THE 19TH INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELLING AND SIMULATION

SEPTEMBER 18 – 20, 2017
BARCELONA, SPAIN

EDITED BY
ELEONORA BOTTANI
AGOSTINO G. BRUZZONE
FRANCESCO LONGO
YURY MERKURYEV
MIQUEL ANGEL PIERA

PRINTED IN RENDE (CS), ITALY, SEPTEMBER 2017

ISBN 978-88-97999-95-9 (Paperback)
ISBN 978-88-97999-87-4 (PDF)

ISBN 978-88-97999-95-9 (Paperback)
ISBN 978-88-97999-87-4 (PDF)

The 19th International Conference on Harbor, Maritime & Multimodal Logistics Modelling and Simulation

September 18 – 20, 2017

Barcelona, Spain

Organized by

DIME – University of Genoa

Liophant Simulation

Simulation Team

IMCS – International Mediterranean & Latin American Council of Simulation

DIMEG, University of Calabria

MSC-LES, Modeling & Simulation Center, Laboratory of Enterprise Solutions

Autonomous University of Barcelona

Modeling and Simulation Center of Excellence (MSCOE)

Latvian Simulation Center – Riga Technical University

Logisim

LSIS – Laboratoire des Sciences de l'Information et des Systemes

MIMOS – Movimento Italiano Modellazione e Simulazione

MITIM Perugia Center – University of Perugia

Brasilian Simulation Center, LAMCE-COPPE-UFRJ

MITIM - McLeod Institute of Technology and Interoperable Modeling and Simulation – Genoa Center

M&SNET - MCLEOD MODELING AND SIMULATION NETWORK

LATVIAN SIMULATION SOCIETY

ECOLE SUPERIEURE D'INGENIERIE EN SCIENCES APPLIQUEES

FACULTAD DE CIENCIAS EXACTAS. INGEGNERIA Y AGRIMENSURA

UNIVERSITY OF LA LAGUNA

CIFASIS: CONICET-UNR-UPCAM

INSTICC - INSTITUTE FOR SYSTEMS AND TECHNOLOGIES OF INFORMATION, CONTROL AND COMMUNICATION

NATIONAL RUSSIAN SIMULATION SOCIETY

CEA - IFAC

UNIVERSITY OF BORDEAUX

UNIVERSITY OF CYPRUS

DUTCH BENELUX SIMULATION SOCIETY

I3M 2017 INDUSTRIAL SPONSORS

CAL-TEK SRL

LIOTECH LTD

MAST SRL

SIM-4-FUTURE

I3M 2017 MEDIA PARTNERS

INDERSCIENCE PUBLISHERS – INTERNATIONAL JOURNAL OF SIMULATION AND PROCESS MODELING

INDERSCIENCE PUBLISHERS – INTERNATIONAL JOURNAL OF OIL, GAS AND COAL TECHNOLOGY

INDERSCIENCE PUBLISHERS – INTERNATIONAL JOURNAL OF SERVICE AND COMPUTING ORIENTED MANUFACTURING

IGI GLOBAL – INTERNATIONAL JOURNAL OF PRIVACY AND HEALTH INFORMATION MANAGEMENT

HALLDALE MEDIA GROUP: MILITARY SIMULATION AND TRAINING MAGAZINE

HALLDALE MEDIA GROUP: THE JOURNAL FOR HEALTHCARE EDUCATION, SIMULATION AND TRAINING

SAGE
SIMULATION TRANSACTION OF SCS

DE GRUYTER
INTERNATIONAL JOURNAL OF FOOD ENGINEERING

EDITORS

ELONORA BOTTANI
UNIVERSITY OF PARMA, ITALY
eleonora.bottani@unipr.it

AGOSTINO BRUZZONE
MITIM-DIME, UNIVERSITY OF GENOA, ITALY
agostino@itim.unige.it

FRANCESCO LONGO
DIMEG, UNIVERSITY OF CALABRIA, ITALY
f.longo@unical.it

YURI MERKURYEV
RIGA TECHNICAL UNIVERSITY, LATVIA
merkur@itl.rtu.lv

MIQUEL ANGEL PIERA
AUTONOMOUS UNIVERSITY OF BARCELONA, SPAIN
MiquelAngel.Piera@uab.cat

The International Multidisciplinary Modeling & Simulation Multiconference, I3M 2017

General Co-Chairs

Agostino Bruzzone, *MITIM DIME, University of Genoa, Italy*
Miquel Angel Piera, *Autonomous University of Barcelona, Spain*

Program Co-Chairs

Francesco Longo, *DIMEG, University of Calabria, Italy*
Yury Merkuryev, *Riga Technical University, Latvia*

The 19th International Conference on Harbour, Maritime & Multimodal Logistics Modelling and Simulation, HMS 2017

General Co-Chairs

Agostino Bruzzone, *MITIM – Genoa Center University of Genoa, Italy*
Yuri Merkuryev, *Riga Technical University, Latvia*

Program co-Chairs

Eleonora Bottani, *University of Parma, Italy*
Miquel Angel Piera, *Autonomous University of Barcelona, Spain*

HMS 2017 International Program Committee

Michael Affenzeller, *University of Applied Sciences, Austria*
Eleonora Bottani, *University of Parma, Italy*
Kris Braekers, *University of Hasselt*, Belgium
Agostino Bruzzone, *University of Genoa, Italy*
An Caris, *University of Hasselt*, Belgium
Elvezia M. Cepolina, *University of Pisa, Italy*
Diego Crespo Pereira, *University of La Coruna, Spain*
Branislav Dragovic, *University of Montenegro, Montenegro*
Alejandro Garcia, *University of La Coruna, Spain*
Manfred Gronalt, *University of Natural Resources and Applied Life Sciences, Austria*
Witold Jacak, *University of Applied Sciences, Austria*
Thomas Kern, *University of Applied Sciences, Austria*
Francesco Longo, *University of Calabria, Italy*
Marina Massei, *University of Genoa, Italy*
Yuri Merkuryev, *Riga Technical University, Latvia*
Galina Merkuryeva, *Riga Technical University, Latvia*
Roberto Montanari, *University of Parma, Italy*
Jairo Rafael Montoya Torres, Universidad de los Andes Colombia
Letizia Nicoletti, *Cal-Tek srl, Italy*
Antonio Padovano, *University of Calabria, Italy*
Nam Kyu Park, Tongmyong University, Korea
Miguel Angel Piera, *Autonomous University Of Barcelona, Spain*
Tobias Reggelin, *Otto von Guericke University Magdeburg, Germany*
Jose A. Tenreiro Machado, Polytechnic of Porto, Portugal
Manuel Villén-Altamirano, Universidad de Malaga, Spain
Hao Wang, Norwegian University of Science and Technology, Norway
Edward Williams, *PMC-Dearborn, USA*
Nenad Zrnic, *University of Belgrade, Serbia*

Tracks and Workshop Chairs

Modelling & Simulation in Logistics, Traffic and Transportation
Chair: Diego Crespo Pereira, University of La Coruna, Spain

Simulation Metamodelling and Optimisation in Logistics and Supply Chains
Chairs: Edward Williams, PMC-Dearborn, USA; Galina Merkuryeva, Riga Technical University, Latvia

Intermodal Transportation Systems and Services
Chair: Manfred Gronalt, University of Natural Resources and Applied Life Sciences, Austria

Modeling and Simulation of Logistics Networks
Chairs: Tobias Reggelin, Otto von Guericke University Magdeburg / Fraunhofer IFF, Germany; Alejandro Garcia, University of La Coruna, Spain

Modelling & Simulation for Inventory Management and Logistics
Chairs: Eleonora Bottani, University of Parma, Italy; Roberto Montanari, University of Parma, Italy

Innovative Transport Systems for Urban Areas and Urban Freight Transport
Chair: Elvezia M. Cepolina, University of Pisa, Italy

Workshop on Modeling & Simulation in E-Mobility
Chairs: Michael Affenzeller, University of Applied Sciences, Austria; Witold Jacak, University of Applied Sciences, Austria; Thomas Kern, University of Applied Sciences Austria

Planning Sustainable Transport Systems
Chairs: Agostino Bruzzone, DIME University of Genoa, Italy; Miguel Angel Piera, UAB Autonomous University of Barcelona, Spain

Ports and Terminals Modelling
Chairs: Branislav Dragović, University of Montenegro, Montenegro; Nenad Zrnić, University of Belgrade, Serbia; Nam Kyu Park, Tongmyong University Korea

Urban logistics models
Chair: Manfred Gronalt, University of Natural Resources and Applied Life Sciences, Austria

CHAIRS' MESSAGE

WELCOME TO HMS 2017!

Dear attendees,

it is our big pleasure to welcome you to the 19th International Conference on Harbor, Maritime and Multimodal Logistic Modelling and Simulation (HMS 2017)!

The conference has a long history, dating back to 1999, and is now an established forum for scientists, researches and experts to share their latest findings, research efforts, applications and studies related to simulation and modelling applied to the maritime environments, logistics and supply chain management issues. As such, we are happy to mention that the conference received papers from all over the world (Belgium, Spain, Latvia, UK and Germany among the European countries but also China, Japan, Singapore and Brazil among non-European countries), confirming the international audience of the conference themes. Among the set of papers received, 25 were accepted for inclusion in the conference proceedings. Such papers cover a wide range of topics, including railway transport, maritime transport, freight transport, distribution, logistics and scheduling. Papers have been organized into five conference sessions, under the themes of "Logistics & Manufacturing", "Ports and Terminals Modeling & Simulation", "Modelling and Simulation in Railway networks", "Modelling and Simulation in Logistics, Traffic and Transportation" and "Forecasting, Replenishment and Warehouses Simulation".

Overall, the HMS 2017 program clearly shows the inner nature of this conference and its ability to collect scientific contributions that are strictly related each other; this is also strongly reflected by the conference sessions where authors have the possibility to join an environment where researchers and scientists present and discuss similar topics and problems. This automatically provides the opportunity to create new collaborations, synergies and joint research projects.

It is evident that the success of our conference also depends on the work of the authors, who, with their scientific contributions, recognise the importance of the HMS conference. A significant work has also been done by the reviewers, who are responsible to ensure a high quality of the selected papers. Finally, the conference General and Program Chairs obviously play a key role in driving the conference evolution, addressing correctly the conference program and organizing the whole process. In this respect, we are also happy for the conference to be hosted in the beautiful Barcelona, the capital and largest city of Catalonia on the Mediterranean coast of the Iberian Peninsula. We would like to thank the local organization committee for hosting this important event and we wish you a pleasant stay in this beautiful city. We hope you enjoy the HMS conference!

Agostino Bruzzone,
MITIM-DIME, University Of Genoa, Italy

Yuri Merkuryev
Riga Technical University, Latvia

ELEONORA BOTTANI,
University of Parma, Italy

MIQUEL ANGEL PIERA,
Autonomous University of Barcelona, Spain

ACKNOWLEDGEMENTS

The HMS 2017 International Program Committee (IPC) has selected the papers for the Conference among many submissions; therefore, based on this effort, a very successful event is expected. The HMS 2017 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to Prof. Miquel Angel Piera from Universitat Autonoma de Barcelona as local organizer and to all the organizations, institutions and societies that have supported and technically sponsored the event.

I3M 2017 INTERNAL STAFF

This International Workshop is part of the I3M Multiconference: the Congress leading **Simulation around the World and Along the Years**

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

INDEX

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

AN EFFICIENT HEURISTIC FOR MULTI-OBJECTIVE TRAIN LOAD PLANNING: A PARAMETER SENSITIVITY ANALYSIS

Hilde Heggen[a], Kris Braekers[b], An Caris[c]

[a],[b],[c]UHasselt, Research group Logistics, Agoralaan, 3590 Diepenbeek, Belgium
[a]Maastricht University, Department of Quantitative Economics, P.O. Box 616, 6200 MD Maastricht, the Netherlands
[b]Research Foundation Flanders (FWO), Egmontstraat 5, 1000 Brussel, Belgium

[a]hilde.heggen@uhasselt.be, [b]kris.braekers@uhasselt.be , [c]an.caris@uhasselt.be

ABSTRACT
Intermodal transportation is evolving towards a synchromodal system with real-time switching, in which most assignment decisions are postponed until the final planning phase. In such environment, it is important to assist train planners by providing decision support in the operational environment in which they operate. One important task for train planners concerns train load planning, which is concerned with the assignment of load units to the available slots on a train. In this paper, a sensitivity analysis of the parameters of a multi-objective heuristic algorithm for train load planning is presented, which accounts for different aspects of train capacity utilization. The tuned heuristic algorithm provides a number of load plans from which planners can choose the most relevant plan for the specific circumstances they are operating in at that moment.

Keywords: train load planning, intermodal transportation, multi-directional local search

1. INTRODUCTION

The aim of train load planning is to find an assignment of load units to the available locations or slots on a train. The objective can be based on either capacity utilization or handling operations at the intermodal terminal. At the same time, axle payloads, wagon weights and total train weights are restricted and a balance should exist between the payloads on the adjacent axles of each wagon. A major contribution to the development of the train load planning problem has been provided by Corry and Kozan (2008), who developed a first realistic model. Furthermore, Bruns and Knust (2012) are the first to adopt continuous weight restrictions in a train load planning problem.

Current literature often presents linear programming problems and solves them using commercial software. Heuristic solution methods are usually based on a local search, sometimes combined with simulated annealing. Commonly used neighbourhoods are a load unit swap and a configuration change for two wagons. These heuristic methods are mainly applied to problems in which the load units to be loaded are fixed and known, and only the final assignment to specific locations on the train must be determined. The actual load unit's location on the train is uncertain because not all information about handling operations at the terminal is known in advance and a slot may still be occupied at the moment of arrival of a load unit assigned to that slot. In these cases, it becomes a problem with a rolling horizon in which the current load plan serves as initial solution and new events trigger a local search.

Recently, the optimization of train load planning has been integrated with optimization of other operational decisions in an intermodal seaport terminal. The topic is first introduced by Ambrosino et al. in 2011, who combine it with the optimization of crane and storage planning. A number of linear programs have been solved for this type of problem. Moreover, a combination of a primal heuristic with a RANS matheuristic (Anghinolfi and Paolucci 2014) and a GRASP (Anghinolfi et al. 2014) have been proposed.

In this paper, we focus on various aspects of train capacity utilization. During train load planning, the planning department is responsible for managing all transport orders, assigning them to the right transport route, and in a second phase the assignment of these orders to the available locations on a train. Especially with the rising importance of synchromodality, which is associated with a dynamic process and real-time switching, and more load units available than the number of slots on a given train, planners are facing a complex decision process. They receive a lot of information and should decide on the most appropriate load plan using this information.

Although planners in real life should take many objectives into account, to the best of our knowledge, only one paper (Ambrosino et al. 2016) applies a multi-objective approach, comparing three exact approaches to solve the train load planning problem in seaport terminals, hereby focusing on operations in the crane and storage area. We propose a multi-directional local search heuristic focusing on a number of capacity-related objectives which train planners take into account during their planning process in Section 2. Moreover, the heuristic parameters are tuned (Section 3) and a sensitivity analysis is performed (Section 4). Finally, Section 5 presents the main conclusions.

2. HEURISTIC FRAMEWORK

We extend the case of Heggen et al. (2016), who consider a real-life case study of a network operator which owns and manages its own trains, to a multi-objective problem and solve it using a multi-directional local search (MDLS) heuristic. The aim is to find a configuration for each wagon, respecting axle payload, wagon weight and total train weight limits, while preserving a balance between the payloads on adjacent wagon axles. Furthermore, trains stop at an intermediate terminal and some wagons are decoupled before arriving at the final destination terminal due to a more restrictive path weight in the last part of the itinerary. The proposed multi-objective heuristic to solve the problem (Section 2.1) and its components (Section 2.2-2.5) are described, as well as indicators for the heuristic quality assessment (Section 2.6).

2.1. Multi-Directional Local Search Heuristic

The multi-directional local search heuristic framework of Tricoire (2012) is used to solve the train load planning problem with three objectives to be maximized:

1. Length utilization;
2. Destination preference scores for assigning load units to wagons unloaded at a more preferred unload terminal;
3. Priority scores for more urgent load units.

The method relies on the knowledge that it is sufficient to search in the direction of each of the objectives individually to find new, non-dominated solutions (Braekers et al. 2016). Consequently, single-objective operators can be implemented in the framework. Other advantages include the flexibility and simplicity of the method. A global pool of non-dominated solutions *E* is maintained and updated during the search. In an MDLS-iteration, a solution is selected randomly from the solution pool *E*. Then, starting from this solution, a distinct local search for each objective is performed.

For the train load planning problem, an initial solution is generated in a first constructive phase. Next, in the MDLS-framework, the local search operators are defined by altering the configuration of two wagons. For each objective specifically, wagons are selected in a different way, and a distinct acceptance criterion is used. Each local search ends if a maximum number of consecutive iterations without improvement is reached.

2.2. Constructive Phase

An initial solution is constructed by assigning load units to slots on each wagon, one by one, going from the front to the back of the train, using an intelligent candidate list to select load units first based on the highest priority, then highest weight. First, only critical load units are considered. Only after these are feasibly assigned, the remaining load units are considered. For the wagon under consideration, configurations which are more preferred with respect to the available length used are selected first. The available slots of the selected configuration are filled with load units matching the slot dimensions as long as the bogie, wagon and train weight limits are respected. If either not all slots in a configuration can be filled with the remaining available load units or the bogie balance limits are not respected, a next configuration is selected. Otherwise, all slots in the configuration are filled and the assignment procedure continues with the next wagon. This constructive phase results in a single initial solution, which is added to solution pool *E*. No randomness is involved at this point to avoid ending up with critical load units not being assigned.

2.3. Local Search Operators

Next, $n_{it(MDLS)}$ iterations of the MDLS heuristic are performed. One MDLS-iteration consists of three local searches on a single randomly selected solution $s \in E$. Each local search LS_k guides the search primarily towards improving one objective *k*. The neighbourhood is defined by simultaneously altering the configuration for two wagons, i.e. assigning a new configuration to these wagons. The way in which wagons are selected differs depending on the main objective focus of the local search, as discussed in Section 2.5. All load units which were assigned to the two selected wagons are added to the pool of available, currently unassigned load units. Next, configurations for both wagons are selected randomly with a higher probability to be selected if a configuration uses more wagon length. The probability of selecting a configuration is determined by the contribution of the length used in that specific configuration compared to the total length of all possible configurations for one wagon type. In this way, the probability of rejecting a solution because it does not satisfy the acceptance criterion, is reduced. Finally, the selected configurations are fixed for both wagons only if all critical load units can be assigned, dimensions of the selected load units match the slot dimensions and all constraints related to train, wagon and bogie weight limits as well as the bogie balancing are satisfied.

2.4. Evaluation of the Solutions

While other MDLS-approaches use pure single-objective local search procedures, our operators are guided by a normalized, weighted-sum objective function which takes into account all three objectives. This function assigns a weight w_k to the primary objective *k*, while the remaining objectives each receive a weight of $w_r = (1-w_k)/2$ (with $w_r << w_k$) in order to avoid a large negative change in these remaining objectives. Further, a temporary set of non-dominated solutions *T* is updated with new solutions within one local search. If a solution is non-dominated by the solutions in the temporary set, it is added to this set, while dominated solutions are removed. Working with this temporary solution set avoids updating solution set *E* too often when new solutions are found within one local search, especially because one local search primarily focuses on one objective only. Finally, the local search ends with updating the global archive of non-dominated solutions *E* with the temporary set of solutions *T* obtained in LS_k.

2.5. Local Search for each Objective

For the local search in the direction of improving the length utilization, two wagons are selected as follows: the first wagon is chosen randomly from all wagons for which not all loading length is utilized; the second wagon is selected purely random from all available wagons. Finally, the local search procedure is terminated if a maximum number of sequential iterations without improvement, or a solution with the maximum possible length utilization is reached. The search in the direction of improving destination preferences and priority scores is guided by a local search which consists of a similar configuration change operator. However, both neighbourhoods are defined by assigning a new configuration to two randomly selected wagons.

2.6. Quality Indicators

In order to assess the performance of the MDLS, two complementary quality indicators are introduced. First, the hypervolume indicator I_H measures the hypervolume covered by a set of solutions relative to a reference point. Second, the (multiplicative) epsilon indicator I_ε determines the factor by which each point in an approximation set (obtained by the heuristic algorithm) should be multiplied such that a reference set, which ideally consists of the exact Pareto-front, is weakly dominated by the approximation set (Knowles et al. 2006). The closer both indicators are to one, the better the quality of the approximation set. In order to compare the approximation sets obtained by two variants of a heuristic design, the two quality indicators can be used together, as each indicator measures slightly different information. Furthermore, if the indicators show opposite preference, the sets can be considered incomparable.

Both indicators are visualized in Figure 1 for a bi-objective maximization problem. The left-hand side shows the hypervolumes covered by a reference set and an approximation set. On the right-hand side, the crosses indicate the weakly dominated set obtained by the epsilon indicator.

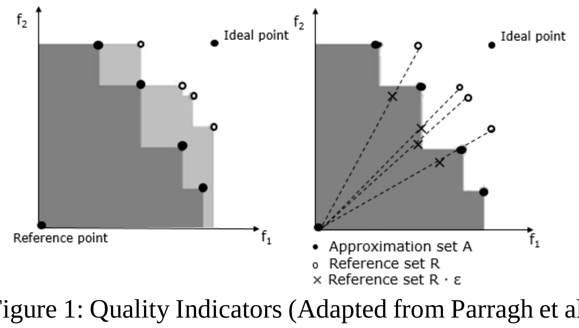


Figure 1: Quality Indicators (Adapted from Parragh et al. (2009))

In this paper, the hypervolume indicator I_H is stated as the hypervolume of the reference set which is covered by the approximation set generated by the MDLS (I_{Ha}/I_{Hr}). Moreover, both indicators are calculated after normalization of the objective values to ensure that each objective contributes more or less equally. The minimum reference point is determined based on the characteristics of the critical load units: the urgency score and length of the critical load units of an instance minus one and a minimum destination preference score of zero.

3. PARAMETER TUNING

irace (López-Ibáñez et al. 2016), a promising iterated racing procedure for tuning algorithm parameters, is used in order to find a parameter setting which leads to an excellent heuristic performance, obtaining solutions of good quality, such that the heuristic can be used as a decision support tool by practitioners. First, the tuning instances (Section 3.1) and considered MDLS-parameters (Section 3.2) are presented. Next, the iterated racing procedure for the multi-objective train load planning problem is described and the parameters are tuned (Section 3.3).

3.1. Instance Classes

A heterogeneous set of instance classes is used as input. Sets of load units with weights (in tonnes) being either light with *TRIA(17,20,23)*, heavy with *TRIA(23,26,29)* or uniformly distributed with *UNIF(17,29)* are considered. Furthermore, the number of critical load units is varied and can be 35% or 20% of the total amount of available load units. These six instance classes are applied to a wagon set of 5, 10 and 20 wagons, resulting in 18 classes.

3.2. Parameters of the MDLS

Two important parameters for the MDLS are the number of times a new solution is selected from the pool of non-dominated solutions, and the number of consecutive iterations without improvement after which the local search phase in the direction of each objective ends. Clearly, a trade-off between the values of these parameters can be expected if a limited computation time is available. In this section, no limit on the computation time is considered, but the relationship between solution quality and computation time for different amounts of MDLS-iterations and LS-iterations are examined in Section 4.

Within the scope of a single local search LS_k, the focus when accepting new solutions is on the main objective k. The weight w_k attached to the main objective of a local search should be tuned carefully. Moreover, within the normalized, weighted objective function used for accepting new solutions, possible criteria for accepting temporary solutions to continue working with within each local search A_{LS_k} (i.e. accepting worse, equal or better solution values for main objective k) are evaluated. Independent of this, only non-dominated, accepted solutions are added to the solution pool.

Finally, it is tested if the local search in the direction of improving destination preferences performs better when changing the configuration of two wagons with different destinations. An overview of the heuristic parameters under consideration, as well as its considered range of values are presented in Table 1.

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

Table 1: Tuning Parameters

Parameter	Description	Range
$n_{it(MDLS)}$	# times a random solution is selected	(10, 1000)
$n_{it(LS\_Length)}$	# consecutive non-improving iterations for LS_{Length}	(100, 2000)
$n_{it(LS\_Urgency)}$	# consecutive non-improving iterations for $LS_{Urgency}$	(100, 2000)
$n_{it(LS\_DP)}$	# consecutive non-improving iterations for LS_{DP}	(100, 2000)
w_k	Weight attached to the main objective *k* in LS_k	(0.8, 1)
A_{LS_Length}	Accepting solutions with main objective ≥ CurrentBest + A_{LS_Length}	(-45,-20,0,20)
$A_{LS\_Urgency}$	Accepting solutions with main objective ≥ CurrentBest+ $A_{LS\_Urgency}$	(-2, 2)
A_{LS_DP}	Accepting solutions with main objective ≥ CurrentBest + A_{LS_DP}	(-2, 2)
$DP_{wgndestin}$	Select two wagons with different destinations in LS_{DP}	(0, 1)

The acceptance criterion in the local search for the length utilization considers only the specified ordinal values, while for the other parameters values between the specified minimum and maximum bounds can be selected by the racing procedure. The weight attached to the principal objective is a real number with a precision of two decimals, all other parameter values are integers. The ranges of all parameters are defined after preliminary testing and based on knowledge about the problem characteristics.

3.3. Iterated Racing Procedure

The iterated racing procedure (Figure 2) is able to automatically configure algorithms, providing a set of parameter values which performs well for a particular problem (López-Ibáñez et al. 2016).

Require: $I = \{I_1, I_2, \ldots\} \sim \mathscr{I}$,
parameter space: X,
cost measure: $C(\theta, i) \in \mathbb{R}$,
tuning budget: B

1: $\Theta_1 \sim SampleUniform(X)$
2: $\Theta^{elite} := Race(\Theta_1, B_1)$
3: $j := 1$
4: **while** $B_{used} \leq B$ **do**
5: $\quad j := j+1$
6: $\quad \Theta^{new} \sim Sample(X, \Theta^{elite})$
7: $\quad \Theta_j := \Theta^{new} \cup \Theta^{elite}$
8: $\quad \Theta^{elite} := Race(\Theta_j, B_j)$
9: **end while**
10: **Output**: Θ^{elite}

Figure 2: Iterated Racing Procedure (López-Ibáñez et al. 2016)

The racing procedure starts with T^{first} instances on which a number of uniformly sampled candidate parameter configurations are tested. After these T^{first} tested instances, the candidate configurations which perform worse than at least one other configuration – calculated by a statistical Friedman test – are discarded (line 1-2). The best configurations (i.e. the configurations with the best objective values) are selected as an elite set, and new configurations are added for the following race based on well-performing parent elite configurations found so far (line 5-8). In the next iterations or races, each time T^{each} instances are evaluated before discarding any configuration. Furthermore, the standard deviation is reduced for each parameter as the number of iterations increases in order to search closer around better performing values. The procedure is terminated if a predefined computational budget *B* is reached. This budget corresponds to a maximum number of experiments, where one experiment consists of one parameter configuration tested on a single instance.

As multiple objectives must be considered, the cost function is represented by the quality indicator value, which should be maximized. López-Ibáñez et al. (2016) tested *irace* for their problem with multiple objectives using the hypervolume and the epsilon indicator and could not find significant differences. Therefore, only the hypervolume indicator is used as measure of the solution quality at this stage. The calculation of this quality indicator requires a reference set, which can be the exact Pareto-front. If not all Pareto-optimal solutions are known, the reference set consists of all non-dominated solutions found by a number of MDLS-runs, combined with the non-dominated solutions found so far in the exact procedure. Therefore, all candidate parameter configurations in a single iteration are tested on one instance before evaluating the cost function, i.e. calculating the quality indicator. Normalization bounds and the reference point can be calculated in advance, independent of the approximation sets found by the heuristic.

Table 2 shows the adapted *irace* parameters used. All other parameters are at their default values.

Table 2: *irace* Parameters

***Irace* parameter**	**Value**
Tuning budget *B*	5000
Cost measure *C*	Hypervolume
T^{first}	36
T^{each}	18
Random samples	Off

The total set of tuning instances consists of two blocks of 18 instances, with a representative set of characteristics. The total amount of 36 instances, containing two instances from each instance class, is first tested before discarding any candidate configuration. In this way, two instances of every class are evaluated before a first elimination occurs, to cope with a possible outlier instance. Next, after every block of 18 instances, the configurations under consideration are again evaluated. Sampling of instances does not occur randomly, but in the order of the instance classes within one block in order to avoid elite configurations being biased towards only a subset of the instance classes.

The best configurations presented by *irace* are summarised in Table 3. These configurations are ordered according to their mean performance, but do not show a statistically significant difference with respect to the solution quality. The average hypervolume indicator value of the best configuration across all considered instances amounts to 0.9996.

Table 3: Best Configurations

Parameter	C_1	C_2	C_3	C_4
$n_{it(MDLS)}$	987	949	759	775
$n_{it(LS\_Length)}$	801	377	434	271
$n_{it(LS\_Urgency)}$	1826	1498	1745	1384
$n_{it(LS\_DP)}$	1716	1541	1388	1631
w_k	0.91	0.92	0.90	0.90
A_{LS_Length}	0	0	0	0
$A_{LS\_Urgency}$	0	0	0	0
A_{LS_DP}	0	0	0	0
$DP_{wgndestin}$	0	0	0	0

Differences exists with respect to the number of iterations $n_{it(MDLS)}$ and $n_{it(LS\_k)}$, while the acceptance thresholds are identical for all best configurations C_1 to C_4. The obtained parameter value for A_{LS_DP} indicates that solutions are accepted only if they are better than the current best solution within a single local search. The acceptance threshold within the other two local searches is defined differently and therefore, the obtained parameter values indicate that solutions are accepted if they are at least as good as the current best solution. One important limitation of *irace* is that the automatic algorithm configuration does not take into account computation times when selecting parameter configurations. Therefore, these results should be further tested and a sensitivity analysis will be performed on the parameters to analyse differences in computation times and solution quality for different parameter settings.

4. SENSITIVITY ANALYSIS

The best parameter configuration C_1 resulting from the *irace* tuning procedure is analysed to examine the influence of changes in these parameter values on solution quality and computation times. For this purpose, two new test instances per class are used, which are not considered in the tuning phase. Varying parameter values are tested on these instances with respect to differences in solution quality, expressed as a proportional deviation from the hypervolume of the reference set (HV_R), as well as differences in computation time. First, interactions between $n_{it(MDLS)}$ and $n_{it(LS\_k)}$ are considered (Section 4.1). Next, it is examined whether a temporary solution pool T, maintained within a single local search, influences computation times (Section 4.2). Finally, variations in parameter values w_k, A_{LS_k} and the possibility of selecting two wagons with different destinations ($DP_{wgndestin}$) in LS_{DP} are tested (Section 4.3). The main findings are summarised in Section 4.4.

4.1. Interaction between $n_{it(MDLS)}$ and $n_{it(LS\_k)}$

It can be expected that a higher number of iterations, both $n_{it(MDLS)}$ and $n_{it(LS\_k)}$, corresponds to a higher solution quality, but at the cost of larger computation times. Therefore, a point may be determined as from which additional gains in solution quality become small relative to the increase in computation time. Values up to 1000 MDLS-iterations $n_{it(MDLS)}$ are considered with steps of 200 iterations. As the largest gains may be obtained during the first MDLS-iterations, 10, 50 and 100 iterations are added. To examine its interaction with the number of consecutive iterations without improvement $n_{it(LS\_k)}$ after which each local search is ended, for each local search LS_k separately multiples of 250 consecutive non-improving iterations are considered with a maximum of 2000 iterations.

Figure 3 shows the average proportional deviation from the hypervolume of the reference set when either varying the number of LS-iterations for destination preferences (*DP*), length utilization (*Length*) or urgency scores (*Urgency*). The remaining parameters are set at the values of the best-performing configuration. Variations in the number of non-improving LS-iterations after which the local search with respect to the length utilization ends do not significantly influence solution quality. This corresponds to the relatively small parameter values for $n_{it(LS\_Length)}$ in the best *irace* configurations. For the destination preference scores and urgency scores, larger differences can be observed for low numbers of MDLS-iterations. Clearly, major improvements with respect to the solution quality are reached during the first MDLS-iterations. These results are consistent with the best configurations found by *irace*, as $n_{it(LS\_DP)}$ and $n_{it(LS\_Urgency)}$ are always larger than 1250.

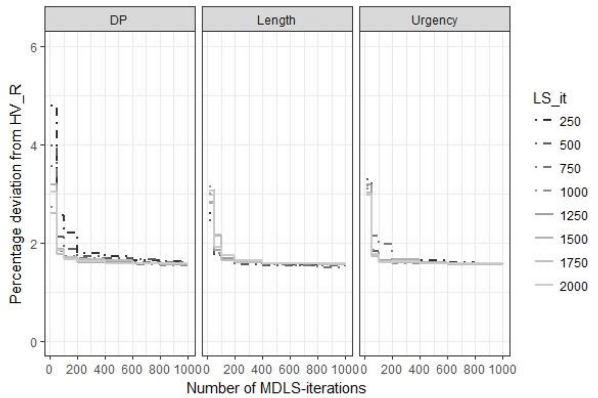


Figure 3: Solution Quality Based on $n_{it(MDLS)}$ and $n_{it(LS\_k)}$

Additionally, Figure 4 displays the average solution quality depending on the number of MDLS-iterations over all experiments, grouped per instance size. These results show that a clear difference exists with respect to the average solution quality: the heuristic performance is highest for instances with 10 and 20 wagons, while the mean performance is lower for 5 wagons. However, the mean deviation is still lower than 5%.

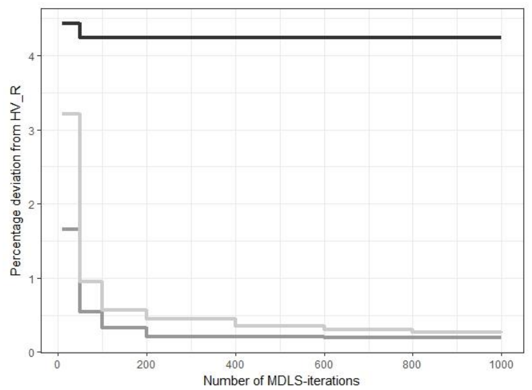


Figure 4: Average Solution Quality per Instance Size

Generally, for low numbers of MDLS-iterations, differences in solution quality are larger between a high and low number of non-improving local search iterations. As from 400 MDLS-iterations, the improvement in solution quality becomes relatively small, independent of the number of non-improving local search iterations.

Figure 5 shows average computation times in seconds for all instances of each possible combination of MDLS- and LS-iterations. The number of MDLS-iterations mainly influences computation time, as it involves additional iterations for all three local searches at the same time. The difference in the slope of the destination preference graph compared to the length and urgency graphs indicates that each LS_{Length} and $LS_{urgency}$ reached the number of consecutive iterations without improvement earlier, ending the local search. For LS_{DP}, this implies that improvements are found at a later stage of the respective local search, initializing the search again with a new best solution without ending the local search.

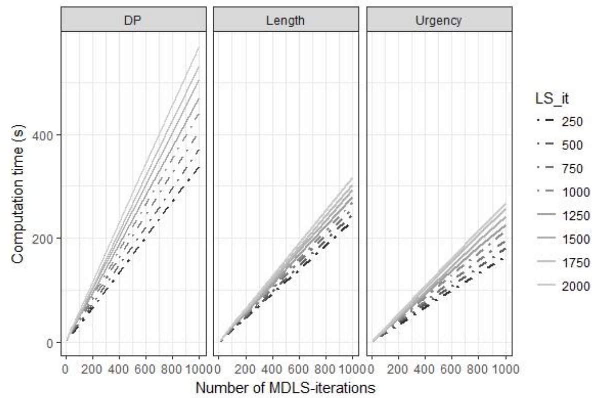


Figure 5: Average Computation Times Based on $n_{it(MDLS)}$ and $n_{it(LS\_k)}$

Computation time primarily rises with the number of MDLS-iterations, while solution quality remains relatively stable beyond 400 MDLS-iterations, regardless of the number of LS-iterations. For the best configurations C_1-C_4 the number of iterations for LS_{Length} varies between 250 and 1000, and for $LS_{Urgency}$ and LS_{DP} between 1250 and 2000. For these intervals of LS-iterations, the solution quality is high and stable as from 200 MDLS-iterations with a short computation time compared to 400 MDLS-iterations. Based on these observations, for the remainder of this paper we use $n_{it(MDLS)}$ = 200, while $n_{it(LS\_k)}$ remains at the best values found by *irace*. This configuration leads to high-quality solutions in relatively short computation times.

4.2. Effect of a Temporary Solution Pool T

Next, the effect of a temporary non-dominated solution pool *T*, used within the scope of a single local search, on computation times is evaluated by means of a paired-samples *t*-test. The temporary solution pool does not influence the solution quality. However, it may impact total computation times. For each instance category, average computation times as well as the *p*-values are displayed in Table 4.

