham, L., Winikoff, M., 2004. *Developing Intelligent Agent Systems. A Practical Guide*. John Wiley & Sons, The Atrium, Southern Gate, Chichester, West Sussex, England.
- Perugini, D., et al., 2003. Agents in Logistics Planning – Experiences with the Coalition Agents Experiment Project. In: *Proceedings of Workshop at the Second International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2003)*. July 2003, Melbourne, Australia.
- Satapathy, G., Kumara, S.R.T., Moore, L.M., 1998. Distributed Intelligent Agents for Logistics (DIAL). *Journal of Expert Systems Applications and Practice*.
- Schoder, D., Eymann, T., 2000. Technical Opinions: the Real Challenges of Mobile Agents. *Communications of ACM*, 42(6), 111–112.
- Stockheim, T., et al., 2004. How to Build a Multi-Multi-Agent System: The Agent.Enterprise Approach. In: *Proceedings of the 6<sup>th</sup> International Conference on Enterprise Information Systems (ICEIS 2004)*.
- Wooldridge, M., 2002. *An Introduction to Multiagent Systems*. John Wiley & Sons, Baffins Lane, Chichester, England.
- Yuan, Y., Liang, T.P., Zhang, J.J. Using Agent Technologies to Support Supply Chain Management: Potentials and Challenges. Available from: <http://merc.mcmaster.ca/wpapers/wpaper456.html>
- Zhengping, L., Low, M.Y.H., Kumar, A.A., 2003. A Framework for Multi-Agent System-Based Dynamic Supply Chain Coordination. In: *Proceedings of the Workshop at the Second International Joint Conference of Autonomous Agents and Multiagent Systems (AAMAS 2003)*. Available from: <http://www.agent-software.com.au/shared/resources/papers/aamas2003/aamas03w5-zhengping.pdf>
- Zhu, K., Bos, A., 1999. Agent Based Design of Intermodal Freight Transportation Systems. NECTAR Conference, Delft, The Netherlands.

# SEQUENTIAL ORDERING PROBLEMS FOR CRANE SCHEDULING IN PORT TERMINALS

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## ABSTRACT

The sequential ordering problem is a version of the asymmetric travelling salesman problem where precedence constraints on vertices are imposed. A tour is feasible if these constraints are respected, and the objective is to find a feasible solution with minimum cost.

The sequential ordering problem models many real world applications, mainly in the fields of transportation and production planning. In particular, it can be used to optimise quay crane assignments.

In this paper we experimentally evaluate the contributions of the basic ingredients of the state-of-the-art algorithm for the sequential ordering problems: local searches, ant colony and heuristic manipulation.

Keywords: quay crane optimization, sequential ordering, heuristic algorithm.

## 1. THE SEQUENTIAL ORDERING PROBLEM

### 1.1. Introduction

Maritime transport has been constantly increasing in the past years. The Review of Maritime Transport published by UNCTAD<sup>1</sup> in 2007 reports an average increase of 13.52% in 2005 and 14.63% in 2006 for the top 20 ports. Such double figures are correlated to the strong development of trade with emerging countries such as China and India, and the trend is expected to continue even in the face of uncertainties in the world economic outlook. Port infrastructures are also growing, but the investments cannot keep up with the pace of the expansion of trade. Problems related to port congestion and lack of storage space are here to stay. The optimization of port terminal resources is therefore a key tool for the success of port operations. Optimization can also play a major role in minimizing the environmental impact of sea freight, since a better usage of the existing resources can also have a significant impact on the quantity of energy required to efficiently operate a large infrastructure such as a maritime port terminal.

A maritime port terminal is a complex system, composed of a number of parts, each one with its specific

purpose and characteristics. Steenken et al. (2004) describe it as an open system of material flow with two interfaces, one on the quay-side, to the sea, and one on the hinterland, to inland. The management of a terminal port is obviously a complex decisional problem, due to the multiple interactions which are present among the various component processes of the port. Efforts have been made towards the systematic classification and solution of the various planning, management and control problems which are encountered in terminal systems. Of particular interest is the classification by Günther and Kim (2006) who divide the problems according to the decisional level (terminal design, operational planning, and operational control) and to the subject of the decisional problem. Thus, at the design level we encounter problems such as the design of the multi-modal interfaces, of the terminal layout, the selection of equipment, while at the planning level the focus is on the synthesis of storage and stacking policies, assigning cranes to ships, planning stowage and berth assignment. Finally, at the operational control level, the terminal manager has to solve problems such as land-side and quay-side transport and crane operations and scheduling.

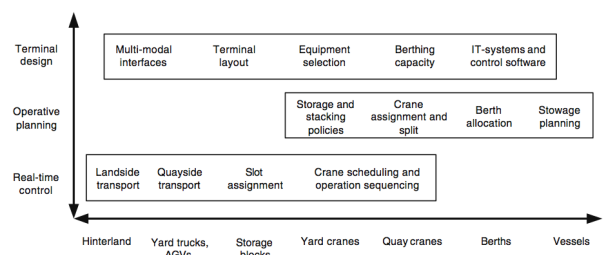


Figure 1. Design, planning and control problems with respect to the components of a maritime terminal (from Günther and Kim 2006).

Given the complexity of the structure and of the processes, many authors have attempted a “divide and conquer” approach. In this approach the global port optimization problem is decomposed into a series of simpler problems, which are solved independently, using bound-

<sup>1</sup><http://www.unctad.org>.



ary conditions to guarantee the overall feasibility of the solution, as also shown by Gambardella et al. (2001), and also by a number of other authors, as reported in the recently updated comprehensive review by Stahlbock and Voß(2008).

In this paper we focus our attention on the problem of the optimisation of quay crane scheduling at the operational control level once the crane assignment and crane split problem have been solved at the planning level. In particular, we assume that a quay crane is dedicated to loading and unloading a specific ship section, as happens in the vast majority of cases, since two cranes serving the same ship section would need interleaving, without any clear advantage in performance. This assumption allows us to formulate the crane scheduling problem as a sequential ordering problem, since we have one machine (the crane) which must serve a number of jobs (the containers) which are subject to precedence constraints, which are given by the stacking positions of the containers on the terminal yard and by the loading/unloading lists of the ship, which are set according to the final destination of the containers.

### 1.2. Problem description

The *Sequential Ordering Problem (SOP)*, also referred to as the *Asymmetric Travelling Salesman Problem with Precedence Constraints*, can be modelled in graph theoretical terms as follows. A complete directed graph  $D = (V, A)$  is given, where  $V$  is the set of nodes and  $A = \{(i, j) | i, j \in V\}$  is the set of arcs. A cost  $c_{ij} \in \mathcal{N}$  is associated with each arc  $(i, j) \in A$ . Without loss of generality it can be assumed that a fixed starting node  $1 \in V$  is given. It has to precede all the other nodes. The tour is also closed at node 1, after all the other nodes have been visited ( $c_{i1} = 0 \forall i \in V$  by definition). This artifact creates an analogy with the asymmetric travelling salesman problem. Such an analogy is exploited by many known algorithms. Furthermore an additional precedence digraph  $P = (V, R)$  is given, defined on the same node set  $V$  as  $D$ . An arc  $(i, j) \in R$ , represents a precedence relationship, i.e.  $i$  has to precede  $j$  in every feasible tour. Such a relation will be denoted as  $i \prec j$  in the remainder of the paper. The precedence digraph  $P$  must be acyclic in order for a feasible solution to exist. It is also assumed to be transitively closed, since  $i \prec k$  can be inferred from  $i \prec j$  and  $j \prec k$ . Note that for the last arc traversed by a tour (entering node 1), precedence constraints do not apply. A tour that satisfies precedence relationships is called *feasible*. The objective of the *SOP* is to find a feasible tour with the minimal total cost.

It is interesting to observe that *SOP* reduces to the classical asymmetric travelling salesman problem (*ATSP*) in the case where no precedence constraint is given. This observation implies that *SOP* is  $\mathcal{NP}$ -hard, being a generalization of the *ATSP*.

### 1.3. Literature review

The *SOP* can model real-world problems such as production planning (Escudero 1988 and Seo and Moon 2003),

single vehicle routing problems with pick-up and delivery constraints (Pulleyblank and Timlin 1991, Savelsbergh 1990) and transportation problems in flexible manufacturing systems (Ascheuer 1995).

Sequential ordering problems were initially solved as constrained versions of the *ATSP*, especially for the development of exact algorithms. The main effort has been put into extending the mathematical definition of the *ATSP* by introducing new classes of valid inequalities to model the additional constraints. The first mathematical model for the *SOP* was introduced by Ascheuer et al. (1993), where a cutting plane approach was proposed to compute lower bounds on the optimal solution. Escudero et al (1994), a Lagrangean relaxation method was described and embedded into a branch and cut algorithm. Ascheuer (1995) has proposed a new class of valid inequalities and has described a new branch-and-cut method for a broad class of *SOP* instances. This is based on the polyhedral investigation carried out on *ATSP* problems with precedence constraints by Balas et al. (1995). The approach by Ascheuer (1995) also investigates the possibility of computing and improving sub-optimal feasible solutions starting from the upper bound provided by the polyhedral investigation. The upper bound is the initial solution of a heuristic phase based on well-known *ATSP* heuristics that are iteratively applied in order to improve feasible solutions. These heuristics do not handle constraints directly; infeasible solutions are simply rejected. A branch and bound algorithm with lower bounds obtained from homomorphic abstractions of the original search space has been presented by Hernàdvölgyi (2003, 2004). A genetic algorithm has been proposed in Chen and Smith (1996). The method works in the space of feasible solutions by introducing a sophisticated crossover operator that preserves the common schemata of two parents by identifying their maximum partial order through matrix operations. The new solution is completed using constructive heuristics. A hybrid genetic algorithm based on complete graph representation has been discussed by Seo and Moon (2003). A parallelised roll-out algorithm has been described by Guerriero and Mancini (2003). Gambardella and Dorigo (2000) presented an approach based on Ant Colony System (ACS) enriched with sophisticated Local Search (LS) procedures. Montemanni et al. (2007, 2008) built on top of this method, adding a Heuristic Manipulation Technique (HMT) on top of the original algorithm. This resulting method can be classified as state-of-the-art for the sequential ordering problem.

The contribution of the present article is an experimental study aiming at understanding the contribution of the basic ingredients (LS, ACO, HMT) in the economy of the composite method described by Montemanni et al. (2008).

The paper is organized as follows: Sections 2, 3 and 4 describe local searches, ant colony optimization and heuristic manipulation for the *SOP*, respectively. These are the basic ingredients of the composite algorithm de-

scribed by Montemanni et al. (2008). Extensive computational experiments, aiming at understanding how the algorithm performs when only a subset of the ingredients is put in operation, are presented in Section 5. Conclusions are drawn in Section 6.

## 2. LOCAL SEARCH (LS)

The extremely efficient *SOP-3-exchange* local search routine (we will refer to it as LS in the remainder of the paper) has been introduced by Gambardella and Dorigo (2000). This local search routine is a specialization to the sequential ordering problem of a known local search method for the asymmetric travelling salesman problem (Savelsbergh 1990). It is able to directly handle multiple constraints without increasing the computational complexity of the original local search.

*SOP-3-exchange* starts from a feasible solution, and generates a new solution by replacing three edges (Figure 2)  $(h, h + 1)$ ,  $(i, i + 1)$ ,  $(j, j + 1)$  with another set of improving three edges  $(h, i + 1)$ ,  $(j, h + 1)$ ,  $(i, j + 1)$ . This operation is iteratively executed until no additional improving 3-exchange is possible. *SOP-3-exchange* explores the set of feasible edges using a lexicographic approach. The lexicographic approach identifies step by step the set of three edges and therefore two paths, *path\_left* and *path\_right*, which once inverted give rise to a new feasible solution. In the lexicographic search these two paths are initially composed of one single node and are incrementally expanded adding one node at each step. This feature makes it possible to test feasibility easily because precedence conditions must be checked only for the new added node.

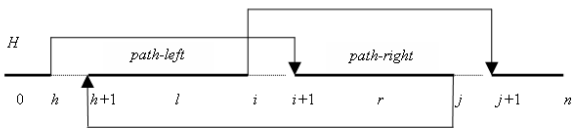


Figure 2. SOP-3-exchange local search.

In fact *SOP-3-exchange* uses a new a labeling procedure whose function is to check feasibility in constant time. The solution is to keep updated a set of global variables that indicates, each time a new node is added to *path\_left* or *path\_right*, if this insertion violates one of the precedence constraints.

Other important *SOP-3-exchange* features are related to the way node  $h$  is selected. The goal is to decrease the number of visited nodes introducing two heuristics that influence how node  $h$  is chosen: one is based on the *don't look bit* data structure introduced by Bentley (1992), while the other is based on a data structure called *don't push stack* introduced by Gambardella and Dorigo (2000). The *don't look bit* is a data structure in which a bit is associated with each node of the sequence. At the

beginning of the search all bits are turned off. The bit associated with node  $h$  is turned on when a search for an improving move starting from  $h$  fails. The bit associated with node  $h$  is turned off again when an improving exchange involving  $h$  is executed. The use of *don't look bits* favors the exploration of nodes that have been involved in a profitable exchange.

The *don't push stack* is a data structure based on a stack, which contains the set of nodes  $h$  to be selected. At the beginning of the search the stack is initialized with all the nodes in the sequence (that is, it contains  $n + 1$  elements). During the search, node  $h$  is popped off the stack and feasible 3-exchanges starting from  $h$  are investigated. In case a profitable exchange is executed the six nodes involved in this exchange are pushed onto the stack (if they do not already belong to it). Using this heuristic, once a profitable exchange is executed starting from node  $h$ , the top node in the *don't push stack* remains node  $h$ . In this way the search is focused on the neighborhood of the most recent exchange: this has been experimentally shown to result in a better performance than that obtained using the *don't look bit* alone.

## 3. ANT COLONY SYSTEM (ACS)

In this section the basic concepts of the ACS algorithm, originally presented by Gambardella and Dorigo (2000), are discussed. The Ant Colony System algorithm is an element of the *Ant Colony Optimization* family of methods (Dorigo et al. 1999). These algorithms are based on a computational paradigm inspired by real ant colonies and the way they function.

ACS for the SOP is an adaptation to the problem of the Ant Colony System algorithm (Dorigo and Gambardella 1997). Informally, ACS works as follows. Constructive computational agents called ants (simulating real ants) are sent out sequentially. Each ant iteratively starts from node 1 and adds new nodes until all nodes have been visited. When in node  $i$ , an ant applies a so-called transition rule, that is, it probabilistically chooses the next node  $j$  from the set  $F(i)$  of feasible nodes.  $F(i)$  contains all the nodes  $j$  still to be visited and such that all nodes that have to precede  $j$ , according to precedence constraints, have already been inserted in the sequence.

The ant in node  $i$  chooses the next node  $j$  to visit on the basis of two factors: the heuristic *desirability*  $\eta_{ij}$  here defined as  $1/c_{ij}$ , and the *pheromone trail*  $\tau_{ij}$ , that contains a measure of how good it has been in the past to include arc  $(i, j)$  into a solution. The next node to visit is chosen with probability  $q_0$  as the node  $j$ ,  $j \in F(i)$ , for which the product  $\tau_{ij} \cdot \eta_{ij}$  is highest (deterministic rule), while with probability  $1 - q_0$  the node  $j$  is chosen with a probability given by 
$$P_{ij} = \frac{\tau_{ij} \cdot \eta_{ij}}{\sum_{l \in F(i)} (\tau_{il} \cdot \eta_{il})}.$$

The value  $q_0$  is given by  $q_0 = 1 - s/|V|$ . The parameter  $s$  represents the number of nodes it would be desirable to choose using the probabilistic transition rule, independently of the number of nodes of the problem, and is set to 10 in the experiments reported here.

In *ACS-SOP* only the best ant, that is the ant that built the shortest tour since the beginning of the computation, is allowed to deposit pheromone trail. If the shortest path generated since the beginning of the computation is referred to as  $OptPath_{Best}$ , and its cost as  $L_{Best}$ ,  $\forall \{i, j\} \in OptPath_{Best}$ , the following formula for pheromone update is used:

$$\tau_{ij} = (1 - \rho) \cdot \tau_{ij} + \frac{\rho}{L_{best}} \quad (1)$$

Notice that in case a local search is used inside ACS, the updating rule (1) is run based on the solution obtained after the application of the local search.

Pheromone is also updated during solution building. In this case, however, it is removed from visited arcs. In other words, each ant, when moving from node  $i$  to node  $j$ , applies a pheromone updating rule that causes the amount of pheromone trail on arc  $(i, j)$  to decrease. This assures variety in the solutions generated. The rule is:

$$\tau_{ij} = (1 - \psi) \cdot \tau_{ij} + \psi \cdot \tau_0 \quad (2)$$

where  $\tau_0$  is the initial value of trails. It was found that good values for the algorithm's parameters are  $\tau_0 = (FirstSolution \cdot |V|)^{-1}$  and  $\rho = \psi = 0.1$ , where *FirstSolution* is the length of the shortest solution generated by the ant colony following the *ACS-SOP* algorithm without using the pheromone trails. The number of ants in the population was set to 10. Experience has shown the chosen parameter settings to be robust.

#### 4. HEURISTIC MANIPULATION TECHNIQUE (HMT)

It is easy to observe that adding precedence constraints to a given problem reduces its search space, making the problem potentially easier to solve. The method described in the remainder of this section is based on this observation.

Having selected an underlying heuristic method, the idea is to monitor the solutions generated by this method, and to identify precedence patterns common to solutions with a low objective value. Once such precedence patterns are identified, they can be added to the original problem as *artificial precedence constraints*. The manipulated problem is likely to be easier than the original one, as it has a reduced solution space.

Notice that any heuristic method that produces a sequence of feasible solutions to the problem (most of the known methods work in this way) can be used as the underlying method for the proposed manipulation approach.

Of course such a heuristic method may cut out all the optimal solutions of the original problem, leading to suboptimal solutions even when the best solution of the

modified problem is retrieved. To overcome this side effect, during the execution of the algorithm artificial precedence constraints will not be added permanently, but will also be retracted (and substituted by other constraints).

Formally, the proposed methodology is built on top of an existing algorithm and makes use of an additional set of variables  $\{m_{ij}\}$ . Variable  $m_{ij}$  will be an indicator for the "quality" of the solutions in which node  $i$  is visited before node  $j$ . The method is regulated by some parameters. Parameter  $u$  regulates the number of solutions generated by the underlying heuristic method before the first artificial precedence constraints are added to the problem; parameter  $v$  regulates the number of solutions generated by the underlying heuristic method between two consecutive updates to the set of active artificial precedence constraints; parameter  $w$  regulates the (approximate) number of artificial precedence constraints active at each moment in time (after the first  $u$  solutions have been generated by the underlying heuristic approach); parameter  $z$  finally regulates the (approximate) number of artificial precedence constraints substituted after every  $v$  new solutions have been generated by the underlying heuristic algorithm (after the first  $u$  solutions have been generated).

The heuristic manipulation technique runs on top of underlying optimization algorithm, and can be summarized as follows.

Initialize  $m_{ij} = 0 \quad \forall (i, j) \in A$ .

Each time a new solution  $OptPath_k$ , with cost  $L_k$ , is generated by the underlying heuristic algorithm, matrix  $m = [m_{ij}]$  is updated as described in (3) and (4), where  $L_1$  is the cost of the very first solution generated by the underlying heuristic algorithm and  $\pi_k(i)$  is the index of the position occupied by node  $i$  in solution  $OptPath_k$ . Notice that  $L_1$  plays here the role of a normalization factor, and is used to avoid numerical problems. The width of the window considered for updates is taken to be 5. According to Montemanni et al. (2008), some tests suggests that the method is not very sensitive to changes to this value, and that good values are however in the range  $[4, 10]$ .

The first update (equation (3)) reinforces the entry corresponding to a sequence which is in solution  $OptPath_k$ . The update is proportional to the inverse of the cost of the solution itself. Equation (4) decreases the value on arcs that are traversed in the opposite direction in the current solution. This second update has been inserted to make those pairs of nodes that do not seem to have a clear ordering relationship less attractive. Notice that only pairs with a positive entry in matrix  $m$  will be potentially transformed into artificial precedence constraints.

Notice that entries of the memory matrix  $m$  corresponding to active artificial precedence constraints are not updated. This will make a rotation of the active constraints more likely (see the remainder of this section).

Now that it has been clarified how the memory matrix  $m$  is handled, it remains to clarify how artificial precedence constraints are managed. After the first  $u$  solutions are created by the underlying heuristic algorithm, a first

$$m_{ij} = m_{ij} + \frac{L_1}{L_k} \quad \forall i, j \in V, \pi_k(i) < \pi_k(j) \leq \pi_k(i) + 5, (i, j) \notin R \quad (3)$$

$$m_{ji} = m_{ji} - \frac{L_1}{L_k} \quad \forall i, j \in V, \pi_k(i) < \pi_k(j) \leq \pi_k(i) + 5, (i, j) \notin R \quad (4)$$

set of (approximately)  $w$  artificial precedence constraints are added to the set  $R$ . The new constraints are selected as the ones not yet present in the precedence digraph  $P$  with the highest entries in matrix  $m$ . If there are less than  $w$  entries of  $m$  with a positive value, then only the precedence constraints corresponding to them will be added to  $P$ .

After the first artificial precedence constraints have been added to the problem, every time  $v$  new solutions are available, artificial precedence constraints are updated by dropping  $z$  constraints, that are substituted by (approximately)  $z$  new constraints. The artificial precedence constraints to be dropped are selected as those with the smallest entries in the memory matrix  $m$ . Conversely, the ones added are those with the highest entries in the same matrix  $m$ . Notice that, since entries of matrix  $m$  corresponding to active constraints are not reinforced (see equation (3)), it is likely that during the time they were active, entries corresponding to other (non active) constraints have reached higher values. Such a strategy leads to a mechanism where artificial precedence constraints are activated in turn. The mechanism should also prevent optimal solutions of the original problem from being permanently hidden by the active artificial precedence constraints.

## 5. EXPERIMENTAL RESULTS

The aim of the experiments reported in this section is to understand the importance of the basic components (described in Sections 2, 3 and 4) in the economy of the composite method described by Montemanni et al. (2008). Therefore, we run experiments with different combinations of active components.

### 5.1. Benchmark problems

Benchmark problems are those already used by Montemanni et al. (2007, 2008). They are publicly available<sup>2</sup>, and are named  $n-r-p$ , where the meaning of each element is as follows:

- **n**: the number of nodes of the problem, i.e.  $V = \{1, 2, \dots, n\}$ ;
- **r**: the cost range, i.e.  $0 \leq c_{ij} \leq r \quad \forall i, j \in V$ ;
- **p**: the approximate percentage of precedence constraints, i.e. the number of precedence constraints of the problem will be about  $\frac{p}{100} \cdot \frac{n(n-1)}{2}$ .

The following values for the parameters above were used, and problems were generated for all possible combinations of them:

- $n \in \{200, 300, 400, 500, 600, 700\}$ ;
- $r \in \{100, 1000\}$ ;
- $p \in \{1, 15, 30, 60\}$ .

The resulting set of problems covers a wide range of situations, with different sizes, different granularity for costs, and with radically different percentages of precedence constraints. The set appears to provide a good test-bed for modern *SOP* heuristic algorithms, and are therefore particularly indicated for our purpose.

### 5.2. Comparison of the different combinations

All the methods considered have been coded in C++. The experiments have been run on a Dual AMD Opteron 250 2.4GHz / 4GB computer. The maximum computation time was set to 600 seconds for all the problems. This computation time is long enough to let all the methods reach a steady state, where further improvements are unlikely to be found. Ten runs are considered for each possible problem/method combination. The results of the experiments are reported in Tables 1-3. The first three columns are parameters of the problems, while the remaining columns are devoted, depending on the table, to the presentation of the average, best and worst results obtained by the following methods:

- **LS**: iterative application of the Local Search routine described in Section 2, starting from random feasible solutions;
- **LS+HMT**: the Heuristic Manipulation Technique described in Section 4 is run on top of the local search algorithm LS;
- **ACS+LS**: the local search algorithm LS is embedded in the Ant Colony System described in Section 3. Notice that in this case LS is run on the solutions built by ACS. This is the method presented by Gambardella and Dorigo (2000);
- **ACS+LS+HMT**: HMT is run on top of the ACS, which in turn embeds LS. This is the method presented by Montemanni et al. (2008).

Parameters of all the algorithms have been set according to Gambardella and Dorigo (2000) and Montemanni et al. (2008), where parameter tuning is accurately documented.

In all the tables bold text is used to highlight the best entry (entries) for each line. Accordingly, italic text is adopted for the worst entry (entries).

The results of Table 1 (average results) confirm that - apart from some sporadic cases - the best results are

<sup>2</sup><http://www.idsia.ch/~roberto/SOPLIB06.zip>.

Table 1. Average results over ten runs.

Problem			Results			
<i>n</i>	<i>r</i>	<i>p</i>	LS	LS+HMT	ACS+LS	ACS+LS+HMT
200	100	1	102.5	103.1	90.3	<b>88.4</b>
300	100	1	87.0	85.3	76.4	<b>71.9</b>
400	100	1	75.8	72.6	64.1	<b>61.7</b>
500	100	1	64.3	62.0	55.0	55.1
600	100	1	57.6	57.2	49.8	<b>47.6</b>
700	100	1	50.8	46.6	42.6	<b>39.5</b>
200	1000	1	1773.7	1757.9	<b>1549.5</b>	1551.5
300	1000	1	1878.6	1837.7	1586.7	<b>1584.9</b>
400	1000	1	2064.8	2065.7	1811.1	<b>1773.1</b>
500	1000	1	2172.1	2151.4	1877.4	<b>1838.4</b>
600	1000	1	2306.5	2132.3	1986.7	<b>1957.6</b>
700	1000	1	2272.5	2092.7	1969.2	<b>1943.1</b>
200	100	15	2373.2	2337.3	2066.0	<b>2025.1</b>
300	100	15	4108.7	4098.9	3738.6	<b>3648.2</b>
400	100	15	5215.7	5183.9	5087.1	<b>4917.7</b>
500	100	15	7005.0	6987.3	6931.5	<b>6826.4</b>
600	100	15	7764.3	<b>7660.1</b>	7806.6	7733.0
700	100	15	9640.5	9507.1	9573.0	<b>9453.7</b>
200	1000	15	25791.3	25628.4	22602.9	<b>22419.2</b>
300	1000	15	38204.1	37939.3	34447.9	<b>34215.0</b>
400	1000	15	51439.7	51111.4	46638.6	<b>46183.2</b>
500	1000	15	66344.8	65635.0	62693.7	<b>61675.7</b>
600	1000	15	76741.6	76294.1	72701.1	<b>70136.9</b>
700	1000	15	90514.0	89973.7	85177.7	<b>82697.0</b>
200	100	30	4454.3	4430.8	4254.6	<b>4236.0</b>
300	100	30	6476.2	6469.6	6228.2	<b>6180.2</b>
400	100	30	8747.3	8718.3	8476.5	<b>8395.3</b>
500	100	30	10508.2	10432.0	10333.2	<b>10108.6</b>
600	100	30	13277.2	13215.0	13001.8	<b>12858.7</b>
700	100	30	15808.7	15810.0	15905.8	<b>15654.8</b>
200	1000	30	42930.0	42685.3	41371.6	<b>41315.2</b>
300	1000	30	58099.5	57710.0	55013.4	<b>54448.5</b>
400	1000	30	90922.9	90320.5	85979.6	<b>85922.9</b>
500	1000	30	105970.0	106018.0	101751.8	<b>100973.3</b>
600	1000	30	136792.7	136948.8	132314.3	<b>131733.7</b>
700	1000	30	146869.5	146000.0	141557.9	<b>141012.6</b>
200	100	60	<b>71749.0</b>	<b>71749.0</b>	<b>71749.0</b>	<b>71749.0</b>
300	100	60	9732.9	9731.1	<b>9726.0</b>	<b>9726.0</b>
400	100	60	15242.1	15250.4	15232.4	<b>15230.2</b>
500	100	60	18316.5	18312.6	18260.4	<b>18251.3</b>
600	100	60	23427.0	23388.6	23357.4	<b>23336.7</b>
700	100	60	24244.5	24218.3	24192.3	<b>24181.6</b>
200	1000	60	<b>71556.0</b>	<b>71556.0</b>	<b>71556.0</b>	<b>71556.0</b>
300	1000	60	109796.5	109750.3	109530.5	<b>109494.8</b>
400	1000	60	141253.7	141174.7	140994.9	<b>140936.9</b>
500	1000	60	178953.5	178803.5	<b>178478.1</b>	178500.4
600	1000	60	215918.7	215851.4	214970.2	<b>214875.1</b>
700	1000	60	246983.5	247031.1	246489.6	<b>246458.9</b>

Table 2. Best results over ten runs.

Problem			Results			
<i>n</i>	<i>r</i>	<i>p</i>	LS	LS+HMT	ACS+LS	ACS+LS+HMT
200	100	1	94	96	88	<b>83</b>
300	100	1	79	78	74	<b>65</b>
400	100	1	69	63	59	<b>54</b>
500	100	1	57	57	<b>51</b>	<b>51</b>
600	100	1	47	46	44	<b>42</b>
700	100	1	41	41	41	<b>32</b>
200	1000	1	1750	1722	1532	<b>1525</b>
300	1000	1	1836	1730	1536	<b>1518</b>
400	1000	1	2032	1989	1783	<b>1714</b>
500	1000	1	2028	2021	1840	<b>1770</b>
600	1000	1	2248	2055	1936	<b>1922</b>
700	1000	1	2199	2050	1912	<b>1873</b>
200	100	15	2307	2243	2002	<b>1926</b>
300	100	15	4056	3991	3520	<b>3383</b>
400	100	15	5149	5110	4838	<b>4735</b>
500	100	15	6897	6875	6584	<b>6536</b>
600	100	15	7700	7565	7610	<b>7217</b>
700	100	15	9538	9229	9383	<b>9124</b>
200	1000	15	25622	24810	21775	<b>21654</b>
300	1000	15	37350	37049	33533	<b>33148</b>
400	1000	15	50890	50614	45055	<b>44749</b>
500	1000	15	65699	63847	60175	<b>58316</b>
600	1000	15	74437	74825	70454	<b>68219</b>
700	1000	15	89506	88474	81439	<b>80887</b>
200	100	30	4406	4408	4247	<b>4216</b>
300	100	30	6406	6428	6151	<b>6148</b>
400	100	30	8680	8589	8289	<b>8276</b>
500	100	30	10365	10228	10047	<b>9974</b>
600	100	30	13123	13138	12810	<b>12689</b>
700	100	30	15695	15611	15733	<b>15180</b>
200	1000	30	42300	41835	41278	<b>41196</b>
300	1000	30	56901	56824	54367	<b>54278</b>
400	1000	30	90212	89383	85579	<b>85288</b>
500	1000	30	105674	105500	100453	<b>100112</b>
600	1000	30	136386	135077	<b>130244</b>	130541
700	1000	30	146437	143887	139769	<b>138695</b>
200	100	60	<b>71749</b>	<b>71749</b>	<b>71749</b>	<b>71749</b>
300	100	60	<b>9726</b>	<b>9726</b>	<b>9726</b>	<b>9726</b>
400	100	60	15238	<b>15228</b>	<b>15228</b>	<b>15228</b>
500	100	60	18271	18282	18246	<b>18240</b>
600	100	60	23370	23374	23342	<b>23259</b>
700	100	60	24191	24192	24151	<b>24149</b>
200	1000	60	<b>71556</b>	<b>71556</b>	<b>71556</b>	<b>71556</b>
300	1000	60	109590	109514	<b>109471</b>	<b>109471</b>
400	1000	60	141096	141021	140862	<b>140816</b>
500	1000	60	178650	178464	178323	<b>178212</b>
600	1000	60	215650	215469	214724	<b>214608</b>
700	1000	60	246611	246477	246128	<b>245753</b>

Table 3. Worst results over ten runs.

Problem			Results			
<i>n</i>	<i>r</i>	<i>p</i>	LS	LS+HMT	ACS+LS	ACS+LS+HMT
200	100	1	109	107	<b>93</b>	94
300	100	1	93	89	79	<b>76</b>
400	100	1	82	79	<b>67</b>	<b>67</b>
500	100	1	70	67	62	<b>58</b>
600	100	1	64	62	54	<b>53</b>
700	100	1	61	48	<b>44</b>	<b>44</b>
200	1000	1	1809	1798	<b>1572</b>	1576
300	1000	1	1940	1856	<b>1604</b>	1633
400	1000	1	2096	2094	1864	<b>1816</b>
500	1000	1	2238	2217	1921	<b>1888</b>
600	1000	1	2419	2181	2025	<b>2001</b>
700	1000	1	2348	2139	<b>2013</b>	<b>2013</b>
200	100	15	2426	2378	2186	<b>2182</b>
300	100	15	4156	4126	4013	<b>3883</b>
400	100	15	5287	5231	5292	<b>5135</b>
500	100	15	7074	7074	7146	<b>7013</b>
600	100	15	7877	<b>7715</b>	7992	8030
700	100	15	9704	<b>9628</b>	9949	9762
200	1000	15	25944	25877	24211	<b>22931</b>
300	1000	15	38632	38608	36808	<b>35687</b>
400	1000	15	51999	51598	51051	<b>49220</b>
500	1000	15	66774	66637	65177	<b>64765</b>
600	1000	15	77807	76582	75082	<b>72542</b>
700	1000	15	91377	91037	90808	<b>84321</b>
200	100	30	4488	4451	4269	<b>4256</b>
300	100	30	6536	6497	6338	<b>6257</b>
400	100	30	8783	8787	8697	<b>8639</b>
500	100	30	10574	10506	10845	<b>10362</b>
600	100	30	13381	13297	13311	<b>13084</b>
700	100	30	15920	<b>15889</b>	16135	15968
200	1000	30	43178	42831	41544	<b>41516</b>
300	1000	30	59283	58338	56606	<b>54725</b>
400	1000	30	91210	90931	86918	<b>86487</b>
500	1000	30	106507	106568	104420	<b>102118</b>
600	1000	30	137492	137513	135642	<b>133236</b>
700	1000	30	147098	146918	148310	<b>143460</b>
200	100	60	<b>71749</b>	<b>71749</b>	<b>71749</b>	<b>71749</b>
300	100	60	9745	9737	<b>9726</b>	<b>9726</b>
400	100	60	15253	15262	<b>15250</b>	<b>15250</b>
500	100	60	18332	18329	18303	<b>18278</b>
600	100	60	23475	23402	<b>23370</b>	23440
700	100	60	24271	<b>24230</b>	24249	24238
200	1000	60	<b>71556</b>	<b>71556</b>	<b>71556</b>	<b>71556</b>
300	1000	60	109940	109849	<b>109590</b>	<b>109590</b>
400	1000	60	141418	141251	<b>141118</b>	<b>141118</b>
500	1000	60	179219	179057	<b>178679</b>	178840
600	1000	60	216294	216093	215389	<b>215348</b>
700	1000	60	247296	<b>246902</b>	247045	247045

obtained when all the components are active (last column). As already observed by Montemanni et al. (2008), the improvements guaranteed by the use of HMT on top of ACS+LS are marginal, but exist. Analogously, we can observe how ACS+LS obtain far better results than LS alone. This phenomenon had already been observed by Gambardella and Dorigo (2000), but in our case the results obtained by the two methods appear much further apart than in the paper by Gambardella and Dorigo (2000). This suggests that the use of more difficult benchmarks amplifies the phenomenon.

It is also interesting to observe that HMT is able to improve the results of LS (column HMT+LS vs column LS) even though the results are worse than those achieved by method ACS+LS. Therefore there is a clear indication that HMT does its job, but it needs a strong underlying method in order to achieve really good results. Another indication is that most of the work done by the whole composite algorithm (last column) is hidden in the combination of ACS and LS methods. Notice, finally, that the worst results are consistently obtained by method LS.

The study of Tables 2 (best results) and 3 (worst results) leads to conclusions that are analogous to those in the comment in Table 1. It is however interesting to observe that the advantages of the use of HMT seems to be amplified in Table 2 and reduced in Table 3. This means that the results of HMT have a higher standard deviation over the ten runs considered. This is due to the heuristic nature of the rules used to select the active artificial constraints: it can lead to very good results in case of a happy choice, or to worse results in case of an unlucky selection.

## 6. CONCLUSIONS

The sequential ordering problem, which is faced in many practical applications, has been studied. The state-of-the-art algorithm for this problem is composed of different components, namely local searches, an ant colony system and a heuristic manipulation technique.

In this paper we have studied - from an experimental point of view - the impact of the different components on the performance of the full method. Specifically, we have run experiments with different combinations of components switched off, and we have analyzed how the results of the method were affected.

The conclusion was that the heuristic manipulation technique is able to slightly improve the results achieved by both the local searches alone, and the combination of local searches and the ant colony system. However, what appears to be crucial is the interaction between the ant colony system and the local search routines. This results was expected. Heuristic manipulation can be seen as a tool useful to further refine already good results, but here it is shown that it needs to be run on a very efficient underlying heuristic method (ant colony system plus local search, in our case) in order to obtain good results.

## REFERENCES

- Ascheuer N., 1995. *Hamiltonian path problems in the on-line optimization of flexible manufacturing systems*. PhD thesis, Technische Universität Berlin.
- Ascheuer N., Escudero L.F., Grötschel M., Stoer M., 1993. A cutting plane approach to the sequential ordering problem (with applications to job scheduling in manufacturing). *SIAM Journal on Optimization*, 3:25–42.
- Balas E., Fischetti M., Pulleyblank W.R., 1995. The precedence-constrained asymmetric traveling salesman polytope. *Mathematical Programming*, 65:241–265.
- Bentley J.L., 1992. Fast algorithms for geometric traveling salesman problem. *ORSA Journal on Computing*, 4:387–411.
- Chen S., Smith S., 1996. Commonality and genetic algorithms. Technical Report CMU-RI-TR-96-27, The Robotic Institute, Carnegie Mellon University.
- Dorigo M., Di Caro G., Gambardella L.M., 1999. Ant algorithms for discrete optimization. *Artificial Life*, 5:137–172.
- Dorigo M., Gambardella L.M., 1997. Ant Colony System: a cooperative learning approach to the traveling salesman problem. *IEEE Transactions on Evolutionary Computation*, 1:53–66.
- Escudero L.F., 1988. An inexact algorithm for the sequential ordering problem. *European Journal of Operational Research*, 37:232–253.
- Escudero L.F., Guignard M., Malik K., 1994. A Lagrangean relax-and-cut approach for the sequential ordering problem with precedence relationships. *Annals of Operations Research*, 50:219–237.
- Gambardella L.M., Dorigo M., 2000. An ant colony system hybridized with a new local search for the sequential ordering problem. *INFORMS Journal on Computing*, 12(3):237–255.
- Gambardella L.M., Mastrolilli M., Rizzoli A.E., Zafalon M., 2001. An optimization methodology for intermodal terminal management. *Journal of Intelligent Manufacturing*, 12:521–534.
- Guerriero F., Mancini M., 2003. A cooperative parallel rollout algorithm for the sequential ordering problem. *Parallel Computing*, 29(5):663–677.
- Günther H.-O., Kim K.-H., 2006. Container terminals and terminal operations. *OR Spectrum*, 28:437–445.
- Hernádvölgyi I.T., 2003. Solving the sequential ordering problem with automatically generated lower bounds. In *Proceedings of Operations Research 2003*, pages 355–362.



Hernádvölgyi I.T., 2004. *Automatically Generated Lower Bounds for Search*. PhD thesis, University of Ottawa.

Montemanni R., Smith D.H., Gambardella L.M., 2007. Ant Colony Systems for large Sequential Ordering Problems. In *Proceedings of IEEE SIS 2007*.

Montemanni R., Smith D.H., Gambardella L.M., 2008. A Heuristic Manipulation Technique for the Sequential Ordering Problem. *Computers and Operations Research*, to appear.

Pullyblank W., Timlin M., 1991. Precedence constrained routing and helicopter scheduling: heuristic design. Technical Report RC17154 (#76032), IBM T.J. Watson Research Center.

Savelsbergh M.W.P., 1990. An efficient implementation of local search algorithms for constrained routing problems. *European Journal of Operational Research*, 47:75–85.

Seo D.-I., Moon B.R., 2003. A hybrid genetic algorithm based on complete graph representation for the sequential ordering problem. In *Proceedings of GECCO 2003*, pages 69–680.

Stahlbock R., Voß S., 2008. Operations research at container terminals: a literature update. *OR Spectrum*, 30:1–52.

Steenken D., Voß S., Stahlbock R., 2004. Container terminal operation and operations research - a classification and literature review. *OR Spectrum*, 26:3–49.

# INTEGRATED DESIGN PROCESS OF MARITIME TERMINALS ASSISTED BY SIMULATION MODELS

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## ABSTRACT

The port design process plays a key role both in the planning of the infrastructures and in quality of provided transport services.

In fact operating conditions near the maximum capacity cause congestion effects with the concerned negative consequences on capacity and regularity.

In this framework, models capable to support the design process, in terms of infrastructural and equipment dimensioning, as well as to simulate the operation of the sea-side and land-side port terminals, to evaluate their capacity and to relate the terminal utilisation degree with the quality of the transport services are very effective.

The paper describes a chain of regressive, analytical and combinatorial models, which has been developed by taking into account, within a stepwise methodological approach, dimensions and handiness of the ships, positions of terminals, accessibility, handling equipment, storage areas.

The results of a pilot application to the Italian port of Livorno are presented.

Keywords: ports, design, model

## 1. INTRODUCTION

The design process is a really complex stepwise series of strategic decision involving the engagement of relevant amount of resources.

Therefore, in order to maximise its effectiveness, a strong need of methodological support is required.

At this aim the research group of the authors developed different methods and models capable to support some of these decisions:

- sea-side operation combinatorial model;
- regressive method for preliminary dimensioning of container terminals;
- container terminals operation stochastic model.

They are able to be integrated in a chain taking into account, within a stepwise methodological approach, dimensions and handiness of the ships, positions of terminals, accessibility, handling equipment, storage areas, etc.

## 2. SEA SIDE OPERATION COMBINATORIAL MODEL

The sea-side port operation, characterised by the overlap of many different ships traffic causes very often congestion effects with negative consequences on the transport services regularity.

In this framework models capable to simulate the operation of the sea-side port terminals, to evaluate their capacity and to relate the terminal utilisation degree with the quality of the transport services are very effective and allow to reach specific objectives:

- operational time saving;
- more rational land-use (better planning of sea front);
- possible prevention of losses due to accidents and incidents;
- sensibility of performances to variations in port terminal lay-out.

Applications on other terminals (railway stations and airports) demonstrated the effectiveness of synthetic models capable to calculate the occupation time of the terminal by the vehicles and the utilisation degree on the basis of a generic operation plan, both on regular and perturbed (because of external causes or the congestion itself) conditions.

These effects are particularly relevant for the fast passengers ships: in fact the advantage to use this kind of ships, which are now strongly extending their market, may be reduced because of the typical congestion conditions during the port entering and exiting movements.

### 2.1. Specific research objectives

From the considerations above arise the specific objectives of the present research, which is aimed to build up models capable to:

- a) simulate the terminal operation;
- b) evaluate the terminal carrying capacity;
- c) relate the utilisation degree of the terminal with its service quality.

The application of combinatorial synthetic models to the sea terminals requires the introduction of the factors characterising the terminal itself and the ship (dimensions and handiness with related cinematic and geometric constraints, regulated movements).

## 2.2. Methodology description

The model is based on the schematisation of ships routes from the port mouth to the docks, which may be partially or totally independent according to the basins morphology and to the safety rules adopted by the port authority.

They depend mainly on the handiness and the dimensions of the ships, which strongly effect their capability to avoid the risk of collisions.

The carrying capacity of the terminal corresponds to the maximum number of movements allowed during the reference time and it depends mainly upon the following factors:

- time distribution of the entering and exiting movements to/from the port and related assignment to the docks;
- terminal topology defined by the docks and the mouths location.

The model approach is based on a constant probability for the arrivals: the demand is known in terms of number of movements for each route in the reference time.

This condition is well representing both:

- high frequency of the arrivals in the peak periods;
- usual data availability in the planning phase, when you necessarily don't possess detailed information on the future ships scheduling.

This condition is formally defined by an array  $P$ , with dimensions corresponding to the number of the routes in the terminal and single elements  $p_i$  defining the number of movements on each route in the reference time  $T$ .

The analysis of the terminal morphology allows to define the whole set of the routes and their reciprocal compatibility/incompatibility.

The compatibility relationships are represented in a square matrix (compatibility matrix)  $C = P \times P$ , with each element  $c_{ij}$  representing the condition of compatibility/incompatibility between the routes  $i$  and  $j$ .

The possible relationships are:

- incompatibility between two routes with:
  - d) common final/initial sections,
  - e) common middle sections,
  - f) same path but opposite versus;
- compatibility between two routes without common sections, allowed to be run contemporarily.

The proposed approach allows to calculate the mean number of possible contemporary movements  $n$  by taking into account the compatibility of the routes and their frequency of utilisation:

$$n = \frac{N^2}{\sum_{ij} m_{ij}} \quad (1)$$

where:

- $m_{ij} = p_i \times p_j$  if  $i$  and  $j$  are incompatible;
- $m_{ij} = 0$  if  $i$  and  $j$  are compatible.

In a similar way the mean terminal utilisation time can be defined as:

$$t = \frac{\sum_{ij} m_{ij} \cdot t_{ij}}{\sum_{ij} m_{ij}} \quad (2)$$

where  $t_{ij}$  is the time during which the route  $j$  may not be run because a ship is moving on the route  $i$  (interdiction time) and  $N$  is the total number of movements during  $T$ .

The total occupation time can be calculated as:

$$B = \frac{N}{n} \cdot t \quad (3)$$

In order to take into account the waiting situations due to contemporary arrivals on incompatible routes it is possible to calculate the delay imposed by the  $p_i$  movements on the  $p_j$  movements because of the interdiction time  $t_{ij}$ :

$$r_{ij} = \frac{p_i p_j t_{ij}^2}{2T} \quad (4)$$

these parameters allow the comparison between the total utilisation time of the terminal, including the delays, and the reference time.

The utilisation degree can be calculated with reference only to the regular running on the routes as:

$$U = \frac{B}{T} \quad (5)$$

or to the total time, including the delays, as:

$$V = \frac{B + R}{T} \quad (6)$$

where is:

$$R = \frac{\sum_{ij} r_{ij}}{n} \quad (7)$$

### 2.3. Model application

The methodology has been validated by means of pilot applications to the port of Livorno (figure 1), located on the middle of the Italian west coast.

The port is shaped as a basin where the docks and the evolution areas are protected on the sea-side by a jetty mainly parallel to the coast line.

This morphology influences the entering and exiting movements because it does not allow, in many cases, more than a single movement.



Figure 1: Lay out of port of Livorno

The long distance from the port mouth to the most far dock (up to 1800 m) causes long interdiction times. The elements characterising the traffic within the basin are:

- a) limited speed allowed within the port (6 knots  $\approx$  10 km/h);
- b) long manoeuvre time because of both the dimensions of the ships (up to 250 m long) and the required assistance (tugboats, mooring men, pilots, etc.);
- c) concentration of the manoeuvres in restricted evolution areas, which limits the use of the main channel for other movements and may require more than a tugboat;
- d) rare movements compatibility, due to the several sections common to various routes (particularly near the channel mouth).

Therefore, though the flows are quite low, the interdiction times are high and the compatible movements are rare.

Further constraints are related with some organisational aspects, particularly the limited amount of some key resources:

- the pilots (its presence is mandatory during the movement within the port);
- the tugboats (the most part of the movements requires at least a tugboat).

The terminals include 21 docks distributed in 6 mooring basins (figure 2) equipped for loading/unloading of freight and passengers, that means 42 routes between them and the port mouth.

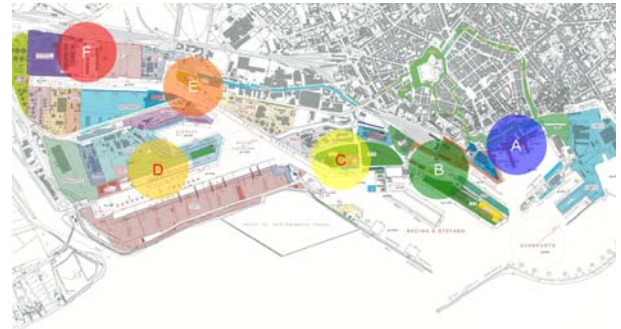


Figure 2: Mooring basins of the port of Livorno

The assignment of the ships to the docks depends on the ships characteristics, the presence of loading/unloading equipment and the accessibility from/to the land transport systems (land-side terminal).

Nevertheless, for the carrying capacity analysis, the routes from/to the adjacent docks can be grouped by taking into account that the manoeuvres from/to them must be run once.

In the meantime the common considered interdiction time takes obviously into account the whole route to the dock.

The routes couples comparison allows to build up the compatibility matrix.

In the present study the following classes of ships are considered:

- a) fast ships (HSC) capable to run at 75 km/h and to manoeuvre without the help of tugboats;
- b) modern Ro-Ro and Ro-Pax ships also manoeuvring without the help of the tugboats;
- c) traditional ferries, requiring the tugboats for manoeuvring;
- d) freight ships, which can require up to 3 tugboats and, if transporting fuels or other dangerous freight, need particular care because of the safety rules;
- e) cruise ships.

The entering movement is composed by various phases, with run time depending on the characteristics of the ships, the distance to be run for reaching the assigned dock, the maximum allowed speed and the time required by the dock approach.

The following phases can be usually identified:

- approach to the port mouth, with speed decreasing from the cruise speed to the maximum speed allowed for the entering movements (about 6 knots  $\approx$  10 km/h): the ship leaves its course for running the entering route;

- running in the channel from the port mouth to the evolution basin, whose extension is depending on the assigned dock;
- evolution, consisting of the ship rotation operated with the help of the tugboats or by means of the transversal propulsion systems on board;
- approach to the dock, to be operated with the help of the tugboats or by means of the warps or the ship propulsion systems themselves;
- ship locking and pre-arrangement of the freight and/or passengers loading/unloading operation.

In figure 3 the mean values of the manoeuvre times calculated for different basin, by taking into account the docks usually assigned, are listed.

Basin	A	B	C	D	E	F
Manoeuvre						
Port mouth approach	7	7	7	7	7	7
Channel running	7	9	13	18	21	26
Evolution	5	5	5	5	5	5
Dock approach	6	6	6	6	6	6
Locking	3	6	6	6	6	6
<b>TOTAL</b>	<b>28</b>	<b>33</b>	<b>36</b>	<b>42</b>	<b>45</b>	<b>50</b>

Figure 3: Main manoeuvre times for each basin [min]

The exiting movements are symmetric in the most cases.

Insofar the interdiction time depend on the safety criteria adopted by the port authorities for avoiding the possible conflicts, which are generally based on the evaluation of the related risks.

Obviously rigid safety criteria impose rigid routes release criteria, which cause long interdiction times; on the contrary flexible criteria, allowing the progressive release of the sections and the contemporary ship movements at a given distance, reduce the interdiction times themselves with positive effects on the carrying capacity of the port terminal.

The evaluation of the utilisation degree was carried out on the basis of the real traffic flows scheduled for the peak day of year 2007 with 63 movements/day distributed during 23 hours (figure 4).

	A Bacino Firenze Bacino Cappellini	B Bacino S. Stefano	C Darsena Pisa	D Darsena Toscana	E Darsena n°1	F Canale Industriale
Molo Elba 66 n	5	Alto Fondale 45	2	Calata Lucca 15a	5	Darsena ugone 36 a
Calata Sgarallino 62	9	Alto Fondale 46	2	Calata Massa 14 b	8	Sintemar 24 c
Calata punto Franco	4	Doc		Tripoli 16	4	Gondar 19
Molo capitaneria 64 n	1					Novaoal 27
Calata Carrara 55	4					Costieri D'alesio 29 n
						Grandi molini italiani
						Leonardo Da vinci

Figure 4: Distribution by basin of arrivals/departures

The corresponding flows distribution on the routes is represented in figure 5.

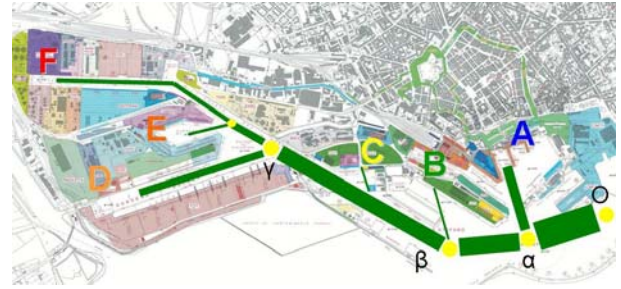


Figure 5: Flows distribution on the routes

On this basis have been calculated the utilisation degree summarised in figure 6.

The mean values of the utilisation degree under perturbed conditions ( $V$ ) for the whole daily operation period is about 1,65, while the mean value of it under regular conditions ( $U$ ) is about 0.8.

Further elements on the carrying capacity can be evaluated by analysing the effects on the utilisation degree of traffic variation, which, on the basis of a maximum reference level of  $V=0,65$ , shows a total carrying capacity value under regular conditions of 48 movements / 23 hours (-15 Movements = -24% in comparison with the present situation), which highlights a substantial congestion condition in the present operation.

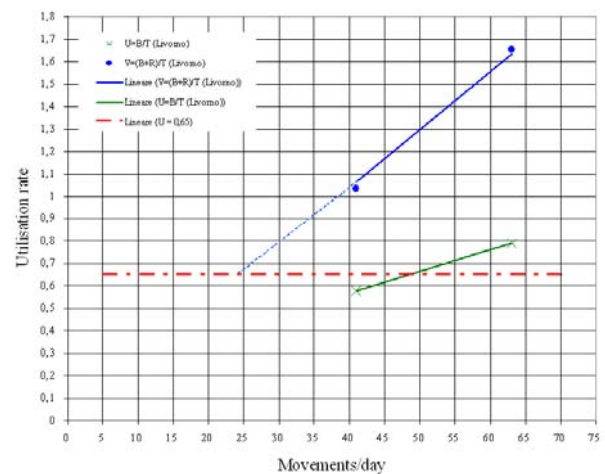


Figure 6: Utilisation degree of Livorno port

Further differences (up to 20%) may be related to different distributions of ships classes and routes utilisation.

### 3. REGRESSIVE METHOD FOR PRELIMINARY DIMENSIONING OF CONTAINER TERMINALS

The maritime container terminals are infrastructures provided with considerable equipments able to overtake the transfer of containers from ship to docks and back.

They are integrated into logistic structures of the most part of commercial ports.

In any terminal fundamental and complementary activities are identifiable:

1. containers loaded and unloading;
2. sea-side and land-side (railway and road) stocking area;
3. traffic management and control;
4. container clearance for the international traffic;
5. storage and reorganization of freight into containers.

Structures and performances of terminals, deduced from a first analysis, may be synthetically represented in three main clusters of parameters respectively representing dimensions, equipment and production:

- A. Dimensional parameters:
  - Quay length (1),
  - Total stacking area (2),
  - Covered stacking area (3),
  - Uncovered stacking area (4);
- B. Equipment parameters:
  - Gantry cranes (5),
  - Other cranes (6),
  - Storage cranes (7),
  - Various loaders (8);
- C. Production parameters:
  - Number of handled containers (9),
  - Number of handled TEU (10),
  - Handled container tonnage (11).

For these parameters an extended investigation on operated port terminals for data acquisition and homogenisation has been carried out..

### 3.1. Definition of the analysis area

The main analysed ports are located in North Europe and in Mediterranean area.

In this area have been identified 73 ports interested by relevant container traffic.

For 93 containers terminals located in 49 of these ports useful data have been collected and elaborated.

In table 1 the amount of observations available for the analysed parameter is shown.

Table 1: Observations available for analysed parameters

Quay length	93
Total stocking area	91
Covered stocking area	91
Uncovered stocking area	29
Gantry cranes	85
Other cranes	37
Storage cranes	59
Various loaders	57
Containers	19
TEU	72
Tonnage	30

Lower amount of observations are available for information more difficult to be obtained.

### 3.2. Methodology application

In the proposed regressive approach have been analysed relationships between parameters:

1. of the same cluster;
2. of different classes.

The amount of useful data for the correlations are summarised in a matrix (figure 7).

N	1	2	3	4	5	6	7	8	9	10	11
1											
2	88										
3	77	91									
4	23	29	28								
5	72	79	79	20							
6	29	35	28	10	24						
7	49	74	46	10	48	22					
8	47	51	39	10	45	23	40				
9	14	19	19	5	18	8	12	12			
10	55	69	63	17	61	25	46	32	17		
11	20	28	27	8	27	16	18	20	12	29	

Figure 7: Available observations by couple of parameters

The collected and homogenised data has been correlated by means of a simple linear regressive method obtaining the correlation coefficients  $R$ .

All the values have been filtered with different relevance threshold values (0.7 and 0.8).

In figures 8 and 9 the values of coefficient  $R$  of the regression lines are presented in matrices.

On these basis it is possible to look for the most direct relationships between parameters corresponding to shortest paths on a graph (figures 10 and 11).

	1	2	3	4	5	6	7	8	9	10	11
1 Quay length											
2 Total stacking area	0,892										
3 Covered stocking area	0,518	0,963									
4 Uncovered stocking area	0,621	0,971	0,921								
5 Gantry crane	0,745	0,925	0,228	0,032							
6 Other crane	0,217	0,410	0,118	0,827	0,000						
7 Storage crane	0,769	0,805	0,905	0,100	0,869	0,232					
8 Various loader	0,551	0,601	0,551	0,330	0,542	0,212	0,764				
9 Containers Lo-Lo	0,346	0,925	0,966	0,825	0,935	0,815	0,844	0,777			
10 TEU	0,706	0,910	0,207	0,134	0,770	0,224	0,823	0,559	0,999		
11 Tonnage Lo-Lo	0,513	0,945	0,983	0,173	0,947	0,462	0,936	0,738	0,999	0,996	

Figure 8: Correlations between couples of parameter with 0.7 as threshold of relevance

	1	2	3	4	5	6	7	8	9	10	11
1 Quay length											
2 Total stacking area	0,892										
3 Covered stocking area	0,518	0,963									
4 Uncovered stocking area	0,621	0,971	0,921								
5 Gantry crane	0,745	0,925	0,228	0,032							
6 Other crane	0,217	0,410	0,118	0,827	0,000						
7 Storage crane	0,769	0,805	0,905	0,100	0,869	0,232					
8 Various loader	0,551	0,601	0,551	0,330	0,542	0,212	0,764				
9 Containers Lo-Lo	0,346	0,925	0,966	0,825	0,935	0,815	0,844	0,777			
10 TEU	0,706	0,910	0,207	0,134	0,770	0,224	0,823	0,559	0,999		
11 Tonnage Lo-Lo	0,513	0,945	0,983	0,173	0,947	0,462	0,936	0,738	0,999	0,996	

Figure 9: Correlations between couples of parameter with 0.8 as threshold of relevance

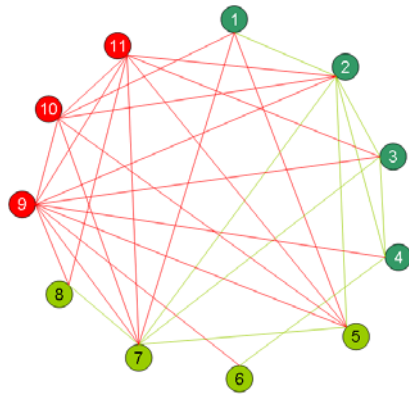


Figure 10: graph of the relevant correlations with  $R > 0.7$

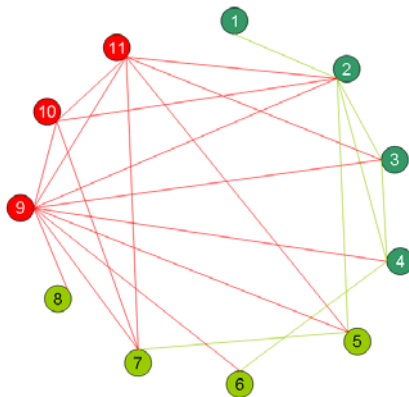


Figure 11: graph of the relevant correlations with  $R > 0.8$

### 3.3. Indirect correlations between parameters

The main performance of the proposed methodology is to calculate on probabilistic basis the main design parameters (dimensions, equipment, etc.) by means of the generalisation of relieved correlations linked them to flow parameters (TEU, tonnage, etc.).