Table 4: Effect of *T* on Computation Time (s)

	Temporary pool		
Instance class	**No**	**Yes**	***p*-value**
(5, 35%, light)	53.53	53.34	0.159
(5, 35%, heavy)	322.67	320.59	*0.001
(5, 35%, unif)	67.92	67.66	0.081
(5, 20%, light)	72.66	72.62	0.911
(5, 20%, heavy)	218.72	218.84	0.070
(5, 20%, unif)	82.20	81.83	0.539
(10, 35%, light)	107.11	108.26	0.252
(10, 35%, heavy)	277.49	279.43	0.267
(10, 35%, unif)	174.63	169.89	0.239
(10, 20%, light)	35.05	35.21	0.726
(10, 20%, heavy)	19.83	20.14	0.055
(10, 20%, unif)	31.27	30.46	*0.035
(20, 35%, light)	129.78	130.38	0.784
(20, 35%, heavy)	136.85	135.47	0.714
(20, 35%, unif)	94.54	99.73	0.266
(20, 20%, light)	36.81	35.69	0.326
(20, 20%, heavy)	42.00	41.93	0.938
(20, 20%, unif)	31.66	31.76	0.828

Contrary to the expectations, we can conclude that, on the 5%-significance level, no statistically significant difference in computation time can be obtained by maintaining a temporary solution pool within a single local search, except for two instance classes (indicated with an asterisk). This may be explained by the fact that the number of non-dominated solutions in the global solution pool is relatively small. Moreover, during the first iterations, the temporary solution pool may provide advantages, as more new, non-dominated solutions are found and the obtained non-dominated solutions may be further away from the Pareto-front. However, as the number of iterations increases, it becomes harder to find new non-dominated solutions as these solutions are already close to the Pareto-front and the temporary solution pool remains relatively small. This implies that a smaller number of evaluations between the temporary pool *T* and the global pool *E* should be performed. Furthermore, computation times are relatively large for the smallest instances. This may partly be due to the fact that the heuristic performs additional iterations, even

when the optimal Pareto-front already may have been reached. For larger instances, increased computation times are observed if a high number of critical load units is available.
Although no significant difference is observed for most instance classes, significantly lower computation times are observed for two instance classes if a temporary solution pool is included. Therefore, the temporary solution pool is maintained as a component of the MDLS-heuristic.

4.3. Sensitivity of w_k, A_{LS_k} and $DP_{wgndestin}$

For all other parameters under consideration, Table 5 (Appendix A) shows an overview of the average solution quality obtained for each instance size as well as the overall average solution quality for each parameter value. For most of the parameters, the sensitivity analysis shows results identical to the *irace* parameter configurations. However, for A_{LS_Length} the parameter value resulting in the overall average best result (indicated with an asterisk) does not correspond to the parameter values selected by *irace* (indicated in bold). This small deviation may be explained by the decision to work with 200 MDLS-iterations instead of a parameter value out of one of the best configurations as well as by the fact that different instances are used. In the remainder of this section, individual results for each parameter are discussed in detail.
With respect to the **weight** attached to the main objective of a single local search, w_k, values between 0.6 and 1 are tested with an interval of 0.05. The parameter value of 0.91 obtained in the best configuration C_1 is also added. The solution quality and computation times (in seconds) for each parameter value and each instance size (5, 10 and 20 wagons) are displayed in Figure 6 and Figure 7.

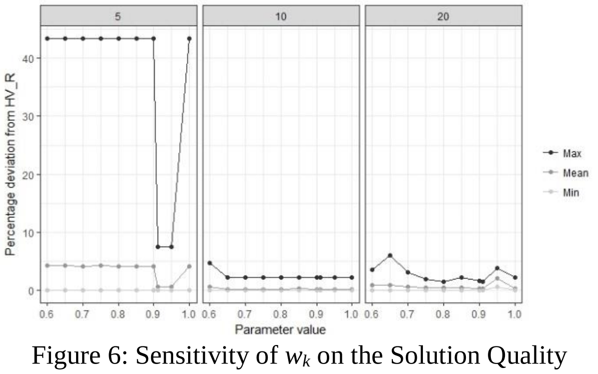


Figure 6: Sensitivity of w_k on the Solution Quality

Based on the results of the test instances used for these sensitivity analysis, for small instances with 5 wagons, the weight could be set to either 0.90 or 0.95. However, one outlier instance severely influences the average performance. For the larger and realistic instances with 10 and 20 wagons, differences in solution quality are smaller. Generally, a weight of 0.91 provides the highest average solution quality, while the lowest solution quality (with a high deviation from *HV_R*) is acceptable for all instances.

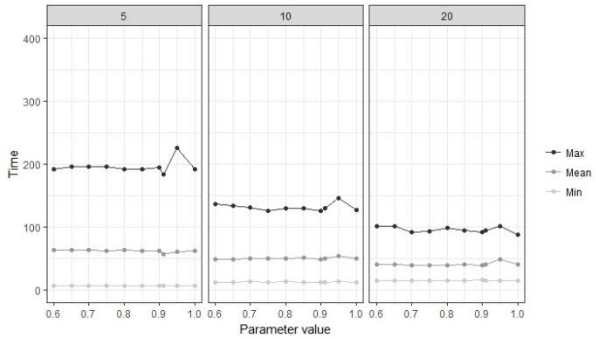


Figure 7: Computation Time (s) Based on w_k

Although computation times are consistent, average and maximum computation times show only small fluctuations, indicating that changes in this parameter do not substantially influence computation times.
Similarly, the influence of the criterion for **accepting solutions** in each local search LS_k for each objective k is evaluated. Figure 8 shows that the best parameter values for A_{LS_Length} are not consistent with the *irace* results for the considered test instances. This can be observed by the difference in solution quality between a small instance size of 5 wagons and larger instance sizes. As the performance for instances with 10 and 20 wagons is independent of the range of parameter values, accepting solutions with a length of 20 or 45 feet less than the current best solution provides a higher overall solution quality.

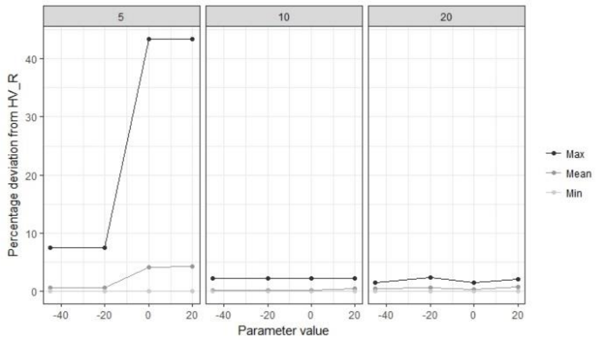


Figure 8: Sensitivity of A_{LS_Length} on the Solution Quality

Only small differences exist regarding average computation times, as demonstrated in Figure 9. The main difference exists for the smallest instance category, where maximum computation times rise, which may be due to the fact that the neighborhood is rather small when only accepting improving solutions. Considering computation times and solution quality simultaneously, allowing the acceptance of worse solutions might be favourable for these small instances.

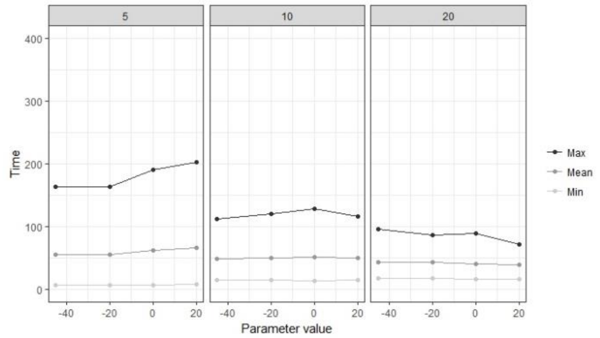


Figure 9: Computation Time (s) Based on A_{LS_Length}

With respect to $A_{LS\_Urgency}$, Figure 10 also shows a clear difference in solution quality for small instances in comparison with the instances of 10 and 20 wagons. However, at $A_{LS\_Urgency} = 0$, for the latter instance categories minimum and maximum solution quality are extremely close, and the overall average solution quality is the highest. This is compatible with the *irace* results.

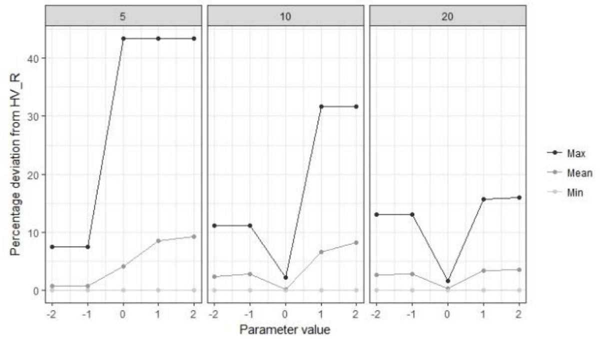


Figure 10: Sensitivity of $A_{LS\_Urgency}$ on the Solution Quality

Figure 11 displays computation times for each of the parameter values of $A_{LS\_Urgency}$. Although maximum computation times show a decreasing trend for instances with 10 and 20 wagons as the parameter value increases, average computation times show only a very weak decrease within each of the three instance sizes.

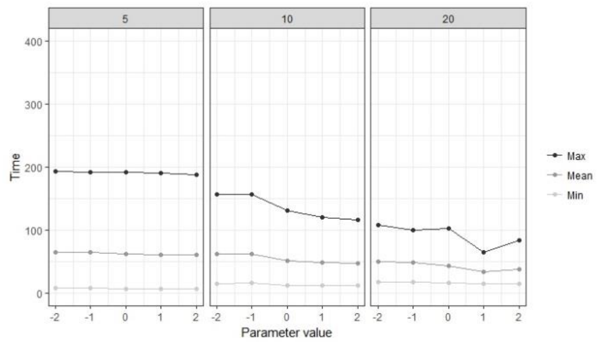


Figure 11: Computation time (s) Based on $A_{LS\_Urgency}$

Figure 12 shows for possible values of A_{LS_DP} a pattern similar to $A_{LS\_Urgency}$ with respect to the solution quality. Although instances with 5 wagons perform worse if $A_{LS\_Urgency} = 0$, the overall performance is highest.

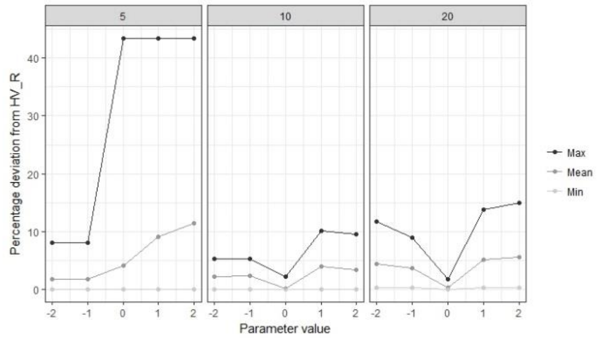


Figure 12: Sensitivity of A_{LS_DP} on the Solution Quality

As shown by Figure 13, only instances with 10 and 20 wagons show clear differences in computation time for different parameter values, especially for the maximum computation times.

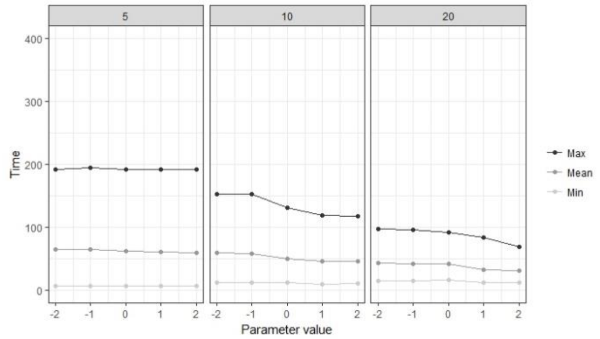


Figure 13: Computation Time (s) Based on A_{LS_DP}

Finally, a parameter $DP_{wgndestin}$ is added and evaluated in order to test whether in the local search focusing on destination preference scores, selecting two wagons with different **destinations** ($DP_{wgndestin} = 1$) leads to a higher solution quality in comparison with two random wagons ($DP_{wgndestin} = 0$). As shown in Figure 14, no substantial difference exists with respect to the solution quality. Moreover, the boxplots in Figure 15 indicate that maximum computation times mostly increase if in the local search is based on swapping two wagons with different destinations. Therefore, selecting two wagons with different destinations does not add value to the heuristic.

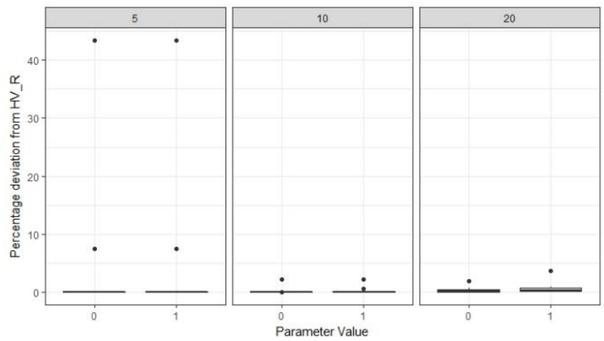


Figure 14: Sensitivity of $DP_{wgndestin}$ on the Solution Quality

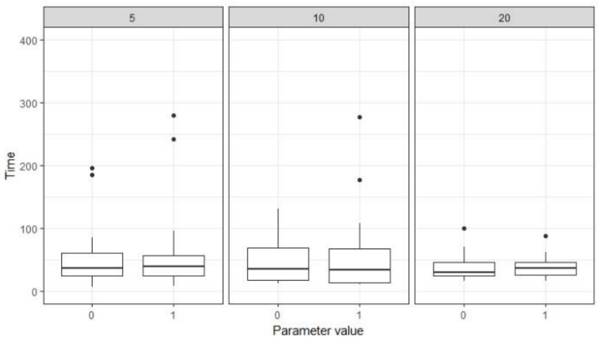


Figure 15: Computation Time (s) Based on $DP_{wgndestin}$

4.4. Practical Implications

Generally, the parameter configuration C_1 found by *irace* provides high-quality results, even with a smaller number of MDLS-iterations. However, one possible outlier instance in the instance category of 5 wagons might have influenced the results of the sensitivity analysis. Moreover, for that specific category a different configuration may be more suitable (e.g. in LS_{Length}, allowing to continue with solutions which are worse than the current best solution found so far), but the tuned parameter configuration presented by *irace* generally provides a reliable performance.

For practical applications it is important that good solutions are obtained in short computation times. Therefore, based on the discussed results, train load plans resulting from the MDLS using no more than 200 MDLS-iterations in order to reduce computation times will be valuable for practitioners. If a smaller number of MDLS-iterations would be considered, the influence of a temporary solution pool on computation times could be tested again.

5. CONCLUSIONS

In this paper, we were able to find a configuration which generally performs efficiently for a heterogeneous set of instance classes. With this parameter configuration, the multi-directional local search heuristic is able to find solutions of high quality within a reasonable amount of computation time. One limitation of this research is that only the hypervolume is used as a performance indicator. The obtained results may be validated with the results of the epsilon indicator. Further, the considered instances are heterogeneous with respect to their characteristics and maybe different parameter configurations would be selected if each category would be considered separately. Further research may focus on finding specific configurations for each category of instances, depending on the intended use of the heuristic. Moreover, while the interaction between the number of MDLS-iterations and the number of LS-iterations is investigated, no interaction effects are studied with respect to the parameters for $w_{k,}$, A_{LS_k}, $DP_{wgndestin}$.

The planning processes in intermodal transport are subject to many dynamics which influence the assignment decision. In this dynamic environment, the presented heuristic with the defined parameter setting can be used to provide decision support for planners in real-life planning contexts, while the final decision on the most appropriate load plan remains with the human planner.

ACKNOWLEDGMENTS

This work is partially funded by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (research project COMEX, Combinatorial Optimization: Metaheuristics & Exact Methods).

The computational resources and services used in this work were provided by the VSC (Flemish Supercomputer Center), funded by the Research Foundation - Flanders (FWO) and the Flemish Government department EWI.

APPENDIX A

Table 5: Average Percentage Deviation from HV_R

Parameter	Value	Wagons 5	10	20	Overall
w_k	0.60	4.3306	0.6157	1.0049	1.9837
	0.65	4.3306	0.2217	0.9655	1.8393
	0.70	4.2386	0.2011	0.7245	1.7214
	0.75	4.2476	0.2095	0.5645	1.6739
	0.80	4.2386	0.2615	0.4667	1.6556
	0.85	4.2386	0.3367	0.4415	1.6723
	0.90	4.2386	0.1963	0.3564	1.5971
	0.91	**0.6272**	**0.2155**	**0.3957**	***0.4128**
	0.95	0.6272	0.2771	2.0622	0.9888
	1	4.2386	0.2001	0.3852	1.6080
A_{LS_Length}	-45	0.6272	0.2374	0.5776	*0.4807
	-20	0.6272	0.2269	0.6710	0.5084
	0	**4.2386**	**0.2073**	**0.4302**	**1.6254**
	20	4.3306	0.4452	0.8677	1.8812
A_{LS_Urg}	-2	0.7481	2.3843	2.7250	1.9525
	-1	0.7481	2.8099	2.8284	2.1288
	0	**4.2386**	**0.2215**	**0.3379**	***1.5993**
	1	8.5737	6.5884	3.4988	6.2203
	2	9.3047	8.3223	3.5622	7.0631
A_{LS_DP}	-2	1.8935	2.2498	4.4634	2.8689
	-1	1.8935	2.3854	3.7206	2.6665
	0	**4.2386**	**0.2105**	**0.3344**	***1.5945**
	1	9.1638	3.9724	5.1280	6.0881
	2	11.4811	3.3848	5.6054	6.8238
$DP_{wgndestin}$	**0**	**4.2386**	**0.1991**	**0.4045**	***1.6141**
	1	4.2386	0.3100	0.6993	1.7493

REFERENCES

Ambrosino D., Bramardi A., Pucciano M., Sacone S., Siri S., 2011. Modeling and solving the train load planning problem in seaport container terminals. Transportation Research Part E: Logistics and Transportation Review, 79, 65-82.

Ambrosino D., Bernocchi L., Siri, S., 2016. Multi-objective optimization for the train load planning problem with two cranes in seaport terminals. IFAC-PapersOnLine, 3 (49), 383-388.

Anghinolfi D., Caballini C., Sacone S., 2014. Optimizing train loading operations in innovative and automated container terminals. Proceedings of the 19th international federation of automatic control World Congress, pp. 9581-9586, August 24-29, Cape Town (South Africa).

Anghinolfi D., Paolucci M., 2014. A general purpose lagrangian heuristic applied to the train loading problem. Procedia - Social and Behavioral Sciences, 108, 37-46.

Braekers K., Hartl R.F., Parragh S.N., Tricoire F., 2016. A bi-objective home care scheduling problem: Analyzing the trande-off between costs and client inconvenience. European Journal of Operational Research, 248 (2), 428-443.

Bruns F., Knust S., 2012. Optimized load planning of trains in intermodal transportation. OR Spectrum, 34, 511-533.

Corry P., Kozan, E., 2008. Optimised loading patterns for intermodal trains. OR spectrum, 30 (4), 721-750.

Heggen H., Braekers K., Caris A., 2016. Optimizing Train Load Planning: Review and Decision Support for Train Planners. Proceedings of the 7th International Conference on Computational Logistics, pp. 193-208, September 7-9, Lisbon (Portugal).

Knowles J., Thiele L., Zitzler E., 2006. A tutorial on the performance assessment of stochastic multiobjective optimizers. TIK-Report No 214, Computer Engineering and Networks Laboratory (TIK), ETH Zurich, Switzerland, revised version.

López-Ibáñez M., Dubois-Lacoste J., Pérez Cáceres L., Birattari M., Stützle T., 2016. The irace package: Iterated racing for automatic algorithm configuration. Operations Research Perspectives, 3, 43–58.

Parragh S.N., Doerner K.F., Hartl R.F., 2009. A Heuristic Two-Phase Solution Approach for the Multi-Objective Dial-A-Ride Problem. Networks, 54 (40), 227-242.

Tricoire F., 2012. Multi-directional local search. Computers & Operations Research, 39 (12), 3089-3101.

AUTHORS BIOGRAPHY

Hilde Heggen graduated in 2014 as a Master of Science in Business Engineering with a major in Operations Management and Logistics at Hasselt University, Belgium. In April 2015, she started her PhD focusing on train planning models in intermodal transportation.

Kris Braekers is Assistant Professor of Operations Management and Logistics at Hasselt University in Belgium since 2015. He obtained his PhD in Applied Economics at Hasselt University in 2012. His main research interest is studying combinatorial optimization problems in the context of transport and (healthcare) logistics (e.g., vehicle routing problems) and applying meta-heuristic techniques to solve these problems. Other research topics include warehouse management, empty container management and modelling intermodal freight transport networks.

An Caris was appointed in 2012 as Assistant Professor at the Faculty of Business Economics (BEW) of Hasselt University. She obtained her PhD in Applied Economics in 2010 and was first a postdoctoral research fellow of the Research Foundation - Flanders (FWO). Her research interest goes to the application of Operations Research (OR) techniques in the field of operations management and logistics. In her PhD thesis she focused on the competitiveness of intermodal transport making use of inland navigation. Currently she studies planning problems in warehouse operations, intermodal rail transport, collaborative logistics and healthcare logistics.

A SIMULATION APPROACH FOR THE TRANSSHIPMENT OPERATIONS AT MARITIME CONTAINER TERMINALS

Iván Castilla-Rodríguez[(a)], Christopher Expósito-Izquierdo[(b)], Rosa M. Aguilar-Chinea[(c)], Belén Melián-Batista[(d)], J. Marcos Moreno-Vega[(e)]

[(a),(b),(c)(d)(e)]Departamento de Ingeniería Informática y de Sistemas. Universidad de La Laguna. Spain

[(a)]icasrod@ull.edu.es, [(b)]cexposit@ull.edu.es, [(c)]raguilar@ull.edu.es,
[(d)]jmmoreno@ull.es, [(d)]mbmelian@ull.edu.es

ABSTRACT
Maritime container terminals must deal with multiple problems when serving the incoming container vessels. Simulation techniques can fill the gap between mathematically robust optimisation algorithms and the practical application of the solutions of these algorithms to real-world scenarios, where uncertainty may lead decision makers to rule out a number of the best analytical solutions. In this context, the main goal of this paper is to introduce a general scheme based on the combination of optimisation and simulation techniques to provide a set of feasible schedules of the container transshipment operations of an incoming container vessel at a maritime container terminal.

Keywords: simulation, optimisation, decision support system, port

1. INTRODUCTION

Serving the incoming container vessels is the main goal of maritime container terminals due to its economic impact. This means to unload a subset of the containers included into the stowage plan of each vessel arrived to the terminal, termed *import containers*. These containers must be temporarily stored on the yard of the terminal until their later retrieval by another transportation mean. At the same time, other containers, termed *export containers*, must be loaded into the vessels to be carried to subsequent terminals along a predefined shipping route (Gunter and Kim, 2006).

The transshipment operations (*i.e.*, loading and unloading containers) in the seaside of a maritime terminal are performed through a pre-established set of quay cranes (Legato, Trunfio, and Meisel, 2012). However, an appropriate schedule of the transshipment operations associated with the containers included into the stowage plan of each incoming vessel must be determined to provide an accurate estimation of the service quality to shipping companies and, thus, becoming attractive infrastructures for them.

The potential number of operations that a quay crane can perform determines its working performance. In most cases, the quay cranes perform up to 25-30 moves per hour due to their technical characteristics (Chao and Lin, 2011). In spite of the latest technological advances, the practical performance of the quay cranes is highly influenced by many factors. These factors include the skills of the crane driver, the availability of internal delivery vehicles, and the interferences between quay cranes in the same berth, among others. However, in this case, it is assumed that the crane cycle corresponds to the time to unload/load a container from/to the incoming vessel. In the end, the interaction of the former factors leads to a scenario characterised by uncertainty, where the duration of the operations is not deterministic but stochastic.

Simulation techniques can fill the gap between mathematically robust optimisation algorithms, and the practical application of the analytical solutions reported by these algorithms to real scenarios, where uncertainty may lead the decision makers to rule out a number of the best analytical solutions. In this context, the main goal of this paper is to introduce a general scheme to provide a set of feasible schedules of the transshipment operations of an incoming container vessel in a maritime container terminal.

2. QUAY CRANE SCHEDULING PROBLEM

Determining an appropriate completion of the transshipment operations associated with an incoming container vessel in a maritime container terminal is formalised as an optimisation problem termed Quay Crane Scheduling Problem, in short QCSP.

Input data of the QCSP is composed of a set of n tasks, denoted as $\Omega = \{t_1, t_2, ..., t_n\}$, and a set of m quay cranes, denoted as $QC = \{qc_1, qc_2, ..., qc_m\}$. It is here assumed that the quay cranes have similar technical characteristics and differences between crane drivers in terms of skill and practice are not present. This means that quay cranes are able to perform the transhipment operations with the same working performance. Also, the movement time of the quay cranes is not negligible. Thus, a travel time is required to move a quay crane between two adjacent bays of the container vessel. In addition, each quay crane $q \in$

QC can operate after its earliest ready time r^q and is initially located on the bay l_0^q. Each task $t \in \Omega$ represents the loading or unloading operation of a set of containers located in a known bay of the vessel. Task t requires certain processing time, denoted as p_t, which derives mainly from the characteristics of the quay crane that performs it and the skills of its crane driver.

Unlike other classic scheduling problems (*e.g.*, job shop scheduling problem), the QCSP introduces a set of complex constraints that restrict the feasibility of the schedules and constitutes a challenge from the algorithmic standpoint. Firstly, the quay cranes are rail-mounted, in such a way that they cannot cross to each other. No impact on the individual working performance arisen from the interferences between quay cranes is considered in this work. In addition, they have to keep a certain safety distance between them to prevent potential collisions. This implies that some tasks cannot be performed simultaneously if they are located at a distance of less than the safety distance between pairs of quay cranes. Moreover, the transshipment operations require the support of a set of internal delivery vehicles aimed at moving the containers between the quay and the yard. Each internal delivery vehicle can be associated with any transshipment operation over the planning horizon, in such a way that a completely free vehicle-crane assignment policy is assumed. The time required to store/retrieve a container on/from the yard depends on the characteristics of the container and its freights, the vehicle, and the source/target location on the yard, among others.

It is worth mentioning that feasible solutions of the QCSP are schedules that determine the starting and finishing times of all the n tasks associated with the incoming container vessel while fulfilling the previous constraints of the optimisation problem. Also, movements and waiting times of the quay cranes are specified in each feasible solution. Lastly, it is assumed that the optimisation criterion of the QCSP seeks to minimise the service time of the container vessel in the remainder of this work.

The QCSP has been addressed in the scientific literature by several authors, especially over the last few years. In general terms, the proposals published so far can be mainly classified according to several criteria: container aggregation, technical characteristics of the quay cranes, level of potential interferences, and performance measure. The former makes reference to how the containers included into the stowage plan can be handled by the quay cranes. Tasks at the highest level of aggregation usually comprise all the containers located into a given bay. For example, this is the case of the work by Boysen, Emde, and Fliedner, 2012. At the lowest level of aggregation, tasks comprise individual containers of the stowage plan. This is the approach by Than, Zhao, and Liu, 2012, and that assumed in the present work. Also, the technical characteristics of the quay cranes have produced a wide range of relevant works. Some authors have studied the impact of the temporal availability of the cranes on the overall performance of the transshipment operations (Unsal O., Oguz C., 2013) whereas a few works consider the movement of the quay cranes as non-negligible (Lu, Han, Xi, and Erera, 2012). Furthermore, one of the distinguishing factors of the problem under analysis is the presence of potential interferences between adjacent quay cranes when performing the transshipment operations. In this regard, some authors include a safety distance in their proposals with the aim of avoiding risk situations. This is the case of the work by Chung and Chan, 2013. Lastly, the performance measure has given rise to the widest range of approaches to solve the QCSP. In this regard, some of the most relevant optimisation criteria are aimed at providing a fast service of the vessels (Lee and Chen, 2010), maximising the crane utilisation rate (Vis and Anholt, 2010). Finally, the interested reader is referred to the work by Bierwirth and Meisel, 2015 to obtain a comprehensive literature review of the QCSP and its related fields.

3. DESIGN OF THE DECISION SUPPORT SYSTEM

The present paper proposes a decision support system aimed providing high-quality solutions of the QCSP, while handling the inherent uncertainty of the environment. Figure 1 depicts the general structure of the proposed decision support system. As shown in the figure, this structure relies on two main components: an optimisation technique and a simulation model. The optimisation technique is an efficient implementation of an Estimation of Distribution Algorithm designed to solve the QCSP (Expósito-Izquierdo, González-Velarde, Melián-Batista, and Moreno-Vega, 2013). Furthermore, the simulation model of the decision support system is implemented using a process-oriented Java-based discrete-event simulation library (PSIGHOS), developed by the Simulation Group at the Universidad de La Laguna (Castilla, García, and Aguilar, 2009).

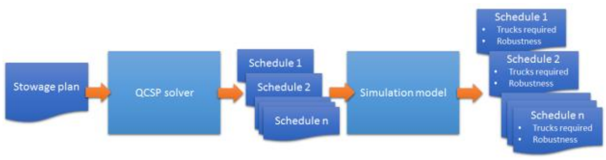


Figure 1. Basic schema of the decision support system

3.1. Optimisation technique

As indicated in the introduction of the paper, the QCSP has received a great deal of attention of the scientific community. In particular, one of the most competitive optimisation techniques to solve the QCSP so far is the Estimation of Distribution Algorithm proposed by Expósito-Izquierdo, González-Velarde, Melián-Batista, and Moreno-Vega, 2013. Broadly speaking, it is a meta-heuristic technique based on the principles of probability theory. In the case of the QCSP, this technique uses a probabilistic learning model to record statistical information about the search space, in such a way that the probability of performing a given task by means of a quay crane depends on the quality of the previous solutions in which this assignment has appeared.

Unfortunately, up to now the QCSP has been only addressed in the literature from a deterministic point of view, where no uncertainty of the environment is considered. In practice, a wide range of uncertainty sources affects the transshipment operations. Some of these are the individual productivity of the crane drivers, the changing arrival of the container vessels, and the availability of internal delivery vehicles, among others. In fact, one of the main unrealistic assumptions considered by previous authors relates to the full availability of internal delivery vehicles. Specifically, the works in the literature consider that there are always enough internal delivery vehicles to support the needs of the quay cranes assigned to the incoming container vessel. Therefore, each quay crane obtains a steady flow of containers.

3.2. Simulation model

Discrete-event simulation (DES) is a widespread simulation paradigm, especially common in the engineering field. DES is based on identifying the most relevant "milestones" that make the system state to change, i.e., the events. The most basic DES engine simply handles a time-ordered list of events by going through each event, updating a global simulation clock, and executing the actions associated to the event (which may include the creation or cancellation of future events) (Pidd, 2004). Although the "event worldview" is a flexible and mathematically robust conceptual framework, many problem statements benefit from a higher-level approach, such as that based on modelling the behaviour of the system as a set of interacting processes (Balci, 1988).

PSIGHOS (Castilla, García, and Aguilar, 2009) adheres to this process-oriented worldview, and allow a modeller to structure a real system in terms of "processes" and its atomic steps ("activities"). This approach makes easier the management of simulated resources (either human or material).

The designed discrete-event simulation model focuses on the quay cranes as the main entities of the system. Each quay crane starts at a specific position and has an associated process, comprising movements among adjacent bays and transshipment operations. The process is built from the schedule reported by the optimisation technique previously described when solving a QCSP instance.

The simulation model requires some additional adjustments and time parameters with respect to the QCSP solver. First, *tasks*, as defined by the QCSP solver must be divided into single transshipment operations, since every one requires a delivery operation to be completed. Each transshipment operation is assumed to last one time unit. Travel time, *i.e.*, the time that a quay crane spends moving from one bay to an adjacent one, is assumed to be equal to the operation time. Finally, delivery time, *i.e.*, the time that an internal delivery vehicle spends bearing the container to the yard and coming back to the incoming vessel, is assumed to be proportional to the operation time and can be set to any value K = {1, 2, 3, …}.

The simulation model includes some of the factors that affect crane performance:

- Interferences among quay cranes are included by explicitly modelling the physical position of the cranes. Each position represents a bay of the vessel, and is treated as a resource to avoid collisions among quay cranes. A crane can only move from one bay to an adjacent one as a single step of the workflow.
- Internal delivery vehicles are also treated as resources. In order to start a transshipment operation, the quay crane must be placed at the correct bay and seise an available delivery vehicle. Once the operation has finished, the vehicle moves to the yard and, after storing/retrieving the incumbent container, returns to the vessel and becomes available again.

We assessed the validity of the simulation model by checking that it was able to accurately reproduce the schedule of the optimisation technique, thus obtaining the same result.

The simulation model serves two different purposes. Firstly, it allows the decision-maker to estimate the minimum amount of internal delivery vehicles *dv* required to achieve the theoretical performance of the schedule reported by the optimisation technique. It is worth recalling that this estimation assumes deterministic duration of the tasks. The second purpose is to estimate the robustness of the solutions with respect to the variability of the estimated duration of tasks. We assigned a uniform error *e* to each time parameter *pt* (*i.e.*, transshipment operation, travel time, and delivery time). For each pair <stowage plan, number of delivery vehicles>, we replicated *k* times the simulation and collected the percentage of solutions below (or equal to) the deterministic result.

4. RESULTS

We analysed the decision support system for the instance represented in Figure 2. This instance defines a 21-bay container vessel requiring to perform 533 transshipment tasks. There are three quay cranes available to perform these tasks.

First, we run the QCSP solver, which obtained a set of feasible solutions. We took the best of those solutions to continue with the simulation analysis (Figure 3). Although the solution incorporates some potential interferences among cranes, they are distant enough in the time schedule so to result almost negligible. Hence, we would only expect delays in the schedule due to the unavailability of internal delivery vehicles.

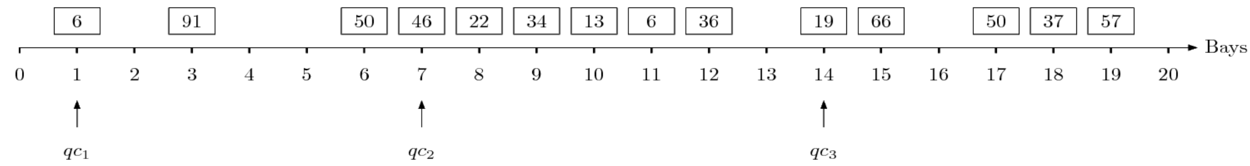


Figure 2. Tasks in the vessel. Each box represents a set of # load/unload tasks to be performed in this bay

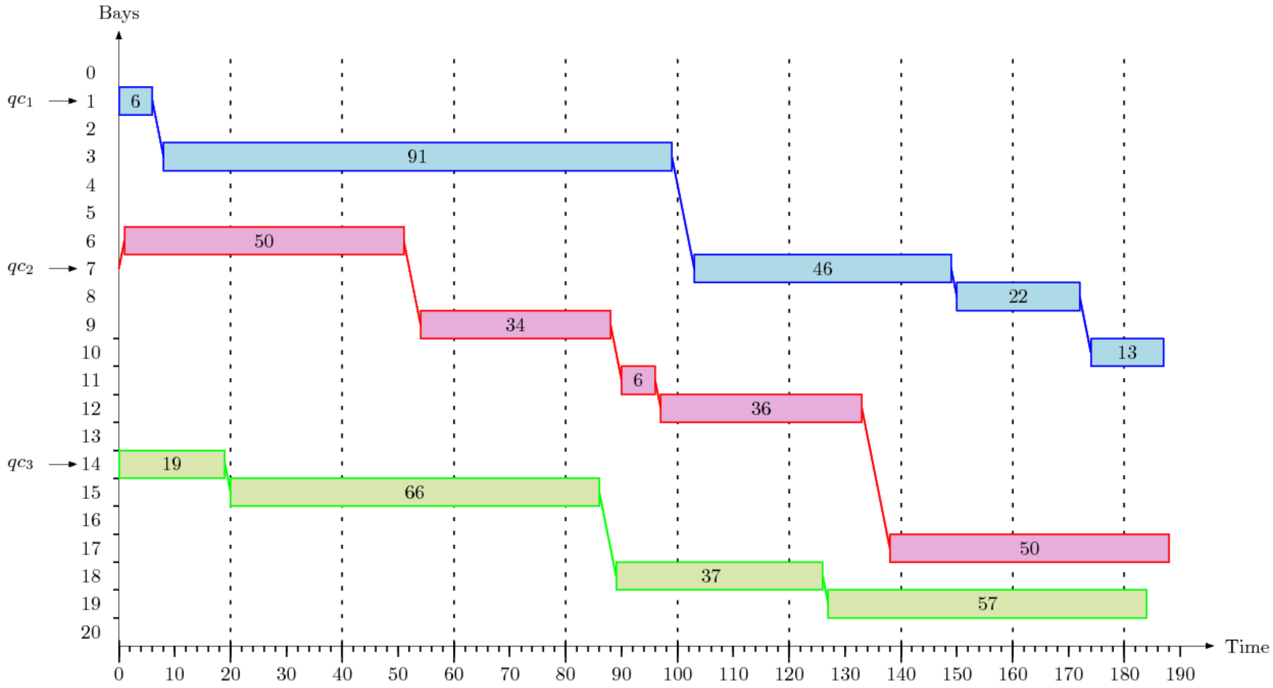


Figure 3. Best schedule reported by the QCSP Solver

Figure 4 shows a simplified schema of the simulation model obtained for the schedule of the first crane in the solution from the QCSP solver. Actually, the simulator splits "Transshipment Task 6" and "Transshipment Task 91" into a set of individual transhipment operations, each one lasting one time unit, and every one requiring a delivery vehicle.

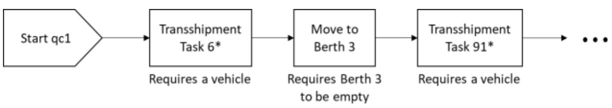


Figure 4. Simplified simulated process for quay crane 1

Table 1 summarises the main parameters set in the simulation analysis. We assumed the delivery time to be three times the operation time. Consequently, the whole load/unload operation takes 4 TUs.

In order to estimate the optimum amount of internal delivery vehicles, we run the simulation model for *dv = 1 to 16*. As seen in Figure 5, the case study requires at least 12 delivery vehicles to achieve the best solution posed by the QCSP solver (the dashed line). As it is expected, adding more vehicles does not provide any further reduction in the objective time.

Table 1: Main parameters of the simulation experiments

Parameter	Value
# Quay cranes	3
# Transshipment operations	533
# Bays	21
Operation time	1 TU
Delivery time	3 TUs
Travel time	1 TU
Percentage error for probabilistic analysis	25%
Replications per simulation experiment	500

TU: Time Unit

We observed the robustness of the solutions after adding a 25% uncertainty. Table 2 presents both the objective time and the average busy time of the quay cranes. The latest is an estimation of how balanced is the workload among cranes.

Table 2: Results of the Probabilistic Simulations

	Objective time			% average busy time of quay cranes	
# Delivery vehicles	Deterministic	Probabilistic (average [CI 95%])	Robustness	Deterministic	Probabilistic (average [CI 95%])
1	2129	2120.41 [2098.40, 2141.97]	80.60%	8.79%	8.75% [8.63, 8.85]
2	1065	1059.78 [1048.99, 1070.85]	83.40%	17.58%	17.51% [17.25, 17.73]
3	709	706.59 [699.28, 713.87]	76.40%	26.33%	26.26% [25.91, 26.60]
4	533	530.75 [525.26, 536.33]	81.40%	35.11%	35.04% [34.53, 35.49]
5	426	425.84 [421.27, 429.98]	54.00%	43.91%	43.70% [43.08, 44.25]
6	355	356.33 [352.50, 359.84]	24.40%	52.74%	52.24% [51.49, 52.94]
7	305	307.58 [304.07, 311.08]	8.00%	61.29%	60.64% [59.70, 61.43]
8	267	271.66 [268.53, 275.40]	0.00%	69.96%	68.77% [67.80, 69.67]
9	240	244.29 [241.18, 247.53]	0.00%	78.18%	76.53% [75.41, 77.48]
10	218	223.56 [220.04, 227.30]	0.00%	86.40%	83.66% [82.67, 84.64]
11	202	208.15 [205.08, 211.48]	0.00%	93.80%	89.99% [88.97, 91.02]
12	188	196.79 [194.00, 200.25]	0.00%	100.00%	95.18% [94.34, 95.98]
13	188	190.19 [187.02, 193.65]	9.60%	100.00%	98.50% [97.95, 99.02]
14	188	187.67 [184.67, 191.11]	63.00%	100.00%	99.80% [99.62, 99.95]
15	188	187.30 [184.09, 190.78]	69.80%	100.00%	99.99% [99.96, 100.00]
16	188	187.29 [184.09, 190.78]	70.00%	100.00%	100.00% [100.00, 100.00]

Det,: Deterministic

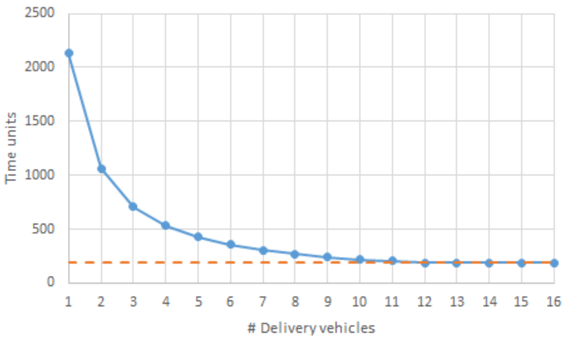


Figure 5. Results of the deterministic simulations

When a reduced number of vehicles is used, the objective time is high but it presents a remarkable robustness. These are configurations where there is a considerable room to improve the deterministic solution.
For solutions with a number of vehicles slightly lower or equal to (|QC| * 4), we find a robustness of 0%. The rationale behind this behaviour relies on two main aspects:

1. There is less room to improve the deterministic solution, since quay cranes are busier and objective value is closer to the optimum.
2. Any small discrepancy between the deterministic length of a task and its probabilistic value leads to a desynchronising pace. If a task lasts for more time than expected, there will be delays that will affect the whole schedule. Even more, if a task lasts for less time than expected, a crane will be preempting a delivery vehicle over another crane that is finishing its own tasks. Because we have less delivery vehicles than those expected to achieve the optimum (dv ≤ (|QC| * 4), this pre-emption prevents the simulated system to achieve the deterministic result.

When we assign more delivery vehicles than those stated in the deterministic analysis, the robustness improves until all the cranes are completely busy.

5. CONCLUSIONS AND FURTHER RESEARCH

The present paper introduces a decision support system that integrates an approximate optimisation technique and a simulation model to address the Quay Crane Scheduling Problem. This hybrid approach allows the decision-maker to estimate the minimum amount of internal delivery vehicles required to achieve the theoretical performance of schedules of the transshipment operations and to estimate the robustness of these solutions with respect to the variability of the estimated duration of tasks.
We have presented an example of the use of this system with a single QCSP solution. Dealing with multiple solutions is straightforward.
Although we have presented a synthetic case study, both the optimisation and simulation approaches are very flexible, and would allow a much more detailed specification of the optimisation problem. Indeed, the simulation model might include different specifications for quay cranes and internal delivery vehicles;

unexpected perturbations (*i.e.*, accidents, adverse meteorological conditions…); different strategies for the assignment of internal delivery vehicles to tasks, among others.

The simulation model described in this paper can handle non-null safety distances when reproducing the deterministic case. However, it is worth mentioning that when adding a probabilistic error, unexpected interferences among cranes might produce deadlocks in some realistic scenarios. Handling these deadlocks require providing the simulator with a number of decision rules. The application of these rules would result in a rescheduling, what is out of the scope of this work, but it is an interesting line to explore in further research.

ACKNOWLEDGMENTS

This work has been partially funded by the Spanish Ministry of Economy and competitiveness (TIN2015-70226-R) with FEDER funds.

REFERENCES

Balci O., 1988. The implementation of four conceptual frameworks for simulation modeling in high-level languages. In Proceedings of the 20th conference on Winter simulation - WSC ’88, pages 287–295, New York, ACM Press.

Bierwirth C., Meisel F, 2015. A follow-up survey of berth allocation and quay crane scheduling problems in container terminals. European Journal of Operational Research 244 (3):675-689

Boysen N., Emde S., and Fliedner M, 2012. Determining crane areas for balancing workload among interfering and noninterfering cranes. Naval Research Logistics, 59 (8):656–662

Castilla, I., García, F.C., Aguilar, R.M., 2009. Exploiting concurrency in the implementation of a discrete event simulator. Simulation Modelling Practice and Theory 17, 850-870

Chao, S., Lin, Y., 2011. Evaluating advanced quay cranes in container terminals. Transportation Research Part E: Logistics and Transportation Review 47, 432-445

Chung S.H., Chan F.T.S., 2013. A workload balancing genetic algorithm for the quay crane scheduling problem. International Journal of Production Research, 51 (16): 4820–4834

Expósito-Izquierdo, C., González-Velarde, J.L., Melián-Batista, B., Moreno-Vega, J.M., 2013. Hybrid Estimation of Distribution Algorithm for the Quay Crane Scheduling Problem. Applied Soft Computing 13, 4063-4076

Gunter H. O., Kim K. H., 2006. Container terminals and terminal operations. OR Spectrum, 28:437–445.

Lee D.H., Chen J.H., 2010. An improved approach for quay crane scheduling with non-crossing constraints. Engineering Optimization, 42 (1):1–15

Legato P., Trunfio R., Meisel F., 2012. Modeling and solving rich quay crane scheduling problems. Computers & OR 39(9):2063-2078

Lu Z., Han X., Xi L., Erera A.L., 2012. A heuristic for the quay crane scheduling problem based on contiguous bay crane operations. Computers & Operations Research, 39 (12):2915–2928

Pidd M., 2004. Computer Simulation in Management Science. Chichester, UK.

Tang L., Zhao J., and Liu J., 2012. Modeling and solution of the joint quay crane and truck scheduling problem. European Journal of Operational Research, 236 (3):978–990

Unsal O., Oguz C., 2013. Constraint programming approach to quay crane scheduling problem. Transportation Research Part E: Logistics and Transportation Review, 59 (0):108–122

Vis I.F.A., Anholt R.G., 2010. Performance analysis of berth configurations at container terminals. OR Spectrum, 32 (3):453–476

AUTHORS BIOGRAPHY

Iván Castilla-Rodríguez is assistant professor at the Departamento de Ingeniería Informática y de Sistemas at the Universidad de La Laguna. He obtained his degree in Computer Engineering and his PhD on Modelling and Simulation at the same university. He has worked for the Canarian regional health service by developing economic models for health technology assessment, and is currently applying modelling and simulation to several domains, including harbour, industrial optimisation and healthcare among others.

Christopher Expósito-Izquierdo is engineering in Computer Science and has obtained his PhD on the optimisation of the transshipment operations in maritime container terminals at the Universidad de La Laguna. He is nowadays researcher at the Departamento de Ingeniería Informática y de Sistemas of the Universidad de La Laguna, in which his activity is mainly dedicated to the analysis and optimisation of logistic operations and transportation, especially focused on maritime container terminals.

Rosa M. Aguilar-Chinea received her MS degree in Computer Science in 1993 from the University of Las Palmas de Gran Canaria and her PhD degree in Computer Science in 1998 from the Universidad de La Laguna. She is full professor at the Departamento de Ingeniería Informática y de Sistemas, Universidad de La Laguna. Her current research interests are decision making based on discrete event simulation systems and knowledge-based systems, intelligent agents, and intelligent tutorial systems.

Belén Melián-Batista received her MSc degree in Mathematics in 1999 and her PhD degree in Computer Science in 2003, both at the Universidad de La Laguna. She has a large amount of international publications focused on the analysis and improvement of logistic operations and transportation by applying optimisation techniques. She is nowadays associate professor in the

Departamento de Ingeniería Informática y de Sistemas at the Universidad de La Laguna, where she lectures subjects related to artificial intelligence, optimisation, and data mining, among others.

J. Marcos Moreno-Vega received his MSc degree in Mathematics in 1990 and his PhD degree in Computer Science in 1997, both at the Universidad de La Laguna. Nowadays, he is an Associate Professor at the Departamento de Ingeniería Informática y de Sistemas, Universidad de La Laguna, in the area of Computer Science and Artificial Intelligence. His research interests include soft computing, metaheuristics and data mining applied to logistic problems. In particular, he is interested in the optimisation techniques Tabu Search, Genetic Algorithms, Scatter Search, Path Relinking and Variable Neighborhood Search. Currently, he is involved in a research project devoted to develop an intelligent system for the management of the freight transportation in ports.

THE IMPACT OF RISKS ON THE DELIVERIES OF A LOGGING COMPANY: SIMULATION MODEL CASE STUDY

Peter Mensah[a], Yuri Merkuryev[b], Eric Klavins[c], Francesco Longo[d]

[a],[b]Riga Technical University, Department of Modelling and Simulation, 1 Kalku Street, Riga, LV-1658, Latvia
[c]Riga Technical University, Department of Computer Networks and System Technologies
[d]Modeling & Simulation Center, University of Calabria, Via P. Bucci, 87036, Rende, Italy

[a]peters.mensahs@rtu.lv, [b]jurijs.merkurjevs@rtu.lv, [c]eriks.kalvins@rtu.lv
[d]f.longo@unical.il

ABSTRACT

The supply chain today is vulnerable to risks that might affect the flow of materials, information and money anywhere between its upper and lower levels that could yield to a drastic loss in productivity, profitability as well as competitive advantages. Hence, it is vital for organizations to be agile and flexible enough to combat any form of risks that could be a threat to their success especially in deliveries. This paper therefore uses a case study approach to study and portray the effect of risks on the deliveries of a logging company. A simulation model is developed to represent the delivery process whereby the impact of the risks is discussed to raise awareness of uncertainties.

Keywords: supply chain, supply chain risks, deliveries, simulation model

1. INTRODUCTION

The essence of this article is to study and discuss the risks affecting the supply chain with reference to deliveries. By exploiting Simulink, a simulation model is developed utilizing both primary and secondary data obtained from a logging company and the government statistic office respectively. Risk variables are generated from the data and then used in the model to show how they affect deliveries in order to raise awareness of the logging company about uncertainties. The article is divided into three sections. The first section examines the supply chain and its overlapping definitions by various authors, whilst the second section considers the risk affecting the supply chain. The last section is a case study which is subdivided into the simulation model and the simulation results.

2. THE SUPPLY CHAIN

As various definitions have been given by different authors, in some cases with overlapping meanings of the supply chain, it is essential to take some of the definitions into consideration so as to grasp better understanding of the supply chain. According to Mensah and Merkuryev(2013), the supply chain is defined as 'a sequenced network of business partners involved in production processes that convert raw materials into finished goods or services in order to satisfy the consumers' demand'. In this case, various factors like the quantity and quality of products together with on time delivery are vital to sustain customers' satisfaction. From a more global point of view, LU (2011) highlights that the supply chain is a 'group of inter-connected participating companies that add value to a stream of transformed inputs from their source of origin to the end products or services that are demanded by the designated end-customers'. A shorter definition similar in meaning to the former is given by Cholette (2011), which states that it is 'a sequenced network of facilities and activities that support the production and delivery of a good or service'. From another perspective Croker (2003) defines the supply chain as the flow of materials, information and money between the upper and lower levels of the supply chain through a business network from the suppliers' suppliers to the customers' customers. Hence, taking figure 1 into consideration, the flow of information, materials and products is illustrated. In most cases, the customers can trail the origin of raw materials or products through barcodes. For example, after harvesting trees in a logging company, the logs are stamped with barcodes containing information about its origin, quantity and quality etc.

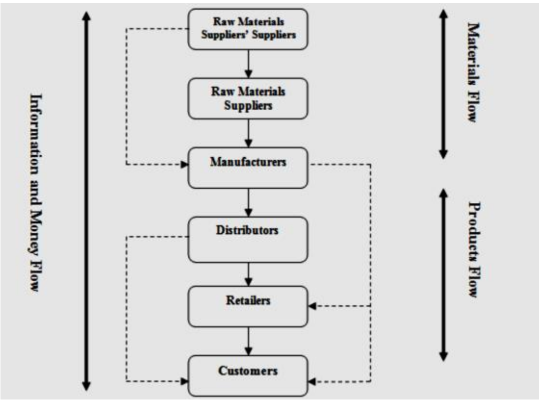


Figure 1: The Supply Chain (Mensah and Merkuryev, 2013)

These codes could be easily scanned by customers using their mobile phones or scanners to obtain appropriate pieces of information. Another example is in the gem industry where the diamonds are encrypted with codes so that their origin could be traced along the supply chain especially from areas with conflicts in order to avoid 'blood diamonds'. Figure 1 also portrays materials flow interchangeably between the suppliers' suppliers, likewise products between the manufacturers and customers.

Table 1: Supply Chain Definitions

Author(s)	Year	Definition of Supply Chain
Lu, D.	2011	...a group of inter-connected participating companies that add value to a stream of transformed inputs from their source of origin to the end products or services that are demanded by the designated end-customers...
Pienaar, W.	2009	...a general description of the process integration involving organizations to transform raw materials into finished goods and to transport them to the end-user...
Bridgefield Group	2006	...a connected set of resources and processes that starts with the raw materials sourcing and expands through the delivery of finished goods to the end consumer...
S, Cholette	2011	...a sequenced network of facilities and activities that support the production and delivery of a good or service...
Sunil, C., Meindl, P.	2004	...consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves. Within each organization, such as manufacturer, the supply chain includes all functions involved in receiving and filling a customer request...
Croker, J.	2003	...a total flow of materials, information and cash through a business network, all the way from the suppliers' suppliers to the customers' customers...
Tecc.com.au	2002	...a chain starting with raw materials and finishing with the sale of the finished good...
Ayers, J. B.	2001	...life cycle processes involving physical goods, information, and financial flows whose objective is to satisfy end consumer requisites with goods and services from diverse, connected suppliers...
Little, A.	1999	...the combined and coordinated flows of goods from origin to final destination, also the information flows that are linked with it...
Beamon B.	1998	...a structured manufacturing process wherein raw materials are transformed into finished goods, then delivered to end customers...

Looking back at the definitions of the supply chain, a tabular form is illustrated in table 1 with various definitions. This section has given a brief description of the definitions of the supply chain. The risks involved in the supply chain are considered next.

3. SUPPLY CHAIN RISKS

Uncertainties could lead to disruptions anywhere along the supply chain if not managed effectively in today's globalized and competitive world. In fact, Sheffi (2005) points out that organizations are now facing greater challenges in managing risks due to the increase in the number of threats that can undermine a supply chain. Furthermore, Christopher and Perk(2004) stress that the risks in supply chains increase as they become more complex due to global sourcing. This is evident in the Business Continuity Institute (BCI) report which states that 'business interruption and supply chain losses account for around 50-70% of all insured property losses, as much as $26bn a year for the insurance industry' with reference to the Allianz Risk Barometer (BCI 2014). Some of these risks in the supply chain are given below in bullet points, and if they are not managed accordingly, organizations could face a decrease in productivity, profitability and competitive advantages.

- adverse weather disruption
- natural disasters
- terrorism
- cyber attacks
- credit crunch
- shrinking product lifecycles
- volatile and unpredictable markets
- miscommunication
- deliveries/ transport disruptions etc.

A further study conducted by the BCI(2014) in 71 countries involving 519 organizations, shows a surprising result whereby, '75% of respondents still lack full visibility of their supply chain disruption levels, 55% of the respondents having their primary source of disruption as unplanned IT or telecom outages, 40 % of the respondents experienced adverse weather disruption and 37% of the respondents with outsourcer service provision failure'. When taking logging companies into consideration, they are quite vulnerable to natural disasters, weather disruptions, and transport disruptions. These could affect both harvesting and transportation, resulting in a delay in production and deliveries. Obviously, there would be an increase in lead time and decrease in profitability due to high costs. Risks could be managed by having a mitigation strategy, business continuity strategy or any other form of resilient strategy. In addition, Jansons et.al. (2016) specify that risks could be minimized by utilizing computer technology. However, Longo (2012) stresses the importance of using simulation as decision support tools to reduce risks and vulnerability whilst improving the supply chain management. Moreover, Merkuryeva and Bolshakov(2015), place emphases on the importance of simulation model when evaluating the performance of a system, whereas Klimov et. al(2010) point out that simulation processes can easily represent any network of the supply chain. Hence, by exploiting Simulink, a simulation model is developed in the next section to study the impact of risks on deliveries on the supply chain of a logging company.

4. CASE STUDY OF LOGGING COMPANY *X*

Company *X* is a logging company that harvests approximately 51% of country's *Y* forest. As it is a government company, it mainly uses a push strategy to inform its customers about the possible available products. Company *X* receives a quota with a five-year maximum allowable volume of trees, from the Ministry of Agriculture in country *Y*, it may cut down from the state forest. After tactical planning, Company *X* then decides on the volume to harvest on yearly basis to meet with the sustainable customer supply in each product group for the necessary sales. The sales are mainly conducted through negotiations and auctions depending on the type of agreement. Volumes are usually provided for negotiation for a three-year period and auctions for a six- month period two times a year. Having informed the customers about the available quotas and terms, the customers then place their orders, and if approved, planning is started which leads to the harvesting operations. Hence, forest harvesters, felling units and forwarders, cut, process and transport the logs respectively to the approximately 1000 warehouses located on roadsides in different areas of country *Y*. The local customers then receive their products by road whilst international customers receive theirs by sea on FOB basis. In order to keep transparent flow of information, an ICT infrastructure allows the machines and trucks to immediately send information concerning operations to the head office which in turn monitors operations. However, Company *X* faces challenges in harvesting and deliveries due to uncertainties mainly depending on weather conditions that leads to road closures and delays. For example, roads leading to the warehouses might not be accessible due to:

- damaged road
- heavy rainfall
- heavy snow
- foggy weather
- road works
- accidents

This case study focuses on how the risks affect deliveries and their impact on company *X* logging company. The percentage of yearly sales was obtained from company *X* from which sales were forecasted between the year 2017 and 2023. The actual sales figure in 2016 was included within the forecasted data and this brings it to a total of eight years data. The company actually planned to increase sales by 100,000 m^3 on yearly basis till 2023. This was verified by the supply chain manager of company *X*. Variables affecting deliveries and their coefficients, illustrated in table 2, were considered as road availability, car accidents, weather/precipitation and truck breakdown. The road availability coefficient was obtained from company *X*. On the other hand, the car accidents, weather/precipitation and truck breakdown coefficients were calculated from secondary data obtained from the government statistics office between 2011 and 2016.

Table 2: Variables affecting Deliveries and their Monthly Coefficients

Variables / Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Road availability	0.95	0.8	0.70	0.45	0.87	0.91	0.87	0.83	0.97	0.92	0.84	0.63
Car accidents	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Weather/precipitation	0.47	0.33	0.36	0.31	0.58	0.68	0.82	0.85	0.60	0.7	0.59	0.56
Truck breakdown	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

4.1. Simulation Model

By exploiting Simulink, a simulation model is developed as illustrated in figure 2. The yearly sales data was used as the input imported form an excel file to 'simulink_import.mat' as shown in figure 2. The variables (road availability, car accidents, weather/precipitation, and truck breakdown) receive input data from 'simulink_import.mat' supported up by the counter. The counter also inputs a vector indicating the number of months. The coefficients are used in the model as input interruptions in order to study how they affect deliveries. The output depicts the impact of the risks on deliveries namely the 'affected volume of logs by total risk' as well as affected volume on logs by road availability, car accidents and weather/precipitation risks.

4.1.1. Simulation Results

After running the model with eight years data and 200 simulation runs, the following results were obtained as illustrated in figure 3, which shows how the volume (m^3) of logs delivered by trucks to potential customers are affected by the total risks.

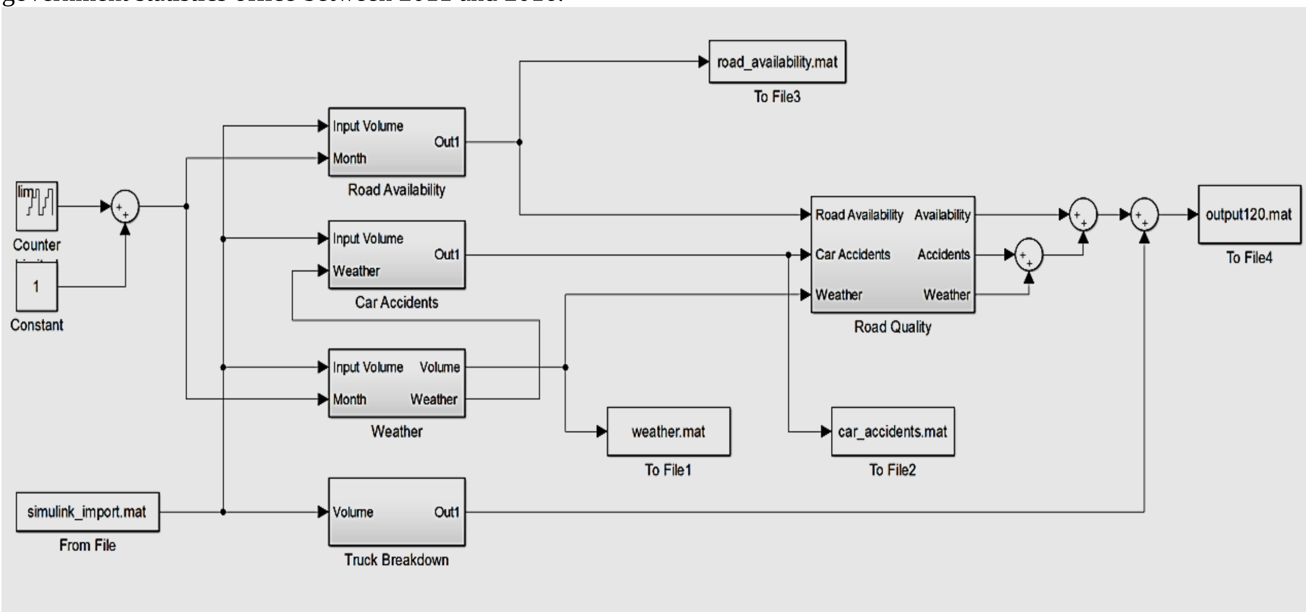


Figure 2: Simulation Model

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

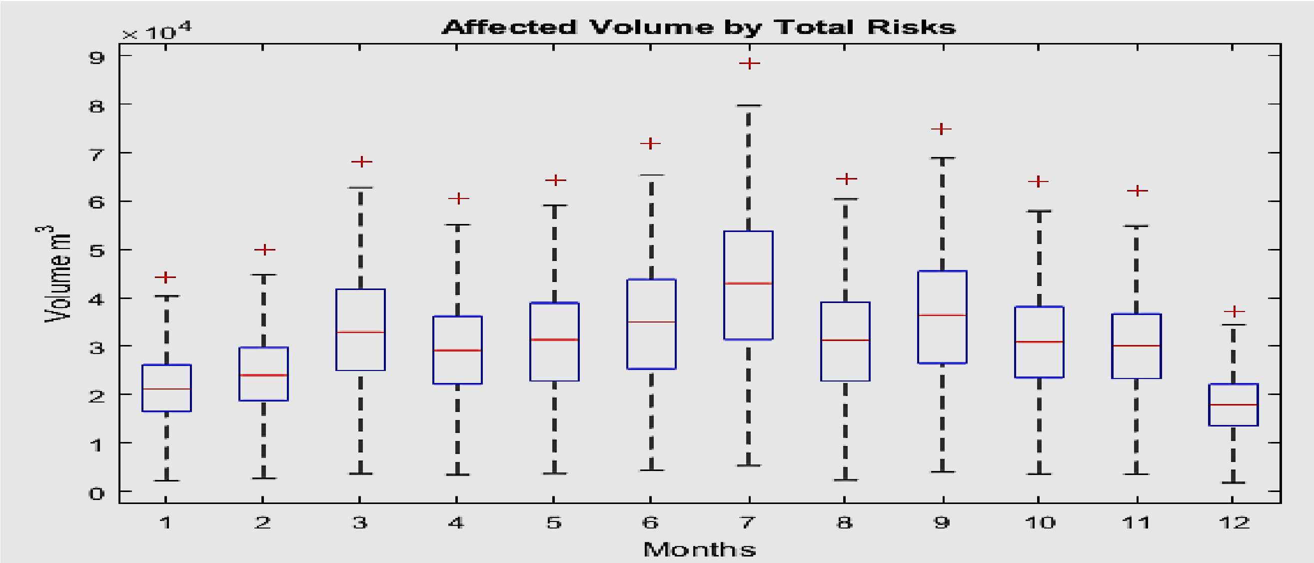


Figure 3: Simulation Results: Affected Volume (m^3) by Total Risks

The total risks is derived as the sum of all the risks, where;

- *T_r – total risk*
- *R_{ra} - road availability risk*
- *R_{rca} - car accidents risk*
- *$R_{rw/p}$ - weather/precipitation risk*
- *R_{rtb} - truck breakdown risk*
- *$C\_ R_{ra}$ - road availability coefficient*
- *C_R_{rca} - car accidents coefficient*
- *$C\_R_{rw/p}$ - weather/precipitation coefficient*
- *C_R_{rtb} - truck breakdown coefficient*
- *Iv - Input volume*

From the model;

- $R_{ra} = Iv * C\_ R_{ra}$
- $R_{rw/p} = Iv * C\_R_{rw/p}$
- $R_{rca} = (Iv * C\_R_{rca}) + R_{rw/p}$
- $R_{rtb} = Iv * C\_R_{rtb}$

Hence, the total risk is given as:

$$\boldsymbol{T_r = R_{ra} + R_{rw/p} + R_{rca} + R_{rtb}}$$

With reference to figure 3, the risks are divided into three parts, low, medium and high and they indicate the volume of logs (m^3) that could be affected in the delivery process between January and December. The impact of the risks will definitely increase the lead time due to delays and the customers might not be able to receive the ordered logs on time. The low risk is shown by the bottom ‘dash line’ just above zero with respect to the *y* axis. This indicates that there are almost no disturbances in deliveries as the risks are almost negligible. In other words, it shows the volume of logs that could be delivered to customers assuming the risks are negligible. However, when considering the medium risks level, indicated in the blue rectangle equally divided by a red line showing the average, there is a trend in the volume of trees to be delivered due to the risks. For example, it increases steadily from 21000 m^3 in January to 31000 m^3 in March. There is a slight drop in May followed by a slight increase but peaks at approximately 41000 m^3 in July. This is significant due to the rise in car accidents and unfavourable weather conditions yielding to a decrease in road availability as shown in figures 4, 5 and 6 respectively. Furthermore, there is a drop in the volume in August, but slightly increase in September before falling steadily with the lowest indicator in December (month 12) around 18000 m^3. Interestingly, the patterns of the low, medium and high risk levels affecting the volumes seem to be identical. The high risk level is indicated with the red plus (+) sign in figure 3. This is the worst scenario that could occur in case of uncertainties. The highest risk level affects approximately 90000 m^3 in July as a result of very high precipitation, car accidents yielding to very low road availability. This is a disaster, as 90000 m^3 may be delayed July and this might lead to higher costs and dramatic drop in profitability.

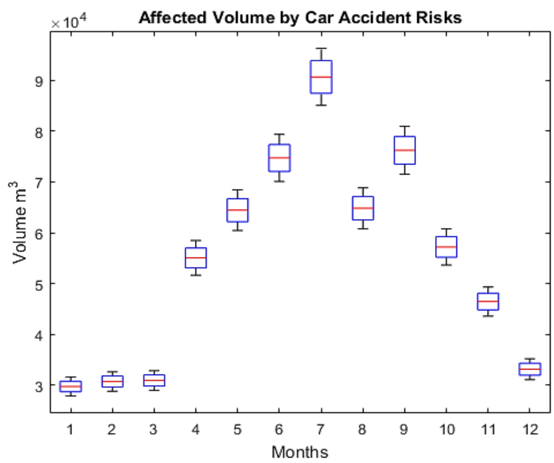


Figure 4: Affected Volume by Car Accidents Risks

Between 2011 and 2016, car accident historical data was obtained from the government statistics office. The coefficient of car accident risk *($C\_R_{rw/p}$)* was obtained from the mean of car accident data with respect to the average number of cars with the same time period.

Hence, the car accident risk is the product of the data input, and its coefficient is given as, $R_{rca} = (Iv* C\_R_{rca}) + R_{rw/p}$. The affected volume by car accident risks displayed in figure 4, is derived from the display '*To File 2*'of the simulation model, figure 2. Figure 4 shows the way car accidents can affect deliveries. For example, in January, 30000m^3 of logs could be delayed or not delivered due to accidents. January to March is marked as car accidents at their minimum. This is followed by a dramatic increase from April and continues rising until it peaks at 90000 m^3 in July. Furthermore, there is a drop to approximately 65000m^3 in August which unexpectedly jumps to 76000 cm^3 in September before falling steadily till December at almost 35000m^3.

Figure 5 illustrates the effect of weather/precipitation risks on volumes of logs. Interestingly it has a trend similar to that of the car accident risks. This clearly shows that adverse weather conditions contribute greatly to car accidents. As indicated earlier, the weather/precipitation risks is given as $R_{rw/p} = Iv* C\_R_{rw/p}$. The coefficient was calculated as the average monthly precipitation 2011 and 2016 (obtained from the government statistics office) with respect to the arear covered which is 0.77%of the total area of country *Y*. December, January, February and March put the impact of adverse weather condition at low. However, a significant increase is experienced in April that continues to rise until it peaks at 450000m^3 in July. This indicates that, approximately 450000m^3 of logs might be delayed or not be delivered in July. The trend between August and December is quite similar to the trend pattern of figure 4.

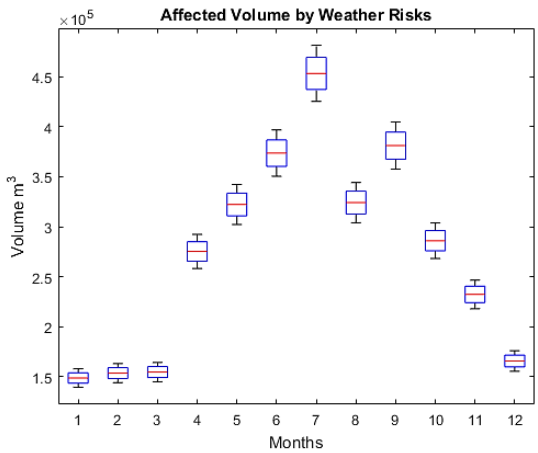


Figure 5: Affected Volume by Weather Risks

The road availability is enforced by the government as a strategy to protect the roads from damages caused by heavy trucks. As a result, the coefficient (as shown in table 2) was obtained from the government statistics office by the company's supply chain manager. The road availability risks was derived as $R_{ra} = Iv* C\_ R_{ra}$. After 200 simulation runs with respect to eight years data, the road availability risks in figure 6 was obtained from the display *'To File3'* of the simulation model in figure 2. Figure 6 shows that the road is available to a specific volume of logs through the whole country. For example, in January, approximately 60000 m^3 is the total volume of logs allowed to be transported by trucks in the country as a whole. The simulation runs show March as the month with the highest volume of logs allowed to be transported by trucks.

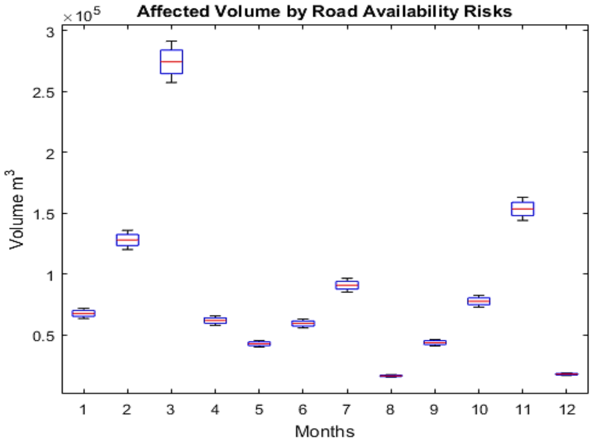


Figure 6: Affected Volume by Road Availability Risks

The truck breakdown risks were derived as *Rrtb = Iv* C_Rrtb.* The coefficient was obtained through assumptions after consulting the supply chain manager; this include data of the average truck breakdown with respect to the average number of trucks between 2008 and 2016.

5. CONCLUSION

The supply chain and its risks have been analysed theoretically and then applied practically in a case study exploiting a logging company. Eight years forecasted data generated which was verified by the supply chain manager of company *X*, and the coefficients of variables were the input. These variables that could affect the deliveries of the input data to the customers were given as R_{ra} - *road availability*, R_{rca} - *car accidents*, $R_{rw/p}$ - *weather/precipitation and* R_{rtb} - *truck breakdown.* These are all interdependent and contributed to the affected volume by total risks in figure 3. After running the simulation model with 200 simulation runs, the results showed three levels of volume of logs affected by risks. The levels are low, medium and high with almost identical patterns. Interestingly, the highest risk occurred in July for all three categories of risks and they were obviously affected by the variables in figures 4, 5 and 6. Hence, this model could be used as a managerial tool for decision making processes in the deliveries of a logging company.

Further Research:

Although it has been recommended that the model could be used for decision making processes, a further research is still needed to combat uncertainties more effectively, and to develop a resilient strategy for company *X* to be able to bounce back and start operations in the shortest possible time after disruptions in deliveries.

REFERENCES

Ayers, J. B., 2001. APICS Series on Resource Management. Handbook of Supply Chain Management, The Saint Lucie Press, Boca Raton, Florida.

Beamon, B., 1998. Supply Chain design and analysis: Models and methods. Available at: http://www.damas.ift.ulaval.ca/~moyaux/coupfouet/beamon98.pdf, 05.01.2013.

Bridgefield Group Erp Supply Chain (SC) glossary, 2006. Bridgefield Group. Available at: http://bridgefieldgroup.com/bridgefieldgroup/glos7.htm#P, 03.01.2013.

Cholette, S,. 2011. Sustainable Supply Chain, Basics Decision Sciences, San Francisco State University USA.

Christopher, M., Peck, H., 2004. Building the Resilient Supply Chain. International Journal of Logistics Management, 15, pp.1-13.

Croker, J., 2003. The supply chain. Increasing value through process involvement. Available at: http://www.clermiston.com.au/Documents/Supply%20Chain%20Increasing%20Value%20Process%20Imp%20JRC%20Handout%202x.pdf, 05.01.2013.