For this purpose it is necessary to determine also the indirect relationships requiring intermediate parameters able to establish between inputs and outputs. Normally different routes exist in the correlations graph. For the selection of shortest paths (highest global correlation) has been applied the Dijkstra algorithm.

Starting from the inputs corresponding to production parameters (containers, TEU and tonnage) it is possible to define the tree of shortest paths with the parameters linked directly and indirectly.

Six different scenarios have been obtained by combination of threshold value (0.7 and 0.8) of correlation parameters with possible input parameters (figures 12 to 16).

### 3.4. Methodology application

The regressive method has been applied to the pilot case represented by the terminal container of the port of Livorno Darsena Toscana.

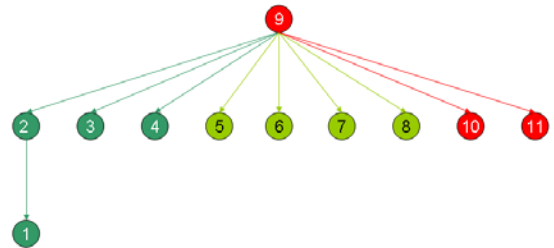


Figure 12: Shortest paths starting from the number of containers (threshold  $R=0.7$  and  $R=0.8$ )

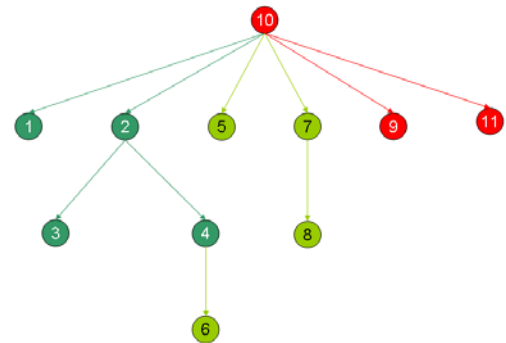


Figure 13: Shortest path starting from TEU (threshold  $R=0.7$ )

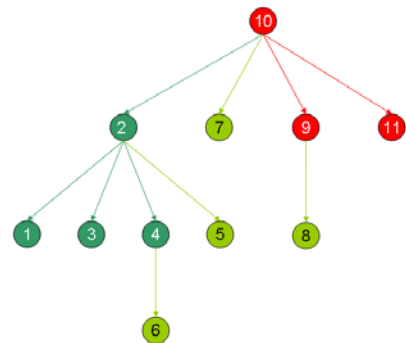


Figure 14: Shortest path starting from TEU (threshold  $R=0.8$ )

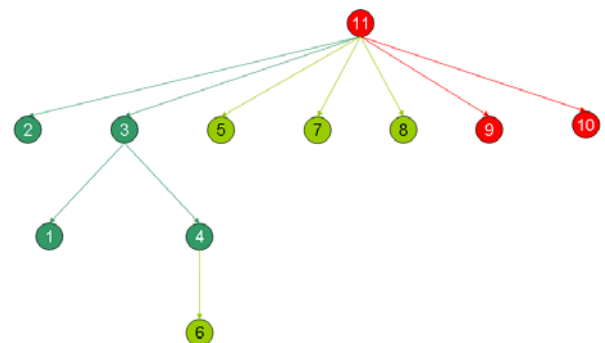


Figure 15: Shortest path starting from containers tonnage (threshold  $R=0.70$ )

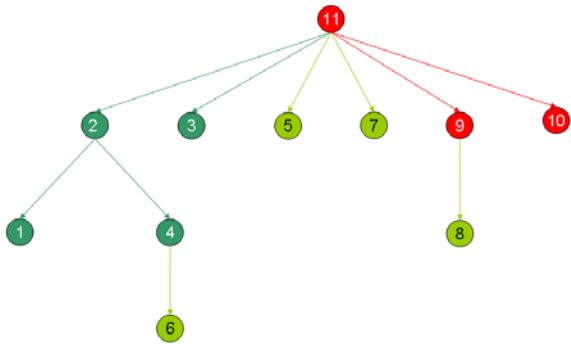


Figure 16: Shortest path starting from containers tonnage (threshold  $R=0.80$ )

The value of input (production) parameters available for year 2007 are showed in table 2.

Table 2: Production parameters in year 2007

Handled containers	323.708
Handled TEU	500.000
Handled Containers tonnage	6.677.350

On the basin of the defined shortest paths have been determined the dimensional and equipment parameters (tables 3 to 8).

This allows the comparison with the real observed values in order to validate the model.

Table 3: Parameters estimated starting from numbers of containers ( $R>0.80$ )

Parameters	Estimated value	Real value	$\Delta$ %
Quay length [m]	1.244	1.430	-13
Total stocking area [m <sup>2</sup> ]	363.319	412.000	-12
Covered stocking area [m <sup>2</sup> ]	373.555	0	-
Uncovered stocking area [m <sup>2</sup> ]	180.084	0	-
Gantry cranes [n]	8	8	0
Other cranes[n]	4	0	-
Storage cranes [n]	26	8	228
Various loaders [n]	41	20	106
TEU [n]	513.687	500.000	3
Tonnage Lo-Lo [t]	5.252.670	6.677.350	-21

### 3.5. Remarks

The analysis of the model application results have been synthetically reproduced for the main dimensional and equipment parameters (quay length, total storage area and number of gantry cranes) in figures 17, 18 and 19.

Table 4: Parameters estimated starting from TEU ( $R>0.80$ )

Parameters	Estimated value	Real value	%
Quay length [m]	1.077	1.430	-25
Total stocking area [m <sup>2</sup> ]	244.250	412.000	-41
Covered stocking area [m <sup>2</sup> ]	280.601	0	-
Uncovered stocking area [m <sup>2</sup> ]	-2.767	0	-
Gantry cranes [n]	6	8	-19
Other cranes [n]	1	0	-
Storage cranes [n]	16	8	99
Various loaders [n]	41	20	104
Containers Lo-Lo [n]	315.784	323.708	-2
Tonnage Lo-Lo [t]	4.685.331	6.677.350	-30

Table 5: Parameters estimated starting from containers tonnage ( $R>0.80$ )

Parameters	Estimated value	Real value	%
Quay length [m]	1.468	1.430	3
Total stocking area [m <sup>2</sup> ]	523.757	412.000	27
Covered stocking area [m <sup>2</sup> ]	460.417	0	-
Uncovered stocking area [m <sup>2</sup> ]	107.526	0	-
Gantry cranes [n]	10	8	21
Other cranes [n]	9	0	-
Storage cranes [n]	26	8	225
Various loaders [n]	232	20	1059
Containers Lo-Lo [n]	411.525	500.000	-18
TEU [n]	697.085	323.708	115

Table 6: Parameters estimated starting from numbers of containers ( $R>0.70$ )

Parameters	Estimated value	Real value	%
Quay length [m]	1.244	1.430	-13
Total stocking area [m <sup>2</sup> ]	363.319	412.000	-12
Covered stocking area [m <sup>2</sup> ]	373.555	0	-
Uncovered stocking area [m <sup>2</sup> ]	180.084	0	-
Gantry cranes [n]	8	8	0
Other cranes [n]	4	0	-
Storage cranes [n]	26	8	228
Various loaders [n]	41	20	106
TEU [n]	513.687	500.000	3
Tonnage Lo-Lo [t]	5.252.670	6.677.350	-21

Table 7: Parameters estimated starting from TEU ( $R>0.70$ )

Parameters	Estimated value	Real value	%
Quay length [m]	1.066	1.430	-25
Total stocking area [m <sup>2</sup> ]	244.250	412.000	-41
Covered stocking area [m <sup>2</sup> ]	280.601	0	-
Uncovered stocking area [m <sup>2</sup> ]	98.152	0	-
Gantry cranes [n]	7	8	-16
Other cranes [n]	8	0	-
Storage cranes [n]	16	8	99
Various loaders [n]	51	20	155
Containers Lo-Lo [n]	315.784	323.708	-2
Tonnage Lo-Lo [t]	4.685.331	6.677.350	-30

Table 8: Parameters estimated starting from containers tonnage ( $R>0.70$ )



Parameters	Estimated value	Real value	%
Quay length [m]	1.468	1.430	3
Total stocking area [m <sup>2</sup> ]	523.757	412.000	27
Covered stocking area [m <sup>2</sup> ]	460.417	0	-
Uncovered stocking area [m <sup>2</sup> ]	107.526	0	-
Gantry cranes [n]	10	8	21
Other cranes [n]	9	0	-
Storage cranes [n]	26	8	225
Various loaders [n]	37	20	86
Containers Lo-Lo [n]	411.525	500.000	-18
TEU [n]	697.085	323.708	115

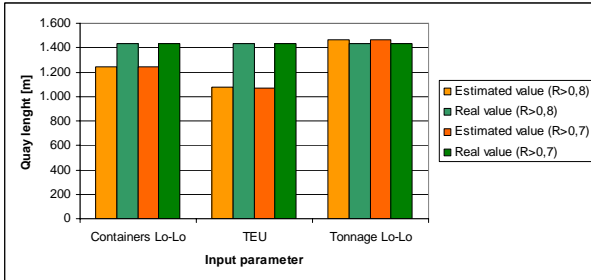


Figure 17: Estimated and real values of quay lengths for different input parameters

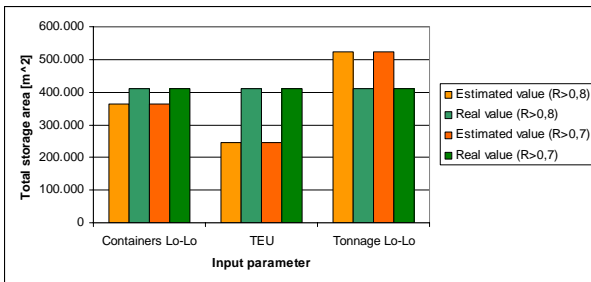


Figure 18: Estimated and real values of total storage for different input parameters

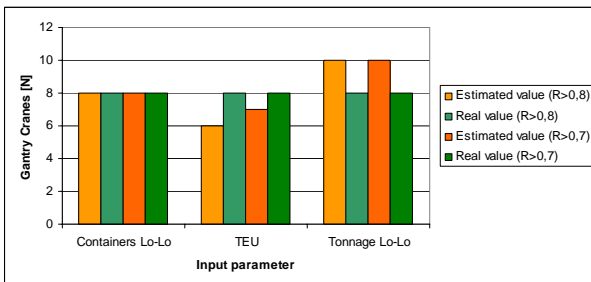


Figure 19: Estimated and real values of number of gantry cranes for different input parameters

The following considerations may be drawn:

1. the most reliable results are those related to quay length, total stocking area and gantry cranes number; the other parameters are in fact strongly influenced by local organisational issues and less suitable to be managed in a generalised approach;
2. the value of estimated parameters with the 0.7 and 0.8 threshold values are similar; therefore

it may be considered not relevant on the results the choice of this threshold;

3. the number of handled containers seem to be more reliable than TEU and their tonnage as input values: in fact TEU value is not completely representative of container movements within the terminal;
4. the estimated dimensional requirements seem to be satisfied in the present situation, as well as the existing equipment seem to be just corresponding the minimum requirements.

Of course more detailed operational feedbacks may be derived by the application of the container terminals operation stochastic model.

#### 4. CONTAINER TERMINALS OPERATION STOCHASTIC MODEL

The transit time of the generic transport unit through these terminals (TTR) represents one of the most relevant terminal performances and at the same time a key component of the freight transport generalized cost.

The TTR is composed by deterministic and stochastic components, which increases significantly the problem complexity.

The authors developed an original model based on the queuing theory allowing the calculation of the total transit time (TTR) of the single freight transport units through the terminals.

The model is applicable to a large variety of terminals.

Here its application to rail maritime terminals (sea-rail interchanges in ports) is performed and the results obtained in a real application are described.

After a synthetic description of the model structure, a methodological approach based on real collected data taking into account the influence of the following relevant parameters affecting the quality of the results is exposed:

- different typologies and sizes of intermodal units;
- additional unit movements due to co-existence of empty and full unit flows.

##### 4.1. Methodological approach

The analysed model is based on the following minimum total transit time (TTR) definition: “time period from the arrival of the single (and generic) freight unit to the terminal gate from an external transport system (e.g. by ship) to its exit from the terminal towards a different transport infrastructure (e.g. by train)”.

Obviously it does not take into account further stocking periods due to commercial reasons, which normally cause longer dwell times (sometime hundreds of hours).

The second step is the formalisation of the model finalised to the determination of the transit time.

The model concept is the decomposition of the terminal activities in a sequence of operations performed on the generic freight unit.

The single operations have been analysed into details and for each of them have been identified:

- an Operational Phase (OP) and a previous Waiting Phase (WP);
- the corresponding durations, Operation Time (TO) and Waiting Time (TW).

The following list shows the single phases, which have been identified for the most general cases:

1. Waiting before entering the terminal + Entering movement;
2. Waiting before check-in + Check-in operations;
3. Waiting before the first units transfer + First units transfer;
4. Waiting before the second unit transfer + Second units transfer;
5. Waiting before check-out + Check-out;
6. Waiting before exiting the terminal + Exiting movement.

In the generic maritime terminal the classes of entering and exiting vehicles to be considered are three ( $V'$ ,  $V''$ ,  $V'''$ ) and they may allow the transport of very different amounts ( $NU'$ ,  $NU''$ ,  $NU'''$ ) of freight units.

In the rail maritime terminals is  $NU'''(\text{truck}) < NU'(\text{train}) < NU''(\text{ship})$ .

Opposite flows of freight units entering and exiting on  $V'$ ,  $V''$  and  $V'''$  may be accordingly identified (figure 20).

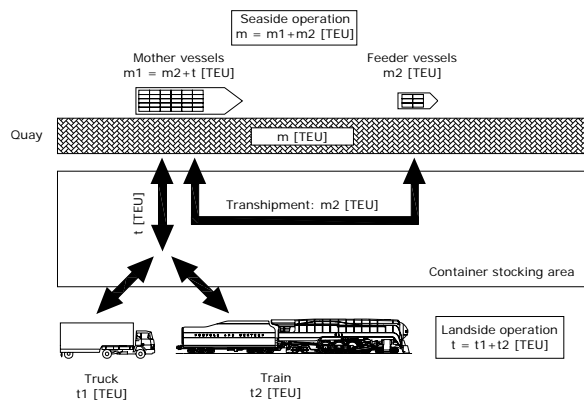


Figure 20: Freight unit flows in a generic maritime container terminal

#### 4.2. Minimum total transit time calculation

In figure 21 are represented the duration of the single phases and the mean total transit times for the freight units running in both the directions ( $TTR'$  and  $TTR''$ ) in a generic maritime terminal.

The figure shows an imaginary space-time diagram where the operations performed within the terminal are considered in sequential order: the yellow line

represents the generic freight unit entering on a vehicle  $V'$  (train) runs on it towards the transfer area and, after the stocking phase, proceeds on the vehicle  $V''$  (ship); similarly the red line represents the generic freight unit entering on  $V''$  and exiting on  $V'$ .

According to the units flows within the plant represented in figure 22, the transit time may be formalised as follows:

$$TTR' = \sum_{i=1}^4 TW'_{i'} + \sum_{i=1}^4 TO'_{i'} + \sum_{i=5}^6 TW''_{i'} + \sum_{i=5}^6 TO''_{i'} \quad (8)$$

$$TTR'' = \sum_{i=1}^4 TW''_{i'} + \sum_{i=1}^4 TO''_{i'} + \sum_{i=5}^6 TW'_{i'} + \sum_{i=5}^6 TO'_{i'} \quad (9)$$

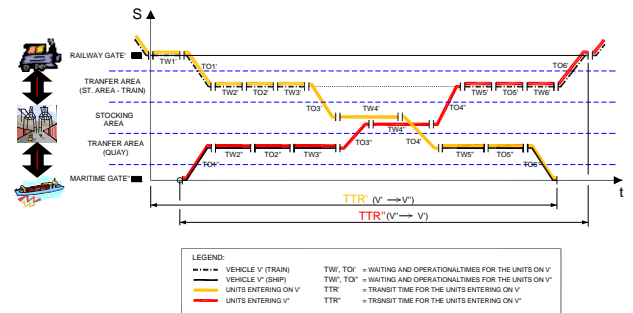


Figure 21: Single phases duration and total transit time in a generic maritime terminal

Equations (8) and (9) clearly show that the model structure can be adapted to many kinds of intermodal terminals due to the modularity of its formalisation.

The waiting times ( $TW_i$ ) represent the stochastic portions of the TTR and are calculated by an application of the queuing theory; the operational times descend from the schematic representation of the single activities within the terminal.

#### 4.3. Unit size variability

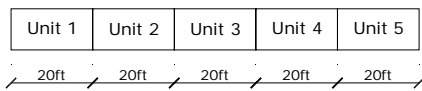
An aspect affecting the sensitivity of the model results is the presence in the terminal of different sized transport units; in fact with the same quantity of Twenty feet Equivalent Unit (TEU) it is possible to handle a different number of intermodal transport units (ITU).

The EIA (European Intermodal Association), on the basis of extended investigations, suggests the following conventional equivalence between TEU and ITU:

$$1,4 \text{ ITU} = 2,3 \text{ TEU} \Rightarrow 1 \text{ ITU} = 1,6 \text{ TEU}$$

On this basis figure 22 shows two typical situations that can occur in the terminal: case b (corresponding to the EIA conventional value) is easier to work because the transhipping device can transfer the same freight quantity with less handled units than in case a (100%TEU).

Case a: 5 Units = 5 T.E.U.



Case b: 3 Units = 5 T.E.U.

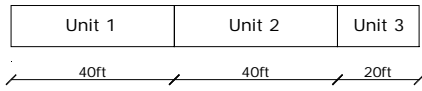


Figure 22: TEU – ITU correspondence.

Accordingly to these observations, the TTR is expected to decrease when the TEU / ITU ratio increases.

Table 9 shows a set of data collected at the Terminal Darsena Toscana in Livorno port related to the period from 1/1/2007 to 1/7/2007.

Table 9. TEUs export traffic exchange at Terminal Darsena Toscana

Export traffic	TEU/ITU			
	ITUs [n]	TEUs [n]	TONS [t]	TEUs/ITUs
	61593	92881	1189563	1,51

The two diagrams of figure 10 represent the linear interpolations to calculate the average empty weight ( $E_w$ ) and the average full weight ( $F_w$ ) of the units handled within the terminal on the basis of the value

#### 4.4. Empty units management

Another important aspect to be considered in the future model applications is represented by the additional unit movements due to co-existence of empty and full unit flows. A simple methodology to calculate empty units percentage is described below.

Table 9 shows a set of data collected at the Terminal Darsena Toscana – Livorno Port related to the period January-June 2007.

Table 9. TEUs export traffic exchange at Terminal Darsena Toscana

Export traffic	TEU/ITU			
	ITUs [n]	TEUs [n]	TONS [t]	TEUs/ITUs
	61593	92881	1189563	1,51

The diagrams of figure 22 and 23 represent the linear interpolations to calculate the average empty weight ( $E_w$ ) and the average full weight ( $F_w$ ) of the units handled within the terminal on the basis of the  $TEU/ITU$  value.

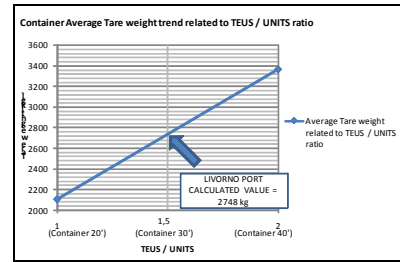


Figure 22: Determination of mean unit tare weight

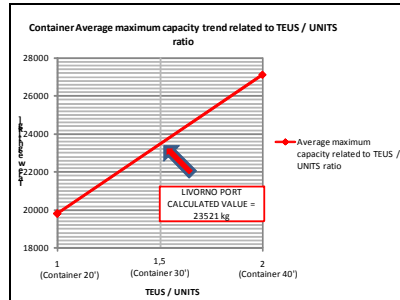


Figure 23: Determination of mean unit capacity weight

From table 9:

- total weight = 1.189.563 [t],  $N_{TOT} = 61.593$  (total number of handled units);
- from figures 22 and 23  $TEU/ITU = 1,51 \Rightarrow E_w = 2,75$  [t],  $F_w = 23,52$  [t];
- the calculation allows to determine the empty units percentage  $\%(e) = 20,22\%$ .

#### 4.5. Model application

In figure 24 and 25 is reported a graphic representation of the model application results to Livorno maritime terminal on the basis of the collected data.

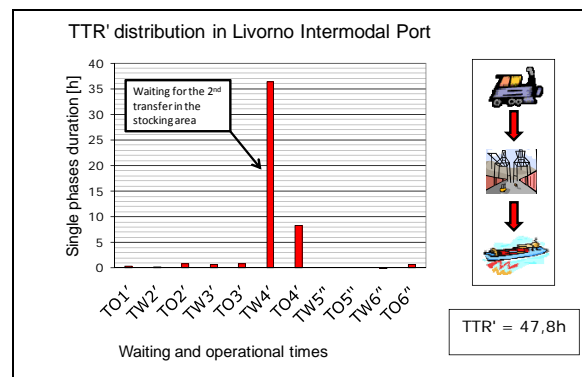


Figure 24: Model application results – Livorno Port (unit entering on train, exiting on ship).

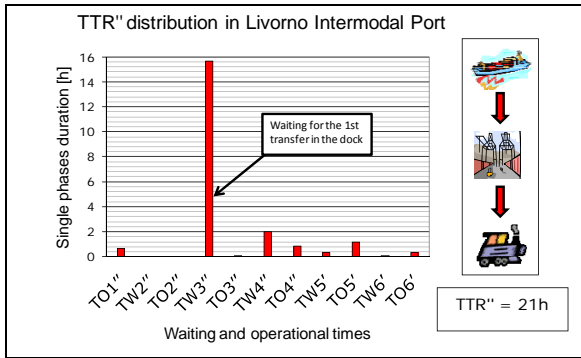


Figure 25: Model application results – Livorno Port (unit entering on ship, exiting on train).

The analysis of the numerical values of the single time components calculated by the model leads to the following considerations:

- for the units entering by train and exiting by ship:
  1. the waiting for the second transfer in the stocking area (TW4') is largely the most extended within the terminal (about 76% of the global transit time); it depends on the mean time between 2 arriving ships;
  2. other important time period is the operation of the second transfer (TO4'), mainly due to the large quantity of transport units to be loaded on the ship;
- for the units entering by ship and exiting by train:
  1. the waiting for the first transfer in the dock area (TW3'') is the longest period (about 75% of the global transit time), mainly depending on the large quantity of units to be unloaded from the ship;
  2. other important time period is the waiting for the second transfer in the stocking area (TW4''), mainly influenced by the mean time between 2 arriving trains.
- the waiting times are largely higher (86÷89% of TTR) than the operational ones.

Figure 26 and 27 show the TTR' and TTR'' sensibility to the TEU/ITU ratio variation.

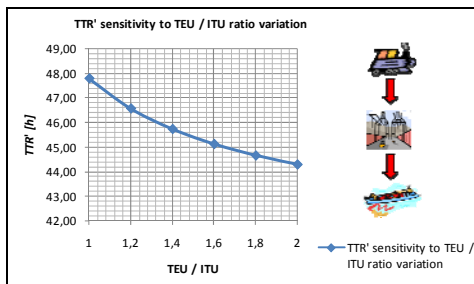


Figure 26: TTR' sensitivity analysis to the TEU / ITU ratio variation.

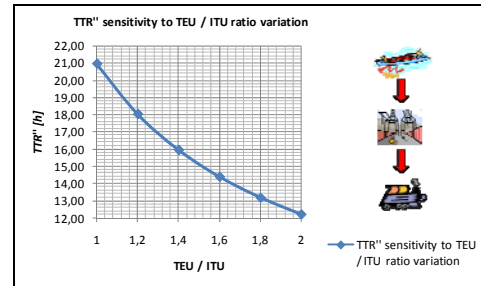


Figure 27: TTR'' sensitivity analysis to the TEU / ITU ratio variation.

The figures indicate an appropriate reduction of the TTR values when the ratio increases (less handled transport units with the same freight quantity).

In the border case (only 40' units handled, that means TEU/ITU = 2), TTR' and TTR'' would reduce their value by about 7% and 41% respectively.

TTR'' is strongly influenced by TW3'' (waiting for the first transfer from the ship to the dock and to the stocking area) also directly depending upon the number of transport units to be unloaded from the ship (it practically depends upon TEU/ITU variation).

#### 4.6. Remarks

The model is characterised by wide generality and applicability to different terminal typologies, lay-outs, dimensions and transfer technologies.

It allows to highlight contributions and weights of the various activities and phases of the freight unit transit through the terminal by distinguishing operational and waiting periods, whose duration depends not only upon internal performances (technologies, dimensions and operational rules) but also upon external parameters and constraints (time distribution of vehicles arrivals and departures)

At present the authors are continuing model experimentation on maritime terminals in order to consolidate the methodological approach and to fine tune the most relevant parameters by means of the comparison with collected data in various operational contexts.

#### REFERENCES

- Florio L., Malavasi G., 1995. Introduzione all'analisi strutturale degli impianti portuali di trasbordo container, *Ingegneria Ferroviaria*, August, 454.
- Kia M., Shayan E., Ghotb F., 2002. Analisi della capacità portuale attraverso una simulazione informatica, *Computers & Industrial Engineering* – Volume 42, Issues 2-4.
- Malavasi G., Marinacci C., Ricci S., 2007. Capacità portuale lato mare: un modello di valutazione sintetica – *Binari sul mare. Scenari di integrazione del trasporto merci*, Officina edizioni, Roma.
- Malavasi G., Marinacci C., Ricci S., 2008. Performances and application fields of sea side port capacity models – *AATT 2008*, Athina.
- Malavasi G., Quattrini A., Ricci S., 2006. Effect of the distribution of the arrivals and of the intermodal

unit sizes on the transit time through freight terminals. 2006. *Computer in Railways X. Computer System Design and Operation in the Railway and other Transit Systems*. WIT Press, 2006, Prague.

Malavasi G., Ricci S., 2002. Generalized model for the performance evaluation of different railway freight terminals. *9th International Symposium, Railways on the Edge of the 3rd Millennium*, Zilina.

Noli A. and others, 1984. *Calate portuali e terminali marittimi. Criteri generali di pianificazione e costruzione*, Roma, ESA.

Park C.S., Noh Y.D., 1987. An interactive port capacity expansion simulation model – *Engineering Costs and Production Economics*, Volume 11, Issue 1 (109-124).

Potthoff G., 1979. *Verkehrsströmungslehre*, Vol. 1-5 – Transveb, Berlin.

Quattrini A., Ricci S., 2008. Application of a stochastic model to intermodal units operations in rail – maritime terminals. *16<sup>th</sup> International Symposium Towards sustainable and competitive European rail system EURNEZ-ZEL 2008*, Zilina.

Romano F., 1979. *Trasporti aerei e navali*. Roma, Edizioni Sistema

# ADVANCED HANDLING OF STEEL PRODUCTS IN SEAPORTS USING MAGNET SYSTEMS

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## ABSTRACT

The intense growth of cargo traffic leads to a higher movement of goods in German seaports. Due to limited possibilities to upgrade existing infrastructure and the demand to ecologically extend the seaport's capacity, technological innovations are needed to fulfil these requirements.

Especially, the handling of steel products is dominated by classical, mechanical load handling attachments which usually consist of hooks, chains, ropes and belts. These attachments are comparatively heavy and unwieldy but are convincing regarding design, quality and reliability. However, this technology offers very little potential for innovation and process optimisation. Additionally, damage of the handled steel products cannot be excluded. But as an innovative alternative to mechanical load handling attachments different magnet systems are available. This article is focused on the basic conditions of the development of the handling technology and the development of an innovative logistics concept which is necessary because of the employment of the new technology.

Keywords: Seaport logistics, steel handling, magnet systems

## 1. INTRODUCTION

In the past years a trend towards a globalised economy was observed, resulting in the development of new strong economical centers in Eastern Europe or in Asia. Particularly in this context, logistics is facing ever larger challenges to ship the appropriate raw materials and products in the demanded time and quantities. The world-wide maritime traffic profited from this development strongly (Bloomberg, LeMay and Hanna 2001, Eversheim and Schuh 1996, Gudehus 1999).

However the capacities in the seaports are limited. Because of this fact a strong need for new, innovative technologies and concepts is given to transport and handle the quantities fairly, since a simple extension of the port area is often not possible or economically reasonable. The handling of steel products, which is analysed in this paper represents no exception, since the

immense need of steel all over the world led to rising quantities which have to be shipped (David 2004, Murphy and Wood, 2007, Rushton, Croucher, and Baker 2006).

The special characteristics of handling steel products in seaports arise from the variability of the products, which cover a range from coils to sheet metals of different forms and very high weights. Nowadays the handling of steel products is dominated by classical, mechanical load handling attachments which usually consist of hooks, chains, ropes and belts. Due to the high loads that can occur when steel products are handled a special protection of the handled load is strictly needed. This is realized by a complex and unhandy system using pole shoes.

The security requirements are optimally fulfilled by employing this system. But the handling process is enormously slowed down. Regarding the given situation, which is characterized by rising handling quantities, this is unfavorable. Therefore an innovative approach is chosen here to accelerate the steel handling processes accordingly by the development of a magnetic system, which will provide the same level of security as the common handling technologies.

A further central content of the work will be the development of an innovative logistics concept. This will be arranged in such a way that the rising quantities can be handled and at the same time the given port area will be not unnecessarily impaired by further traffic or repositories.

Following this introduction at first the technology itself, which is to be used in the context of this project and the technological requirements will be presented. Then a description of the typical steel products with its special characteristics as well as a description of the logistics concept which will be generated is given. The goals of the project presented here then finally lead to the results and a outlook.

## 2. MAGNET SYSTEMS

### 2.1. Electromagnet systems

An electromagnetic field is generated by the flow of an electric current through a conducting wire (Griffiths 2003). The electromagnet is then constructed by winding up long wires to a coil so that every turn counts for the magnetic field. Usually, a core of paramagnetic or ferromagnetic material (commonly soft iron) is placed inside the coil, which further concentrates and amplifies the magnetic field. The electromagnet can be switched on and off by simply regulating the current flowing through the coil.

An electromagnet can be operated with direct current as well as with alternating current. In the first case, the non-linear characteristic curve of force and displacement leads to a small force in the attracting phase when there is a large gap between the magnet and the target (Kallenbach, Eick, Quendt, Ströhla, Feindt and Kallenbach 2008). Therefore, this technique is generally inappropriate in cases where a strong force is needed immediately. One solution would be to raise the current in the attracting phase.

In contrast, electromagnets operated with alternating current yield large forces already in the beginning of the attracting phase. But the force has to be conserved also in zero crossings of the current flow, which increases the technological complexity of the system.

One big advantage of this technology is the fact that the force is controllable continuously. Thus, an

adaption to different weights is easily possible. Furthermore, the magnetic force is no longer present when the system is switched off at the resting position. The magnetism is only produced by the electromagnet and cannot be destroyed by collisions (the magnet itself can certainly be damaged). But also certain disadvantages are obvious. The security of workers and equipment has to be guaranteed even in the case of an electrical power breakdown or cable breaks. This can only be achieved by redundant magnetic system and/or a mechanical backup. A point of economical interest are the operating costs. Due to the heavy load and the almost equal distances for empty and loaded runs the power consumption is an economic factor, which has to be regarded but in contrast, the acquisition costs are low.

### 2.2. A-stable permanent magnet systems

A permanent magnet is a piece of a magnetisable material, for example iron, cobalt or nickel. In contrast to electromagnets, this material keeps its static magnetic field without a current flow (Michalowski and Schneider 2006). So the magnetic field cannot be switched off, which is necessary for its application in handling systems. The solution is to use additionally an electromagnet here to generate a magnetic field that has the opposite orientation of the one produced by the permanent magnet. Both then compensate. Thus, in sum no magnetic field is present and the cargo is not attracted (see figure 1).

Permanent magnets can be made from different materials, which affect the characteristics like size or

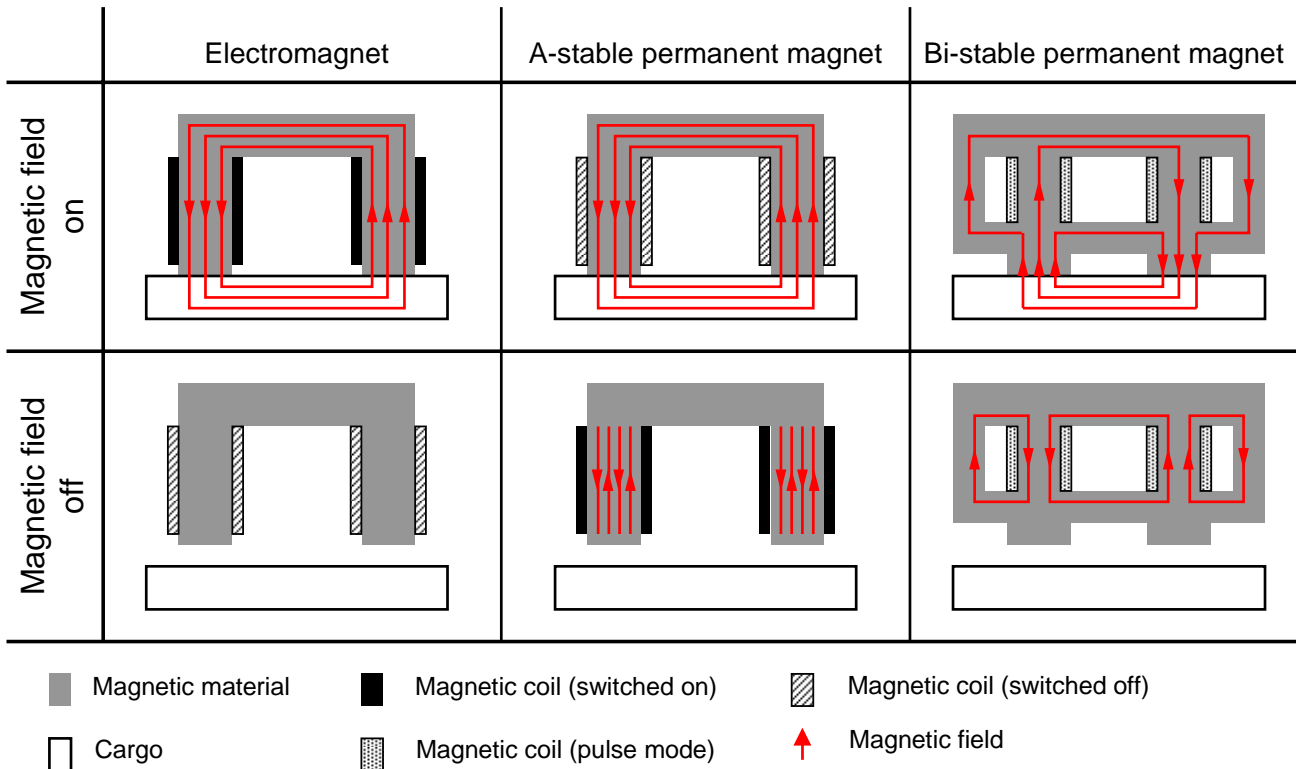


Figure 1: Visualisation of the Technology of the three different Magnet Systems.

strength of the magnetic field (Cassing and Seitz 2007). Cheap materials are ferrites. But magnets based on that substance are relatively weak and not sufficient for this kind of application.

Aluminium-nickel-cobalt (AlNiCo) based magnets are basically iron alloys with aluminium, nickel and cobalt as main elements. These materials can be employed up to temperatures of 500°C and are corrosion-resistant. But they are very hard and breakable. Neodymium-iron-boron (NdFeB) based permanent magnets provide very strong magnetic fields relative to their mass, are relatively cheap in production but are also mechanically fragile. For a long time, an application of this material was only possible in the range of temperatures up to 60-120°C. New developments allow temperatures up to 200°C.

One fact that has to be regarded in practice when operating the magnet systems is that permanent magnets can lose their magnetism due to various reasons:

- a decaying alternating magnetic field,
- exposure of the material above a critical temperature, known as the Curie point and
- especially in the regarded scenario of seaport handling occurring collisions.

One big advantage of this technology is the fact that the magnetic force is controllable continuously. Thus, an adaption to different weights is easily possible. Also security of workers and equipment can be guaranteed because the magnetic force will keep up even in cases of electrical power breakdown or cable breaks. Thus, a mechanical back up system is not needed. Nevertheless, this technique also reveals disadvantages. Due to the almost equal distances for empty and loaded runs the power consumption is an economic factor, which has to be regarded but like the

electromagnet, its acquisition costs are low. A serious problem which is to be solved is the fact that the permanent magnet cannot be switched off, so that the magnetic force is present in the resting position when the electromagnet is not active.

### 2.3. Bi-stable permanent magnet systems

This new technology is a combination of two different kind of permanent magnets and electromagnets. The system is able to take two stable and permanent states: a magnetised and a demagnetised.

This is achieved by innovative configuration of the different single magnets. One kind of permanent magnet is used to establish a strong magnetic field. The electromagnets are used to reverse the polarity of the second kind of permanent magnets. The polarity of that magnet determines whether the magnet system has an external magnetic field and is attracting the cargo or the field is kept inside the magnet system (see figure 1 for illustration).

Like the other presented solutions, this system has several advantages as well as disadvantages. In contrast to the a-stable permanent magnet system, the bi-stable permanent magnet can be switched off, so that no magnetism is left. The magnet then is inactive in its resting position. Also security issues can be guaranteed because the magnetic force will keep up even in cases of electrical power breakdown or cable breaks since the electric power is only needed to switch the state between magnetised and demagnetised. Thus, a mechanical back up system is not needed.

The economic disadvantage of the other systems due to the power consumption of the electromagnets is not relevant here. There is only little power needed for switching the polarity of the permanent magnets. Thus, the heavy load and the almost equal distances for empty and loaded runs do not affect the power consumption.

Table 1: Summary of the Advantages and Disadvantages of the three regarded Magnet Systems

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Electromagnet</b>	<ul style="list-style-type: none"> <li>• Magnet inactive in resting position</li> <li>• Magnetic force controllable continuously</li> <li>• No loss of magnetism due to collisions</li> <li>• Low acquisition costs</li> </ul>	<ul style="list-style-type: none"> <li>• Security issues in case of electrical power breakdown or cable breaks</li> <li>• High operating costs due to power consumption</li> </ul>
<b>A-stable permanent magnet</b>	<ul style="list-style-type: none"> <li>• Magnetic force controllable continuously</li> <li>• In case of electrical power breakdown or cable break no loss of magnetic force</li> <li>• Low acquisition costs</li> </ul>	<ul style="list-style-type: none"> <li>• High operating costs due to power consumption</li> <li>• Magnet active in resting position</li> <li>• Possible loss of magnetism caused by collisions</li> </ul>
<b>Bi-stable permanent magnet</b>	<ul style="list-style-type: none"> <li>• Magnet inactive in resting position</li> <li>• Low operating costs</li> <li>• In case of electrical power breakdown or cable break no loss of magnetic force</li> </ul>	<ul style="list-style-type: none"> <li>• Possible loss of magnetism caused by collisions</li> <li>• High acquisition costs</li> <li>• Magnetic force not controllable continuously</li> </ul>



But this new technology has high acquisition costs.

Like other permanent magnets the magnetism can be lost due to collisions especially when operating the system in seaport environments (and the reasons stated in 3.2). One major deficiency is the fact that the magnetic force is not controllable continuously since only two stable states, on and off, are possible. This will complicate the development of tandem strokes of steel sheets enormously.

### 3. TECHNOLOGICAL REQUIREMENTS

Magnetic systems for the handling of steel products are already in use in these days. Main focus is here in production environments. Also industrial trucks in port environments can be equipped with this technology.

But the steel handling with large cranes makes great demands to the applied magnet technology. A pilot installation in the inland port of Duisburg, Germany was installed and is operated by ThyssenKrupp AG (Preuss 2007). They use the new and innovative technology of bi-stable permanent magnets for the optimisation of the handling processes of steel slabs.

But the handling in seaports poses a certain challenge due to higher safety standards, which mainly result from the changed environmental conditions due to the vicinity of the sea. Thus, the existing technology does not yet fulfil the following requirements:

- larger lifting heights in combination with stronger winds,
- higher acceleration forces and
- longer traverse paths.

The safety of workers and material has to be guaranteed at all times. The different reasons for loss of magnetic force have to be eliminated or backup solutions have to be found. In detail that means in case of an electromagnet to install a redundant electromagnet system and / or install mechanical backup solutions to prevent the cargo from falling down. A further possibility is a battery pack, which ensures the current flow for at least 20 minutes. In case of the different permanent magnet systems collisions of the magnets have to be avoided and eventually, depending on the government safety organization, mechanical backup systems have likewise to be installed. A detailed summary of advantages and disadvantages of the different regarded technologies is given in table 1.

Furthermore, the technology is not yet able to handle other steel products like coils and stacks of sheets. Necessary for the development are solutions for

- tandem lifts and
- inhomogeneous masses (air gaps between the steel products).

### 4. RESEARCH

The research focuses on the development of innovative magnet systems regarding the above mentioned

boundaries, restrictions and requirements. Typical handling problems will be solved and the necessity of permanent maintenance of the mechanical system will be reduced.

The process of the steel handling can be improved by the use of bi-stable permanent magnet systems significantly. The large number of electromagnet systems, which already led to impressive improvements in the landlateral handling, indicate this. The special challenge is the adjustment of the technology to the requirements in a seaport and to its high safety standards (the fulfillment of these safety standards is a condition for the certification of the technology by the responsible association).

At present bi-stable magnetic systems are used in a pilot project for unloading single slabs from ships at inland ports. However still no closing experiences and permissions exist. In principle this system is suitable for an advancement for the application in seaports. Therefore in addition solutions for tandem strokes, inhomogeneous bodies (gaps between the steel bodies and/or sheet metals or sheet metal layers), higher vertical lifts in combination with stronger wind influence, higher acceleration forces and larger traverse paths must be developed.

Innovative magnet cross beams will be developed, which will reduce typical handling problems and the necessity for constant maintenance of handling systems as well as to avoid damages of the steel products. Altogether the handling of steel products will become more material caring, fast and safe. This higher quality and the more economical processes will lead to an improved competitiveness of the seaports.

The requirements to the bearing pressure for the handling of different product types of sheet metals, slabs and coils require differently laid out magnet cross beams. These will differ mainly in the arrangement of the magnets and their dimensioning. Logically in three modules three prototypes will be developed and tested. These modules and prototypes will be described in the following shortly:

- Module Sheets

In the sector of sheet metal loading maximally two metal sheets per lift can be handled by a jib crane working at full capacity at present. An increase of the load quantity per lift will lead to an acceleration of the shipping process. The innovative approach is the further development of a magnetic system in such a way that several sheet metals can be handled at the same time. The special challenge consists of developing a sufficient adhesive force which corresponds to the safety standards for the seaport. To guarantee the operating licence of the government safety organisation the strength of the force has to be proven also in presence of gaps between the sheets.

- **Module Slabs**

In case of the slab loading a versatile system has to be developed, which is suitable for the handling of two or more light or one heavy slab. Further the special requirements in a seaport must be considered, in order to be able to deal with e.g. higher lifting speeds and wind influences. For this application a special design of the magnetic system is necessary, which at present does not exist.

- **Module Coils**

The transport of coils represents the largest challenge, since the weights and the outside diameters vary within a certain range. Thus, no optimal adjustment of the pole shoes to the circular geometry of a coil can be achieved. In comparison to the employment of other handling technologies the magnetic lift leads to a larger air gap between the single windings, which leads to a reduction of the adhesive forces. Besides, a coil is wound and depending on the rolling up tension different air gaps between the individual turns occur. That is in particular relevant for coated coils. It is here necessary to consider a large number of different parameters, like the mode of conveyance whether horizontal or vertical, whether additionally packed with a sheet-steel jacket or not. Furthermore, it must be examined whether the positions of the clips of the coil fit to the range of the pole shoe and which kind of coils have to be handled (cold rolled sheet or hot rolled sheets). In addition the range of the thickness of the sheet must be analysed. Especially, this case requires a thorough investigation of the individual parameters.

To allow the control of the magnetic force a special force measurement device (Cassing and Stanek, 2002) is used. This system must be further developed and adapted for all three modules. Furthermore the basic conditions for each application must be coordinated, in order to receive an operating permit.

Along with this technical development, a new integrated logistic concept will be developed which takes into account the advantages of this specific technology. This is primarily an optimisation of the handling processes of the transportation media by the employment of the new technology leading to a large amount of shipped materials. The logistics concept which must be developed has primarily to be designed in a way that the handling capacities can be used completely. So it must be particularly guaranteed that a sufficient amount of material is present on the land side at the right time in direct range of the crane.

In comparison to the existing situation this can be obtained on the one hand by improved storage capacities and on the other hand by an improved connection to the traffic infrastructure in combination with coordinated planning and control methods. An extension of the storage spaces for the different steel products is surely the simplest way to meet the

quantitative requirements. But this is possible only rarely because today the work space is already strongly limited in the seaports. Thus, a first approach to meet the situation is to look for intelligent possibilities to store the material which will be shipped. However it becomes immediately clear that this makes necessary extensive investments in storage engineering, which will effect the cost balance of the technology altogether surely negatively.

Regarding this background it seems to be more success-promising to develop new innovative logistics concepts which are particularly adapted to the requirements of the regarded scenario. If no further storage spaces can be made accessible, the requirements on the rising transport of the often very large and heavy steel products into the seaport are of a major interest. Here in any case an improved synchronisation of the logistics chain from the manufacturer over the logistics service provider to the customer is strictly necessary.

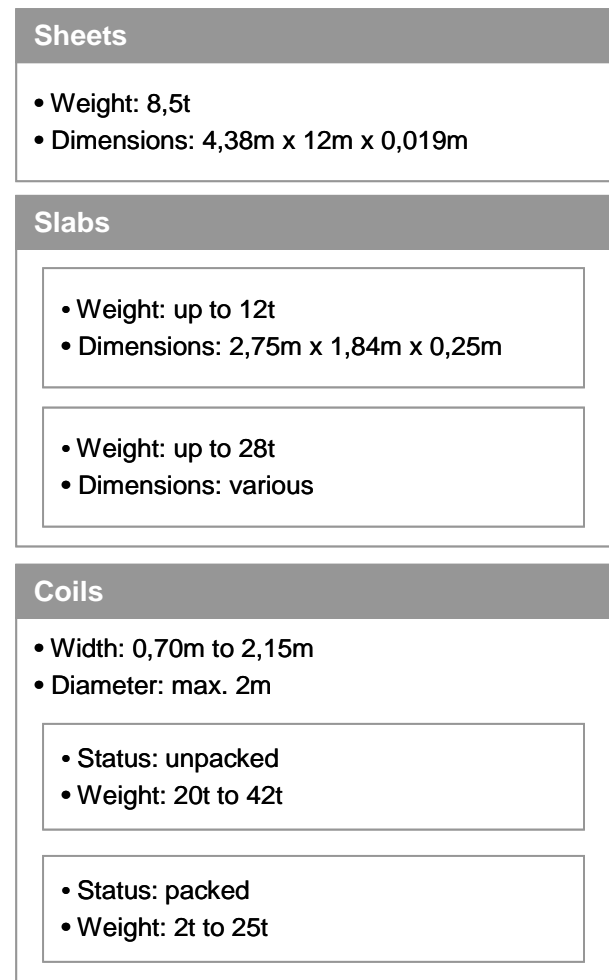


Figure 2: Steel Product Overview

Due to the very high dimensions and weights of the products especially the railway is applicable as transportation medium beside trucks. It must be examined in detail, to what extent the rising throughput can be transported by the different media. This will be

analysed in detail in the progress of the project in order not to use up the economic advantages of the new technology by the costs of the upstream processes completely.

## 5. GOALS

The goal is to solve existing problems in handling as well as storage of steel products by the development of a magnetic handling system. This new and innovative handling technology will lead to a higher quality of processes and a significantly decreased handling time because load bearing will be reduced to some seconds, handling performance per shift will be increased and setting down of the load will be reduced to some seconds.

Additionally, the use of magnet systems and the automation of handling processes will help to avoid damage of steel products and significantly increase the operational safety. Altogether, the handling of steel products will be faster, safer and gentle to material.

Regarding the expected costs for purchasing and operating the new technology, the internal costs of the handling processes will be reduced in a range that this technology is supposed to amortise within about four years. This will be determined in detail. In particular the advantageous facts are:

- an acceleration of handling processes,
- an increase of operational safety and
- a minimisation of damage.

## 6. SUMMARY AND CONCLUSION

The steel handling processes not only in seaports become more and more complex because of the rising quantities. As shown in this article, an intelligent technological approach is necessary, in order to deal with this situation. Among other things it is the aim to relieve the available storage spaces and to increase the turnover rate at the same time.

In the opinion the authors the use of magnetic systems for the handling of steel products represents a concept, which is particularly suitable for the described requirements. Reasons lie here on the one hand in the high variability, which characterizes this technology. This is particularly favorable, since steel products of different form and weight must be handled. On the other hand a special focus of the development of the technology is drawn to the fulfillment of safety conditions of the government safety organisation, which have to be fulfilled in seaports, so that the systems can be used accordingly.

## REFERENCES

- Bloomberg, D.J., LeMay, S.B. and Hanna, J.B., 2001. *Logistics*. Upper Saddle River: Prentice Hall.
- Cassing, W. and Seitz, D., 2007: *Dauermagnete*. Renningen: Expert-Verlag.
- Cassing, W. and Stanek, W., 2002: *Elektromagnetische Wandler und Sensoren*. 2nd ed. Renningen: Expert-Verlag.

- David, P.A., 2004: *International Logistics*, Atomic Dog Publishing.
- Eversheim, W. and Schuh, G., 1996: *Produktion und Management, Band 2: Produktmanagement*. Berlin: Springer.
- Griffiths, D.J., 2003: *Introduction to Electrodynamics*. 3rd ed. Prentice Hall International.
- Gudehus, T., 1999: *Logistik: Grundlagen, Strategien, Anwendungen*. Berlin: Springer.
- Kallenbach, E., Eick, R., Quendt, P., Ströhla, T., Feindt, K. and Kallenbach, M., 2008 : *Elektromagnete : Grundlagen, Berechnung, Entwurf und Anwendung*. 3rd ed. Wiesbaden: Vieweg + Teubner.
- Michalowski, L. and Schneider, J., 2006: *Magnettechnik: Grundlagen, Werkstoffe, Anwendungen*. 3rd ed. Vulkan.
- Murphy Jr., P.R. and Wood, D., 2007: *Contemporary Logistics*, 9th ed., Prentice Hall.
- Preuss, A., 2007. In *Zukunft mit Magneten, ThyssenKrupp Inside*, 05/07, p. 11.
- Rushton, A., Croucher, P. and Baker, P., 2006: *The Handbook of Logistics and Distribution Management*, 3rd ed., Kogan Page.

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# THE SHIP STOWAGE PLANNING PROBLEM

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## ABSTRACT

In this work we deal with the Ship Stowage Planning Problem. It is a two-step process. The first step is executed by the shipping line, which designs the stowage plan for all ports of a vessel's rotation. At a given port, the stowage plan indicates containers that must be discharged and, for each available slot, a class of containers which can be loaded there. Here we focus on the second step, which pertains to the terminal planners. On the basis of the stowage plan, they must assign exactly one container, of a given class, selected in the yard, to a slot of the same class. The objective is the minimization of the total loading time. We present a Linear Integer Model and a heuristic algorithm, to get feasible solutions for the problem.

Keywords: maritime logistics, container stowing, heuristic

## 1. INTRODUCTION

Nowadays the world container traffic calls for very large containerships, whose capacity is around ten thousand of TEUs. Moreover each of them visits several hubs, where some containers are discharged and some are loaded. Therefore, during a trip, the *configuration* of a containership's cargo can vary from a port to the next one the ship has to visit (this sequence of ports is called *port rotation*). In this high dynamic scenario, planning the position of containers transported by a containership is a key factor to guarantee a fast turnaround time.

Before discussing how the stowage plan is drawn up, it is instructive to describe, briefly, the structure of a modern containership. It consists, basically, of several *slots* capable of accommodating one TEU. Two adjacent slots are used to stow a 40' container.

Slots belonging to the same cross section of the containership constitute a *bay*, those sharing the same vertical section a *row*, and, finally, those which are on the same horizontal section a *tier* (see Figure 1). Thus, to identify the position of container within a vessel, a three index code ( $b,r,t$ ) is used. The first index  $b$  represents the bay and takes positive numbers, usually

increasing from the bow to the stern of the containership. To differentiate 20' containers from 40' containers, odd bay numbers and even bay numbers, respectively, are used. The second index, the row index  $r$ , is a positive odd number for rows on the quay-side of the vessel, while rows on the sea-side are indexed by even numbers (the row  $r = 0$  is the central one). Finally the tier index  $t$  takes even values from 02 (indicating the lowest position) to the maximum allowed for slots located below the deck (hold), while positions on the deck are labelled by indexes starting from 80.

Designing a stowage plan for a containership consists of two sequential processes (Steenken, Voss, and Stalhbock 2004; Álvarez, 2006). The first step is executed by the shipping line, whose planners have a complete view both of all containers that have to be loaded or discharged during the vessel's trip, and of the cellular structure of the vessel. They provide stowage plans for each port of the vessel's port rotation.

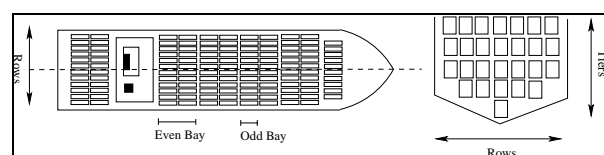


Figure 1: Horizontal and Cross sections of a vessel

At this stage of the stowage planning process, the reference unit is not the specific container, but a class of containers, identified by several attributes: the size, the type, the destination port, the weight. Containers of the different classes are assigned to specific positions within the ship, taking into account a number of constraints, basically related to the ship's capacity and stability. The shipping line's objectives are to minimize the number of on-board shifts during the port rotation and to maximize the ship utilization. The result of this process is a list of documents, which are sent to the terminals' planners of all ports the containership will visit.

A first document summarizes all container moves (loading, discharging, and restowing) that have to be

performed at a specific port. Then a series of other sheets gives a detailed view of each ship bay and indicates positions from which containers have to be discharged (*Discharging Plan*) or in which containers have to be loaded (*Loading Plan*). Figure 2.a shows that at the port labelled by “2” 32 containers must be discharged from bay 1. More precisely 16 containers are located below into the hold and 16 are up the deck. Furthermore Figure 2.a shows that to reach containers into the hold a *hatchcover* (represented in the figure by a thick black line) must be beforehand removed.

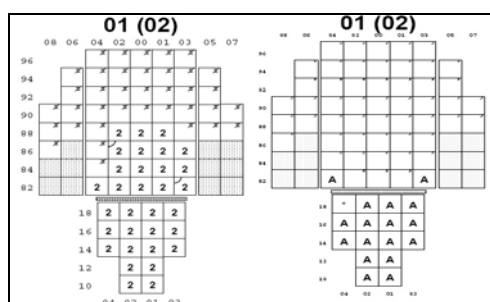


Figure 2: Discharging (a) and Loading (b) Plans.

The *Loading Plan* for bay 1 is depicted in Figure 2.b, from which one can retrieve that at bay 1 15 containers must be stowed into the hold and two must be placed on the deck. All containers stowed into the bay 1 belong to the same class. In particular these containers will be discharged, successively, at the port labelled by “A”. As regards this issue, it is worthy to highlight that the *class* of a container incorporates several container characteristics: the port of destination, of course, but also the weight class (*heavy, medium, light*), the dimension (*standard, high cube, oversized*), the type of load (*perishable, dangerous*).

These documents act as guidelines (*Prestow Plans*) for the terminals’ planners, which are involved in the second step of the stowage plan design, sometimes referred as *ship loading* or *load sequencing* problems. In the reported example, planners of port “2” must assign exactly one container (identified by a unique code) of class “A”, selected in the yard, to each slot of bay 1. In this phase the basic constraint planners have to comply with is that the weight of container stacks must decrease from the hold to the deck.

As regards the objectives the terminal planners have to pursue, they are quite different from the shipping line's ones. In order to speed up the ship loading process, it is possible to minimize the transportation time of containers from the yard to the quay, or minimize the yard reshuffles. Reshuffles, or yard shifts, are very time consuming unproductive moves, which occur whenever some containers on the top of a yard stack have to be removed (and then restacked) in order to pick up a suitable container on the bottom of the same stack.

The paper will address the ship stowage planning problem as it arises at a transshipment container terminal. The strong interaction between the problem under consideration and the yard layout and equipment

is evident. We will consider an extensive yard, where containers are moved by a fleet of straddle carriers (*Direct Transfer System - DTS*). In such a context, yard stacks are almost three-four containers height.

Looking at the problem from the point of view of the terminal manager, the objective to minimize will be the ship's total berthing time. The contribution to the ship's berthing time related to the loading process is given by two terms: the total transportation time of containers from yard to quay, including the time wasted by reshuffles, and the total loading time. Since the shipping line's prestow plan is an input datum, as well as the number of cranes allocated to the containership and the sequence of ship bays each of them has to handle, the time the cranes will take to load all the containers into the ship can be considered a constant. It is worth noting that the stowage planning is an offline optimization process, in the sense that the stowage plan is generated by the ship planner before ship loading starts. Hence, the main modelling difficulty, in the case of many cranes working on the same vessel, relies on the reshuffles estimation, since the yard stack configurations vary dynamically during the loading process.

Here we will reduce our attention to the minimization of the transportation times and of yard reshuffles, by formulating the stowage planning problem as an integer linear programming problem. The outline of the paper is as follows. In Section 2 we provide an analysis of related literature. A Linear Integer Model for the stowage problem is presented in Section 3. Section 4 describes a heuristic algorithm and is followed by preliminary results in Section 5. Some conclusions are driven in Section 6.

## 2. LITERATURE REVIEW

The Ship Stowage Planning Problem (SSPP in what follows) has received, to our knowledge, not much attention by researchers. Moreover in some of previous studies the distinction between the two phases is not so clear, which makes difficult the application in a real context of models and algorithms developed.

(Avriel, Penn, Shpirer, et al. 1998) have studied the SSPP from the point of view of the shipping companies. The authors propose an Integer Linear Model, where the objective is the minimization of on-board shifts, and a heuristic algorithm to get feasible solutions to the problem.

In the paper of (Wilson and Roach 1999) the whole stowage planning problem is considered. First, the authors propose a Branch-and-Bound algorithm for the *Prestow Planning*. Then the second phase is performed by a Tabu Search algorithm. Similar studies are reported in (Wilson and Roach 2000; Wilson, Roach, and Ware 2001).

(Dubrovsky, Levitin, and Penn 2002) propose a genetic algorithm for the problem as described in (Avriel, Penn, Shpirer, et al. 1998), but taking into account constraints on the ship stability.

In (Ambrosino, Sciomachen, and Tanfani, 2004) the ship planning problem at the first port of the port rotation is described. The authors propose a Mixed Integer Program and a three-step heuristic, with the aim of minimizing the total loading time. A different algorithm for the same problem is given in (Ambrosino, Sciomachen, and Tanfani 2006).

In our opinion the most meaningful papers on the SSPP are those of (Álvarez, 2006) and (Kim, Kan, and Ryu, 2004).

In (Álvarez, 2006) the author considers a port where containers are moved by reachstackers and analyzes the problem from the point of view of the terminal managers. The author provides an Integer Program, whose objective function to minimize is a linear combination of the yard reshuffles and of the total distance travelled by the reachstackers. The problem is solved via a Tabu Search algorithm.

The paper by (Kim, Kan, and Ryu, 2004) considers a port where an *Indirect Transfer System* is adopted: a fleet of trucks moves containers between the yard and the quay, while stacking and retrieving of containers in the yard is performed by transfer cranes. The authors present a Nonlinear Integer Model for the load-sequencing problem, which consists in determining, for each transfer crane, a pick-up sequence of containers and, then, for each container, a loading sequence. The objective function, which is a combination of several terms, relates to the maximization of the efficiency of both transfer and quay cranes. The solution of the problem is tackled by a Beam Search algorithm.

### 3. MATHEMATICAL MODEL

To derive a Linear Integer Model for the SSPP we consider, as input data, the following:

1. the configuration of the ship;
2. the prestow plans, assuming that constraints related to the ship capacity, the cross and longitudinal equilibrium, are satisfied;
3. the number of cranes allocated to the ship, as well as the sequence of bays each crane will handle and, for each bay, the *operational modality* of the crane (sea-to-shore, shore-to-sea, row-wise, stack-wise);
4. the set of all containers whose classes match the classes of ship's lots to be filled, together with their codes, attributes, and positions in the yard;

Thanks to assumptions (1) and (3), it is possible to map each slot  $(b,r,t)$  in to a sequence position index  $p^k$ , if the slot  $(b,r,t)$  is the  $p$ -th container in the sequence of slots where the crane  $k$  has to load containers. Since for each slot the prestow plan indicates the class of container which can be stowed in that slot, the problem reduces to assign a suitable container to each position index  $p^k$  subject to side constraints. These further constraints have to guarantee that the weight of

containers piled up on the same stack must decrease from the bottom to the top.

We now introduce our main notation. We define:

- $N$  the set of containers as previously defined ( $|N| = n_c$ );
- $T \subseteq N$  and  $F \subseteq N$  the set of 20' and 40' containers, respectively;
- $\forall i \in N, w_i$  the weight of container  $i$ , and  $c_i$  its class;
- $K$  the set of cranes assigned to handle a given containership ( $|K| = m$ );
- $\forall k \in K, P^k$  the set of slot positions associated to the crane  $k$  ( $|P^k| = n^k$  and  $\sum_{k \in K} n^k = n_p$ );
- $\forall k \in K, P_E^k \subseteq P^k$ , the set of slot positions where the crane  $k$  can load a 40' container;
- $\forall k \in K, P_O^k \subseteq P^k$ , the set of slot positions where the crane  $k$  can load a 20' container;
- $\forall k \in K, \forall p \in P^k, c_p$  the class of the slot related to the position  $p$ ;
- $\forall i \in N, k \in K, p \in P^k, \tau_{ip}^k$  the time needed to transport the container from its location in the yard to the bay corresponding to the position  $p$  of crane  $k$ ;
- $\sigma$ , the time needed to perform the shift of a container in the yard.

Moreover we introduce the following  $\{0,1\}$  matrices:

- $\forall k \in K, \Phi_{n^k \times n^k}^k$  whose elements  $\phi_{pq}^k = 1$  if and only if the slots associated to position indexes  $p$  and  $q$ ,  $(b_p, r_p, t_p)$  and  $(b_q, r_q, t_q)$  respectively, satisfy  $b_p = b_q, r_p = r_q, t_p < t_q$ ;
- $\Gamma_{n_c \times n_c}$ , which relates the positions of containers in to the yard. In particular the generic element  $\gamma_{ij} = 1$  indicates that containers  $i$  and  $j$  are in the same yard stack and  $i$  lies below  $j$ .

By means of the decisional variables

- $x_{ip}^k = 1$  if and only if the container  $i$  is assigned to the position  $p$  of the crane  $k$ ;
- $z_{ij} = 1$  if and only if container  $i$  is handled before  $j$  in a sequence  $P^k$  for some  $k \in K$

the SSPP can be formulated as follows:

$$\min \sum_{i \in N} \sum_{k \in K} \sum_{p \in P^k} \tau_{ip}^k x_{ip}^k + \sigma \sum_{i \in N} \sum_{j \in N} \gamma_{ij} z_{ij} \quad (1)$$

s.t.

$$\sum_{k \in K} \sum_{p \in P^k} x_{ip}^k \leq 1 \quad \forall i \in N \quad (2)$$

$$\sum_{i \in N} x_{ip}^k = 1 \quad \forall k \in K, p \in P^k \quad (3)$$

$$x_{ip}^k = 0 \quad \forall i \in T, k \in K, p \in P_E^k \quad (4)$$

$$x_{ip}^k = 0 \quad \forall i \in F, k \in K, p \in P_O^k \quad (5)$$

$$x_{ip}^k = 0 \quad \forall i \in N, k \in K, p \in P^k, c_i \neq c_p \quad (6)$$

$$\sum_{i \in N} w_i x_{ip}^k - \phi_{pq}^k \sum_{j \in N} w_j x_{jq}^k \geq 0 \quad \forall k \in K, p, q \in P^k \quad (7)$$

$$z_{ij} \geq x_{ip}^k + \sum_{\substack{q \in P^k \\ q > p}} x_{jq}^k - 1 \quad \forall i, j \in N, k \in K, p \in P^k, \gamma_{ij} = 1, p \neq n^k \quad (8)$$

$$x_{ip}^k \in \{0, 1\} \quad \forall i \in N, k \in K, p \in P^k \quad (9)$$

$$z_{ij} \in \{0, 1\} \quad \forall i, j \in N \quad (10)$$

In this model the objective function (1) consists of the containers' transportation time from the yard to the quay plus the time needed to perform possible yard shifts and represents the *variable* share of the total handling time. The latter includes also the containers' loading time which, as discussed in the Introduction, can be considered constant.

Constraints (2) and (3) are the classical assignment constraints (note that we are assuming  $n_C \geq n_p$ , which is a necessary condition for the model to be feasible), while variable settings (4) to (6) avoid to assign containers to incompatible positions. Decreasing weight of containers on the same stack is ensured by constraints (7). Finally constraints (8) define the  $z$  variables and count the yard shifts. As regards constraints (8), one could observe that they do not take into account possible shifts of containers belonging to the same yard stack but handled by different cranes. Nevertheless, although we do not consider these possible shifts, the value we get by the model is not so far from the optimal one. Actually, as previously disclosed, we are considering a *DTS* transshipment port. Since yard stacks are homogeneous with respect to the destination port and since the *crane split*, that is the allocation of quay cranes to the ship bays, is commonly done so that each crane handles whole groups of homogeneous containers, it is unusual that two

containers belonging to the same yard stack are handled by different cranes.

#### 4. A HEURISTIC ALGORITHM FOR THE SSPP

To get feasible solutions to the Ship Stowage Planning Problem, we devised a heuristic algorithm, based on two sequential phases: *Construction* and *Improvement*.

The first phase generates a starting feasible solution  $(\bar{x}, \bar{z})$ , while the second one attempts to improve this solution, exploring a suitable neighborhood system.

##### 4.1. The construction phase

Adopting the same notation introduced in the previous Section, a starting solution  $(\bar{x}, \bar{z})$  can be found as follows:

1. Let  $i$  be the heaviest container in  $N$ , breaking ties arbitrarily.
2. Examine the cranes and choose the first crane  $k \in K$  whose positions  $P^k$  have not been filled yet. If there exists  $p \in P^k$  such that  $c_p = c_i$ , set  $\bar{x}_{ip}^k = 1$ ,  $N = N \setminus \{i\}$ ,  $P^k = P^k \setminus \{p\}$  and update  $\bar{z}$ , if necessary.
3. If  $P^k = \emptyset \quad \forall k \in K$  STOP, otherwise GOTO 1.

This simple routine assigns containers to the first suitable position of the first available crane. Since we process containers in decreasing order of their weights and since we stop when in all available positions a container has been stowed, it yields a feasible solution.

##### 4.2. The Improvement phase.

To improve the starting solution  $(\bar{x}, \bar{z})$  we use a local search algorithm, which explores a neighborhood  $I(\bar{x}, \bar{z})$  of this solution. It is obtained performing swaps of container pairs either within the same crane sequence or between different sequences. We define these moves *swap* and *change*, respectively.

For each sequence  $P^k$ , the swap move takes two containers  $i$  and  $j$ , of the same type and class, currently assigned to positions  $p$  and  $q$ . If swapping positions of these containers does not violate weight constraints (7):

- $w_i x_{iq}^k - \phi_{qr} \sum_{l \in N} w_l x_{lr}^k \geq 0 \quad \forall r \in P^k$
- $w_j x_{jp}^k - \phi_{pr} \sum_{l \in N} w_l x_{lr}^k \geq 0 \quad \forall r \in P^k$

then assigning container  $i$  to position  $q$  and container  $j$  to position  $p$  leads to a new feasible solution.

The *change* rule, similar to the previous one, operates swaps of containers  $i$  and  $j$  belonging to the sequences  $P^k$  and  $P^h$ , respectively. In this case one has to check if

- $w_i x_{iq}^h - \phi_{qr} \sum_{l \in N} w_l x_{lr}^h \geq 0 \quad \forall r \in P^h$
- $w_j x_{jp}^k - \phi_{pr} \sum_{l \in N} w_l x_{lr}^k \geq 0 \quad \forall r \in P^k$

are satisfied.

## 5. PRELIMINARY RESULTS

To verify the correctness of the heuristic algorithm, we have generated three set of small test problems, whose characteristics are listed in Table 1.

Table 1 : Characteristics of the test instances

Set	$n_p = n_c$	Classes	$m$
I1	20	4	1
I2	20	4	2
I3	64	4	2

The transportation times of containers are uniformly distributed in the range  $[1, 2]$  minutes. Assuming an average speed of straddle carriers equal to  $4m/s$ , the above choice corresponds to consider distances between containers' positions and the quay in the range  $[240m, 480m]$ , which turns out to be realistic in a *DTS* terminal. As regards the configuration of the yard stacks, we have considered almost three containers on each stack. The number of stacks together with the distribution of their heights in the yard are summarized, for each test set, in Table 2.

Table 2 : Yard stacks heights

Set	Total	1	2	3
I1	8	1	2	5
I2	8	1	2	5
I3	24	0	8	16

The heuristic algorithm has been coded in Java and run on a *2GHz* PC equipped with *2GB* of RAM. Results of the runs has been compared with the value of the optimal solution computed by a commercial solver (LINGO 10). This first computational experience has shown that the proposed heuristic is attractive, since the larger gap with respect to the optimal solution is about 3.5% in the worst case.

Undoubtedly, to face with instances of realistic size, the search mechanism of our algorithm must be improved. At the present a Tabu Search algorithm, embedded in a Lagrangean Relaxation scheme, is under investigation, in order to obtain tight lower bounds and good feasible solutions.

## 6. CONCLUSIONS

In this paper we have discussed the Ship Stowage Planning Problem as it arises at a container terminal. Starting from the analysis of a case-study, the Gioia Tauro Container Terminal in the southern Italy, we have devised a Linear Integer Model for the problem.

In our opinion, the main contribution of this work is related to the particular and seemingly conflicting features of the model: it is very realistic, but surprisingly simple, compared to similar models in the literature. This nice characteristic is obtained by a rational use of the information available to the terminal planners.

The design of an efficient solution algorithm is the object of the current work.

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## REFERENCES

- Álvarez J., 2006. A heuristic for vessel planning in a reach stacker terminal. *Journal of Maritime Research*, 3, 3–16.
- Ambrosino D., Sciomachen A., Tanfani E., 2004. Stowing a containership: the master bay plan problem. *Transportation Research - A*, 38, 81–99.
- Ambrosino D., Sciomachen A., Tanfani E., 2006. A decomposition heuristics for the container ship stowage problem. *Journal of Heuristics*, 12, 211–233.
- Avriel M., Penn M., Shpirer N., Witteboon S., 1998. Stowage planning for containerships to reduce the number of shifts. *Annals of Operations Research*, 76,55–71.
- Dubrovsky O., Levitin G., Penn M., 2002. A genetic algorithm with a compact solution encoding for the container ship stowage problem. *Journal of Heuristics*,8, 585–599.
- Kim K.H., Kang J.S., Ryu K.R., 2004. A beam search algorithm for the load sequencing of outbound containers in port container terminals. *OR Spectrum*, 26, 93–116.
- Stahlbock R., Voss S., 2008. Operations research at container terminals: a literature update. *Operations Research Spectrum*, 30:1–52.
- Steenken D., Voss S., Stahlbock R., 2004. Container terminal operation and operations research - a classification and literature review. *Operations Research Spectrum*, 26, 3–49.
- Wilson I., Roach P., 1999. Principles of combinatorial optimization applied to container-ship stowage planning. *Journal of Heuristics*, 5, 403–418.
- Wilson I., Roach P., 2000. Container stowage planning: A methodology for generating computerised solutions. *Journal of the Operational Research Society*, 51, 1248–1255.
- Wilson I., Roach P.;Ware J., 2001. Container stowage pre-planning: using search to generate solutions, a case study. *Knowledge-Based Systems*, 14, 137–145.

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# ASSIGNMENT AND DEPLOYMENT OF QUAY CRANES AT A MARITIME CONTAINER TERMINAL

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## ABSTRACT

The complex logistic process of vessel berthing followed by container discharge/loading, at maritime container terminals (MCTs), is focused in this paper. Discrete-event simulation models are well capable of representing the entire process in a stochastic, dynamic environment. Hence, simulation results to be an effective planning and control tool for decision making and evaluation. The assignment of quay cranes to berthed vessels and their deployment along the berth represent crucial decisions that could be well supported by integer programming (IP) models. Usually, these models are used as standalone tools. Starting from a discrete-event simulator for the berth planning, previously developed for a real maritime container terminal, we propose two IP models that can be embodied within the simulator to verify whether or not the weekly plan of the berth schedule produced by the simulator itself is feasible with respect to the available quay cranes. If not, the manager would be asked to repeat the berth planning step by rerunning simulation. The goodness of the proposed IP formulations is established by a numerical comparison against a test case taken from literature.

Keywords: scheduling problem, quay cranes, maritime container terminals, discrete-event simulation,

## 1. INTRODUCTION

A maritime container terminal is a complex set of physical and human resources organized around a set of logistic processes. In a pure transshipment terminal, logistic processes are defined around the pure “store and forward” function of the terminal. This asks for the respect of high standards in the quality of service provided to shipping companies, otherwise, the terminal could lose some of these companies to competition. Thus the internal organization should be carefully optimized. Vice versa, in a different terminal devoted to an import/export function, possibly connected to a dry port (Roso 2007), the logistic operations and infrastructures for optimally supporting inland/outland transportation by different modal choices should also be

carefully considered (Parola and Schomachen 2005) to improve the reasons of competitiveness.

Here we focus on a real terminal of pure transshipment: the container terminal in Gioia Tauro, Italy, which is situated along the major maritime routes from the far-east port sources in Asia to the ports of Northern Europe and other western destinations. Our preliminary consideration when addressing the modelling efforts referred to this system, is that the major operational activities and resources should be managed by considering that they belong to multiple, interacting logistic processes (e.g. vessel arrival and vessel discharge/loading processes) where some limited resources should be adequately shared. This fact is critical for a cost-effective management of the system and the choice of the modelling approach for performance evaluation and system optimization. Terminal competitiveness can be improved by optimizing the internal organization through the introduction of decision support systems in resource allocation and scheduling of logistic resources and operations (Vis and de Koster 2003, Steenken et al. 2004), with the objective of decreasing the operating costs and service times.

Several papers focus on IP models for specific processes in port logistics (Park and Kim 2003, Ambrosino et al. 2004, Legato and Monaco 2004, Cordeau et al. 2005). Besides, other papers based on simulation, such as (Yun and Choi 1999, Legato and Mazza 2001, Bielli et al. 2006, Canonaco et al. 2008) point out the opportunity of evaluating starvation and congestion phenomena occurring at those major resources on which both the terminal productivity and response time strongly depend.

Recently, a simulator (Canonaco et al. 2007) has been developed and tuned for the container terminal located at the port of Gioia Tauro. The tool was mainly requested to perform a scenario analysis meant to highlight the possibility that the entrance channel to the port could become the terminal bottleneck, as the channel itself became progressively more shared by different flows of maritime traffic entering the port of Gioia Tauro. Currently, the same tool is being refined to support the formulation of the so called weekly plan under the programmed flow of containership arrivals,

provided that the statistical analysis of delays upon arrivals is continuously updated taking into account all the sources of uncertainty of the arrival process. In this context, the estimation of the vessel processing time (at berth) for discharge/loading operations is recognized as the second key point upon which the effectiveness of the whole planning process depends. The current release of the simulator asks the user to provide the so called “crane intensity”, i.e. the average number of cranes that work, simultaneously, on the same vessel, as it is fixed by formal agreement with the shipping company to which the same vessel belongs. Hence, a decisional problem arises for the cranes manager because he should dynamically deploy the right number of rail mounted quay cranes along the berth and assign these cranes to the vessels that succeed at the various berthing points, day by day, according to the weekly plan. The major constraints consist in respecting the vessels’ due-time of departure and shifting the cranes (on rail) along the quay-side. The objective to pursue is that of employing the minimum number of quay cranes, while maximizing crane productivity.

In the language of Operations Research the above decisional problem may be referred as *the quay crane deployment problem* (QCDP) (Legato et al. 2008). It is a complex assignment-scheduling problem that we tackle by two separated IP-based formulations. The first is focused on the assignment phase and produces the optimal number of cranes that must be assigned to each berthed vessel on the basis of a one-hour time-slot, under the guarantee that due-times of departure are respected. In the second IP formulation, the cumulative number of cranes returned by the first model is deployed over all the vessels previously berthed, each in their own position, in order to establish which cranes should service any given vessel on berth and minimize the number of crane shifts between adjacent vessels.

The paper is organized as follows. In the next section some necessary details on the logistic processes of interest are given. Afterwards, the focus is on the QCDP and on the mathematical models applied within the two-phase approach. Finally, some computational results are presented.

## 2. LOGISTICS AND DECISION PROBLEMS

The container terminal at the port of Gioia Tauro is a logistic platform of pure transshipment characterized by a relatively large roadstead where incoming container ships have to stop and wait for a pilot boat, before they are allowed to seize the entrance channel for some minutes (10 to 15) and reach their assigned berth position. Berthing positions are all sequenced on the unique available quay, which amounts to 3,300 meters and bears different levels of water depth. A significant number of rail-mounted gantry cranes (RMGCs) are available along the quay, to allow for a significant degree of parallelism under a high discharge/loading rate of service offered to berthed vessels. A fleet of several dozens of straddle carriers (SCs) are available to transfer containers between the berth and the yard and

pick-up/deliver containers from/to selected storage positions reached within a very regular layout based on “blocks”. Each yard block is divided into approximately 16 lines of 32 slots organized on 3 tiers, therefore the average block capacity is about 1500 TEUs.

Containership entrance at the terminal is planned on the basis of its expected time of arrival (ETA), but it depends on the following requirements: *i) formal conditions* (e.g., contractual agreements between the vessel’s shipping line and the port of call for the use of port facilities), that ask for a priority policy when managing the port entrance queue; *ii) operational settings* (i.e., pilot/tug availability, berth space assignment). If requirements are met, the vessel is maneuvered into its berth slot by one or two pilot tugs; otherwise it must wait in the roadstead. This is the arrival of the so-called vessel process. Vessels are of two types: mother vessels and feeders. The first one is a large container ship (whose capacity ranges between 3,000 and 14,000 TEUs) that covers transoceanic routes (hub-to-hub connections). Feeders are smaller ships that cover short and middle routes. They are widely used to connect the spokes to the transshipment hub (and vice versa).

Once a vessel is berthed, operations for container discharge/loading can be initiated only if mechanical (and human) resources are allocated; if not, the ship waits in its berth position until resource assignment takes place. Discharge/loading operations are performed by RMGCs placed along the berth: one or multiple cranes move containers between the ship and the quay area. The maximum number of quay cranes that may be assigned to each vessel is restricted by *i) the total number of cranes in the quay* and *ii) the maximum number of cranes allowed for each vessel*, due to physical (i.e. the length of the vessel) and logical constraints (i.e. interference between cranes). Considering the span of the cranes (approximately 30 m) and the horizontal space necessary to stack and transfer the incoming/outgoing containers of a vessel, the maximum number of cranes allowed for the longest vessel is usually 5 (this number is proportionally decreased for shorter vessels). When multiple cranes are assigned to the same ship, crane interference has to be avoided and a complex scheduling problem is required to manage the relationships (precedence and mutual exclusion) existing among the holds of the same vessel. Considering that the service rate of an RMGC is 28 TEUs/hour, the performance of the discharge/loading process highly depends on the availability of this type of crane and the related turnover speed. Therefore, the best deployment of these resources affects the overall completion time of each vessel.

### 2.1. The Quay Crane Deployment Problem

An IP formulation of the *quay crane deployment problem* together the *berth allocation problem* (BAP) has been successfully discussed by Park and Kim (op cit). In real life, the QCDP arises as follows.

The planning office of the terminal operating company constructs a weekly “berth schedule”, which contains the berthing position and time window for each incoming vessel (this being the solution to the so-called *berth scheduling problem*). A time window shows the expected time of berthing and un-berthing for a single vessel; time windows are constructed using the ETA (Expected Time of Arrival) and PTD (Promised Time of Departure) of each vessel (a penalty cost must be sustained if the departure of a vessel occurs later than its previously committed PTD). Figure 1 shows an example of a berth schedule, where the berth time and space are partitioned into 22 x 24 grid squares (24 one-hour time-slots).

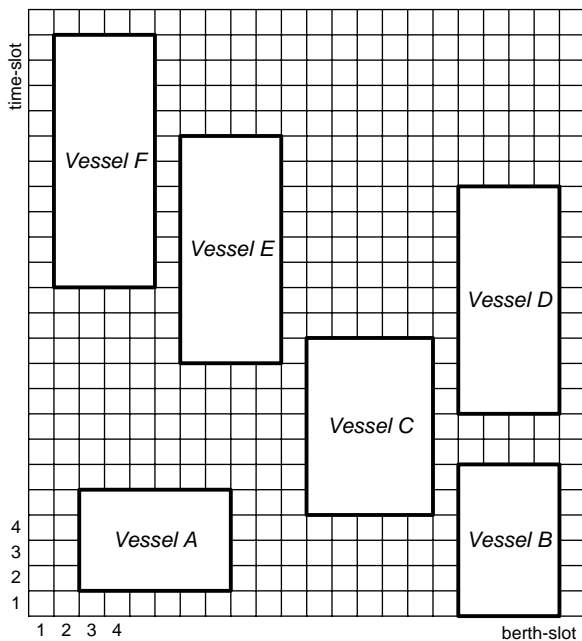


Figure 1: An Example of Berth Schedule Presented by Park and Kim

The berth schedule is used to assign the RMG quay cranes to the incoming vessels on a daily basis. The double goal is to *i*) minimize the number of quay cranes to be employed and *ii*) maximize their utilization, under the constraint of completing the discharge/loading operations, for each vessel, within the related expected time of un-berthing,

The QCDP is solved under the following assumptions.

1. Each vessel has a time window; the lower bound of the time window is the vessel’s expected time of berthing, while the upper bound is the vessel’s expected time of un-berthing.
2. Each vessel has a total number of TEUs to be handled within its time window: this number is related to the container discharge/loading moves required by the vessel.
3. Each vessel has a maximum and minimum number of cranes that can and must be

assigned when operations starts. The maximum number of cranes that can be simultaneously assigned to a vessel is limited by vessel length. Vice versa, the minimum number of cranes to be assigned (usually for mother vessels) depends on the contract terms between the terminal operating company and the vessel’s shipping company. By default, when operations start on a vessel, mostly all of the time-slots related to that vessel receive one crane.

4. Quay cranes are RMGCs, so non-crossing constraints must be guaranteed. Furthermore, cranes are never unavailable.

The solution approach we propose here to the QCDP follows a previous promising research study by Legato, Gulli and Trunfio (2008). It is decomposed into two phases, as shown in Figure 2.

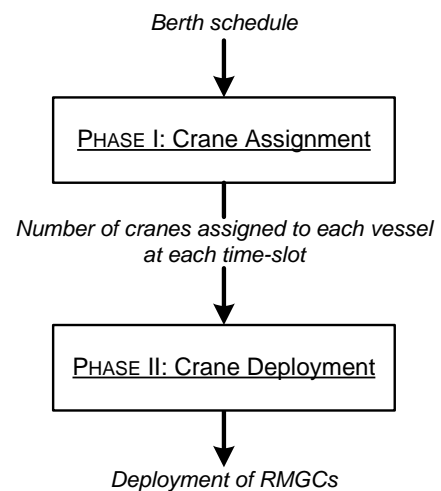


Figure 2: The Schema of the Two-Phase Approach to the QCDP

In the first phase (*crane assignment phase*), we solve an IP mathematical model using CPLEX (ILOG 1999) to identify the optimal number of cranes that must be assigned to each vessel at each time-slot. Thus, the model is able to identify exactly when the discharge/loading operations start and end within the vessel’s time-window. In literature, this problem is known as the *quay crane assignment problem* (QCAP) and it is usually studied together with the BAP as in (Meisel and Bierwirth 2006).

In the second phase, another IP model is used to deploy the cranes along the quay, with the aim of matching the previously identified vessel-crane assignment in order to *i*) respect the non-crossing constraints, and *ii*) minimize the number of crane shifts from one vessel to another.

With respect to the two phases, the first IP model is the well-known QCAP, while the second is called the *quay crane deployment problem*; nevertheless, one could give a mathematical model which combines both of the previous IP models and still refers to a QCDP.

## 2.2. IP Model for the Crane Assignment Phase

The following notations will be used for the formulation of the QCAP:

- $T$  : the set of time-slots, with  $|T| = N$
- $\Omega$  : the set of vessels
- $C$  : the set of quay cranes, with  $|C| = M$
- $s_c$  : the service rate for crane  $c$ , expressed in TEUs per time-slot
- $m_i$  : the number of moves for vessel  $i$
- $etb_i$  : the berthing time for vessel  $i$ , i.e. the time-slot starting from which vessel  $i$  is ready for the first lift, where:  

$$1 \leq etb_i \leq N - etu_i + 1$$
- $etu_i$  : the un-berthing time of vessel  $i$ ; thus it is the last time-slot during which vessel  $i$  is available for operations, where:  

$$etb_i \leq etu_i \leq N$$
- $min_i$  : the minimum number of cranes that must be assigned to vessel  $i$  when operation starts
- $max_i$  : the maximum number of cranes that can be assigned to vessel  $i$ .

We introduce the following decisional variables:

- $V$  : the maximum number of cranes used to performs vessel operations
- $\theta_{it}^c$  : 1, if crane  $c$  works on vessel  $i$  at time-slot  $t$ , 0 otherwise
- $\phi_{it}$  : 1, if vessel  $i$  is processed at time-slot  $t$ , 0 otherwise
- $\gamma_{it}$  : 1, if operations for vessel  $i$  start at time-slot  $t$ , 0 otherwise.
- $\eta_{it}$  : 1, if operations for vessel  $i$  have not been completed at time-slot  $t$ , 0 otherwise
- $\rho_{it}$  : is the difference between the number of cranes assigned at time-slot  $t$  and those assigned at the previous time-slot ( $t-1$ ).

The QCAP can be formulated as follows:

$$\min N \cdot V + \sum_{i \in \Omega} \sum_{t=etb_i}^{etu_i} \phi_{it} + \sum_{i \in \Omega} \sum_{t=etb_i+1}^{etu_i} |\rho_{it}| \quad (1)$$

s.to

$$\gamma_{it} \leq \gamma_{i(t+1)} \quad \forall i \in \Omega, t = etb_i, \dots, etu_i \quad (2)$$

$$\eta_{it} \geq \eta_{i(t+1)} \quad \forall i \in \Omega, t = etb_i, \dots, etu_i \quad (3)$$

$$\gamma_{it} + \eta_{it} = \phi_{it} + 1 \quad \forall i \in \Omega, t = etb_i, \dots, etu_i \quad (4)$$

$$\sum_{c \in C} \sum_{t=etb_i}^{etu_i-1} s_c \theta_{it}^c = m_i \quad \forall i \in \Omega \quad (5)$$

$$\sum_{c \in C} \sum_{t=1}^{etb_i-1} \theta_{it}^c = 0 \quad \forall i \in \Omega \quad (6)$$

$$\sum_{c \in C} \sum_{t=etb_i+1}^n \theta_{it}^c = 0 \quad \forall i \in \Omega \quad (7)$$

$$\sum_{i \in \Omega} \theta_{it}^c \leq 1 \quad \forall c \in C, t \in T \quad (8)$$

$$\sum_{c \in C} \theta_{it}^c \leq \max_i \phi_{it} \quad \forall i \in \Omega, t = etb_i, \dots, etu_i \quad (9)$$

$$\sum_{c \in C} \theta_{it}^c \geq \min_i \phi_{it} \quad \forall i \in \Omega, t = etb_i, \dots, etu_i \quad (10)$$

$$\sum_{c \in C} \theta_{it}^c - \sum_{c \in C} \theta_{i(t-1)}^c = \rho_{it} \quad \forall i \in \Omega, t = etb_i + 1, \dots, etu_i \quad (11)$$

$$\sum_{c \in C} \sum_{i \in \Omega} \theta_{it}^c \leq V \quad \forall t \in T \quad (12)$$

$$V \geq 0, \in \mathbb{N} \quad (13)$$

$$\rho_{it} \in \mathbb{N} \quad \forall i \in \Omega, t \in T \quad (14)$$

$$\theta_{it}^c \in \{0, 1\} \quad \forall i \in \Omega, t \in T, c \in C \quad (15)$$

$$\phi_{it}, \gamma_{it}, \eta_{it} \in \{0, 1\} \quad \forall i \in \Omega, t \in T \quad (16)$$

The objective function of the previous mathematical model aims to the minimization of *i*) the number of quay cranes employed in the planning horizon, *ii*) the overall number of time-slots required to perform vessel discharge/loading operations, and *iii*) the crane back and forth movements (implicitly accounted for by the  $|\rho|$  factor, to be linearized as usual). Clearly, function (1) appears as the sum of inhomogeneous terms and must be suitably adjusted for numerical experiments.

Constraints (2)-(4) ensure that for every vessel, once discharge/loading operations start, the operations must be performed without interruption until they are completed (the vessel operations cannot be preempted). Constraints (5) specify that for each vessel, the discharge/loading operations must be executed and completed within the vessel time-window. Constraints (6) and (7) ensure that no cranes can be assigned to a vessel before its  $etb$  and after its  $etu$ . Constraints (8) guarantee that every crane can be assigned to only one vessel at each time-slot. Constraints (9) and (10) ensure that the number of cranes assigned to a vessel during its operations time is between a *minimum* (i.e., due to contractual agreement) and a *maximum* (i.e., due to the vessel length). Constraints (11) evaluate the value of variables  $\rho_{it}$ . Constraints (12) guarantee that, for each time-slot  $t$ , the number of assigned cranes result not greater than the number of available cranes. Constraints (13)-(16) are the basic constraints on the decision variables.

The IP model defined above is a refinement of the QCAP developed by Legato, Gulli and Trunfio (op cit).

## 2.3. IP Model for the Crane Deployment Phase

As stated before, the solution of the QCAP provides the number of cranes that must be assigned in order to

complete the operations in time. This data is used in the following to deploy, for each time-slot, the RMG quay cranes. The deployment follows the criteria of non-crossing cranes and crane shifting reduction between vessels during different time-slots.

In the following we introduce the notations that will be used for the formulation of the quay crane deployment problem (QCDP):

- $T$  : the set of time-slots, with  $|T| = N$
- $\Omega$  : the set of vessels
- $C$  : the set of quay cranes, with  $|C| = M$
- $ac_t$  : the number of cranes assigned to the vessels berthed at time-slot  $t$
- $ac_{it}$  : the number of cranes assigned to vessel  $i$  at time-slot  $t$
- $cb_{it}$  : the number of cranes assigned to the vessels berthed at time-slot  $t$  before (from the left-side of the berth) vessel  $i$
- $ca_{it}$  : the number of cranes assigned to the vessels berthed at time-slot  $t$  after (from the left-side of the berth) vessel  $i$
- $w_i$  : the time-window of vessel  $i$ ; this time-window is computed from the first time-slot in which discharge/loading operations start to the time-slot in which operations end.

Moreover, the following decisional variables are introduced:

- $\phi_{it}^c$  : 1, if crane  $c$  is assigned to vessel  $i$  at time-slot  $t$ , 0 otherwise
- $\gamma_{it}^c$  : 1, if crane  $c$  is after (or is itself) the left-most crane assigned to vessel  $i$  at time-slot  $t$
- $\eta_{it}^c$  : 1, if crane  $c$  is before (or is itself) the right-most crane assigned to vessel  $i$  at time-slot  $t$
- $f_{it}$  : is the left-most crane assigned to vessel  $i$  at time-slot  $t$
- $l_{it}$  : is the right-most crane assigned to vessel  $i$  at time-slot  $t$
- $sf_i$  : it is the sum over time of all the left-most crane indexes of vessel  $i$
- $sl_i$  : it is the sum over time of all the right-most crane indexes of vessel  $i$ .

The QCDP can be formulated as follows:

$$\min \sum_{t \in T} \sum_{i \in \Omega} (M - ac_t) \cdot \left( \left| \frac{sf_i}{w_i} - f_{it} \right| + \left| \frac{sl_i}{w_i} - l_{it} \right| \right) \quad (17)$$

s.to

$$\sum_{c \in C} \phi_{it}^c = ac_{it} \quad \forall i \in \Omega, t \in T \quad (18)$$

$$\gamma_{it}^c \leq \gamma_{it}^{c+1} \quad \forall i \in \Omega, t \in T, c = 1, \dots, M-1 \quad (19)$$

$$\eta_{it}^c \geq \eta_{it}^{c+1} \quad \forall i \in \Omega, t \in T, c = 1, \dots, M-1 \quad (20)$$

$$\gamma_{it}^c + \eta_{it}^c = \phi_{it}^c + 1 \quad \forall i \in \Omega, t \in T, c \in C \quad (21)$$

$$\sum_{c \in C} \gamma_{it}^c \leq M - cb_{it} \quad \forall i \in \Omega, t \in T \quad (22)$$

$$\sum_{c \in C} \eta_{it}^c \leq M - ca_{it} \quad \forall i \in \Omega, t \in T \quad (23)$$

$$\sum_{c \in C} \gamma_{it}^c + f_{it} = M + 1 \quad \forall i \in \Omega, t \in T \quad (24)$$

$$\sum_{c \in C} \eta_{it}^c - l_{it} = 0 \quad \forall i \in \Omega, t \in T \quad (25)$$

$$\sum_{t \in T} f_{it} - sf_i = (M + 1) \cdot w_i \quad \forall i \in \Omega \quad (26)$$

$$\sum_{t \in T} l_{it} - sl_i = 0 \quad \forall i \in \Omega \quad (27)$$

$$\phi_{it}^c, \gamma_{it}^c, \eta_{it}^c \in \{0, 1\} \quad \forall i \in \Omega, t \in T, c \in C \quad (28)$$

$$f_{it}, l_{it}, sf_j, sl_j \geq 0, \in \mathbb{N} \quad \forall i \in \Omega, t \in T \quad (29)$$

In this IP mathematical model, we aim to identify the RMG quay cranes that must process the berthed vessels at each time-slot, with the goal of minimizing the number of cranes shifting from one vessel to another (i.e., if possible, the model tries to assign to each vessel always the same quay cranes,).

Constraints (18) specify that exactly the desired number of quay cranes is assigned to every vessel at each time-slot. Constraints (19)-(21) ensure that RMG quay cranes are assigned with respect to non-crossing constraints.

Constraints (22) force the assignment of quay cranes to vessel  $i$  at time-slot  $t$ , once the preceding vessels along the berth have received the expected amount of quay cranes. Likewise, constraints (23) ensure that crane assignment to vessel  $i$  at time-slot  $t$  is done coherently with the assignment of the considered cranes to the vessels that follows along the berth.

Constraints (24) identify the first crane from the left-side of the quay (i.e., the *left-most crane*) that must perform discharge/loading operations on vessel  $i$  at time-slot  $t$ ; otherwise, constraints (25) assign the last crane from the left-side of the quay (i.e., the *right-most crane*) that must perform discharge/loading operations on the same vessel and at the same time-slot. Likewise, constraints (26) and (27) extend constraints (24) and (25), respectively, over all the time-slots that constitute the vessel time-window.

Constraints (28)-(29) are the basic constraints on the decision variables.

### 3. NUMERICAL EXPERIMENTS

Numerical results obtained by the exact solution of the two IP formulations proposed in previous section are compared against the results reported by Park and Kim (2003).

In Figure 3 we repeat the optimal assignment reported in the paper by Park and Kim based on the berth schedule previously shown in Figure 1. For each vessel, ringed numbers depict the quay cranes assigned

to each vessel. As it is possible to see, the QCDP solved by Park and Kim makes use of 9 cranes to complete all the operations in time.

In this case study, the minimum number of cranes that must be assigned to the vessels during operations is one, while the maximum number of cranes that can be assigned to a specific vessel is equal to the number of occupied berth-slots (each corresponding to 50 meters).

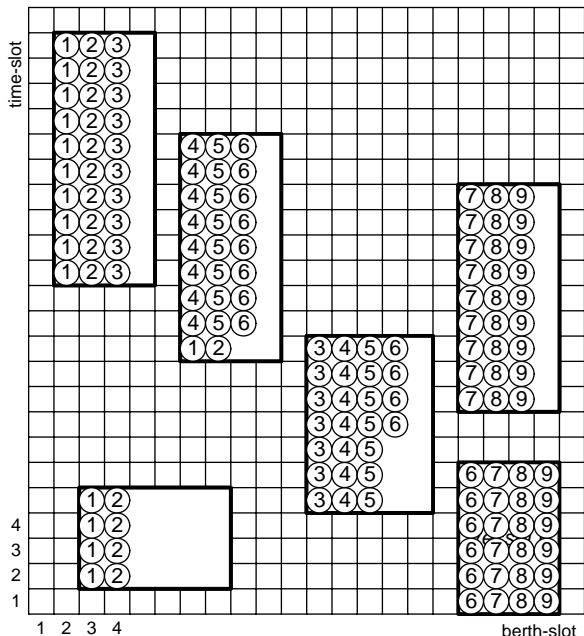


Figure 3: The Optimal Deployment Found by the Park and Kim Methodology

The first step of our approach produces the assignment depicted in Figure 4. In this berth schedule, the optimal value of  $ac_{it}$ , for each couple of vessel  $i$  and time-slot  $t$ , is reported within each corresponding rectangle.

As it is easy to recognize, our mathematical model fills-in a berth schedule while minimizing the overall number of cranes that must be used to process all of the vessels. In fact, the first phase of our approach produced an assignment of 7 quay cranes against the 9 quay cranes found by Park and Kim. Moreover, in our solution, once operations start, no operation discontinuity can occur for any vessel: this is a primary contractual agreement requested to the terminal operating company by shipping companies, along with the minimum number of cranes to be assigned and the respect of the bounds on operation completion time.

As a result of the second phase of our methodology, we propose the quay crane deployment shown in figure 5.

The improvement obtained with the approach proposed in this paper is not only due to the minimization of the activated cranes. In fact, in three cases *i*) we obtained a reduction of the vessel overall completion time and *ii*) we improved the average crane utilization (0.69 vs. 0.87).

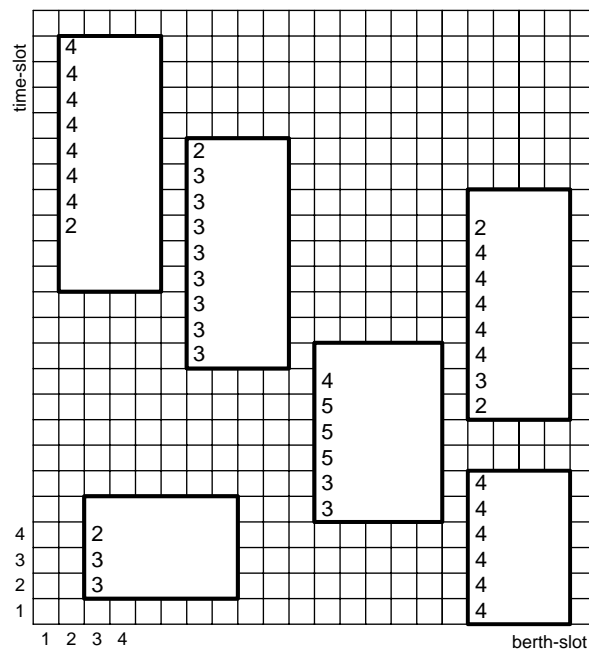


Figure 4: The First Phase Output of our Methodology

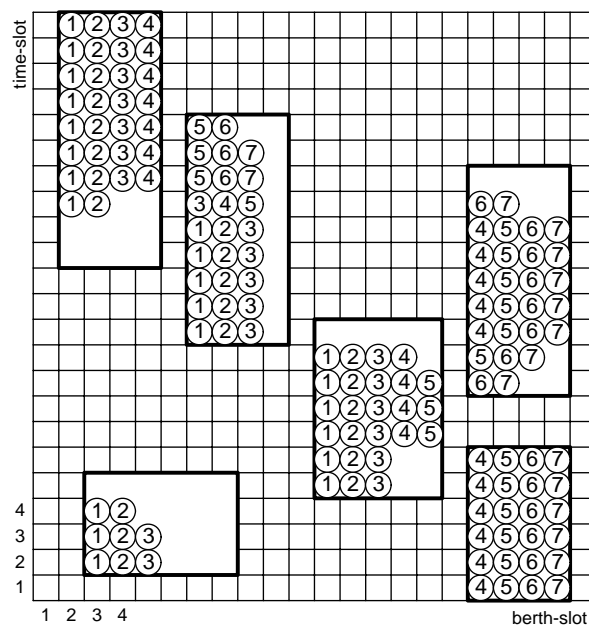


Figure 5: The Final Output by our Methodology

#### 4. CONCLUSION

We have reported on the possibility of improving the benefit of using a simulator when managing the logistic process of vessel berthing and discharge/loading at a maritime container terminal. Combining discrete-event simulation with integer programming models results in a very powerful tool, where the solution of assignment and scheduling problems plays a crucial role. We have proposed a practical solution to the problem of guaranteeing the respect of the planned time windows (berthing–unberthing) but also pursuing the objective of minimizing quay crane idle time. The novelty is that we avoid handling a unique, unmanageable formulation and, furthermore, that for practical applications in real life, we may use a berth schedule produced by a

simulator, i.e. in a more realistic modelling environment where operation delays and unpredictable events may occur. Thus we may integrate the IP models with their respective solution algorithms in a new release of the available discrete-event simulator to support run-time crane assignment using a berth schedule. A metaheuristics based approach will be clearly pursued to develop solution algorithms for real instances; this will also enable simulation based optimization features within the above discrete-event simulator.

## REFERENCES

- Ambrosino, D., Sciomachen, A., Tanfani, E., 2004. Stowing a containership: the master bay plan problem. *Transport Research part A*, 38, 81–99.
- Bielli, M., Boulmakoul, A., Rida, M., 2006. Object oriented model for container terminal distributed simulation. *European Journal of Operations Research*, 175, 1731–1751.
- Canonaco, P., Legato, P., Mazza, R.M., 2007. An Integrated Simulation Model for Channel Contention and Berth Management at a Maritime Container Terminal. In *Proceedings of the 21st European Conference on Modelling and Simulation*, 353-362. Prague, Czech Republic.
- Canonaco, P., Legato, P., Mazza, R.M., Musmanno, R., 2008. A queuing network model for management of berth crane operations. *Computers & Operations Research*, 35(8), 2432–2446.
- Cordeau, J.F., Laporte, G., Legato, P., Moccia, L., 2005. Models and tabu search heuristics for the berth allocation problem. *Transportation Science*, 39(4), 526–538.
- ILOG. 1999. CPLEX 6.5. Mountain View, CA.
- Legato, P., Mazza, R.M., 2001. Berth planning and resources optimisation at a container terminal via discrete event simulation. *European Journal of Operational Research*, 133, 537–547.
- Legato, P., Monaco, M.F., 2004. Human resources management at a marine container terminal. *European Journal of Operational Research*, 156(3), 769–181.
- Legato, P., Gullì, D., Trunfio, R., 2008. The quay crane deployment problem at a maritime container terminal. *Proceedings of the 22th European Conference on Modelling and Simulation*, 53-59, June 3-6. Nicosia (Cyprus).
- Meisel, F., Bierwirth, C., 2006. Integration of berth allocation and crane assignment to improve the resource utilization at a seaport container terminal. *Operations Research Proceedings 2005*, 105-110.
- Park, Y.-M., Kim, K.H., 2003. A scheduling method for berth and quay cranes. *OR Spectrum*, 25, 1–23.
- Parola, F., Sciomachen, A., 2005. Intermodal container flows in a port system network: analysis of possible growths via simulation models. *International Journal of Production Economics*, 97, 75–88.
- Roso, V., 2007. Emergence and significance of dry ports. *Proceedings of the World Conference on Transport Research* (CD-ROM). June 24-28, Berkeley (California, USA).
- Steenken, D., Voss, S., Stahlbock, R., 2004. Container terminal operation and operations research - a Classification and Literature Review. *OR Spectrum*, 26, 3–49.
- Yun, W.Y., Choi, Y.S., 1999. A simulation model for container-terminal operation analysis using an object-oriented approach. *International Journal of Production Economics*, 59, 221-230.
- Vis, I.F.A., De Koster, R., 2003. Transshipment of containers at a container terminal: An overview. *European Journal of Operational Research*, 147(1), 1–16.

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# RFID FOR AUTOMATING ACCOUNTING PROCESSES IN LOG CABIN CONSTRUCTION

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## ABSTRACT

RFID has the potential to significantly improve the accounting processes in log cabin construction, but before introduction a new technology to existing business processes it is necessary to analyse the risks and gains that are connected to it. A downside of RFID is the weak data protection capabilities that current solutions on the market offer; therefore a new accounting process model is provided that features non-standard security solutions.

Keywords: Radio Frequency Identification, RFID, Logistics, Data security, Log Cabins, Inventory.

## 1. INTRODUCTION

The accounting and management of log cabin building processes in Latvia is mostly handled manually. By reaching certain levels of building capacities the manual handling of material flow becomes too complex and time consuming. Especially as all materials (Logs) undergo multiple processing operations, which often is done by external companies. Thus there is the need for process automation to increase productivity and manageability of production.

It would be possible to use bar-codes for this purpose, but these have several limitations. Barcodes need to be scanned each separately which slows down the process of registering material movement. The fastest way would be to scan all logs simultaneously while moving through a gate. Another downside is that barcodes can not be rewritten which can be useful if data about each log needs to be changed because it has been processed and it is necessary to store data like measurements directly on the tag for quick access.

RFID is a promising technology that allows organizing accounting and material flow tracking in a fast and effective way, but it is necessary to determine if an RFID system is feasible in terms of economics and process organization.

Several companies like *Cambium-Forstbetriebe*, (Germany) are already using RFID for controlling timber freight movement which has allowed minimizing theft and material losses by up to 90% (Progress software 2007). In the U.S. RFID has found other application. It is

used to fight smuggling of wood legally cut materials are marked with RFID tags so they can be uniquely identified, thus it is made difficult for smugglers to sell illegally cut materials as certified (Cooper 2007).

## 2. BUILDING LOG CABINS

The log cabin building process is similar in almost all companies. Generally there are four steps (See Figure 1): (i) acquiring materials, logs can be bought or cut by the company itself; (ii) processing of materials, before using logs for construction they have to be dried and shaved (often these are outsourced processes); (iii) assembling of the log cabin, the house is pre-built so the joints of the logs can be shaped to match each other; (iv) building at customers site, finally all the necessary materials are transported to the customers site and the log cabin is built. Logs with different lengths and widths are necessary for the building of log cabins, so it is necessary to have up-to-date information about the inventory. For this it is necessary to track (i) what materials have been acquired and what processing do they need (drying, shaving); (ii) what materials are being processed and when will they be ready; (iii) and of course what materials have been used for construction, for knowing what materials are left in the inventory and how economically have materials been used in construction.

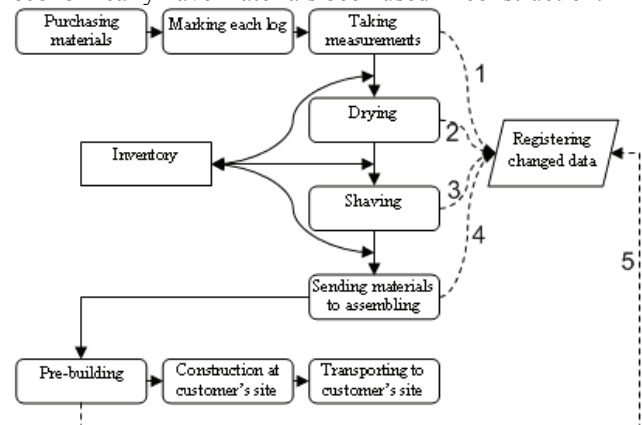


Figure 1: Log cabin building process

Depending on the predicted requirement for log cabins a truck load of materials is ordered after variable period of time. When acquired, logs usually are marked either by writing a number directly on the log or by attaching a plastic number tag, thus at every processing stage of logs their numbers are written down and subsequently entered in the accounting software. This process is time consuming and often it is difficult to supply up-to-date inventory information. The introduction of an RFID based material tracking system can reduce time required for data entry and processing up to 20 times at each material processing step. Data about material processing and flow has to be entered at multiple points marked with numbers 1 through 5 in the log cabin building process diagram (See Figure 1). If RFID would be used for marking the logs, then the information gathering at every next material processing step could be partly or completely automated. When taking log measurements (step marked 1), RFID can be used to store a logs measurements or to associate a log with its measurements stored into a database. This way it is possible to quickly access inventory state data. In combination with electronic measuring instruments the time necessary for this process can be reduced to a minimum and the accuracy of measurements increased.

### 3. DATA SECURITY ISSUES AND SOLUTIONS

The wireless communication abilities of RFID devices not only introduce benefits in process improvement, but also potential data misuse. As with RFID data is communicated over the air anyone can listen to the communications or unnoticed read and write data to RFID tags, thus it is important to use secure communication channels, to prevent unauthorized persons to gain access to data.

There are several malicious purposes, for what RFID can be misused: (i) *Unauthorized data altering* – the identification number of a tag is typically read-only data, but if other information like log measures are written on tags, then someone might alter it to gain financial benefit; (ii) *Counterfeit* – The U.S. example mentioned previously shows that even construction materials like wood are being counterfeited; (iii) *Sabotage*; (iv) *Competitive intelligence*. Other goals like person tracing and profiling, identity theft and financial fraud are possible to achieve using RFID, but these are not likely to occur in the case of log cabin inventory management (Porniaks, Ginters and Neumann 2007).

To protect an RFID system from these attacks it is necessary to ensure that only authorized persons have controlled access to the RFID tags. In current solutions on the market this issue is weakly supported, but several

scientists have offered their data security solutions. In the following a list of criteria (**K**) is described that allows comparing these solutions. For the eligibility to criteria a solution can receive up to five points, depending on how well this solution satisfies the requirements. And for each criterion a weight (**W**) is assigned that shows how important it is to satisfy this criteria for the use in logistics. Thus a protocol can achieve a score (**S**) of maximum 100 points, that are calculated as follows:

$$S = \sum_{i=1}^6 K_i \times W_i$$

The criteria taken in to account are: (i) *Tag cost* is an essential factor in the decision to use this technology or not, as it can have significant influence on the overall costs of business processes. If a protocol requires less on-tag resources the tag can be produced cheaper, therefore this criteria receives the weight=5; (ii) *Usability* receives w=3, because it is important to create an simple and cheap to setup RFID system, that can be easily aligned to required business processes, but this must only be done once; (iii) *Data protection* has w=2, as sensitive data rarely have to be stored on the tag itself, typically such data is stored in centralized databases, that are easier to control and protect. In this case the tag is only used to hold reference data; (iv) *Anti-counterfeit* receives w=5, because one must be able to correctly identify the producer of the material/product so the supplier is ensured that counterfeiters are not able illegally benefit from his effort in building customer relations or to damage his reputation with low quality goods. But the recipient can be sure to receive the expected quality and services; (v) *Privacy* is required to prohibit unauthorised analysis material movement. This feature is more important for tags identifying end-user products, but also businesses are not protected from privacy attacks, so it receives w=4; (vi) *Additional features* that protect data security are welcome, but not essentially important in the decision to use this protocol or not, therefore w=1.

The solution overview diagram (see Figure 2) displays the total performance of each protocol and the performance in each of the selected areas. The protocols are displayed as follows: 1-LMAP (Peris-Lopez 2006), 2-Supply Chain (Li and Ding 2007), 3-Tree Search (Molnar 2005), 4-PUF (Batina, Guajardo, Kerins, Mentens, Tuyls and Verbauwhede 2007), 5-ECC (Batina, Guajardo, Kerins, Mentens, Tuyls and Verbauwhede 2007), 6-AES (Aigner and Feldhofer 2005), 7-OHLCAP (Choi, Lee and Lee D.H., 2005), 8-TI PKI (Pearson 2006) and 9-Distance Bound (Reid 2007). For reference a column (Max) with the maximum possible scores in each area is added.

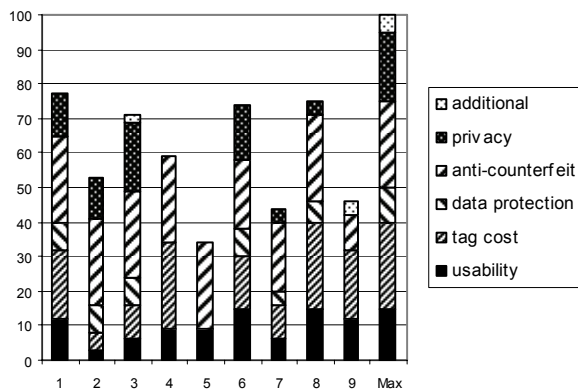


Figure 2: Solution performance overview diagram

The most promising protocol appears to be LMAP that requires quite low amounts of resources and offers protection against most attacks. It uses few simple binary calculation operations for cryptographic needs, but requires more space for the storage of secrets than most other protocols, but this solution also requires permanent online access to the database which is difficult or expensive to support in log cabin building processes, thus a solution with offline working capabilities like AES might be more feasible.

#### 4. SIMULATION FOR EFFICIENCY

The LMAP protocol requires always an online connection with the database, this also means that the data gathered, with RFID devices is always up-to-date, but more initial investment is required to connect remote locations and the necessary RFID devices to the companies internal network. In some cases it is very difficult to supply a permanent and stable internet connection to guarantee the necessary data flow.

On the contrary the AES protocol is less secure, but allows working with the RFID devices, while not having a connection to the database, unfortunately this way data is sent to the database with a delay typically this would be on the end of the shift, when the responsible employee would setup a connection to the database and transfer new data to the database in a batch. In this case data that is required for planning further processes arrives hours later than with the LMAP protocol. Therefore it is necessary to understand how much the delay in data flow influences the production process.

To clarify which solution is better suited for the log cabin accounting processes two EXTEND models are created where one covering the LMAP solution, but the second – AES. And with both models simulations with identical input data are performed so that the efficiency of each security solution and data processing model can be compared.

The initial data can be divided in 3 groups. First of all the incoming material flow is determined by material purchase. In the current case the materials are supplied by two partners with each in average delivering one truck load every month. The dimensions and moisture of logs

differs slightly in each load. The material processing time generally depends on the quantity of materials and the time needed to process one unit, which varies little. And finally the incoming orders for building new log cabins and availability of workers and working area determines the material usage in the current case up to 3 log cabins houses can be built simultaneously.

After each material processing step, data about the state of the materials is gathered (See Figure 3).

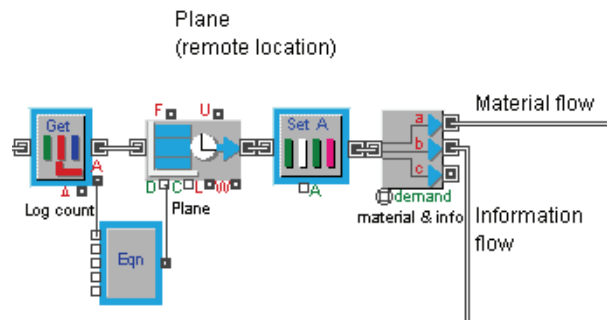


Figure 3: Information and material flow

And the use of the two different RFID protocols is simulated. In case of LMAP data like, the inventory state, is updated as soon as the information is available, but with AES information is updated with delay, at the end of shift (See Figure 4).

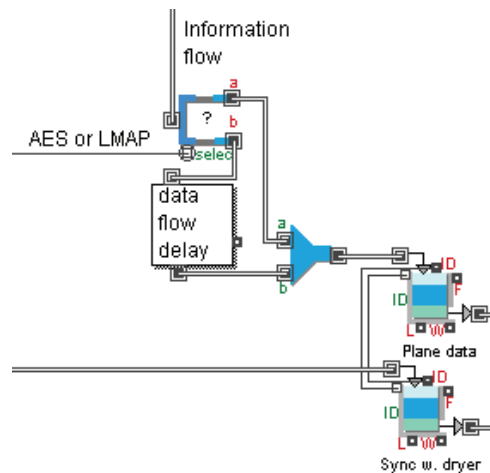


Figure 4: Information flow and synchronisation

The models have been verified and validated in a workshop together with industry experts. The models structure complies with the existing business processes. Process execution time corresponds to the measured real-world values. Statistical validation of the models has been conducted, by comparing the simulation results with mathematically calculated results. Data sets were evaluated using Kolmogorov-Smirnov test.

The analysis of both models shows that the LMAP solution overall would be more effective in data gathering and more secure, but it requires more initial investments to ensure uninterrupted reader connection to the database which becomes even more difficult when remote data gathering locations must be considered. Differences of both protocols do not show much influence on the

process in the current case, but it would be important where data is more often generated and processed.

## 5. CONCLUSIONS

While prices for RFID devices are falling the RFID technology becomes a more important part of logistics and supply chain. However the use of a wireless solution causes data security problems, but the solving of these must not reduce the usage efficiency of RFID systems. The proposed two level evaluations of information security techniques is a useful approach not only for log cabin builders, but as well for other RFID technology users.

When selecting a passive RFID communication protocol it's security capabilities, time the protocols requires for processing data and the cost of implementation and maintenance must be considered. The first evaluation level allows selecting an appropriate protocol for the necessary information security level taking in account also the cost of tags, but the second level (modeling) shows the influence of a protocol on business processes and data processing speed. With this information the feasibility of implementing a passive RFID system can be calculated.

## REFERENCES

- Aigner M., Feldhofer M., 2005, *Secure Symmetric Authentication for RFID Tags*, <http://tmc.tugraz.at/tmc2005/PDF/20050228-IAIK-SecureAuthentication.pdf>, [accessed 2007.09.11]
- Batina L., Guajardo J., Kerins T., Mentens N., Tuyls P., Verbauwhede I., 2007, *Public-Key Cryptography for RFID-Tags*, PerCom Workshops, IEEE Computer Society, pages 217-222
- Choi E. Y., Lee S.M., Lee D.H., 2005, *Efficient RFID Authentication protocol for Ubiquitous Computing Environment*, <http://protocol.korea.ac.kr/~dhlee/papers/Efficient%20RFID%20Authentication%20protocol.pdf>, [accessed 2007.09.11]
- Cooper S., 2007, *Global Timber Smugglers-and How You Can Stop Them*, <http://www.popularmechanics.com/science/earth/4215504.html>, [accessed 2007.12.03]
- Li Y., Ding X., 2007, Protecting RFID communications in supply chains, ASIACCS, ACM, pages 234-241
- Molnar D. et.al., 2005, *A Scalable, Delegatable Pseudonym Protocol Enabling Ownership Transfer of RFID Tags*, Selected Areas in Cryptography, Springer, pages 276-290
- Pearson J., 2006, *RFID Tag Data Security Infrastructure: A Common Ground Approach for Pharmaceutical Supply Chain Safety*, <http://whitepapers.zdnet.co.uk/0,1000000651,260270952p,00.htm>, [accessed 2007.08.16]
- Peris-Lopez P. et.al., 2006, *LMAP: A Real Lightweight Mutual Authentication Protocol for Low-cost RFID tags*, <http://events.iaik.tugraz.at/RFIDSec06/Program/papers/013%20-%20Lightweight%20Mutual%20Authentication.pdf>, [accessed 25.11.2007]
- Porniaks V., Ginters E., Neumann G., 2007, *RFID usage and data security*, ICTE in Regional Development, ISBN 9984-633-10-1.
- Progress software, 2007, *Cambium-Forstbetriebe*, <http://www.progress.com/openedge/customers/manufacturing/cambium/index.ssp>, 2007.11.24
- Reid J. et.al., 2007, *Detecting relay attacks with timing-based protocols*, ASIACCS, ACM, pages 204-213
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# INVESTIGATION OF ACCIDENT AND NOISE INTENSITY ON LATVIAN ROADS USING SCAN STATISTICS

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## ABSTRACT

In most cases the possibility of traditional statistical conceptions and methods for investigation of real socio-economic objects is limited. Traditional statistical methods are more appropriate for investigation of impact due to internal factors. Scan statistics allows investigating the socio-economic problems having extremely complex, i.e. synergic structure of interrelations (structure of the open systems). The analytical description of such systems enables to consider the likelihood scenarios of development of objects under investigation in a simplified way, but very seldom of objects on the whole. The use of scan statistics enables to understand and analyse the reasons of the clusters of accident and noise intensity in some specific areas of Latvia.