Jansons, V., Didenko, K,. Jurenoks V., Zarina, I. (2016) Computer Realization of Algorithms for Minimisation of Financial Risks. Second International Conference on Systems Informatics, Modelling and Simulation, SIMS 2016. Riga, Latvia, 1-3 June 2016. Edited by David Al-Dabass, Yuri Merkuryev, Andrejs, Romanovs, Galina Merkuryeva. IEEE, 2016. P. 161-166.

Klimov, R., Merkuryev, Y., Tolujev, J., 2010. A Theoretical Framework for a Simulation-Based Analysis of Supply Chain Risk Management. Managing Risk in Virtual Enterprise Networks: Implementing Supply Chain Principles, IGI Global, pp. 162-182.

Little, A., 1999. A European Supply Chain Survey. Available at: http://www.adlittle.be/insights/studies/pdf/european_supply_chain_survey.pdf, 05.01.2013.

Longo, F., 2012. Sustainable supply chain design: an application example in local business retail. Transactions of the Society for Modelling and Simulation International. Available at: http://intl-sim.sagepub.com/content/88/12/1484.abstract 10.01.2013.

Lu, D., 2011. Fundamentals of supply chain. Dawel Lu and Ventus Publishing Aps. Available at: http://www.tutorsindia.com/document/management-organisation/fundamentals-of-supply-chain-management.pdf, 05.01.2013.

Pienaar, W,.2009. Introduction to Business Logistics, Southern Africa, Oxford University.

Mensah, P., Merkuryev, Y., 2013. The role of ICT in the supply chain resilience, Proceedings of the 6-th International Conference on Applied Information and Communication Technologies (AICT2013), pp. 129-135. April 25-26, Jelgava, Latvia.

Merkuryeva, G., Bolshakov, V. 2015. Simulation-Based Fitness Landscape Analysis and Optimisation of Complex Problems. Technological and Economic Development of Economy, Vol.21, Iss.6, pp. 899-916.

Sheffi, Y., 2005. Building a resilient SC. Supply chain strategy, Harvard Business Review, October, 1.

Sunil, C., Meindl, P., 2004. Supply chain management, Upper Saddle River, Pearson Prentice Hall.

Tecc.com.au., 2002. Available at: http://www.tecc.com.au/tecc/guide/glossary.asp?letter=S, 05.01.2013.

The Business Continuity Institute, 2014. Supply Chain Resilience 3rd Annual Survey, The Business Continuity Institute, Caversham, UK.

AUTHORS BIOGRAPHY

PETER MENSAH has an MBA in Business Management, MSc in Computer Science, and is also a Cambridge CELTA qualified English language teacher. He is currently a lecturer in Management System Analysis, Corporate Social Responsibly and Organizational Behavior at Riga Technical University, Latvia. He is also an English Language tutor at Riga Business School, Riga, Latvia. He has also worked as a PSE tutor, and guest lecturer in areas of Project Management, Systems Thinking and Teaching and Learning from a Cultural Perspective' at Coventry University for the past five years. He is currently a PhD Candidate and a researcher at Riga Technical University, Department of Modelling and Simulation. He is interested in Supply Chain Resilient Strategy Simulation and Management. He has written several publications, and his research area is mainly in 'Using Simulation to Develop a Resilient Supply Chain Strategy'.

YURI MERKURYEV is a Professor and Head of the Department of Modelling and Simulation at Riga Technical University. He obtained the Dr.sc.ing. degree in System Identification in 1982, and Dr.habil.sc.ing. degree in Systems Simulation in 1997, both from Riga Technical University. His professional interests include modelling and simulation of complex systems, methodology of discrete-event simulation, supply chain simulation and management, as well as education in the areas of simulation and logistics management. Professor Merkuryev is Full Member of the Latvian Academy of Sciences, Fellow of the European Academy for Industrial Management, president of Latvian Simulation Society, board member of the Federation of European Simulation Societies (EUROSIM), senior member of the Society for Modelling and Simulation International (SCS), senior member of the Institute of Electrical and Electronics Engineers (IEEE), and Chartered Fellow of British Computer Society, FBCS CITP. He is an associate editor of "Simulation: Transactions of The

Society for Modelling and Simulation International", and editorial board member of "International Journal of Simulation and Process Modelling". He has authored/co-authored more than 340 scientific publications, including 8 books, as well as 6 textbooks.

ERIC KLAVINS graduated with a bachelor degree in computer science in 2010 and master degree in 2012 at Riga Technical University(RTU). He is currently a PhD student and works at RTU as researcher. His research includes Unmanned Aerial Vehicle control system, sensor fusion filters and sensor data processing techniques. He specializes in use of MATLAB and C/C++ programing languages for mathematical modeling and control system development on ARM processors. His PhD thesis main research is on UAV control system, which is independent to other external systems, in which one UAV without additional modifications can be used for both indoor and outdoor flights.

FRANCESCO LONGO graduated with a Masters degree in Mechanical Engineering, 'summa cum Laude', in October 2002 from University of Calabria, and a PhD in Mechanical Engineering from the same university in January 2006. He is currently the Director of the Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES), a laboratory operating at the Department of Mechanical, Energy and Management Engineeringof University of Calabria. Moreover, he is the General Co-Chair of the European Modeling & Simulation Symposium (EMSS 2008-2017) and Program Chair of the International Multidisciplinary Modeling & Simulation Multi-conference (2007 and 2008, 2011-2017). Furthermore, he actively cooperates with many research institutions worldwide including DIPTEM, University of Genoa, Kennedy Space Center, NASA (Cape Canaveral, USA), University of Ottawa (Canada), and Rutgers University (The State University of New Jersey). In addition, he lectures "Industrial Plants and Facilities" and "Industrial Plant Management" for Master Degree Students in Mechanical and Management Engineering. He was also the General Chair of the International Conference on Modeling & Applied Simulation (MAS 2009, 2010), Vice General Chair of Summer Simulation Multiconference (SummerSim2011) as well as the Program Chair of Summer Simulation Multiconference (2012 and 2013). He has published more than 150 scientific papers on international conferences and journals, and has also been a speaker and chairman in different international conferences. His research interests include Modeling & Simulation for production systems design and supply chain management. Since 2003, he has been working on private research projects involving manufacturing and logistics systems operating in Italy. He has acquired lots of experiences in consulting different areas of Business Process Re-engineering and Logistics.

VARIABLE-DEPTH ADAPTIVE LARGE NEIGHBOURHOOD SEARCH ALGORITHM FOR OPEN PERIODIC VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

Binhui Chen[(a)], Rong Qu[(b)], Hisao Ishibuchi[(c)]

[(a),(b)]School of Computer Science, The University of Nottingham, United Kingdom
[(c)]1) Department of Computer Science and Engineering, Southern University of Science and Technology, Shenzhen, China. 2) Department of Computer Science and Intelligent Systems, Osaka Prefecture University, Japan

[(a)]Binhui.Chen@nottingham.ac.uk, [(b)]Rong.Qu@nottingham.ac.uk ,[(c)]hisaoi@cs.osakafu-u.ac.jp

ABSTRACT
The Open Periodic Vehicle Routing Problem with Time Windows (OPVRPTW) is a practical transportation routing and scheduling problem arising from real-world scenarios. It shares some common features with some classic VRP variants. The problem has a tightly constrained large-scale solution space and requires well-balanced diversification and intensification in search. In Variable Depth Neighbourhood Search, large neighbourhood depth prevents the search from trapping into local optima prematurely, while small depth provides thorough exploitation in local areas. Considering the multi-dimensional solution structure and tight constraints in OPVRPTW, a Variable-Depth Adaptive Large Neighbourhood Search (VD-ALNS) algorithm is proposed in this paper. Contributions of four tailored destroy operators and three repair operators at variable depths are investigated. Comparing to existing methods, VD-ALNS makes a good trade-off between exploration and exploitation, and produces promising results on both small and large size benchmark instances.

Keywords: adaptive large neighbourhood search, variable depth neighbourhood search, open periodic vehicle routing problem with time windows, metaheuristic

1. INTRODUCTION
Vehicle Routing Problem (VRP) is a well-studied topic in Operational Research, and has a large number of variants. In the classic model of Vehicle Routing Problem with Time Windows (VRPTW) (Solomon 1987) starting from a depot, a fleet of vehicles visits a number of customers satisfying the time constraints. The depot and customers visited compose a *route* of a vehicle. The total demands on the route cannot exceed the vehicle's capacity. All vehicles have to return to the depot within the planning horizon (so called a *close route* (Hamilton Cycle) (Tarantilis et al. 2005)). The objective of VRPTW is to minimize the total cost of all routes (e.g., travel distance, and the number of vehicles used). Derived from various real-world problems, a large number of extended VRP models are proposed with various *Side Constraints* to VRPTW (e.g. driver working hour regulations, demand type, vehicle type and customer preference), or combined with other problems (e.g. inventory routing problem (Coelho, Cordeau and Laporte 2014)), while both exact approaches and heuristic algorithms are heavily studied (Toth and Vigo 2001).

1.1. Variants of Vehicle Routing Problem
The problem model in our study is related to three classical VRP variants. In Vehicle Routing Problem with Pickups and Deliveries (Golden et al. 2008), customers have pickup and delivery demands. Each vehicle picks up goods from a number of pickup points, then delivers them to the appointed destinations within the associated time windows. In *Less-than Truckload Transportation* problem, goods delivered can be consolidated; otherwise, it is a *Full Truckload Transportation* problem (Wieberneit 2008).

In Multi-Period Vehicle Routing Problem, the service to a customer could be performed over a multi-period horizon (Mourgaya and Vanderbeck 2007). Especially in grocery distribution, soft drink industry and waste collection, goods are delivered at a specified service frequency for customers over a multi-period horizon. In this so-called Periodic Vehicle Routing Problem (Eksioglu et al. 2009), the objective is to minimize the total cost of vehicles routing on all workdays servicing all customers.

To reduce cost, in practice many companies hire external carriers via third party logistic providers, instead of having their own fleet. Those hired vehicles do not return to the starting depot after completing the tasks, so all routes end at the last customers serviced. The routes are called *open routes* (Hamilton Paths instead of Hamilton Cycles) in Open VPRs, first proposed by Eppen and Schrage (1981).

1.2. Existing Methods
As a well-known NP-hard problem (Toth and Vigo 2001), VRPs have been investigated by a huge number of exact methods and heuristic algorithms. Exact methods guarantee optimality (Baldacci et al. 2012),

however, become unrealistic when solving larger scale real-world problems with complex constraints (El-Sherbeny 2010). Heuristic and Metaheuristic algorithms generate good approximations of optimal solutions in an acceptable computational time and have made great achievements in solving large-scale VRPs in the last three decades (Bräysy and Gendreau 2001).

Population-Based Metaheuristics evolve improved solutions in populations and have shown high-performance on problems such as multi-objective problems (Lourens 2005, Ghoseiri and Ghannadpour 2010). However, when facing high-dimensional complex solution structures and large problem size in real-world problems, they could be intractable. For the large scale and highly constrained problem in this study, we focus on single solution-based metaheuristics.

Single solution-based metaheuristics, by calling neighbourhood operators, explore only one new solution in each iteration. In Tabu Search (TS), specific solutions in a tabu list are forbidden to avoid cyclic search, and worse solutions within a certain extend are accepted to escape from a local optima trap. A TS is proposed for PVRPTW in (Cordeau et al. 2001), considering travel time, capacity, duration and time windows. TS has been widely applied to many applications in VRPs (Laporte et al. 2000).

Variable Neighbourhood Search (VNS) explores a solution space by changing neighbourhood structures systematically (Mladenoviċ and Hansen 1997). It has obtained good results on various optimization problems (Hansen et al. 2010) including OVRPTW (Redi et al. 2013). In Variable-Depth Neighbourhood Search (VDNS), one operator is used, but at variable neighbourhood depths. It is widely applied in *Very Large Scale Neighbourhood search* (Pisinger and Ropke 2010). Chen et al. (2016) develop a combined VNS and VDNS with compounded neighbourhood operators for VRPTW and obtained a number of new best solutions for benchmark instances.

Large Neighbourhood Search (LNS) (Shaw 1997, 1998) applies *destroy operators* (removal heuristics) and *repair operators* (insertion heuristics) to remove and reinsert a number of customers/demands from the current solution, producing a new solution with a larger difference. Schrimpf et al. (2000) also propose a similar *Ruin & Recreate* scheme. Pisinger and Ropke (2007) introduce the Adaptive Large Neighbourhood Search (ALNS), which employs an LNS strategy with adaptive operator selection, to solve five VRP variants.

When traditional operators of small change (e.g. λ-opt, CROSS-exchange (Bräysy and Gendreau 2005)) are used to explore tightly constrained large neighbourhood, the search can easily stuck into local optima. LNS operators (*destroy & repair*) and ALNS efficiently conquer this weakness by introducing larger changes to the current solution, and produce promising results in a large number of problems compared to existing methods (Pisinger and Popke 2010; Laporte et al. 2010).

In (Azi et al. 2014), the operation depth of neighbourhood operators in the ALNS for VRPs with Multiple Routes changes. E.g., the Random Removal operator can randomly remove workdays, routes or customers from the operated solution. Note that each of the three different depths is used for only once by turn. More ALNS algorithms for practical VRPs can be found in (Ribeiro and Laporte 2012; Schopka and Kopfer 2016).

In this paper, we propose a Variable-Depth Adaptive Large Neighbourhood Search algorithm (VD-ALNS) for the Open Periodic Vehicle Routing Problem with Time Windows (OPVRPTW) (Chen et al. 2017). Inspired by the idea of systematically adjusting neighbourhood operators during the search in VNS and VDNS, the operation depth of LNS operators in our algorithm is variable.

2. PROBLEM MODEL

Based on a practical *Full Truckload Transportation* problem at the Ningbo Port, the second biggest port in China, Chen et al. (2017) propose an OPVRPTW model. A fleet of 100 identical trucks is available in the depot to complete container transportation tasks among nine terminals. The objective of this problem is to minimize the total unloaded travel distance of the fleet.

The problem is a Periodic VRP with a planning horizon of two to four days, each day has two shifts. One shipment request may contain a number of containers. At the beginning of a working day, the trucks leave the depot to complete a number of tasks of container pickup and delivery between terminals and return to the depot at the end of the day. In the middle of a workday, due to regulations of working hours on Labour Law, drivers working on the first (*Odd-Indexed*) shift of a day handover a truck to a driver working on the second (*Even-Indexed*) shift at a terminal. The terminal can be the first pickup point (source terminal) to the even-indexed shift driver or the last delivery point (destination terminal) to the odd-indexed shift driver. The routes in this problem are *open*, i.e. routes in odd-indexed shifts do not have to end at the depot, and routes in even-indexed shifts do not need to start from the depot.

We use the same problem model as (Chen et al. 2017). All tasks of transporting a container are represented as one *task node* including: loading the container into a truck at the source terminal, travelling from the source to the destination terminal, and unloading at the destination terminal. Therefore, the travel between two nodes is always unloaded travel, because the loaded travel has been packaged into the task nodes. In this *Open Periodic VRP with Time Windows*, one truck can carry only one container at a time for its capacity.

To connect the route of a truck from an odd-indexed shift to the following even-indexed shift, *Artificial Depots* are used in between on each workday. In one shift, every route starts from a *starting depot* and ends at a *termination depot*. The main notations used in this model are summarized in Table 1.

In Figure 1, a small example of one workday schedule (of two consecutive shifts) is presented. A fleet of five trucks completes 14 transportation tasks. The physical move of the truck in the top route is demonstrated on the right side, with a handover at the artificial depot from Shift 1 (odd-indexed) to the driver in Shift 2 (even-indexed). It is worth to note that, the second and third routes in Shift 1 and the third and fourth routes in Shift 2 are *empty routes*, which directly connect artificial depots and the physical depot. This means no task is completed on these routes. Notice that the cost of an empty route is not always zero, e.g. the cost of the fourth route in Shift 2 could be non-zero, due to the unloaded travel distance from the last destination of the fourth route in Shift 1 to the physical depot is not zero. The cost of empty route will be zero only if the connected artificial node actually represents the physical depot.

Table 1: The List of Notations

Input Parameters:	
K	Fleet size.
S	The set of time-continuous working shifts, which can be divided into odd-indexed shifts (S_{odd}) and even-indexed shifts (S_{even}).
$[Y_S, Z_S]$	Time window of shift s.
$N = \{0,1,2,\cdots,n\}$	Set of $n+1$ nodes. Each node represents a task except node 0 is the *physical depot*.
$[a_i, b_i]$	The time window for node i. The time window for a depot is zero at the boundary of a shift. If a truck arrives at the source of i early, it has to wait until a_i.
W	Set of *Artificial Depots*. This set of nodes are introduced to represent the destination terminals in S_{odd} or source terminals in S_{even} on each day, which is decided by if the associated trucks in S_{odd} can arrive at their terminals before the end of the shift. This set varies in different solutions, i.e. a physical terminal may not appear or may appear more than once in W.
A	Set of arcs. Each arc (i,j) represents that node j is immediately serviced/visited after servicing/visiting node i.
c_{ij}	The cost (distance) of unloaded travel from node i to node j. If the destination terminal of task i and the source terminal of task j is the same, $c_{ij} = 0$.
t_{ij}	The travel time from node i to node j. When both i and j are task nodes, t_{ij} is the travel time from the destination of i to the source of j. Otherwise, it is the travel time from or to a depot.
T_i	The arrival time at node i.
B_i	The time to begin the service of node i.
l_i	The time for servicing node i, which includes the loading time, transportation time (from pick-up source to delivery destination) and unloading time. The service time of a depot is zero.
Decision Variable:	
x_{ij}^s	A binary decision variable for nodes $i, j \in N \cup W$. Its value is 1 if arc (i,j) is included in the solution in shift s, otherwise is 0. i and $j \in W$ at the same time is not allowed

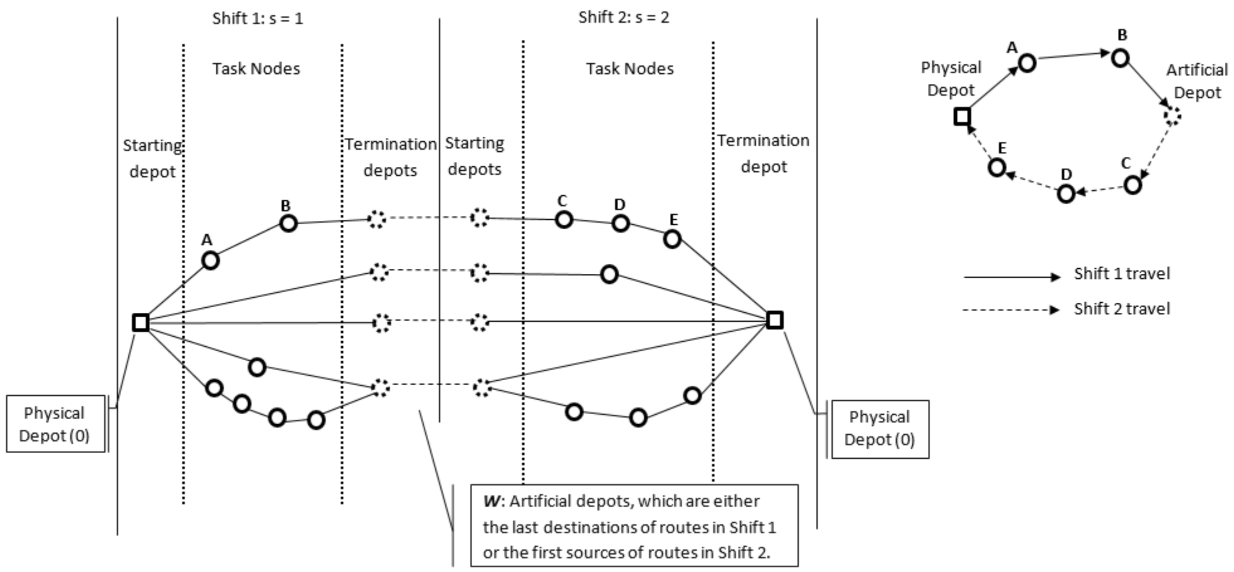


Figure 1： A scheduling example of two consequent shifts with five trucks.

This OPVRPTW problem can be formally defined as follows.

$$Minimise \quad \sum_{s\in S}\sum_{i\in N\cup W}\sum_{j\in N\cup W} c_{ij}\cdot x_{ij}^s \quad (1)$$

Subject to

$$\sum_{s\in S}\sum_{i\in N\backslash\{0\}} x_{ij}^s = 1, \quad \forall\, j \in N\backslash\{0\} \quad (2)$$

$$\sum_{s\in S}\sum_{j\in N\backslash\{0\}} x_{ij}^s = 1, \quad \forall\, i \in N\backslash\{0\} \quad (3)$$

$$\sum_{i\in N\cup W} x_{ij}^s = \sum_{f\in N\cup W} x_{jf}^s, \quad \forall j \in N\backslash\{0\}, s\in S \quad (4)$$

$$T_j = \sum_{i\in N\backslash\{0\}} \left(B_i + l_i + t_{ij}\right)\cdot x_{ij}^s + \sum_{i=\{0\}\cup W}\left(Y_s + t_{ij}\right)\cdot x_{ij}^s, \quad \forall j\in N\backslash\{0\}, s\in S \quad (5)$$

$$B_j = T_j + max\{a_j - T_j, 0\}, \quad \forall j\in N\backslash\{0\} \quad (6)$$

$$x_{ij}^s\cdot Y_s \le x_{ij}^s\cdot T_j, \quad \forall i\in\{0\}\cup W, j\in N\cup W, s\in S \quad (7)$$

$$x_{ij}^s\cdot(B_i + l_i) \le x_{ij}^s\cdot Z_s, \quad \forall i\in N\cup W, j\in\{0\}\cup W, s\in S \quad (8)$$

$$a_i \le B_i \le b_i - l_i, \quad \forall i\in N\backslash\{0\} \quad (9)$$

$$x_{ij}^s \in \{0,1\}, \quad \forall i,j\in N\cup W, s\in S \quad (10)$$

$$x_{vw}^s = 0, \quad \forall v\in W, w\in W, s\in S \quad (11)$$

In odd-indexed shifts ($\forall s \in S_{odd}$):

$$\sum_{j\in N\backslash\{0\}\cup W} x_{0j}^s = K, \quad \forall\, s\in S_{odd} \quad (12)$$

$$x_{i0}^s = 0, \quad \forall i\in N\backslash\{0\}\cup W, s\in S_{odd} \quad (13)$$

$$\sum_{i\in N}\sum_{w\in W} x_{iw}^s = K, \quad \forall s\in S_{odd} \quad (14)$$

In even-indexed shifts ($\forall s \in S_{even}$):

$$\sum_{j\in N} x_{jw}^{s-1} = \sum_{e\in N} x_{we}^s, \quad \forall w\in W, s\in S_{even} \quad (15)$$

$$x_{0j}^s = 0, \quad \forall j\in N\backslash\{0\}\cup \mathrm{W}, s\in S_{even} \quad (16)$$

$$\sum_{w\in W}\sum_{j\in N} x_{wj}^s = K, \quad \forall s\in S_{even} \quad (17)$$

$$\sum_{i\in N\backslash\{0\}\cup W} x_{i0}^s = K, \quad \forall s\in S_{even} \quad (18)$$

The objective of this problem (1) is to minimize the total unloaded travel distance. Constraints (2) and (3) denote that every task node can be visited exactly once, and all tasks are visited. Constraint (4) specifies that a task may only be serviced after the previous task is completed. Constraints (2) - (4) together make sure arcs of over more than one shift are unacceptable. Constraint (5) is the arrival time at a task node. Constraint (6) defines the beginning time of servicing a task node, calculated by the arrival time plus the waiting time at the source of the task. Constraints (5) and (6) enforce the correct successive relationship between consecutive nodes.

Constraints (7) and (8) are the time window constraints of each shift, while constraint (9) represents the time constraint on each task. The domain of the respective decision variable is defined by constraints (10) and (11). Constraint (11) prohibits the travel between two artificial depots.

In odd-indexed shifts and even-indexed shifts, the constraints for the start and termination depots are different. Constraints (12) and (14) represent that K trucks leave the physical depot 0 at the beginning of an odd-indexed shift, and they would stop at artificial depots at the end of the shift. Constraint (13) represents that no truck returns to the physical depot in odd-indexed shifts. Constraints (16) - (18) place the reverse restraints in even-indexed shifts. Constraint (15) defines the shift change from an odd-indexed shift to the following even-indexed shift on artificial depots, where the incoming of each artificial terminal in S_{odd} equals its outgoing in the following S_{even}.

It is easy to see that, this problem is highly constrained with an exponential growing search space ($|S|\cdot K\cdot n!$). It has been proofed that exact methods are not suitable to solve this problem due to the exorbitant computing requirement (Chen et al. 2017). To address the tightly constrained problems with large neighbourhood, a Variable-Depth ALNS algorithm (VD-ALNS) is proposed.

3. VARIABLE-DEPTH ADAPTIVE LARGE NEIGHBOURHOOD SEARCH

3.1. Framework of VD-ALNS

The framework of VD-ALNS is shown in ALGORITHM 1. An emergency-based construction heuristic (Chen et al. 2017) is firstly used to generate an initial solution by considering shifts chronologically, and assigning the tasks with higher emergency first. According to their time windows, those tasks that must be completed before the next shift will be assigned first. Starting from the initial solution, four destroy operators and three repair operators are then used to produce new solutions by modifying the current solution ($S_{current}$), pursuing solutions with higher quality.

$Weight$ and $Score$ in Step 1 are two scalars used to guide the subsequent search. Specifically, $Score_i$ records the contributions of operator i in solution improvement within a fixed number of iterations (so called a *Segment*). $Score_i$ is used to update the value of $Weight_i$, which determines the probability of operator i being adopted during search, in the next *Segment*. Their values are set as the same for all operators at the beginning, and then updated during the search. The algorithm iteratively explores the solution space until the Stopping Criterion is met, i.e. the quality of the best found solution (S) has not been improved in the last $UNIMPR_{MAX}$ iterations, or the improvement is less than 1% in the last $INCRE_{MAX}$ iterations.

In Step 2.1, $Depth$ is the range the operators work upon. It is systematically switched between the whole planning horizon ($HORIZON$) and a specified shift

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

($SHIFT$) to balance the exploration and exploitation. In Step 2.2, a pair of a destroy operator (D_i) and a repair operator (R_j) are used to generate a new solution (S').

Every single operator in ALNS has its own weight ($Weight_i$). However, a research issue here is whether an operator should be assigned two different weights for two different depths to separately record its contribution to improvement at depths $HORIZON$ and $SHIFT$, or only one weight is sufficient to record all previous contribution. In the literature, this question has been addressed in VNS and VDNS (Pisinger and Ropke 2010). Using two independent weights separately records knowledge collected during the search employing two independent operators at different depths, thus would prevent the knowledge collected at the other depth from being used. However, in our preliminary experiments, it is found that search experience at different operation depths can contribute and promote each other. In VD-ALNS, thus, we adopt one operator in both scenarios and record an operator's information with only one scalar.

ALGORITHM 1: Framework of VD-ALNS

Input: An initial feasible solution (S) generated by the construction heuristic in (Chen et al. 2017), Stopping Criterion, ITE_{MAX} and LEN_SEGMENT.

Step 1. Set up the initial parameters.
 $Weight \leftarrow \{1, \cdots, 1\}$.
 $Score \leftarrow \{0, \cdots, 0\}$.
 $S_{current} \leftarrow S,\ Depth \leftarrow HORIZON$.

Step 2.
 while Stopping Criterion is not met **do**
  Step 2.1 Variable-Depth Setting.
   if S is not improved in the last ITE_{MAX} iterations
    if $Depth = HORIZON$ **then**
     $Depth \leftarrow SHIFT$.
    else
     $Depth \leftarrow HORIZON$.
    end
   end
  Step 2.2 Operators Selection and Execution.
   Select a Destroy Operator (D_i) and a Repair Operator (R_j) based on $Weight$.
   Execute D_i and R_j at Depth, and obtain a new solution: $S' \leftarrow R_j(D_i(S_{current}))$.
  Step 2.3 Accept or Reject.
   A Record-to-Record Travel algorithm is employed to determine if the newly generated solution is accepted ($S_{current} \leftarrow S'$) or rejected. If the quality of S' is better than S, update the best-found solution $S \leftarrow S'$.
  Step 2.4 Weight Adjustment.
   The Scores of D_i and R_j ($Score_i$ and $Score_j$) are updated at every iteration according to the quality of S'.
   At every LEN_SEGMENT iteration, $Weight$ is updated based on the accumulated *Score*, *Score* is then reset.
 end

Output: An improved solution S.

A pair of operators is selected by *Roulette Wheel* based on the weights of operators in Step 2.2. The probability of an operator i being selected is calculated with Eq. (19), where h is the number of candidate operators.

$$Pr_i = \frac{Weight_i}{\sum_{k=1}^{h} Weight_k} \quad (19)$$

Step 2.3 decides if S' is accepted as new $S_{current}$ and S is updated, while Step 2.4 adjusts the scores and weights of operators according to the quality of S'. These adaptive weights guide the search to promising solution regions. More details are introduced in Sections 3.2 – 3.5.

3.2. Variable-Depth Setting

Variable search depth endows a balanced search performance. When $Depth$ is $SHIFT$, the destroy operators remove a number of nodes from one specified shift, while the repair operators reinsert them back into that shift. All the shifts are specified and checked sequentially. When $Depth$ is $HORIZON$, the removal and reinsertion happen within the whole planning horizon. Obviously, $HORIZON$ is a greater depth than $SHIFT$, and lead to a greater change in a solution, thus improves the diversification of search. Contrarily, using a $Depth$ of $SHIFT$ modifies routes in a single shift by locally optimizing the solution, thus increases the intensification of search.

$Depth$ is systematically switched to seek a trade-off between exploration and exploitation. Searching with smaller depth exploits a relatively smaller solution area intensively, while larger search depth avoids search trapping into local optima. In the proposed algorithm, $Depth$ would be switched to the other value when S is not improved in ITE_{MAX} iterations, to keep both the diversification and intensification in searching the large scale tightly constrained solution space.

3.3. Operators of Destroy and Repair

Four destroy operators and three repair operators are developed in our proposed VD-ALNS.

3.3.1. Destroy Operators

In each iteration, q nodes are removed by a destroy operator (Removal Heuristic). The value of q increases by 5 when the solution is not improved in the last iteration. As a too small q will hardly bring change to a solution, while a too large q will significantly increase repair operation time and the algorithm becomes a random search, a lower bound of $\max\{0.1n, 10\}$ and an upper bound of $\min\{0.5n, 60\}$ are set for q, where n is the total number of nodes.

1. *Random Removal*: The q nodes to be removed are randomly selected.
2. *Worst Removal*: This is a greedy heuristic, where the top q nodes causing the greatest cost will be removed. In other words, removing the q task nodes brings the greatest cost reduction to the solution.
3. *Worst Edge Removal*: This is also a greedy heuristic, which deletes q nodes adjacent to arcs of the highest cost.
4. *Related Removal*: Shaw (1997) proposes this operator based on the observation that, if nodes relate to one another are removed together, there would be an opportunity to interchange them in the later repaired solution. In VD-ALNS, we define the *Relatedness* of two task nodes (i and

j) from five aspects: Service Time (R_{ij}^{ST}), Time window (R_{ij}^{TW}), Service Starting Time (R_{ij}^{SST}), Vehicle used (R_{ij}^{V}) and Source and Destination (R_{ij}^{SD}) as follows.

$$R_{ij}^{ST} = \frac{|l_i - l_j|}{(l_i + l_j) \cdot 0.5} \quad (20)$$

$$R_{ij}^{TW} = \frac{0.5 \cdot (|a_i - a_j| + |b_i - b_j|)}{max\{b_i, b_j\} - min\{a_i, a_j\}} \quad (21)$$

$$R_{ij}^{SST} = \frac{|B_i - B_j|}{Length\ of\ Planning\ Horizon} \quad (22)$$

$$R_{ij}^{V} = \begin{cases} 0 & i\ and\ j\ are\ serviced\ by\ a\ same\ vehicle \\ 0.5 & i\ and\ j\ are\ servieced\ by\ different \\ & vehicles\ in\ the\ same\ shift \\ 1 & otherwise. \end{cases} \quad (23)$$

$$R_{ij}^{SD} = \begin{cases} 0 & i\ and\ j\ have\ the\ same\ source\ AND \\ & destination \\ 0.5 & i\ and\ j\ have\ the\ same\ source\ OR \\ & destination \\ 1 & otherwise. \end{cases} \quad (24)$$

Correspondingly, the relatedness of two task nodes (R_{ij}) is a linear combination of the five components above-mentioned (25). The values of the five linear coefficients are discussed in Section 4.2. In *Related Removal*, the first node to be removed is randomly selected, then the other nodes are sorted in ascending order of their relatedness R_{ij} to the first node.

$$R_{ij} = \alpha \cdot R_{ij}^{ST} + \beta \cdot R_{ij}^{TW} + \gamma \cdot R_{ij}^{SST} + \delta \cdot R_{ij}^{V} + \varepsilon \cdot R_{ij}^{SD}$$
$$(s.t.\ \alpha + \beta + \gamma + \delta + \varepsilon = 1) \quad (25)$$

The rest $q - 1$ nodes to be removed are selected with a preference of smaller R_{ij}, where the nodes with the index of $\lceil N\rho^D \rceil$ will be removed. Here, N is the number of the current candidate nodes, ρ is a random number between 0 and 1, and D is a constant greater or equal to 1. The greater D is, the stronger the preference would be, while D is set to 3 in VD-ALNS. This selection scheme with a preference has been widely used in ALNS methods (Ropke and Pisinger 2006; Prescott-Gagnon 2009; Azi et al. 2014).

3.3.2. Repair Operators

The nodes removed in the Destroy phase will be reinserted back into the solution following the below specific rules of each repair operator (Insertion Heuristic).

1. *Random Insertion*: The removed nodes are randomly inserted into feasible positions.
2. *Greedy Insertion*: The removed nodes are inserted into their best feasible positions causing the least cost increase.
3. *Regret2 Insertion*: This greedy insertion heuristic is proposed by Pisinger and Ropke (2007), which always inserts firstly the node of the largest *REGRET* value into its best feasible position. The *REGRET* of a node is the cost difference between inserting the node to its best and second best feasible positions.

3.4. Acceptance Criterion

Record-to-Record Travel acceptance criterion (Dueck 1993) is used to determine if the newly generated solution (S') is acceptable in the search. If S' is better than the best-found solution S (i.e. $COST(S') < COST(S)$), S' will be accepted as the current solution ($S_{current}$). A new solution worse than $S_{current}$ is still acceptable as long as the gap between their *COST* is less than a *DEVIATION* threshold (i.e. $0.01 \cdot COST(S)$).

3.5. Weight Adjustment

In each iteration, the employed operator i is rewarded a value $\sigma \geq 0$ based on the quality of the generated solution S' (see Eq. 26). The effect of σ is further studied in Section 4.2.

$$\sigma = \begin{cases} \sigma_1 & S'is\ accepted\ and\ COST(S') < COST(S) \\ \sigma_2 & S'is\ accepted\ AND \\ & COST(S) < COST(S') < COST(S_{current}) \\ \sigma_3 & S'is\ accepted\ AND \\ & COST(S_{current}) < COST(S') \\ \sigma_4 & S'is\ rejected \end{cases}$$
$$\text{s.t.} \quad \sigma_1 > \sigma_2 > \sigma_3 > \sigma_4 \geq 0 \quad (26)$$

After a fixed number ($LEN\_SEGMENT$) of iterations (a *Segment*), the total accumulated reward saved in $Score_i$ in the current *Segment t-1* is used to update the weight of operator *i* for the next *Segment t* (see Eq. (27)). In Eq. (27), the reaction factor r controls how quickly the adjustment scheme reacts. u_i is the number times operator i is used in *Segment* $t - 1$. After updating $Weight_i^t$, $Score_i$ will be reset to zero to start the accumulation of reward in Segment t.

$$Weight_i^t = r \cdot Weight_i^{t-1} + (1 - r) \cdot \frac{Score_i}{u_i} \quad (27)$$

4. EXPERIMENTS AND ANALYSIS

4.1. Benchmark

Bai et al. (2015) generate a dataset including 15 real-life instances extracted from the container transportation historical data at Ningbo Port, and 16 artificial instances with diverse features. The planning horizons are four, six and eight shifts in the real-life instances, and four or eight shifts in artificial instances, respectively. The artificial instances are classified and named by the tightness of the time windows (Tight/Loose) and workload balance at terminals (Balanced/Unbalanced). For example, the instance named NP4-1 is the first real-life instance with four shifts, and instance TU8-7 is the seventh artificial instance with eight shifts, tight time window and unbalanced workload at terminals.

The sizes of these 31 instances are large comparing to the classical VRP datasets (Solomon1987; Gehring and Homberger 1999). To test the effectiveness and efficiency of the proposed algorithms on small size instances, the Ningbo Port dataset is scaled down by

25%, while keeping the same features in Chen et al. (2017). We test our proposed VD-ALNS on both the original and scaled down datasets.