Keywords: modelling, scan statistics, clustering, black spots, intensity of noise, road system management

## 1. INTRODUCTION

With the increasing road transport vehicle saturation on highways the role of road transportation network monitoring becomes more and more significant. Taking into consideration that Latvia is a transit country with a heavy road traffic, reduction of noise level on the highways of Latvia and control of the physical condition of roads has become the most urgent problems. For several years measurements of noise level intensity on roads have been made and maps of highway noise spreading near densely populated areas are compiled. Although full information of road accidents and high noise intensity level on highways is not yet amassed, in some cases it has already become possible to highlight some clusters of road accidents and noise intensity. Gathering of information and its intermediate processing will contribute to identification of clusters, so that prompt decisions could be taken. Statistical modelling is used to state the clusters of accidents and level of noise intensity on the roads of Latvia. Alongside with the Monte-Carlo method when calculating the p-value, it is possible to use the direct method of scan modelling, taking into consideration the empirical rules of distribution of road accidents on the highways of Latvia. In this case both parametric and non-parametric methods may be used to describe the

distribution of road accidents and noise intensity in Latvia. The research data may be used for developing an efficient strategy of road system management in Latvia leading to reduction of the number of road accidents and noise intensity in Latvia.

## 2. METHODOLOGY OF SCAN STATISTICS

In each area  $Z$ , we assume that the data  $X$  about accidents or noises have a distribution function DF (to be distributed under null hypothesis  $H_0$ ) i.e.:

$$X \sim DF. \quad (1)$$

We also compute the maximum of  $L_1$ , which is the same function with parameters unrestricted. Each zone  $Z$  has different parameters, given the heterogeneous accident distribution. We want to find the zone which maximizes the LR (likelihood ratio) between likelihoods  $L_1$  and  $L_0$ :

$$LR(Z) = \left( \frac{L_1}{L_0} \right)_Z. \quad (2)$$

In the case of Poisson distribution process, the likelihood ratio takes the following form:

$$LF_i = \left( \frac{\left( \frac{c_{in}}{n_{in}} \right)^{c_{in}} \left( \frac{c_{out}}{n_{out}} \right)^{c_{out}}}{\left( \frac{c_{tot}}{n_{tot}} \right)^{c_{tot}}} \right) \cdot I, \quad (3)$$

where:

- $c$  - counts;
- $n$  - expected number of cases;
- $n_{in}$  and  $n_{out}$  - within or outside the scanning window;
- $I$  - indicator function.

The scan statistics  $LR_{st}$  is defined as:

$$LR_{st} = \max_Z LR(Z). \quad (4)$$

### 2.1. Null Hypothesis Significance Testing

For each potential cluster, we generate  $N$  datasets ( $N > 1000$ ) using the parameters  $\lambda_0$  estimated for that zone  $Z$ , and we obtain a distribution for LR.

Later the distribution LR is used for identifying the statistical value of the cluster detected. The scheme for identifying a significant cluster using the Monte-Carlo method is presented in Figure 1.

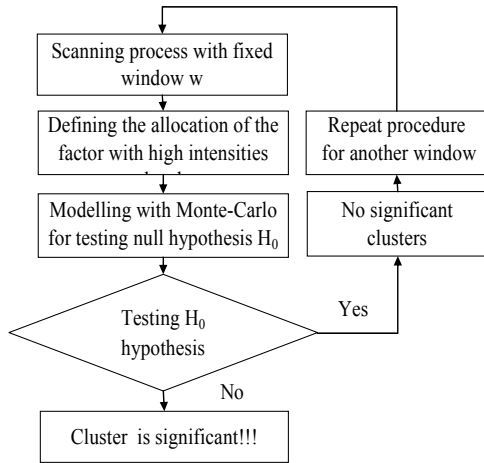


Figure 1: Algorithm of defining a significant cluster

For each potential cluster, we generate  $N$  datasets (at least 1000) using the parameters  $\lambda_0$  estimated for that zone, and we obtain a distribution for LR (see Figure 2):

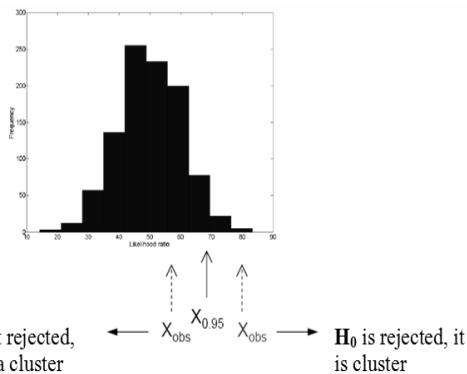


Figure 2: Histogram for ratio test statistic

The algorithm developed enables to detect the statistically significant clusters of the phenomena under investigation.

Let us have  $N$  accidents, distributed at road interval  $(0, L)$ . Denote  $S_w$  as maximal number of events at a road interval with length  $w$  (the window of fixed length  $w$ ). The maximum cluster  $S_w$  is called the scan statistics from the viewpoint that one scans interval  $(0, L)$  with a window of size  $w$  and observes a large number of points.  $W_k$  is the shortest interval of road containing a fixed number of  $k$  events. The interval  $W_{r+1}$  is called the minimum  $r^{\text{th}}$  order gap, or  $r$ -scan statistics. The

distributions of the statistics  $S_w$  and  $W_k$  are related. If the shortest window that contains  $k$  points is longer than  $w$ , then there is no window of length  $w$  that contains  $k$  or more points:

$$P(W_k > w) = P(S_w < k). \quad (5)$$

It is easy to understand that there is an infinite number of sliding windows during the road interval. To solve this problem in a constructive way we must assume some finite set of sliding windows (Figure 3).

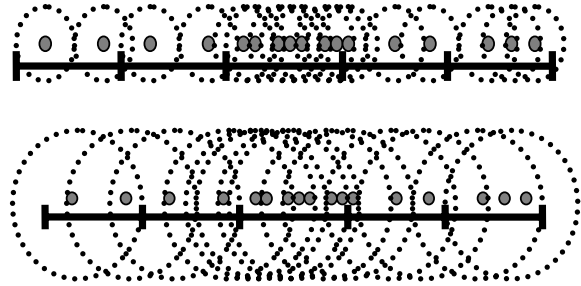


Figure 3: Illustration of the scanning window of two fixed lengths  $w=0.1$  and  $w=0.2$ . The centres of scanning windows are points with road coordinates  $L_1, L_2, \dots, L_N$

The Poisson process has been used for modelling real systems dealing with the occurrence of events in time or space. First useful applications of spatial scan statistics are shown in “A spatial scan statistics. Communications in Statistics. Theory and Methods” (Kulldorff, M. 1997).

Spatial scan statistics is a powerful method for spatial cluster detection. With spatial scan statistics it is possible to search over a given set of spatial regions, find those regions which are most likely to be clusters and correctly adjust for multiple hypothesis testing. Figure 4 illustrates a suspicion cluster – region in  $S$  with a high level of intensity  $q_{in} = 0.02$  of accidents. Scan statistics gives answer to the question – is this cluster real or is it a “visual illusion”?

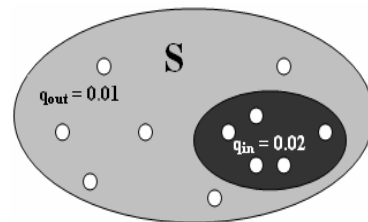


Figure 4: Frequency model of cluster - critical region

The simplest frequency model for this situation (Figure 4) can be written as:

Null hypothesis  $H_0$  (no clusters)  $q_{in} = q_{all}$  everywhere (use maximum likelihood estimate of  $q_{all}$ );  
 Alternative hypothesis  $H_1$  (cluster in region  $S$ ),  $q_{in} = q_{out}$  elsewhere (use maximum likelihood estimates of  $q_{in}$  and  $q_{out}$ , subject to  $q_{in} > q_{out}$ ).

This algorithm can be used for scanning accidents on the territorial unit of Latvia (Figure 5).



Figure 5: Illustration of the scanning process of accidents on roads of Latvia (small territorial fragment)

Preliminary results of investigating accidents on the roads of Latvia show the following specific features of their distribution:

- lack of traffic saturation in rural areas does not allow to correctly identify clusters of road accidents in these regions;
- significant clusters occur in big cities of Latvia showing possibilities of improving road management system in Latvia (see Figure 6).

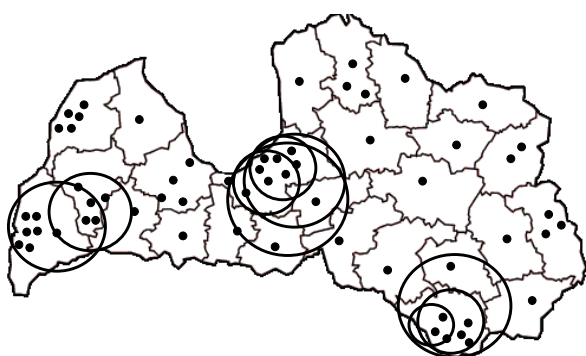


Figure 6: Two dimensional scan statistics with different circle windows

### 3. NOISE MAPS

Recent years have seen an increasing need to determine the noise from road traffic. This is often necessary, for example, when are implementing traffic and environmental action plans, when planning new housing

estates and roads, and when residents complain about noise. Data on noise in urban environment may be obtained through a direct measurement or by means of model calculations. Both the methods (modelling and noise measurement) have their advantages and drawbacks. The measurement provides more accurate data and reflects the real noise level from all sources of noise at the locality monitored. Performance of the measurement over a larger area is, however, very financially demanding because it requires a great deal of resources to take qualified noise measurements. The uncertainty involved in measurement is roughly the same as with modelling. If noise modelling is performed, on the other hand, the noise in any given situation can be determined relatively quickly. Furthermore, the modelling method is particularly applicable in planning situations, where the noise cannot yet be measured. This is why modelling is generally used to determine the noise. The noise modelling is limited not just due to the modelling method employed, yet most of all by availability of input data. On the other hand, it enables making of qualified assessments of expected impacts of planned development and transport measures.

The most important source of excessive noise affecting the largest portion of the city population is road traffic, because number of automobiles and transported volumes in Latvia has been rapidly increasing.

The example of benchmarking process for noise level investigation in Latvia is presented in the paper (as example of "best practice" has been used the investigation and measurement of noise level in the Czech Republic).

Information on noise levels on the Prague's territory has been generated at various occasions. Number of occasional measurements and assessments are implemented in the relation to the investments and development of environmental studies. Since 1984 in Prague have been regular measurements performed at selected localities within the IOŽIP system (Prague Environmental Information System). Noise level measurement is also performed by the Public Health Authority of the City of Prague within the National programme "Monitoring of the Public Health Related Environmental Aspects".

Illustration of results of measurement of noise on roads of some Prague's district is presented in Figure 7.

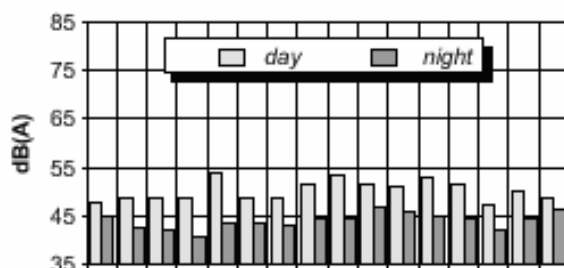


Figure 7: Illustration of results of measurement of noise on roads of some Prague's district

The objective of benchmarking is to understand and evaluate the current position of a business or organisation in relation to "best practice" and to identify areas and means of performance improvement. Any business process can be benchmarked. Benchmarking is a tool to help you improve your business process and begin comparing the results in an "apples-to-apples" format, to determine the gap between your object (process) and the best-in-class examples and to implement programs and actions for achieving needed result. Application of benchmarking in investigation process involves four key steps:

1. understand in detail existing business processes;
2. analyse the business processes of others;
3. compare own business performance with that of others analysed;
4. implement the steps necessary to close the performance gap.

Benchmarking module scheme is presented in Figure 8.

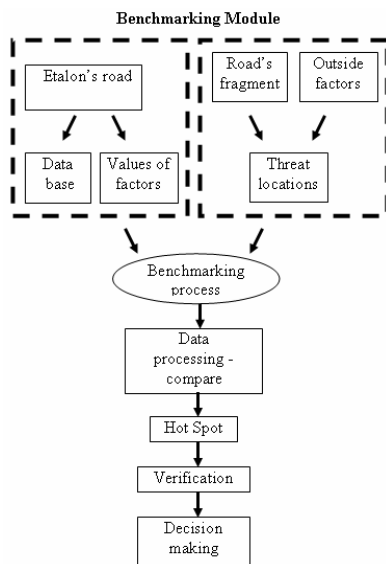


Figure 8: Benchmarking Module

Benchmarking should not be considered a one-off exercise. To be effective, it must become an ongoing, integral part of an ongoing improvement process with the goal of keeping abreast of ever-improving best practice. Detailed algorithm of realization of benchmarking process presented in Figure 9.

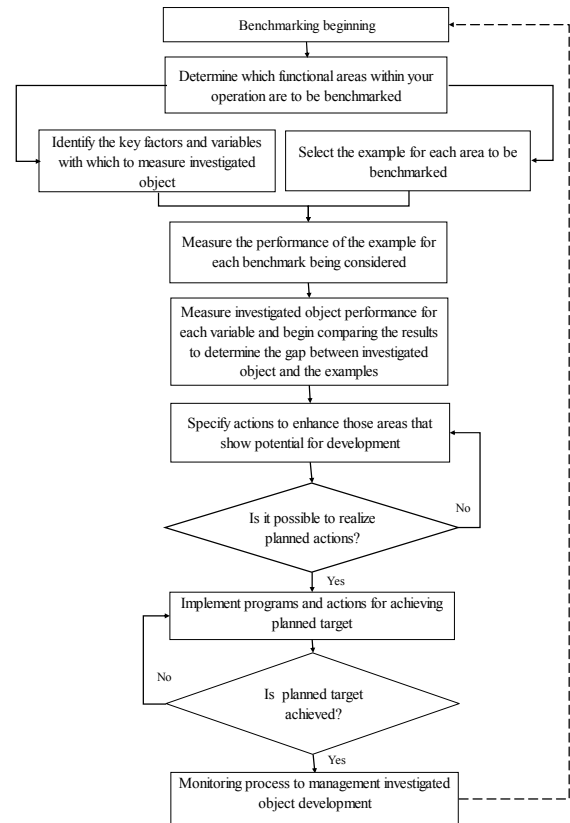


Figure 9: Algorithm of realization of benchmarking process

Accordingly with Directive 2002/49/ec of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise the level of noise is divided by 7 sublevels (intervals):

- Level 1. – 15 dB;
- Level 2. – 35 dB;
- Level 3. – 60 dB;
- Level 4. – 75 dB;
- Level 5. – 85 dB;
- Level 6. – 115 dB;
- Level 7. – 125 dB.

Illustration of results of measurement of noise on roads of Latvia is shown in Figure 10.

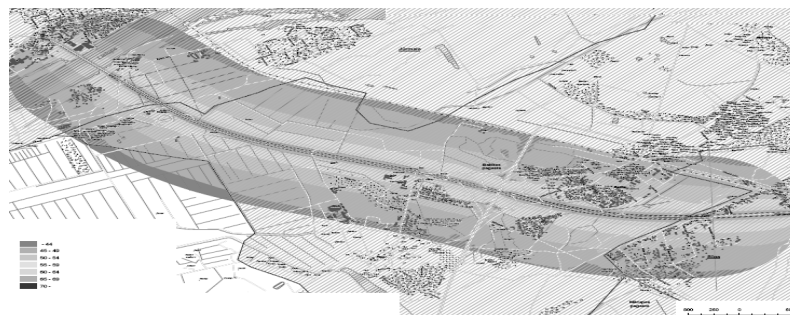


Figure 10: Illustration of results of measurement of noise on roads of Latvia (small territorial fragment)



#### 4. CONCLUSION

The use of scan statistics enabled:

- to make analysis of road accidents and intensity of noise in towns and regions of Latvia;
- to detect clusters with utmost intensity of road accidents applying scan windows of different sizes;
- to detect clusters with utmost noise intensity applying scan windows of different sizes;
- to check significance of clusters detected with highest frequency of road accidents on the basis of null hypothesis equal to value of 0.05;
- to analyse the dynamics of changes of clusters detected taking into consideration the time factor.

Detection of significant clusters of road accidents or level of noise intensity on the roads of Latvia enables to take prompt actions for improving the quality of road infrastructure.

#### REFERENCES

- Berman, M. and Eagleson, G. K. Dec., 1985. A Useful Upper Bound for the Tail Probabilities of the Scan Statistics. *Journal of the American Statistical Association*, Vol. 80, No. 392, doi: 10.2307/2288548, 886-889.
- Directive 2002/49/ec of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. <http://eur-lex.europa.eu/LexUriServ/>
- Glaz, J.; Naus, J. and Wallenstein, S. 2001. Scan Statistics. *Springer Series in Statistics*, 367-370.
- Jurenoks, V., Jansons, V., Didenko, K., Modelling of financial stability in logistics in conditions of uncertainty. *21-st European Conference on Modelling and Simulation*, Prague, Czech Republic, June 4 – 6, 2007.
- Jurenoks, V., Jansons, V., Didenko, K., Modelling of multidimensional flows in logistics using nonparametric method. *International Mediterranean Modelling Multiconference*, Bergeggi, Italy, October 4 – 6, 2007.
- Kulldorff, M. 1997. A spatial scan statistics. *Communications in Statistics. Theory and Methods*, Volume 26, Issue 6, 1481 – 1496.
- Road traffic accidents. <http://www.csb.gov.lv/csp/>
- Tuia, D., Kaiser, C., Da Cunha, A., Kanevski, M. 2007. Socio-economic cluster detection with spatial scan statistics. *Case study: services at intra-urban scale. Geocomputation*, National University of Ireland, Maynooth, 3-5 September 2007.
- Wallenstein S. and Naus J. 2003. Statistics for temporal surveillance of bioterrorism. *Syndrome Surveillance: Reports from a National Conference, Morbidity and Mortality Weekly Report*. 2004; 53, 74-78.
- Wallenstein, S. 2005. Scan Statistics. <http://c3.biomath.mssm.edu/wscan.html>
- Ward, M.P. and Carpenter, T.E. 2003. Methods for Determining Temporal Clusters in Surveillance and Survey Programs. *Animal disease Surveillance and Survey Systems. Methods and Applications*. Ed. Salman, M.D. Iowa State Press, Ames Iowa, 87-99.
- Yearbook Prague Environment 2006 - B5.2 Road Traffic Noise. [http://envis.prahamesto.cz/rocenky/pr06\\_hm/ab5\\_02.htm](http://envis.prahamesto.cz/rocenky/pr06_hm/ab5_02.htm).

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# NONLINEAR MODELS FOR CRUDE OIL SCHEDULING ON PORTS

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## ABSTRACT

In this paper we present a continuous nonlinear programming approach to crude oil scheduling on ports. The main idea is to consider the schedule as a dynamic system which must operate under certain constraints. As the optimal control theory is well-fit for optimizing the operation of dynamic systems, our scheduling problem is modeled as an optimal control problem, where transfer operations are carried out by flows from the ships to the port facilities (tanks). Such flows are mapped as control variables, whilst equipment contents (volume and properties) are mapped as state variables. Yes-No decisions are modeled as complementarity constraints, instead of with the use of discrete variables, allowing a continuous nonlinear model. We illustrate this approach with computational examples, which were solved to local optimality in reasonable computational time.

Keywords: port scheduling, crude oil scheduling, mathematical programming

## 1. INTRODUCTION

The maritime transportation is responsible for an almost-monopoly on the Import & Export international good transactions, with an increasing importance year after year. During the last decade, this industry has been pressured to adopt modern management techniques, in order to succeed in face of new challenges posed by global commerce, market deregulation, and companies' merges (Christiansen et al. 2004). On one hand, shippers must use the full capacity of their fleets, as they cannot afford having empty vessels laying still in ports, waiting for new customers. On the other hand, customers who rent or hire ships must know that the vessels will be available in time to attend their contracts. This complex fleet management is a rich field for optimization techniques. One of the bottlenecks of maritime transportation is the handling of ships in ports, considering the berthing and cargo loading/unloading processes: a vessel must be handled within a given time-frame, in order to minimize demurrage fees. There is a limited number of berth places and the port storage must be ready to handle the ship without incurring in delays. For instance, in 2006, the maritime transportation costs in Brazil amounted to US\$ 7 billions, from which US\$ 1.5 billions were spent with

demurrage fees only, caused by delays in ports (Collyer 2006).

This work addresses the schedule of ships in ports, considering the storage facilities, jetties and operational constraints, such as jetty unavailability and load/unloading limitations. A widespread approach for scheduling problems is the use of mixed-integer programming models, which formulate discrete decisions as 0-1 variables. The main advantage of this approach is that, in the case of mixed-integer linear programming (MILP) problems, when an optimal is found, there is a guarantee that it is a global optimum – as in the Linear Programming case. The main disadvantage of such models is the computational burden on real-world instances, which usually end in huge MIP models that may not be solved to optimality in reasonable time. Bearing that in mind, we decided to model the problem from a different angle, noticing that a scheduling system is actually a dynamic system, susceptible to an optimal (controlled) operation. Control variables are the loading/unloading flows, and state variables are the inventory on ships and port facilities. Moreover, schedule decisions can be modeled as complementarity constraints on the control variables. The main advantage of this formulation is that the problem does not suffer from an exponential growth with the addition of time intervals, whereas the main disadvantage is that the problem, although continuous, becomes nonconvex (with many local minima).

We tested the proposed approach with crude oil scheduling in ports problems (Figure 1), and compared to an alternative MILP formulation, based on the literature.

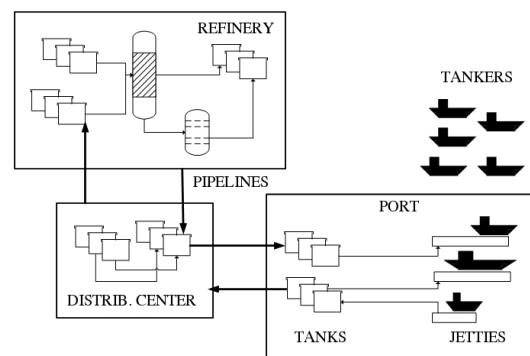


Figure 1: Crude Oil Scheduling

## 2. CRUDE OIL SCHEDULING ON PORTS

Planning and scheduling are activities of major economic importance. Efficient planning and scheduling can optimize resources usage, reduce waste and increase operational profits. They can avoid delays and assure that demands are supplied without degrading the quality of services. It is well-known that to find an optimal schedule is a NP-Complete problem (Más and Pinto, 2003). Therefore, many companies build some feasible schedules only and then make comparisons among them. The use of computational techniques such as simulation and mathematical optimization can help the decision-maker, as they can fasten the evaluation of different scenarios and find optimal or sub-optimal schedules. In this paper we propose a dynamic optimal control model that can be used in schedule simulations as well as in scheduling optimization.

Amid various planning and scheduling problems, we focus on the scheduling of crude oil on ports. This problem is of major importance for oil companies, as it directly affects the refineries' production plan. One can divide the logistic system related to crude oil and derivatives production and distribution in three subsystems: harbor, distribution center (intermediate storage), and plants or refineries (Figure 1). Each subsystem is connected to the others by pipelines, and the sequence of transferred material in the pipelines is how a subsystem affects the scheduling of the others.

The plant or refinery subsystem is very complex, while distribution centers coordinate the distribution of crude oil among different refineries. One example is the problem studied in (Más and Pinto, 2003), where the center acts as a buffer between the maritime terminals and four refineries. Depending on the desired scope, it is possible to consider each subsystem separately as subject to optimization, and to represent the others as external inputs to the problem.

Our objective is to schedule the ships within the port, and the subsequent port tank operations to unload their cargoes. Therefore, we detail the port subsystem only, considering planned crude oil volumes on the pipelines – to meet the refineries' demand – and known estimated time of arrival (ETA) for all ships. In many companies this is actually the case (Más and Pinto, 2003).

The port has its own park of tanks, large enough to store material pumped to or from the vessels for a certain number of days. The tanks may belong to the same company of the materials or may be hired from third parties. Even if the renting costs are negligible, the cost of immobilized capital is not. Therefore, stocks represent losses of interests on the value of the stored material, and stocking costs have to be considered in the problem formulation.

Tanks are dedicated to certain kind of materials, which can be crude oil or finished products. In the case of finished products, it is common to inspect the product's quality inside the tank, and to seal the tank to assure that no new product is going to be blended and modify its quality. In the case of crude oils, it is common to find impurities in the oil, such as salt, water

and minerals. Therefore, tanks must let the oil (which they had received) to settle during a certain period of time in order to segregate the impurities. From these two examples, an operational rule is inferred: no tank in the harbor should be able to start a new delivering transfer if it had not been idle for a certain amount of time. This time is usually called “settling time” or simply “idle time”. Another rule to operate tanks is not to use two tanks in parallel, transferring to a common final destination as it would cause blending inside the pipes.

The port is composed by a certain number of jetties, each one with defined draught and extension, and pumps that may be restrictive on what material to transfer. Therefore, ships can berth only on a restricted set of jetties, defined by their cargo or physical dimensions. The period of time that a vessel occupies a jetty is calculated as the following: time to approach the berthing place, plus the pumping time to the tanks, plus the time to leave the jetty. Therefore, the jetty will be available for another ship only a few hours after the previous ship stopped pumping. If the vessel cannot be completely processed until its contractual leaving date, the contractor is penalized (demurrage). One of the main goals of this scheduling problem is to minimize the demurrage.

## 3. THE MODEL

The fundamental scheduling activity is the transfer operation, defined by a single source equipment and a single destination equipment, and a flow of material from the source to the destination. The control vector  $u(t)$  is the vector whose each entry stands for a possible flow rate between two equipments at a given time  $t_i$ , subject to upper and lower bounds and operational constraints. Basically, one can consider a schedule infrastructure as a graph (Figure 2), whose arcs are possible flows, and whose nodes are equipments. Therefore, every positive entry  $u_j(t_i)$  stands for the scheduled flow rate of a transfer operation at time  $t_i$ , in arc  $j$ , which connects a pair of equipments. The optimization problem is to define a feasible sequence of  $u(t)$ , for all time instants  $t_i$ , which minimizes an objective function  $J$ . Operational constraints, such as “One equipment cannot be the destination of two transfer operations at the same time, in order to avoid blending in the inlet lines” can be modeled in different manners.

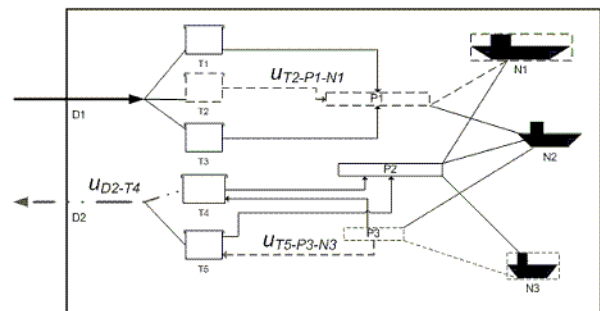


Figure 2: Problem structure as a graph

Table 1 presents two possible approaches: (a) MILP, and (b) complementarity based (NLP).  $A_N$  is the set of indexes for all arcs whose destination is equipment N. As N can participate in at most one transfer operation at time  $t_i$ , either all flows in the  $A_N$  arcs are zero at  $t_i$  (no transfer happens with destination N at time  $t_i$ ), or only one flow is greater than zero at  $t_i$  (N is the destination of only one transfer operation at time  $t_i$ ).

Table 1: Modeling Approaches

Type	Model
MILP	$\sum_j b_j(t_i) \leq 1$ $0 = b_j(t_i) u_j^{\min} \leq u_j(t_i) \leq b_j(t_i) u_j^{\max}(t_i)$ $u_j(t_i) \in \mathbb{R}^n, b_j(t_i) \in \{0, 1\}, j \in A_N$
NLP	$\sum_{k \in A_N} \sum_{j > k \in A_N} u_k(t_i) u_j(t_i) = 0$ $0 = u_j^{\min} \leq u_j(t_i) \leq u_j^{\max}(t_i)$ $u_j(t_i) \in \mathbb{R}^n, j \in A_N$

Model (a) is a typical mixed-integer program (Shah 1996, Más and Pinto 2003), which requires an additional control vector  $b(t_i)$  of binary variables, whose each entry is directly related to the  $u(t_i)$  entry of same index. If  $b_j(t_i)$  is set to 1 (one), then a flow is allowed through arc  $j$ ; otherwise, no flow is allowed through arc  $j$ . This is enforced by the manipulation of the upper and lower bounds on  $u_j(t_i)$ : if  $b_j(t_i) = 1$ , the bounds are preserved; otherwise, they are set to zero. The summation constraint guarantees that at most one  $b_j(t_i)$  can be evaluated as 1 (one) at  $t_i$ ,  $j \in A_N$ . All others binary variables associated to  $A_N$  must be evaluated as zero.

Model (b) is a complementarity-based nonlinear program, which relies on the control vector  $u_j(t_i)$  only. There is no need for additional binary variables. The summation of the products of all  $A_N$  flows two by two is equal to zero if and only if all flows are equal to zero or only one flow is greater than zero, making N as the destination of at most one transfer operation, as required. The main disadvantage of this formulation is that it defines a nonconvex nonlinear program.

A point defined by the MILP formulation can be transformed in an NLP point by simply removing the binary variables from the problem and replacing the mixed-integer constraints for the complementarity ones. A point defined by the NLP formulation can be transformed in an MILP point by simply adding the binary variables and replacing the complementarity constraints by the mixed-integer ones. For each positive flow, the corresponding binary variable is set to 1 (one), while for each naught flow, the corresponding binary variable is set to 0 (zero). A feasible point in the NLP is equivalent to a feasible in the MILP. The opposite is not necessarily true: if the NLP features additional nonlinear constraints that could not be equivalently modeled in the MILP, a feasible MILP point may not be a feasible NLP point.

Based on these foundations, one can analogously extend the problem to consider many other constraints and variables. In order to illustrate this, we model the crude oil scheduling problem with both approaches. One wants to determine: (i) tanker allocation on the port jetties; (ii) transfer operations between ships, tanks, and pipelines; (iii) sequence of pipeline parcels (end products and crude oil), in such a manner that an objective cost function is minimized and operational constraints are respected. The problem considers: (i) crude oil demand as known; (ii) ETA are given for all tankers. Ideally, a good schedule would use a small number of tanks, but it is important to notice that inventory costs are secondary when compared to the cost of not meeting a refinery production plan. Jetties can be restrictive on what vessels and cargoes they handle, in accordance to their dimensions (draught and length) or pumping capacity. A ship must berth, unload (or load), and leave the port during the time window defined by contract and she can berth in a jetty only if the ship that had previously used this jetty had enough time to leave the port. An ideal schedule must minimize the demurrage costs. Other constraints are considered as well: (i) blending operations are not allowed in lines, i.e., each transfer operation has only one source equipment and one destination equipment; (ii) a tank can deliver material to another equipment only if the necessary “settling time” or “idle time” has been observed (e.g. to separate brine from crude oil or to assure the lab analysis of an end product).

The NLP model is composed by control variables (Eq. 2), state variables (Eq. 3), state equations (Eq. 4, 5, and 6), and complementarity equations to model scheduling decisions: unique definition of source and destination in a transfer operation (Eq. 7), idle time to segregate impurities (Eq. 8), berthing time (Eq. 9), and constant flow constraints (Eq. 10). Both control and state variables are bounded by upper and lower limits. The objective-function (Eq. 1) is a summation of different costs, that can be prioritized with the use of weights. In the case of crude oil scheduling, we considered the following costs: demurrage (Eq. 11), unattained demand (Eq. 12), inventory (Eq. 13), and changeovers (Eq. 14).

$$\min J = \sum_{\text{cost}} w_{\text{cost}} C_{\text{cost}} \quad (1)$$

$$u_{\min} \leq u(t_i) \leq u_{\max}(t_i) \quad (2)$$

$$x_{\min} \leq x(t_i) = [v(t_i) \ p(t_i)]^T \leq x_{\max} \quad (3)$$

$$v(t_i) = v(t_{i-1}) + (t_i - t_{i-1})Uu(t_{i-1}) \quad (4)$$

$$p(t_i) = F(x(t_{i-1}), u(t_{i-1}), t_i - t_{i-1}) \quad (5)$$

$$p_n^{\text{density}}(t_i) = (u_{\text{inlet}, n}(t_{i-1}) p_{\text{inlet}, n}^{\text{density}}(t_{i-1})(t_i - t_{i-1}) + v_n(t_{i-1}) p_n^{\text{density}}(t_{i-1})) / (u_{\text{inlet}, n}(t_{i-1})(t_i - t_{i-1}) + v_n(t_{i-1})) \quad (6)$$

$$0 = r_n(t_i) = \sum_{k \in \text{In}, n} \sum_{j > k \in \text{In}, n} u_k(t_i) u_j(t_{i-1}) \quad (7)$$

$$0 = z_n(t_i) = \sum_{t' = t_i - \text{Tiidle}}^{t_i - 1} \sum_{k \in \text{In}, n} \sum_{j \in \text{Jin}, n} u_k(t_{i-1}) u_j(t') \quad (8)$$

$$0 = s_n(t_i) = \sum_{t' = t_i - T_{berth}}^{t_i - 1} \sum_{j \text{ in } J_{n,p}} \sum_{j \text{ in } J_{n,p}} u_k(t_{i-1}) u_j(t') \quad (9)$$

$$0 = q_n(t_i) = u_{0,n} - \sum_{j \text{ in } J_n} u_j(t_{i-1}) \quad (10)$$

$$C_{demurrage} = \sum_{j \text{ in } Ships} \sum_t c_j^{demurr} \text{cargo\_gap}_j(t) \quad (11)$$

$$C_{demand} = \sum_{j \text{ in } Pipelines} \sum_{p \text{ in } Products} c_j^{demand} (\text{demand}_{j,p} - \sum_t^T v_{j,p}(t)) \quad (12)$$

$$C_{inventory} = \sum_{j \text{ in } Storages} \sum_t c_j^{inventory} v_j(t) \quad (13)$$

$$C_{changeover} = \sum_j \sum_t c_j^{changeover} (u_j(t_i) - u_j(t_{i-1}))^2 \quad (14)$$

Note: Eq. 4 features  $U$  as an incidence square matrix with entries in  $\{0, 1, -1\}$ . Eq. 5 is a general blending functional, while Eq. 6 is a particular blending function (for density), which is the one we employ in our test cases. Eq. 7 enforces that only one flow can be used by an equipment  $n$  at time  $t_i$ , therefore, a transfer operation has only one source and only one destination at time  $t_i$ . Eq. 8 enforces the idle time, while Eq. 9 enforces the necessary berthing time for ships. Eq. 10 force a constant flow  $u_{0,n}$  for a given equipment  $n$  – this constraint can be easily changed to force a variable flow, if needed. Eq. 11 deals with demurrage cost: we do not employ the classic demurrage formulation, but one that is also proportional to the remaining volume to be transferred that is delayed (`cargo_gap`). Eq. 14 accounts for changeovers in the problem, by penalizing the differences in the flows. In all cost equations  $c_{jcost}$  is a different arbitrary unitary cost.

The MILP model is similar to the NLP model, with the replacement of Equations 2, 7, 8, and 9 by Equations 2a, 7a, 8a, and 9a. Complementarity constraints were replaced by mixed-integer constraints, featuring binary decision variables ( $b_j$ ), leading to larger models. This model was based in the crude oil scheduling literature, mainly (Shah 1996) and (Más and Pinto 2003):

$$D(b_j(t_i)) u_{\min} \leq u(t_i) \leq D(b_j(t_i)) u_{\max}(t_i), \quad b_j(t_i) \text{ in } \{0,1\} \quad (2a)$$

$$r_n(t_i) = \sum_{j \text{ in } J_n} b_j(t_{i-1}) \leq 1 \quad (7a)$$

$$z_n(t_i) = \sum_{j \text{ in } J_{out,n}} b_j(t_{i-1}) + \sum_{t' = t_i - T_{idle}}^{t_i - 1} \sum_{j \text{ in } J_{in,n}} b_j(t') \leq 1 \quad (8a)$$

$$s_n(t_i) = \sum_{j \text{ in } J_{n,p}} b_j(t_{i-1}) + \sum_{t' = t_i - T_{berth}}^{t_i - 1} \sum_{j \text{ in } J_{n,p}} b_j(t') \leq 1 \quad (9a)$$

Note: Eq. 4a features a diagonal matrix  $D(b_j(t_i))$ , composed by the binary variables  $b_j$ , which are added to the model in the MILP formulation. These variables represent scheduling decisions: there is no flow  $u_j$  at time  $t_i$  if  $b_j = 0$  at time  $t_i$ , and there is a flow  $u_j$  if  $b_j = 1$ . Equations 7a, 8a, and 9a model represent the following constraints: only one flow can be used by an equipment  $n$  at time  $t_i$ , idle time, and berthing time constraints.

#### 4. RESULTS

Typical NLP methods can solve problems with complementarity constraints efficiently (Leyffer 2005). As the formulation is nonconvex, the method initialization is an important issue. We define trivial

points as the points where the control vector  $u$  is equal to zero at all time instants. These points are very easy to be constructed, but not feasible in the original problem formulation. At trivial points, the demurrage costs are maximum and the norms of the additional states are  $\|z\| = \|r\| = \|s\| = 0$  and  $\|q\| \gg 0$ . However, a trivial point is feasible in a relaxation of the original model, if we remove equations (7) to (10) from the constraints, and add them as penalties on the objective function, obtaining a merit function:

$$J' = J + M \sum_t e^T r(t) + e^T s(t) + e^T z(t) + e^T q(t) \quad (15)$$

A penalty method based on the optimization of successive relaxed problems with merit function  $J'$  can solve the original problem, converging to local minimum. A multistart procedure can be employed as well in the initialization of the relaxed problems.

Five test instances were coded in AMPL (Fourer et al. 2003). The MILP and NLP instances share a common objective function, and do not feature equations (5) and (6) as a means to allow the comparison between their optimal solutions. It is clear that the NLP model is more compact than the MILP model, as shown in Table 2. The number of variables is the one determined after AMPL's pre-solve procedure, which eliminates redundancies.

Table 2. Models' dimensions

	MILP		NLP	
	Binary/ Continuous variables	Linear Con- straints	Linear / Nonlinear variables	Linear / Nonlinear constraints
1(A)	12 / 25	31	12 / 19	19 / 6
1(B)	12 / 25	36	12 / 19	24 / 6
2	34 / 82	111	34 / 77	64 / 23
3(A)	93 / 158	265	93 / 76	92 / 11
3(B)	93 / 158	275	57 / 78	86 / 11

No specialized software was employed to optimize the test instances, but only standard commercial solvers:

- For MILP cases: CPLEX (v. 10.1.0) (ILOG 2002);
- For NLP cases: SNOPT (v. 6.1) (Gill et al. 2002), and MINOS (v. 5.5) (Murtaugh e Saunders 1982).

All cases were initialized at trivial points – as previously defined – and solved on a workstation with the following configuration: Intel Core Duo T2250 1.73GHz, RAM 1GB, Linux OpenSUSE 10.1. All cases were solved in reasonable time to optimality: around 1 second. Moreover, the solutions found in all cases were able to handle the ships with no delays – as desired – and meet the refineries crude oil demand – as desired as well.

The test cases are detailed as follows:

- **Test 1:** Two crude tanks and one pipeline connected to a refinery, whose crude demand has to be fulfilled. There are 2 configurations for this scenario: (A) allows the pipeline to be

idle in certain periods, (B) keeps the pipeline with a constant flow, during the entire schedule. The MINOS run converged to a local minimum in (B) configuration. The NLP objective function is (Eq. 15), while the MILP is (Eq. 1). The penalty parameter M was set as 1.0.

- **Test 2:** Two crude tanks, one jetty and two tankers, whose cargo had to be unloaded. The NLP objective function is (Eq.15) with  $M=1.0$ , while the MILP is (Eq.1).
- **Test 3:** Three crude tanks, one jetty, three tankers, whose cargo had to be unloaded, and one pipeline, whose demand has to be fulfilled. There were 2 configurations: (A) allows the pipeline to be idle in certain periods, (B) keeps the pipeline with a constant flow. The SNOPT run converged to a local minimum with demurrage costs in (B) configuration. The NLP objective function is (Eq. 15) with  $M=0.05$ , while the MILP is (Eq. 1).

Table 3 shows that the optimal solutions were achieved in both models (MILP and NLP).

Table 3. MILP and NLP results

	MILP		NLP	
	CPLEX	MINOS	SNOPT	
1(A)	J = 1460 14 iterations	J = 1460 17 iterations	J = 1460 51 iterations	
1(B)	J = 1600 13 iterations	J = 1625 5 iterations	J = 1600 13 iterations	
2	J = 0.33 63 iterations	J = 0.33 191 iterations	J = 0.33 12 iterations	
3(A)	J = 0 324 iterations 8 B&B nodes	J = 0 411 iterations	J = 0 812 iterations	
3(B)	J = 0 397 iterations 25 B&B nodes	J = 0 472 iterations	J = 18.27 544 iterations	

The number of iterations are similar for both models, but, as larger problems are approached, the MILP branch and bound procedure expands a larger number of nodes. As the complementarity model is nonconvex, a nonlinear programming method, such as MINOS and SNOPT, may converge to local optima, differently from what happens with the mixed-integer model when solved by a typical branch-and-bound method, such as CPLEX. On the other hand, the complementarity model is more compact, featuring less variables and constraints than the MILP one.

Noticing that one NLP solution is equivalent to an MILP feasible point, we propose a hybrid scheme (Figure 3): solve the continuous NLP problem and then transform its solution as an initial point for the MILP. If needed, call NLP runs in difficult nodes of the MILP B&B tree. This scheme may be able to reduce the total number of branches and Simplex iterations in the MILP optimization, as the NLP point is an integral MILP good solution.

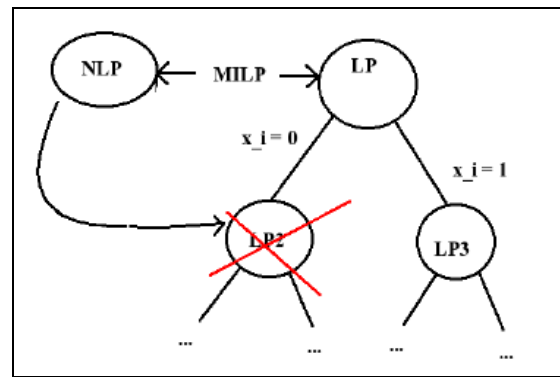


Figure 3: Hybrid scheme

At the current state of our research, we employed the NLP solutions to initialize the MILP models, and compared the number of iterations and branched nodes. A substantial reduction in the number of iterations in the MILP optimization run is detected (Table 4).

Table 4. MILP cases with trivial and NLP starts

	MILP Iterations		
	$(x,u)^0=(x^0, 0)$	$(x,u)^0=(x,u)^{SNOPT}$	$(x,u)^0=(x,u)^{MINOS}$
1 (A)	14	13	13
1 (B)	13	4	4
2	63	47	40
3 (A)	324 (8 nodes)	215	215
3 (B)	397 (25 nodes)	265 (6 nodes)	215

## 5. CONCLUSIONS

One of the bottlenecks in maritime transportation industry is how ships are handled in ports: delays are very common and expensive, incurring in high demurrage costs. We proposed a NLP model for this problem, and presented some computational examples in order to illustrate the suitability of the proposed model. Oil companies, port administrators, and freighter companies are possible users of this model. The most important advantage of using mathematical models for this problems is to find schedules that incur in no demurrage costs and meet all operational constraints. All cases were solved in reasonable time to optimality (around 1 second), showing that this approach is an interesting option for industry applications. Finally, it is important to notice that the complementarity equations herein described can be employed in others scheduling problems.

## REFERENCES

- Christiansen, M., Fagerholt, K., Ronen, D., 2004. Ship routing and scheduling: status and perspectives *Transportation Science*, 38 (1), 1-18.

- Collyer, W. , 2006. Sobreestadia de navios: a regra 'once on demurrage, always on demurrage' *Jus Navigandi*, 10 (1166) 10. [in Portuguese]
- Fourer, R. Gay, D.M. and Kernighan, B.W., 2003. *AMPL: A Modeling Language for Mathematical Programming*. Pacific Grove: Duxbury Press Brooks/Cole-Thomson Publishing Company.
- Gill, P. E., Murray,W. and Saunders, M.A., 2002 SNOPT: An SQP algorithm for large-scale constrained optimization. *SIAM Journal on Optimization*, 12 (4) 979.
- ILOG, Inc., 2002. *ILOG AMPL/CPLEX System Version 8.0 User's Guide*. ILOG, Inc.
- Leyffer, S. (2005) Complementarity Constraints as Nonlinear Equations: Theory and Numerical Experience. *Technical Report ANL/MCS-P1054-0603*, Argonne National Laboratory, Argonne.
- Más, R., Pinto, J.M., 2003. A mixed-integer optimization strategy for oil supply in distribution complexes. *Optimization and Engineering*, 4 (1) 23.
- Murtagh B.A. and Saunders M.A., 1982. A projected Lagrangian algorithm and its implementation for sparse non-linear constraints. *Mathematical Programming Studies*, 16, 84.
- Shah N., 1996. Mathematical Programming Techniques for Crude Oil Scheduling. *Computers and Chemical Engineering*, 20 (sup.), S1227-S1232.

# A QUANTITATIVE FRAMEWORK TO ASSESS CAPABILITY TRADEOFFS OF THE TRANSFORMABLE-CRAFT WITHIN THE SEABASING CONCEPT

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## ABSTRACT

Seabasing has been identified as a critical future joint military capability for the United States. The complexity of the Seabasing architecture requires a coordinated development effort to address identified issues and to create a joint Seabasing system-of-systems. New technologies that provide updated capabilities are needed to make the Seabasing concept feasible. It is essential to identify what capabilities are required of these new technologies and to quantify the impact of capability tradeoffs on the Seabasing concept in order for Seabasing to be considered a viable alternative to current force projection methods. This paper presents a quantitative framework to assess capability tradeoffs of systems on the overall system-of-systems. The proposed approach is applied to the Transformable-Craft (T-CRAFT) within a Seabasing context. An architecture-driven object-oriented approach is employed to develop a physics-based model of a Seabasing scenario. Surrogate models are employed to enable rapid capability tradeoffs to enable optimization of the T-CRAFT.

Keywords: capability-based tradeoff environment, probabilistic design space exploration, agent-based model, T-CRAFT

## 1. MOTIVATION

Seabasing has been identified as a critical future joint military capability for the United States (Howard and Pilling 2003). Seabasing is a sovereign, maneuverable capability for sustainable global force projection, exploiting the sea as a maneuver space 365 days a year. The current Seabasing concept involves a fourteen-ship Maritime Prepositioning Group (MPG) supporting a Marine Expeditionary Brigade (MEB)-sized force. Figure 1 depicts the different assets in an MPG and Figure 2 depicts the composition of a notional MEB. The Sea Base will also employ a Carrier Strike Group (CSG) to support air operations and an Expeditionary Strike Group (ESG) to support amphibious assault.



Figure 1: Fourteen-ship MPG (Conant 2005)

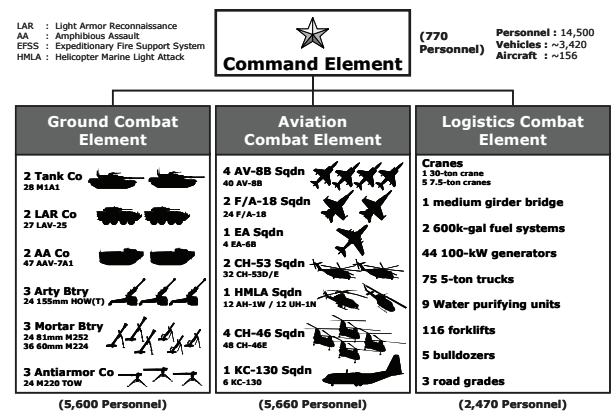


Figure 2: Notional MEB

The complexity of the Seabasing architecture, as depicted in Figure 3, requires a coordinated development effort to address identified issues and to create a joint Seabasing system-of-systems (SoS) (Howard and Pilling 2003). New technologies that provide updated capabilities are needed to make the Seabasing concept feasible. Five top-level threshold measures of performance have been identified in order to realize the Seabasing concept as a viable alternative to current systems (Seabasing Joint Integrated Concept 2005):

1. **Close** a MEB-sized force within 10 – 14 days
2. **Assemble** a MEB-sized force within 24 – 72 hours
3. **Employ** a minimum of one MEB via surface within 8 – 10 hours
4. **Sustain** selected joint forces and up to two MEBs operating up to 150 nautical miles (nm) inland with minimal logistics footprint ashore
5. **Reconstitute** forces for future operations within 30 days



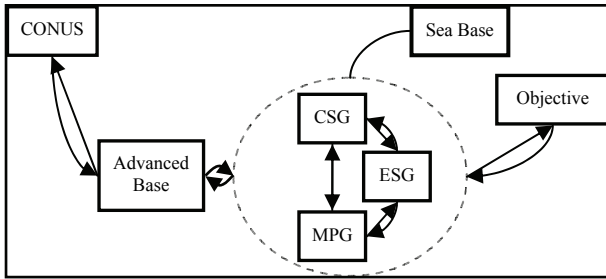


Figure 3. Seabasing architecture (based on Skinner 2004)

Independent studies have concluded that current assets do not meet the required capabilities to meet the threshold measures of performance, e.g., Bishop 2005, CBO 2007, Howard and Pilling 2003. One capability gap identified by the National Defense Industry Association for Seabasing is *Ships of Appropriate Design* (Bishop 2005). Emerging requirements by the Office of Naval Research (ONR) dictate that a 400%–1000% increase in payload capacity over the current Landing Craft, Air Cushion (LCAC) is required to make the Seabasing concept feasible. Thus, the ONR has solicited proposals for a new type of fully amphibious vessel known as the Transformable-Craft (T-CRAFT). The T-CRAFT is a variable hull form vessel that enables rapid, high capacity Sea Base-to-shore transfer of materiel and personnel, and is also self-deployable from an Advanced Base. Table 1 lists some of the new capabilities offered by the T-CRAFT as listed in ONR Broad Agency Announcement (BAA) 05-020 (2005). Figure 4 shows the primary mission profile for the T-CRAFT (BAA 2005).

Table 1: Desired operational capabilities of the T-CRAFT prototype

Mission Segment	Desired Capability	
Open Ocean (un-refueled, no-cargo condition)	Range	2500 nm
	Speed	20 knots (kts) through NATO STANAG 4194 Sea State (SS) 5
	Seakeeping	Operation through SS 6 and survivable in SS 8
Intra-Sea Base	Seakeeping	Ability to mitigate wave induced motions in SS 4/5
High Speed Transit (un-refueled, full cargo condition)	Range	500nm – 600nm
	Speed	~40 kts through top end of SS 4
	Payload Capacity	300 long tons (lt) (threshold)/700 lt (objective)
Fully Amphibious	Beach Slope Climbing	0.5% (threshold)/2% (objective)
	Inland Range Requirement	No range requirements, but must provide “feet dry on the beach” capability
Other	~	Ability to convert between modes at sea without any external assistance

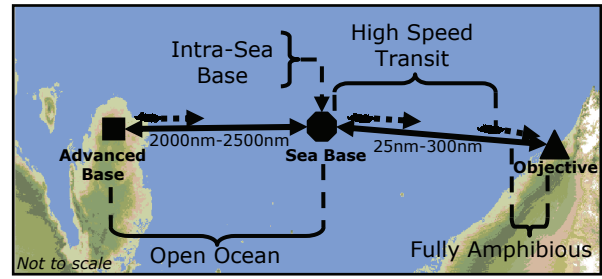


Figure 4: Primary mission profile for the T-CRAFT

Although Seabasing measures of performance have been defined, the Seabasing SoS is still being developed from the bottom-up, that is, in the same sense as forward design. Capabilities are defined deterministically, or at best intervals, for systems within the Seabasing SoS to obtain the resulting measures of performance. This process is inefficient, as it requires iteration at the systems level. The Seabasing concept has not been planned out in its entirety, thus the process of defining system capabilities requires a top-down approach, or inverse design. Inverse design allows for “design for capabilities” via surrogate modeling and probabilistics. Using this technique, it is possible to highlight a desired capability in relation to the SoS level metrics and identify potential designs at the systems level (Biltgen 2007). The Sea Base-to-shore system consists of a large number of entities governed by independent local rules, dimensional parameters, goals, and interactions. The combined effect of these properties produces emergent behaviors that are required to be understood in order to analyze and design the Seabasing SoS. However, these emergent behaviors are difficult to predict *a priori*, and require simulation.

One method to test how dimensional parameters affect the overall SoS is to simulate the T-CRAFT using an agent-based model. This work details the development of a probabilistic capability-based tradeoff environment for the T-CRAFT within the Seabasing concept; however, the methodology is equally applicable to similar systems of interest and can be used to identify critical capabilities and their effect on SoS performance.

## 2. PROPOSED APPROACH

The proposed approach combines methods from Leite and Menseh (1999), whose work develops a methodology for the generation of evaluation criteria for system acquisition modeling and simulation based on the underlying system requirements, and Kirby (2001), whose work outlines a methodology for technology identification, evaluation, and selection in conceptual and preliminary aircraft design.

### 2.1. Identify System

The first step in the development is to identify the system to be explored and to scope the problem to the desired level of detail. For this application, the focus is on the cargo delivery aspect of the T-CRAFT mission profile.

## 2.2. Identify Capabilities of Interest

The second step is to identify the system capabilities that will be modeled. This step bounds the model. It is assumed that the system provides the capabilities that are not modeled for all cases to be studied. In many cases, it is not possible to model all of the system's capabilities due to resource constraints. Furthermore, some systems may be too complex or undefined to be modeled in their entirety. This is particularly true for new developments such as the T-CRAFT.

## 2.3. Identify System Metrics

The third step is to extract and/or develop the metrics for the capabilities being modeled. These metrics are defined for the operational system and are in the form of Measures of Performance (MOPs), Measures of Effectiveness (MOEs), and Measures of Force Effectiveness (MOFEs).

## 2.4. Identify Systems Functionality

The fourth step is to identify the system functions that must be modeled to test the identified capabilities. Functions that are not related to the capabilities being modeled are assumed to perform correctly for all cases being studied and may be represented by nominal inputs.

## 2.5. Develop System Model

The fifth step is to develop a deterministic model that will quantify the impact of capability tradeoffs on the SoS. The level of the capabilities and metrics determine the scope of modeling and simulation that is required. Before the model can be used as a representation of a system, it must be shown to accurately represent the system at hand. This step is accomplished by model verification and validation. In general, verification involves tracing the model inputs through the system functions and ensuring that the model correctly implements the required system functions. If possible, the model must be validated against a set of inputs with known outputs. Model behavior must match that which is expected beforehand; when performance anomalies are encountered, developers must determine whether an anomaly is due to an incorrect representation in the model or whether the system itself is flawed.

## 2.6. Develop Tradeoff Environment

The sixth step is to sample the model using a Design of Experiments (DoE) in order to develop a surrogate model. The surrogate model is developed via regression of the DoE results. This enables the development of a rapid tradeoff environment that can be explored in real-time. If the model runs sufficiently quickly or the design space is small, the model may be executed directly. The surrogate model must be validated against original model data and in general should not extrapolate solutions to areas outside the original design variable ranges.

## 2.7. Design Space Exploration

The seventh step is to use the tradeoff environment to explore the impact of capability tradeoffs on the SoS. A probabilistic assessment of achieving desired capabilities is enabled by sampling the surrogate model via, e.g., Monte Carlo sampling or Latin Hypercube sampling. Due to uncertainty in the design process, this step is probabilistic rather than deterministic in nature. Sensitivities are studied to determine the robustness of selected designs. Design space exploration is iterative, as the initial design space may not capture a sufficient number of feasible solutions; in this case, the tradeoff environment must be re-evaluated to determine the cause of failure in meeting the desired capabilities.

## 3. PROOF OF CONCEPT

The proposed approach is applied to study the T-CRAFT within a Seabasing context. The goal is to develop a quantitative capability-based tradeoff environment that can be used to explore the design space in real-time and can offer insight into the probability of meeting desired capabilities.

### 3.1. Identify System

The T-CRAFT was modeled in a payload delivery scenario in its High Speed Transit mode. The Seabasing architecture depicted in Figure 3 is reduced to the right-hand side of Figure 4, where the T-CRAFT will be operating between an MPG and a beachhead. Each vessel in the scenario continuously delivers fully-outfitted M1A1 tanks from the Ground Combat Element (GCE) of a MEB between an MPG and a beachhead.

### 3.2. Identify Capabilities of Interest

The desired capabilities defined in Table 1 are in the form of dimensional parameters (DPs), i.e., physical properties of the T-CRAFT whose values determine system behavior and structure even when at rest (Hootman 2003). The High Speed Transit DPs from Table 1 are range, speed (which includes sea state operations), and payload capacity. The range is the round-trip distance between the MPG and the beachhead, so half of the range will be used as the distance to objective. The upper value of 300 nm is used as a more stringent capability. The ships that form the Seabase would be vulnerable to weapons such as naval mines, submarines, strike aircraft, and antiship missiles. In recognition of those threats, DoD's plans call for such ships to remain at least 25 nm offshore (CBO 2007). Payload capacity was discretized into M1A1 tanks for the purpose of modeling loading and unloading delays under a single load plan; in the general case, payload capacity is a continuous variable with a large number of loading plans. Since the T-CRAFT is vulnerable to attrition when it is beached and to address the required rapid, sequential off-loading of vehicles during an assault, the number of tanks on board (which is between zero and the payload capacity) were also considered (CBO 2007). Finally, the physical architecture of the Sea Base was explored by varying

the number of T-CRAFT operating in the scenario. Table 2 summarizes the identified capabilities of interest and their ranges in the design space. Where applicable, the ranges were taken from the BAA; in all other cases, a literature search on current amphibious operations served to bound the parameters (CBO 2007).

**Table 2. Dimensional parameters and ranges**

Dimensional Parameter	Design Space Range	Units
Distance to Objective	25 – 300	nm
HST Speed	30 – 60	kts
Payload Capacity	4 – 10	Number of M1A1s
Tanks On Board	1 – 10 (constrained by payload capacity)	Number of M1A1s
Sea State Operations	0 – 4	NATO STANAG 4194 Sea State
Number of T-CRAFT	1 – 4	~

### 3.3. Identify System Metrics

The metrics were derived from literature to be relevant to the system being modeled (Milton 2004). They were separated into two categories: performance metrics and economics metrics. Each metric was carefully selected to provide insight into the system. The metrics are summarized in Table 3 and discussed below.

**Table 3. Quantitative system metrics**

Metric	Nomenclature	Units
<b>Performance</b>		
Steady-state tank delivery rate	SSTDR	M1A1 tanks/day
Sorties per vessel per day	SVD	sorties/No. T-CRAFT/day
Loading efficiency	$\eta_{loading}$	%/100
Loading effectiveness	$e_{loading}$	minutes/minutes
<b>Economics</b>		
Fleet acquisition cost	Acq \$	total tank capacity
Operational cost	Oper \$	lit of fuel consumed (fleet)/tanks/No. T-CRAFT

For the Seabasing concept to be feasible, a certain number of tanks from the MEB must be delivered within a specified time period. A natural metric for this capability is the steady-state tank delivery rate, defined in Equation (1).

$$SSTDR = \frac{\text{Tanks Delivered}}{\text{Mission Duration (Days)}} \quad (1)$$

T-CRAFT utilization is important in meeting readiness requirements; a system with a higher sortie generation rate exhibits a higher utilization and hence is more capable of meeting readiness requirements (NAVRIIP 2008). This measure of performance was considered in terms of sorties per vessel per day as shown in (2).

$$SVD = \frac{\text{Sorties}}{\text{No. T-CRAFT} \times \text{Mission Duration (Days)}} \quad (2)$$

The loading configuration was also investigated in terms of the loading efficiency  $\eta_{loading}$  (how efficiently deck space is used) and the loading effectiveness  $e_{loading}$  (how quickly the cargo is unloaded on shore relative to the full load condition). These metrics are defined in (3) and (4), respectively.

$$\eta_{loading} = \frac{\text{Tanks On Board}}{\text{Payload Capacity}} \quad (3)$$

$$e_{loading} = \frac{\text{Full-load Unload Time}}{\text{Unload Time}} \quad (4)$$

Finally, cost was considered in terms of fleet acquisition cost and operational cost. Fleet acquisition cost is based on number of T-CRAFT and payload capacity. It is assumed that the lightship displacement (and hence cost of the vessel) scales with its payload capacity. The operational cost is defined as mission fuel consumption normalized by number of T-CRAFT and total tanks delivered in order to derive the fuel-equivalent cost of delivering one tank. These metrics are defined in (5) and (6), respectively.

$$\text{Acq \$} = \text{No. T-CRAFT} \times \text{Payload Capacity} \quad (5)$$

$$\text{Oper \$} = \frac{\text{Mission Fuel Consumption}}{\text{Tanks Delivered} \times \text{No. T-CRAFT}} \quad (6)$$

### 3.4. Identify Systems Functionality

Standard Department of Defense Architecture (DoDAF) products were created to guide the modeling process by creating representative functional networks (DoD 2007). The DoD defines an architecture as “the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time.” It is evident that, given enough resources, all possible architectures could be examined over all functions, operational activities, and capabilities; for limited resources, the architectures determine the modeling fidelity that can be implemented based on the available resources and desired modeling detail (Biltgen 2007). The following DoDAF products were developed from literature search (UNTL 2007):

- **AV-1:** Overview and Summary Information
- **OV-1:** High Level Operational Concept Graphic
- **OV-5:** Operational Activity Model
- **SV-4a:** Systems Functionality Description
- **SV-5a:** Operational Activity to Systems Functionality Traceability Matrix

Figure 5 shows a graphical depiction of the *Operational Activity to Systems Functionality Traceability Matrix* (SV-5a), which maps the T-CRAFT *Operational*

Activity Model (OV-5) to the T-CRAFT *Functionality Description* (SV-4a). This mapping identifies the transformation of an operational need into a purposeful action performed by the system. SV-5a outlines the functions that need to be modeled in order to evaluate the capabilities that were identified in §3.2. Note that SV-5a in Figure 5 is for the complete T-CRAFT mission profile. Blocks A1.1 and A1.2 in Figure 5 correspond to the parts of the mission that are not modeled and are assumed to perform correctly for all cases being studied.

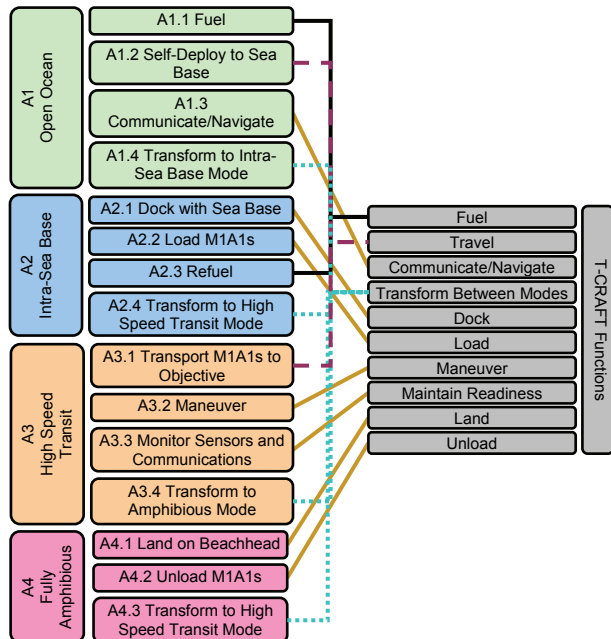


Figure 5: Operational Activity to Systems Functionality Traceability Matrix (SV-5a)

### 3.5. Develop System Model

#### 3.5.1. Model development

DoDAF products were used in conjunction with Unified Modeling Language (UML) 2.0 to develop the system software architecture to the fidelity determined in §3.4. UML is a standardized visual specification language for object modeling that is being developed by DoD (2007). UML enables the rapid design, development, and sustainment of code via an object-oriented approach. In many cases, portions of the DoDAF products and UML diagrams were interchangeable. The following UML 2.0 diagrams were employed in the software development (Rational Software 1997):

- **Use Case Diagram:** How a user employs the system software
- **Component Diagram:** Dependencies amongst software components
- **Class Diagram:** Static structure diagram
- **Sequence Diagram:** Message exchange between objects

The units in the constructive simulation consisted of platforms whose motion was governed by physics-based rules and whose intelligence was governed by cognition models simulating human decision. Figure 6 shows the *Class Diagram*, which describes the structure of the platform and cognition classes, their attributes, methods, and relationships to other classes.

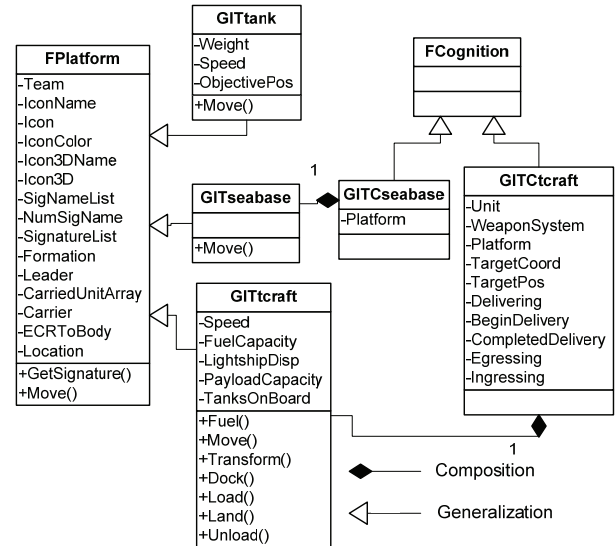


Figure 6. Class diagram showing platform/cognition composition and generalization

The code was compiled and linked with the Flexible Analysis, Modeling, and Exercise System® (FLAMES®) 6.1.1 (Ternion 2006) via Microsoft Visual Studio® 2005 (Microsoft 2005). FLAMES was integrated with Phoenix Integration ModelCenter® 7.1.2 (Phoenix 2007) to allow a DoE to be performed. Figure 7 shows the final, physics-based modeling and simulation environment developed for this study.

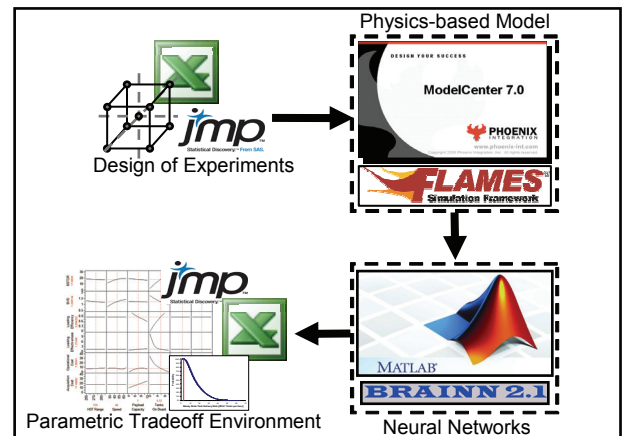


Figure 7: Modeling and simulation environment.

#### 3.5.2. Verification

The T-CRAFT capabilities were successively decomposed into quantifiable, implementable solutions at three levels: high-level requirements, software requirements, and source code. Each level was verified and linked with the level above it. At the source code

level, test cases were used and the inputs were traced through execution to ensure that there were no bugs in the code. Tracing was performed via incremental output files and animation. From a verification perspective, animation is a graphical form of tracing that provides information about the internal behavior and physics of the model (Eteessami 2007). Figure 8 shows a screen capture of a fleet of four T-CRAFT leaving an MPG and headed towards shore.

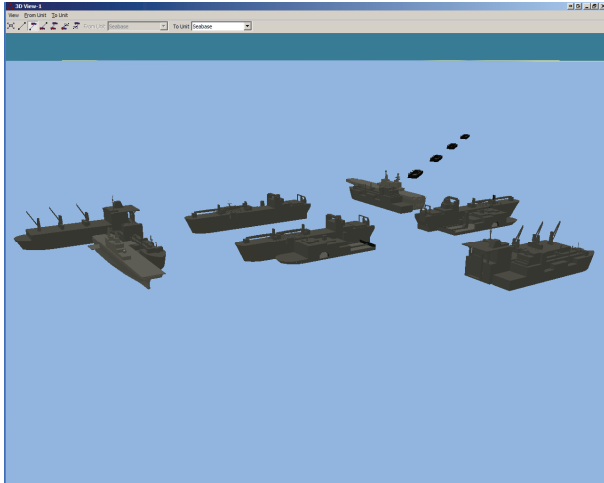


Figure 8. FLAMES animation screen capture of T-CRAFT fleet leaving MPG

### 3.5.3. Validation

In practice, the validation process is difficult for agent-based constructive simulations of future concepts where there is no empirical evidence to validate against. This is a typical situation and the best practice for validation of this type of simulation is to independently assess each of the physics-based models to ensure that the physics are being modeled correctly. For cognition models, the agents must be tested under various conditions to ensure that they follow the correct decision paths. It is then usually inferred that the aggregated behavior is as correct as possible (Biltgen 2007).

Unfortunately, critical measures of amphibious operations are unavailable, thus the scenario as a whole cannot be validated; however, following Biltgen's approach, the kinematics were validated against simpler relations, and powering was compared against experimental model data. Kinematics were validated via animation and application of the kinematical equation  $s = v\Delta t$ , which relates distance traveled to the product of a constant speed and a change in time. The time is given as an output of the animation and the speed and distance are inputs. Thus, the time was validated and was found to agree with the simulation results.

Resistance was calculated using standard powering calculations (Yun 2000). The resistance code was compared to experimental performance data obtained from a scale model of the SES 100B (Fridsma 1974). The comparison is shown in Figure 9. The discrepancy at higher Froude numbers is due to the assumption that the draft is constant with speed; in reality, the draft of a surface effect ship decreases with speed thus resulting

in a decrease in resistance, as seen in the experimental data.

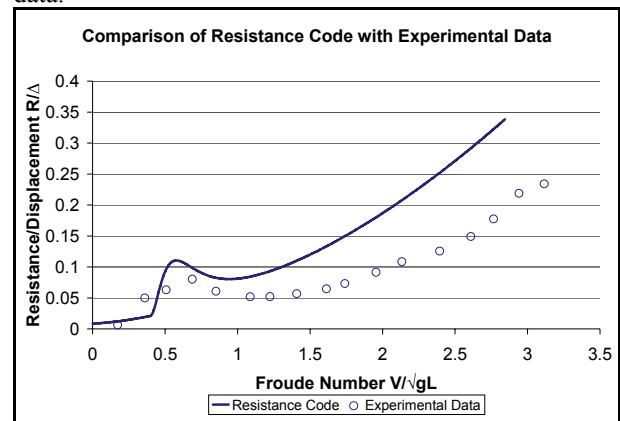


Figure 9. Comparison of resistance code with experimental data from Fridsma (1974)

### 3.6. Develop Tradeoff Environment

To address the long run-times associated with constructive simulations, surrogate models are implemented to enable rapid trade studies. The current model was executed for 60 hours of simulation time, which took approximately two minutes of actual time per run on a Windows XP Professional SP2 platform with a 2.0 GHz Pentium M Processor and 1 GB of RAM. The development of the surrogate models begins with creation of a DoE table. Due to the combination of continuous and discrete inputs, a custom orthogonal DoE of 80 cases was constructed using SAS JMP<sup>®</sup> 7.1 (SAS 2007). Neural networks were selected as the surrogate models in order to capture any highly nonlinear behavior that would arise in the responses. Using Basic Regression Analysis of Integrated Neural Networks (BRAINN) 2.1 developed at Aerospace Systems Design Laboratory (Johnson 2007), neural networks were trained and their functional forms were passed into JMP.

BRAINN provides the means to validate the surrogate models against the original model data via four “goodness of fit” tests:  $R^2$ , actual by predicted plot, residual by predicted plot, and model error distribution. These tests are discussed in detail in Kirby (2001). In general, the surrogate model data points should be as close as possible to the actual data points, residuals should be randomly distributed, and error should be approximately distributed as a standard normal distribution. Figure 10 shows the results of these four tests for the SSTDR neural network.

With the goodness of fit tests accepted, the next step is to visualize the design space. JMP was used to visualize the results in the form of a tradeoff environment. JMP provides a suite of visualization tools that enable visual tradeoffs and probabilistic analyses to be performed. Note that the environment developed in this study is not unique; combinations of other commercial or in-house tools may be used.

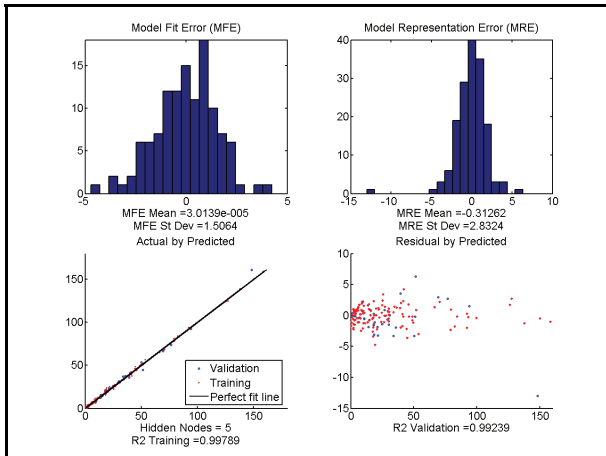


Figure 10. Neural network validation tests for SSTDR

JMP was used to produce an interactive prediction profiler as shown in Figure 11. This matrix of bivariate plots enables the designer to visually check the model for unexpected behavior and to establish the sensitivities of each metric to the input parameters. Thus the designer can determine the main drivers for each metric. For example, for the settings shown in Figure 11, the steady-state tank delivery rate is most sensitive to distance to objective.

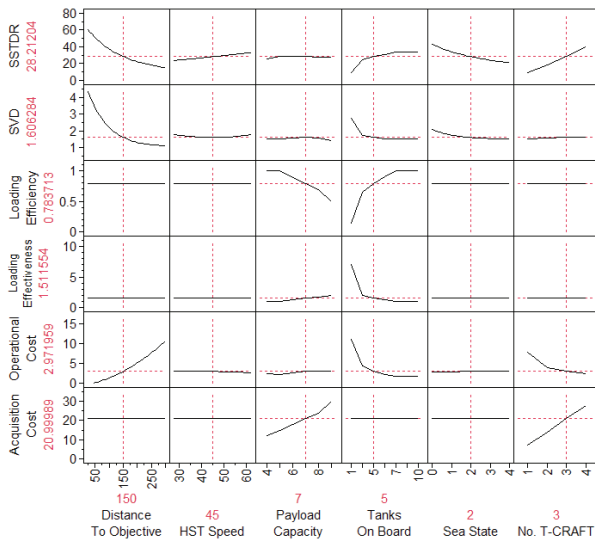


Figure 11. Prediction profiler

### 3.7. Design Space Exploration

The first step in the design space exploration is to establish a baseline vessel as a basis for comparison. A baseline configuration was established for an LCAC in amphibious assault and is shown in Table 4. The baseline will aid in the comparison of cost metrics, due to their relative rather than absolute measures, as well as the performance metrics. This in turn will aid in determining if the T-CRAFT is a viable alternative to the LCAC. The baseline metrics for the LCAC, shown in Table 5, are obtained from the original model because the dimensional parameters fall out of the ranges of validity of the neural networks.

Table 4. Baseline vessel dimensional parameters

Dimensional Parameter	LCAC Baseline	Units
Distance to Objective	45	nautical miles (nm)
HST Speed	25	knots (kts)
Payload Capacity	1	Number of M1A1s
Tanks On Board	1	Number of M1A1s
Sea State Operations	0	NATO STANAG 4194 Sea State
Number of T-CRAFT	1	~

Table 5. Baseline vessel metrics

Metric	LCAC Baseline	Units
<b>Performance</b>		
Steady-state tank delivery rate	5.87	M1A1 tanks/hour
Sorties per vessel per day	5.87	sorties/No. T-CRAFT/day
Loading efficiency	1	%/100
Loading effectiveness	1	minutes/minutes
<b>Economics</b>		
Fleet acquisition cost	1	total tank capacity
Operational cost	7.17	lt of fuel consumed (fleet)/tanks/No. T-CRAFT

The next step is to extract the capabilities that are required to make Seabasing feasible. Recall from Figure 2 and the five top-level Seabasing measures of performance that 28 M1A1 tanks must be delivered in an 8 – 10 hour period. The additional equipment in the GCE will not be considered. The T-CRAFT is capable of transporting these vehicles; however, this model is only valid for tank payload. For 8 hours, the steady state-tank delivery rate is 84 tanks per day; for 10 hours, the rate is less stringent at 63 tanks per day. No requirement currently exists for the operational and acquisition cost other than that cost should be “reasonable and realistic” (BAA 2005). For this problem, cost will be minimized. The LCAC operational cost in Table 5 shall serve as a basis for comparison to existing systems and methods.  $e_{loading}$  is to be maximized in order to effect rapid off-loading, and  $\eta_{loading}$  is left unconstrained. Finally, in order to maximize T-CRAFT utilization, the sorties per vessel per day are maximized. Table 6 summarizes the targets for the system metrics

Table 6. Targets for system metrics

Metric	Target	Units
<b>Performance</b>		
Steady-state tank delivery rate	$\geq 63$ (T), $\geq 84$ (O)	M1A1 tanks/day
Sorties per vessel per day	maximize	sorties/No. T-CRAFT/day
Loading efficiency	~	%/100
Loading effectiveness	maximize	minutes/minutes
<b>Economics</b>		
Fleet acquisition cost	minimize	total tank capacity
Operational cost	minimize	lt of fuel consumed (fleet)/tanks/No. T-CRAFT

The last step is to explore the design space via Monte Carlo simulation. The inputs to the system are treated as random variables with uniform distributions within the ranges of validity of the neural networks. The resulting outputs are presented as cumulative distribution functions (CDFs). The goal of this approach is to determine the percent feasibility of the design space with respect to the metric targets. If a metric has a high probability (or confidence) of achieving a desired target, the design space available for optimization is considered plentiful and robust. A low probability of success implies that the design space is not sufficiently wide for optimization, and the design variable ranges should be increased to capture potentially feasible solutions.

From the reverse cumulative distribution function (CDF) in Figure 12, the probability of achieving the threshold tank delivery rate is 5.1%. This means that 5.1% of the designs in the design space meet the delivery rate for the 10-hour employment time; 1.6% of the designs meet the delivery rate for the 8-hour employment time. Figure 12 shows one aspect of why the Seabasing concept is difficult to implement: even with new assets there is still a high probability of failure if the Seabasing SoS is not planned correctly. The design space is not robust and optimization is not recommended. At this stage, there are three options: (a) relax the constraints or requirements; (b) expand the design space ranges and repeat 3.6; or, (c) infuse new technologies into the baseline vessel. (a) is not an option at this time since the requirements are set and the approach for (c) has not been developed in this work but is outlined in Kirby (2001). (b) is the recommended option, and would entail increasing the number of T-CRAFT in the mission. For illustrative purposes, optimization will continue with the current design space.

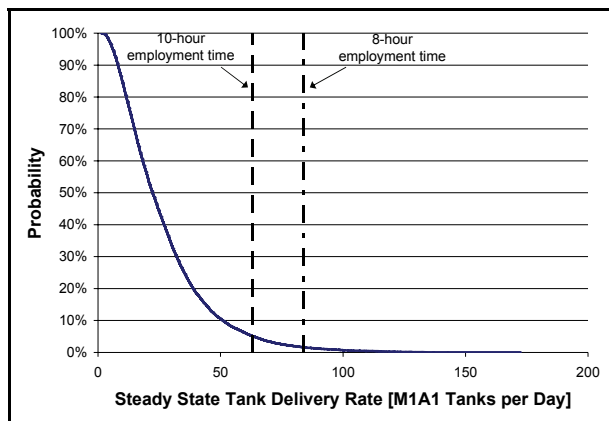


Figure 12. Probability of success in meeting the required steady-state tank delivery rate

Optimization in the JMP<sup>®</sup> prediction profiler is enabled via desirability functions (Rèthy 2004, Engineering Statistics Handbook 2003). Desirability functions convert a multidimensional objective function into a one-dimensional objective function. The optimization results are shown in Figure 13. Table 7

compares the results from the neural networks to the results from the actual model. This indicates the error in neural networks and also obtains actual values for the optimal point.

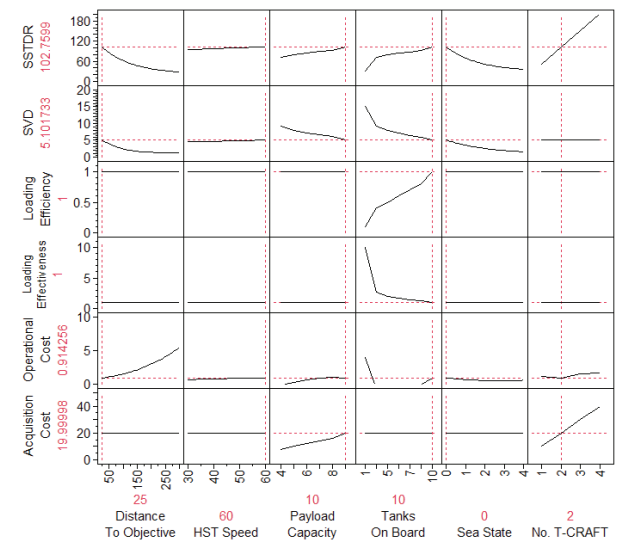


Figure 13. Optimization results

Table 7. T-CRAFT optimization results

Metric	Optimized Value (Surrogate Model)	Optimized Value (Actual Model)	Units
<b>Performance</b>			
Steady-state tank delivery rate	103	102	M1A1 tanks/hour
Sorties per vessel per day	5	5	sorties/No. T-CRAFT/day
Loading efficiency	1	1	%/100
Loading effectiveness	1	1	minutes/minutes
<b>Economics</b>			
Fleet acquisition cost	20	20	total tank capacity
Operational cost	0.91	0.49	lit of fuel consumed (fleet)/tanks/No. T-CRAFT

In this example, the operational cost is highly constraining on the resulting design. Relaxing this constraint yields designs that may operate beyond 150 nm from shore and still meet the required delivery rates. The optimization process presented above is useful for determining system parameters that meet desired capabilities for a single design and for interpolating between design points for more solutions; however, it is inefficient for obtaining a *family* of solutions that provide the desired capabilities. A scatterplot matrix, an example of which is shown in Figure 14, visualizes correlations between selected capabilities and metrics. The points shown may be obtained from the actual model or from the surrogate models. Figure 14 implements the surrogate models so that more design points may be included without re-running the actual

model. In this example, the metrics along with distance to objective are shown. This plot allows the designer to implement constraints and to down-select a family of feasible solutions. Constraints for an 8-hour employment time and distance to objective of 100 nm are implemented as an example. The down-selected scatterplot is shown in Figure 15; only feasible design points are shown.

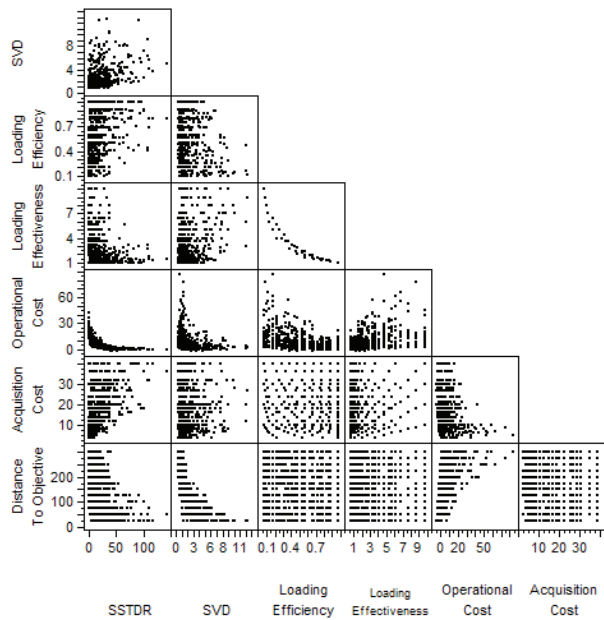


Figure 14. Scatterplot matrix

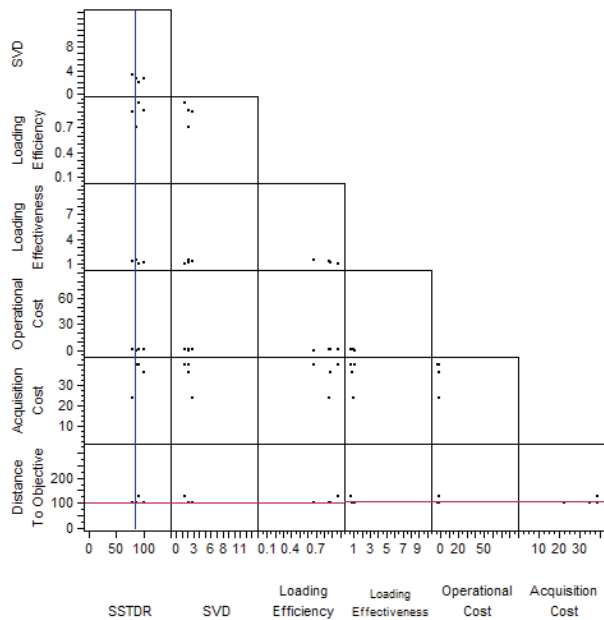


Figure 15. Down-selected scatterplot

#### 4. CONCLUSIONS

A parametric tradeoff environment is developed that enables rapid, probabilistic design space exploration. This quantitative framework can be used to assess capability tradeoffs of the T-CRAFT within the Seabasing concept and is expandable to accommodate additional entities and variable-fidelity physics or

cognition models. The design space can be explored probabilistically in order to determine the feasibility in meeting certain goals. Furthermore, if desired capabilities of the T-CRAFT are defined, a probabilistic simulation can be performed on the neural networks to produce cumulative distributions of the probability of meeting these capabilities under uncertainty.

The neural networks that are developed may be employed in higher level models that depict more than one system for rapid capability-based tradeoffs. This large-scale, multi-aspect system of models is currently being developed by the Aerospace Systems Design Laboratory at Georgia Institute of Technology under funding from the ONR. Using decomposition of the SoS and aggregation of the surrogate models, a high-fidelity Seabasing model may be developed to perform inverse design and capability analysis.

#### ACKNOWLEDGEMENTS

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#### REFERENCES

2003. Multiple Responses: The Desirability Approach. In: *Engineering Statistics Handbook*. National Institute of Standards and Technology. Available from: <http://www.itl.nist.gov/div898/handbook/index.htm> [6 June 2008].
2005. *Sea Base Connector Transformable-Craft (T-CRAFT) Prototype Demonstrator*. Office of Naval Research BAA 05-020. Available from: [http://www.onr.navy.mil/02/baa/docs/baa\\_05\\_020.pdf](http://www.onr.navy.mil/02/baa/docs/baa_05_020.pdf) [5 May 2008].
2005. *Seabasing Joint Integrated Concept*. Department of Defense. Available from: [www.dtic.mil/futurejointwarfare/concepts/jic\\_seabasing.doc](http://www.dtic.mil/futurejointwarfare/concepts/jic_seabasing.doc) [5 June 2008].
2007. *DoD Architecture Framework Version 1.5, Volume II: Product Descriptions*. Department of Defense. Available from: [http://www.defenselink.mil/cio-nii/docs/DoDAF\\_Volume\\_II.pdf](http://www.defenselink.mil/cio-nii/docs/DoDAF_Volume_II.pdf) [5 May 2008].
2007. Live, Virtual, Constructive Training. US Army Combined Arms Center. Available from: <http://usacac.army.mil/CAC/functions/constructive.asp> [5 June 2008].
2007. *Universal Naval Task List (UNTL) Version 3.0*. Department of the Navy. Available from: [http://www.nwdc.navy.mil/content/UNTL\\_NMET\\_L/Files/UNTL%203%20of%2030%20Jan%2007%20CH%201.doc](http://www.nwdc.navy.mil/content/UNTL_NMET_L/Files/UNTL%203%20of%2030%20Jan%2007%20CH%201.doc) [7 June 2008].
2008. Naval Aviation Readiness Integrated Improvement Program (NAVRIIP). *Readiness CpC Summary Definitions*. Available from: [www.cnaf.navy.mil/navriip/content.asp?ItemID=797](http://www.cnaf.navy.mil/navriip/content.asp?ItemID=797) [7 June 2008].
- Biltgen, P. T., 2007. *A Methodology for Capability-Based Technology Evaluation for Systems-of-*



- Systems. PhD Dissertation. Georgia Institute of Technology.
- Bishop, P., 2005. *NDIA Seabasing Study*. 10<sup>th</sup> Annual Expeditionary Conference. Available from: [www.dtic.mil/ndia/2005expwarfare/bishop.ppt](http://www.dtic.mil/ndia/2005expwarfare/bishop.ppt) [5 May 2008].
- Conant, T. L., 2005. *Seabasing: A National Imperative For the Joint Battlespace*. 10<sup>th</sup> Annual Expeditionary Conference. Available from: [www.dtic.mil/ndia/2005expwarfare/conant.pdf](http://www.dtic.mil/ndia/2005expwarfare/conant.pdf) [5 May 2008].
- Copper, K., 2006. *Seabasing Enabler INPs*. 2006 Naval S&T Partnership Conference. Available from: [https://onroutside.onr.navy.mil/aspprocessor/public\\_access/getdoc.asp?pid=3527054&dID=3610367](https://onroutside.onr.navy.mil/aspprocessor/public_access/getdoc.asp?pid=3527054&dID=3610367) [5 May 2008].
- Congressional Budget Office (CBO), 2007. *Sea Basing and Alternatives for Deploying and Sustaining Ground Forces*. Available from: <http://handle.dtic.mil/100.2/ADA469802> [5 June 2008].
- Etessami, K., Gilmore, S., 2007. Model Validation and Verification. In: *Computer Science 4 & MSC: Modelling and Simulation*. Edinburgh: The University of Edinburgh School of Informatics. 102-109. Available from <http://www.inf.ed.ac.uk/teaching/courses/ms/notes/note14.pdf> [5 June 2008].
- Fridsma, G., 1974. *Performance, Stability, and Seakeeping Characteristics of a Model of the 100-B SES Testcraft. Part 1: Performance and Stability Characteristics*. Hoboken, NJ, USA:Stevens Institute of Technology.
- Hootman, J. C., 2003. *A Military Effectiveness Analysis and Decision Making Framework for Naval Ship Design and Acquisition*. Master of Science. Massachusetts Institute of Technology.
- Howard, W., Pilling, D., 2003. *Defense Science Board Task Force on SEA BASING*. Office of the Undersecretary of Defense for Acquisition, Technology and Logistics. Available from: <http://handle.dtic.mil/100.2/ADA429002> [5 May 2008].
- IEEE Std 1471-2000, 2000. *IEEE Recommended Practice for Architectural Description of Software-Insensitive Systems*. Available from: <http://ieeexplore.ieee.org/> [5 June 2008].
- Johnson, C., Schutte, J., 2007. *Basic Regression Analysis and Integrated Neural Networks (BRAINN) Documentation, Version 2.1*. Atlanta, GA, USA:Aerospace Systems Design Laboratory, Georgia Institute of Technology.
- Kirby, M. R., 2001. *A Methodology for Technology Identification, Evaluation, and Selection in Conceptual and Preliminary Aircraft Design*. PhD Dissertation. Georgia Institute of Technology.
- Leite, M.J., Mensh, D.R., 1999. Definition of Evaluation Criteria for System Development Acquisition Modeling and Simulation. *Naval Engineers Journal*, 111 (1), 55-64.
- Microsoft Corporation, 2005. *Microsoft Visual Studio 2005 Professional Edition*. Redmond, WN, USA:Microsoft Corporation.
- Milton, R., 2004. *Using Agent-based Modeling to Examine the Logistical Chain of the Seabase*. Master's Thesis. Naval Postgraduate School.
- Phoenix Integration, Inc., 2007. *ModelCenter 7.1.1*. Blacksburg, VA, USA :Phoenix Integration.
- Rational Software, 1997. *UML Notation Guide Version 1.1*. Available from : [www.omg.org/docs/formal/03-03-10.pdf](http://www.omg.org/docs/formal/03-03-10.pdf) [6 June 2008].
- Rèthy, Z., Koczor, Z., Erdélyi, J., 2004. Handling Contradicting Requirements Using Desirability Functions. *Acta Polytechnica Hungarica* 1:5-12.
- SAS, 2007. *JMP User Guide, Release 7*. Cary, NC, USA:SAS.
- Skinner, D. P. 2004. *Seabasing Roadmap: A Littoral Warfare Systems Perspective*. Available from: [www.dtic.mil/ndia/2004expwarfare/skinner.ppt](http://www.dtic.mil/ndia/2004expwarfare/skinner.ppt) [5 June 2008].
- Ternion Corporation, 2006. *FLAMES Online Documentation, Version 6.1.1*. Huntsville, AL, USA:Ternion Corporation.
- Yun, L., Bliault, A., 2000. *Theory and Design of Air Cushion Craft*. New York, NY, USA:John Wiley & Sons, Inc.

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# CONROCAPS – MODELLING INTERMODAL TERMINALS TO CALCULATE THEIR CAPACITY

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## ABSTRACT

The worldwide increase in transportation leads to capacity problems on seaside as well as hinterland terminals. Based on the rough layout, productivity figures and realistic traffic schedules the capacity of a terminal will be calculated by ConRoCAPS. The system handles Containers as well as RoRo (Roll on, Roll off) cargo. The capacity of each interface (quayside, road, rail) is calculated in a similar manner, based on the facility structure, the carrier mix and available resource types and the annual turnover regarding shift schedules and terminal processes. The results show figures concerning utilization and productivity as well as operation, idle and waiting times. This tool enables the planner to detect bottlenecks in very early phases and dimension the interfaces of the terminal in a balanced way.

Keywords: capacity, terminal planning, productivity

## 1. INTRODUCTION

Actual studies predict a continuing growth in seaborne trade and especially the worldwide container flow (Heideloff et al. 2007, Stenvert et al. 2007). Multimodal hinterland terminals as well as seaport terminals have to cope with these demands. For the planning of new terminals as well as for the reconstruction existing ones the calculation of terminals capacity is based on the layout, the equipment needed and facility parameters.

Various authors have developed container terminal simulation systems to estimate the capacity. Boll (2002) presented a tool to calculate maritime terminal's capacity and also presented an example (Boll 2005). Gronalt (2006) developed SimConT, a tool for hinterland terminals. Schütt (2006) presented a similar tool for intermodal rail terminals, developed for the demands of the US market. Further papers are listed by Steenken et al. (2004) and Stahlbock et al. (2007).

## 2. CONROCAPS

ConRoCAPS is a simulation system for capacity investigation regarding the various terminal facilities. The system is able to simulate combined terminals, i.e. RoRo (Roll on – Roll off) and LoLo (Lift on – Lift off) handling. Both kinds of operation can be simulated separately and also combined. The simulation model

considers the quay (vessel service), the railway tracks (train services) and the gate operation (truck handling) of a combined terminal.

Out of this layout information and a given throughput the required quay length, the number and length of railway tracks and the number of lanes for the in-gate/out-gate can be determined. Furthermore the model gives information about service time and waiting queues at these interfaces as well as information about the yard space needed. It is possible to analyse various strategies with their pros and cons (e.g. consequences of elimination of processes, parallelisation and aggregation of processes, different berthing strategies of vessels, shunting of railroading, optimal productivity in terms of volume utilisation of trains, trucks and vessels).

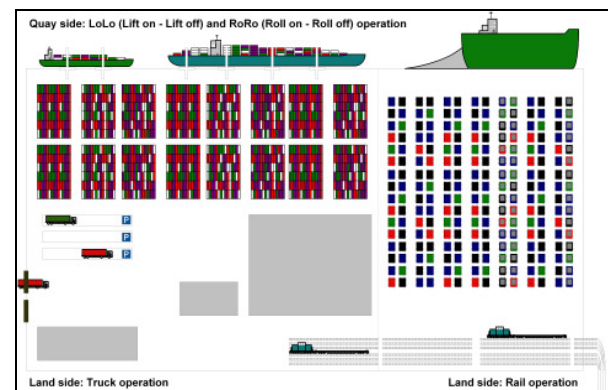


Figure 1: Terminal Interfaces which can be Analysed by ConRoCAPS

### 2.1. The structure of ConRoCAPS

Each interface is developed as an individual and independent simulation systems. Each simulation system consists out of an input module, the simulation module itself and the output part. Global parameters which have relevance for all three interfaces, e. g. type of cargos to be handled on the terminal, can be defined as global parameters.

Each interface is identically structured as shown in figure 2:

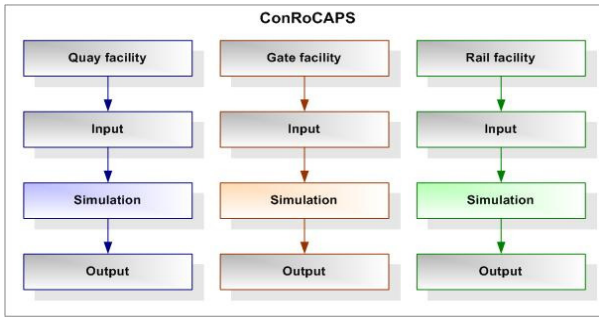


Figure 2: Interface Structure

Besides others the following questions can be analysed by this simulation model:

- Influence of changes in the modal split (vessel : rail, vessel : road, road : rail etc)
- Influence of different vessel types and types of trains (more big vessels or more small vessels, length and utilization of trains)
- Test of different process chains
  - Elimination of processes
  - Parallelisation of processes
  - Aggregation of processes.

The simulation course of the interfaces is executed in the following manner:

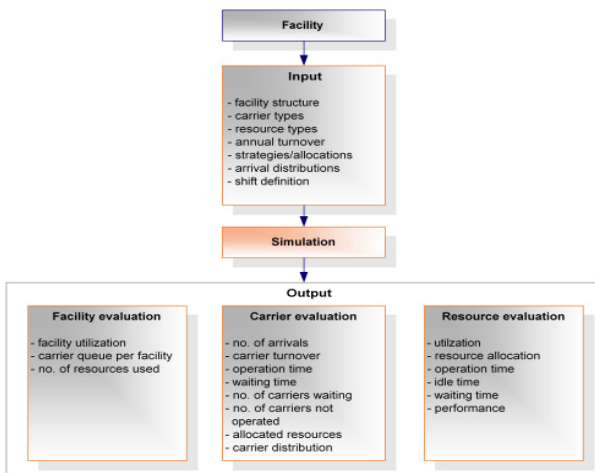


Figure 3: Interface Simulation Course

On the basis of the annual turnover, the carrier volume and weekly as well as annual arrival distributions the system calculates an arrival pattern for each carrier type which is executed during simulation.

Adapted from restrictions, allocations and strategies, which are part of the data input, the system simulates the operation of the carriers and saves continuously variable data which are aggregated after the simulation time of one year and prepared for three kinds of evaluation (fig 3):

- facility evaluation
- carrier evaluation
- resource evaluation

## 2.2. Types of cargo

The definition of different types of cargo is essential for the ConRoCAPS as shown in figure 4. Typical cargo types are container, cars, chassis, break bulk and other.

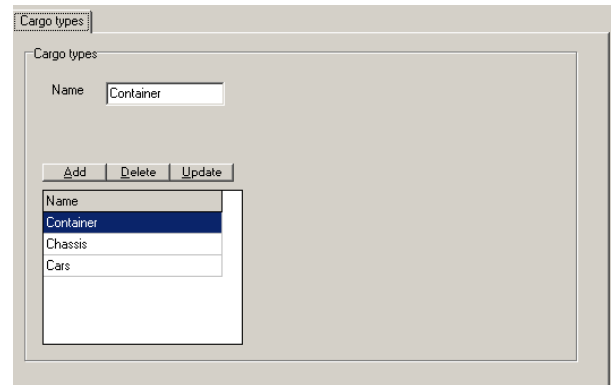


Figure 4: Screenshot of Cargo Type Definition

Each carrier and resource type will depend on the cargo types in behaviour and productivity.

## 2.3. Rail facility

The rail facility will be taken to demonstrate the input, simulation and animation as well as the output of the system.

First the annual throughput and seasonal distributions have to be entered (fig. 5). These information are dependent on the cargo type. The number of moves is split up to the cargo types and the distribution may differ between the types.

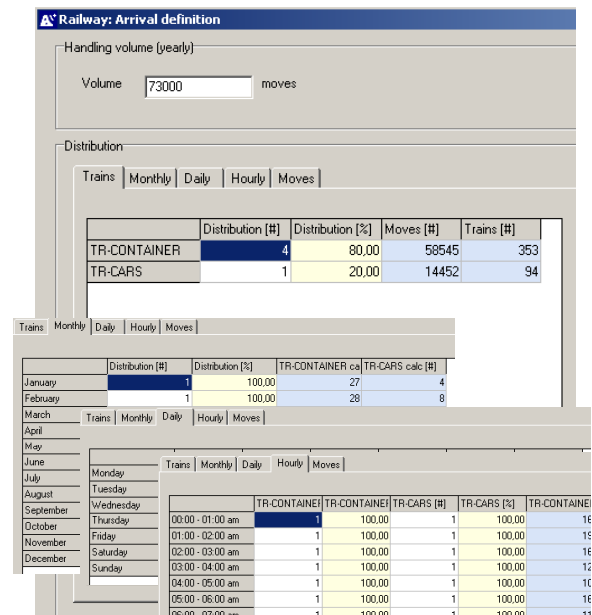


Figure 5: Input of Annual Turnover and Seasonal Distributions

On the other hand the carrier types (i.e. the trains) have to be defined (fig 6). In a first step the wagon types have to be entered. Each wagon type may carry different types and amount of cargo. The train definition

is based on these wagon types and includes additional information about the utilization and the cargo split.

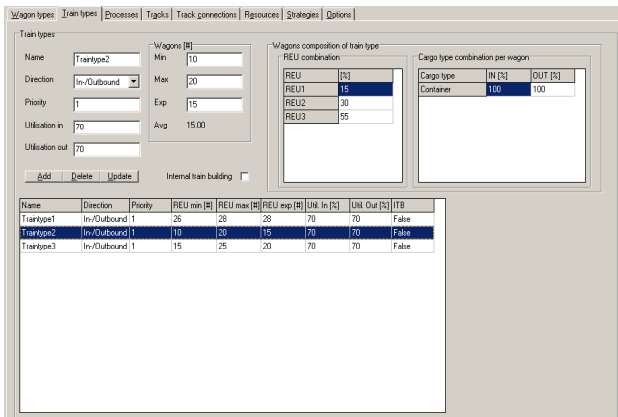


Figure 6: Train Definition

Based on these information (throughput and train types) the system generates train schedules automatically.

In the next step the operation has to be defined. First the resources for the service (i. e. equipment, e.g. cranes, fork lift trucks, terminal tractors) are entered (together with a shift schedule) regarding different productivities (moves/hour) for the various cargo types (fig. 7). They are used for the loading and unloading of the cargo. Besides these default processes other ones may be defined by the user (e.g. for air testing, cargo checking).

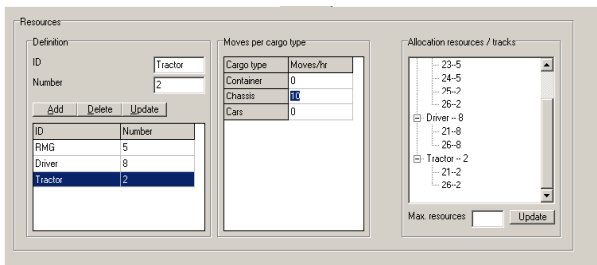


Figure 7: Resource Definition

The description of railway facilities (length and number of tracks) defines the layout of the terminal. And last but not least the strategies of the operation (i.e. allocation of processes to train types, allocation of tracks to train types, allocation of trains and resources to tracks)

With these information the simulation (fig. 8) may be started. The simulation system is based on a discrete event manager. After generating the train schedule the trains are generated in a hub (interface to the external railway system). They enter the assigned track if the connection and the track itself is ready for them. The attached processes start their work, whereas the assigned resources are split to all trains in a FIFO (first in first out) sequence regarding tracks productivity and the shift schedule.

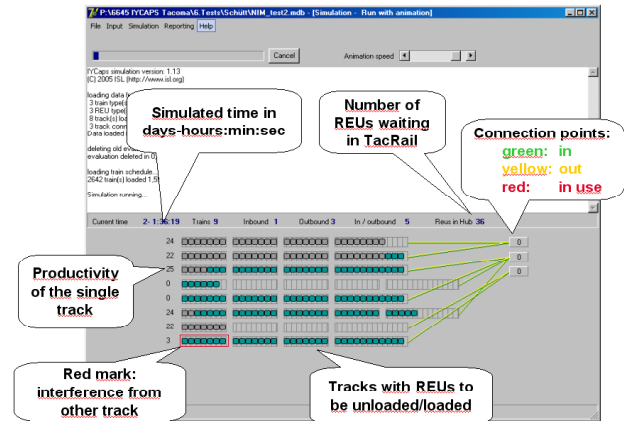


Figure 8: Simulation and Animation

Nearly all events are saved in a database for further evaluations. In this way the user may define his own queries besides the standard evaluations of ConRoCAPS. These are throughput, productivity and utilisation analysis of trains, tracks, and resources.

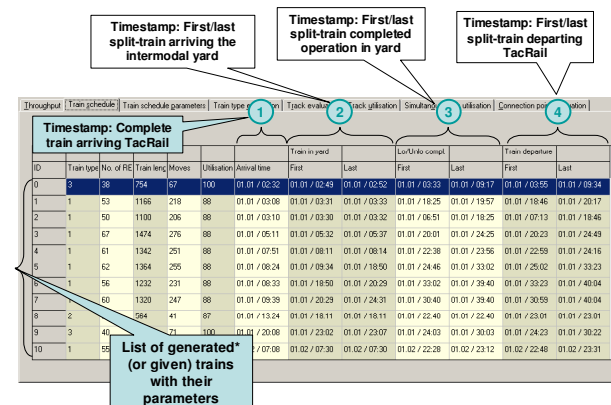


Figure 9: Generated Train Schedule with Event Timestamps

The train schedule (fig. 9) is enhanced by various times of operation (train in yard, start of operation, load/unload complete, train departure). Furthermore information about operation time, time for waiting for equipment, and average as well as max. productivity are available.

Connection point	Total split trains	Waiting trains	Waiting time total	Waiting time avg.
CP1	1574	68	03:15:04	00:00:32
CP2	3186	327	16:00:06	00:02:37
CP3	1634	47	02:10:40	00:00:21

Figure 10: Layout Analysis

The available facilities may be analysed using figures about the utilisation of tracks and/or the connection points (fig. 10). The main figure in analysing the simulated operation is the *staying in terminal* evaluation as shown in Figure 11.

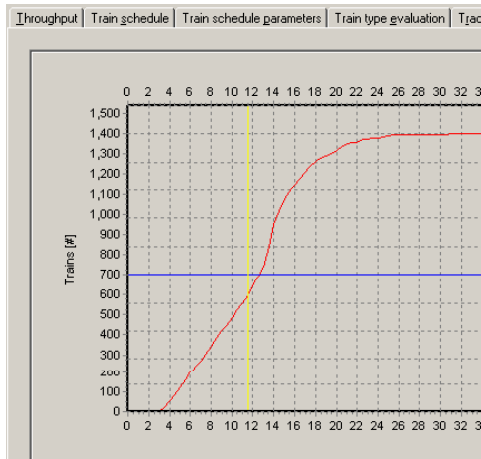


Figure 11: Staying in Terminal Analysis

The diagram shows the total time of each train in the terminal (sorted by duration). In this case 100% of all trains (1.400 trains) left the terminal at the latest after 31 hours. No train was faster than 3 hours, more than 1.250 trains (90%) left within 18 hours. This figure may be used as a service figure within contracts (i.e. *we guarantee 90% of your trains will be operated within 18 hours*).

#### 2.4. Quay facility

The simulation of the quay facility is very similar to the train simulation. Mostly the layout definition varies (of course). As to be seen in Figure 12 the quay is split up into various quay segments.

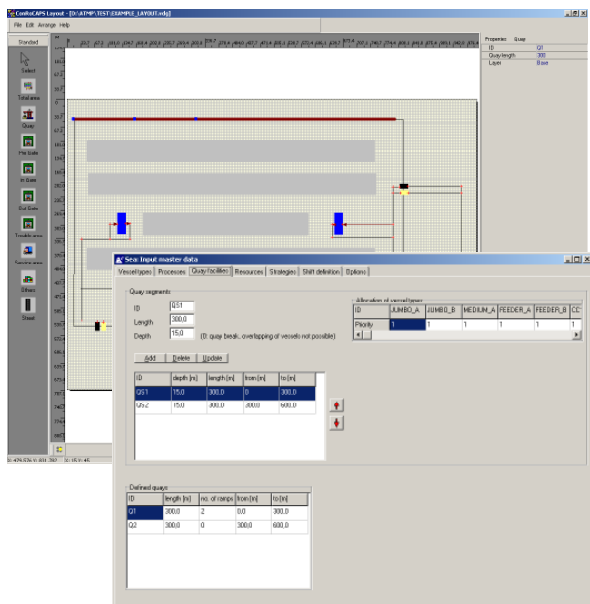


Figure 12: Staying in Terminal Analysis

The definition of vessels, of the throughput, of processes and within these also the schedule generation is nearly the same as used by the rail module.

The main analysis figure in the quayside module is the number of cranes used in parallel.

no. of StSC	Share of time	Availability
1	0.64%	0.64%
2	12.20%	12.83%
3	3.84%	16.67%
4	11.57%	28.24%
5	9.32%	37.57%
6	10.10%	47.66%
7	8.19%	55.85%
8	9.12%	64.98%
9	7.95%	72.93%
10	7.22%	80.15%
11	6.40%	86.55%
12	3.54%	90.09%
13	2.07%	92.16%
14	2.84%	95.00%
15	2.53%	97.53%
16	1.35%	98.87%
17	0.31%	99.18%
18	0.56%	99.74%
19	0.26%	100.00%

Figure 13: Crane Analysis

As to be seen in Figure 13, 15 cranes or less were simultaneous used in 97.5 % of the time. The other four cranes may not be needed for operation, without loss of productivity. Another simulation with a reduced amount of cranes will answer this question.

#### 2.5. Gate facility

The main difference of the Gate facility module (regarding quay and rail module) is the additional usage of a traffic network on the terminal.

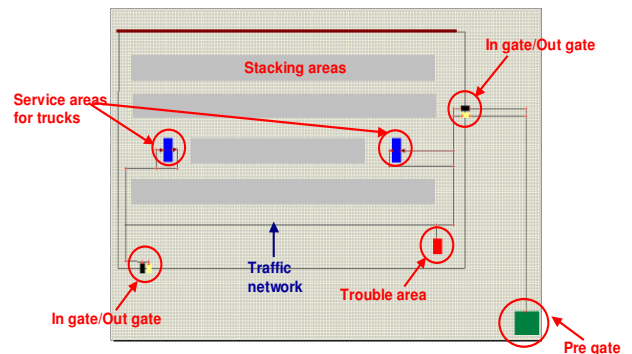


Figure 14: Truck Traffic Network

The network (fig. 14) contains the pregate, the in/outgate, trouble areas and the service areas for trucks as well as the roads to be used by the trucks. In this way the *staying in terminal analysis* includes also driving and waiting times at these service points.

### 3. CONCLUSION AND OUTLOOK

ConRoCAPS allows the planner of seaport as well as hinterland terminals to calculate terminals capacity and some other key data in the beginning of the planning phase. The results are based on few input parameters and may be detailed in the planning progress step by step.

The tool (and its preceding versions) has been used for terminal planning in various projects. Various terminal operators calculated their quay side capacity, so done by the JadeWeserPort Realisation Company in a very early project state. The Port of Tacoma (US) uses it for planning their intermodal yard facilities including double stack container trains. The project MOSES (Motorways Of the Sea European Style, supported by the European Commission) will use it for analysing RoRo facilities.

The next step in development will be a yard analysis module, which will calculate the needed space for given throughput scenarios.

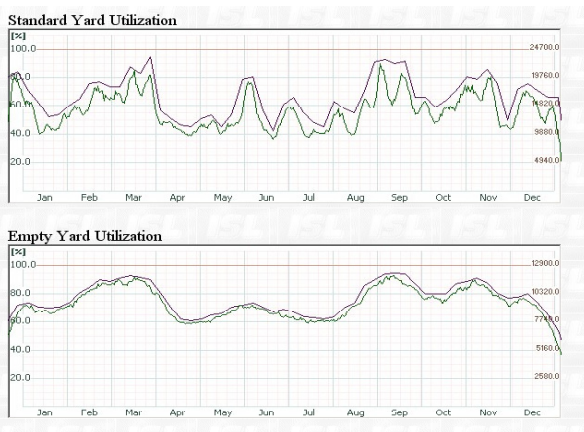


Figure 15: Yard Utilisation of Different Cargo Types

Figure 14 shows the result of a yard analysis module, where the utilisation of all defined cargo types may be shown in the diagram.

With this extension ConRoCAPS will be a simulation based tool supporting the planner of seaside as well as hinterland terminals by analysing the quay, the rail, gate and the yard facilities. It may be used in a very early state of planning to calculate terminals capacity. Furthermore it may be detailed simultaneously to the planning and allows dimensioning the facilities (e.g. number of tracks, amount of resources) as well as test operation processes and strategies.

### REFERENCES

Boll, Carsten, 2002. CAPS – Simulationsmodell zur Bestimmung der Umschlagkapazitäten von Seehafenterminals (german). *Proceedings zum 8. Symposium Simulation als Entscheidungshilfe: Neue Werkzeuge und Anwendungen aus der Praxis*, pp 217-225. March 11-13, Braunlage Germany.

Boll, Carsten, 2005. Future of Container Ports - handling and productivity -. *Proceedings of Port*

*Congestion Solutions USA*. October 27-28, San Francisco, USA.

Gronalt, M., Benna, T., Posset, M. 2006 SimConT: A Tool for Quick Layout and Equipment Portfolio Evaluation and Simulation of Hinterland Container Terminal Operations. *Proceedings of the VEAM IFIP Working Group 7.6 Workshop on Virtual Environments for Advanced Modelling*, pp 7-10. June 6-9, Hamburg, Germany,.

Heideloff, Christel and Zachcial, Manfred (editors), *2007 Shipping Statistics and Market Review, Vol. 51, No. 12-2007*, ISSN 0947- 0220

Schütt, Holger , 2002 Kapazitätsbestimmung für intermodale Terminals (german). *Proceedings zum 8. Symposium Simulation als Entscheidungshilfe: Neue Werkzeuge und Anwendungen aus der Praxis*, pp 245-254. March 11-13, Braunlage Germany.

Stahlbock R., Voß S., 2007 Operations research at container terminals – a literature update. *OR Spectrum DOI 10.1007/s00291-007.0100-9*.

Steenken D., Voß S., Stahlbock R., 2004 Container terminal operation and operations research – a classification and literature review, *OR Spectrum* 26: pp 3-49.

Stenvert, Remco and Penfold, Andrew , 2007. *Container Port Strategy – Emerging issues*, Chertsey/Surrey: Ocean Shipping Consultants,

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# A RISK ASSESSMENT APPROACH FOR INLAND CONTAINER TERMINALS

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## ABSTRACT

Inland container terminals are, due to their operational daily business and environmental conditions faced with several risks having different degrees of consequences. Current risk assessment methods for terminals just consider dramatic events like terrorist attacks. We present a new method for the assessment of risk and vulnerability of inland container terminals, also including terminal internal and environmental factors.

Keywords: risk assessment methodology, inland container terminals, risk profile

## 1. INTRODUCTION

Ever more frequent disturbances and irregularities in the flow of goods in transport chains and transport systems reflect the importance of evaluating supply chain risk potentials. Disturbances in the supply chain can be caused by an act of sabotage on transport chains or their infrastructure, as well as by natural hazards, including flooding or earthquakes. Specifically in Austria natural hazards like storms, heavy rains, avalanches and floods are of great importance.

A supply chain can be defined as a “network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer” (Christopher, 1992). An intermodal supply chain is a multi-element transport chain consisting of pre-carriage of cargo to a terminal, the transshipment to another means of transport and the following actual change of location on that modus. The transportation process ends after a further transshipment and the on-carriage of the goods or containers. Container terminals thereby represent the essential infrastructure for the turnover process.

The German authority Federal Office for Information Security defines critical infrastructure as “organisations or facilities of key importance to public interest whose failure or impairment could result in detrimental supply shortages, substantial disturbance to public order or similar dramatic impact”, which

includes transportation and traffic (Hellström, 2007). Austrian inland container terminals can be considered as critical infrastructure, because major industry branches depend on container transport logistics. As a consequence, the terminal nodes are crucial hubs for intermodal (rail, truck, ship) container turnover in logistics networks.

In contrast to numerous national and international security guidelines and initiatives for seaports, there exist no obligatory legal guidelines for inland terminals.

A longer persisting disruption of a certain stage - respectively a node - of a supply chain can cause massive damages which are hard to quantify. Such an incident can affect the whole supply chain, i.e. from suppliers, who no longer can deliver their goods, up to the customers, who don't receive them.

The remainder of the paper is organized as follows. In Chapter 2 we highlight related works in supply chain risk assessment and classification. Chapter 3 gives a presentation and critic of the pro and cons of a risk assessment method for terminals developed by the International Union of combined Road-Rail transport companies (UIRR). In Chapter 4 we then present a new risk assessment approach, developed in a field study of Austrian inland terminals. Furthermore, we show the differences of our developed risk assessment approach to the mentioned industry guidelines and give reasons for our modifications. In addition to that, we illustrate our method, using a real-world example of an Austrian inland terminal. We conclude in Chapter 5 with the identification of future research needs.

## 2. RELATED WORKS

Supply chains can be exposed to many forms of risks, which emphasises the importance of research. Minor (2005) points out four major reasons why intermodal supply chains are especially prone to risks. First, supply chains today are time-sensitive. If supply chains are just-in-time, disruptions have more severe effects, than if there would be a time buffer. Second, there exists a massive reliance on non-standardised or tailored inputs. If goods are tailored to exact specifications, a new supplier would take weeks or even months to reengineer

its supply lines. Third, most companies rely on single- or limited-source supplies – the reliance on tailored goods indicates, inherently, a limited-source supply chain. The last point Minor mentions, is the reliance of (producing) companies on single geographies - sometimes one country is simply the best supplier for a good.

Therefore, the handling of risks and complex processes is gaining importance in managing supply chains. Risks in supply chains generally can be classified in several ways. Out of many approaches there are several that are adequate for inland container terminals. A distinction between market risks and operational risks is proposed by Chopra and Sodhi (2004). Market risks comprise demand and exchange rate risks; operational risks can be subdivided in acquisition and process risks. Christopher and Peck (2004) use the “point of origin” approach which could be used to classify risks for terminals. On the one hand, there are process and control risks arising within the regarded organisation. On the other hand, there are supply and demand risks emanating from supply chain partners. In addition to that, environmental risks can occur due to socio-political or macroeconomic reasons or natural disasters.

An overview on supply chain management with an account to risk is presented by Kersten et al. (2006). Supply chain management includes the corresponding risk and complexity management, since various stages are obliged to co-operate. Thus, risk assessment is also considerably relevant for each individual company involved. The authors also show that there is a difference in assessing sources of risks between producing companies and logistics firms.

A framework of risk assessment and characterisation of risks in supply chains is presented by Deleris and Erhun (to appear). Their analytical process starts by defining the considered system and performance value using expert opinions and flow charts. In the next step they identify possible risks and show how they interdependently influence each other. This step is based on statistics and expert opinions. The last two stages of the framework are risk quantification and risk management.