4.2. Parameter Sensitivity Analysis

Parameters in VD-ALNS are studied one at a time, fixing the other parameters. It is easy to understand that, higher $UNIMPR_{MAX}$ and $INCRE_{MAX}$ lead to more iterations in search, so might bring better solutions but at the cost of longer time. ITE_{MAX} represents the times of one $Depth$ value would be continuously used. The trade-off between the solution quality and running time needs to be considered to strike a balance between effectiveness and efficiency of the search. The values of parameters used in VD-ALNS are presented in Table 2.

Table 2: Parameters in VD-ALNS.

Parameter	σ_1	σ_2	σ_3	σ_4	$UNIMPR_{MAX}$	$INCRE_{MAX}$	ITE_{MAX}
Value	30	15	5	0	150	200	4*No. of shifts
Parameter	α	β	γ	δ	ε	r	*LEN_SEGMENT*
Value	0.3	0.2	0.1	0.2	0.2	70	0.4

In adaptive weight adjustment, the values of rewards represent the contributions in solution improvement. To obtain the best setting of reward values, σ_4 is set to zero, which indicates $Score_i$ stays the same when S' is rejected. Besides, σ_3 is set to 5 as a base unit. Different σ_1 and σ_2 are tested in parameter tuning experiments to find the setting generating the best solutions. It is observed that a too large σ_1 would cause premature search. The best solutions are obtained when the reward to producing a new best solution (σ_1) is two times of that of generating an acceptable solution better than $S_{current}$ (σ_2), and six times of that of obtaining an acceptable solution worse than $S_{current}$ (σ_3).

When tuning the definition of *Relatedness* (Eq. (25)), all the five components are firstly assigned equal weights ($\alpha = \beta = \gamma = \delta = \varepsilon = 0.2$). Then, each coefficient is gradually increased to reflect the contribution of the associated component to the total relatedness. It is found that when the weight of Service Time Relatedness (R_{ij}^{ST}) is high, the quality of solutions is higher. This indicates that reassigning two tasks with a higher similarity of Service Time leads to a higher possibility to produce a better solution. Since the Service Staring Time of a task may change for various reasons (e.g., a task is assigned to a new truck, and a precedent task is reassigned, etc.), R_{ij}^{SST} can hardly represent the relatedness of two tasks and shows low contribution in tuning tests. A lower coefficient is given to R_{ij}^{SST}.

A too small *LEN_SEGMENT* will change the weights of operators frequently and thus the search may converge prematurely. On the other hand, a large *LEN_SEGMENT* cannot update the guidance information in time. Our preliminary experiments show that the best performance is found when *LEN_SEGMENT* is between 50 and 80. In Eq. (27), the higher r is, the slower the algorithm reacts to the latest guidance information. VD-ALNS performs the best when r is between 0.4 and 0.6.

4.3. Comparison of Solution Algorithms

To demonstrate the contribution of variable depth, a standard ALNS for OPVRPTW is also implemented, where the Destroy and Repair operators are only used at the depth of *HORIZON* in global searching. Comparing to other metaheuristics using small change operators, both VD-ALNS and ALNS have a stronger ability to escape from local optima in a tightly constrained solution space. They are compared to VNS-RLS (Chen et al. 2017), which uses neighbourhood operators with small changes.

The comparison results on the 25% scaled down instances are presented in Tables 3 and 4. The three algorithms are compared from four aspects: best-found solution (Best), average solution (Ave), evaluation times (Times) and standard deviation (S.D.). All the results are obtained from 30 runs. In these results, we convert the objective value into Heavy-Loaded Distance Rate (HLDR) (Eq. (28)), which is widely used by logistic companies in practice. This objective is equivalent to the lowest unloaded travel distance in Eq. (1), but it converts the problem into a maximization problem. The lower and upper bounds of optimal solutions, which are obtained by CPLEX (Chen et al. 2017), are also given. NF in the tables means no feasible solution can be found.

$$HLDR = \frac{Loaded\ Distance}{Loaded\ Distance + Unloaded\ Distance} \quad (28)$$

Table 3: HLDR on the 25% scaled down real-life instances. (Best-found HLDR in bold.)

Instance		NP4-1	NP4-2	NP4-3	NP4-4	NP4-5
VNS-RLS	Best	**82.89%**	62.32%	**75.64%**	59.76%	**79.24%**
	Ave	**81.51%**	61.42%	**74.92%**	59.18%	**78.48%**
	Times	469,233	311,885	319,202	347,134	326,956
	S.D.	1.16%	0.60%	0.62%	0.35%	0.42%
ALNS	Best	81.15%	65.51%	75.17%	61.86%	77.14%
	Ave	79.80%	65.08%	73.60%	61.47%	76.15%
	Times	385	500	458	499	395
	S.D.	0.72%	0.33%	0.80%	0.27%	0.57%
VD-ALNS	Best	81.74%	**65.45%**	75.54%	**62.53%**	77.67%
	Ave	79.61%	**65.16%**	74.15%	**61.75%**	77.03%
	Times	483	529	503	549	573
	S.D.	1.20%	0.25%	0.82%	0.27%	0.53%
Lower Bound		78.36%	65.14%	64.83%	54.39%	NF
Upper Bound		92.36%	97.04%	100%	97.72%	100%
Instance		**NP6-1**	**NP6-2**	**NP6-3**	**NP6-4**	**NP6-5**
VNS-RLS	Best	76.24%	**73.39%**	62.32%	**80.50%**	82.44%
	Aver	74.99%	**72.83%**	62.06%	**79.84%**	80.53%
	Times	698.514	624,078	253,037	541,548	365,435
	S.D.	0.96%	0.41%	0.20%	0.41%	1.72%
ALNS	Best	79.07%	70.28%	65.00%	78.43%	82.15%
	Ave	78.03%	69.42%	64.26%	77.07%	**80.58%**
	Times	420	449	412	426	450
	S.D.	0.69%	0.49%	0.42%	0.80%	0.69%
VD-ALNS	Best	**79.95%**	70.75%	**65.31%**	78.26%	**82.75%**
	Ave	**78.33%**	69.85%	**64.40%**	77.07%	80.34%
	Times	549	537	553	515	496
	S.D.	0.92%	0.49%	0.47%	0.76%	1.19%
Lower Bound		NF	NF	54.30%	NF	66.11%
Upper Bound		NF	NF	95.20%	NF	98.39%
Instance		**NP8-1**	**NP8-2**	**NP8-3**	**NP8-4**	**NP8-5**
VNS-RLS	Best	**76.91%**	**77.76%**	**75.35%**	60.90%	**72.27%**
	Ave	**74.72%**	**77.16%**	**74.93%**	60.47%	**71.68%**
	Times	607,961	525,479	442,103	430,962	516,872
	S.D.	1.20%	0.37%	0.31%	0.32%	0.36%
ALNS	Best	74.74%	74.32%	75.08%	61.85%	71.60%
	Ave	73.90%	73.07%	74.29%	61.66%	71.05%
	Times	445	444	442	421	439
	S.D.	0.54%	0.49%	0.59%	0.14%	0.29%

VD-ALNS	**Best**	75.50%	74.76%	75.09%	**61.92%**	71.58%
	Ave	74.22%	73.53%	74.53%	**61.70%**	71.10%
	Times	579	524	528	456	527
	S.D.	0.57%	0.58%	0.36%	0.14%	0.31%
Lower Bound		NF	NF	NF	NF	NF
Upper Bound		98.98%	100%	100%	NF	100%

Table 4: HLDR on 25% scaled down artificial instances. (Best-found HLDR in bold.)

Instance		LB4-1	LB4-2	TB4-3	TB4-4	LU4-5	LU4-6	TU4-7	TU4-8
VNS-RLS	**Best**	76.92%	**83.42%**	**69.08%**	66.41%	**60.71%**	61.08%	48.75%	54.97%
	Ave	74.80%	**81.61%**	**67.78%**	64.95%	**59.29%**	**60.62%**	48.54%	**54.68%**
	Times	313,707	280,849	286,059	298,651	321,835	290,082	166,248	193,536
	S.D.	0.95%	1.09%	0.65%	0.75%	0.64%	0.29%	0.30%	0.33%
ALNS	**Best**	78.85%	81.85%	68.41%	66.94%	58.87%	59.35%	**49.42%**	54.12%
	Ave	77.84%	80.08%	67.36%	66.06%	57.84%	58.60%	48.87%	53.35%
	Times	438	421	426	410	396	287	371	287
	S.D.	0.67%	1.01%	0.51%	0.39%	0.52%	0.37%	0.39%	0.43%
VD-ALNS	**Best**	**79.16%**	**83.42%**	68.92%	**67.01%**	59.84%	**60.16%**	**49.42%**	**55.31%**
	Ave	**77.98%**	80.92%	67.45%	**66.22%**	58.74%	59.37%	**49.05%**	54.19%
	Times	445	448	457	443	472	477	411	448
	S.D.	0.75%	0.95%	0.65%	0.36%	0.47%	0.46%	0.38%	0.48%
Lower Bound		66.62%	76.41%	69.91%	69.30%	NF	58.65%	50.37%	55.36%
Upper Bound		100%	94.87%	86.31%	83.51%	79.94%	73.90%	52.17%	66.38%
Instance		**LB8-1**	**LB8-2**	**TB8-3**	**TB8-4**	**LU8-5**	**LU8-6**	**TU8-7**	**TU8-8**
VNS-RLS	**Best**	**91.25%**	**93.56%**	63.05%	66.31%	**65.76%**	**66.58%**	**56.46%**	52.29%
	Ave	**89.76%**	**92.09%**	61.78%	63.25%	**64.86%**	**65.58%**	**55.79%**	**51.93%**
	Times	492,628	547,853	296,837	517,855	438,295	439,782	269,164	281,479
	S.D.	0.95%	0.87%	0.54%	1.16%	0.44%	0.49%	0.29%	0.18%
ALNS	**Best**	87.37%	87.87%	63.61%	66.12%	64.84%	60.34%	55.37%	51.89%
	Ave	83.02%	84.41%	62.75%	64.89%	63.61%	58.13%	54.69%	51.28%
	Times	398	396	403	461	437	318	334	385
	S.D.	2.40%	1.40%	0.59%	0.74%	0.54%	0.73%	0.23%	0.42%
VD-ALNS	**Best**	88.71%	89.62%	**64.37%**	**67.01%**	65.30%	63.08%	55.52%	**52.41%**
	Ave	84.32%	84.35%	**62.99%**	**65.26%**	63.93%	59.95%	54.78%	51.81%
	Times	515	499	549	535	598	590	482	577
	S.D.	1.87%	1.95%	0.59%	0.54%	0.57%	1.29%	0.14%	0.39%
Lower Bound		NF	NF	56.85%	52.40%	57.42%	NF	47.65%	50.74%
Upper Bound		100%	100%	82.33%	88.75%	78.33%	86.84%	71.59%	70.43%

From the experiment results, we can find that VD-ALNS beats ALNS in almost all instances, indicating that the variable depth scheme does improve the performance of ALNS. This scheme enhances the exploitation in local areas, leading to increased total evaluation times in ALNS. Comparing to VNS-RLS, on 6 of 15 real-life instances and half of artificial instances, VD-ALNS finds better or equally good solutions, showing no significant difference. However, VD-ALNS takes remarkably fewer evaluation times and 90% running time of VNS-RLS to obtain those results. All the three methods have the similar stability of a difference on S.D. lower than 1%.

Table 5: HLDR on the original full real-life dataset. (Best-found HLDR in bold.)

Instance		NP4-1	NP4-2	NP4-3	NP4-4	NP4-5
VNS-RLS	**Best**	**83.29%**	**69.85%**	72.90%	66.61%	**80.65%**
	Ave	**81.88%**	**69.56%**	72.20%	65.91%	**80.48%**
	Times	779,504	575,894	661,384	923,891	718,219
	S.D.	0.55%	0.16%	0.38%	0.47%	0.17%
ALNS	**Best**	81.68%	69.08%	**74.72%**	66.63%	78.16%
	Ave	80.21%	68.62%	**74.06%**	66.11%	77.78%
	Times	212	281	288	271	267
	S.D.	0.99%	0.36%	0.49%	0.29%	0.22%
VD-ALNS	**Best**	82.30%	69.13%	73.94%	**67.05%**	78.96%
	Ave	81.42%	68.83%	73.01%	**66.28%**	78.11%
	Times	313	501	243	345	297
	S.D.	0.58%	0.21%	0.86%	0.56%	0.49%
Upper Bound		90.43%	70.23%	79.58%	73.72%	81.20%

Instance		NP6-1	NP6-2	NP6-3	NP6-4	NP6-5
VNS-RLS	**Best**	79.64%	**74.14%**	58.94%	**79.52%**	**79.99%**
	Aver	**79.07%**	**73.72%**	58.62%	**79.10%**	**78.36%**
	Times	1.03×10^6	1.16×10^6	513,974	1.05×10^6	984,987
	S.D.	0.47%	0.21%	0.23%	0.53%	0.99%
ALNS	**Best**	76.73%	69.16%	**65.27%**	77.99%	77.43%
	Ave	76.27%	64.76%	64.79%	77.11%	76.64%
	Times	265	44	251	236	274
	S.D.	0.29%	3.04%	0.35%	0.49%	0.56%
VD-ALNS	**Best**	**81.74%**	71.73%	65.16%	78.67%	77.39%
	Ave	77.04%	70.95%	**64.84%**	77.86%	76.52%
	Times	483	300	303	381	387
	S.D.	1.20%	0.69%	0.24%	0.50%	0.54%
Upper Bound		83.93%	76.67%	66.90%	80.97%	84.30%
Instance		**NP8-1**	**NP8-2**	**NP8-3**	**NP8-4**	**NP8-5**
VNS-RLS	**Best**	**73.80%**	**75.27%**	**74.20%**	**61.97%**	**73.62%**
	Ave	**73.48%**	**74.86%**	**73.96%**	**61.91%**	**73.26%**
	Times	1.49×10^6	978,695	867,663	693,779	1.18×10^6
	S.D.	0.15%	0.28%	0.22%	0.06%	0.35%
ALNS	**Best**	69.53%	71.88%	74.02%	61.13%	72.63%
	Ave	68.58%	71.56%	73.22%	61.00%	72.05%
	Times	113	253	227	322	290
	S.D.	0.45%	0.23%	0.40%	0.09%	0.45%
VD-ALNS	**Best**	70.13%	72.48%	74.02%	61.17%	73.07%
	Ave	69.72%	71.39%	73.67%	60.98%	72.59%
	Times	303	284	338	306	365
	S.D.	0.31%	0.28%	0.23%	0.09%	0.34%
Upper Bound		77.04%	77.55%	78.82%	62.53%	76.09%

Table 6: HLDR on the original full artificial dataset. (Best-found HLDR in bold.)

Instance		LB4-1	LB4-2	TB4-3	TB4-4	LU4-5	LU4-6	TU4-7	TU4-8
VNS-RLS	**Best**	73.52%	**78.08%**	**69.32%**	72.24%	**64.67%**	**68.12%**	**53.21%**	**53.80%**
	Ave	72.93%	**77.70%**	**68.54%**	71.42%	**64.38%**	**67.52%**	**53.03%**	**53.61%**
	Times	642,796	617,656	616,237	635,130	724,154	782,608	399,970	290,599
	S.D.	0.32%	0.32%	0.42%	0.49%	0.20%	0.40%	0.16%	0.08%
ALNS	**Best**	75.98%	77.28%	68.68%	73.03%	61.11%	64.45%	52.75%	53.39%
	Ave	75.41%	76.68%	68.05%	71.52%	60.59%	63.85%	52.01%	53.39%
	Times	328	193	222	257	316	202	242	106
	S.D.	0.48%	0.35%	0.43%	1.26%	0.35%	0.30%	0.43%	0.00%
VD-ALNS	**Best**	**76.05%**	77.15%	69.03%	**73.66%**	61.04%	65.33%	52.88%	53.66%
	Ave	**75.14%**	76.83%	68.51%	**72.78%**	60.40%	64.80%	52.49%	53.47%
	Times	379	253	309	315	400	255	294	151
	S.D.	0.60%	0.18%	0.38%	0.64%	0.43%	0.49%	0.39%	0.10%
Upper Bound		79.47%	86.33%	84.05%	88.74%	74.11%	74.47%	64.05%	63.50%
Instance		**LB8-1**	**LB8-2**	**TB8-3**	**TB8-4**	**LU8-5**	**LU8-6**	**TU8-7**	**TU8-8**
VNS-RLS	**Best**	85.49%	**94.03%**	**69.59%**	**66.85%**	**67.81%**	**68.41%**	**59.60%**	**54.50%**
	Ave	84.11%	**92.83%**	**69.04%**	**65.70%**	**67.20%**	**68.07%**	**59.21%**	**54.23%**
	Times	1.44×10^6	1.13×10^6	669,136	1.47×10^6	$1{,}11\times10^6$	1.03×10^6	572,065	859,770
	S.D.	0.95%	1.05%	0.38%	0.76%	0.34%	0.21%	0.21%	0.16%
ALNS	**Best**	**91.22%**	92.98%	68.60%	63.76%	66.95%	61.68%	59.26%	53.78%
	Ave	83.01%	84.98%	67.80%	63.33%	65.28%	60.12%	58.86%	53.18%
	Times	231	212	236	232	275	225	242	210
	S.D.	3.44%	3.35%	0.49%	0.28%	0.34%	0.57%	0.15%	0.32%
VD-ALNS	**Best**	88.71%	89.74%	69.53%	64.95%	67.01%	62.30%	58.99%	54.31%
	Ave	**85.96%**	86.67%	68.52%	63.78%	65.38%	61.29%	58.77%	53.10%
	Times	339	347	427	336	280	343	251	175
	S.D.	2.43%	1.77%	0.55%	0.75%	0.53%	0.76%	0.15%	0.50%
Upper Bound		98.26%	97.97%	87.06%	92.44%	74.27%	71.36%	70.29%	56.54%

Tables 5 and 6 present results on the original Ningbo Port instances. The upper bounds are obtained with relaxing the travels of leaving and returning to the depot (Bai et al. 2015). It can be found that, with the variable depth scheme, VD-ALNS outperforms ALNS again from the aspects of both the average and best found solution. New best solutions are generated by VD-ALNS on 7 out of 31 benchmark instances.

4.4. Contributions of Operators

Table 7 provides statistics on the Destroy and Repair operators. On the scaled down dataset, one single operator is excluded at a time in VD-ALNS to record the resulting solution quality deterioration. The second and third columns show the average deterioration on the best found solution and average solution, while the last two columns give the maximum deterioration on the dataset.

Table 7: Contributions of each operator

Operator	Best sol. deg.	Avg. deg.	Max best sol. deg.	Max avg. deg.
Random Removal	0.15%	0.23%	1.08%	0.13%
Worst Removal	0.33%	0.60%	2.18%	2.14%
Related Removal	0.09%	0.08%	1.32%	0.68%
Worst Edge Removal	0.55%	0.56%	2.87%	2.14%
Random Insertion	0.21%	0.12%	1.80%	1.09%
Greedy Insertion	4.84%	5.34%	9.64%	7.69%
Regret2 Insertion	0.54%	0.25%	4.07%	1.31%

The results indicate the contributions of each operator in VD-ALNS. It can be found that Worst Edge Removal is the most efficient destroy operator, followed by Worst Removal. Related Removal contributes the least. Among all repair operators, Greedy Insertion is the most useful, followed by Regret2 Insertion. Overall, greedy heuristics provide effective complement on search intensification and outperform the others in VD-ALNS.

4.5. Analysis of Runtime

The Destroy and Repair operators in ALNS bring greater changes than the traditional neighbourhood operators by operating on more nodes and making greater perturbation. Therefore, the computation time spent on choosing removal nodes and insertion positions is considerable. The evaluation times of ALNS and VD-ALNS to obtain these results are significantly less than that of VNS-RLS, but the running time of VD-ALNS compared to VNS-RLS is around 17% more on the original instances, and slightly less on small instances. This observation indicates that scalability of the runtime of VD-ALNS is worse (increases faster) than VNS-RLS along with the instance size.

Choosing the insertion position is time-consuming. Actually, the computational time of the repair operators accounts for a larger proportion of the overall time, around 3.5 times of the destroy operators' on scaled down instances. What's more, on the original dataset, the repair operation may spend more than 95% of the total computing time.

5. CONCLUSIONS

This paper investigates an open Periodic Vehicle Routing Problem with Time Windows (OPVRPTW) from a real-world container transportation problem. To address this OPVRPTW of large scale search space with tight side constraints, a Variable-Depth Adaptive Large Neighbourhood Search algorithm (VD-ALNS) is proposed, using four destroy operators and three repair operators at variable neighbourhood depth. In this OPVRPTW with high-dimensional solution structure, the variable depth scheme shows to significantly improve the performance of the proposed algorithm on benchmark instances.

On both small and big size benchmarks, it was demonstrated that the proposed variable depth scheme can handle the trade-off between exploration and exploitation and find good solutions efficiently, significantly promoting the performance of the classic Adaptive Large Neighbourhood Search algorithm. Comparing to an existing solution metaheuristic with small change operators, a number of new best-found solutions are obtained by VD-ALNS.

In our future research, the multi-objective feature will be considered, and other effective trade-off strategies between solution quality and search speed will be adapted within ALNS. It will be interesting to also integrate advanced customized exact methods into both the destroy and repair operators.

ACKNOWLEDGMENTS

This research was supported by Ningbo Science & Technology Bureau (2014A35006) and School of Computer Science, the University of Nottingham.

REFERENCES

Azi N., Gendreau M., and Potvin J.Y., 2014. An adaptive large neighborhood search for a vehicle routing problem with multiple routes. Computers & Operations Research 41 (2014), 167–173.

Bai R., Xue N., Chen J., and Roberts G.W., 2015. A set-covering model for a bidirectional multi-shift full truckload vehicle routing problem. Transportation Research Part B: Methodological 79 (2015), 134–148.

Baldacci R., Mingozzi A., and Roberti R., 2012. Recent exact algorithms for solving the vehicle routing problem under capacity and time window constraints. European Journal of Operational Research 218, 1 (2012), 1–6.

Bräysy O. and Gendreau M., 2001. Metaheuristics for the vehicle routing problem with time windows. Report STF42 A 1025 (2001).

Bräysy O. and Gendreau M., 2005. Vehicle routing problem with time windows, Part I: Route construction and local search algorithms. Transportation science 39, 1 (2005), 104–118.

Chen B., Qu R., Bai R., and Ishibuchi H., 2016. A variable neighbourhood search algorithm with compound neighbourhoods for VRPTW. Springer, 25–35.

Chen B., Qu R., Bai R., and Laesanklang W., 2017. A Reinforcement Learning Based Variable Neighborhood Search Algorithm for Open Periodic Vehicle Routing Problem with Time Windows. Submitted to the Special Issue of the Journal "Networks" on Vehicle Routing and Logistic, 2017.

Coelho, L.C., Cordeau, J.F. and Laporte, G., 2013. Thirty years of inventory routing. Transportation Science, 48(1), pp.1-19.

Cordeau J.F., Laporte G., and Mercier A., 2001. A unified tabu search heuristic for vehicle routing

problems with time windows. Journal of the Operational research society 52, 8 (2001), 928–936.
Dueck G., 1993. New Optimization Heuristics: The Great Deluge Algorithm and the Record-to-Record Travel. J. Comput. Phys. 104, 1 (1993), 86–92.
Eksioglu B., Vural A.V., and Reisman A., 2009. The vehicle routing problem: A taxonomic review. Computers & Industrial Engineering 57, 4 (2009), 1472–1483.
El-Sherbeny N.A., 2010. Vehicle routing with time windows: An overview of exact, heuristic and metaheuristic methods. Journal of King Saud University-Science 22, 3 (2010), 123–131.
Eppen G. and Schrage L., 1981. Centralized ordering policies in a multi-warehouse system with lead times and random demand. Multi-level production/inventory control systems: Theory and practice 16 (1981), 51–67.
Gehring H. and Homberger J., 1999. A parallel hybrid evolutionary metaheuristic for the vehicle routing problem with time windows. In Proceedings of EUROGEN99, Vol. 2. Citeseer, 57–64.
Ghoseiri K., and Ghannadpour S.F., 2010. Multi-objective vehicle routing problem with time windows using goal programming and genetic algorithm. Applied Soft Computing 10, 4 (2010), 1096–1107.
Golden B.L., Raghavan S., and Wasil E.A., 2008. The Vehicle Routing Problem: Latest Advances and New Challenges: latest advances and new challenges. Vol. 43. Springer Science & Business Media.
Hansen P., Mladenoviċ N., and Pėrez J.A.M., 2010. Variable neighbourhood search: methods and applications. Annals of Operations Research 175, 1 (2010), 367–407.
Laporte G., Gendreau M., Potvin J.Y., and Semet F., 2000. Classical and modern heuristics for the vehicle routing problem. International transactions in operational research 7, 45 (2000), 285–300.
Laporte G., Musmanno R., and Vocaturo F., 2010. An adaptive large neighbourhood search heuristic for the capacitated arc-routing problem with stochastic demands. Transportation Science 44, 1 (2010), 125–135.
Lourens T., 2005. Using population-based incremental learning to optimize feasible distribution logistic solutions. Thesis.
Mladenoviċ N. and Hansen P., 1997. Variable neighborhood search. Computers & Operations Research 24, 11 (1997), 1097–1100.
Mourgaya M. and Vanderbeck F., 2007. Column generation based heuristic for tactical planning in multi-period vehicle routing. European Journal of Operational Research 183, 3 (2007), 1028–1041.
Pisinger D. and Ropke S., 2007. A general heuristic for vehicle routing problems. Computers & operations research 34, 8 (2007), 2403–2435.
Pisinger D. and Ropke S., 2010. Large neighborhood search. Springer, 399–419.
Prescott-Gagnon E., Desaulniers G, and Rousseau L.M., 2009. A branch-and-price-based large neighborhood search algorithm for the vehicle routing problem with time windows. Networks 54, 4 (2009), 190–204.
Redi A.A.N.P., Maghfiroh M.F.N., and Yu V.F., 2013. An improved variable neighborhood search for the open vehicle routing problem with time windows. In Industrial Engineering and Engineering Management (IEEM), 2013 IEEE International Conference on. IEEE, 1641–1645.
Ribeiro G.M. and Laporte G., 2012. An adaptive large neighborhood search heuristic for the cumulative capacitated vehicle routing problem. Computers & Operations Research 39, 3 (2012), 728–735.
Ropke S. and Pisinger D., 2006. An adaptive large neighborhood search heuristic for the pickup and delivery problem with time windows. Transportation science 40, 4 (2006), 455–472.
Schopka K. and Kopfer H., 2016. An Adaptive Large Neighborhood Search for the Reverse Open Vehicle Routing Problem with Time Windows. Springer, 243–257.
Schrimpf G., Schneider J., Stamm-Wilbrandt H., and Dueck G., 2000. Record breaking optimization results using the ruin and recreate principle. J. Comput. Phys. 159, 2 (2000), 139–171.
Shaw P., 1997. A new local search algorithm providing high quality solutions to vehicle routing problems. APES Group, Dept of Computer Science, University of Strathclyde, Glasgow, Scotland, UK (1997).
Shaw P., 1998. Using constraint programming and local search methods to solve vehicle routing problems. Springer, 417–431.
Solomon M.M., 1987. Algorithms for the vehicle routing and scheduling problems with time window constraints. Operations research 35, 2 (1987), 254–265.
Tarantilis C.D., Ioannou G., Kiranoudis C.T., and Prastacos G.P., 2005. Solving the open vehicle routeing problem via a single parameter metaheuristic algorithm. Journal of the Operational Research Society 56, 5 (2005), 588–596.
Toth P. and Vigo D., 2001. The vehicle routing problem. Siam.
Wieberneit N., 2008. Service network design for freight transportation: a review. OR spectrum 30, 1 (2008), 77–112.

HEURISTIC OPTIMISATION AND SIMULATION AS DECISION SUPPORT FOR OPERATION AND MAINTENANCE OF OFFSHORE WIND FARMS

Fariba Mostajeran[a], Philip Joschko[a], Johannes Göbel[a]

[a] University of Hamburg, Dept. of Informatics, Modelling and Simulation, Vogt-Kölln-Str. 30, D-22527 Hamburg

[a]mostajeran@informatik.uni-hamburg.de, joschko@informatik.uni-hamburg.de, goebel@informatik.uni-hamburg.de

ABSTRACT

The rise of offshore wind energy production poses a complex resource allocation problem with respect to operation and maintenance (O&M) of offshore wind farms: O&M tasks need be performed by teams of specialists, subject to limited availability of qualifications, means of transport and appropriate weather conditions. Among others, NP-complete problems like shortest return routing ("Travelling Salesman") and job scheduling are embedded into the challenge of determining O&M schedules, which in real-world wind farm operation is often still conducted by hand. In this work, we address this problem by proposing a heuristic approach based on a "compatibility rating", attempting to anticipatorily allocate tasks to teams such that the remaining tasks *not* yet allocated can still be conducted efficiently, e.g. by a different team. This means of decision support relies on simulation to evaluate the feasibility of the schedules generated.

Keywords: scheduling, simulation, offshore wind farms, decision support system

1. INTRODUCTION

One of the most important and risky undertakings of today's Germany is the energy transition. It is expected that by the year 2050 up to 80 percent of Germany's energy supply may be provided by renewable sources (BMWi 2015). Offshore wind energy, as one of the generously available sources of renewable energy in the North of Germany, has become a key part of energy transition, without which the targets of this venture cannot be met (WAB 2017). Since average wind speed off the coast is significantly higher than on land, offshore power plants can generate more electricity at a steadier rate and almost every hour of the year (BMWi 2015).

Furthermore, achieving an ecologically and economically successful transition requires a reliable and reasonably priced energy (BMWi 2015). Specifically for the case of offshore wind energy, reducing the costs of operation and maintenance (O&M) of the wind farms are particularly seen as a challenge in this area. Operating experiences of existing offshore wind farms show that the share of operating costs over the service life is relatively high. Likewise, the costs of produced electricity have not yet reached the level of the onshore wind (Greiner, Appel, Joschko, Renz and Albers 2015).

Constructing wind farms further away from the shore can on the one hand increase the turbine performance and hence the financial revenue (Prognos AG and The Fichtner Group 2013). But on the other hand the distance of the offshore wind farm from the port extends its influence over the specific operating and maintenance costs (BMWi 2015). Giant turbines and their foundations have to endure the harsh conditions of the high seas. Repair and maintenance of turbines located far away from the coast is a tough challenge for the operators. Highly trained personnel and modern transport infrastructure have to come together in order to successfully provide maintenance services.

In fact the level of expertise in operating and maintenance of offshore wind farms can reduce up to 19 percent of the specific annual operating costs (BMWi 2015). Such expertise is unfortunately not always documented or verified (Mostajeran, Joschko, Göbel, Page, Eckardt and Renz 2016). Having a relatively low level of experience can result in an unpredictable loss.

The use of Decision Support Systems (DDS) in this context can potentially reduce the pressure on authorities and save the ultimate costs. However, existing systems are still very limited for the area of offshore wind farms. The results of a questionnaire (Pahlke 2007) sent to 350 institutions related to development of offshore wind farms in the North sea region suggest that the demand to use DDS specially for planning is very high (73.9%).

The individuals who are in charge of making planning decisions have to not only deal with the complexity of the resource planning problem but also make their decisions efficiently in a limited time. A typical wind farm has up to 80 turbines (BMWi 2015). Aggregating the O&M of several wind farms would enable more resource-efficient work, but also increase the planning complexity. Therefore, a sustainable decision support algorithm should scale well with the size of given turbine and resource clusters.

This paper proposes a research prototype to support decision makers during the O&M phase of offshore wind farms, particularly for the purpose of resource planning using simulation technology. It has to be emphasised that simulation cannot autonomously find the optimal result, but rather compare given proposals for the solution. In this work, we show how to generate promising O&M plans to select the best solution by means of an adjusted simulation component. This objective is accomplished in three main steps (compare Figure *1*):

1. Identifying and collecting essential input data (Data Model)
2. Generating feasible resource and action plans (Scheduling)
3. Assessing and suggesting the best plans (Simulation)

The following sections describe each step and our approach in more detail.

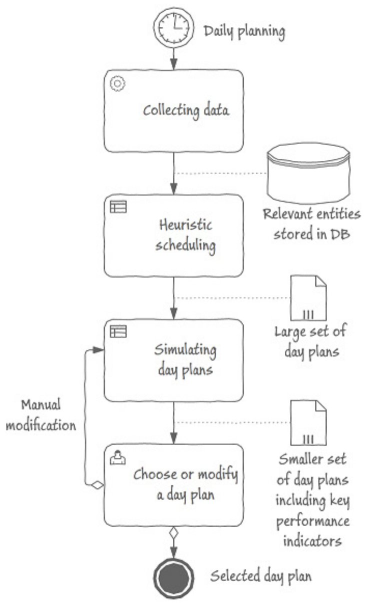


Figure 1: Main steps of the proposed Decision Support System

2. DATA MODEL

The first step in developing a DDS is to identify all relevant data entities and their relationships. In general, not every data entity required for optimisation purposes is very well-known in industry. There are often data gaps and identifying them has to be initially done in optimisation and simulation projects.

In the offshore wind farm context, many entities play important roles and engage in complicated relationships. We identified the most important data entities relevant for resource planning and their relationships. Furthermore, data gaps and their potential sources of information were identified. While the original version of the identified data model was too comprehensive for the purpose of this paper, a simplified version is given in Figure *2*.

The O&M of offshore wind farms are normally controlled from service stations on land. For example, the service station of the Riffgat wind farm in North Sea is 15 kilometres away on the island of Borkum. Despite Riffgat, which is relatively close to the shore, other offshore wind farms are located further away (e.g. BARD Offshore I for around 100 km) from the coast. Additionally, each service station can potentially manage more than one wind farm.

Activities representing the O&M tasks that have to be conducted on the site are the most influential entities in this context. Their type, duration, priority, location and qualifications form the basis of planning and resource allocation. Taking into consideration that activities are rarely unique and often repeat themselves in the case of more or less homogeneous wind turbines (WTs) in an offshore wind farm, identifying reusable types of activities makes sense. Consequently, common characteristics of each type of activity, most importantly the duration, can be gathered from empirical data. Naturally, due to the sea conditions, the precise duration of an activity cannot be predicted reliably. However, expected fluctuations can be estimated from empirical data, and consequently reproduced in stochastic simulation experiments (see section 5).

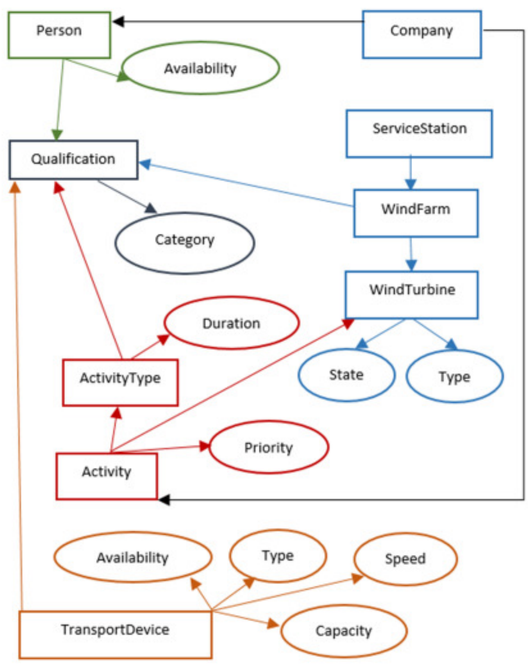


Figure 2: Simplified Input Data Model

The most important resources required for O&M activities are the personnel in charge of service and the means of transportation. Also the availability, i.e. the dates on which they are available for service, plays a crucial role for planning. The same applies to speed, capacity, and type of each means of transport.

Moreover, there are typically different companies involved in operating and maintenance of each wind farm, each of which brings its own resources and activities. Therefore, a dedicated entity for each company seems reasonable. This entity is also connected with personnel and activities.

Finally, qualifications and certificates are of significant importance for the entire decision making process since they bear a direct relationship to almost every other entity in the data model. For example, a safety briefing may be mandatory for just entering a wind farm. Activities may demand a certain level of expertise (e.g. industrial climber, electrician qualification). Apart from the activities, using a means of transportation (e.g. helicopter) may also require specific skills from passengers (e.g. hoist training). Only personnel who possess all related qualifications may be assigned to a task and enter the means of transport.

During the course of several sessions with O&M practitioners, we presented our data model and received their assurance that our designed model is valid.

3. OPTIMISATION CHALLENGES

The next step after identification and collection of the necessary data is to generate feasible O&M plans. This is a challenging task, as the number of determining factors is relatively large. It consists of several complex partial problems, which can also impact on one another.

3.1. General

For resource planning, the first step is to check whether the marine weather is safe to conduct any mission on the site. After that, the requirements (e.g. qualifications) and characteristics (e.g. priority, typical duration, etc.) of the pending tasks can be considered. The pending tasks are the ones which are already known but not yet executed.

Figure 3 illustrates the distribution of a sample of pending tasks within a wind farm, which we use as an example in this paper. Having the triangles as WTs, our sample wind farm represents 30 homogeneous WTs, which are arranged in 3 lanes. Each WT is identified with a number, starting from the most upper left tringle as WT1 and ending to the lowest right triangle as WT30. In Figure 3, the distribution of the tasks are shown with the help of a heat map. In addition to their location, the intensity of the heat represents the number and duration of the tasks.

The available and qualified personnel for performing these tasks can in the next step be arranged into small teams. According to the location and duration of the tasks, the order of sending and picking up the teams by available and suitable transport devices could form the last step that finalizes the schedule.

An automated resource planner should at the same time consider all these factors. But the complexity of this problem is so enormous (NP-equivalent) that simply evaluating all combinations and finding the best solution (Brute-force algorithm) is not an option for real-world instances. Therefore, only a heuristic optimization algorithm can account for all partial problems at the same time and generate time and cost efficient yet not necessarily optimal resource plans. Moreover, the complexity of such algorithm, the quality of the outcomes and the difficulty of implementation have to be examined.

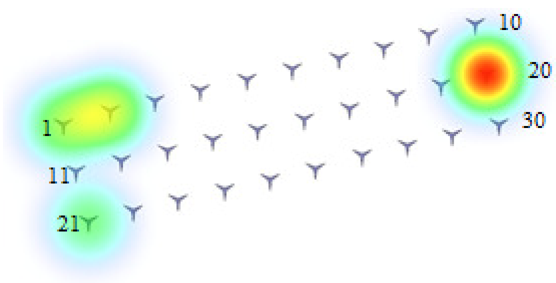


Figure 3: Heat-map of sample pending tasks. The intensity of the heat represents the number and duration of the tasks.

3.2. Weather

The weather conditions off the coast on the one hand give economic viability to offshore wind farms, but on the other hand challenge the personnel to maintain the turbines. Due to safety regulations, dropping off personnel at the turbines is only allowed when the weather and sea conditions are compliant to safety measures.

Therefore, an automated resource planner should also account for the weather forecast in order to provide feasible suggestions. Given perfect weather conditions, the time windows may also depend on legal regulations or availability of sunlight.

For evaluation purposes, historical data instead of a weather forecast can be used. Another approach is described in (Joschko, Widok and Page 2013). They proposed a software tool for simulation of the processes of O&M, which includes stochastic marine weather generator. It supplies a simulation tool with realistic weather data, which are generated by analysing the historic weather data and containing their distributions.

3.3. Team Building

The planned activities in offshore wind farms are assigned not to single individuals, but rather to small teams of personnel. Although the size of such teams can be different for different types of activities, their minimum size has been determined as three by the security policies of many wind farms.

An important criterion for building these teams is the qualifications of their members. Since performing each task demands certain qualifications, the potential performers of the tasks can be arranged in the associated teams, only if they hold the required qualifications. Building teams of available personnel is a challenging task since each person may possess quite different qualifications, which gives rise to combinatorial explosion of possible team combinations. Assuming a team size of *t* and availability of *n* persons, equation (1) shows the number of possible team combinations. For instance, building teams of the size of 3 from 24 personnel, when each of them has a unique qualification and hence cannot be replaced by others, results in nine trillion combinations (2).

$$\text{team combinations} = \frac{\binom{n}{t}\binom{n-t}{t}\binom{n-2t}{t}\dots\binom{t}{t}}{\frac{n}{t}!} \quad (1)$$

$$\text{e.g. } \frac{\binom{24}{3}\binom{21}{3}\binom{18}{3}\dots\binom{3}{3}}{8!} = 9.161.680.528.000 \quad (2)$$

In practice, the problem is often less drastic, since a lot of personnel have the same set of qualifications. In addition, some offshore wind farm operators may delegate a pre-selection of tasks to sub-contractors. Thus, the planner has a pre-selected set of teams in terms of the sub-contractors' staff.

Assigning the planned tasks to qualified personnel is similar to the knapsack problem in combinatorial optimization, having the duration and priority of tasks as respectively weight and value criteria. Preliminarily, we implemented a greedy algorithm for solving this problem. For this purpose, the tasks were ordered by their priority. Starting from the highly prioritized tasks and considering their required qualifications, the qualified personnel were arranged in teams and assigned to the tasks. This process was repeated until the duration of all tasks assigned to each team does not exceed their working time limit, e.g. an offshore wind farm working day.

3.4. Transport Routing

After having the teams assigned to the activities, the best route for traveling to and returning from the wind farm should be calculated. Similar to the classic Traveling Salesman Problem (TSP), this partial problem deals with the shortest path with maximum gain. Since the movements of the transport device within the wind farm has direct relationship with the costs of transportation, i.e. consuming time and fuel, finding the best route for the transport device can save this part of the O&M costs.

Considering a wind farm as a Euclidean graph with WTs (only those which require service activities) as its nodes and the port as the start node, the distance between each WT can be seen as the weighted edges of the graph. However, the influence of the weather, like wind speed and direction, can potentially cause different weights for different directions of the edges, resulting in an asymmetric TSP, in which the distance from node A to B can be unequal to the distance from B to A. Besides, there are many other sea conditions and dependencies to different types of ships, which were not considered in detail for this work. A project which goes more into detail is described in (Quandt, Beinke, Ait-Alla and Freitag 2017).

The marine weather can be also a reason for choosing between different types of transport devices (e.g. helicopter or ship), impacting on traveling costs. For instance, travelling with a helicopter is on the one hand much faster, but on the other hand much more expensive than any ship. They have also a smaller capacity than ships. Observe that also multiple travels for a mission are possible, for example if apart from the team, bulky materials need be transferred.

The main difference between the classic TSP and our offshore wind farm scenario under investigation is that we require each node being visited usually twice, namely for drop-off and pick-up of the team, subject to conducting planned activities in-between.

Therefore, a TSP solver for offshore wind farm scenario suggested by (Korff 2015) was used for this part of the problem. In the first place and before running the algorithm, some preparations have to be done. First, due to the weather influence, the Euclidean graph of the wind farm has to be mapped into an asymmetric graph. After that, the nodes which have to be visited, i.e. the location of the maintenance tasks, have to be identified. Finally, calculation of the best route is done only on a partial graph of the entire wind farm graph, from which irrelevant nodes were omitted. After dropping off all the teams on their working sites, the algorithm listens on the pick-up calls from the teams. As soon as a team is ready to be picked up, the TSP includes their locations into its graph and re-calculates the best path. This continues until all teams are picked up. Only then will the journey back to the harbour begin (Korff 2015).

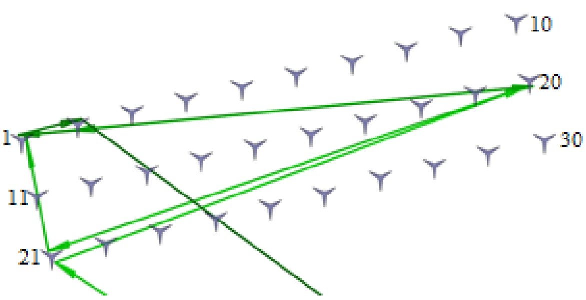


Figure 4: A sample transport route

Figure 4 shows a sample route for a ship within our wind farm example. In addition, Table 1 lists and explains every step of this route in detail.

Table 1: The steps of a sample transport route

Step	Location	Action
1	Harbour	Pick up Team1 and Team2
2	WT21	Drop Team1
3	WT20	Drop Team2
4	WT21	Pick up Team1
5	WT1	Drop Team1
6	WT20	Pick up Team2
7	WT2	Drop Team2
8	WT1	Pick up Team1
9	WT2	Pick up Team2
10	Harbour	Drop Team1 and Team2

4. HEURISTIC APPROACH

The problems described in the previous sections are already very complex themselves. However, the more fundamental problem is that all these sub-problems have an impact on each other, which makes it nearly impossible to find an optimal solution at all.

The planner has to regard different priorities, qualifications, time durations, means of transport and tasks needed on different sites. In order to solve this matter, we developed a compatibility rating for O&M activities, which considers all the relevant characteristics at the same time. Through this, it is possible to compare how similar activities are to be grouped into clusters (see section 4.2).

4.1. Compatibility rating

We propose a compatibility rating defined as weighted average of a tuple of aspects. Each aspect describes how far apart activities are in one respective dimension.

For example, in the case of locations, being "apart" uses a natural definition: If two activities are planned for the same turbine, the return value is 1, representing the ideal case. If they are located diametrically opposite in the wind farm, the return value is 0, indicating the worst case. Everything in-between is linearly interpolated. When we compare two clusters of activities, we consult the geometrical centre of the geo-coordinates of each turbine. We call this the Location Aspect.

All other aspects are non-spatial. The Qualification Aspect describes how similar the demands for qualifications are. If there are two sets of qualifications (Q_{c1}, Q_{c2}) required for two sets of activities (C_1, C_2), the "distance" d between these demands can be evaluated as ratio of qualifications shared per union of all qualifications required as shown in equation (3):

$$d = |Q_{c1} \cap Q_{c2}| \; / \; |Q_{c1} \cup Q_{c2}| \qquad (3)$$

The Priority Aspect suggests that important tasks have to be preferred. This does not mean that one task is strictly to be performed before another, but rather that for economic, safety or environmental reasons this order is recommended. The priority has to be manually set by the human planner, e.g. on a discrete scale like [very low, low, medium, high, very high]. We normalize this scale to a continuous value between [0,1]. Then, we evaluate the average of the tasks to be compared as the return value for the Priority Aspect. As a result, higher priority tasks will receive a higher compatibility rating than lower priority tasks, which is completely independent from the similarity of the tasks.

We can add any further aspects, which return continuous values between [0,1] when two activity clusters are given as input parameters. For each aspect a factor has to be provided for evaluating a weighted average.

In addition to continuous aspects, further Boolean "knock-out" criteria may describe whether two activities are compatible. There may, for example, be activities which have to be processed by a specific company, but this company must not process other types of tasks. The return value indicates whether two given sets of activities may be processed by the same company (Company Aspect). Some tasks require specific type of ships, e.g. a jack-up barge, some do not (Transportation Aspect). Our Goal is to develop clusters for given time slots, which must not be exceeded. The Duration Aspect returns true, if two given activity clusters could be processed together in time, and false if not.

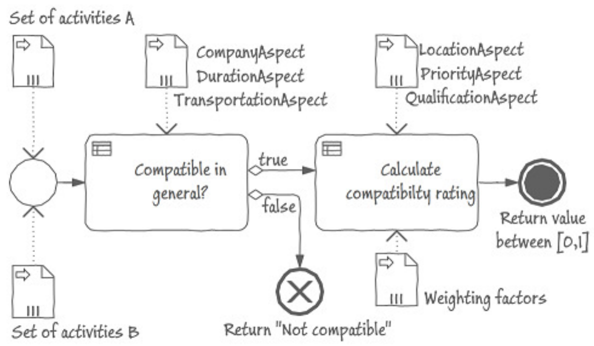


Figure 5: Conceptual process of the calculation of the compatibility rating as BPMN diagram

When a set of knock-out criteria and a set of tuples (Aspect, Weight) are defined, the overall result value for the compatibility rating is calculated as follows (compare Figure 5):

1. if any knock-out-aspect is true, return 0.0
2. evaluate each continuous aspect
3. return weighted average of continuous aspects

Adding aspects or changing the weighting factors for the continuous aspects will lead to a different return value.

4.2. Clustering

As mentioned before, a permanent waiting queue holds the O&M activities that need be performed. We therefore can create a matrix (see Figure 6), which shows the compatibility ratings as described in the last section for all tuples of activities. Figure 6 shows activities on four different WTs. Every cell shows the rating for the activities listed in the respective column and row titles. On this basis, we can form clusters of tasks. One cluster applies to being executed by one team and within one day. Thus, the maximum size of a cluster corresponds to the given time window (section 3.2).

A very simple clustering algorithm puts the two items which have the highest ranking together in one cluster (flagged with a 'C' in Figure 6). After that, the matrix has to be partially re-evaluated, since two items have been removed and a new item was added, representing the items aggregated into a cluster of tasks. Then, again the two best fitting items (single tasks or clusters of tasks) will be merged. The algorithm stops, when there are no ratings left which are higher than zero, indicating no further aggregation being possible. In a typical case, such a limit will be due to the Duration Aspect.

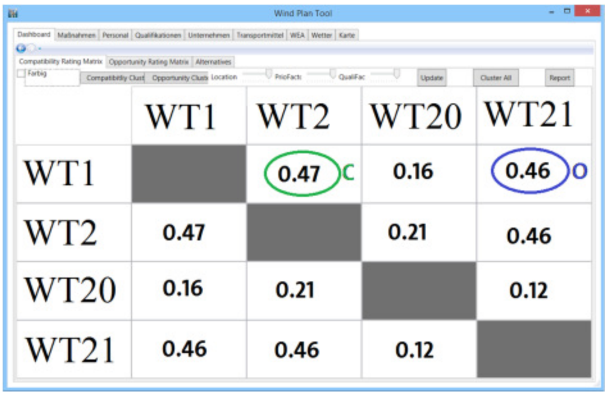


Figure 6: Screenshot of GUI showing compatibility matrix

However, such an approach is only optimal in the very short term. In Figure 6, the best compatibility rating 0.47 is given for the tuple (WT1, WT2). But using the pre-assumption that the time slot given by weather conditions allows only clusters with up to two activities, and the activities WT1 and WT2 would be merged, there will remain no adequate partner for activities at WT20 and WT21, because their compatibility rating is very low at 0.12.

Our clustering algorithms focuses on overall gain, which has an efficient utilization of calculation time but finds a more 'long-term' satisfying solution. We applied the concept of "opportunity cost" from economics when we implemented a heuristic algorithm, which calculates the resulting loss when an item does not get its favourable partner task.

First, the compatibility ratings for each activity are stored in a sorted list, so that the best partner is the first item and the worst is the last. Then, we calculate the difference (Δ) between compatibility ratings of the first and the second item, between the first and the third item and so on and store results into a new sorted list. Every entry quantifies a lower bound to the loss incurred in case not being allocated to its best partner, to none of its best two partners, to none of its best three partners and so on.

Now, we establish the weighted average of these Δ-values, while the weighting factor for every Δ can be calculated with a selection of formulas. Let n be the number of list items to be regarded (begin counting at the second best partner which is compared to the best partner), and p is the position in the sorted list of Δ, we use equation (4) for a simple linear approach of determining weighing factors w_p for every Δ_p.

$$w_p = n + 1 - p \,/\, \sum_{k=1}^{n} \mathrm{k} \qquad (4)$$

Table 2 shows the linear weighting factors for the case of 4 potential partners, compared to 5 potential partners in Table 3.

Another approach is a recursive algorithm, see Equation (5). The procedure requires to set a descent factor *f*. In table 1 and 2, *f* = 0.6 was chosen. The weighting factor for the first Δ is f, the rest r_1 is 1–*f*. The weighting factor for the second Δ is r_1f. There still remains a rest r_2 of (1–*f*) (1–*f*). At the end, a rest of $(1-f)^n$ resides, which has to be distributed proportional to the already calculated factors.

$$w_p = f(1-f)^{p-1}(1+(1-f)^n) \qquad (5)$$

As it is shown in the tables, the recursive algorithm places more weight on the first Δ, while the linear algorithm places more weight on the last Δ. Thus, the linear approach will tend to avoid worst case scenarios earlier than the recursive approach. Additionally, the recursive approach offers an additional degree of freedom in terms of the possibility of adjusting the impact of the first Δ by changing the value for *f*.

Table 2: Weighting factors for opportunity rating regarding the best five partners (n=4)

	p	linear	recursive
$\Delta_1(1^{st}, 2^{nd})$	1	40 %	61.5 %
$\Delta_2(1^{st}, 3^{rd})$	2	30 %	24.6 %
$\Delta_3(1^{st}, 4^{th})$	3	20 %	9.8 %
$\Delta_4(1^{st}, 5^{th})$	4	10 %	3.9 %

Table 3: Weighting factors for opportunity rating regarding the best six partners (n=5)

	p	linear	recursive
$\Delta_1(1^{st}, 2^{nd})$	1	33.3 %	60.6 %
$\Delta_2(1^{st}, 3^{rd})$	2	26.7 %	24.2 %
$\Delta_3(1^{st}, 4^{th})$	3	20.0 %	9.6 %
$\Delta_4(1^{st}, 5^{th})$	4	13.3 %	3.8 %
$\Delta_5(1^{st}, 6^{th})$	5	6.7 %	2.5 %

Now having a matrix containing compatibility ratings for activity tuples (respectively tuples of activity clusters) and one opportunity rating for each activity (respectively activity cluster), the algorithm proceeds as follows:

1. The activity with the highest opportunity rating (highest potential loss) is selected.
2. This activity is merged with its best partner due to the compatibility rating.
3. The matrix has to be re-evaluated, and afterwards the algorithm starts at step one again, until there are no ratings left, which are bigger than zero.
4. The result is a set of clusters, within which all activities are potentially appropriate of being processed by one team and in one day.

In Figure 6, the worst opportunity rating applies to WT21. Therefore WT21 gets its best partner WT1 first (flagged with an O), although the best partner for WT1 would be WT2. This approach finds a more 'long-term' efficient solution than the solution described at the beginning of this section, because the remaining activities at WT2 and WT20 have a compatibility rating of 0.21, which is significantly better than the rating of 0.12 for WT20 and WT21.

Once we have clustered all the O&M activities in the waiting queue, we can run the team building algorithm from section 3.3 on these clusters rather than running it on the whole waiting queue. Thus, the possible search space becomes very much smaller, because activities with similar needs for qualifications tend to lie in the same cluster. At the same time, we have a better basis for transport routing described in section 3.4, because activities located spatially close to each other, tend to lie in the same cluster, too. Figure 7 shows four tasks, scheduled in 2 clusters. The first cluster contains the tasks, located at WT1 and WT21 and assigned to Team1. Cluster 2 contains the assigned tasks of Team2 located at WT2 and WT20.

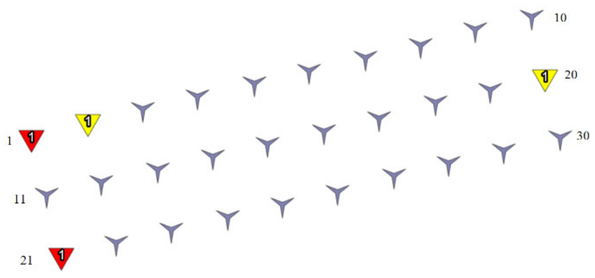


Figure 7: Scheduled tasks in two clusters: C1 (WT1 & WT21) for Team1 and C2 (WT2 & WT20) for Team2

Changing the parameters for the compatibility rating will result in different clusters, which is an appropriate method to get alternative proposals for solutions for daily plans. On that basis, we are able to compute a large set of promising solutions in a short time without having to iterate the whole solution space.

5. SIMULATION

Once we have generated a set of promising day plans in reasonable time, each plan will be analysed in detail. The goal is to identify the best performing plans and to sort out the worse plans, so that a reasonable amount of plans remain for the human decision maker.

For calculating key performance indicators of interest, we use stochastic, event-discrete simulation. The main indicators to be provided as a basis for decision are:

- Success probability of each task in a plan
- Resource utilization and costs
- Generated wind energy (or opportunity costs for stagnant turbines)
- Identification of the critical path

Durations of tasks depend on external influences, which are abstracted with help of stochastic distributions. The critical path is the chain of transport and O&M activities, which has no time buffers. If a delay occurs, the whole day plan is deferred. The available time window depends on the weather conditions (see 3.2). Because all teams must leave the turbines within that time windows, it may happen that some tasks have to be aborted. The 'success probability' quantifies the probability that a task can be completed in time. This does not indicate whether the task was completed successfully in technical manner. Another point of interest for the planner is the utilization of resources, i.e. personnel and means of transport should use offshore time efficiently to process tasks. The last indicator relates to the actual objective of wind farm operation: generating energy. Energy productions depends on the wind speed and the turbine properties cut-in speed, cut-off speed and rated power (Byon, Perez, Ding and Ntaimo 2011). For our objectives, generated power is less interesting than the power which was not generated, because a turbine was not ready for operation. Minimising these opportunity costs is the main goal of O&M optimisation.

Some works have already been successful in the simulation of offshore wind farms' O&M processes. (Lange, Rinne and Haasis 2012) describes how different logistic strategies can be compared already in the planning process. (Joschko, Widok and Page 2013) describes how operative O&M processes can be described abstractly as BPMN-Models and simulated in order to identify critical system parts. These works inspired us to focus on in short-term planning – independently from the long-term strategy of choice.

As always, we have to determine our requirements first and identify the relevant area of the O&M system afterwards to find a suitable approach for implementing the simulation model. The system to be mapped into a model was introduced in the previous sections. Relevant entities are the same for the simulation component: means of transports, teams, activities and wind turbines. Some, but not all entities' attributes are furthermore needed for simulation experiments. E.g. we can abstract from people's qualifications, because we already have a plan fixed in time, describing which team is responsible for which O&M activity without need to double-check this. In contrast, the duration of an activity and the speed of a ship or helicopter are relevant for simulation, because we now take a deeper look at the time-dependent behaviour of entities and their concurrent execution of tasks.

There are no dynamic entities which enter or leave the system. Only static entities exist, which are announced before starting the simulation experiment. They may interact with each other, which could be interpreted as 'dynamic behaviour'. However, this only implies waiting in queues for transports and all other activities based on shared resources. But also these tasks are already announced before the simulation run.

Thus, it was not necessary to use a scheduler or an event-list, which is typically for dynamic, event-discrete simulation. A more basic and much faster approach fits our needs: A task is built up of a start-event and an end-event. Durations of tasks (time-spans between start- and end-events) are samples from different stochastic distributions, as well as in event-discrete simulation. First, we announce all tasks with their stochastic parameters. Afterwards, instead of scheduling such tasks on concrete time instants on an event-list, it suffices to determine their execution order, so that each task has a defined set of references to its predecessors and successors.

Hereby, we need only one method call, which contains recursive (pending a potentially even more efficient iterative implementation) method calls for every task to calculate the start- and the end-points of all tasks in a day plan, depending on stochastic samples. The critical path, which has no time buffer, is identified.

Because we don't need any list operations or dynamic objects' instantiations, a lot of computing power is saved compared to dynamic simulation. In our first approach, which still used a scheduler and an event list, we computed 100,000 experiments in about 13 minutes on a single standard PC. The elaborated generation of reports also played a role here. But since any component not strictly required was removed, the transition to the model logic described above, we are now able to compute 1,000,000 experiments in 1.5 seconds. Since the simulation is stochastic, we have to repeat experiments for every scenario to get reliable results. But even if we require 100 to 1000 experiments for every scenario, we are still able to compare more than 1000 day plans in less than two seconds for a wind park of medium size.

As simulation engine we have used DESMO-J, which is an open-source, discrete event simulation framework developed at the University of Hamburg. It offers several ready-to-use components for developing simulation applications in the object-oriented languages Java or C#. DESMO-J provides an experimentation framework, abstract model components, waiting queues, stochastic distributions, as well as several statistic data collectors for quantifying the dynamic system behaviour. (Göbel, Joschko, Koors and Page 2013).

Every time a model is implemented with DESMO-J by deriving entities and events from DESMO-J classes, a 'domain-specific application' is written. In this case, however, we have made adjustments to the library itself. DESMO-J offers a lot of technical simulation components, like a scheduler or an event-list which are commonly needed for dynamic simulation, or optional add-ons like a 2D animation module. As described above, we deactivated most of these components, which was quite straightforward due to the clear structure of the freely available DESMO-J source code. We just used selected components like queues, stochastic and statistic classes.

6. RESULTS

Finally, the proposed solutions of all partial problems were integrated in one working research prototype, which is a .Net based application, implemented in the C# programming language. Moreover, the input as well as output data models were used to create a database on a Microsoft SQL Server, whose tables were employed to automatically generate one-to-one Classes in C# using Entity Framework technology.

Besides, our heuristic algorithm is able to generate many alternative resource plans, which are compared using discrete event simulation. Thus, the best plans can be automatically preselected. These suggested plans are displayed in the form of a Gantt chart. Figure 8 shows a generated sample plan. For any selected date, several alternative plans can be accessed, each of which consists of multiple lanes for each team and transport device.

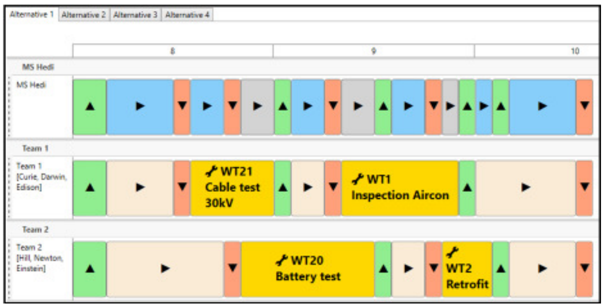


Figure 8: Suggested day plan

The lane of each transport device shows the suggested route for traveling to and returning from WTs. The bars with an upward or downward arrow show respectively the boarding and de-boarding of the teams and the ones with an arrow to the right show the movements of the transport device within the wind farm. These movements are also reflected in the lanes of teams. The team lanes show also the tasks, which are assigned to them.

Each plan is rated by the costs and execution probability. These information can be seen below each Gantt chart. Tabs allow users to display the automatically preselected plan proposals. The number of proposals should be small enough to be quickly overlooked by a human being. At the end, each plan is only a suggestion and can be modified by the human planner. The modified plan will be evaluated using simulation and stored as a new alternative plan for the day.

7. DISCUSSION

Resource planning during O&M of offshore wind farms is a very complex problem. However, our research prototype, as an automated resource planner, supports the decision makers by dividing the problem into partial problems and conquering its complexity.

Our novel heuristic algorithm considers various aspects of developing a valid resource plan. These aspects include the availability of the personnel and means of transportation, the priority, duration, location of the performance, and required qualifications of the activities. The proposed algorithm considers all these aspects and groups the activities into clusters. The clusters do not necessarily contain the most similar activities, but rather those which give an overall best result (regarding the cost and execution time). The qualified personnel are then arranged into teams and the best route for the transport device is calculated.

The results are presented in the form of several Gantt charts which represent the generated plans for the day. Each plan is additionally rated by means of discrete event simulation technique.

8. FUTURE WORK

In future we still need to conduct scheduling and simulation runs based on real historical data from our project partners for the purpose of validation. In scheduling, an extremely large spanning tree of resource plans shall intentionally be generated, which are then simulated in a multi-day experiment. This will enable us to find suitable factors for the weighting in the compatibility rating. As a result, the scheduling algorithm will be able to work more efficiently by requiring a much smaller spanning tree in real-life situations.

Besides, we would like to evaluate different algorithms for the partial algorithms of our heuristics algorithms, i.e. team building, task allocation, and transport routing.

Finally, it is of our interest to evaluate our research prototype in the service station of an offshore wind farm. Therefore, parallel to the human resource planner, our prototype will receive the input data, such as the planned tasks for the day, available personnel, etc. The quality of the suggested plans can then be evaluated in practice and with real data. This requires a live connection for weather forecasting to determine the available time windows.

As by the conditions of the research project grant, our implementation is intended as prototype and cannot be developed further into a commercial product by our research group. Of course, commercial software developers are free to contact us if they are interested in more details about our research results to provide a valuable supportive tool for O&M of offshore wind farms.

9. CONCLUSION

This paper described various aspects of resource planning during the O&M of offshore wind farms. Considering the immense complexity of the problem, a heuristic approach is necessary for generating time and cost efficient resource plans. We introduced a compatibility rating as core element of our heuristic algorithm. Lastly, with the help of discrete event simulation, our approach can be examined using artificial as well as real-world data.

Data management and saving useful pieces of information can make a huge difference in the quality of optimisation algorithms. More specifically, collecting important information about activities and their types can make their common characteristics, such as typical duration, clear for the planner. Having mobile solutions (e.g. documentation apps on tablets) can probably make the documentation and collection of data easier for the users on-site. It is important to mention that the sooner the authorities start collecting such data, the better the quality of the data provided for an optimisation algorithm can get.

Ultimately, due to the stochastic nature of on-site plan execution under stochastic conditions (e.g. weather), the heuristic algorithm to identify alternative plans in a live operation had to augmented with simulation technology for evaluation.

ACKNOWLEDGMENTS

This work is a part of the research project "KrOW! - Kosten- und risikogesteuerter Betrieb von Offshore Windparks" (Cost and Risk Controlled Operation of Offshore Wind Farms) funded by German Federal Ministry for Economic Affairs and Energy (support code: 0325728C). Further project partners are the University of Applied Sciences Bremen, the IZP Dresden, EWE Erneuerbare Energien and BTC AG. For their support we are grateful.

REFERENCES

BMWi, 2015. Offshore wind energy. Berlin: Federal Ministry for Economic Affairs and Energy (BMWi) Public Relations.

Byon E., Perez, E., Ding, Y., Ntaimo, L., 2011. Simulation of wind farm operations and maintenance using discrete event system specification. Simulation, 87 (12), 1093-1117.

Göbel J., Joschko P., Koors A., Page B., 2013. The Discrete Event Simulation Framework DESMO-J: Review, Comparison to other Frameworks and Latest Development. Proceedings of the 27th European Conference on Modelling and Simulation, 27th-30th May, Ålesund.

Greiner S., Appel S., Joschko P., Renz T., Albers H., 2015. GOWOG German Offshore Wind Operation Guide. Available from: http://www.systop-wind.de/fileadmin/pdf/systop_ gowog_20150630_webseite.pdf [accessed 15 April 2017]

Joschko P., Widok A., Page B., 2013. A Simulation Tool for Maintenance Processes of Offshore Wind Farms. 15th International Conference on Harbor, Maritime & Multimodal Logistic Modelling and Simulation, 25th-27th Septembre, Athens.

Korff O., 2015. Evaluation von heuristischen Verfahren zum Traveling Salesman Problem. Master Thesis. University of Hamburg.

Lange K., Rinne A., Haasis H.D., 2012. Planning Maritime Logistics Concepts for Offshore Wind Farms: A Newly Developed Decision Support System. International Conference on Computational Logistics. Berlin, Heidelberg: Springer.

Mostajeran, F., Joschko P., Göbel J., Page B., Eckardt S., Renz T., 2016. Offshore Wind Farm Maintenance Decision Support. Proceedings of International Conference Environmental Informatics, 14th-15th September Berlin. Aachen: Shaker.

Pahlke T., 2007. Software & Decision Support Systems for Offshore Wind Energy Exploitation in the North Sea Region, Oldenburg: Overspeed GmbH & Co. KG.

Prognos AG & The Fichtner Group, 2013. Cost Reduction Potentials of Offshore Wind Power in Germany, Berlin: The German Offshore Wind Energy Foundation and partners.

Quandt M., Beinke T., Ait-Alla A., Freitag M., 2017. Simulation Based Investigation of the Impact of Information Sharing on the Offshore Wind Farm Installation Process. Journal of Renewable Energy Volume 2017 (2017), Article ID 8301316.

WAB, 2017. Gute Argumente für Offshore-Windenergie. Available from: http://www.wab.net /images/stories/Gute-Argumente-Offshore-Windenergie.pdf [accessed 16 March 2017].

AUTHORS BIOGRAPHY

Fariba Mostajeran received her B.Sc. in Computer Engineering-Software from University of Isfahan (Iran) and her M.Sc. in Digital Media from University of Bremen (Germany). She works as research assistant at the University of Hamburg since 2015.

Philip Joschko received his Ph.D. in computer sciences from the University of Hamburg in 2014. He favors applied research and focuses on business process modelling and simulation. Since 2009 he worked on several research projects funded by German federal ministries. Amongst others, he has already worked on offshore wind energy in the SystOp-Project and has been one of the initiators of the KrOW-Project, from which partial results are presented in this paper.

Johannes Göbel received a diploma in business information technology and the Ph.D. from the University of Hamburg, Germany. His Ph.D. studies focused on decentralized transport network optimization by the means of genetic programming. Recent teaching and research interests focus on modelling and simulation methodology and, apart from the work presented here, on Bitcoin simulation and protocol improvements.

APPLYING MONTE CARLO SIMULATION IN AN INDICATOR-BASED APPROACH TO EVALUATE FREIGHT TRANSPORTATION SCENARIOS

Laura Baumann [(a)], Fabian Behrendt, PhD[(b)], Niels Schmidtke [(c)],

[(a),(b),(c)] Fraunhofer Institute for Factory Operation and Automation IFF, Magdeburg (Germany)
[(c)]Otto von Guericke University Magdeburg (Germany)

[(a)] laura.baumann@iff.fraunhofer.de, [(b)]fabian.behrendt@iff.fraunhofer.de, [(c)]niels.schmidtke@ovgu.de

ABSTRACT

Policymakers and decision makers are often unable to estimate the impacts and interdependencies of new transportation concepts. Methodological approaches do not include macroscopic ex-ante assessments of new technological and economic concepts. That is why a new method called the VLVI method has been developed at Otto von Guericke University and the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg. Based on a large number of key performance indicators (KPI) that describe transportation infrastructures and their processes, the method maps various effects in and between freight transportation systems. The uncertainty of predictions is factored into the model by integrating Monte Carlo simulation. One comparative indicator with a confidence interval is calculated for every concept assessed with this method, thus specifying a concept's impact on the German transportation system.

Keywords: Monte Carlo simulation, decision support, indicator-based approach, freight transportation system

1. INTRODUCTION

An efficient freight transportation system is fundamental to a country's economic growth and prosperity (Daehre et al. 2012). Germany's location in Central Europe and German companies' substantial exports intensify this reliance (Schenk et al. 2014). According to the Logistics Performance Index (LPI), which shows the efficiency of logistics by a survey among leading logistics experts, Germany is ranked first in 2016 (Arvis et al. 2016). Regarding the infrastructure, however, Germany is only in the eighth place in the evaluation of the "infrastructure" pillar of the Global Competitiveness Index (GCI), tendency declining (Schwab and Sala-i-Martín 2016). This development was already shown by a federal and state commission established in 2012 that € 7.2 billion is lacking every year for the renewal infrastructure and deferred investments (Daehre 2012).

This makes it even more important to predict the impact of transportation policy decisions and technological innovations on the transportation system in advance (Holmgren et al. 2014). Yet expert's opinions on new concepts' impacts often diverge. For instance, the impact of the introduction of a special type of long combination vehicles (LCVs) on German roads is a topic of vigorous debate at present. Instead of 100 m³, this LCVs haul 150m³, their maximum total weight being limited to 40 tonnes (or 44 tonnes intermodal transportation), though. Advantages of LCVs are their lower axle load and their larger freight volume's reduction of daily runs (bast 2016). At the same time, consequent shifts from rail to road transportation are feared. LCVs could haul freight in the future, which has been forwarded by freight trains (Sonntag and Liedtke 2015), and thus increase the trucks' number of daily runs. The impact of the introduction of LCVs on the freight transportation system can hardly be assessed without a sound method of analysis.

Such a method should be able to incorporate as many of the long-range impacts of technological innovations in its assessment as possible. Since simulation models can depict the dynamic behavior of systems (Reggelin and Tolujew 2011, Fierek and Zak 2012, Sokolowski and Banks 2009) they are a suitable addition for the approach method, which should be developed here.

2. MODELING IN THE TRANSPORTATION SECTOR

Simulation is defined as a controlled statistical sampling technique (Fierek and Zak 2012, Hillier and Lieberman 2001), which carries out a series of experiments using a computer. Various input data is transformed into a set of output data by estimating the effect of data to the simulation model, which describes the operations of the real system (Fierek and Zak 2012). Simulation models in the transportation sector generally are algorithmic mathematical models, classifiable by their purpose and degree of detail (Reimann 2007).

Regarding the purpose a distinction is made between demand, assignment models and flow models. Demand models forecast transportation demand and are usually static, while assignment models assign generated demand data to an existing transportation network and generate line load data. Flow models are time dynamic, i.e. the system state changes dynamically with time and is calculated at certain intervals.

Simulation models can also be classified as microscopic, mesoscopic or macroscopic according to their degree of detail. Microscopic models usually incorporate not only individual units in the transportation flow with their performance and interactions among each other but also the transportation environment like traffic lights and intersections (Bungartz et al. 2009, Liebermann and Rathi 1997, Fierek and Zak 2012). Macroscopic models describe all vehicles of a transportation network or

system as a uniform traffic flow with characteristics like volume, speed and density (Bungartz et al. 2009, Liebermann and Rathi 1997, Fierek and Zak 2012). Mesoscopic models combine microscopic and macroscopic approaches (Reggelin 2011). Since they can represent large networks with vehicles as individual elements, they are mainly used for routing and traffic control.
Extensive literature covers general methods pertaining to the transportation sector and traffic trends in particular. Most tools are applied microscopically and mesoscopically, while macroscopic tools are rare (Behrendt 2016).
Cost-benefit analysis (CBA) is one of most widely used methods to evaluate new transportation infrastructure projects macroscopically. It only evaluates monetizable items, non-monetizable items being treated in separate (environmental) analyzes (BMVI 2016b). That is why (Gühnemann et al. 2012) introduce the results of a CBA to a multiple-criteria decision analysis (MCDA) by involving decision makers in the development of a cost-effective investment program consistent with strategic objectives. Even (Macharis and Bernardini 2014) use MCDA in connection with a multi-actor approach for the evaluation of transportation concepts in urban and regional areas. Unfortunately, only transportation infrastructure projects are evaluated and the impact of new financing instruments (e.g. truck tolls) and technological innovations are not taken into account. This is the point of departure for a novel approach that compares new proposals and the advantages of new actions and concepts, which was developed jointly by Otto von Guericke University and the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg, Germany.