A lot of work on risk assessment in supply chains has been undertaken by many authors. Research concerning risk and transportation infrastructure is presented for example by Knoflach et al. (2002), Riley (2004) or the Volpe National Transportation Systems Center (2003). As well, considerable work has been done in the topic of container security, focusing on the transport loading unit itself (for example Seidelmann, 2007). The International Labour Organization and the International Maritime Organization present a framework for port security assessment (ILO/IMO, 2003). To the best of our knowledge, except for the UIRR guidelines, which we present in the following chapter, no corresponding work for inland container terminals exists.

### **3. UIRR METHOD OF RISK ASSESSMENT FOR COMBINED TRANSPORT TERMINALS**

The need to develop a method of risk analysis for inland container terminals evolved on the basis of the reviewed literature and guided framework interviews, expert opinion polls and on-site-inspections at several Austrian inland terminals.

Among others, the method and guidelines for the risk analysis of combined transport terminals, provided by the International Union of combined Road-Rail transport companies - UIRR, (UIRR, 2007a and 2007b), were a starting point for our risk analysis approach. In the UIRR's view an exposure to threats of a terminal is given by the mean and possibility of destructing the terminal itself, or the mean of affecting the natural or technical infrastructure surrounding the site.

The first step of the UIRR analysis is the identification of possible threats, starting with a framework of possible malicious terrorist operations. Questions asked in this context are for example, why a terminal could be the target of an attack, and how this could happen. Basically, the analysis distinguishes here between three scenarios. First, the attempt to destroy the terminal or parts of its contents, second, the use of the terminal as a source for products or material for the later deployment for an attack, and third, the usage of the terminal as starting point or transit facility for concealed persons or material in a loading unit.

The second step of the analysis presents the evaluation of the sensitivity of the terminal. The susceptibility and the location of the terminal are considered as the two main factors of vulnerability. A measure for the susceptibility is the presence of dangerous substances on the site. This represents the key role for a feasible terrorist interest in combined transport terminals. The location of a terminal is of importance in case of nearby densely populated areas or crowded areas like schools, hospitals, stadiums etc. or the closeness to critical infrastructures like air ports, transport corridors, chemical plants or other facilities.

In order to estimate the sensitivity of the terminal site, two other factors - on the one hand already taken precaution measures to ensure the security, and on the other hand the state of alert as published by public authorities - have to be considered. Eventually, risks can be defined on the basis of the threats to which a terminal is exposed to, and its specific vulnerabilities in combination with the possible consequences of a terrorist act for the terminal in question and its surrounding environment.

The UIRR itself criticises some points of its method of risk analysis. One of them is the difficulty of estimating probabilities of occurrence for actions of terror. For these cases no statistic argumentation is possible. Moreover, distances between the terminal and its surrounding infrastructure and environment are specified arbitrarily for the determination of the area of vulnerability, thus, a (negative) discrimination of terminals can happen. In addition, no domino effects are



considered in the evaluation of the consequences of a possible act.

According to our opinion, the method of the UIRR is a further general framework for risk analysis and doesn't give concrete suggestions for the computation of the potential risks of a terminal and therefore, its vulnerability. Furthermore, the view of the risks, a terminal can encounter, refers purely to possible threats of terrorism. This focus is understandable, considering the world-wide developments in the last years. However, operational risks and risks to the terminal, emanating from the surrounding infrastructure and from environmental conditions play an important role as well. In general, effects of these risks are considered to be less dramatic than a terrorist attack, but a much higher frequency and probability of occurring can be assumed.

For this reasons, the method of the UIRR did not seem appropriate enough to cope with the situation of Austrian intermodal supply chains. As a consequence, we developed our own approach for the classification of risks and vulnerability assessment for intermodal transport nodes.

#### 4. A NEW APPROACH FOR RISK AND VULNERABILITY ASSESSMENT OF INLAND TERMINALS

The structuring of risk sources builds the basis for our directed identification and analysis. Risk categories, including their subclasses for inland container terminals, can best be illustrated by using a three-step process, which is oriented towards the framework of Deleris and Erhun (to appear). In the first step a complete description of the terminal regarding its operations and all other risk assessment factors is developed. It is also arranged according to the three risk dimensions identified by Christopher and Peck (2004). In the second step, we picture the point of origin of all possible disturbance events to a terminal, corresponding to the aforementioned description. The following impacts of these disturbance events are classified in the third step. Thus, a logically consistent path is guaranteed.

##### 4.1. Risk Identification and Classification Step 1: Terminal description

The elements describing a terminal are classified into the three main-categories "terminal internal factors", "network factors" and "surrounding conditions". The components of the first sub-category (see Table 1) are specified in more detail through another sub-categorisation. For example, a terminal is described through the internal factor "yard", which is characterised by the storage area, the empty-container storage and the storage area for dangerous goods. A further description of the singular subcategories is realised in additional stages.

##### Step 2: Risk identification and classification

The classification of the potential risks for a terminal is undertaken by the determination of their point of origin. The categories of risk sources are: "diminished availability", "capacity overload", "accidents", "failures and communication failures", "acts of sabotage and attacks", "natural disasters and weather" and "economical and political incidences". These sources are appropriately assigned to the three main-categories corresponding to the terminal description.

Table 1: Terminal Description

Categories	Factors
terminal internal factors	workforce
	external persons at the site
	turnover
	yard
	edificial facilities
	equipment
	rail-road-waterway infrastructure
	ICT
	security facilities
	risk management
	backup facilities
network factors	network-role of the terminal
	transport connection
	network ICT
surrounding conditions	natural environment
	technical environment
	economical and political situation

In this context it is important to be aware of the fact that the sources designated in this classification could be the cause of a risk, but also concurrently the result, respectively the consequence of a cause, which denotes the mutual relationship.

The link between the first and the second step of the method is given by the elements of the first sub-category of the description of the terminal and the second sub-category of the risk classification (see Table 1 and Figure 1). For a better understanding we give a few examples in the following:

- *Terminal operations* are negatively affected through a *diminished availability* of the *workforce*, caused through *absenteeism*.
- *Terminal operations* are negatively affected through a *high utilisation* in the *network*, specifically a *capacity overload of the rail track*, which belongs to the *network connection*.
- *Terminal operations* are negatively affected through an event in the *surrounding conditions* of the terminal, more precisely an *attack on the technical environment*, with the result of a *fire* and consequently a *blockade of the motorway intersection*.



Figure 1: Risk Classification

The intuitive simple form of presentation in a mind map of the risk classification in Figure 1, is selected intentionally for getting an easy overview to the extensive components. The outermost branches are exemplary for concrete scenarios, and therefore don't represent an exhaustive enumeration.

To describe a scenario in more detail, one can use the terminal description from step 1, and hence, specify the description of the elements by the use of the conjunctive layer between step 1 and step 2.

For more information about the terminal description, please contact the authors.

### Step 3: Assignment of consequences

The third step in our risk analysis approach subdivides the possible consequences of feasible disturbances or disruptions of terminal operations. We try to estimate the extent and the duration of impact, as well as its intensity. Effects of disruptions can concern the incoming and outgoing of loading units through road-, rail- and/or waterways, and as a consequence reduce the total performance of the terminal (see Table 2).

Table 2: Structure of Consequences

Consequence		Extension (yes / no)	Duration	Intensity 0-100 %
Throughput	Rail	Incoming		
		Outgoing		
	Road	Incoming		
		Outgoing		
	Waterway	Incoming		
		Outgoing		

#### 4.2. Analysis of vulnerability

The next step after the identification of all possible risks, a terminal and its operations can face, is to conduct a vulnerability assessment on the level of the particular factors describing a terminal. For this purpose, we developed a set of several two-dimensional matrices, which only take into consideration the decisive elements for causing potential vulnerabilities to disruption or disturbance, out of all the describing elements of a terminal from step 1. We assess the susceptibility to suffer a disturbance, and in a second instance, the ability to react adequately to a negative event happening in these decisive elements.

Assigned to the matrix is a scale with five grades, ranging from “strongly negative” to “positive” in concern to terminal vulnerability. In case of multiple applicable categories, the terminal is classified by the most negative one. Primarily, the assessment is performed with a view to terminal operations, and secondarily it considers other risk sources, like the possibility of natural hazards or acts of sabotage.

For example, a terminal is assessed by risk and vulnerability resulting from its workforce. The dimensions of evaluation are the workforce structure and its utilisation. The structure of the workforce is characterised by the cumulative job tenure of the own staff, and by the employment of leased staff. The extent of the job tenure allows implications on the qualification and routine of the workforce. (Short time) leased staff generally is less familiar with terminal operations than the permanent staff. Performing the evaluation, we assume that a highly skilled own staff is able to compensate flaws caused by temporary employees. Figure 2 shows the result for the factor “workforce” for one of the analysed Austrian terminals, classified in the way depicted above.

Another, very significant factor for inland container terminals is the transshipment equipment. Regarding this factor, the vulnerability is evaluated by the utilisation of the equipment and the ad-hoc availability of potential substitutes. In the event of a breakdown, equipment can thus be replaced by other existing equipment of the same or of another type. For the evaluation, we assume that in the latter case larger constraints emerge in the transshipment process. Moreover, the overall utilisation considerably affects the substitutability. It defines the free capacities of the remaining functional equipment (see Figure 3).

A framework with the same procedural method for all factors of the terminal description (see Table 1) was developed.

Scale: Assessment of vulnerability  
strongly negative    negative    slightly negative    neutral    positive

WORKFORCE		Structure			
Utilisation		leased staff, short job tenure of company's staff	just company's staff, short job tenure	leased staff, long-time job tenure of company's staff	just company's staff, long-time job tenure
full					
high					X
normal					
low					

Figure 2: Assessment of Workforce

EQUIPMENT		Substitutability			
Utilisation		no substitutability	possible through other type of equipment	possible through same type of equipment	possible through other and same type of equipment
full			X		
high					
normal					
low					

Figure 3: Assessment of Equipment

The overall picture of a terminal’s vulnerability evolves from the depiction of the evaluated complete set of factors in a vulnerability profile. Hence, the identified weaknesses are visible at a glance. Figure 3 shows the vulnerability profile of one of the analysed Austrian terminals. The marked area indicates the non-critical factors in the terminal.

With such a vulnerability profile a clear form for contrasting different terminals against each other is provided, and an extensive reflexion of the vulnerability of a terminal network, respectively a supply chain network, is possible.

### 5. CONCLUSION AND NEED FOR FUTURE RESEARCH

We have shown that inland container terminals as important nodes of international supply chains face more and ever more complex risks. Not only dramatic terrorist events can pose a challenge and risk to supply chains (even though not a single incident in the last years of terrorists attacks on supply chains or container terminals is known – one can only speculate on the reason for this). Other risks, emanating from the daily business, the structure of terminal operations, its environment or surrounding infrastructure can be named and are often much more frequent, and sometimes even

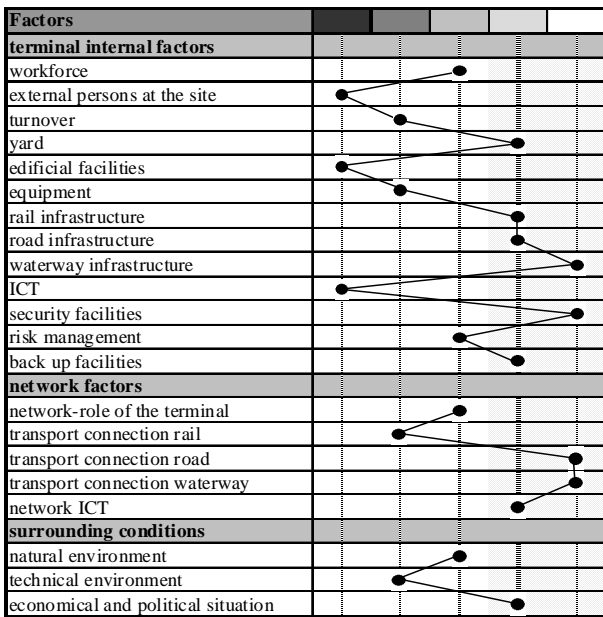


Figure 3: Vulnerability Profile of a reference terminal

as severe as terrorists attacks. Therefore, we developed a methodology and framework to undertake more comprising risk and vulnerability assessment of inland container terminals.

As container terminals just constitute the nodes in intermodal supply chains, an extension of our research will focus on the several carriers and modes of transportation in such multimodal supply chains. Further, as a chain is ever only as weak as its weakest link, the assessment of the nodes can only be one part in a comprising risk assessment of supply chains. Hence, we intent in further research to take an unagitated look on the matter of risk assessment of the different possible edges between the nodes in intermodal supply chains.

### ACKNOWLEDGMENTS

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### REFERENCES

Chopra, S., Sodhi, M.S., 2004. Managing Risk To Avoid Supply-Chain Breakdown. *MIT Sloan Management Review* 46(1): 53-61.

Christopher, M., 1992. *Logistics and supply chain management*. London: Pitman Publishing.

Christopher, M., Peck, H., 2004. Building The Resilient Supply Chain. *International Journal of Logistics Management* 15(2): 1-14.

Deleris, L.A., Erhun, F., to appear. Quantitative risk assessment in supply chains: a case study based on engineering risk analysis concepts. In: Kempf, K., Keskinocak, P., Uzsoy, R., eds. *Handbook of Production Planning*. Boston: Kluwer Academic Publishers.

Hellström, T., 2007. Critical infrastructure and systemic vulnerability: Towards a planning framework. *Safety Science* 45: 415-430.

ILO/IMO, 2003. *Code of practice on security in ports*. International Maritime Organization. Available from: [http://www.imo.org/includes/blastDataOnly.asp/data\\_id%3D9179/ILOIMOCODEDRAFTmesshp-cp-aEnglish.pdf](http://www.imo.org/includes/blastDataOnly.asp/data_id%3D9179/ILOIMOCODEDRAFTmesshp-cp-aEnglish.pdf) [accessed 7 May 2008].

Kersten, W., Böger, M., Hohrath, P., Späth, H., 2006. Supply Chain Risk Management: Development of a Theoretical and Emperical Framework. In: Kersten, W., Blecker, T., eds. *Managing Risks in Supply Chains, How to built reliable collaboration in logistics*. Berlin: Erich Schmidt Verlag GmbH & Co, 3-18.

Knoflacher, H., Pfaffenbichler, P.C., Nussbaumer, H., 2002. Quantitative risk assessment of heavy goods vehicle transport through tunnels – the Tauerntunnel case study. *Proceedings of 1<sup>st</sup> International Conference Tunnel Safety and Ventilation*, NA. April 8-10 (Graz, Austria).

Minor, J., 2005. *Protecting Supply Chains Against Political Risks*. Aon Political Risk Service, Aon Trade Credit. Available from: [http://www.aon.com/about/publications/pdf/issues/Supply\\_Chain\\_Risk\\_2005.pdf](http://www.aon.com/about/publications/pdf/issues/Supply_Chain_Risk_2005.pdf) [accessed 23 October 2007].

Riley, J., 2004. *Terrorism and rail security*. RAND Corporation. Available from : <http://www.rand.org/pubs/testimonies/CT224/index.html> [accessed 20 March 2008].

Seidemann, C., 2007. Developing and Implementing global interoperable standards for container security. In: Bichou, K., Bell, M.G.H., Evans, A., eds. *Risk management in port operations, logistics and supply-chain security*. London: Informa, 55-60.

UIRR, 2007a. *UIRR Risk Analysis, Guidelines for Combined Transport Terminals*. International Union of combined Road-Rail transport companies. Available from: <http://www.uirr.com> [accessed 12 July 2007].

UIRR, 2007b. *UIRR Recommendations on improving Security in Combined Transport*. International Union of combined Road-Rail transport companies. Available from: <http://www.uirr.com> [accessed 12 July 2007].

Volpe National Transportation Systems Center, 2003. *Risk assessment and prioritization*. Volpe Center: Volpe Journal 2003. Available from: <http://www.volpe.dot.gov/infosrc/journal/2003/pdfs/chap1.pdf> [accessed 14 May 2008].

# SHIP-TO-SHORE GANTRY CRANE SIMULATOR DESIGN: CRANE OPERATOR PERFORMANCE ANALYSIS AND ASSESSMENT TOOL OF CAGLIARI UNIVERSITY

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## ABSTRACT

This paper describes the ship-to-shore gantry crane simulator developed by authors at Cagliari University. The simulator has been designed and constructed as a means for reducing quayside crane operator error through virtual reality training and investigations, using a physical simulation model. Quayside crane operators in container terminals are increasingly exposed to latent sources of stress because of the continuing advances in crane functionality. This has led to an increasing demand for highly skilled operators in container shipping, a sector that has been experiencing exponential growth for many years now. This work describes the main features and components of the simulator, a transportable containerized facility provided with a 6 degrees-of-freedom motion platform. The simulator has been designed to provide a full immersion environment for high performance training, but also and above all for basic and applied research, monitoring and analysing operator performance by means of electromedical instruments. The specific activities conducted with the Cagliari simulator (training, research, technological advance) aim to reduce the possibility of accident occurrence, which are largely caused by the onset of fatigue.

Keywords: Ship-to-shore Gantry Crane Simulator, 6 DOF Motion Platform, HLA Federation, Electromedical Instruments for Performance and Fatigue Assessment

## 1. INTRODUCTION

Over the last few years container traffic has registered an exponential growth that has resulted in:

- the gigantism trend with container ships of increasingly larger size and capacity, and consequent adaptation of gantry crane design;
- demand for quayside cranes with improved functionality (Fig. 1);
- the need to reduce likelihood of accidents occurring during crane operator task execution.

This has resulted in the need for increasingly skilled gantry crane operators accompanied however by an increase in workplace stress levels creating situations where accidents are likely to occur.

Indeed, in spite of the high degree of automation achieved over the last few years in container handling equipment in general (AGV, Shuttle Carrier etc.), for the ship-to-shore gantry crane, the real “bottleneck” in container terminals, the human operator continues to play a prominent role. Though on the one hand this maintains high levels of employment, on the other it increases the possibility of operator error leading to an accident resulting in injury and/or damage.

This study falls within the area of “activity safety, defined as the discipline that analyses factors influencing operator performance and that studies those processes underlying human error. It encompasses human factors and other branches such as anthropometry and ergonomics.

The causal factors of accidents in transportation systems can commonly be divided into *human*, *technical* and *environmental*. Human error can be the result of improper task and/or equipment design and ineffective training.

The major contributory factors to reducing accident occurrence are enhanced operator skill development, including periodic refresher training to

maintain high operational efficiency of quayside crane operators, and performance studies and assessment.

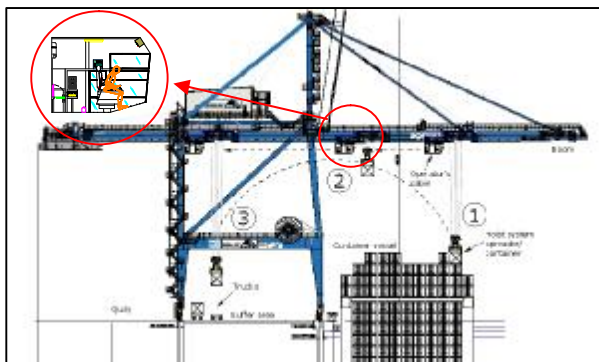


Figure 1: Quay crane unloading sequence from ship to truck

However, actual task performance and fatigue analysis does entail some difficulties, which combined with the challenges of virtual reality training, prompted the idea to set up a simulator that was able to record and analyse performance curves in a virtual environment.

The paper describes the gantry crane simulator conceived and designed by researchers at CIREM, University of Cagliari (D'Errico 2008) jointly with MAST Srl and Genoa University in the frame of the CyberSAR Project - OR13, in collaboration with the COSMOLAB Consortium, and constructed by MISS-DIPTM, Genoa as a training and research facility for the purpose of analysing and assessing gantry crane operator performance.

## 2. BACKGROUND AND STATE OF ART

### 2.1. Ship-to-shore gantry crane operator task

The operator works inside the cab of these giant cranes that travel along the container terminal quayside, loading and unloading containers from the ships using spreaders, that are mechanically connected to the hoist motors via a beam suspended from cables and electrically connected to the crane. The container is hooked/unhooked by means of four corner flippers on the spreader.

The containers are transferred from ship to shore through a combination of two movements (Fig. 1): the spreader-container system is hoisted to the maximum clearance height, and the crane then travels with its load along the bridge rails to the buffer area.

The main difficulty lies in the fact that this operation has to be continuously repeated to move on average over 20 containers per hour, the cab travelling back and forth from the ship to the yard..

Thus throughout the six hour shift the crane operator is exposed both to high vibration, due to cab movements, and to high noise levels generated by the very nature of the operation,. Added to this, is the

discomfort caused by the bent forward posture and awkward head/neck positions that the operator is forced to assume to follow the movement of the container some 40 m below.

### 2.2. Analysis of gantry crane operator performance and fatigue: first results and difficulties encountered

Fatigue, and impaired performance in general, is regarded as a significant factor in the majority of accidents occurring in transport systems (Fadda 1984a). Past research conducted on human fatigue prevention has focused on both the physiological mechanism and on methods for measuring fatigue levels (Sherry 2000; Czeisler 1995; Ji, Lan, and Looney 2002). The most common physiological measurements for determining the extent and length of reduced alertness, considered as an indicator of increased fatigue and/or drowsiness, employ the electroencephalogram (EEG) (Lal and Criag 2002). A training manual prepared by the Transportation Development Centre of Canada in November 2002, provides guidelines for analysing fatigue, drowsiness and the resulting performance deterioration of Canadian navy personnel, combining EEG, EOG (eye movement), ECG (heartbeat) and EMG (muscle tone). Behavioural measurements, that have gained credibility recently, are used to gauge fatigue and are based on the frequency of body movements: the number of movements recorded during task performance over a specific time interval is significantly correlated with the EEG.

Fatigue can also be readily detected by observing facial behaviour: changes of facial expression, eye and head movements, gaze are all indicators of fatigue.

As can be observed from the state of the art review no significant in-depth studies have been conducted concerning port operations, specifically ship-to-shore crane operators. The only data available are those reported by Italian (Colombini, 2006) and Dutch (Huysmans, de Looze, Hoozemans, van der Beek, and van Dieën 2006) researchers on quayside crane operator posture. The Interuniversity Research Centre for Economics and Mobility (CIREM) at Cagliari University has provided two major contributions in this area, providing arousal-performance curves for the gantry crane operators at CICT (Cagliari International Container Terminal), at Cagliari's industrial port. The curves were constructed using the well-known Yerkes-Dodson model (Fadda 1984a), that relates quality of performance with workload. These curves are discussed in two recent papers. The first (Fancello, D'Errico, and Fadda 2007) compares subjective measurements - drawn from questionnaires distributed among CICT crane operators - with objective measurements obtained from an actual performance indicator, i.e. the number of containers moved per hour corrected for operator idle time. Accounting for idle times, associated with vehicle

coordination within the terminal, allows to properly determine workload during each hour of the shift.

In this way it has been possible to provide the first contribution to actual gantry crane operator performance, establishing a relationship between the curve for perceived fatigue, based on self-assessment, and actual performance measured from hourly container handling data and corrected for idle time for two shifts (afternoon and night). The deviation between performance indicated in terminal operator records and what should be the actual performance curve less idle time, has also been determined.

The second paper (Fancello, D'Errico, and Fadda 2008) concerns an extension of the performance analysis of container terminal stevedores using monthly handling data contained in the data base. (Fig. 2): An average performance curve has been constructed for all the crane operators for each of the four work shifts.

This curve highlighted a number of significant shortcomings concerning the specific job task . However, numerous problems and shortcomings were encountered in field research when attempting to take measurements without interfering in operators' performance:

- difficulties in determining idle time and the real time recording of environmental parameters inside the crane cab during operation, because of high vibration and noise levels throughout the 6 hour shift;
- conflicts with terminal operability and retrieval of handling data;

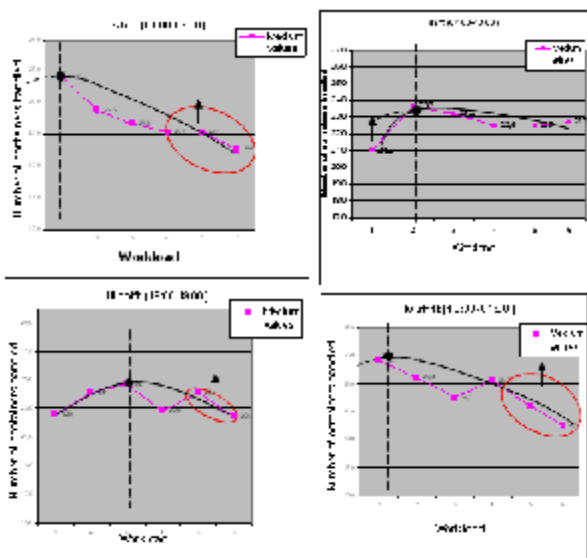


Figure 2: CICT crane operators average performance curves for the 4 shifts and corresponding parabolic trend (September 2007)

- disturbances experienced by operator inside the crane cab during task execution;
- inability to determine the influence of boundary conditions on performance: for example with regard to idle time, it was not possible to ascertain whether this affected performance positively (reducing stress and fatigue while crane sits idle) or negatively (decline in alertness and concentration);
- impossibility of analysing changes in operator response to single parameter variations (environmental or boundary conditions).

Added to these limitations are the problems associated with operator training in a real world environment:

- forced waiting times until optimal environmental and boundary conditions are attained;
- prohibitive costs of training infrastructures;
- productive cranes have to be taken out of service for training.

Thus, using a physical simulation model to represent the real world may well be the most suitable and effective solution. The training and research gantry crane simulator at Cagliari University has been conceived for this purpose.

### 2.3. Physical task training simulators

Task simulators are tools typically used in human factor applications and are an essential ingredient in safety optimisation processes in the transportation sector. They allow to reproduce and assess, also singly, all those factors contributing to fatigue.

The early simulators, that appeared about 40 years ago, were used in aerospace applications by NASA (Fadda 1984b), for the virtual reality reproduction of conditions encountered during the first space missions. In the 1970's they began to be used for military flight training and in more recent years as a research tool for assessing motor vehicle driver fatigue.

The increasingly skill intensive tasks involved in port operations, such as those executed by ship-to-shore gantry crane operators, have led to the need for training simulators in this area too (Rouvinen, Lehtinen, and Korkealaakso 2005).

Ship-to-shore crane simulators are now commonly used worldwide. Many, largely fixed, simulators owned by container terminal operators are available for training in ports. Others designed and constructed by universities or research institutions are mobile training facilities (containerized) and provide services at terminals. However, generally speaking these simulators are designed for training purposes alone.

European ports with gantry crane simulators for operator training include Antwerp (Belgium), Hamburg (Germany), Le Havre and Marseille (France) while around 50 simulators are installed in the United States. All these ports have achieved excellent results in terms of operator training effectiveness, reducing above all times and costs of training compared to training using real cranes

#### 2.4. General description and universal features of ship-to-shore crane simulators

Like existing training simulators, the ship-to-shore simulator comprises five main components :

1. **operator cab interface (cockpit):** a faithful replica of the crane operator workstation, comprising a seat and control console with two joysticks, one for moving the gantry and the other for spreader-container lifting. It is generally fixed to a **motion platform**, with 2, 3, 4 or 6 degrees of freedom (DOF) depending on load capacity, that not only imparts visual and sound stimuli to the operator, but also stimulates sensations of movement. The platform is supported by actuators placed underneath the cab that move the cab in response both to user input and to the tasks performed. The motion system simulates the vibrations and collisions that occur in real operating conditions;
2. **instructor workstation interface:** outside the operator cab, it is equipped with special monitors for following the exercise in real time. The instructor can:
  - create innumerable simulation scenarios, in all climatic conditions (wind, rain, sun etc.) and at all times of day (daytime with natural light, night-time with artificial lighting) and for any boundary condition (when selecting different settings a multitude of alternative scenarios can be developed, changing ship and port configuration, as well as equipment employed, like for example different types of spreader);
  - make trainees repeat a test in the same conditions, in the event he has not performed well in a particular scenario, and can analyse a posteriori any errors made;
  - move on to higher level training, gradually introducing more demanding scenarios as the trainees gradually enhance their skills.
3. **visual display system:** recreates through a projection screen the same environment that the operator would actually experience;
4. **audio System:** recreates the sound effects generated by vibrations (cab moving during gantry travel), collisions, wind noise;

5. **central operating system:** the simulator “brain”, controls operations and executes different simulation scenarios.

Generally, when representing a quayside container crane in virtual reality the focus is either on the visual display system or the motion, with highly advanced platforms. In other cases the emphasis is placed on ergonomics, installing the most technologically advanced cab seats.

The main indicators used for assessing performance level include number of containers handled per hour, number of major and minor collisions, joystick handling (for hoisting and trolley movement), trajectory chosen by the operator versus optimal container trajectory, etc.

#### 2.5. Operator fatigue and performance measurements in physical task simulators

Simulators are increasingly used for researching human factors in transport as these devices allow to reproduce and evaluate, also singly, all those factors contributing to fatigue. In a study conducted at the Northeastern University of Boston (Yang, Jaeger, and Mourant 2006) the behaviour of 12 novice and 12 experienced drivers, recorded during three right-to-left lane change scenarios was investigated. Each lane change involved: 1) a preparatory period; 2) the actual steering manoeuvre from right to left 3) a post lane change period, accomplished maintaining a specific speed. Novice drivers were found to be less secure than experienced drivers, showing significantly more variance in lane position during the preparatory and post-lane change phases. They also spent less time looking at the speedometer and mirrors.

The findings of this study suggest that virtual reality driving simulators may be a useful aid for improving novice driver skills in manoeuvres such as lane changes.

One particularly interesting area of human factors is the determination of the visual field using specific devices that identify and record operator gaze points during a work cycle. These applications aim to study the field of vision and the information required by the operator to cope with changing conditions, to determine whether any distractor signals exist that alter perception time and consequently the ability to make the right decision.

The majority of driving simulators (for example the DriveSafety Simulator at the North Dakota State University) are equipped with an oculometer, a gaze tracker that records fixations points and saccades - from the pupil. In addition, with this device it is possible to evaluate, for example, whether any objects outside the field of vision create sources of distraction, thus impairing performance.



Recent studies conducted by the Universities of Taiwan and San Diego on the assessment of driver performance interpreting EEGs using fuzzy neural networks (Wu, Lin, Liang, and Huang 2004), have shown that accidents caused by sleepy drivers involve a high percentage of fatalities due to a marked impairment in driver ability to control the vehicle.

### 3. SIMULATION ARCHITECTURE

The simulation architecture developed by the authors is based on the idea that it is necessary to create a dynamic and flexible framework not only for gantry crane simulation, but even for integrate in further step different equipment in order to develop a cooperative training; from this point of view the authors decided to develop an innovative federation of simulator inter-operating open to redefine the set of entities involved in the scenario; as basic architecture it was decided to use the High Level Architecture (HLA, IEEE Standard and regulation for US DoD Simulators) that allows to interoperate different simulators in an interactive real time framework operating on a distributed network.

The simulator is organized in a real-time Federation composed by different federates, each represent an entity entitled to model some specific element.

The basic object is defined as Actor; currently the general object architecture is based on the structure proposed in figure 3.

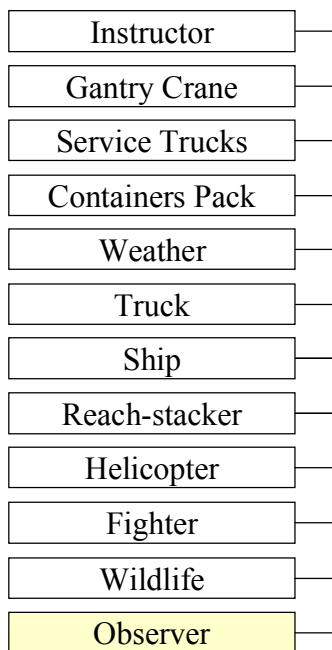


Figure 3: Interoperable Object Example

Each object can be owned by a different federate; for the specific case the general structure of federates is proposed in figure 4.

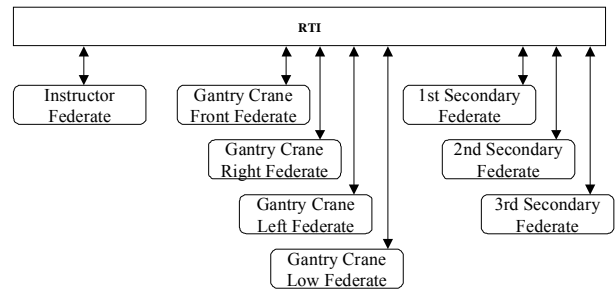


Figure 4: Federation Architecture for the Gantry Crane Simulator

The federation is running over a LAN/WAN (Local Area Network/Wide Area Network) by using RTI (Run-Time Infrastructure) 1.3.7.

The solution proposed allows to create a wide range of alternative configurations for different applications; the federates operates on simple workstation and the federation can run on a single stand alone computer on a single PC to creating a federation of cranes interacting in a networks.

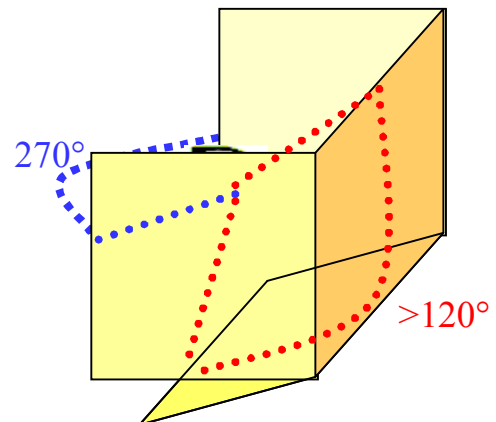


Figure 5: Federates Example for a basic Configuration

Secondary Federates are devoted to manage other entity to interoperate (i.e. a reachstacker Simulator); while observer are used to provide possible re-configurable workstation for covering different view opportunities; in the proposed case the visual coverage for standard configuration of the gantry crane simulator is 270° horizontal and over 120° vertical, corresponding to a basic cave as proposed in figure 5. The solution proposed is designed to allow dynamic reconfiguration of each PC in order to reallocate the equipments and to create different scenarios; obviously this is in some way limited by the availability of proper hardware device on each Workstation for driving/operating a specific vehicle.

In this project the authors developed basic I/O interfaces in order to guarantee that also by using simple game interface it could be possible to drive many different vehicles, while the gantry crane

operation position is based on ad hoc developed motion platform able integrating multiple devices and joysticks. In addition in this case the architecture is designed in order to guarantee possibility to integrate also High Performance Computing Platforms; the project in fact will be used also as pilot to test the possibility complete by distributed processing real-time simulation including very time consuming models such as that ones devoted to consider stress/strain on cables or sea keeping on complex configurations; these models will be elaborated by supercomputing facilities integrated in the federation or substituted by simplified metamodels in case these are not available.

Figure 6 proposes an example of configuration for driving the main gantry crane as well as instructor and secondary positions for other trainees; as proposed in this case the configuration obtained is easy to be adapted by the users.

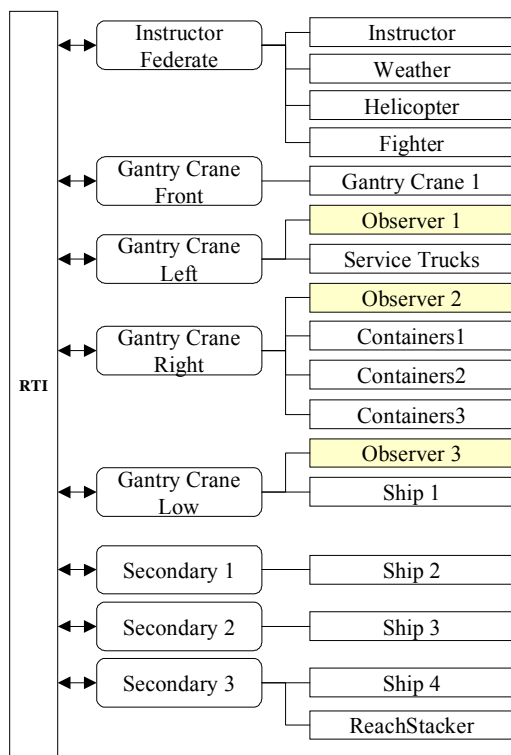


Figure 6: Federates Example for a basic Configuration

#### 4. SIMULATOR INFRASTRUCTURE FOR CAGLIARI SIMULATOR

The overall structure for the Cagliari simulator is based on the idea to integrate the proposed architecture in a compact complex to be located inside a shelter based on a high cube 40' container. This solution allows to relocate quickly the whole simulator anywhere just by transporting around as a standard container; obviously this decision force to design ad hoc solutions for many systems (i.e. visualization, motion etc.), but guarantee to obtain a very flexible training equipment.

considering these aspect the simulator is based on the specific layout corresponding to following main modules:

- Main Gantry Crane Simulator;
- Instructor Station;
- Secondary Stations;
- Plenary Area.

The hardware is based on PC based workstations and laptops; in fact the main gantry crane simulator includes the motion platform and related I/O, sound/vibration control devices and the cave solution with four screens (2m x 1.5m) covering 4 sides of the cube where the operator is located.

The secondary station are currently based on laptop solution in order to guarantee the possibility to be relocated outside of the shelter if requested for some specific demonstration or training. The secondary stations includes I/O Devices (driving wheels, joysticks etc.); these workstations can be used as dynamic observers by trainee in order to follow the main training session, as concurrent cooperative training platforms or as independent stand-alone scenario for multiple session. By this approach the standard class composed by 8 trainees can be assigned concurrently to real equipment and virtual simulator, allowing to have 4 person concurrently trained on the simulator, 1 on main station and the other one actively operating on secondary positions; respect a traditional simulator this multiplies by 4 the capability of the equipment in term active training time on the simulator for users; at the same time this solution enable the possibility to develop cooperative and competitive training sessions under the supervision of the trainer.

The instructor is located in a specific room in the shelter that enable to control all the environmental conditions (i.e. wind including speed, direction and variations) as well as synchronization with other devices; the instructor is allowed also to activate dynamic review sessions with debriefing capabilities and highlights of errors, collisions and specific events as well as the possibility to visualize interactively in the 3D Virtual framework trajectories (i.e. for the gantry crane spreader).

The Plenary area is based on the concept to be able to reproduce dynamical real-time on-going training sessions or ad hoc debriefing on a framework that allows the instructor to interact in front of the class; the room is equipped with a special smart board that provide the possibility to project a wide representation of the virtual framework with touch screen features including the possibility to put notes and to write over the images.

All the computers operates on a local area network based on RJ-45 that can be connected to external

network; so it becomes possible to setup secondary stations outside of the container and eventually to redesign multiple session with many trainees interacting in the real time simulation.

The solution proposed is open to integrate other models using the FOM (Federation Object Model) and SOM (Simulation Object Model) developed for Cagliari Simulator; due to the conceptual approach in this modeling the architecture can be easily re-configured in order to include other federates and other objects for creating complex scenarios on Port Operations; considering all these aspect this simulator represent a very innovative and unique solution for port simulation.

## 5. ELECTROMEDICAL INSTRUMENTS AND ANALYSIS STRATEGIES FOR BASIC AND APPLIED RESEARCH

### 5.1. Choice of most suitable integrated system of electromedical devices for specific research purposes

In addition to crane operator training, the gantry crane simulator is also a useful tool for conducting both basic and applied research. A research simulator allows to study fatigue and performance of crane operators in a variety of operating conditions by analysing and monitoring objective parameters (EEG, ECG, EMG, EOG plots, etc.), recorded and processed with electromedical devices (Rocca, Bocca, Fadda, Fancello 2007) using known procedures for handling and analysing fatigue test data (performance curves, neural networks). The electromedical devices that will be installed in the Cagliari simulator include: (Fig. 3 shows the final layout of the quayside container crane simulation platform indicating the electromedical devices chosen for research):

- *Eye tracker*: for tracking operator gaze;
- *Dynamic Holter ECG*: for monitoring cardiac frequency;
- *Flicker Fusion Unit (FLIM)*: objective test for analysing flicker fusion frequency;
- *Blood Pressure Monitor (ABPM, Ambulatory Blood Pressure Monitoring)*;
- *Digital EEG*: for measuring psycho-physical stress parameter;
- *EMG*: electromyographic tests.

These electromedical devices are used to measure the significant parameters associated with the onset of fatigue in conditions of psycho-physical stress, brought on by complexity of the task itself, and due to the attentiveness required to avoid errors, as well as to exposure to strain and vibrations reproduced by the motion platform.

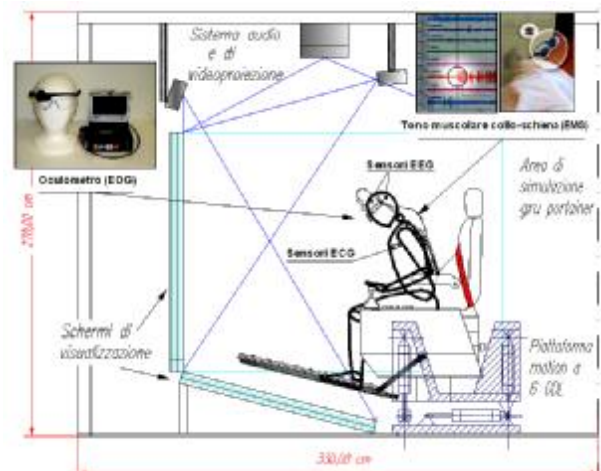


Figure 7: Cross-section of simulation area and electromedical devices envisaged.

### 5.2. Psychophysical parameters to be analysed for studying operator fatigue and analysis techniques

In addition to the equipment typically used for fatigue research purposes (EEG, ECG), an eye tracker will also be installed (for tracking operator gaze: at the end of the task a gaze plot is produced showing dispersion of eye gaze points – saccadic eye movements), for studying the visual activities of operators during task execution, discriminating between objects considered to be visual distractions and those regarded as “receptor signals”, as vision and visibility are a key human factor in crane operator tasks.

The research strategy for analysing visual activities of ship-to-shore gantry crane operators undergoing simulator training will consist in analysing visual behaviour, measuring, using specific analytic tools (Camilli et al., 2007) or trial analysis, “look zones”, fixation points and saccades, in other words the movement between consecutive fixation points (once fixation times/points are known the saccades can be easily detected).

A device for determining muscle tone (EMG test) will also be installed. The system comprises electrodes attached to the body parts to be monitored (neck and back). The electrodes record, display and amplify local nerve response to electrical stimulation and detect muscle anomalies and disorders in particular work postures, providing a measure of operator physical performance.

Some important considerations on awkward and poor posture adopted during task execution, emerged from previous field research on quayside container crane operator stress and fatigue (§ 2.1). In this regard anthropometric measurements (inclination angles) were conducted on crane operators at the Port of Cagliari, as well as task surveys in which operators were asked to

what extent, if any, ergonomic factors contributed to fatigue.

As for the ergonomic analysis, the ship-to-shore gantry crane simulator design envisaged a universal attachment for the main platform so as to accommodate a variety of ergonomic workstations and to determine, by changing the type of seat, the psychophysical parameters in different work postures. In this way it will be possible to detect operator muscle disorders, using the EMG test, for different sitting positions. This will contribute to technology advance in the specific sector, creating innovative design solutions for companies collaborating in the research project.

Another electromedical instrument purposely chosen for the Cagliari simulator, after a thorough literature search, is the FLIM unit, that provides a measure of central-nervous system activation (arousal) and of the level of performance (memory, attention, reaction time).

The reaction time of an individual to light stimulus, measured using FLIM, provides an indicator of the level of performance of quayside container crane operators, given the importance in task execution of visual activities and the degree of precision to be achieved for focusing on the target (latching the container onto the spreader some 40-50 m below and transferring it from ship to quayside).

FLIM validity criteria have been addressed in a study (Daniel, Fabry, and Fickova 1985) investigating the effects of shift work. The authors have been able to demonstrate that the individuals examined adapt far more quickly to work conditions at the subjective psychological level, as emerged from the questionnaire responses, than at the psycho-physiological level, indicated by the FLIM measurements.

The particular simulation architecture of Cagliari's gantry crane simulator (HLA federation), allows for the inclusion of electromedical equipment as federates. The simulation system provides advanced synchronization functionality ensuring that the psychophysical fatigue measurement systems can be combined with simulated time evolution. The debriefing system matches the operating phases with those portions of the electromedical plots whose spectra coincide with fatigue phases. A model such as a neural network (NN) model will be used for reading and interpreting the complex data

In this sense it will be possible to construct performance curves on the simulator along the same lines as for field measurements.

## 6. CONCLUSIONS AND FUTURE RESEARCH

This paper describes Cagliari University's ship-to-shore gantry crane simulator. This simulator is an essential tool for better understanding the underlying causes of accidents incurred by container crane operators who are exposed to increasing levels of stress for the reasons

described in the introduction. Indeed, fatigue and performance assessment through psychophysical parameters monitoring with electromedical devices is instrumental in reducing the likelihood of accidents.

Thus research and training activities conducted with the simulator will be of key importance. The development and management strategies will be decisive for organising and promoting Cagliari's quayside container crane simulator in order to attract potential clients to the training facility (e.g. container terminal operators). Training and refresher courses for container crane operators using the Cagliari simulator are important for two reasons. In economic terms the proceeds from training package sales to terminal operators will be used to fund research activities. Therefore management strategies need to be created for competitive advantage, offering up-to-date training packages at attractive prices. In this sense one strong point of the Cagliari simulator is its transportability. The second reason is that the data recorded during training sessions will be used to build up a database for use in research

Lastly, concerning future research lines, the ship-to-shore gantry crane simulator has been developed within a broader research project aimed at setting up a network of simulators to be located in a number of areas in central-southern Italy (*cyberinfrastructure*). This infrastructure will make it possible to carry out integrated task training, by means of remote experimentation and tests coordinated by an efficient multimedia network. The integrated training programme also envisages the construction of a container trolley simulator. In addition the proposed approach guarantee the possibility reuse and further develop for the simulator new application areas such as operative and safety policy design, re-engineering and validation, terminal analysis and control etc.

## REFERENCES

- Bruzzone A.G., Kerckhoffs (1996) "*Simulation in Industry*", DIPTM Press, Genoa, Vol. I & II, ISBN 1-56555-099-4
- Bruzzone A.G., M.E., Cotta G., Cerruto M.(1997) "Simulation & Virtual Reality To Support The Design Of Safety Procedures In Harbour Environments ", *Proceedings of ITEC97*, Lausanne (CH), April 22-25
- Bruzzone A.G., Giribone P. (1998) "Decision-Support Systems and Simulation for Logistics: Moving Forward for a Distributed, Real-Time, Interactive Simulation Environment", *Proc. of the ASS IEEE*, Boston, April
- Bruzzone A.G., Mosca R. (1998) "Special Issue: Harbour and Maritime Simulation", *Simulation*, Vol.71, no.2, August
- Bruzzone A.G., Mosca R., Degli Esposti P., Vacante S., Carbone A. (1998) "Distributed Development of

- Simulation Models for Harbour Processes", *Proc.of Ports98*, Genoa, September
- Bruzzone A.G., E.Page, A.Uhrmacher (1999) "Web-based Modelling & Simulation", SCS International, San Francisco, ISBN 1-56555-156-7
- Bruzzone A.G., Merkurjev Y.A., Mosca R. (1999) "Harbour Maritime & Industrial Logistics Modelling & Simulation", SCS Europe, Genoa, ISBN 1-56555-175-3
- Bruzzone A.G., Giribone P., Carbone A. (1999) "Terminal Simulation as Support for Port Logistics", *Proc.of HMS99*, Genoa, September
- Bruzzone A.G., Gambardella L.M., Giribone P., Merkurjev Y.A. (2000) "Harbour Maritime & Multimodal Logistics Modelling & Simulation", SCS Europe, Genoa, ISBN 1-56555-207-5
- Bruzzone A.G., Giambiasi N., Gambardella L.M., Merkurjev Y.A. (2001) "Harbour, Maritime & Multimodal Logistics Modelling & Simulation", SCS Europe, Genoa, ISBN 90-77039-03-1
- Bruzzone A.G., Revetria R. (2001) "Web Based Performance Models for Harbours", *Proceedings of Sealift Conference*, Hatton London, June 20-21
- Bruzzone A.G.(2001) "Web Technologies and High Level Architecture for Distributed Ship Manoeuvring Simulation", *Proceedings of ISMF2001*, Arenzano
- Bruzzone A.G. (2002) "Supply Chain Management", *Simulation*, Volume 78, No.5, May, 2002 pp 283-337 ISSN 0037-5497
- Bruzzone A.G.(2002) "Harbour and Maritime Simulation", *Invited Speech at WRV2002*, Rio de Janeiro, Brasil, November
- Bruzzone A.G., Merkurjev Y., Mosca R. (2002) "Harbour, Maritime & Multimodal Logistics M&S", DIPTM Genoa, ISBN 88-900732-9-2
- Bruzzone, A. G. Mosca, R. Viazzo, S. Massei, M., B.C.,B.M. Rocca, A. (2003) "Logistic Cooperative Functional Training System based on HLA Distributed Simulation" *Simulation*, Vol 35; Part 3, page(s) 776-781 Society for Computer Simulation, ISSN-0735-9276
- Bruzzone A.G., Revetria R. (2003) "Web Based Distributed Simulation for Supporting Maritime Terminal Operations", *Proc.of 19th International Port Conference*, Alexandria, Egypt January 26-28
- Bruzzone A.G., Itmi M. (2003) "Summer Computer Simulation Conference", SCS International, San Diego, ISBN 1-56555-268-7 (887 pp)
- Bruzzone A.G., Viazzo S., B.M. (2004) "Massive Training based on Virtual Reality Equipment Applied to Logistics and Heavy Haul Tracking", *Proceedings of SCSC2004*, San Jose', CA, July
- Bruzzone A.G., Cunha G.G., Landau L., Merkurjev Y. (2004) "Harbour and Maritime Simulation", LAMCE Press, Rio de Janeiro, ISBN 85-89459-04-7 (230 pp)
- Bruzzone A.G., Massei M. (2006) "Virtual Reality as Support For Terminal Operation", *Proceedings of Applied Modelling & Simulation*, Buzios, Brazil, April 5-7
- Camilli, M., Nicchia, R., Terenzi, M. and Di Nocera F., 2007. Development of A Simple Tool for Examining Fixations *presented at the Fifth Symposium on Human-Computer Interaction*, June 28-30, University of Padua, Department of General Psychology (ITALY).
- Colombini, D., 2006. Results for an ergonomic re-design of a control station for containers crane for prevention of musculoskeletal disorders during container handling in harbour. *Proceedings of Symposium n° 9 "Prevention of WMSD"*, IEA TC on MSD Plans for IEA 06 Conference, Maastricht, NL
- Czeisler, C.A., 1995. Lecture on fatigue. *Fatigue Symp. Proc.* Tyson Corners, VA: Nat. Transportation Safety Board and NASA Ames Res. Center, 59.
- Daniel, J., Fabry, R. and Fickova, E., 1985. Changes in activation level during circadian rhythm in shift workers, *Studia Psychologica*, 27, pp. 211-217.
- D'Errico, G., (2008) "Il processo di ideazione e realizzazione di un simulatore di gru portainer: strumento per l'analisi e valutazione del livello di prestazione dei gruisti di banchina" *Proc.of the SIDTgiovani 2008 – 1<sup>st</sup> National Meeting of the Transport Engineering PhD students*, April 3-4, Padova, Italy
- Fadda, P., 1984a. Biomeccanica e Antropometria. In *Introduzione al fattore "uomo" nella fenomenologia dei trasporti*, L'Aquila University, Italy: 7-10.
- Fadda, P., 1984b. Interazione uomo-macchina. In *Introduzione al fattore "uomo" nella fenomenologia dei trasporti*, L'Aquila University, Italy: 155-179.
- Fancello, G., D'Errico, G. and Fadda, P. 2007. Human factors involved in container terminal ship-to-shore crane operator tasks: operator fatigue and performance analysis at Cagliari Port. *Proceedings of the HFES Europe Chapter Conference*, October 24-26, Braunschweig, DLR (German Aerospace) (GERMANY).
- Fancello, G., D'Errico, G., and Fadda, P. 2008. Processing and analysis of ship-to-shore gantry crane operator performance curves in container terminals *accepted to Journal of Maritime Research (JMR)*, University of Cantabria, Santander (SPAIN).
- Giribone P. & A.G.Bruzzone (1995) "Object-Oriented Modeling of an AGV System for a Harbor Environment", *Proceedings of WMC95*, Las Vegas, Nevada (USA), January 15-18
- Huysmans, M., de Looze, M., Hoozemans, M., van der Beek, A. and van Dieën J., 2006. The effect of

joystick handle size and gain at two levels of required precision on performance and physical load on crane operators, *Ergonomics*, 49, 1021-1035.

- Ji, Q., Lan, P. and Looney, C. 2006. A Probabilistic Framework for Modeling and Real-Time Monitoring Human Fatigue, *IEEE Transactions on systems, Man and Cybernetics A*, 36, 746-754.
- Lal, S.K.L. and Criag, A. 2002. Driver fatigue: Electroencephalography and psychological assessment, *Psychophysiology*, 39, 313-321.
- Longo F., Mirabelli G., Bruzzone A. (2005) "Container Handling Policy Design By Simulation Framework", Proceedings of HMS2005, Marseille, 20-22 October
- Merkuriev Y., Bruzzone A.G., Novitsky L (1998) "Modelling and Simulation within a Maritime Environment", SCS Europe, Ghent, Belgium, ISBN 1-56555-132-X
- Mosca R., P.Giribone, A.G.Bruzzone (1994) "Graphic, Analog and Statistical Verification of a Computer Simulation of Port Operations", *Proceedings of HPC94*, San Diego, April 10-15
- Mosca R., P.Giribone & A.G.Bruzzone (1994) "Simulation & Automatic Parking in a Training System for Terminal Container Yard Management", *Proc.of ITEC94*, The Hague, April
- Mosca R., Giribone P. & A.G. Bruzzone (1996) "Simulation of Dock Management and Planning in a Port Terminal", *Proc. of MIC'96*, Innsbruck, February 19-21
- Rocca, A., Bocca, E., Fadda, P., Fancello, G., (2007) "Interoperable Simulation Integrating Biomedical Devices for Training Effectiveness", *Proc.of the Euro SIW*, June, S.Margherita L., Italy
- Rouvinen, A., Lehtinen, T. and Korkealaakso, P. 2005. Container Gantry Crane Simulator for Operator Training. *Proceedings of the I MECH E Part K Journal of Multi-body Dynamics*, 219, 4, pp. 325-336.
- Signorile R., Bruzzone A.G. (2003) "Harbour Management using Simulation and Genetic Algorithms", *Port Technology International*, Vol.19, Summer2003, pp163-164, ISSN 1358 1759
- Sherry, P. 2000. *Fatigue Countermeasures in the Railroad Industry: Past and Current Developments*. Washington, D.C.: AAR Press.
- Wu, R.-C., Lin, C.-T., Liang, S.-F. and Huang, T.-Y. 2004. EEG-Based Fuzzy Neural Network Estimator for Driving Performance. *IEEE Transactions on systems, Man and Cybernetics*, 4, pp. 4034-4040.
- Yang, G., Jaeger, B. K. and Mourant, R. R. 2006. Driving Performance of Novice and Experienced Drivers in Lane Change Scenarios. *Proceedings of the 50th Annual Meeting of the Human Factors*

and *Ergonomics Society*, October 16-20, San Francisco (California, USA).

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# ASSESSING PERFORMANCE INDICATORS FOR INLAND TERMINALS

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## ABSTRACT

In this paper, an approach for recognizing and defining correct and operable performance indicators will be shown for evaluating the effectiveness and efficiency of processes in inland terminals (intermodal hubs). The challenge in evaluating the possible improvements of the underlying processes lies in the special nature and complex structure of inland terminals. It is important to consider that all the processes are highly interconnected and that changes in parameters in one process also have an impact on parameters in other processes. Furthermore the performance of intermodal hubs, as they can be seen as the backbone of the system, has a significant impact on the overall performance of the whole transportation network. Therefore it is consistent to integrate measures that allow performance evaluation from different perspectives which correspond to the needs of all stakeholders. The underlying research question is how to work out the drivers of performance and to measure the quality of processes in inland terminals correctly.

Keywords: performance indicators, causalities, inland terminals

## 1. INTRODUCTION

Growing industrialized competition and higher demand on reliability of efficient intermodal systems require a continuous and integrated transport planning process. In fact, reliable and robust networks need more attention in future. Therefore better interfaces are needed to ease intermodality, in order to improve the quality of planning (Sammer, Idea, and Retzko 2008). Long term effective transportation networks require better communication and participation-consensus-oriented planning to guarantee acceptance of public and political decision makers both on national and European level. As a consequence innovative measures should be developed to stimulate self-organizing processes towards improved control and operation of intermodal and multimodal transportation (Sammer, Idea, and Retzko 2008). To minimize the risk of stranded costs when planning life-cycle assessment of intermodal hubs, more consideration has to be given to maintenance and extension of existing and future infrastructure. Innovative logistics concepts require

better forecasts, quality management and reliable performance indicators for a more intelligent use of limited infrastructure. Therefore new concepts which encourage improvement of infrastructure performance and agreed definitions and standards for robust and objective comparison of performance are needed (Stölzle, Browne, and Pfohl 2008).

We focus on a conceptual approach for measuring process quality of Austrian inland terminals because performance measurement is not only a powerful method for inland terminal operators, but also constitutes a most important input for informing regional and national authorities (Cullinane, Song, and Wang 2005). In fact, improving the performance of an inland terminal system improves the country's international market access. As a consequence, efficient inland connection raises the productivity and profitability and leads to increased trade and higher levels output, income and employment (Park and De 2004).

Increasing overload of capacity at inland terminals and the concentration of freight transport on fewer main hubs force the need to understand the cooperation requirements of all transportation modes (Stölzle, Browne, and Pfohl 2008). In near future intermodal services and the quality of existing inland terminal operations will not suffice to keep up with the transshipment capacity needed (Klotz 2007). In fact, inland terminals are fundamental nodes in transportation networks that allow the frictionless turnover of goods between different modes of transportation. Most of the intermodal hubs are constrained in their storage capacity, are faced with high load unit diversity and hardly predictable time windows for delivery and pickup. Increasing flows of goods along with increasing road transportation emphasizes the important role of intermodal hubs to match future demands with regard to economical and ecological needs. As a consequence intermodal container turnover and the corresponding infrastructure have to be evaluated exactly to guarantee efficient, quick and flexible intermodal transportation (Hansen, Rießberger, and Hollborn 2008). It is important to evaluate inland terminals as part of the whole transportation system because the effectiveness and efficiency of these intermodal hubs substantially contributes to the overall competitiveness and



attractiveness of an industrial area. Further the efficiency and performance of inland terminals affects to a large extent the economic well-being of a country. In inland terminals the problem of obtaining data on each of the variables across large samples is likely to be virtually insurmountable. Actually comparisons of productivity between inland terminals are usually made at a high level of aggregation, excluding major influencing factors. Quite often efficiency and productivity analysis are exclusively based on financial reports because of data unavailability.

Our ambition is to develop suitable metrics and to collect data on the determinants of inland terminal efficiency. The point in the conceptualization task is to avoid unnecessary complexity and focus on finding causalities and effects, often unnoticed in the pressure of day-to-day inland terminal operations. The result is intended to be an integrative perspective for decision makers of different areas. The complexity of operations and the significant number of participants in the process of planning and operating intermodal infrastructure emphasize the need for a standardized way of measuring the quality of processes to gain benefits of a coordinated strategy of hub development.

## 2. REVIEW OF LITERATURE

Performance measurement and benchmarking are a commonly accepted method to identify and adopt best practices in the field of open sea ports. In a more traditional context Tongzon and Heng (2005) mention that the performance of ports traditionally has been evaluated by measuring a single factor or by comparing actual with optimum throughput over a specific time period (Cullinane, Song, and Wang 2005). Tongzon and Heng (2005) postulate that the efficiency of inland transport has become a critical factor of port's potential future. The quality of hinterland connectivity and the accessibility of port facilities are already an important indicator for port evaluation and further a requirement for port users' port selection (Tongzon and Heng, 2005). In recent years more holistic approaches like the data envelopment analysis (DEA) and the stochastic frontier analysis (SFA) were applied on container port to analyze container terminal efficiency and productivity. DEA is the most prominent approach in literature to measure port and container terminal efficiency. Wang and Cullinane (2006) mention that it is extremely important to note that although the results derived from DEA provide important information on 'theoretically' optimum production; such results should be always interpreted with a fair degree of caution in practice; especially with respect to applications to the port industry. The optimal production achievable in one port is not necessarily achievable for another port. The findings of Tongzon (2001) show that there is no clear relationship between port's efficiency level and its size and its function. Cullinane, Wang, Song, and Ji (2006) compare the efficiency of land use and point out that city ports, where land is at a premium, are invariably more efficient than where this is less a constraint.

Pestana Barros and Athanassiou (2006) note that large seaports, with higher book value of assets, tend to have higher efficiency; an effect explained by the economies of scale. Cullinane, Wang, Song, and Ji (2006) also emphasize that high levels of technological efficiency are associated with scale, private sector participation. Cullinane, Song, and Wang (2005) postulate that appropriate variable definition of input and output factors is a crucial element of meaningful applications in the area of DEA. Wang and Cullinane (2006) point out that an important area deserving of further study is the analysis of the relationship between DEA efficiency estimates and more widely used industry data and indicators. Cullinane, Wang, Song, and Ji (2006) conclude that input and output variables should reflect the objective and the process of container port production as accurate as possible.

Coto-Millán, Baños-Pino, and Rodríguez-Álvarez (2000) found that the type of organization has a significant effect on efficiency and they showed that port size is not significant when trying to explain economic efficiency. Le-Griffin (2008) points out that comparison of productivity between major container ports and terminals are usually made at a high level of aggregation. Most studies are based on publicly available data, such as facility characteristics and physical resources and annual throughput demand. One of the main challenges to terminal operations and port authorities is how to improve productivity to accommodate a large portion of the anticipated increase in container traffic (Le-Griffin and Murphy 2006). Keller and Hellingrath (2007) highlight the problem of diversity of indicator definition in practice and theory. In fact, it is virtually impossible to compare indicators of different areas of application or even within the same industry.

A common conclusion drawn in the literature is that a uniform system for evaluating the productivity of container terminals would require the disclosure of a substantial amount of data. Experience showed that needed data for analysis is not accessible it is related to data which terminal operators generally consider to be proprietary in nature (Le-Griffin and Murphy 2006). As a consequence comparisons of productivity between major container ports and terminals are usually made at a high level of aggregation, excluding major influencing factors (Le-Griffin and Murphy 2006). Wang and Cullinane (2006) postulate that the ambition is to develop suitable metrics and to collect data on the determinants of port efficiency. There is a need for commonly accepted and accessible data and measures for the future. The data has to be included within models to measure the direct quantitative influence over estimates derived to have a more profound basis for comparison (Wang and Cullinane 2006). Cullinane, Wang, Song, and Ji (2006) conclude that container terminals no longer enjoy monopoly and that they are not only concerned with whether they can handle cargo, but also whether they can successfully compete for it.

### 3. METHOD

The special nature of inland terminals and the complexity of its operations, arising from the complex operational interactions between the different service processes, are the most challenging aspects when analyzing and evaluating the performance. The study is focused on a set of selected Austrian inland terminals. A total of 16 terminals in Austria can be classified as bi-modal (rail and road) and tri-modal (rail, road and inland waterway navigation). There are 11 locations for unattended combined transportation, two for rolling road and three offering both unattended combined transportation and rolling road. We decided to concentrate only on locations which offer unattended combined transportation, including the three locations offering both services. The reason for this lies in our focus on intermodal container turnover that only takes place in these inland terminal locations. The objective of our work is to collect analyze data through questionnaires and to develop recommendations on performance indicators related to the process quality of inland terminals.

In a first round of field visits we collected data on the infrastructure, utilization, reliability and performance of each location. In this context it was important to work out standard processes to get an idea of inland terminal operations and to locate the sources of performance indicators. During our field visits we also applied a first questionnaire to check the availability of generic data and collect available information on the performance of the terminals to define the gap between needed indicators and availability of data. The combination of field visits and workshops ensured the integration of practice based data and know-how on both operational and strategic level. The aggregated information then was used to design the second questionnaire which was then sent again to the operational terminal managers who were intended to rate the information quality of each indicator. The returned questionnaires were analyzed to define the performance indicators for the causal loop diagram.

Further we focus on causal loop diagrams to work out the connectivity in a small space. In a first step we want to develop a purely qualitative model, a sketch of cause and effect, to understand the interconnected processes and the resulting dynamics (Reiner 2005). When building the model of inland terminal dynamics it is important to be aware of operating details and causality that lie behind the scenes. It is important to be clear and precise about how such links actually work in terms of underlying behavioral responses and dependencies. Further we also have to keep in mind the numerical strength of the effects by specifying underlying relationships with reasonable accuracy. The complexity of the underlying system emphasizes that the linking of the indicators has to be done with care. Otherwise the comparison of these indicators can lead to misplaced efforts.

The study is based on a discrete event simulation which was developed in an earlier stage of our research. The simulation model is based on three standard processes (Gronalt, Benna, and Posset 2006). It takes consequently into account the delivery and pick-up process of train and truck, the storage of containers in the yard and the handling of empty containers. In this context the aim of the simulation model was to conduct experiments regarding causes and effects within the underlying processes. The simulation model is used to quantify and evaluate performance indicators which are used as input for the evaluation of the dynamic cause and effects model by setting the following parameters:

- Throughput (ITU/Year)
- Rate of fast movers and non stackable ITU (%)
- AVG storage time of fast movers (days)
- AVG storage time of slow movers (days)

Based on the findings of Benna and Gronalt (2008) the simulation collects performance indicators on the overall performance (AVG = average) of the terminal, the utilization of resources and the quality of services (see Table 1).

Table 1: Performance Indicators

Overall	AVG rate of Unproductive Moves (%)
	AVG Moves per day
	AVG Lifting Time (minutes)
Utilization	AVG usage rate Crane (%)
	AVG usage rate Reach Stacker (%)
	AVG ITU on Stock
	AVG fill rate of Storage (%)
Quality	AVG dwell time Train (hours)
	AVG dwell time Truck (hours)
	AVG dwell time ITU (days)

The setting of the simulation model was done according to the expert opinion of inland terminal managers. The simulation was used to analyze the behavior of the system when changing parameters in the setting. By analyzing the results of the different scenarios it was possible to work out first causes and relations between parameters (see Figure 1).

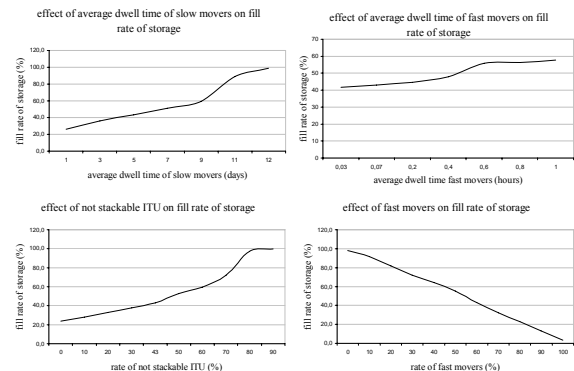


Figure 1: Causes and Effects

The plots in Figure 1 show the effects of changing parameters in the simulation setting. The upper four graphs emphasize the effect on the fill rate of the storage when changing dwell times or proportions of not stackable ITU and fast movers. Fast movers are ITUs with dwell time less than two days (measured in hours). Intermodal transport units having an average dwell time of seven days and up to twelve days are called slow movers (measured in days). Plot 1 (top left) in Figure 1 shows the effect of increased slow mover dwell time on the fill rate of the storage. The longer the slow mover ITU dwell time in the terminal, the more ITUs are in the storage at the same time, the higher the fill rate. Because of the shorter dwell time, slow movers are typically not stored within the block, but in front of the block, to avoid unproductive moves.

As a consequence an increased dwell time of slow movers block the storage and increase the fill rate of the storage (Plot 2, top right). Further it is significant to differentiate between stackable and non-stackable ITUs because latter decrease the capacity of the storage significantly (Plot 3, lower left). For example three non-stackable ITUs take the same storage space as nine stackable ITUs (Gronalt, Posset, and Benna 2007). An increase in the rate of non-stackable ITUs leads to an increase in the fill rate of the storage. When the rate of fast movers decreases (Graph 4, lower right) the fill rate of the storage also decreases because the average dwell time of the ITUs also decreases. The cause and effect diagrams then were used as starting point for the definition of the inland terminal sector map (see Figure 2). This allows a rough overview of links in the underlying system.

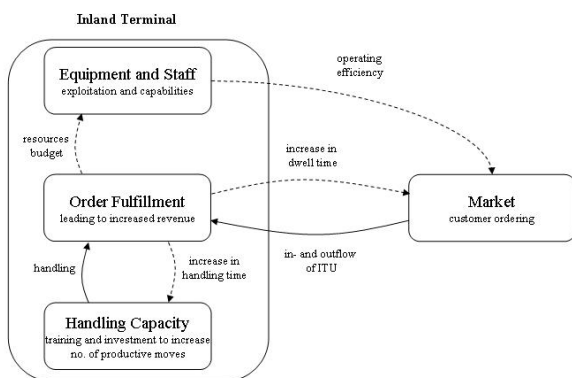


Figure 2: Sector Map

The aim is to find out the settings that determine the overall success of an inland terminal location. Within our approach we want to include possible explanations involving factors which are under the control of the management. We assume that the potential market share of an inland terminal depends on the coordination of orders and capacity. Therefore we developed a sector map which is shown in Figure 2 in a first step. The inland terminal is represented by the sectors equipment and staff, production capacity,

storage capacity and order fulfillment on the left side. The sectors include the strategies and policies like investment and exploitation of the terminal management. The right side of Figure 2 depicts the market or customers who order empty load units and deliver and pick up load units. When combining the inland terminal and the market, the mission of the terminal management is to force customers to use the terminal as place of transshipment for their load units through handling efficiency, optimized storage usage and to match handling capacity with customer requirements. In a next step we linked the five sectors by feedback loops (see Figure 3).

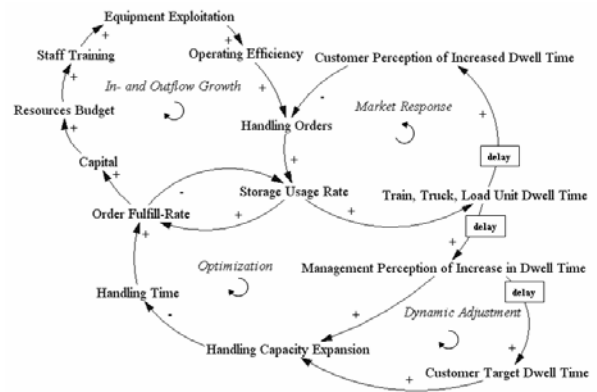


Figure 3: Causal Loop Diagram

Therefore we decided to model the system with causal loops as to guarantee a structural system including architecture that considers cause and causality relations (Morecroft 2007). The causal loop diagram in Figure 3 consists of four sub causal loops. In the middle of the diagram is the investment loop that adapts the capacity according to the management's perception of an increase in dwell time. To the right of the investment loop on the lower right is the dynamic adjustment loop that follows the customer target dwell time and to the left the storage optimization loop. At the top there is the in- and outflow growth and the market response loop. The analysis of the causal loop diagram allows for a comprehensive understanding of the underlying complexity and dynamics of the system.

Let us assume an increase in the operating efficiency of the in- and outflow growth loop in the top left of Figure 3. The better the operating efficiency of the inland terminal equipment and staff the more customers the terminal can attract and the more customers will pace handling orders. More handling orders result in an increase of the storage usage rate which also induces a greater order fulfill-rate. The higher the order fulfill-rate the higher is the available capital of the terminal and the greater the resources budget. A greater resources budget allows the management for more staff training to increase equipment exploitation which again results in an increase of operating efficiency. An increase in the operating efficiency induces extra handling orders which generates more gains and further allow for more

staff training and better equipment exploitation. As a result an increase in the operating efficiency has a reinforcing impact on customer's handling orders.

The optimization loop in the lower center of Figure 3 considers the optimization of the capacity in case of a high storage usage rate. Many handling orders result in an increased storage usage rate which leads to an increase in the dwell time of trains, trucks and load units. An increase in the dwell time attracts management's and customer's attention and after a time delay forces management's perception to expand handling capacity. The larger the handling capacity the lower the handling time and the higher is the order fulfill-rate. Finally a higher order fulfill-rate reduces the storage usage rate. As a result an increase in the dwell time of trains, trucks and load units induces a balancing capacity optimization action of the management to reduce the dwell time. Consequently the optimization loop functions as balancing loop for the inland terminal.

The target dwell time is set by the customers of the terminal in subject to the perception of the terminal's management. Depending on the power of the terminal location and the importance of the customer the management is willing to perceive customer's target dwell time. The dynamic adjustment loop allows the management to relax optimization pressure by dynamically adjusting the target dwell time pointing out the reinforcing nature of this loop. This means that an increase in the dwell time does not necessarily lead to an expansion of the handling capacity.

The stated aim of the inland terminal is to attract customers by providing sufficient handling time in turn to keep dwell times low. On the other hand customers are willing to reduce handling orders if the dwell time is too long. As a result the market response loop in the upper right has a limiting impact on the handling orders. Therefore we assume an increase in the dwell time of trains, trucks and load units and imply that it has shifted the impact on customer's perception. The dwell time is the most critical parameter of inland terminal operation and therefore customer's reaction is very sensitive. An increase in dwell time will lead to a reduction in handling order in the long-run. But, a reduction in handling orders induces a lower storage usage rate and further to a reduction of the dwell time. Consequently an under fulfillment of customer expectations resulting from a too long dwell time results in a decrease of handling orders allowing dwell time to fall and match customer's target dwell time again. This indicates that the market response loop acts as a balancing loop.

#### 4. RESULTS

The causal loop diagram allows the user to directly see the impact of changes in the system and therefore contributes to the understanding of the continuity of events. During our expert interviews and field studies practitioners always pointed out that there is a need for a theoretical model to support the understanding of the underlying simulation model. Although it was possible for them to validate simulation results the simulation

itself remained some kind of a black box for them. Therefore we decided to model the underlying causalities in causal loop models to ease understanding. By combining the simulation input and the corresponding performance indicators with the causal loop diagram it is possible to understand causes and effects in inland terminal operations (see Table 2).

Table 2: Performance Indicators and Objectives

PI	AVG Lifting Time
Objective	↓ Dwell Time
Loop	Optimization
Impact	Order Fulfillment
Cause	Staff qualification, Equipment Technology, Fill Rate Storage
PI	AVG Moves Per Day
Objective	↑ Revenue
Loop	Optimization
Impact	Operating Efficiency
Cause	Staff Qualification

Performance indicators are assigned to causal loops to emphasize the impact of an improvement or deterioration within the context of the system. Further it is possible to point out the corresponding causes to deduce necessary actions. When thinking of actions and the expressiveness of performance it is important to formulate corresponding objectives to measure the impact or contribution of performance indicators.

Table 2 gives a comprehensive insight into the link of performance indicators and inland terminal objectives. Imagine the performance indicator of average unproductive moves. This performance indicator gives information on the effectiveness of terminal operations. It is part of the in- and outflow loop and it has an impact on the operating efficiency. The cause for an increase of the average unproductive moves can be the qualification of the terminal staff, the usage rate of the storage or a combination of both. By measuring the average number of unproductive moves the management follows the objective of reducing dwell times of trains, trucks and load units. To reduce the dwell the management has the possibility to increase staff qualification, to optimize the storage strategy of the storage or to expand capacity. So there exists a link between the dwell time and the average unproductive moves. In fact, only the linking of the simulation results and performance indicators with the causal loop diagram allows for a comprehensive and intuitive understanding of the interplay of parameter setting as cause and the corresponding effects.

#### 5. DISCUSSION

During our study, specifications for further research and development subjects arose. Only recently more and more work on inland terminals is done. The importance of hinterland and inland transportation is growing with the same rate as the transportation of goods increases. Larger open sea vessels and increasing capacity of deep

sea container terminals require efficient inland terminals to distribute containers and goods to the consumers. Major findings showed that there is a need to go more into detail. We identified that our actual causal loop diagram that we have to incorporate much more details in the corresponding causal loops to show the impact and importance of further performance indicators. Therefore we want to incorporate details like for example the impact of the equipment failure probability. It shows the effect of increased equipment failure on the lead time of trucks. The reliability of the equipment determines the lifting performance per hour which increases or decreases the lead time of both trucks and trains. By incorporating more and more details in the causal loop diagram it will be possible to provide a comprehensive picture of the system including a more practicable set of performance indicators.

The underlying concept for assessing performance indicators to measure the process quality of inland terminals is a first approach towards a standardized process for collecting and evaluating data on the performance of inland terminals. With our approach we want to show that inland terminals have to be considered as complex systems that will need much more attention in future. This will allow bearing in mind the big picture while not losing sight of operating detail.

## REFERENCES

- Benna, T., Gronalt, M., 2008. *Generic simulation for rail-road container terminals*. Working Paper. University of Natural Resources and Applied Life Sciences, Vienna. Department of Economics and Social Sciences. Institute of Production and Logistics.
- Coto-Millán, P., Baños-Pino, J., Rodríguez-Álvarez, A., 2005. Economic efficiency in Spanish ports: some empirical evidence. *Maritime Policy and Management* 27: 169-174.
- Cullinane, K., Song, D.W., Wang, T.F., 2005. The application of mathematical programming approaches to estimating container port production efficiency. *Journal of Productivity Analysis* 24: 73-92.
- Cullinane, K., Wang, T.F., Song, D.W., Ji, P., 2006. The technical efficiency of container ports: comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A* 40: 354-374.
- Gronalt, M., Benna, T., Posset, M., 2006. SimConT: Simulation of Hinterland Container Terminal Operations. In: Blecker, T., Kersten, W., eds. *Complexity Management in Supply Chains-Concepts, Tools and Methods 2*, Berlin/Germany: Erich Schmidt Verlag, 227-246.
- Gronalt, M., Posset, M., Benna, T., 2007. Standardized Configuration in the Domain of Hinterland Container Terminals. In: Blecker, T., Edwards, K., Friedrich, G., Hvam, L., Salvador, F., eds. *Series on Business Informatics and Application Systems Innovative Processes and Products for Mass Customization 3*. Berlin/Germany: GITO-Verlag, 105-120.
- Hansen, I., Rießberger, K., Hollborn, H.J., 2008. *Rail Traffic, Traffic and Transport 2030*. International Workshop and Congress, 27<sup>th</sup> to 29<sup>th</sup> February 2008, Science and Congress Centre Darmstadt (Germany). Available from: <http://www.tt2030.com> [March 2008].
- Keller, M., Hellingrath, B., 2007. Kennzahlenbasierte Wirtschaftlichkeitsbewertung in Produktions- und Logistiknetzwerken. In: Otto, A., Obermeier, R., eds. *Logistikmanagement. Analyse, Bewertung und Gestaltung logistischer Systeme*. Wiesbaden/Germany: Deutscher Universitäts-Verlag, 51-75.
- Klotz, H., 2007. *Kombi-Kapazität kann Wachstum kaum fassen, Kombinierte Verkehr VDV-Workshop: Erste Ergebnisse der DIOMIS Studie*. DVZ Deutsche Logistik Zeitung. 13 November, 4.
- Le-Griffin, H.D., 2008. *Assessing container terminal productivity: Experiences at the port of Los Angeles and Long Beach*. Technical Report. Department of Civil and Environmental Engineering, University of Southern California.
- Le-Griffin, H.D., Murphy, M., 2006. *Container terminal productivity: Experiences at the port of Los Angeles and Long Beach*. Technical Report. Department of Civil Engineering, University of Southern California.
- Morecroft, J. 2007. *Strategic Modelling and Business Dynamics: A feedback systems approach*. West Sussex/England: John Wiley & Sons Ltd..
- Park, R.K., De, P., 2004. An alternative approach to efficiency measurement of seaports. *Maritime Economics & Logistics* 6: 53-69.
- Pestana Barros, C., Athanassiou, M., 2004. Efficiency in European seaports with DEA: Evidence from Greece and Portugal. *Maritime Economics & Logistics* 6: 122-140.
- Reiner, G., 2005. Customer-oriented improvement and evaluation of supply chain processes supported by simulation models. *International Journal of Production Economics* 96: 381-395.
- Sammer, G., Idea, H., Retzko, H.G., 2008. *Transport Planning and Intermodal Concepts*. Traffic and Transport 2030, International Workshop and Congress, 27<sup>th</sup> to 29<sup>th</sup> February 2008, Science and Congress Centre Darmstadt (Germany). Available from: <http://www.tt2030.com> [March 2008].
- Stölzle, W., Browne, M., Pfohl, H.C., 2008. *Freight Traffic, Logistics, Inland and Ocean Shipping*. Traffic and Transport 2030, International Workshop and Congress, 27<sup>th</sup> to 29<sup>th</sup> February 2008, Science and Congress Centre Darmstadt (Germany). Available from: <http://www.tt2030.com> [March 2008].
- Tongzon, J., 2001. Efficiency measurement of selected Australian and other international ports using data envelopment analysis. *Transportation Research Part A* 35: 107-122.
- Tongzon, J., Heng, W., 2005. Port privatization, efficiency and competitiveness: some empirical evidence from container ports (terminals). *Transportation Research Part A* 39: 405-424.
- Wang, T.F., Cullinane, K., 2006. The efficiency of European container terminals and implications for supply chain management. *Maritime Economics & Logistics* 8: 82-99.

# LOAD CARRIER MANAGEMENT ON RO-RO TERMINALS

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## ABSTRACT

The transparency of location and status of loadings and load carriers is particularly important for efficient warehouse management on seaport terminals. Today detection of load carrier movement processes and modified status information is insufficiently supported by software systems. An automated IT-based load carrier management system offers a wide range of opportunities for tracking and tracing positions and status information of loadings and load carriers. A permanent monitoring of changes regarding location and status allows the usage of innovative stock-keeping strategies, search time reduction, decrease of relocation processes and overall an improvement of the traffic flow on the seaport terminal area.

This article addresses the design and modelling of a system that enables automated detection of location and status of load carriers on seaport terminals combining innovative information and communication technologies for identification, communication and localisation tasks. Superior objective is the improved process monitoring in the context of Ro-Ro traffic.

Keywords: load carrier management, Ro-Ro terminals, track and trace

## 1. INTRODUCTION

In relation to globally increasing trade flows of goods the role of sea harbours for unobstructed cargo handling is gaining in importance. The amount of goods traded via the German sea ports alone increased from 224 million tons in 1999 to 302 million tons in 2006. The sea traffic prognosis passed by the German federal government in May 2007 forecasts a continuing growth of cargo shipping from German sea harbours to reach 759 million tons in 2025. Next to container traffic the Ro-Ro (Roll on / Roll off) traffic in particular is regarded as a main driver of this development with high potential for growth. The mentioned prognosis forecasts that Ro-Ro traffic of the German Baltic range sea harbours will grow over-proportionally with average growth rates of 4.8% and thusly increase by more than a factor of three from 27 million tons in 2004 to 71.7

million tons<sup>1</sup> in 2025 (ZDS 2007). In order to successfully manage the challenges related to this growth, next to increasing harbour capacities by expanding harbour infrastructure and connection to the hinterland, better use of existing capacities is required. In this context process improvements using intelligent storing position management systems and automatic freight or load carrier identification systems have been proposed (Oppel 2007).

A substantial part of the goods in Ro-Ro traffic is transported with specialised load carriers. Load carriers are defined by the German industrial norm DIN 30781 as carrying means for combining loadings to a loading unit and fulfilling transport, aggregation and handling functions as well as protective functions for these goods (Arnold 2002, Pfohl 2003).

The transport function for bridging spatial differences requires optimised size for efficient usage of transport spaces, e.g. fitting into ship hull spaces. Additionally load carriers fulfil a storage function for bridging timely differences and, in some cases, a handling function for assembly, picking and finishing processes (Heimbrock 2001).

The protective function or quality keeping function of the load carriers includes protection of the loadings against external strains from the surrounding (e.g. cold, humidity, electromagnetic fields) and also protection against damages resulting from inept or accidental handling (e.g. hits, scrapes etc.). Finally, load carriers also serve to mark and identify the loadings they contain (Pfohl 2003).

Load carrier management as a logistics function involves on the one hand load carrier life-cycle management, which includes the design of the load carriers, the development of the load carrier cycles, the maintenance of the load carriers during their life-cycle phases and their disposal at the end of the life-cycle, taking into account cost, time and quality aspects. During design of the load carriers the optimised size, handling and space efficiency as well as minimal manufacturing, maintenance and repair costs have to be considered. During operation the load carrier quality

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<sup>1</sup> Data without own weight of load carriers

and functionality has to be monitored and maintenance or repair actions have to be initiated.

The second main function of load carrier management comprises operational planning and control of the load carriers during their use within logistic and supply chains. This means the continuous tracking and tracing of the load carriers during the related processes, including documentation and filing of the process data, and disposition of the load carriers (Gudehus 2004).

This contribution focuses on the second task of load carrier management. Operational planning and control depends on a permanently up-to-date overview of load carrier inventory sizes as well as state and position of the load carriers. In this context innovative technologies like radio frequency identification and satellite based positioning offer potentials for improved load carrier processes and management (Fleisch 2005).

## 2. OBJECTS OF INVESTIGATION

Load carriers that are used particularly in Ro-Ro traffic are roll-trailers (mafis) and their prime movers (tug masters). They are used to transport high and heavy loadings. The so-called high and heavy segment is a niche market dealing with the import and export of trucks, busses, and construction or agricultural vehicles. In addition to self-propelling vehicles, heavy goods such as large boats or machines are placed on roll-trailers, which can be moved inside the Ro-Ro ships (Mattfeld 2006). The benefit of this technical solution results from the low conception of the trailer-chassis and the flexible connection through a z-shaped, hydraulically driven part of the tug master which can be raised and lowered.

Voluminous charges can be transported even into shipping spaces where ceilings are low. Acute angles can be negotiated during the loading and unloading of ships which induces an optimal utilization of shipping space.

The German MAFI Transportsysteme GmbH in Stuttgart developed these Systems, which are now enforced in the worldwide Ro-Ro system. Roll-trailers are property of the shipping companies who call at a port or are rented by them for a period of time. The trailers are partly denoted with standard alpha-numeric identities.

In the section “High & Heavy” of German automotive logistics provider BLG LOGISTICS AUTOMOBILE, 16 tug masters are used to move loaded and empty trailers, while ships are discharged and loadings are stored, externalized or charged. In 2006 approx. 330.000 tons of high & heavy goods were handled. For this task approx. 5.500 roll-trailers were used. Approximately 450-550 empty roll-trailers have been used on the seaport terminal in average. In the year 2007 the volume grew to approx. 380.000 tons of high & heavy goods, which were transported by approx. 6.300 roll-trailers. 500 to 650 empty roll-trailers have been the average of this year.

Figure 1 shows the essential processes of current load carrier management on a Ro-Ro terminal and the weaknesses in the process chain. Cargo-loaded roll-trailers are drawn down the ship and placed onto the terminal’s high & heavy areas. If the cargo is carried on quickly, the loaded goods will remain on the trailers.

After moving the cargo onto trailers that are usable for road traffic, empty trailers are stocked on disposable surfaces. The roll-trailers are put on top of each other by fork lifts to form stacks and thus reduce storage space.

Directed storage on specific fields occurs – if at all – only on the basis of information concerning place or status that is collected via a barcode system or keyboard entry. As manual data input bears risks concerning faulty or fragmentary collection of data, significant costs of following blemishes are expected e.g. through unknown and wrong captured positions of roll-trailers which causes costly actions to look for them.

Furthermore, generally missing and insufficient integration of information regarding status and position of load carriers into existing inventory management systems does not allow consideration of the load carriers in the context of planning inventory allocation.

This results in an intermediate storage of load carriers on temporary areas which leads to time-consuming and resource-expensive processes of relocation.

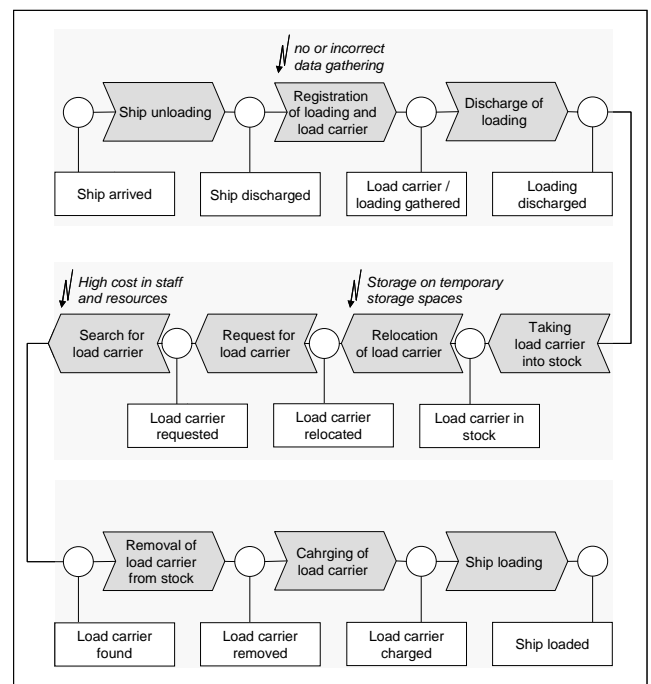


Figure 1: Current load carrier management processes

A similar problem to the use of mafi and tug master is handling sport boats on trailers. Every trailer is affixed by a number that refers to the boat number as a rule. This way of attaching an identification mark is restricted due to inconsistent weather. Capturing the boats is very disaffected.

Movements or changes of state (load carrier loaded, load carrier stocked etc.) of load carriers are currently not captured by IT systems.

Roll-trailers are not captured or captured manual via keyboard entry or barcode systems in which different standards to label goods (e.g. barcode, barcode-labels and identification plates) are used which complicates the process of capturing.

Locations of logistic objects are not often known due to missing or blemished capturing. Many inventory management systems do not consider load carriers which causes their storages on temporary surfaces. This causes rearrangements of the load carriers and position-tracing is hindered additionally.

Figure 2 shows the weaknesses and requirements of current inventory management systems regarding planning and control of load carrier processes as well as the deduced requirements to an effective inventory management. The lack of transparency concerning the whereabouts and condition of logistic objects affects uncertainties of planning such as absent correlation of load carriers and loadings. Otherwise it is necessary to bring in expensive arrangements such as searching on the huge seaport terminal to reduce disturbances.

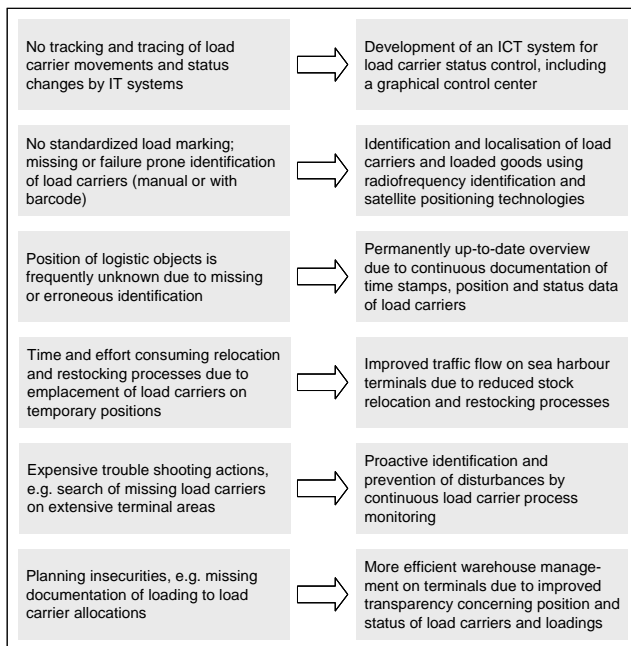


Figure 2: Weaknesses and requirements

Due to missing integration into inventory management systems a complete observance of all objects is not possible although it would be possible to plan the inventory management measures. This situation leads to an inefficient administration of inventory surface areas overall.

### 3. PROCESS IMPROVEMENT

The super-ordinate objective of the concept consists of improved transparency concerning position and status of load carriers and loadings in sea harbour Ro-Ro terminals by combination of innovative technologies

like radio frequency identification and satellite positioning as well as control center approaches. The continuous identification and localisation results in a permanent overview of load carriers and loadings concerning time, position and status information. This allows to realise potentials for added value logistic processes like e.g. permanent allocation of load carriers to their owners, and thus exact storage fee calculations.

Automatic documentation of load carrier storage positions allows to significantly reduce time and effort, spent searching load carriers or goods. Additional potentials are offered by improved capability to control storage relocations and stock transfers, prevention of loading errors and acceleration of stock inventory taking processes. Integration of load carrier position and status information into existing warehouse management systems allows to improve storage allocation planning and to use new intelligent storage strategies like e.g. chaotic storage allocation.

The time stamp, position and status data can be used to monitor terminal processes. Such a process monitoring, combined with the capability to analyse the data, which has previously been documented over longer periods, using adequate data analysis and business intelligence methods, allows to better capture longer term developments related to the load carrier processes. This offers further potential for lasting and effective improvements in process planning and execution.

In the prospect of logistic potentials for improvement several effects can be identified and formulated as objectives for implementing the concept, which has been described in this paper:

- Improved traffic flow on sea harbour Ro-Ro terminals due to reductions of storage relocation and restocking processes:*  
The overview of Ro-Ro terminals which the system can provide enables improved, proactive planning of the terminal processes, allowing to reduce time consuming and capacity fixing storage relocation and restocking processes of the load carriers which are currently necessary due to planning inconsistencies.
- Reduced search efforts to find missing load carriers:*  
Due to localisation and tracking and tracing of also individual load carriers, losses of load carriers and resulting searches for missing load carriers on the extensive terminal areas can be prevented almost completely. This will allow to reduce fuel consumption during searching activities and thus operating costs of the Ro-Ro terminals.
- Reduced fuel consumption:*  
As implementing the system allows to reduce erroneous dispositions during removal of the



load carriers from storage positions, fuel consumption of the tug masters (towing machines for the load carriers) may be significantly reduced. One example might be the allocation of a tug master for dissolving the different load carriers stacked onto each other in order to get to the single load carrier required.

- *Proactive identification and prevention of disturbances:*

An IT-based graphical control centre allows a real-time monitoring of the load carrier processes and thus enables improved planning and control within load carrier management.

Additionally, in the medium term it will be possible to reduce over a mid term horizon the amount of trailers on the terminals by using exact storage fee calculation and accounting, which will free storage areas for other terminal processes. Generally an increased throughput may be achieved on sea harbour terminals and such in the respective sea harbours as a whole.

#### 4. TECHNICAL IMPLEMENTATION

The adoption of innovative information and communication technologies for identification, communication and localisation tasks offers a wide range of opportunities for tracking and tracing positions and status of loadings and load carriers. In this context localisation systems as well as automated identification technologies are of particular importance. Via satellite positioning systems such as GPS (Global Positioning System) or the upcoming European Galileo system any object can be localised at anywhere in the world with an accuracy of several meters. This means that the exact position of an object can be determined in an appropriate frame of reference, e.g. in a geodetic graticule. The main purpose of automated identification systems is fast and reliable identification of several objects. In addition to identification technologies such as barcode and OCR (optical character recognition), especially radio frequency technologies are currently within the centre of attention. A radio frequency system consists of at least one storage medium fixed to the corresponding object (a transponder) and a reading / writing device, which communicate with each other via radio signals. A transponder contains an unique identification number and possibly additional data. These data stored onto the transponder is transmitted to the reading device in the form of an electromagnetic signal responding to a request impulse. Both the transponder as well the reading device have an integrated transmitting and receiving antenna. The reading / writing devices are connected to the operational planning and control software system via suitable network and communication interfaces. Due to the fact that the data acquisition is done automatically at the moment of emergence by the reading / writing

devices, the data inventory of the logistic planning and control system is always up-to-date, which allows real-time planning and control of logistic order processing.

Regarding the logistic objects suited for adoption of the described technologies, several layers and levels of aggregation respectively can be distinguished, which range from loading via load carrier to means of transportation. At the bottom layer loadings and load carriers are equipped with transponders containing a unique identification number and possibly additional order data. The middle layer includes mobile and stationary reading / writing devices at specific locations in order processing recording relevant status information of loading and load carrier. The logistic backend software system represents the upper level of the considered load carrier management system.

As illustrated in figure 3, the technical implementation of the designed system for tracking and tracing load carriers on seaport terminals is based on innovative information and communication technologies for identification (RFID, mobile character recognition), communication (WLAN) and positioning (GPS, Galileo) tasks including necessary hard- and software components. The adoption of existing technologies for automated detection of seaports is the basis for the development of comprehensive process improvements which results from new opportunities for communication between logistic objects, handling equipment and seaport systems.

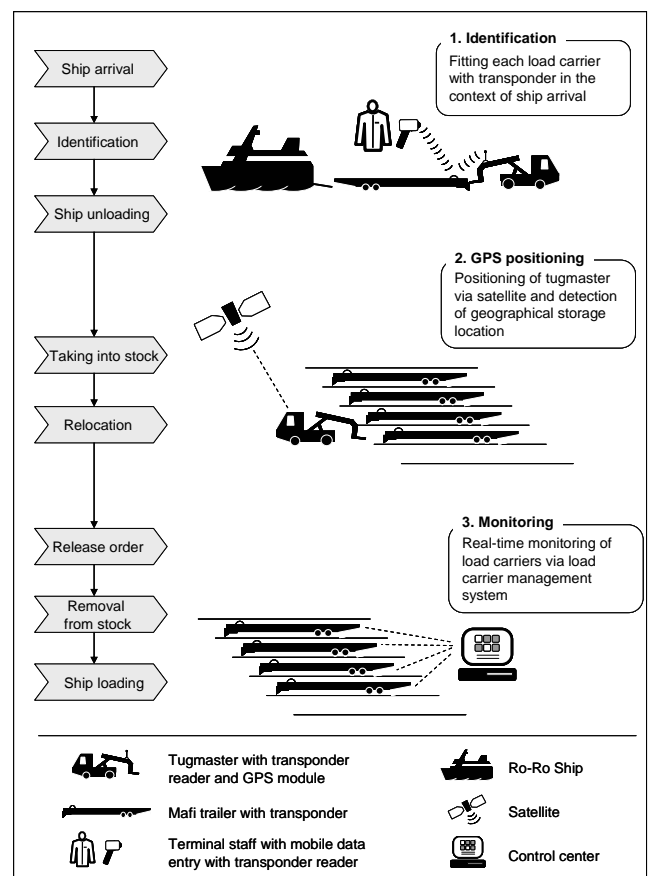


Figure 3: Technical implementation

The combination of these technologies in the form of a so-called hybrid solution with appropriate interfaces to warehouse management systems allows the identification and localisation and consequently the ongoing position and status monitoring of load carriers and loadings. The last mentioned aspect is an essential condition for the comprehensive and efficient storage allocation planning based on current planning data.

The focus of the designed system is directed onto stationary and mobile detection of position and status information of load carrier on seaport terminals as well as on ships in the harbour. For this purpose, roll-trailers are fitted with passive UHF transponder. Tug masters and fork lifts are equipped with combined data terminals, which contain each an UHF reader to identify the related roll-trailers, a positioning component for locating the current position as well as a communication component for transmitting transport orders, positioning and status data. The position of the tug master or fork lift determined by GPS or Galileo in the near future is assigned to the roll-trailer identified by its RFID tag. So a detection of the specific position of the roll-trailer can be achieved both in the case of moving the roll-trailer with a tug master from one location to another and in the case of taking into storage or stack building by a fork lift. An appropriate combination of the described technical components allows a continuous monitoring of position and status of the roll-trailers (loading status, current allocation of roll-trailer to tug master, movement status etc.) on the huge terminal area. As a result, the main stock keeping processes of load carriers such as taking into stock, removing from stock and relocation can be tracked. For each process step (ship loading / unloading, taking into stock / removal from stock / relocation of roll-trailers, unloading of roll-trailers etc.) a timestamp as well a location stamp is documented. The identification number of the roll-trailers and loadings as well as the voyage numbers are documented in the corresponding software system and are assigned to the related ships and shipping companies in their function as invoice recipient for storage charge. At neuralgic points of the seaport terminal area (ship ramp, storage gates etc.) additional stationary reader devices can be implemented, which complete the monitoring of roll-trailer movements by identifying passing roll-trailers fitted with passive transponders.

By means of the designed IT-based load carrier management system described above, the process chain in the field High & Heavy of the BLG LOGISTICS AUTOMOBILE (ship unloading, taking into stock, relocation of load carrier, removal from stock to ship loading) can be permanently observed and therefore significantly improved. Further sub processes are primary data collection and receiving inspection in the context of the ship arrival process. On the seaport terminal of the BLG LOGISTICS AUTOMOBILE the RFID system represents a temporary closed loop solution with main focus on the time periods, during which the roll-trailers are staying on the terminal area.

Transponders, which are tagged to the roll-trailers in the context of the ship unloading process, are read by stationary RFID reader devices at the ship ramp. When a roll-trailer leaves the seaport terminal area, the transponder is read again by the RFID reader at the ship ramp and after that removed from the roll-trailer. Another field of application of the described system is the inventory of load carriers, which can be significantly accelerated using a mobile data entry device (MDE) with integrated RFID reader and GPS component.

## 5. CONCLUSION AND OUTLOOK

Central aspect and aim of the present article is design and modelling a system that captures position and status of load carriers to achieve an improved load carrier management in Ro-Ro traffic on sea harbour terminals. Whereas information and communication systems are used in several areas of harbour logistics, similar technological support does not occur in collecting changes of load carriers' status and positions.

The described analysis points out weaknesses in the process steps. Rearrangement of mafi trailer load carriers causes high effort and use of temporary stocking areas. Searching for load carriers is expensive in terms of time and resources (e.g. additional employment of staff, additional fuel consumption, additional motor tractors etc.) and results in increased costs.

Weaknesses as demonstrated particularly result from faulty or completely missing collection of data, while load carriers are collected or used as the ship is unloaded. Based on detailed inventory and documentation of actual-processes on the harbour terminal of BLG LOGISTICS AUTOMOBILE an analysis of critical points could be enforced. It uncovered different potential for advancements. Requirements on an IT-based load carrier management system have been developed on the analysis results. The described method of resolution regarding the technical implementation was also developed in adopting the results.

System implementation includes the development of software for load carrier management and as the selection of appropriate hardware components. The developed theoretical model adjoins limits in its practical use. Therefore further steps of work will be implementation of software and hardware according to the model.

A prototypical system based on the shown model and system concept will be implemented on the Ro-Ro terminal of the BLG LOGISTICS AUTOMOBILE. Beside the identification of load carriers also changes of location and time will be recorded and monitored by a IT-based control center.

The phase of implementation is followed by field tests within an installation for testing. Logistic and economic benefits regarding the rollout of implemented hardware and software prototypes for load carrier management are explored under commercial aspects.

The designed system can be seen as an exemplary system that raises different expectations. Beside real time monitoring of load carriers it is the aspect of up-to-date transparency that shows at what place and in what kind of state a load carrier stands in a certain moment. Planning and control processes are to be improved which will result a significant impact on the logistic performance of Ro-Ro terminals.

It is expected that sea harbours will be increasingly frequented in the future. Considering this aspect, the profitability of Ro-Ro traffic in sea harbours cannot be disregarded.

## 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

- Arnold, D.; H. Isermann, A. Kuhn, H. Tempelmeier (Hrsg.), 2002. *Handbuch Logistik*. Springer Verlag Berlin.
- Fleisch, E., F. Mattern (Hrsg.), 2005. *Das Internet der Dinge*. Springer Verlag Berlin.
- Gudehus, T., 2004. *Logistik - Grundlagen, Strategien, Anwendungen*. Springer Verlag Berlin.
- Heimbrock, H., 2001. *Palettenlose Lager- und Transportsysteme als Alternative zu konventionellen Ladungsträgern*. Deutscher Fachverlag, Frankfurt am Main.
- Mattfeld, D. C., 2006. *The management of transshipment terminals: decision support for terminal operations in finished vehicle supply chains*. Springer New York NY.
- Oppel, J.-A., 2008. *Der Seehafen als Engpass*. März 2007. Online source. Available from: <http://www.dmkn-beta.de/downloads/51/De/FILE451/DerHafenalsEngpass.pdf> [Accessed: 31 March 2008].
- Pfohl, H.-P., 2003. *Logistiksysteme. Betriebswirtschaftliche Grundlagen*. Springer-Verlag Berlin.
- Zentralverband der deutschen Seehafenbetriebe: Jahresbericht 2006/2007. September 2007. Online source. Available from: <http://www.zds-seehaefen.de/pdf/jahresberichte/2007.pdf> [Accessed: 31 March 2008].

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# CONTRIBUTION TO A FULLY AUTOMATIC CONTAINER TERMINAL AS PART OF THE LOGISTICS FACTORY OF THE FUTURE

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## ABSTRACT

To withstand international pressure of competition logistics added value processes will have a similar level of automation as production added value processes.

This paper describes possibilities for automation and to increase efficiency of logistic processes on and around container terminals as a part of the logistics factory of the future, which is the vision of a fully automatic process along the whole logistics chain. The presented approaches will be turned into praxis in cooperation of BIBA and container terminal operators.

Keywords: automation, container terminal, logistics

## 1. INTRODUCTION

A rising transport of goods is caused by increasing globalization. Most of the consumable goods are packed in standardized packing as parcels and are transported in containers from Asia to Europe.

Efficient processes are demanded on the terminal and around the terminal to obtain cost-effective processes as costs for container ship berths in harbours are high, capacities on the container terminal and on the traffic routes are limited. These reasons result in a high demand on rationalization and automation, which also is identified by the study RoboScan (Pfeffermann 2007). In RoboScan 60% of the companies, who have taken part summarized their need for investments, which is not put into praxis as appropriate solutions are not available.

Logistics factory of the future focuses on research and development activities, which aim for smooth processes in logistic networks. Hence this concept is part of the logistics factory of the future.

The following paper is parted in three main sections. The first section describes the vision for the logistics factory of the future. Afterwards the container terminal as part of the logistics factory of the future is focused. The first section describes a process on a container terminal in which the usage of sensors increases safety for transporting containers. The second section focuses on alternative approaches for a container transport systems to get over horizontal barriers. The third section is concerned with processes behind the container terminal as loading and unloading of containers in Container Freight Stations.

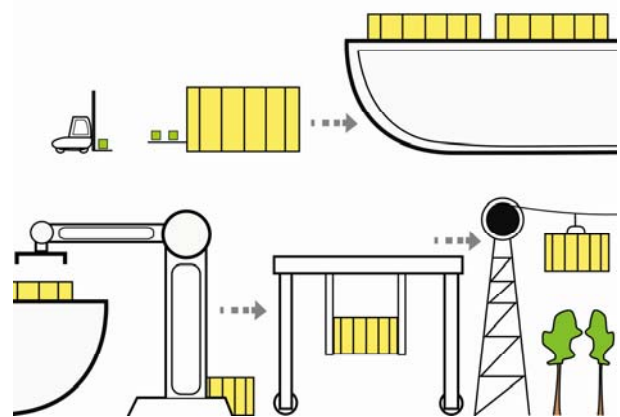


Figure 1: Logistics chain in the logistics factory of the future

## 2. LOGISTICS FACTORY OF THE FUTURE

A logistic network describes the way of a product from its origins to the finished product and recycling after its use. Various organisations and companies are involved in this product life cycle, which add new features to the products by means of value added actions of the production or service areas. The so called entities of these networks can be described as logistic factories. From a macroscopic perspective their field of activities and their operational sequences cover three areas: the input of commodities and goods, the provision of value added services (the so called through put) and output to the next station of the supply chain.

A closer view of a logistic factory shows a variety of different processes. Business processes significantly characterise the operative corporate task of an organisation. As a result, processes vary in different countries, between different branches and also between different companies within one branch. Therefore the efficient realisation of productive business processes is especially important for a strong competitive position. The term logistic factory describes companies that only carry out logistic activities (i.e. distribution or warehousing) or those with mostly classical production that have logistic functions (i.e. component manufacturing, assembly or food production, etc.).

According to the survey conducted by BIBA in 2007, the area of logistics and robotics has great need for modernisation. Automation solutions are needed

desperately and the determination to invest in this area is high. The RoboScan study also shows a central meaning for new technologies. Technical components, for example image processing, automatic identification of objects and the combination of robotics with advanced sensor technology, are required. It is not only interviewees of the study that have recognised the many possibilities for the efficient development of processes. With the concept of the logistic factory of the future, researchers have already begun to adapt their requirements and visions.

Hence, logistic processes within the area container terminals are a part of the logistics factory of the future.

### 2.1. On the container terminal

Container terminal operators are forced to organize their handling of cargo efficiently as the quantity of handled cargo increases (Echelmeyer 2005).

Amongst others this is achieved by smooth processes on the container terminal. Delays on the container terminal have an effect on subsequent processes and costs increase. An example which results in a delay is an accident on the container terminal, which is avoided by safe handling of containers. Containers are unloaded by Van Carriers (VC) from the container ship and are transported by Straddle Carriers (SC) on the terminal. To lift a container a spreader is moved on top of it and a twist lock, which is a mechanical locking device, establishes a connection between the container and the VC or SC. If over sized cargo is transported special carriers (open top containers, platforms or flats) are used and an over height frame is fastened at the spreader. In the past special carriers have fallen down due to instable locking states between over height frames and the special carrier. Instable locking states are caused due to the working principle. Between the four legs of the over height frame and the four corner points of the special carrier a locking is achieved with twist locks. The locking is checked by a mechanical state device, which shows red if a locking state is detected and green if no locking state is detected. The driver of the straddle carrier is allowed to lift the container only if a locking state is detected. Instable locking states occurred in the past, caused by several tries to obtain a locking state. As a consequence the container has fallen during the lifting process or the transport of the container. Accidents on the container terminal cause economic damage and block subsequent processes. Furthermore, processes have to be designed in a way that the risk for accidents is minimized.

Therefore, container terminal operators ask for an additional component on the spreader, which is able to check the locking state between the over height frame and the special carrier to provide safe processes on the container terminal. Within the next paragraphs a concept for an electronic system is presented, which is capable to detect locking states. The system consists of an additional sensor, and a communication device.

### 2.2. Extension of container terminals

Container terminals' area capacities are fully utilized as container handling has increased constantly the last decades. Most usable areas besides the container terminals have already been integrated to the terminals. Hence no further extensions of the areas are available and as an alternative areas near the container terminals are used for storing containers, which gives contribution to the traffic collapses in harbours. Containers are transported between these depots and the container terminal via trucks, which use public streets. As the capacities of the public streets have often been designed before the trend for container handling was visible, the capacities of public streets are also exploited. Moreover, reloading containers to trucks is time consuming, many truck drivers are necessary and further costs for the trucks evolve. Taking the high costs and the prediction of further increasing handling of containers into account, it is necessary to provide an alternative transport system. Direct transshipping from container ship to barges is inefficient as the way between depot and terminal is often short and the depot is not always located besides a quay. Trans shipping to trains is inefficient as the track infrastructure is not flexible.

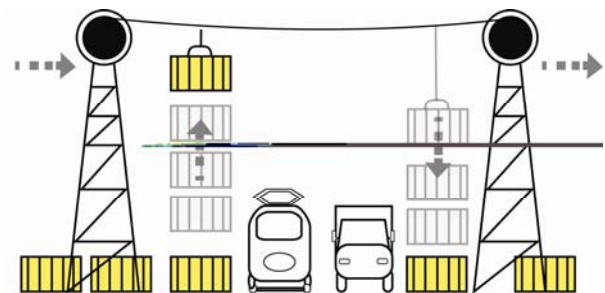


Figure 2: Cable Railway for Containers

The challenge is to design an alternative transport system, which uses the airspace for short distances between a container terminal and associated container depot areas. To achieve efficient logistic processes the system has to be fully automatic and could consist of following components:

- A fully automatic handover station, which transfers containers between straddle carrier / van carrier and the transport system and which transfers containers from the transport system to a straddle carrier / van carrier
- A buffer system, as the number of straddle carriers / van carriers on a terminal is limited and therefore a permanent availability can not be granted
- A transport system between the automatic handover stations to overcome horizontal barriers like streets and train tracks

Further requirements have to be covered by the technical system

- Bi-directional transport to provide storing and releasing
- A height of about 15m to allow the crossing of horizontal barriers as streets or train tracks
- Appropriate capacities are provided to guarantee economic efficiency
- Means of transports is variable to cover fluctuating handling of goods
- Design for standardized carriers with a maximum weight of 40 tons

Besides technical requirements, further challenges evolve from the safety demands.

### 2.3. Behind container terminals

A significant amount of containers are unloaded and loaded within the harbour areas. Loading and unloading of containers is a relocation of piece good handling from the harbour into the surroundings of the harbour. Piece goods, which have been stored manually in nets into the hatchway, are nowadays stored in Container Freight Stations. Two major challenges within Container Freight Stations are the storing of inhomogeneous goods and the unloading of parcels.

Two typical scenarios from praxis are stated for visualization.

Case 1: Textiles and small articles are shipped in parcels, which are loaded loose to save the space which would be needed for pallets. Depending of the customer structure, up to 60% of incoming containers are packed in such a manner. As single parcels have a weight up to 25kg and a container has the capacity of about 1800 parcels, the worker has to conduct monotonous and physical stressful work.

The demand of ergonomic working places and the pressure to provide efficient processes, causes a request of technical systems for automatic unloading of containers. At first glance, it may be surprising that a container filled with loosely stored parcels poses a challenge for a robot. But in the classic area of robot application, which are production processes in the automotive industry, robots are involved in repetitive activities and work with exactly the same parts. The different sizes and composition of packages make it extremely difficult to introduce automation in this area. Hence, most packages are still unloaded and transhipped by humans. Over the past six years a consortium from business and research communities have developed a parcel robot. This robot was put into daily service in the spring of 2007.

The parcel robot is the first intelligent system that automatically unloads containers and swap bodies that are filled with loose parcels. In the past, this work was always done manually.

Once a parcel robot has a container positioned in front of it, it independently works out the best unloading sequence. It removes the parcels one after the other and places each onto a conveyor belt. In principle, it is similar to the job performed by a human worker.

The parcel robot consists essentially of the following components: a chassis, a telescopic conveyor belt, a 3-D laser scanner and an interchangeable gripping system - consisting of an articulated arm and a grabber.

The robot is positioned over the chassis, which does not have its own drive system. The chassis is connected to the telescopic conveyor belt. This belt is extended electronically, and positions the chassis and the robot in the container. The robot is equipped with a passive steering system, but can only move forward and backward - the container must be positioned directly in front of it. This is not a critical matter for application in places such as parcel distribution centers because the unloading situations there are always the same.

In the first step of the unloading process, the 3-D laser scanner examines the situation. An integrated computer then analyzes the sizes of the parcels and determines the optimal unloading sequence.

The articulated arm attached to the front of the robot has six joints and gives the machine its necessary freedom of movement. As a result, the robot can reach every point in its surroundings, regardless of whether a parcel is located at the top, in the middle or on the floor of the container.

The grabber itself is attached to the articulated arm and is equipped with suction cups that create a vacuum to clutch and hold the parcels. The grabber also has sensors, giving it something like the "sense of touch." In difficult situations in which the 3-D scanner cannot provide sufficient data on its own, the data yielded by the sensors are incorporated into the decision-making process.

In principle, the parcel robot works like a person who stands, with legs apart, over the conveyor belt, picks the parcels in front of him and places them through his legs onto the belt behind him.

The parcel robot facilitates a seamless, automated connection between delivery of parcels in a transshipping center and their subsequent distribution. In the past, this connection had to be created manually. As a result of continuous automation, logistics processes can be optimized in the future and workers can be spared from doing physically demanding jobs.

At the moment, the robot does not work as rapidly as a human. But as a result of technical refinements, it can be expected that the robot will soon become considerably faster. In the future, it will unload several parcels at the same time or be able to adapt to the variety of demands posed by distribution centers around the world by using different gripping mechanisms. With the help of RFID Radio frequency identification, the parcel could electronically inform the robot how the individual handling process could optimally proceed.

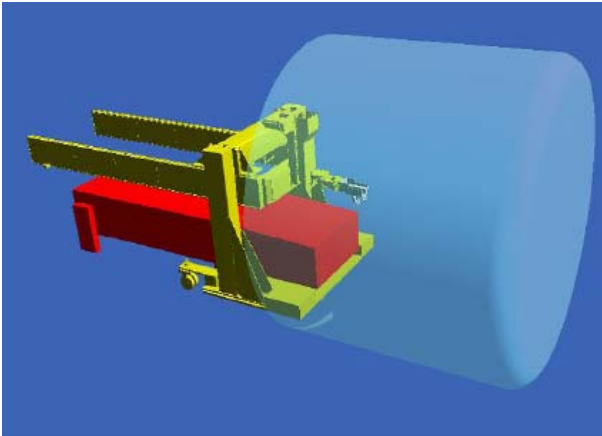


Figure 3: Simulation of working space

Case 2: Packing of bulky and heavy piece good is done often with fork lifters, which possibilities to manoeuvre inside of a container are small as containers have their opening on the slender side. This causes time consuming loading and suboptimal utilization of container space.

The main idea for part-automatic loading of containers is to compose and securing the complete content of the container before loading. Therefore, the container content is put on a loading device in front of the container, the content is secured and afterwards it is pushed into the container. The loading device is lowered and pulled out of the container when it reaches the bottom.

The loading device, which is designed, developed and built as a prototype is the basis for optimized processes within the area of container loading.

The optimization of the material flow gives the opportunity for fast reaction times due to the possibility of buffers for complete freight. This has an effect on the processing time in combination with higher quality of storing. Another advantage of using a loading device is the possibility to put the goods from all sides onto the device. Furthermore, the storage capacities are used better and the time of the containers at the loading places is reduced. New opportunities from the loading device rise the need of an appropriate software system.

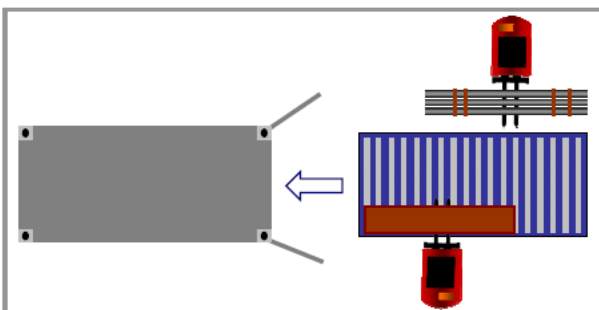


Figure 4: Loading device

Besides the development of a new loading device a new software is designed, which shall take dynamic loading planning into account. To achieve this, the

loading device is equipped with sensors to acquire data from incoming goods. The acquired data, which could be freight consolidation or information for subsequent production processes, are used for the planning of the loading process. Furthermore, the data are integrated in control systems for container loading, which is responsible for sending data to subsequent processes. This results in optimized overall processes, i.e. short term break-down of planned goods or incoming but not scheduled goods. By having a flexible software system these events can be integrated into the loading plans dynamically. The impuls for computing a new loading plan might be implemented either event-based or in predefined cycles.

Event-based adaption of loading processes might be in dependence of product types, which are only loaded if a defined amount of goods is reached. In contrast to event-based adaption of loading processes time-based adaption of loading processes are similar to existing solutions. Besides the computing of loading plans it is possible to have further advantages by acquiring product specific information directly from the goods e.g. it is possible to pack goods with respect to their destination.

Both processes are a bottle neck during the processing of import and export. Hence, a technical system for automatic loading and unloading provides more efficient processes. As changing environments have to be taken into account only a cognitive system is able to fulfil the necessary requirements (Scholz-Reiter 2008).

## REFERENCES

- Pfeffermann, N., Echelmeyer, W., et al. 2007. Study Regarding the Developments, Potentials and Future Fields of the Activity of Robotics-Logistics for Service and Intralogistics, Springer Verlag, Heidelberg 2007
- Echelmeyer, W., Tank, S., et al. 2005. Einsatzmöglichkeiten von Industrierobotern in Paketverteilzentren, Roboter in der Intralogistik, 2005
- Scholz-Reiter, B., Kirchheim, A., et al. 2008. Konzept zur automatischen Entladung von Stückgütern durch ein kognitives Robotersystem, in press: Industrie Management 26 2008 (4)

## AUTHORS BIOGRAPHY

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# OPTIMIZING YARD ASSIGNMENT AT AN AUTOMOTIVE TRANSSHIPMENT TERMINAL

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## ABSTRACT

We present an optimization model for the yard allocation process in an automotive transshipment terminal. The cars arrive and depart by ships in large batches and the yard planners have to dynamically assign incoming cars to parking rows. The integer linear programming model has been implemented in a commercial solver (CPLEX). We will present at the conference the model, the CPLEX computational results, and a new meta-heuristic.