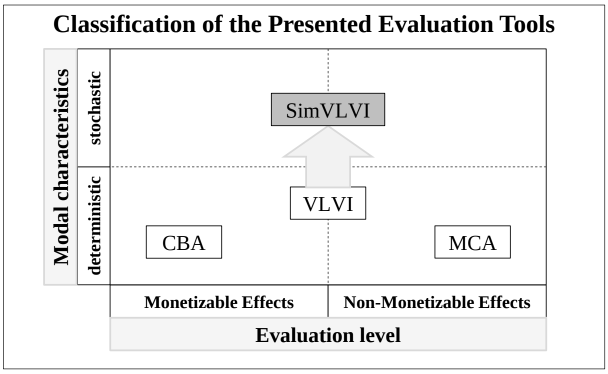


Figure 1: Classification of Tools for the Assessment of Transportation Concepts including SimVLVI

This static, deterministic model called the VLVI tool is being upgraded with simulation components in order to incorporate stochastic elements in the modeling (Figure 1).

3. VLVI METHOD: DESCRIPTION AND INTEGRATION OF RANDOM SIMULATION

The VLVI method enables ex-ante assessments of future scenarios that will affect the German transportation system's infrastructures and processes (Behrendt 2016). The model integrates key performance indicators (KPIs) in causal networks (Figure 6), which represent the relationships between the KPIs. Combined with a set of specific KPIs (based on the scenario), the method models the future impacts of political policies and technological innovations. A procedural model consisting of five procedural steps (Figure 2) is used to perform the ex-ante assessment.

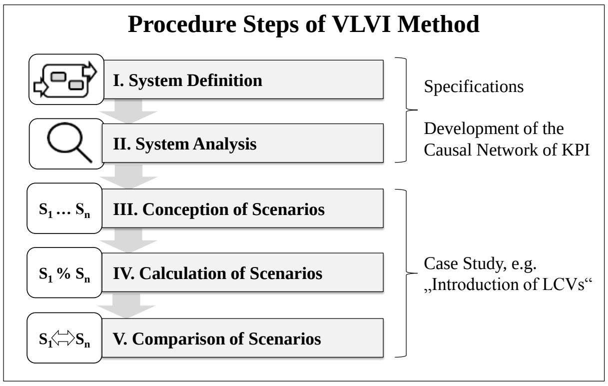


Figure 2: The Steps of the VLVI Method (Behrendt 2016, Schmidtke and Behrendt 2017)

Within the first two procedure steps a classification of KPIs is compiled and analyzed by means of a relevance analysis to determine their relevance and importance (weighting factors) towards defined objectives. For the approach presented the objectives of the German national infrastructure plan, so called "Bundesverkehrswegeplan" (BMVI 2016b) are used. An additional impact analysis identifies relationships between all relevant KPIs in order to develop causal networks of KPIs, one for each transportation mode (road, railroad and waterway). Regarding the ex-ante assessments of future scenarios and based on historical data, all KPIs are forecasted by using appropriate forecasting methods such as linear regression analysis or exponential smoothing. As a result the method analyzes influencing factors on the German transportation system by using a specific calculation schema and its comparative indicator named "VLV-indicator" (VLVI). A more detailed description and application of the VLVI method is given in Chapter 4 by the case study "Introduction of Long Combination Vehicles".
Since the VLVI method does not factor in concepts' uncertainties regarding the mentioned case study, a static, stochastic model was developed to create SimVLVI.

3.1. Stochastic Modeling

The inclusion of randomness is the underlying idea of stochastic modeling. One of the basic approaches, Monte Carlo simulation (Nahrstedt 2015) employs random number generators to generate data from specific stochastic distributions. Every computation generates a different output based on the random input. The output is utilized to simulate sampling of an infinite base population. The required sample size is definable by methods of inductive statistics (Chapter 4.4) and is a function of the confidence level preferred. Statistical inference is employed to estimate the sample statistics and transfer them to the base population. This delivers a random model describing the system's uncertainty with a corresponding confidence interval.

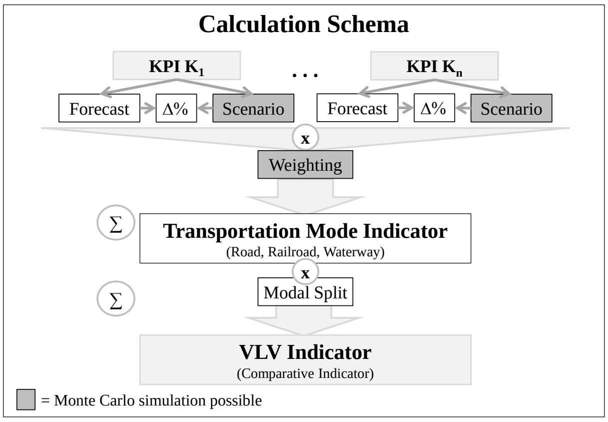


Figure 3: Basic Calculation Schema of the VLVI Method

The core of the VLVI method is its calculation schema (Figure 3). Weighted KPIs (weighting results from relevance analysis) changed by the scenario are aggregated in indicators that specify the scenario's impact on transportation modes. Multiplying the totaled indicators by their modal split yields a comparative indicator referred to as the VLVI. It specifies the pros and cons of changes to a system in a weighted percentage.
Various stochastic simulations (shaded in Figure 3) can be applied in the method to vary the scenario values or to employ variable rather than static weighting. The following examines variable scenario values of the impact of LCVs on the German transportation system. The analysis of the case study follows the five steps of the VLVI method.

3.2. Validation

For the validation of the VLVI method an ex-post analysis has been realized. The introduction of an electronic truck toll system in 2005 provides a suitable scenario. Since 2005 trucks heavier than 12 tonnes have to pay toll (a distance dependent charge) for using German highways (VIFG 2015). This method should enhance the financing situation of infrastructure by shifting to a user financing principle (Doll and Schade 2005). Two scenarios for the analysis year 2005 were developed:

1. In 2005 a revenue of € 2.8 billion per year was expected due to the new truck toll, which should be reinvested in the German road infrastructure by 40% (Doll and Schade 2005). These expected revenues raise the KPI "gross fixed assets" as well as the KPI "net fixed assets" and set appropriate scenario values for the forecast year 2015. The VLVI method calculated a positive effect for 2015, which could not be seen in reality. Taking into account the simultaneous decrease of tax financing (general budget for transportation infrastructure) in the following years this discrepancy is explainable (Bernecker and Fichert 2013).
2. The real data, KPIs measured in "Transportation in Figures" which is published each fall by the Federal Ministry of Transport (BMVI 2016a), was set as scenario values. As a result a loss of economic substance for the German transportation system was calculated, which is congruent to the results of the federal and state commission work (Daehre 2012) and confirms the representation accuracy of the VLVI method.

4. CASE-STUDY: INTRODUCTION OF LONG COMBINATION VEHICLES IN GERMANY

In many European countries new truck concepts are debated or put already into practice. In Sweden for example, trucks with a length extended to 25.25m are common, while trucks on roads in Germany were limited to 18.75m (Figure 4). In 2012 a field trail with long combination vehicles (LCV) started investigating the use of vehicles and its combinations with a length of up to 25.25m in Germany. This field trail was initially limited to a period of five years and was accompanied by a comprehensive program of scientific tests from the Federal Highway Research Institute (bast 2016). Since 2017 LCV are allowed to use German roads while the maximum total weight is still limited to 40 tonnes (or 44 tonnes in combined transport). Heavier vehicle combinations of up to 60 tonnes reveal safety concerns because bridges and cash barriers are constructed for lower maximum total weights, expensive expansion measures would be necessary. Therefore only the introduction of LCV as shown in Figure 4 are taken into account for the following case-study. LCV have the characteristic of higher volume increased from 100 m³ to 150 m³, which offers the possibility of decreasing the total number of trucks on roads, while transporting the same volume of cargo. Additional axes are needed in comparison to conventional trucks and decreases the average axes load of LCVs.

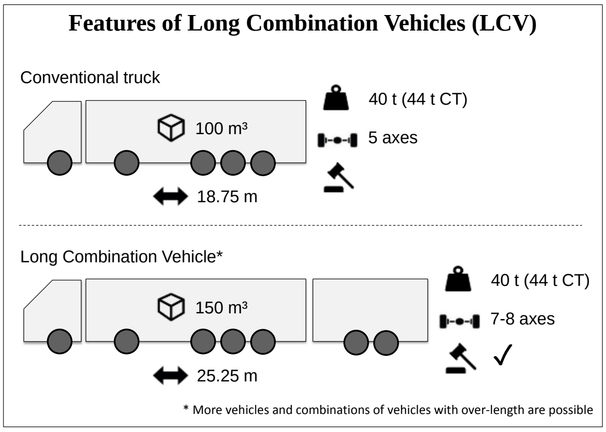


Figure 4: Features of Long Combination Vehicles (LCV) (bast 2016; VDA 2006)

4.1. System Definition

The model created when the system is being defined (Behrendt 2016) has to be able to represent the desired development of the transportation system. In the case presented here, the German national infrastructure plan (BMVI 2016b) is the source of the development aims. Its goals are both quantitative, e.g. "reducing shipping costs", and qualitative, e.g. "modernizing and maintaining transportation infrastructure". As a whole the following development aims are considered:

1. Modernizing and maintaining transportation infrastructure
2. Reducing shipping costs
3. Improving traffic flow
4. Increasing reliability of transports
5. Reducing emissions
6. Improving connection of intermodal hubs

These development aims underlying the analysis are contingent on the object of analysis.
To describe the system a morphological box (Figure 5) is used. It is divided into the categories of system, process and object, which are analyzed in subcategories. This division facilitates a structured approach when categorizing concepts (Illés et al 2007; Zsifkovits 2013; Schenk et al. 2010). The morphological box presented here is suitable for classifying most scenarios but can be expanded if necessary.

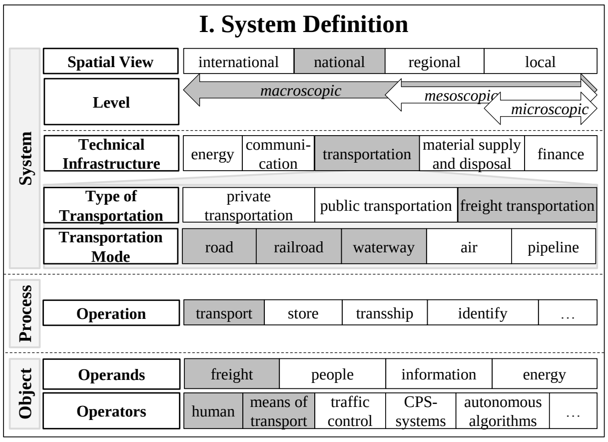


Figure 5: Morphological Box of Freight Transportation (Behrendt 2016; Illés et al. 2007; Zsifkovits 2013; Schenk et al. 2010)

The system definition for the introduction of LCVs is shaded in Figure 5. A macroscopic view has been selected to describe changes in the national transportation system. Since the share of freight transported by air or pipeline is insignificant compared to other transportation modes, this analysis only examines the transportation modes of road, railroad and waterway. The effects to the system will be assessed for the year 2025, a long-term period, which represents a good basis in order to indicate realistic developments.

4.2. System Analysis

Each of the transportation modes (road, railroad and waterway) has to be examined separately to develop the appropriate causal networks of KPIs. Potential KPIs are subjected to a relevance analysis to determine their relevance for the defined objectives (Chapter 4.1). This leads to an assessment of the KPI's influence on the respective development aims, whereby a distinction is made between "positive influence", "negative influence" and "not clearly assessable".
The KPIs are weighted against each other in a subsequent impact analysis using Vester's scale (Illés et al 2007) for pairwise comparison: A quantifier of "1" denotes a weak relationship, "3" an intense relationship. This analysis makes it possible to classify KPIs into a causal network (Figure 6) with the direction of influence running from top to bottom. For instance, "transport volume" affects the "percentage of empty run kilometers", which is simultaneously a function of the "average distance carried".
Causal networks are rendered similarly for the transportation modes but the outcomes differ in part. Weighting may differ and other KPIs may be employed, e.g. "rate of electrification" (in a railroad causal network) or "quality of port infrastructure indicator" (in a waterway causal network).

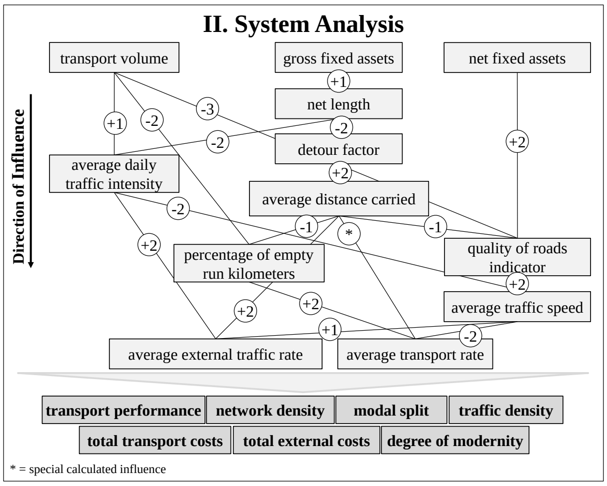


Figure 6: Road Transportation Causal Network

All KPIs are forecast based on their historical data by using such methods as linear regression analysis or exponential smoothing. An annual value can thus be forecast for every KPI, which ought to appear without changing the system. As is evident in the calculation schema (Figure 3), this forecast value is compared with the KPI value that could be generated by the scenario.
In general the first two procedure steps, system definition and system analysis, form a basis for the following case studies. After defining and analyzing the causal networks once the procedure steps three to five can be repeated for each exemplary application, as long as the same view and objectives are regarded.

4.3. Conception of Scenarios

In general, two different approaches can be used for the conception of scenarios. On the one hand, an environmental analysis can be carried out collating external opportunities and risks derived from political, economic, social, technological, environmental and legal conditions ("PESTEL", Johnson et al. 2011). As in the case presented, a future scenario can be also defined due to vigorous debates at present (field trail for LCVs, bast 2016) on the other hand.
A future scenario describes the changes in the transportation system caused by political policies or technological innovations in a certain year. The scenario has to be calculable in order to simulate its impact. By surveying literature and interviewing experts, the impacts are quantified so that a scenario can be described by a set of changed KPIs. The scenario value of a KPI not set by experts is calculated by weighted change (Figure 3) of the higher level KPIs (Figure 6).
Since experts often disagree or are uncertain about future developments, the literature occasionally only delivers an interval rather than any exact value for the scenario values of KPIs. For instance, (bast 2016) does not expect the introduction of LCVs to cause a shift of freight between the transportation modes of road and rail; whereas (Sonntag and Liedtke 2015) estimate that 7.6% of the volume transported will shift from railroad to the road. An interval [0; 0.076] can be set to include both views in the approach.
Scenarios with at least one of these intervals are referred to as trend scenarios. A deterministic method such as the (original) VLVI method necessitates using one best and one worst case scenario to approximate trend scenarios. This is no longer necessary in SimVLVI. Using Monte Carlo simulation to vary input, a trend scenario can be mapped directly. While the interval boundary can be extracted from the source, statistical distributions are often lacking even if the interval originates from a single source. Then it must be defined to compute the VLV indicator. Since the distribution of the random numbers can heavily influence the results, the statistical distributions that fit the situation best have to be chosen. Because rectangular and beta distribution are both definable in a closed interval, they are particularly suitable for implementing trend scenarios. The following are helpful guidelines whenever sources do not contain any information for a distribution:

- Rectangular distribution fits best when the interval comes from a single source.
- Beta distribution fits best when the interval is a combination of two values from two different sources. It can be adjusted according to the sources' credibility: If both are equally credible, the parameter should be set as a=b=0.5 (Figure 7, left), thus weighting both source values highly. If one source is more credible, the parameters may, for instance, be altered as a=3.5 and b=1 (Figure 7, right), so one value is weighted higher.

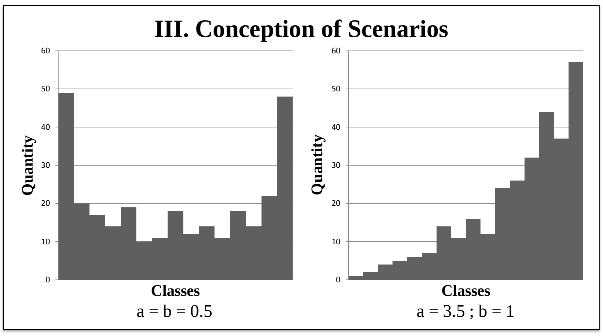


Figure 7: Histograms of Beta Distributions with a Sample Size of 300

4.4. Calculation of Scenarios

Inland vessels usually transport heavy cargo such as turbine parts or bulk cargo like coal or gravel. Since it is unlikely that LCVs used to haul bulk cargo (bast 2016), which would impact inland shipping, a shift between inland shipping and LCV is not considered here.
(bast 2016) expects LCVs to take over 2.6-6.9% of conventional trucks' kilometrage, which accords to all point-to-point transportation of more than 25 km and over 70% of the truck's volume utilized (bast 2016). A rectangular distribution in [0.026; 0.069] has been chosen for the simulation (Table 1). All other impacts of

LCVs are a function of this percentage share of kilometrage. The "average distance carried" of 240 km for LCVs ascertained by (bast 2016), is significantly higher than the distance of 165.4 km forecast for conventional trucks. The scenario's value of "average distance carried" is a function of both values yielded by percentage calculation. The same applies to "average daily traffic intensity", which drops as the number of LCVs increases: One shipment with an LCV can replace 1.545 shipments with a conventional truck (bast 2016). Not only is the axle load lower (bast 2016) but there is also significantly less stress on the road infrastructure, thus leading to improvement at no additional cost. The impact of the "quality of roads indicator" is therefore assumed to be positive in the model. The impacts described are employed as scenario values in the model (Table 1).

Table 1: Simulation Scenario Values for the Introduction of LCVs

IV. Calculation of Scenarios

KPI	Source value	References	Simulation
Railroad			
Transport Volume	-7.6%	Sonntag and Liedtke 2015	Beta Distribution with a=b=0.5 for [0; 0.076]
	0.0%	bast 2016	
Road			
LCVs Percentage	*2.6 – 6.9%*	*bast 2016*	*Rectangle Distribution for [0.026; 0.069]*
Transport Volume	Transferred tonnage	Sonntag and Liedtke 2015	Transferred Tonnage depending of the Railroad Transport Volume
	0.0%	bast 2016	
Average Distance carried	240km	bast 2016	Depending of the LCV Percentage
Average daily Traffic Intensity	1 LCV ≈ 1.545 trucks	bast 2016	Depending of the LCV Percentage
Quality of Roads indicator	Lesser road pressure	bast 2016	Equally distributed Value [0.01; 0.023] depending of the LCV Percentage
Waterway			
No changes			

The minimum required sample size is a function of the confidence level and the tolerable error. Both variables have to be defined so that they are significant enough for the analysis. They were defined for the LCV scenario as follows:

- confidence level = 95%
- tolerable error = 3%

These variables are used to calculate the minimum required sample size with Formula 1 (Waldmann 2016, Rössler and Ungerer 2008). A pilot survey of a sample size of n = 30 (Mossig 2012, Bahrenberg et. al 2010) ascertains that the VLV indicator varies by 7.5%.

$$n \geq z^2_{1-\frac{\alpha}{2}} * \frac{s_0^2}{\varepsilon^2} \quad (1)$$

- n = sample size
- $z^2_{1-\frac{\alpha}{2}}$ = quantile of the standard deviation distribution for the confidence level $1-\frac{\alpha}{2}$
- s_0 = standard deviation of the pilot survey
- ε^2 = tolerable error

Formula 1 calculates a minimum required sample size of n = 320.

4.5. Comparison of Scenarios

The VLV indicator is calculated 320 times as described in Chapter 4.4 to generate the required sample size. The fit of the data to the normal distribution is checked by various tests, thus the arithmetic mean and the standard deviation of the transportation mode indicators and the VLV-indicator can be assessed. Formula 2 delivers the proper confidence interval for the data (Waldmann and Helm 2016, Rössler and Ungerer 2008). This is the way sample uncertainties are usually expressed in statistics.

$$\bar{x} - z_{1-\frac{\alpha}{2}} * \frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + z_{1-\frac{\alpha}{2}} * \frac{s}{\sqrt{n}} \quad (2)$$

- $\bar{x}$ = mean of the sample
- s = standard deviation of the sample
- μ = mean of the base population

The outcome is presented on the right side of Figure 8. The impact of LCVs can also be estimated with the deterministic VLVI method (Figure 8, left). Then, the trend scenario has to be split into sub-scenarios defined by varying the input parameters. This treatment is necessary in any kind of deterministic method. It gives decision makers many different outcomes for sub-scenarios of a single decision, which they have to use as the basis of decisions without any information on the probability of the sub-scenarios' occurrence. A model based on the Monte Carlo method, on the other hand, solely delivers information on the impact of a decision-making option.

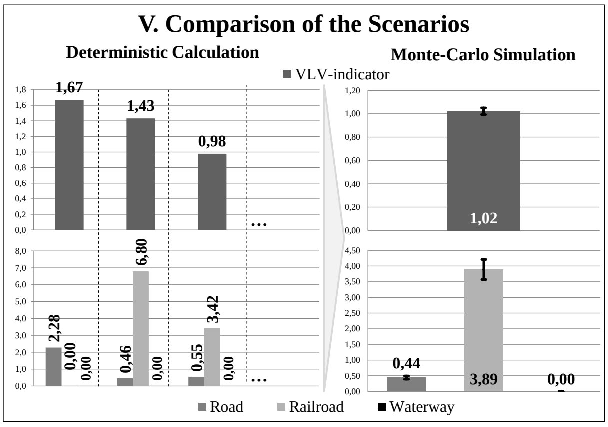


Figure 8: Comparison of the Results of deterministic VLVI and SimVLVI

Based on these sources and the aforementioned constraints, the introduction of LCVs can be expected to improve the freight transportation system by 1.02±0.03%. The rail freight transportation system, operating virtually to capacity, will transport up to 7.6%

less. The greatest improvement of 3.89±0.32% can thus be expected there.
The road transportation system will not deteriorate as feared. The additional load from shifted rail freight will not offset the positive impact of LCVs, e.g. lower axle load and higher volume of freight. It may even contribute to a slight improvement of 0.44±0.05%. Moreover, the lower cost of haulage using LCVs rather than conventional trucks can benefit shippers.
Since the influence of transportation modes on the entire system is a function of its modal split, the relatively strong improvement of the rail transportation system has only slight influence on the complete system.

5. CONCLUSION AND OUTLOOK

The macroscopic SimVLVI demand model assesses new transportation concepts in advance. This enables political policymakers and industry decision makers to assess their options using a statistically grounded number that factors in ever impact, which is important according to the literature. The various views of experts and the literature can be aggregated and an objective basis for an assessment can be established. The Monte Carlo simulation implemented facilitates risk analysis of concepts without decreasing the VLV indicator's interpretability. The widest variety of options can thus be compared easily, even if they are as different as a financing instrument and an innovative transportation system.
In addition to trend scenarios, Monte Carlo simulation can also be employed to vary the weighting defined in impact and relevance analyses. Even if there is consensus on the approximate assessment of the correlations between the KPIs, a precise definition may require compromise. Applying the Monte Carlo method to the weighting in the VLVI model could reproduce this uncertainty like the uncertainties in trend scenarios. This would make an even more exact assessment of the concept possible.

REFERENCES

Bahrenberg, G., Giese, E., Mevenkamp, N., Nipper, J., 2010. Statistische Methoden in der Geographie. Band 1 univariate und bivariate Statistik. Stuttgart. Borntraeger; p.20f.

Bernecker, T., Fichert, F., 2013. Optionen zur Finanzierung der Bundesfernstraßen. Final Report. Stuttgart: Baden-Württembergische Industrie- und Handelskammertage; p.44.

Behrendt, F., 2016. Entwicklung eines Vorgehensmodells zur Untersuchung multidimensionaler Einflüsse auf Güterverkehrssysteme. Dissertation. Otto von Guericke University Magdeburg; p.59ff, 66.

Bundesanstalt für Straßenwesen (bast), 2016. Feldversuch mit Lang-LKW – Abschlussbericht. Bergisch Gladbach; p.12, 27, 32ff.

Bundesministerium für Verkehr und digitale Infrastruktur (BMVI), 2016a. Verkehr in Zahlen 2016/2017, Statistics, DVV Media Group GmbH, 45. Edition, Hamburg.

Bundesministerium für Verkehr und digitale Infrastruktur (BMVI), 2016b. Bundesverkehrswegeplan 2030 – Draft March 2016. Berlin; p.5.

Bungartz, H.-J., Buchholz, M., Pflüger, D., Zimmer, S., 2009. Modellbildung und Simulation – Eine anwendungsorientierte Einführung. Berlin, Heidelberg: Springer; p.156, 179.

Daehre K.-H., Behrendt, F., Trojahn, S., 2012. Sicherung einer nachhaltigen und soliden Verkehrsinfrastruktur für den Wirtschaftsstandort Deutschland. DVWG-Jahresband 2011/2012: p.112-119; p.112f.

Daehre K.-H., 2012. Zukunft der Verkehrsinfrastrukturfinanzierung. Magdeburg; p.37.

Doll, C., Schade, W., 2005. How using the Revenues of the German HGV motorway system efficiently and equitable under different regulatory frameworks and institutional settings. Proceedings of the 4th Infra-Train Conference, 08. Oct 2005, Berlin; p.4.

Fierek S., Zak, J., 2012. Planning of an Integrated Urban Transportation System based on Macro-Simulation and MCDM/A. Procedia – Social and Behavioural Sciences 54: p. 567 – 579; p. 569.

Gühnemann, A. Laird, J., Pearman, A., 2012. Combining cost-benefit and multi-criteria analysis to priorities a national road infrastructure program. Transport Policy 23; p.15-24.

Hillier, F., Lieberman, G., 2001. Introduction to Operational Research. Boston: McGraw – Hill.

Holmgren, J., Ramstedt, L., Davidsson, P., Edwards, H., Persson, J.A., 2014. Combining Macro-level and agent-based modeling for improved freight transport analysis. Procedia Computer Science 32: p.380-387; p.380.

Illès, B., Glistau, E., Machado, N., 2007. Logistik und Qualitätsmanagement. Miskolc; p.4, 7f, 137.

Johnson, G., Scholes, K., Whittington, R., 2011. Strategisches Management – Eine Einführung. Munich: Pearson Studium; p.80.

Liebermann, E., Rathi A.K., 1997. Traffic simulation. In: Revised Monograph on Traffic Flow Theory, p.268-270.

Marcharis, C., Bernardini, A., 2014. Reviewing the use of Multi-Criteria Decision Analysis for the evaluation of transport projects: Time for a multi-actor approach. Transport Policy 37, p.177-186.

Mossig, I., 2012. Stichproben, Stichprobenauswahlverfahren und Berechnung des minimal erforderlichen Stichprobenumfangs. Beiträge zur Wirtschaftsgeographie und Regionalentwicklung 1 – 2012; p.8.

Nahrstedt, H., 2015. Die Monte Carlo-Methode. Wiesbaden: Springer Vieweg; p.VII.

Reggelin, T., 2011. Mesoskopische Modellierung und Simulation logistischer Flusssysteme. Dissertation. Otto von Guericke University Magdeburg.

Reggelin, T., Tolujew, J., 2011. A mesoscopic approach to modeling and simulation of logistics processes. Proceedings of the Winter Simulation Conference, p. 1513-1523, 11-14 Dec 2011, Phoenix; p. 1513.
Reimann, M., 2007. Simulationsmodelle im Verkehr. Term paper. University of Karlsruhe (TH); p.4ff.
Rössler, I., Ungerer, A., 2008. Statistik für Wirtschaftswissenschaftler. Heidelberg: Physica-Verlag; p.135.
Schenk, M., Behrendt, F., Trojahn, S., Müller, A., 2014. Verkehrsinfrastruktur – Entwicklungschancen durch effiziente Logistik. Jahrbuch Logistik 2014: p.95-100; p.95ff.
Schenk, M., Müller, E., Wirth, S., 2010. Factory planning manual. Berlin, Heidelberg: Springer-Verlag; p.225ff.
Schmidtke, N., 2016. Entwicklung einer Beurteilungsmethodik zur Untersuchung multidimensionaler Einflüsse auf Personenverkehrssysteme in der Bundesrepublik Deutschland. Master Thesis. Otto von Guericke University Magdeburg; p.46.
Schmidtke, N., Behrendt F., 2017. Impact analysis of freight transport scenarios on the German transport system – an indicator based approach. Proceedings of the 31. microCAD International Multidisciplinary Scientific Conference. 20-21 Apr 2017, Miskolc (Hungary).
Schwab, K., Sala-i-Martín, X., 2016. The Global Competitiveness Report 2016-2017. Geneva: World Economic Forum; p.188f.
Sokolowki J., Banks C.M., 2009.Principles of Modeling and Simulation: A Multidisciplinary Approach. New York: John Wiley and Sons.
Sonntag H., Liedtke G., 2015. Studie zu Wirkungen ausgewählter Massnahmen der Verkehrspolitik auf den Schienengüterverkehr in Deutschland – Modal Split der Transportleistungen und Beschäftigung. Berlin: Allianz pro Schiene e.V.; p.15.
Verband der Automobilindustrie (VDA), 2006. Mehr Güter – Weniger Verkehr. Brochure. Frankfurt/Main; p.10f.
VerkehrsInfrastrukturFinanzierungsGesellschaft mbH (VIGF), 2015. Geschäftsbericht 2014. Berlin: VIFG; p.10ff.
Waldmann, K.-H., Helm, W.E., 2016. Simulation stochastischer Systeme - Eine anwendungsorientierte Einführung. Berlin, Heidelberg: Springer Gabler; p.116.
Arvis, J.-F., Saslavsky, D., Ojala, L., Shepherd, B., Busch, C., Raj, A., Naula, T., 2016. Connecting to Compete 2016 – Trade Logistics in the Glocal Economy. Washington: World Bank; S.X.
Zsifkovits, H. E., 2013. Logistik. Konstanz: UVK-Verl.-Gesellschaft.

AUTHORS BIOGRAPHY

Laura Baumann is studying Industrial Engineering with the mayor logistics at the Otto von Guericke University (OvGU) in Magdeburg. She works as a research assistant at the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg. Her Bachelor thesis' was about the application of random simulation for the analysis of multidimensional effects to transportation systems**.**

Fabian Behrendt is the head of the Fraunhofer Group of Production, the leading network of applied production research in Germany. In 2016 his dissertation was awarded as the best thesis at the Faculty of Mechanics (OvGU) in Magdeburg. He developed the indicator-based approach presented with its procedure model for estimating multidimensional effects on freight transportation systems in Germany.

Niels Schmidtke is working as a research manager at both, the Institute of Logistics and Material Handling Systems (OvGU) (transport logistics) and the Fraunhofer IFF (Industry 4.0) in Magdeburg. He graduated adapting the approach presented for the analysis of multidimensional effects on passenger transportation systems in Germany**.**

THE EFFECT OF STORAGE AND ROUTING POLICIES ON PICKER BLOCKING IN A REAL-LIFE NARROW-AISLE WAREHOUSE

Teun van Gils[(a)], An Caris[(b)], Katrien Ramaekers[(c)]

[(a),(b),(c)]UHasselt, research group Logistics, Agoralaan, 3590 Diepenbeek, Belgium

[(a)]teun.vangils@uhasselt.be, [(b)]an.caris@uhasselt.be, [(c)]katrien.ramaekers@hasselt.be

ABSTRACT
Upcoming e-commerce markets force warehouses to handle a large number of orders within short time windows. Narrow-aisle order picking systems allow to store a large number of products in small areas. In manual order picking systems, narrow aisles can result in substantial waiting time compared to wide-aisle systems. The objective of this study is to analyse the joint effect of the two main operational order picking planning problems, storage location assignment and order picker routing, on order picking time, including travel time and waiting time due to picker blocking. Multiple horizontal and vertical storage assignment policies, as well as multiple routing policies are simulated with the aim of reducing order picking time. The results of a full factorial ANOVA are used to formulate managerial guidelines to increase order picking efficiency in narrow-aisle systems in order to face the new e-commerce market developments resulting in enhanced customer service.

Keywords: warehouse planning, order picking, picker blocking, simulation

1. INTRODUCTION

Upcoming e-commerce markets force warehouses to handle a large number of orders within short time windows. In order to differentiate from competitors with respect to customer service, warehouses aim at providing quick deliveries to customers. Consequently the remaining time to handle orders is reduced. Moreover, the order behaviour of e-commerce customers is characterised by many orders consisting of only a limited number of order lines (De Koster et al. 2007).

In order to fulfil customer orders, order pickers should retrieve the ordered products from storage locations (i.e. order picking). In this paper, two of the main operational planning problems are studied in a narrow-aisle order picking system: storage location assignment (i.e. determining the physical location at which incoming products are stored) and order picker routing (i.e. determining the sequence of storage locations to visit to compose customer orders) (De Koster et al. 2007).

Order picking management has been identified as an important and complex planning operation as a consequence of the existing relations among planning problems (Van Gils et al. 2016) and the existing trade-offs among decisions. Narrow-aisle picking systems are designed to increase the storage capacity, but multiple order pickers may require to enter the same aisle which results in blocking of order pickers. Moreover, most storage location assignment policies aim to increase the pick density by assigning fast moving stock keeping units (SKUs) to storage locations closely located to the depot in order to reduce the order picker travel time. High pick densities in certain order picking areas increase the probability of picker blocking (Pan and Shih 2008).

The objective of this study is to analyse the joint effect of the two main operational order picking planning problems, storage location assignment and order picker routing, on order picking time, including travel time and waiting time due to picker blocking. Multiple combinations of storage and routing policies are simulated in a real-life narrow-aisle order picking system with the aim of reducing order picking time. Order picking systems in previous research are subject to a large number of assumptions to simplify operations, such as ignoring picker blocking (De Koster et al. 2007; Petersen and Aase 2004) and low-level storage locations (Pan and Wu 2012; Petersen and Aase 2004; Van Gils et al. 2016). Our study narrows this gap between practice and academic research by simulating a real-life business-to-business (B2B) warehouse storing automobile spare parts in a narrow-aisle high-level order picking system, which is a convenient system to store spare parts.

To the best of our knowledge, we are the first to analyse the joint effect of storage and routing policies on the trade-off between travel time and picker blocking time in high-level order picking systems. The main contributions of this paper are managerial insights into the trade-off between reducing travel time and picker blocking by varying storage location assignment and routing policies in a narrow-aisle picking system. Results of this study can be used by warehouse managers to increase order picking efficiency in order to face the new e-commerce market developments.

The remainder of this paper is organised as follows. Section 2 describes the problem context and related literature, followed by the introduction of the case study and the experimental design used in our simulation in Section 3 and Section 4, respectively. In Section 5 results of the simulation study are presented. Section 6 concludes the paper.

2. PROBLEM CONTEXT

As industrial land is expensive in Western Europe, storage space of most warehouses is limited. However, a rising number of customised products require an increased storage capacity. Narrow-aisle warehouse systems allow to store a large number of SKUs in small areas. In manual order picking systems, narrow aisles can result in substantial waiting time due to picker blocking compared to wide-aisle systems (Parikh and Meller 2009). The effect of picker blocking is mainly influenced by three operational factors: storage location assignment (Pan and Shih 2008), routing (Chen et al. 2016), and batching (Hong et al. 2012). As storage location assignment and routing are expected to have the largest influence on picker blocking, we assume the current first-come-first-served batching policy as given. Related literature analysing storage and routing planning problems to minimise the picker blocking is discussed below.

Storage location assignment policies have been introduced in order to reduce the time travelled by order pickers. By increasing the pick density in pick areas close to the depot, picker blocking typically increases as pickers work in the same area (Gue et al. 2006). In contrast to turnover-based storage location assignment, randomly assigning SKUs to storage locations allocates items uniformly over the entire picking area. In this way, order pickers generally utilise the picking area more uniformly resulting in minimal picker blocking to the detriment of an increased travel time (Pan and Shih 2008). Pan and Shih (2008) deal with the effect of storage location assignment policies on blocking and traveling of order pickers in low-level picking systems. High-level order picking systems require traveling in both horizontal and vertical direction (Chan and Chan 2011). As travel time increases, picking aisles will be occupied longer. Consequently, picker blocking is expected to increase in a high-level order picking system. In low-level picking systems, storage classes need to be assigned in horizontal direction, while high-level order picking systems additionally require vertical storage assignment. Fast moving items are preferred at lower levels of storage racks to reduce the traveling and blocking of order pickers.

A wide range of routing methods (e.g. traversal, return, largest gap) have been evaluated in literature in a system with a single order picker, focusing on reducing either travel time or travel distance (De Koster and Van Der Poort 1998; Theys et al. 2010). In practice, multiple order pickers are working in the same order picking area to retrieve items. Efficient methods have been proposed to dynamically change order picking routes during the pick tour for two order pickers and multiple order pickers (Chen et al. 2013; Chen et al. 2016). These complex methods require innovative automation technologies to implement the dynamic order picker routing methods in practice to minimise travel time and picker blocking time simultaneously. Due to this complexity, straightforward routing methods are still widely used in practice (Van Gils et al. 2016).