Keywords: automotive transshipment terminal, yard management, integer linear programming

## 1. INTRODUCTION

We discuss an operational problem arising in an automotive transshipment terminal. Maritime automotive transportation is developing along lines similar to container transportation where the hub and spoke arrangement is widely adopted (Mattfeld, 2006). Deep-sea vessels operate between a limited number of transshipment terminals (hubs). Smaller vessels (feeders) link the hubs with the other ports (spokes). This network topology results in the consolidation of capacity along the routes linking the transshipment ports and in the growth of their importance. Deep-sea car carriers have a capacity up to 6000 vehicles while ships deployed on the short-sea segment attain a capacity up to 1000 vehicles. Therefore, automotive transshipment terminals manage large flows of incoming and outgoing cars. Unlike containers, cars are “fragile” objects that require careful and consequently labour intensive handling. For example, cars can not be stacked and this results in larger yards with respect to container terminals. The yard management process is the heart of a transshipment terminal. The cars arrive and depart by ships in large batches and the yard planners have to dynamically assign incoming cars to parking rows. Once assigned to parking rows, the cars are not relocated inside the yard, i.e. their initial yard position is not modified during their duration of stay.

The reason is that a re-handling process will augment the risk of damage which has to be kept at the lowest possible level. This “no-relocation” rule, combined with the low density yard, augments the importance of optimal yard assignment. In fact, the total traveled distance becomes a critical issue in such a low density yard. The transport of a car from the quay to the parking slot is performed by a driver. The drivers are grouped in teams and they are assisted by a mini-bus that brings back the drivers to the quay when unloading (to the yard in the loading case). This driver gathering process is another relevant operational problem. In the following we will indicate as a group a set of cars that arrive and depart by the same pair of vessels, and are of the same type (car model and brand). In order to facilitate the yard management and the driver gathering process, a group is allocated to a set of adjacent parking rows, Figure 1. The number of required parking rows depends upon the car length, and upon the row length since the rows have variable lengths in the yard. Yard managers prefer not to share a row between different groups. Therefore, partially empty rows are possible.

We present an optimization model for the yard allocation process. The model has been implemented in a commercial integer linear programming solver (CPLEX). We will present at the conference the model, the CPLEX computational results, and a new meta-heuristic. The meta-heuristic is inspired by the well-known Greedy Randomized Adaptive Search Procedure (GRASP), (Resende and Ribeiro, 2003), and it is guided by the principle of maximizing the rotation index of the most favorable yard positions (Goetschalkx and Ratliff, 1990).



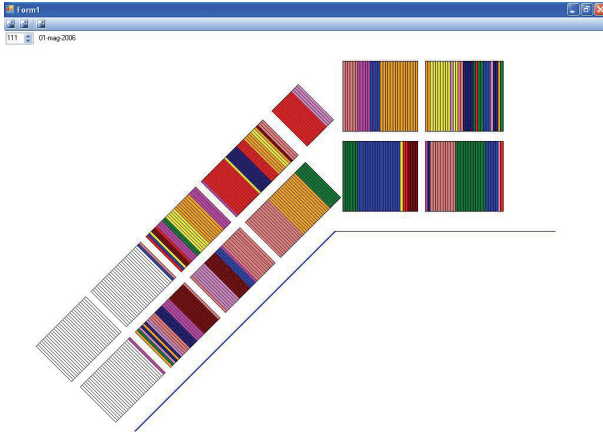


Figure 1: Example of yard allocation

## 2. MATHEMATICAL MODEL

We assume a discretized rolling time horizon, and we define as a time step a fraction of a work shift. Let  $t$  express the time step index,  $t \in T = \{1, \dots, |T|\}$ , i.e. the time horizon consists in  $|T|$  time steps. The set of groups to allocate during the time horizon is indicated by  $K = \{1, \dots, |K|\}$ , and  $R = \{1, \dots, |R|\}$  is the set of parking rows. The group related data are:

- $\eta^k$ , number of cars of the group  $k$ ;
- $v_r^k$ , maximum number of cars of the group  $k$  that can fill the row  $r$ ;
- $a^k$ , arrival time;
- $b^k$ , departure time;
- $o^k$ , quay unloading position;
- $d^k$ , quay loading position;
- $c_a^k$ , largest admissible unloading handling time, i.e. transport from the quay unloading positions to the assigned parking rows;
- $c_b^k$ , largest admissible loading handling time, i.e. transport from the parking rows to the the quay loading positions.

Rows are numbered in the filling direction, i.e. if row  $r$  is filled before row  $s$  then  $r < s$ . The row ordering is such that if rows  $r$  and  $s$ ,  $r < s$ , are adjacent then  $s = r + 1$ . We will consider later in this section the case of an “ending-row” arising when a given row  $r$  does not have an adjacent row in the filling direction. In the following we assume that it always exists an adjacent row. For each group  $k$  we have to find a set of free adjacent rows of sufficient capacity. Since we consider parking rows of variable length, the number of required rows is variable as well. Let  $r$  be the first row in the filling direction assigned to group  $k$ . Then the last row will be  $r + q_r^k$ , where  $q_r^k$  is the smallest positive integer value satisfying the following inequality:

$$\sum_{\alpha=0}^{q_r^k-1} v_{r+\alpha}^k \geq \eta^k$$

The  $q_r^k$  value expresses the number of rows needed by the group  $k$  when the group first row is  $r$ , i.e. the group would occupy the row interval  $I_r^k$  defined as  $I_r^k = \{r, r+1, \dots, r+q_r^k-1\}$ . Analogously, we define as  $g_s^k$  the number of rows that the group  $k$  would require if  $s$  is the last row of the group, i.e.  $g_s^k$  is the smallest positive integer value satisfying the following inequality:

$$\sum_{\alpha=0}^{g_s^k-1} v_{s-\alpha}^k \geq \eta^k$$

Consequently, we have the row interval  $\{s - g_s^k + 1, s - g_s^k + 2, \dots, s\}$  which is equivalent to  $I_r^k$  if  $r = s - g_s^k + 1$ . Since the  $q_r^k$  and  $g_s^k$  values are related to the filling direction, we indicate them as “forward row request”, and “backward row request”, respectively.

Thanks to this notation we can indicate an assignment of a group to the yard as an assignment to a first row. The “ending-row” case is now treated by considering non-admissible an assignment of a group  $k$  to a first row  $r$  such that  $q_r^k > 1$  and the set  $\{r, r+1, \dots, r+q_r^k-2\}$  contains an ending-row. Let  $\bar{R} \subset R$  be the set of ending-rows, we define as  $R(k)$  the subset of  $R$  such that we do not have an intermediate ending-row for any assignment of  $k$  to  $r \in R(k)$  i.e.

$$R(k) = \left\{ r \in R : I_r^k \setminus \{r + q_r^{k-1}\} \cap \bar{R} = \emptyset \right\}.$$

Our decision variables are:

- QuickTime™ è un decompressore sono necessari per visualizzare quest'immagine. if the first row of the group  $k$  is  $r$ , i.e. the group occupies the row set  $\{r, r+1, \dots, r+q_r^k-1\}$ .

Since we want to minimize the total handling time, we define as  $c_{vz}$  the time distance between  $v \in R \cup O$  and  $z \in R \cup D$ , where the set  $O$  represents the unloading positions  $O = \bigcup_{k \in K} \{o^k\}$ , and, similarly we indicate by  $D$  the set of loading positions,

$$D = \bigcup_{k \in K} \{d^k\}.$$

The time distances are derived by the terminal operational database. Thus, these values incorporate set-up times and reflect real average speeds between positions. Our decision variables induce cost coefficients defined as follows:

- $c_{o^k r}^k$ , unloading handling time for the group  $k$  when the first assigned row is  $r$ :  

$$c_{o^k r}^k = \sum_{\alpha=0}^{q^k-2} c_{o^k, r+\alpha} \times v_{r+\alpha}^k + c_{o^k, r+q^k-1} \times (\eta^k - \sum_{\alpha=0}^{q^k-2} v_{r+\alpha}^k)$$
- $c_{rd^k}^k$ , loading handling time for the group  $k$  when the first row is  $r$ :  

$$c_{rd^k}^k = \sum_{\alpha=0}^{q^k-2} c_{r+\alpha, d^k} \times v_{r+\alpha}^k + c_{r+q^k-1, d^k} \times (\eta^k - \sum_{\alpha=0}^{q^k-2} v_{r+\alpha}^k)$$

We express by  $H_t, \forall t \in T$ , the largest desired handling per time step. We use the  $H_t$  values to avoid, if possible, handling peaks. The model can be solved iteratively by using, at the first iteration, arbitrarily large  $H_t$  values. Then, if the planners prefer to smooth the resulting handling peaks of this first solution, the model is solved by imposing the desired  $H_t$  values. The process is iterated until a feasible and satisfying solution has been found.

The following sets are defined for notational compactness:

- $T(k) = \{t \in T : a^k \leq t \leq b^k\}, \forall k \in K$ , the set  $T(k)$  represents the duration of stay of group  $k$ ;
- $K(t) = \{k \in K : t \in T(k)\}, \forall t \in T$ , groups that at the time step  $t$  are into the terminal;
- $K_a(t) = \{k \in K : t = a^k\}, \forall t \in T$ , groups that at the time step  $t$  arrive at the terminal;
- $K_b(t) = \{k \in K : t = b^k\}, \forall t \in T$ , groups that at the time step  $t$  leave the terminal.

We can now formulate our problem, in the following indicated as Adjacent Row Dynamic Assignment Problem (ARDAP):

$$\min \sum_{k \in K} \sum_{r \in R(k)} (c_{o^k r}^k + c_{rd^k}^k) y_r^k \quad (1)$$

subject to

$$\sum_{r \in R(k)} y_r^k = 1 \quad \forall k \in K \quad (2)$$

$$\sum_{k \in K(t)} (y_r^k + \sum_{\alpha=1}^{\theta_r^k-1} y_{r-\alpha}^k) \leq 1 \quad \forall r \in R, \forall t \in T \quad (3)$$

$$\sum_{r \in R(k)} c_{o^k r}^k y_r^k \leq c_a^k \quad \forall k \in K \quad (4)$$

$$\sum_{r \in R(k)} c_{rd^k}^k y_r^k \leq c_b^k \quad \forall k \in K \quad (5)$$

$$\sum_{k \in K_a(t)} \sum_{r \in R(k)} c_{o^k r}^k y_r^k + \sum_{k \in K_b(t)} \sum_{r \in R(k)} c_{rd^k}^k y_r^k \leq H_t \quad \forall t \in T \quad (6)$$

$$y_r^k \in \{0, 1\} \quad \forall k \in K, \forall r \in R(k) \quad (7)$$

The objective function (1) minimizes the handling times. The constraints (2) state that every group  $k$  must be allocated to one and only one admissible row  $r$ , since  $r$  must belong to  $R(k)$ . The feasibility of the assignment is guaranteed by constraints (3): a row  $r$  at a time step  $t$  is occupied if a group  $k \in K(t)$  is allocated to  $r$  as its first row,  $y_r^k = 1$ , or if its first row belongs to the interval  $\{r - \theta_r^k + 1, r - \theta_r^k + 2, \dots, r - 1\}$ . Constraints (4) and (5) model loading and unloading priorities, respectively. The  $c_a^k$  (equivalently  $c_b^k$ ) coefficient can be set to a smaller value to ensure that the group  $k$  is assigned to rows closer to the unloading (loading) quay position. This results in user controlled parameters to specify group priorities, since closer rows mean faster handling times. Observe that constraints (4) and (5) could be eliminated incorporating them in the definition of the admissible row assignment set  $R(k)$ . However, these constraints highlight the degree of available intervention and we prefer to maintain them. Constraints (6) limit the maximum handling for each time step. The model dimensions are as follows:  $|K| \times |R|$  binary variables and  $3|K| + |T| \times (|R| + 1)$  constraints. In term of computational complexity we prove that ARDAP is strongly *NP*-hard.

**Theorem 1** ARDAP is strongly *NP*-hard.

*Proof-* We will prove this by showing that the *Generalized Assignment Problem* (GAP) is a particular case of the ARDAP. In the GAP (Martello and Toth, 1992) we have to find a minimum cost (or equivalently a maximum profit) assignment of a set of weighted items to a set of knapsacks. Let  $N$  be the set of items,  $N = \{1, \dots, n\}$ , and  $M$  the set of knapsacks,  $M = \{1, \dots, m\}$ . We indicate by  $c_{ij}$  the assignment cost of the item  $i$  to the knapsack  $j$ , by  $w_{ij}$  the weight of the item  $i$  when assigned to the knapsack  $j$ , and by  $w_j$  the capacity of the knapsack  $j$ . An equivalent ARDAP instance could be defined as follows:

- an item  $i$  corresponds to a group  $k$  and vice versa, i.e.  $K = N$ , and in the following we equivalently refer to items or groups;
- the ARDAP time horizon consists of only one time step, i.e.  $|T| = 1$ , and all the groups defined above arrive and leave the terminal at this time step, i.e.  $K(1) = K$ ;

- the set of rows has cardinality equal to the sum of the knapsacks capacities,  $|R| = \sum_{j \in M} w_j$ ;
- the set of ending rows has cardinality equal to the number of knapsacks,  $|\bar{R}| = m$ ;
- we define a partition of the set  $R$  in  $m$  subsets  $S_j, j \in M$ :  $S_j = \{r_j, \dots, s_j\}$  where  $r_j = \sum_{l=1}^{j-1} w_l + 1$  and  $s_j = r_j + w_j - 1$ , i.e.  $|S_j| = w_j$ , and the row  $s_j$  is an ending-row,  $s_j \in \bar{R}$ ;
- the group forward row request  $q_r^k$  is constant for the row belonging to a given subset  $S_j$  and it is equal to the corresponding weight of the item, i.e.  $q_r^k = w_{kj}, \forall r \in S_j, j \in M$ ; similarly, the group backward row request  $\theta_s^k$  is equal to the weight of the item in each subset  $S_j$ ;
- the group to row assignment cost  $c_{o^k r}^k + c_{rd^k}^k$  is constant for the row belonging to a given subset  $S_j$  and it is equal to the corresponding cost of the item, i.e.  $c_{kj}, \forall r \in S_j, j \in M$ ;
- the right-hand side coefficients of constraints (4) - (6) are set to arbitrarily large values.

It is immediate to see that the procedure outlined above constructs an ARDAP instance equivalent to the GAP one. An optimal solution for this ARDAP instance could be polynomially transformed in an optimal solution for the GAP. Therefore, if it exists a pseudo-polynomial algorithm  $A$  for the ARDAP, then  $A$  would solve the GAP as well. Since the GAP is known to be strongly  $NP$ -hard, the result follows.

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#### REFERENCES

- Goetschalkx, M. and Ratliff, D. H. (1990). Shared storage policies based on the duration stay of unit loads. *Management Science*, 36(9):1120–1132.
- Martello, S. and Toth, P. (1992). Generalized assignment problems. In *Algorithms and Computation*. Springer-Verlag.
- Mattfeld, D. C. (2006). *The Management of Transshipment Terminals, Decision Support for Terminal Operations in Finished Vehicle Supply Chains*. Springer.
- Resende, M. and Ribeiro, C. (2003). Greedy randomized adaptive search procedures. In Glover,

F. W. and Kochenberger, G. A., editors, *Handbook of Metaheuristics*, volume 57 of *International Series in Operations Research & Management Science*. Springer.

# A DECISION SUPPORT SYSTEM FOR PLANNING MAINTENANCE PROCESSES IN A TRANSHIPMENT CONTAINER TERMINAL

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## ABSTRACT

The objective of the research project developed in cooperation with CICT (Cagliari International Container Terminal) is to determine and organize a Decision Support System (DSS) capable of introducing an engineering process of the maintenance activities (emergency and planned maintenance). This system is aimed at representing a useful operating tool for maintenance managers, which assists them in choosing different maintenance policies to take on and also in introducing the management data system, which is interpreted as an essential tool to schedule interventions and, more generally, to manage the resources which form the logistics support system.

In particular, the aim of this paper is to describe the architecture concerning the DSS under construction, the logical-functional relations existing among different modules of which it is made of and to show the first goals achieved up to now.

Keywords: maintenance engineering, decision support system, emergency and planned maintenance, reliability centered maintenance

## 1. INTRODUCTION

The continuous and constant growth of container transport via sea and the many fleet expansions and load capacity increase programmes pursued by maritime carriers in the field, call for the research of new organization methods and new technological solutions for planning and managing all the operating activities performed when handling containers inside a terminal.

Conditions therefore require a greater use of automated systems and new technology to carry out and handle the operations, that ultimately depend on the contemporary efficiency of the handling system in the ship-quay section, of the container horizontal transport system and the stock yard handling system.

These three individual phases, that make up a complete operating cycle, are very closely correlated and performed in sequence inside the port logistics chain cycle and any efficiency failure in one alone of these phases could limit and reduce the performance of the others, causing an operational and overall production loss in a terminal.

Under this prospect the role played by the management of equipment and means of carrying maintenance becomes extremely important, seen as the main process of the “*core business*” performed, and not just a mere element of support. The companies operating in the transport and logistics field, in fact, are ever more oriented towards the implementation of techniques and tools that develop efficient maintenance process planning and management reliability, good function and safety of their systems, together with operating procedures, in order to contend with the ever growing competition of this market.

The elements ruling operational availability of a system are reliability, maintainability and logistical organization of supporting tools (handling spares, maintenance operator training, action scheduling, computer system used for collecting data, data recording and analysis managing outsourced activities, etc.), that allow supplying the required activities within the required scheduled times.

To minimize the overall charge connected to maintenance processes, represented by the sum of direct costs (connected to performing operations) and indirect costs (related to the lack of equipment availability and therefore, to the failure to perform a service), it is actually necessary to identify the most appropriate strategy for optimizing the maintenance policies adopted, choosing the most suitable for each component or subsystem analysed (Buglione 2006).

The role of Maintenance Engineering over the past years is, in fact, the result of the evolution of maintenance from merely reaction forms, enhanced

following a break-down/failure, towards ever more sophisticated forms of intervention where concepts and methods typical of engineering techniques have been introduced to obtain improvingly better results in terms of safety, efficiency, effectiveness and costs (Furlanetto, Garetti, and Macchi 2006).

The scope of the development and implementation presently in progress of the DSS described below, is to create a support and control tool capable of, in the same measure as the systems adopted in operating areas for the planning phases of container handling activities and monitoring & reporting (management board), allowing an effective and efficient planning and management of the maintenance interventions performed.

## 2. EVOLUTION OF THE CONCEPT AND THE ROLE OF MAINTENANCE: THE METHODOLOGICAL APPROACH DETERMINED

In the past maintenance has always been considered as a “necessary” cost that “inevitably” had to be supported and therefore had to be minimized while operating a given system (Carpignano and Vivalda 2005).

This kind of concept has determined interventions considered as operating activities for the repair of a system that has failed and requires restoration of indispensable functionality. This kind of old concept has to be overcome in order to introduce a new approach where maintenance is to be considered as a process capable of producing benefits, as an element of the profit sheet on which it be necessary to intervene to improve competitiveness and functionality of the transport system taken into consideration. This scope can be reached creating a system of interventions to prevent the failures or the malfunctions typical to a specific system.

Another fundamental aspect encountered in the transport field, and more specifically relating to the activities performed in a container terminal, is represented by the cultural and technical gap existing compared to other fields of activities, such as industry – plant design, manufacturing and the aeronautical field, in planning and managing maintenance procedures together with the growing importance of the role of maintenance and the overall life cycle of the systems we are considering.

In relation to the different types of production that characterize a company, we can hypothesize three main general organizational schemes designed to obtain, each within its own field, specific maintenance objectives: the matching function model, the radically separate function model, the partly overlapping function model (Pozza 1999).

Thus the requirement to overcome also in the transport field the traditional kind of interpretation becomes obvious together with the necessity to define the relationship and the ties between the two types of processes according to a new and innovative approach

that allows reaching a binding integration between operating and maintenance activities, as shown in figure 1 (Naseddu 2008).

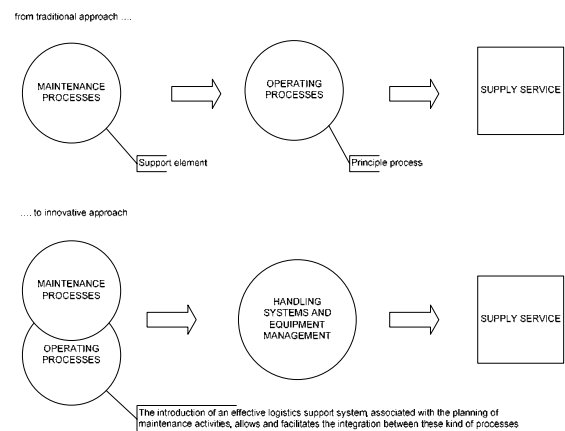


Figure 1: Evolution of the role of maintenance processes in a terminal container: from traditional approach to innovative approach

## 3. THE REFERENTIAL CONTEXT: OPERATING AND MAINTENANCE PROCESSES PERFORMED INSIDE A CONTAINER TERMINAL

The technological scenario that characterizes container handling activities, considering the Cagliari transshipment terminal as the field of application, can be described through a three step operating cycle:

- the quay crane picks up the container from the ship at dock using the “spreader”. The container is lifted and transferred in parallel to the boom (crane jib) to be then positioned on a trailer
- once this operation is finished the truck trailer, the means of carrying used for horizontal movements, transfers the container to the storage area, corresponding to the destination yard in which it is located
- the yard crane picks up the container from the trailer waiting in a specific aisle and places it in the assigned storage slot. The containers are distributed in given areas within the operating yard

The maintenance interventions performed on the handling systems available and on the equipment used for these operations can be distinct in two different typology:

1. *Planned maintenance*: ordinary routine maintenance managed through a time planned schedule (different deadlines according to types of equipment), performed on various components of the systems in order to maintain functionality. The elements required for

planning maintenance operations are the maintenance repair sheets, the frequency with which the work indicated is performed and any possible malfunction reports indicated by the operators

2. *Emergency calls*: maintenance performed during operations following a call for a technical failure, a non technical failure or an accident in order to restore functional operability of the handling systems /equipment in order to ensure continuity of the operating process

#### 4. THE DSS ARCHITECTURE

The DSS architecture consists of four modules or sub-system (Sprague Jr. and Watson 1993):

- the *data base*, which splits into two elements: a “static” data bank which is a simple sub-system used for ensuring a detailed collection and accurate recording of all the information associated with the operations performed; a “dynamic” data bank which allows subsequent data analysis and statistical elaboration
- the *model base*, which consists of various sub-models which are used for describing and examining the quantitative and qualitative aspects concerning functionality, reliability and operating costs of the quay crane (F.M.E.C.A - Failure Modes, Effects and Criticality Analysis, a modelling approach to examine and to analyse the reliability and the availability of complex systems, total cost function associated with different maintenance policies adopted, integration between maintenance and spares managing procedures)
- the *evaluation model*, which is distinguished among various sub-models used to define the appropriate techniques through which the different alternative strategies are assessed
- a *dialog system*, link element between the user and the same system, represents the external image through which it can operate

DSS set up in this manner represents the specific tool which allows to build and test various possible scenarios through the integration and the contemporary evaluation of:

- technical aspects: maintenance policies and strategies adopted
- operational aspects: planning operating procedures
- management control and cost controlling: budget, forecast and balance analysis
- management procedures and optimization of spare parts stored in the technical warehouse
- improvements, technical changes made to equipment and investments

- human resources management: managing maintenance teams, outsourced activities and supplier management

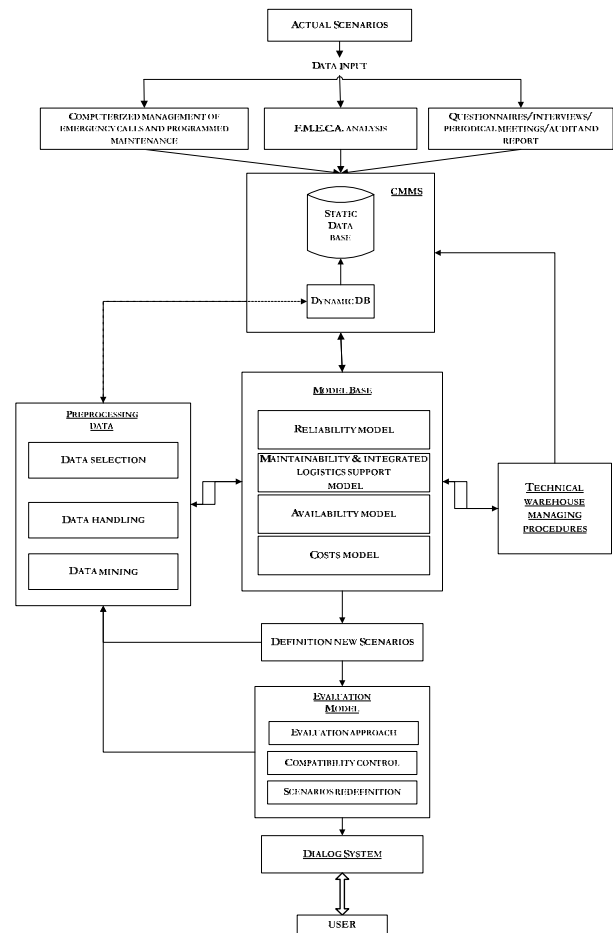


Figure 2: An overview of logical-functional DSS architecture

Analysis of the existing scenarios and simulation of future possible scenarios represents the active and most important component of the entire system, allowing the development of a DSS capable of being used as an effective tool to assist maintenance activities planning.

The data pre-processing activity is an intermediate sub-module located between the data base and the assessment module and it is a fundamental part required to adequately select, transform and handle the information associated with emergency calls and planner maintenance that will be collected and recorded.

The preparation of a similar support tool, so that it completely and effectively satisfies its scope, should be accompanied by an engineering process of all maintenance activities and by the introduction of Maintenance Engineering as a company function. In fact, the use of reliability, management and organizational type analysis principles, methods and techniques, allows a company to manage maintenance in a scientific engineering principle based manner.

The approach method chosen for this scope is to develop R.C.M. technique in order to concentrate

maintenance planning interventions on the reliability study and analysis of the complex quay crane system, in compliance with a procedural scheme developed in 5 fundamental macro phases:

1. formation and training: active involvement and participation of the maintenance teams. "The best maintenance programme is one which can be effectively used... It needs to take a proactive form in which maintenance personnel can use it to perform the work efficiently and effectively" (Bello 2005)
2. creating a specific Maintenance Information System
3. functional breakdown of the quay crane system into sub-systems to be analysed separately, as shown in figure 3
4. setting-up the F.M.E.C.A analysis
5. determining maintenance requirements and choosing the most appropriate strategy for each subsystem individualized

These different phases, determined to optimize all the resources employed, should be supported by the introduction of specific engineering parameters where the reciprocal relations (reliability, availability, maintainability) can be modelled, and by the definition of a cost function associated with the maintenance policy adopted, in order to dispose of the most adequate tools for a correct comparison and the consequent choice of the most efficient and effective strategy.

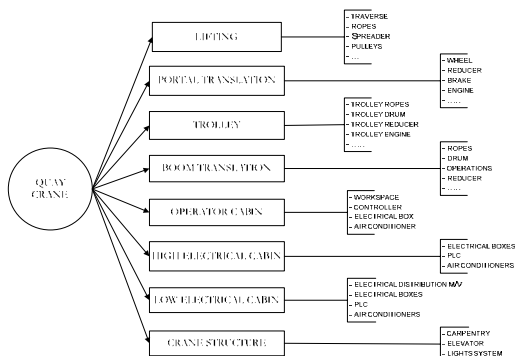


Figure 3: Quay crane functional breaking down

#### 4.1. The Data Base structure

The Data Base module has been set up in order to represent an actual Maintenance Information System, not just a simple information file. Introduction of this module is an indispensable tool which allows for a detailed and effective recording of the interventions performed and a guaranteed analysis of the criticalities and performances based on the maintenance strategies adopted. It is characterized by:

- a *static* component, that is the archive in which all the information collected after an emergency call and/or an ordinary maintenance work (work sheet) performed on the quay cranes, are recorded and sorted

- a *dynamic* component, that has been introduced as a tool to combine the various static data elements subsequently used to compose different models. This second sub-module is the fundamental element within the logical-functional structure of the DSS that is being implemented, because if the designed system is to completely and exhaustively satisfy the functions for which it has been created, availability and correct handling of the information is indispensable for the subsequent phases of analysis and assessment. For this reason the module has to be very versatile and capable of dialoguing with the static data base and the base model, in a continuous and reciprocal exchange of outputs

The method of collecting and recording the information related to the maintenance activities performed, that correctly treated and indicated represent the data for subsequent development (Base Model), can be distinguished in:

- computerized management of emergency calls and programmed maintenance (as shown in figure 4)
- F.M.E.C.A. analysis, both quantitative and qualitative. It is performed to systematically evaluate mode, cause, mechanism and effect of each type of failure determined. In this way it is possible the correctly evaluate the level of criticality of the system being observed (Furlanetto, Garetti, and Macchi 2007)
- dedicated questionnaires to be filled in by the people responsible, the coordinators and the maintenance operators
- regular tests performed contemporarily between technical areas and operation areas (information reports)
- shared computer tools and applications for a technical-operational equipment management

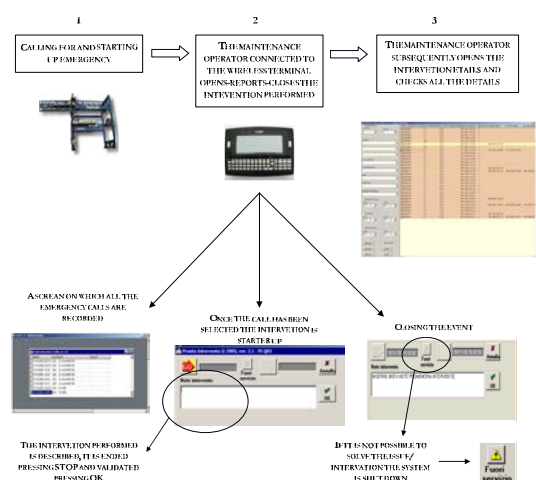


Figure 4: An application of the Computerized Maintenance Management System (CMMS)

#### 4.2. The Model Base structure

The Base Model is divided into 4 different sub-models (of which the first and the second are in an advanced phase of developing), through which it is possible to analyse the maintenance management and planning issues by combining together all the most significant operational-engineering variables and the cost and spare parts management methods:

- *reliability model*, the construction of which strongly depends on the accuracy and detail of the recording of all failures and the time required for repair. In fact, from this information it is possible to formulate a reliability rule of the system whose improvement or maintenance within certain values represents a decisive tool for obtaining a greater availability of the quay crane. Main reliability engineering tools are: accurate failure data for making good decision, reliability indices like MTBF, probability plots, bathtub curves (Barringer 1996), which are described in detail by (Smith 1993) and (Moubray 2001) and regarded one of the basic tenets of reliability engineering. By using reliability analysis quantitative methods and analytic techniques, such as simulation of discrete events, Monte Carlo simulation and genetic algorithms it is also possible to simulate the behaviour of the system under identified conditions and thus verify if the solutions implemented to increase reliability are actually reaching the expected results. In particular, the Monte Carlo method is a powerful modeling tool for performing realistic reliability and availability of complex systems (Merseguerra and Zio 2002). In this way it is possible to compare the various maintenance organization and planning scenarios with the scope of reducing emergency call work and increasing ordinary type maintenance interventions with scheduled equipment break-downs based on the operating area production requirements (close integration between operating processes and maintenance processes)
- *maintainability and logistic organization support model*, with which it is possible to determine the methods required to increase availability of a complex system, such as the quay cranes, by appropriately evaluating both the intrinsic attitude to maintenance (ease of intervention, accessibility, etc.) and the logistic support management (size of the service, support equipment, maintenance plans, efficiency of spare parts management, maintenance team management, etc.) upon which it be necessary to act in order improve the organization of maintenance intervention schedules (Chiesa 2007). These two variables

represent two important competitive levers to work upon in order to reduce equipment down times that cause unavailability of the cranes. Another interesting application of the model, presently under development, is the representation and analysis of the close tie between maintainability, safety and human factor aspects, associated with performing emergency call interventions. The approach adopted is based on the construction of a general critical index, that was associated to the different sub-systems of which the complex system such as quay crane is made of, through the analysis and the match of quantitative and qualitative aspects concerning maintenance process which have been extracted by means of the exhaustive survey data about emergency calls and maintenance operator's task

- *availability model*, with which it is possible to measure the availability of the quay crane system compared to the requirements set forth by operations area for its employment in container handling activities, in consideration of the great flexibility of employment required for this equipment in relation to planning ship operations. Furthermore, measuring availability allows to evaluate the level of service the system has reached and to quantify, in terms of lack of production, the value of loss of availability
- *cost model*, the specification of a general cost function (1), to be related with a given maintenance strategy, has the scope of evaluating the total costs sustained and researching the most effective technical-organizational solution for reducing them, by optimizing the available resources (human resources, spare parts and stores, financial resources and investments) and reducing any costs tied to the non availability of the crane (failure to provide the service):

$$C_{\text{tot}} = C_{\text{human resource}} + C_{\text{stock}} + C_{\text{financial}} + C_{\text{failed output}} \quad (1)$$

#### 4.3. The Evaluation Model structure

The structure that distinguished the evaluation model can be outlined as described in Figure 5.

The type of algorithm used to compare the different maintenance policies, depending on the crane components or subsystems taken into consideration and based on the level of detail chosen, depends on the kind of analysis performed and on the type of intervention required. Through one-scope analyses such as cost-benefit, it is possible to estimate the monetary value of a part or all the modelled variables (reliability, maintainability, logistic support, availability) by associating each one, if feasible, to a cost and then be able to compare the total costs of two different strategies or organizational models and thus choose the most effective and efficient one. While with multi-scope



analyses it is possible to overcome the difficulties tied to any monetary evaluation that finds place in the system to describe the maintenance processes taken into exam and it is possible to develop general indexes to compare two or more management methods. The final choice of the algorithm obviously depends on the requirements of the decision maker (maintenance responsible and company management) and by the level of analysis desired.

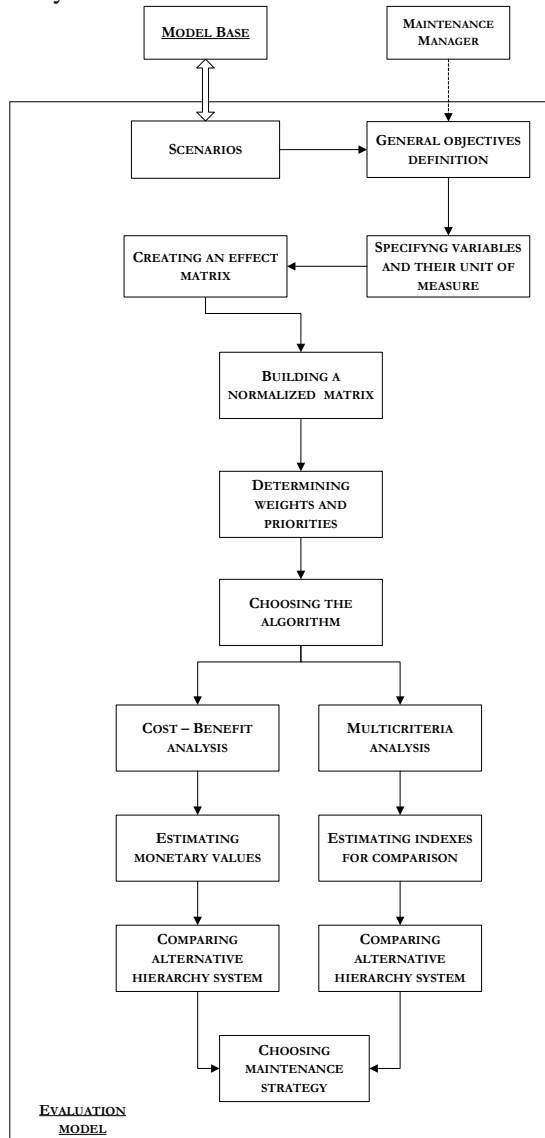


Figure 5 : Evaluation model structure

#### 4.4. The Dialog System structure

The Dialog System is the interface between the entire system with the user. It is the component with which the user operates to take advantage of all the various functions and applications the DSS can perform. Its main characteristics should be user friendly, high flexibility and capability of supplying effective and thorough reports, while elaborating performance indicators, responding to the various levels of detail required.

Its 4 main sub-modules are (Fadda, Meloni, Cherchi, and Fancello 1997):

- *Knowledge base*, which contains all the systems required by the user to get the information he needs, in either number or text format
- *Action language*, which includes all the various systems which enable to act directly on DSS by performing a physical action, such as using a mouse, a keyboard, or a screen (for example employing touch-screen or vocal system solutions)
- *Presentation language*, which collects all the systems that record information in the data base and their subsequent elaboration using the various models present in the base model
- *Dialog system*, which consents interaction and creation of the reports required by the previous sub-modules and their employment by the user, creating a single language that allows access and communication with DSS and an effective interaction man-machine thanks to its modular structure

#### 5. CONCLUSIONS

The introduction of a Decision Support System, in this context and with this above mentioned rationale, becomes an essential tool for maintenance managers to obtain, through the close link of all sub-systems that form its structure:

- the detailed and efficient recording of the interventions performed
- the analysis of criticalities and failures involving the quay cranes
- the evaluation of guaranteed performances based on the maintenance strategies which are adopted and compared

#### REFERENCES

- Barringer, H.P., 1996. *An Overview of Reliability Engineering Principles*. Barringer & Associates. Humble, Texas. Available from: <http://www.barringer1.com/Papers.htm> [accessed 21 January 2008]
- Bello, A.E., 2005. Gantry crane maintenance: proactive or reactive?. *Port Technology International*, 27 (Autumn), 97-99.
- Buglione, P., 2006. Ottimizzazione delle politiche di manutenzione. Proposta di una metodologia per un'azienda di medie dimensioni. *Manutenzione, Tecnica e Management*, Anno XIII (2), 40-45.
- Carpignano, A., Vivalda, C., 2005. Dalla manutenibilità alla manutenzione. *Manutenzione, Tecnica e Management*, Anno XII (4), 1 - 8.
- Chiesa, S., 1990. *Affidabilità, Sicurezza e Manutenzione nel progetto dei sistemi*. Torino: CLUT.
- Chiesa, S., 2007. *Manutenzione e Integrated Logistics Support*. *Seminario Tecnico Scientifico - La manutenzione programmata nella gestione*

*aziendale dei sistemi di trasporto*, Vol. 2 pp. 6 – 9. 27 – 29 Giugno, Cagliari (Italy).

- Fadda, P., Meloni, I., Cherchi, E., Fancello, G., 1997. Un sistema di supporto alle decisioni per la pianificazione dei sistemi di trasporto a scala regionale. In: Amoroso, S., Crotti, A., ed. *Il trasporto pubblico nei sistemi urbani e metropolitani*. Milano: Franco Angeli, 508-532.
- Furlanetto, L., Garetti, M., Macchi, M., 2006. *Principi generali di gestione della manutenzione*. Milano: Franco Angeli.
- Furlanetto, L., Garetti, M., Macchi, M., 2007. *Ingegneria della manutenzione. Strategie e metodi*. Milano: Franco Angeli.
- Merseguerra, M., Zio, E., 2002. *Basics of the Monte Carlo Method with Application to System Reliability*. Hagen, Germany: LiLoLe – Verlag GmbH (Publ. Co. Ltd.).
- Moubray, J., 2001. *Reliability-centered Maintenance*. 2<sup>nd</sup> Ed. New York, NY: Industrial Press Inc..
- Naseddu, M., 2008. L'ingegnerizzazione dei processi manutentivi realizzati in un terminal container. *I Riunione Nazionale Dottorandi in Ingegneria dei Trasporti. SIDT giovani 2008*, pp 65-69. 3-4 Aprile, Padova (Italy).
- Pozza, R., 1999. *Ingegneria del supporto logistico. Reinventare il processo di manutenzione*. Milano: Franco Angeli.
- Smith, A.M., 1993. *Reliability Centered Maintenance*. New York, NY: McGraw-Hill.
- Sprague, R.H. Jr., Watson, H. J., 1993. *Decision Support System: putting theory into practice*. New Jersey: Prentice Hall Inc..

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# HUMAN RESOURCES DAILY ALLOCATION IN A TRANSHIPMENT CONTAINER TERMINAL

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## ABSTRACT

In this paper we present a mathematical model for optimal human resources daily allocation in a transshipment container terminal.

The aim is to support planners in finding the minimum cost choice fulfilling different customers' needs and priorities.

Problem formulation is mainly based and validated on the direct observation of the real complex decision processes at Cagliari International Container Terminal.

The testing phase is performed by an open source code: GLPK (Gnu Linear Programming Kit) up to a problem size of 12.144 variables and 1032 constraints in less than 2 seconds.

Keywords: human resources, resource allocation, operation planning, terminal container, optimisation,

## 1. INTRODUCTION

Operations Planning has an important role in order to improve container terminal's efficiency and advanced support systems are absolutely needed to offer high quality services and improve port competitiveness (Steenken et al., 2004, Vis and Koster, 2003).

Taking in consideration terminal planners needs we focused the research on daily planning level, where the main target is the allocation of resources (human resources and equipment), in order to improve productivity and reduce costs of operations. At this planning level information about vessel arrival time is greatly affected by uncertainty. Even if line operators send the ETA (Estimated Time of Arrivals) 24 hours before vessel arrivals, lot of delays occurs. For this reason, resources are planned with a certain flexibility that involves high costs.

A forecasting model, predicting vessel delays, could give planners more certainty knowing in advance demand size in any daily work shift, in order to consecutively allocate resources minimising costs and maximising productivity.

## 2. SURVEY OF THE LITERATURE

The problem of planning resources on daily level in terminal containers is studied in literature with different approaches.

Complexity of daily planning is described by Dell'Olmo and Lulli (2004). They present both human resources and equipment in the same way, taking into consideration the possibility to share resources in different points of work. The problem is then formalized by a "generalized" scheduling model. Even if having a unique model both for equipment and human resources can reduce complexity, on the other hand a generic model could imply less support for final users, which would do better with their experience.

The scheduling approach (Kim et al., 2004; Hartmann, 2004) implies a precise sequence of jobs assigned to specific resources, programming time and location of every ring of the jobs chain. Observing real operations we found that they are characterized by frequent presence of fortuitous circumstances (like damages, lack of documentation etc.) that could imply the reformulation of the scheduling problem many times. This can be not compatible with model solving computational time.

The resource allocation approach (Gambardella, 2001; Legato and Monaco, 2004; Zaffalon et al 1998) allows describing the general problem, without giving a precise schedule of jobs but considering volumes to perform.

In this paper we focus on the problem of human resources allocation in terminal containers at daily planning level (Gaudio et al. 1999, Legato and Monaco 2004), including different peculiarities of human resources allocation, traced on direct observation of planning processes.

## 3. PROBLEM DESCRIPTION

Operational process related to daily human resources allocation can be described as follows.

A work day is divided in 4 shifts, of 6 hours each, in which any operator can perform only one task. Available operators come from the monthly planning and are divided in two groups: those who are already allocated to a precise work shift and those who are "flexible", e.g. available in the planning day but not yet assigned to a precise work shift.

In addition to standard workers, the operations manager can assign additional external workers only for the lower skill task (Truck-Trailer driving task),

Tasks can be classified in driving tasks (on lift cranes and horizontal transport equipment) and ground tasks (checker, deck man, raiser). In our model we consider only driving tasks. Any operator has a main task, that represents his higher skill level and determines his salary, but he can also perform lower level tasks if is needed, conserving his main task salary, while the contrary is not allowed.

Operators are grouped in so called gangs (teams), each of them is generally employed to serve one quay crane. Quay cranes operational speed (Gross Crane Productivity) determines terminal productivity (Ferraro, 2006) that is the most important parameter for client's satisfaction. Quay crane productivity depends on many factors such as: equipment performances, operator's skill, gang performances, operational conditions (congestion), vessel typology (mother, feeder, hold structure), containers yard location.

Gangs can perform two kinds of work: vessel loading/unloading works (vessel to/from yard) and housekeeping works (yard to yard). Housekeeping works don't need any quay crane operator.

Works have to be performed for different "clients" (groups of containers are related to trade lines, vessels), having different contract agreements, that means different productivity constraints and priorities.

Historical values of any operator task performances (productivity in moves/hour) are stored on a data base and considered before allocation in order to assign higher performance operators to high priority works, building a high performance gang.

#### 4. THE MATHEMATICAL MODEL

Let  $N$  be the total set of  $nt$  available workers in the planning day. As a result of the monthly planning, set  $N$  consists of the following subsets:  $T_j$ , set of  $na$  workers assigned to each period  $j$  of the planning day;  $F$ , set of  $nt-na$  workers on flexible duty for the planning day. So

$$N = \bigcup_{j=1}^4 T_j \cup F$$

$$T_j \cap F = 0 \text{ for } j=1, \dots, 4.$$

Let  $J$  be the set  $\{1,2,3,4\}$  of 4 workshifts, of six hours each, in which is divided the planning day.

Let  $K$  be the set of driving tasks  $\{qc,rt,ra\}$  where  $qc$  states for quay crane operator task,  $rt$  denotes yard crane operator task and  $ra$  indicates the truck trailer driver.

Let  $Z$  be the complete set of works to be performed during the planning day. The set is constituted by the set  $Na$  of  $nv$  vessel works (ship to/from yard) and the set  $H$  of  $l-nv$  housekeeping works (yard to yard). As a consequence the following relationships hold:

$$Z = \bigcup_{j=1}^4 Na \cup H$$

$$Z \cap H = 0 \text{ for } j=1, \dots, 4.$$

We adopt the following notation:

#### DATA

$nm_{j,k}$  denotes the average number of workers performing task  $k$  in a vessel gang on workshift  $j$

$$\forall j \in J, \forall k \in K$$

$nh_{j,k}$  denotes the average number of workers performing task  $k$  in a housekeeping gang on workshift  $j$

$$\forall j \in J, \forall k \in K$$

$r_{j,z}$  denotes the number of vessel gangs needed on period  $j$

$$\forall j \in J, \forall z \in Na$$

$h_{j,z}$  denotes the number of housekeeping gangs needed on period  $j$

$$\forall j \in J, \forall z \in H$$

$p_{i,k}$  priority of task  $k$  for worker  $i$

$$\forall i \in N, \forall k \in K$$

$cmp_i$  salary of worker  $i$  for his main task

$cma_k$  salary of assigned task  $k$

$b$  salary of external worker

$d$  fictitious salary of  $u_{j,k,z}$  workers needed to perform on shift  $j$ , task  $k$  and work  $z$

$prod_{i,k}$  average historical productivity of worker  $i$  on task  $k$

$0 < a_z < 2$  coefficient for reduction/increase average gang productivity in different operational state of work  $z$

$$\forall z \in Z$$

$$y_{i,j} = \begin{cases} 1 & \text{if worker } i \text{ is assigned, by monthly} \\ & \text{planning, to workshift } j \\ 0 & \text{otherwise} \end{cases}$$

$$\forall i \in T_j, \forall j \in J$$

#### VARIABLES

$$x_{i,j,k,z} = \begin{cases} 1 & \text{if worker } i \text{ is assigned to workshift } j, \\ & \text{task } k, \text{ work } z \\ 0 & \text{otherwise} \end{cases}$$

$$\forall i \in N, \forall j \in J, \forall k \in K, \forall z \in Z$$

$$y_{ij} = \begin{cases} 1 & \text{if worker } i \text{ is assigned to workshift } j \\ 0 & \text{otherwise} \end{cases} \quad \forall i \in N, \forall j \in J$$

$v_{j,k,z}$  denotes the number of external workers needed on workshift  $j$ , work  $z$ , only for task  $ra$  (truck-trailer operator)

$$\text{for } k=ra, \forall j \in J, \forall z \in Z$$

$u_{j,k,z}$  denotes the lack of human resources (number of operators) on workshift  $j$ , task  $k$ , work  $z$

$$\forall k \in K, \forall j \in J, \forall z \in Z$$

In order to enforce the assignment, to each worker, of tasks consistent with his own skill, we adopt the same rules of Legato and Monaco (2004), relating costs to the priorities  $p_{i,k}$  (ranging from 1 to 3, if finite).

They define the unitary (i.e. related to a single shift) cost for the worker  $i$  performing task  $k$  (assigned by the model) as follows:

$$c_{i,k} = \begin{cases} cmp_i & \text{if } p_{i,k}=1 \text{ (} k \text{ is the main task of the worker } i \text{)} \\ cma_K + (cmp_i - cma_k) & \text{if } 1 < p_{i,k} < \infty \\ M & \text{if } p_{i,k} = \infty \end{cases}$$

Where  $M$  is large enough with respect to all real costs involved in the function.

Note that an employee with a high skill level (crane-operator:  $p_{i,qc}=1$ ) could perform any other lower level task (with priorities  $p_{i,rt}=2$ ;  $p_{i,ra}=3$ ), while the contrary is not allowed.

In order to enforce the assignment of higher skill operators (with higher average historical productivity) to works that need higher priorities and performances, we define a monetary coefficient  $g_z$  that represents, for each work  $z \in Z$ , different profits/moves for different clients (trade lines, vessels related to each work). In this way, if a client has high priority to be served, more moves gang can perform (higher productivity gang) more profit the terminal gains. So, we define:  $g_z$  as the profit for each move (unit/container move) performed in work  $z$ .

We can now formulate the problem as follows

$$\begin{aligned} MIN \quad & \sum_{i=1,nt} \sum_{j=1,4} \sum_{k=qc,rt,ra} \sum_{z=1,l} (c_{i,k} - ((a_z (prod_{i,qc} + \\ & + prod_{i,rt} + prod_{i,ra}) / 3) g_z) x_{i,j,k,z}) + \\ & + \sum_{j=1,4} \sum_{k=qc,rt,ra} \sum_{z=1,l} (b v_{j,k,z}) + \\ & + \sum_{j=1,4} \sum_{k=qc,rt,ra} \sum_{z=1,l} (d u_{j,k,z}) \end{aligned}$$

SUBJECT TO

$$\sum_{i=1,nt} x_{i,j,k,z} + u_{j,k,z} + v_{j,k,z} = nm_{j,k} * r_{j,z} \quad (1)$$

$$\forall z \in Na, \forall j \in J, \forall k \in K$$

$$\sum_{i=1,nt} x_{i,j,k,z} + u_{j,k,z} + v_{j,k,z} = nh_{j,k} * h_{j,z} \quad (2)$$

$$\forall z \in H, \forall j \in J, \forall k \in K$$

$$y_{ij} = yt_{ij} \quad (3)$$

$$\forall i \in Tj$$

$$\sum_{k=qc,rt,ra} \sum_{z=1,l} x_{i,j,k,z} = y_{ij} \quad (4)$$

$$\forall i \in N, \forall j \in J$$

$$\sum_{j=1,4} \sum_{k=qc,rt,ra} \sum_{z=1,l} x_{i,j,k,z} = 1 \quad (5)$$

$$\forall i \in N$$

$$v_{j,k,z} \geq 0 \text{ integer} \quad (6)$$

$$\forall j \in J, \forall k \in K, \forall z \in Z$$

$$u_{j,k,z} \geq 0 \text{ integer} \quad (7)$$

$$\forall j \in J, \forall k \in K, \forall z \in Z$$

In the objective function we specify two main allocation criteria, taking into account:

1. human resources versatility, minimising costs that could come from a lower skill operator allocation ( $c_{i,k}$ ); the need to allocate high performance gangs to works with more priorities, maximising gang productivity for works having more priority. More precisely we introduce in the objective function the quantity

$$(prod_{i,qc} + prod_{i,rt} + prod_{i,ra}) / 3$$

in order to estimate gang productivity.

More precisely,  $prod_{i,k}$  represents the average historical productivity of worker  $i$  on task  $k$ . This quantity can be corrected by a coefficient  $a_z$ , reducing or increasing gang performance, taking in consideration the operational state of work  $z$  (terminal congestion, vessel structure etc.). We assume that  $a_z$  is a real value between 0 and 2.

This deterministic expression must be taken with care because the gang productivity is an indefinite parameter, influenced by many factors.

The monetary coefficient  $g_z$  ensures that more moves gang performs more profit terminal gains.

Then we associate the “cost”

$$(c_{i,k} - ((a_z(prod_{i,qc} + prod_{i,rt} + prod_{i,ra})/3)g_z)$$

to the Boolean variable  $x_{i,j,k,z}$  equal to 1 if worker  $i$  is assigned to workshift  $j$ , task  $k$ , work  $z$ , 0 otherwise.

Moreover the objective function requires to minimize the total cost charged by external workers (second term) and the lack of human resources (third term).

Constraints (1) and (2) ensure, respectively, manpower demand satisfaction, for vessel works and housekeeping works while maintaining the correct composition, in number and skill-mix, of gangs.

Constraint (3) imposes the monthly allocation to workers just assigned to workshifts.

Constraint (4) imposes the logical link between variables  $x$  and  $y$ : if  $i$  will work on period  $j$ , exactly one task must be assigned to him for that period, otherwise none.

Constraint (5) ensure that only one worker can be assigned to only one workshift, task and work in the planning day.

## 5. RESULTS

The problem was formulated and solved with GLPK (Gnu Linear Programming Kit) an open sources code which contains a tool for problem formulation which uses a comprehensive language (Gnu MathProg), a solver (GLPsol), which automatically generate instances and solves the problem.

First instance was built considering 48 available operators 3 vessel works and 2 housekeeping works to be performed during all 4 workshifts, up to 3.192 variables and 516 constraints. The solver finds a feasible solution in less than 1 second. The problem with 96 available operators for 6 vessel works and 4 housekeeping works, up to 12.144 variables and 516 constraints, was solved in less than 2 seconds.

## 6. CONCLUSIONS

Container terminal operations are characterised by complexity and high costs, that's the reason why, finding optimal solutions in short time means a great support for planning.

In this work we describe the real decision process related to human resource daily allocation observed at Cagliari Container Terminal, representing the “trade off” between costs and client satisfaction involved.

Formalising the problem some simplifications are adopted because of problem complexity and some parameters are found to be not simply “monetized”. For this reason a more careful cost-profit analysis could be the next step of our study.

## 7. REFERENCES

- Dell'Olmo P., Lulli G., 2004. Planning Activities in a Network of Logistic Platforms with Shared Resources. *Annals of Operations Research* 129, 155-169.
- Ferraro A.M., 2006. Indici di valutazione dell'efficienza di terminal marittimi per container. Technical Report n. 5/2006 – (Dicembre 2006) Università della Calabria Laboratorio di Logistica (Rende, CS) Available from:[http://www.rdlog.it/doc/Indici\\_di\\_valutazione\\_dell-efficienza\\_di\\_terminali\\_marittimi\\_per\\_container\\_M-A-Ferraro.pdf](http://www.rdlog.it/doc/Indici_di_valutazione_dell-efficienza_di_terminali_marittimi_per_container_M-A-Ferraro.pdf) [Last access 30/05/2008]
- Gambardella L.M., Mastrolilli M., Rizzoli E., Zaffalon M., 2001. An optimization methodology for intermodal terminal management. *Journal of Intelligent Manufacturing*, 12, 521-534.
- Gambardella L.M., Bontempi G., Taillard E. Romanengo D., Raso G., Piermari P., 1996. Simulation and forecasting in intermodal container terminal. . *Proceedings of Simulation in Industry, 8th European Simulation Symposium*. Genoa, Italy.
- Gaudio M., Giallombardo G., Legato P., 1999. Ottimizzazione e simulazione nella gestione di un terminal container portuale: il caso di Gioia Tauro. In: Cantarella, *Metodi e Tecnologie dell'Ingegneria dei Trasporti*. Rezzo Ed Franco Angeli.
- Hartmann S., 2004. A general framework for scheduling Equipment and manpower at container terminals. *OR Spectrum* 26:51-74,2004 Springer Verlag
- Kim K.H., Kim K.W., Hwang H, Ko C.S., 2004. Operator scheduling using a constraint satisfaction technique in port container terminals. *Computers and Industrial Engineering* 46 (2004) 373-381
- Legato P., Monaco M.F., 2004. Human resources management at a marine container terminal. *O.R. Applications European Journal of Operation Research* 156 (2004) 769-781
- Pisano M., 2008. “La selezione delle variabili di input nella specificazione di un modello a rete neurale per la previsione dei ritardi delle navi in un terminal container” *Proceedings of SIDT Giovani 2008 - Prima Riunione Dottorandi in Ingegneria dei trasporti, Padova, Italy*.
- Steenken D, Voß S, Stahlbock, 2004. Container terminal operation and operations research – a classification and literature review. *OR Spectrum* (2004) 26: 3-49
- Vis, I.F.A. and de Koster, R., 2003. Transshipment of containers at a container terminal: An overview. *European Journal of Operational Research*, 147:1-16.
- Zaffalon M., Rizzoli E., Gambardella L.M., Mastrolilli M., 1998. Resources Allocation and Scheduling of operations in an Intermodal Terminal. *Proceedings of 10th European Simulation Symposium and*

*Exhibition, Simulation in Industry*, pp. 520-528, October 26-28, 1998, Nottingham, UK



## AUTHOR'S INDEX

- Alifieris, 167  
Anderson, 146  
Bai, 160  
Benna, 268  
Bikovska, 20  
Biles, 129, 139  
Bocca, 257  
Borges, 118  
Böse, 274  
Bruzzone, 257  
Caserta, 89  
Chen, 160  
Ciliberti, 150  
Cimino, 35, 123  
Cottyn, 55  
Crainic, 134  
Crespo Pereira, 1  
Curcio, 42, 123  
D'Errico, 257  
Darzentas, 167  
Del Rio Vilas, 1  
Di Francesco, 134  
Didenko, 225  
Dorndorf, 94  
Douma, 81  
Echelmeyer, 280  
Evans, 146  
Facó, 230  
Fadda, 257, 288, 296  
Fagundez, 230  
Fancello, 257, 288, 296  
Ferrari, 288  
Ficke, 246  
Franzese, 118  
Gambardella, 180  
Garcia del Valle, 1  
Ginters, 221  
Govaert, 55  
Gronalt, 251, 268  
Grundspenkis, 174  
Grundstoks, 221  
Gullì, 214  
Hatem, 20  
Häuslmayer, 251  
Hinrichs, 202  
Ilie-Zudor, 10  
Jagerman, 81  
Jammerneegg, 251  
Jansons, 225  
Jurenoks, 225  
Kaarsemaker, 49  
Karimi, 98, 104  
Karnok, 10  
Kassl, 67  
Kemény, 10  
Kirchheim, 280  
Kliewer, 72  
Koullias, 236  
Lamas Rodriguez, 1  
Legato, 214  
Lekkas, 167  
Leleu, 110  
Li W., 160  
Li X., 160  
Lipovszki, 61  
Longo, 35, 42, 123  
Marinacci, 190  
Mavris, 236  
McLean, 129  
Merkuryev, 20  
Merkuryeva, 20  
Mirabelli, 35, 42, 123  
Moccia, 284  
Molnar, 61  
Monaco, 208  
Monostori, 10

Montemanni, 180  
Naseddu, 288  
Nienhuis, 49  
Niessen, 94  
Nixon, 236  
Oh, 98, 104  
Ortiz, 160  
Papoff, 35, 42  
Paz, 118  
Pisano, 296  
Porneiks, 221  
Posset, 268  
Puchert, 67  
Quattrini, 190  
Raab, 29  
Ricci, 190  
Rizzoli, 180  
Samarra, 208  
Sasso, 139  
Savelsberg, 94  
Schindlbacher, 251  
Scholz-Reiter, 202, 274  
Schulze, 29  
Schütt, 67, 246  
Schoor, 81  
Sciannameo, 150  
Scozzi, 150  
Silva, 110  
Simões, 118  
Smith, 180  
Sniedovich, 89  
Sorrentino, 284  
Straßburger, 29  
Suhl, 72  
Szatmári, 10  
Tervo, 202  
Teucke, 274  
Tremori, 257  
Trunfio, 214  
Valentin, 110  
Van Landeghem, 55  
Virnich, 274  
Vosinakis, 167  
Voß, 89  
Wei, 160  
Weishäupl, 251  
Wiese, 72  
Xavier, 230  
Zuddas, 134, 296