Previous research considering picker blocking has focused on either storage or routing to minimise the order picking time. Most studies develop analytical models to estimate the travel and picker blocking time, which are subject to a large number of assumptions to simplify order picking operations, such as similar SKUs in terms of size and weight and low-level order picking systems (Pan and Shih 2008; Pan and Wu 2012; Parikh and Meller 2009). This study significantly differs by simulating and evaluating the joint effect of storage location assignment policies and routing policies on the order picking time, considering both traveling and picker blocking in a real-life warehouse, including varying product categories and a high-level order picking system. Incorporating these real-life characteristics makes research more valuable to practitioners.

3. CASE STUDY

Real-life data of a warehouse storing automobile spare parts are used to analyse the joint effect of storage location assignment and routing policies on travel time and picker blocking time. The case is based on an international warehouse located in Belgium that serves the B2B e-commerce market. The simulation focusses on the fully manually operated part of the warehouse with a storage capacity of approximately 20,000 storage locations. The automobile spare parts that are stored in this warehouse area are characterised by a rather large weight. Small and light products are stored in the automated Miniload. The Miniload products are picked separately from all other products. The Miniload is beyond the scope of this study. Besides the Miniload, the order picking area is divided into two other order picking zones: a zone located at the northern part of the warehouse storing the regular weighted product categories and a zone located at the southern part of the warehouse to which the heaviest products are assigned. The layout of the warehouse is shown in Figure 1.

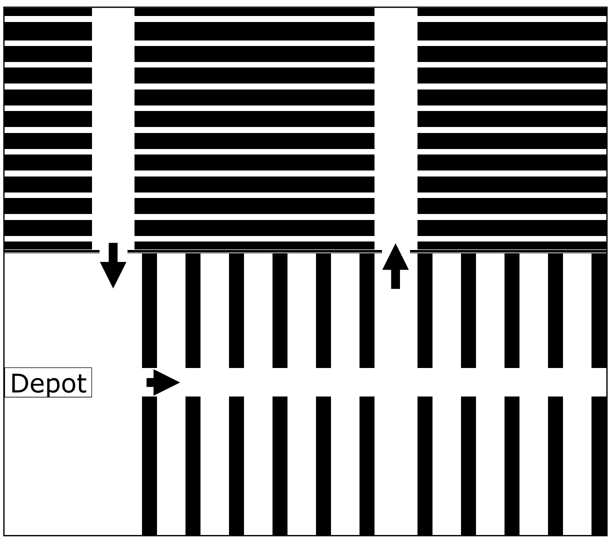


Figure 1: Layout of the Order Picking Area

Both order picking zones consist of three and two warehouse blocks. The number of pick aisles is as follows: eleven and twelve pick aisles in the respective northern and southern zone. A traditional warehouse layout consisting of parallel aisles and cross aisles is frequently used in practice (Roodbergen et al. 2015). Furthermore, cross aisles have proven to result in reduced travel time (Roodbergen and De Koster 2001). However, the number of cross-aisles in the case is limited to a single cross-aisle in the southern zone and two cross-aisles in the northern zone.
Products are divided into eleven product categories, depending on the weight and size, as summarised in Table 1. The heaviest product categories are stored in the southern part of the building in which (vertical) aisles are wide enough to leave the pick truck and pick the items. Leaving the pick truck is not possible in the northern horizontal pick aisles.

Table 1: Order Summary

Product category	Pick zone	# orders (in %)	# storage locations (in %)
A	North	10.53	24.29
B	North	0.26	1.20
C	North	1.15	13.63
D	South	11.57	1.27
E	South	1.32	2.50
F	North	48.92	34.22
G	South	5.53	6.59
H	South	19.71	14.19
I	South	0.08	1.10
J	South	0.16	0.21
K	North	0.76	0.81

The warehouse used for the simulation experiments has the following properties:

- Order picking is performed manually using a picking vehicle with a capacity of four orders. Orders are batched on a first-come-first-served (FCFS) base. Orders from product categories assigned to northern locations cannot be in the same batch as orders from southern product categories.
- Each picking tour starts and ends at the depot in the southern part of the warehouse.
- Due to safety constraints, a maximum of two order pickers is allowed in each subaisle of the southern zone and a single order picker in the smaller subaisles of the northern order picking zone.
- A sort-while-pick strategy is used, maintaining order integrity, so that no downstream sorting is required. Only consolidation of orders from different zones is required after picking.
- Setup times are approximated by an empirical distribution and assumed to be proportional to the number of pick rounds.
- Travel speed is approximated by a Weibull distribution with scale parameter 0.882 and shape parameter 2.29.
- Search and pick times depend on the product category. Times are much larger in case of heavy products compared to the regular products.

4. EXPERIMENTAL DESIGN

The objective of this research is to reduce the order picking time, which results in a more efficient order picking process, by simulating and analysing combinations of storage location assignment and routing policies in a narrow-aisle multi-level warehouse.
Table 2 provides an overview of the three factors and their associated factor levels that will be simulated in this study. The currently applied storage and routing policies are shown in italic and will be used as benchmark to evaluate the proposed policies. In order to generalise the results of the simulation to different order and picker levels, a third factor includes a varying number of order pickers and corresponding number of customer orders: 300 customer orders and 8 order pickers during a pick shift of eight hours corresponds to a low demand, while 375 orders and 10 pickers, and 450 orders and 12 pickers are defined as regular and high demand shifts, respectively. These factor levels have been determined after performing the Resource Schedule Identification Method (RSIM) of Martin et al. (2016), which retrieves resource availability insights from real event logs. The real availability of order pickers during each shift has been retrieved from the picking log using RSMIN, as well as the number of orders corresponding to the levels of order pickers. This method results in a more accurate determination of the demand factor levels.

Table 2: Experimental Factor Setting (Currently Applied Storage and Routing Factor Levels *in Italic*)

Factor	# Levels	Factor levels
Demand	3	8 pickers (300 orders) 10 pickers (375 orders) 12 pickers (450 orders)
Storage	5	random within-aisle 2D perimeter 2D *across-aisle 3D* perimeter 3D
Routing	3	*return* traversal midpoint

The current storage location assignment policy corresponds to a three dimensional (3D) across-aisle policy. The fast-moving items of each product category are stored at the beginning of each aisle, and at the lowest levels of the storage rack, while less frequently ordered items are assigned to storage locations at high levels or storage locations at the end of pick aisles. Besides the 3D across-aisle storage location assignment policy, three policies that are commonly used in studies considering low-level order picking systems are evaluated: random storage, two dimensional (2D) within-aisle (i.e. all items in a pick aisle belong to the same class), and 2D perimeter storage (i.e. storage classes are located around the periphery of the warehouse block). These 2D policies assume racks consisting of a single storage class. Additionally, a 3D perimeter storage location assignment policy is analysed: storage classes are located around the periphery of the warehouse block. Different from the 2D perimeter policy, multiple storage classes can be assigned to different levels of a single storage rack, particularly, storage classes are diagonally distributed within each aisle, as shown in Figure 2: the storage racks are shown horizontally, while the different levels of each rack are illustrated vertically.

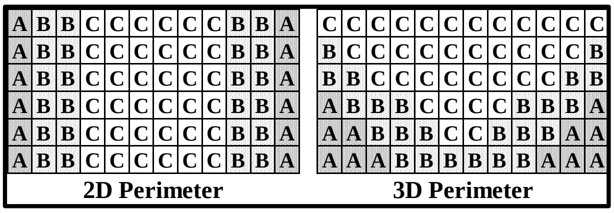


Figure 2: Perimeter Assignment of Storage Classes within each Pick Aisle

Routes are currently constructed based on the return routing (i.e. order pickers enter and leave an aisle from the same end), except for the last aisle to visit in the middle warehouse block of the northern zone, which is traversed completely from right to left. In addition to return routing, the effects of traversal and midpoint routing policies in the middle warehouse block of the northern zone are analysed. As other warehouse blocks are connected to a single cross-aisle, routing is limited to returning to this cross-aisle.

To summarise, the simulation experiment consists of 45 factor level combinations (i.e. three demand levels × five storage levels × three routing levels). The factorial setting results in a 3×5×3 full factorial design. The performance of the policy decisions is evaluated with regard to the travel time of order pickers, the waiting time as a result of picker blocking, and the total order picking time consisting of setup time, search and pick time, travel time and waiting time. The setup time is assumed to be directly proportional to the number of pick rounds, while searching and picking is proportional to the number of order lines in a pick round. Both setup time and search and pick time are assumed to be independent of the storage and routing policy.

5. RESULTS AND DISCUSSION

This sections analyses and discusses the results of the simulation experiments. The simulation model was built in ARENA. Section 5.1 presents the results of the ANOVA test. The interaction effect of storage location assignment and routing is analysed and explained in Section 5.2 using post hoc tests. Managerial implications are provided in Section 5.3.

5.1. ANOVA Results

In order to get a first insight into the results of the simulation experiments, the policy combinations of storage location assignment and routing are statistically analysed with respect to the travel time, waiting time and total order picking time. In accordance with Petersen and Schmenner (1999) and Van Gils et al. (2016), the results of the simulation experiments are evaluated by a full factorial ANOVA to analyse which factors impact travel and waiting time. Moreover, the ANOVA tests whether the interaction of storage and routing decision policies significantly influences the order picking time. The assumptions under which the ANOVA *F* statistic is reliable, are normally distributed observations, homogeneity of variance, as well as independent observations. When group sizes are equal, the *F* statistic is quite robust to violations of normality (Cohen et al., 2011). As the experimental design is balanced and each factor level combination is tested for thirty replications to reduce the stochastic effect resulting from the random generation of orders, normality can be assumed. The homogeneity assumption is violated in the experiments, resulting in an increased type I error rate. The Greenhouse-Geisser (*G-G*) adjustment is the most conservative correction to compensate for the violation in homogeneity. To compensate for the increased error rate, the degrees of freedom in the *F*-test are reduced in accordance with *G-G* (Geisser et al. 1958). In order to ensure the last ANOVA assumption (i.e. independency), the simulation results are analysed by a mixed-model ANOVA (Cohen et al. 2011). Independency is violated as each combination of storage and routing policy is tested on the same randomly generated list of customer orders to stress the effects of the policy decisions. Consequently, the simulation results are not independent and a mixed-model ANOVA with storage and routing as within-subjects factors is required to analyse the main and interaction effects of the policy decisions.

Table 3: 3×5×3 Mixed-Model ANOVA on Travel Time with Storage (*S*) and Routing (*R*) as Within-Subjects Factors and Demand (*D*) as Between-Subjects Factor

Factors	*SS* ($\times 10^9$)	*df*	*F*	Sign.
D	1,001.16	2.0	147.81	0.000
S	88.30	3.4	1,052.07	0.000
R	679.03	1.4	4,515.15	0.000
D×S	1.80	6.9	10.75	0.000
D×R	15.32	2.8	50.94	0.000
S×R	13.34	6.7	100.58	0.000
D×S×R	0.40	13.5	1.50	0.109
Betw. subj.	294.63	87.0		
Within S	7.30	299.4		
Within R	13.08	122.1		
Total	2,114.36	545.3		

The results of the full factorial ANOVA are presented in Table 3, Table 4, and Table 5 showing the importance of each experimental factor, as well as the interaction effect among the factors with regard to travel time, waiting time and total order picking time, respectively. The first columns show the sum of squares (*SS*) and *G-G* adjusted degrees of freedom (*df*) of the main and interaction effects. The last two columns are devoted to the *F* statistic and *p*-value for testing the statistical significance of the demand factor, storage factor, routing factor, and the interaction effects among the three factors.

Table 4: 3×5×3 Mixed-Model ANOVA on Waiting Time with Storage (*S*) and Routing (*R*) as Within-Subjects Factors and Demand (*D*) as Between-Subjects Factor

Factors	*SS* ($\times 10^9$)	*df*	*F*	Sign.
D	36.65	2.0	263.91	0.000
S	56.94	2.0	1,222.32	0.000
R	10.47	1.7	837.38	0.000
D×S	11.79	4.0	126.51	0.000
D×R	1.50	3.3	60.08	0.000
S×R	3.20	5.0	114.83	0.000
D×S×R	0.56	10.1	10.13	0.000
Betw. subj.	6.04	87.0		
Within S	4.05	173.1		
Within R	1.09	144.9		
Total	132.29	433.1		

Table 5: 3×5×3 Mixed-Model ANOVA on Total Order Picking Time with Storage (*S*) and Routing (*R*) as Within-Subjects Factors and Demand (*D*) as Between-Subjects Factor

Factors	*SS* ($\times 10^9$)	*df*	*F*	Sign.
D	2,971.98	2.0	213.64	0.000
S	94.30	2.9	600.38	0.000
R	606.65	1.6	3,943.92	0.000
D×S	10.72	5.7	34.13	0.000
D×R	13.90	3.1	45.19	0.000
S×R	11.43	5.5	54.15	0.000
D×S×R	0.59	10.9	1.41	0.167
Betw. subj.	604.92	87.0		
Within S	13.67	249.8		
Within R	13.38	136.4		
Total	4,340.55	504.9		

In accordance with previous academic literature (Petersen and Schmenner 1999; Van Gils et al. 2016), our results indicate that the main effect of storage location assignment and picker routing, as well as the interaction effect of storage location assignment and picker routing are statistically significant regarding travel time (see Table 3). Furthermore, Table 4 shows that both storage location assignment and the picker routing policy decisions statistically significantly influences waiting time of order pickers. This means that there is a significant difference in average waiting time of order pickers between the five storage location assignment policies, as well as between the three routing policies. In other words, the decision on which storage and which routing policy to use in order picking operations does influence the waiting time of order pickers and resulting total order picking time, as shown in Table 5. These results show that either travel distance or travel time measures are insufficient to evaluate the efficiency of storage and routing policies.

In addition to the main effects of storage and routing, the joint effect of storage location assignment and picker routing is statistically significantly impacting travel time, waiting time and total order picking time. This implicates that warehouse managers should consider decisions on storage and routing simultaneously in order to minimise order picking time.

5.2. Post Hoc Test Results

While the ANOVA results show that storage and routing are related, interaction plots and post hoc tests are able to support explaining why the storage and routing planning problems are related. The statistical significance of all levels of the routing factor for each storage factor are analysed using a Bonferroni t-test. The Bonferroni method seems to be the most robust technique in terms of power and control of the Type I error rate for evaluating multiple hypotheses (Field, 2013).

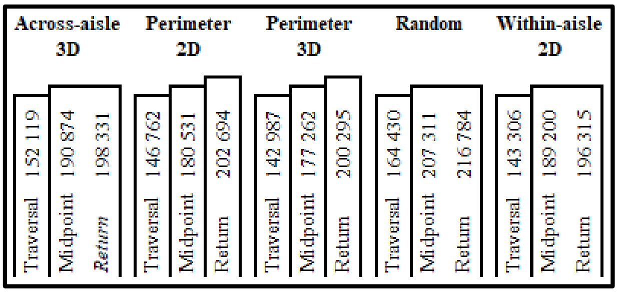


Figure 3: Multiple Bonferroni t-Test (Familywise Error Rate = 0.01) for Routing Policies by Storage Policies on Average Travel Time (in Seconds)

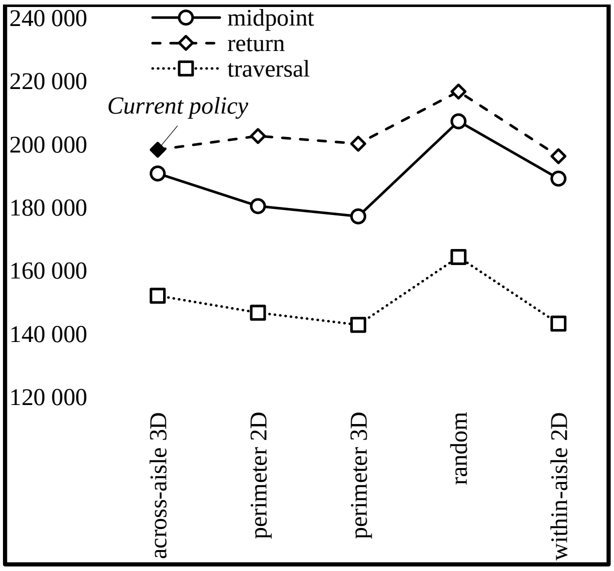


Figure 4: Average Travel Time (in Seconds) for each Combination of Storage, and Routing Policy

Figure 3 shows the results of the post hoc test on average travel time. If two routing policies are listed in the same subset, differences fail to be statistically significant. Minor differences exist in the composition of subsets between the different storage policies. With respect to the travel time of order pickers, the traversal routing policy outperforms return and midpoint routing policies in combination with all storage location assignment policies. The traversal routing policy is located in a separate subset in combination with all storage location assignment policies, while results of the post hoc test indicate that the travel time difference between return and midpoint routing policies is only statistically significant in combination with the 2D and 3D perimeter storage policies. This can be explained as follows: perimeter storage classes assign fast moving SKUs along the periphery of the warehouse, and the midpoint routing heuristic follows the periphery of the warehouse blocks, resulting in a significant reduction in travel time compared to the return routing method. The interaction plot of Figure 4 illustrates the decreased travel time by combining perimeter storage and midpoint routing. Furthermore, the interaction plot shows that on average the combination of traversal routing with either 3D perimeter or 2D within-aisle storage classes yields the minimum travel time.

Post hoc test results on average waiting time are illustrated in Figure 5. The creation of different subsets for the storage policies explain why the storage and routing planning problems are related with respect to average waiting time. The midpoint routing policy outperforms other routing policies in combination with all other storage location assignment policies. Remember that the routing methods only differ in the middle warehouse block of the northern zone. The midpoint routing policy allows two order pickers entering simultaneously in each aisle of the middle warehouse block: one order picker at each side of the warehouse block. Only a single order picker is allowed in each pick aisle in case of return routing and two order pickers may enter each aisle in case of traversal routes, but additional blocking occurs within aisles as the narrow aisles are not wide enough for order pickers to pass each other.

Figure 6 illustrates that the benefits resulting from two-side entering (i.e. midpoint routing) increase in combination with perimeter storage policies and random storage. This can be explained by the fact that fast moving SKUs are diffused across the warehouse block, while across-aisle and within-aisle storage policies concentrate fast moving SKUs across one side of the warehouse block and within a single pick aisle, respectively. Consequently, the combination of midpoint routing and either perimeter or random storage enables retrieving A-items by more order pickers simultaneously: two pickers per aisle can visit A-locations simultaneously. Other routing policies in combination with perimeter or random storage cause additional blocking within a pick aisle (i.e. traversal routing) or the number of pickers that is able to simultaneously visit A-locations is limited to a single picker (i.e. return routing). Combining across-aisle storage with midpoint routing causes A-locations to be visited by a single order picker per aisle as A-items are located at one side of the warehouse block. Within-aisle storage classes allow only two order pickers to visit A-locations simultaneously as all A-items are located in a single aisle resulting in substantially increased waiting times.

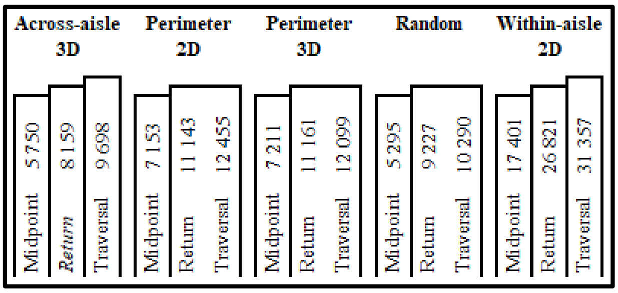


Figure 5: Multiple Bonferroni t-Test (Familywise Error Rate = 0.01) for Routing Policies by Storage Policies on Average Waiting Time (in Seconds)

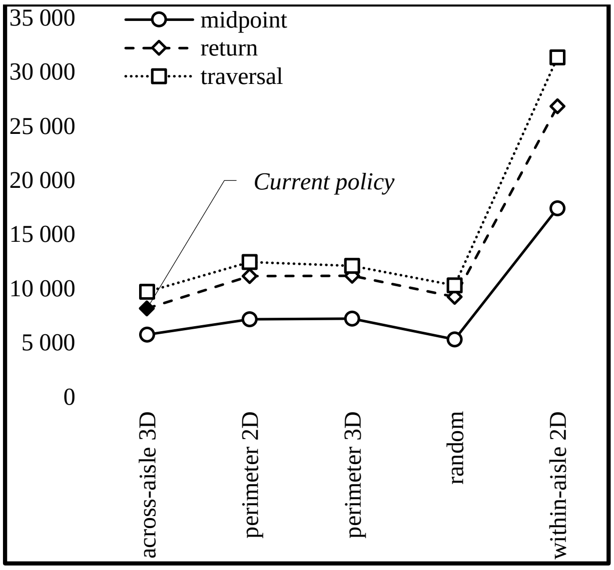


Figure 6: Average Waiting Time (in Seconds) for each Combination of Storage, and Routing Policy

The results of the post hoc test with respect to the average total order picking time, including setup time, search and pick time, travel time, and waiting time are illustrated in Figure 7. Analysing perimeter storage classes, three subsets of routing policies are created, while combining either midpoint or return routing with other storage policies does not result in statistically significant different order picking times, despite the significant lower waiting times resulting from midpoint routing.

While the interaction plot illustrating picker traveling shows that on average the combination of traversal routing with either 3D perimeter or 2D within-aisle storage classes yields the minimum travel time, Figure 8 shows that traversal routing in combination with 2D within-aisle storage classes results in a substantially higher total order picking time compared to the traversal routing combined with 3D perimeter storage. This result supports the ANOVA results that warehouse managers may choose an inefficient storage and routing policy when only travel distance or travel time are considered as these performance measures ignore the strong increase in waiting time in case of within-aisle storage classes. Finally, the interaction plots show that the difference between 2D and 3D storage locations is rather small with respect to all three performance measures. More structured experiments, in which all storage assignment policies are tested on a 2D as well as a 3D factor level, are required to generalise and explain this finding.

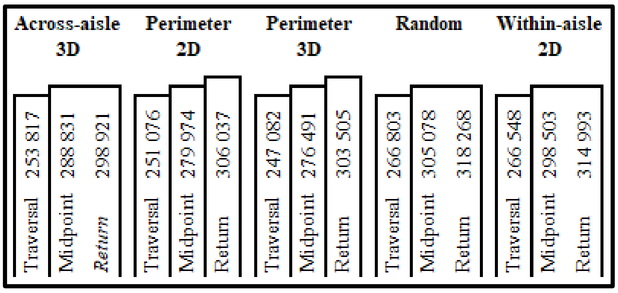


Figure 7: Multiple Bonferroni t-Test (Familywise Error Rate = 0.01) for Routing Policies by Storage Policies on Average Total Order Picking Time (in Seconds)

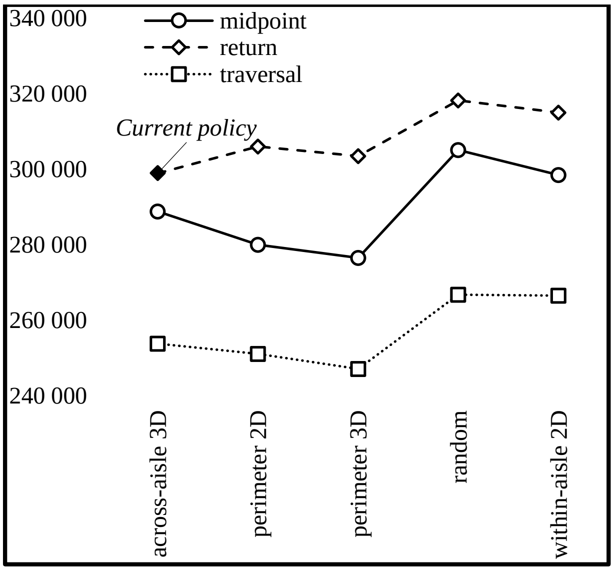


Figure 8: Average Order Picking Time (in Seconds) for each Combination of Storage, and Routing Policy

To summarise, traversal routes results in the shortest average travel times, while order pickers are blocked longer in case of traversal routes. Midpoint routes yield the shortest waiting times, but travel times increase significantly compared to traversal routes. With respect to the average total order picking time, traversal routes outperforms midpoint routes as travel time accounts for a larger part of the total order picking time.

5.3. Managerial Implications

The results of the simulation experiments show the importance of combining storage and routing decisions in order to manage order picking activities efficiently. The benchmark policy combination corresponds to the current applied policy combination to manager order picking operations in the warehouse: 3D across-aisle storage location assignment and return routing, limited to a single order picker per aisle. The results of the benchmark and the best performing policy combination are summarised in Table 6.

Table 6: Total Order Picking Time for Benchmark and Best Policy Combination

	Total order picking time (in s)
Benchmark: across-aisle 3D – return	
High demand	359,241
Regular demand	296,937
Low demand	240,583
Average	298,921
Best policy combination: perimeter 3D – traversal	
High demand	298,292
Regular demand	245,083
Low demand	197,870
Average	247,082
Reduction (in %)	
High demand	17.0
Regular demand	17.5
Low demand	17.8
Average	17.3

The benchmark results in an average total order picking time of 298,921 seconds, including setup time, search and pick time, travel time and waiting time. The simulation experiments show that the 3D perimeter storage policy in combination with traversal routing yields a substantially reduced order picking time, in shifts with high, regular, as well as low demand. On average, the order picking process can be performed 17.3% more efficiently by reconsidering the storage location assignment and routing policy. The average reduced order picking time corresponds to a reduction of 5.4 full time equivalents per day $\left(\frac{17.3\% \times 298{,}921\text{ s}}{28{,}800\text{ s}} \times 3\right)$, assuming three 8-hour shifts (28,800 s) per day. As the simulation experiments have focused on operational order picking planning problems only, the proposed combinations are rather easy to implement and result in substantial performance benefits.

6. CONCLUSIONS

Serving e-commerce markets forces warehouses to handle a growing number of orders in shorter time windows. Decisions on the assignment of SKUs to storage locations, as well as the routing of order pickers in a narrow-aisle warehouse, should be considered in order to optimise order picking operations.
In this paper, the joint effect of the two main operational order picking planning problems (i.e. storage location assignment and picker routing) on order picking time, including travel time and wait time, is analysed and explained for the first time. The simulation results and statistical analysis provides policy combinations that help practitioners to improve the overall order picking performance under varying order picker levels and order levels. The traversal routing policy and 3D perimeter

storage classes can be easily implemented and immediately result in performance increases of up to 17%.

Moreover, the real-life case study shows the value of combining storage and routing decisions in practice. By considering a wide range of real-life characteristics, such as picker blocking, high-level storage locations, and product weight restrictions, the results are highly relevant to practice and largely unexplored in literature combining order picking planning problems. However, we should note that the simulation experiments are based on a single case study. In order to generalise the conclusions of this study, storage location assignment policies and routing policies should be tested on traditional rectangular picking layouts (i.e. order picking areas consisting of parallel pick aisles and one or more straight cross aisles). Moreover, the effect of 3D storage location assignment policies, compared to 2D storage policies, will be valuable knowledge that can be used to design efficient order picking systems.

ACKNOWLEDGMENTS

This work is partially funded by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (research project COMEX, Combinatorial Optimization: Metaheuristics & Exact Methods).

The computational resources and services used in this work were provided by the VSC (Flemish Supercomputer Center), funded by the Research Foundation - Flanders (FWO) and the Flemish Government – department EWI.

REFERENCES

Chan F.T.S., Chan H.K., 2011. Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage. Expert Systems with Applications 38, 2686–2700.

Chen F., Wang H., Qi, C., Xie Y., 2013. An ant colony optimization routing algorithm for two order pickers with congestion consideration. Computers & Industrial Engineering 66, 77–85.

Chen F., Wang H., Xie Y., Qi C., 2016. An ACO-based online routing method for multiple order pickers with congestion consideration in warehouse. Journal of Intelligent Manufacturing 27, 389–408.

Cohen B.H., Welkowitz J., Lea R.B., 2011. Introductory Statistics for the Behavioral Sciences (7th Edition). John Wiley & Sons, Hoboken, NJ, USA.

De Koster R., Le-Duc T., Roodbergen K.J., 2007. Design and control of warehouse order picking: A literature review. European Journal of Operational Research 182, 481–501.

De Koster R., Van Der Poort E., 1998. Routing order pickers in a warehouse: a comparison between optimal and heuristic solutions. IIE transactions 30, 469–480.

Field A., 2013. Discovering Statistics using IBM SPSS Statistics. SAGE.

Geisser S., Greenhouse S.W., 1958. An extension of box's results on the use of the F distribution in multivariate analysis. The Annals of Mathematical Statistics 29, 885–891.

Gue K.R., Meller R.D., Skufca J.D., 2006. The Effects of Pick Density on Order Picking Areas With Narrow Aisles. IIE Transactions, 38 38, 859–868.

Hong S., Johnson A.L., Peters B.A., 2012. Batch picking in narrow-aisle order picking systems with consideration for picker blocking. European Journal of Operational Research 221, 557–570.

Martin N., Bax F., Depaire B., Caris A., 2016. Retrieving resource availability insights from event logs, in: Enterprise Distributed Object Computing Conference (EDOC), 2016 IEEE 20th International. IEEE, pp. 1–10.

Pan J.C.-H., Shih P.-H., 2008. Evaluation of the throughput of a multiple-picker order picking system with congestion consideration. Computers & Industrial Engineering 55, 379–389.

Pan J.C.-H., Wu M.-H., 2012. Throughput analysis for order picking system with multiple pickers and aisle congestion considerations. Computers & Operations Research 39, 1661–1672.

Parikh P.J., Meller R.D., 2009. Estimating picker blocking in wide-aisle order picking systems. IIE Transactions 41, 232–246.

Petersen C.G., Aase G., 2004. A comparison of picking, storage, and routing policies in manual order picking. International Journal of Production Economics 92, 11–19.

Petersen C.G., Schmenner R.W., 1999. An Evaluation of Routing and Volume-based Storage Policies in an Order Picking Operation. Decision Sciences 30, 481–501.

Roodbergen K.J., De Koster R., 2001. Routing methods for warehouses with multiple cross aisles. International Journal of Production Research 39, 1865–1883.

Roodbergen K.J., Vis I.F.A., Don Taylor Jr G., 2015. Simultaneous determination of warehouse layout and control policies. International Journal of Production Research 53, 3306–3326.

Theys C., Bräysy O., Dullaert W., Raa B., 2010. Using a TSP heuristic for routing order pickers in warehouses. European Journal of Operational Research 200, 755–763.

Van Gils T., Braekers K., Ramaekers K., Depaire B., Caris A., 2016. Improving Order Picking Efficiency by Analyzing Combinations of Storage, Batching, Zoning, and Routing Policies, in: Paias, A., Ruthmair, M., Voß, S. (Eds.), Lecture Notes in Computational Logistics, Lecture Notes in Computer Science. Springer International Publishing, pp. 427–442.

AUTHORS BIOGRAPHY

Teun van Gils graduated in 2014 as a Master of Science in Business Engineering with a major in Operations Management and Logistics at Hasselt University, Belgium. In October 2016, he started his PhD focusing on operational order picking planning problems.

An Caris was appointed in 2012 as Assistant Professor at the Faculty of Business Economics (BEW) of Hasselt University. She obtained her PhD in Applied Economics in 2010 and was first a postdoctoral research fellow of the Research Foundation - Flanders (FWO). Her research interest goes to the application of Operations Research (OR) techniques in the field of operations management and logistics. In her PhD thesis she focused on the competitiveness of intermodal transport making use of inland navigation. Currently she studies planning problems in warehouse operations, intermodal rail transport, collaborative logistics and healthcare logistics.

Katrien Ramaekers is Assistant Professor in Operations Management and Logistics at the Faculty of Business Economics (BEW) of Hasselt University (Belgium). She graduated as master in Business Engineering at the Limburg University Centre, Belgium, in 2002. She obtained her PhD in Applied Economics in 2007 at Hasselt University. In her PhD she developed a simulation optimization framework for inventory management decision support based on incomplete information. Her research interest goes to the application of Operations Research techniques in the field of operations management and logistics, with a strong focus on simulation (optimization). Current research domains are warehouse operations, healthcare logistics and cost allocation in intermodal barge transport.

THE IMPACT OF REPLENISHMENT FREQUENCY ON THE LOGISTICS COST-A SIMULATION APPROACH

Sameh M. Saad[a] and Ramin Bahadori[b]

[a][b]Department of Engineering and Mathematics,
Sheffield Hallam University, City campus Howard street Sheffield S1 1WB, UK

[a]S.Saad@shu.ac.uk, [b]b2047010@my.shu.ac.uk

ABSTRACT
The aim of this research is to optimise logistics cost through fractal supply network by investigating the effect of different replenishment frequencies within fractal supply network. A new mathematical model is developed through which inventory holding cost and transportation cost can be integrated and measured at different sub-fractal of the fractal supply network. The proposed mathematical model is implemented through the hypothetical fractal supply network and validated using Supply Chain GURU Simulation Software. Application of the proposed mathematical model provides a systematic method through which practitioners should be able to decide upon replenishment frequency at different sub-fractal of the network. Moreover, it shows that the proposed fractal supply network and its capabilities have ability to optimise and achieve the lowest logistics cost through the supply network.

Keywords: Fractal supply network, Supply network modelling, Logistics cost optimisation.

1. INTRODUCTION

Logistics processes affect the customer satisfaction, product value, benefits and operating costs and it is important in two aspects; essential and costly (Aronsson et al 2003). Enhancing delivery performance and reduce costs which are caused by activities related to logistics of a company or a supply chain are aims of logistics management (Borgqvist and Hultkrantz, 2005).

The concept of total cost of logistics is very important because this criterion can be a good basis for cost-cutting analysis. Effective logistics cost reduction is very dependent on an integrated and systematic approach, while the focus on minimising the cost of each area separately may be offset by increasing costs in other areas (Stock and Lambert, 2001). Total logistics costs are often provided as a large part of total sales revenue (Min et al., 2009). The definitions of logistics costs are vary in different companies. In large number of companies, logistics costs reports are different even with similar business and there are different items at their own expense. However, the main activities of the operational logistics including transportation, handling, storage and maintenance of inventory make up the key logistics costs (Gudehus and Kotzab, 2009). In terms of logistics, inventory holding and transportation are the most important costs for strategic development of enterprises (Cesca, 2006). The result of a study was conducted in the America logistics costs in 2008 shows that transportation costs are the most important component with 50%, followed by inventory holding cost with 20%, warehousing with 20%; costs related to customer service / order processing with 7% and administrative costs was 3% of the total cost of logistics (Rushton, 2010).

Transportation costs include the cost of transportation equipment such as equipment depreciation and operating costs such as fuel costs, payroll, toll and insurance (Chao-yang et al., 2011). Rent and maintenance of vehicles are also part of the cost of transportation. Size and weight of transported goods, travelling distance, number of deliveries, hours of operation (Somuyiwa, 2010), loading capacity, transportation responsibility to the risk of product failure and accidents are drivers of transportation cost (Chao-yang et al., 2011).

Inventory holding costs include the cost of capital, risk, services related to inventory, and variable costs of warehouse space, because it depends on the level of inventory (Stock and Lambert, 2001). Most effective factors in inventory are purchase method, amount of demand, inventory turnover, changes in inventory levels, and types of warehouse and efficiency of data transmission system (Chao-yang et al., 2011).

2. FRACTAL SUPPLY NETWORK

Fractal supply network can be defined as a reconfigurable supply network which has the ability to present many different problem solving methods under the terms of various situations (Fan and Chen, 2008). Fractal supply network attracting many of industrialists because of its capabilities such as self-similarity, self-optimisation, self-organisation, goal orientation, and dynamics (Warnecke, 1993).

Self-similarity means each fractal unit is similar to another fractal unit while they can have their own structure (Attar and Kulkarni, 2014). Although, fractal units may have a different condition and internal structure in comparison to another they can have a same target in the system. Therefore, in the fractal supply network, fractals are self-similar if they can achieve goals in the system with different internal structure while inputs and outputs are same (Ryu et al, 2013). Higher self-similarity in the supply network can increase the information sharing, operation coordination and degree of integration among the fractal units and decrease the complexity of the system and make supply network to be understood and managed clearly (He, 2010).

Self-optimisation means each fractal unit as independent unit has ability to improve its performance continuously. Fractals choose and use suitable methods to optimise operation and decision making processes with coordination of the whole system to achieve the goals (Attar and Kulkarni, 2014; He, 2010; Ryu et al., 2013).

Self-organisation (dynamic restructuring) refers to support the reconfiguration of network connections between fractals and the reorganisation of fractals in the system (Ryu and Jung, 2003). It means each fractal is free to make decision about the organisation dimension which is require for special performance with regards to environmental parameter and the goals (He 2010) without external intervention (Leitão and Restivo, 1999). In fact, self- organisation as a kind of supply chain organisation convert irregular condition into regular condition without outer monitoring and control to offer products and services to customers constantly (Fan and Chen, 2008).

Goal orientation enables the system goals to be achieved from the goals of individual fractals (Warnecke, 1993). Fractal units perform a goal-formation process to generate their own goals by coordinating processes with the participating fractals and modifying goals if necessary (Ryu and Jung, 2003)

Dynamics refer to cooperation and coordination between self- organising fractals which are characterised by a high individual dynamics and an ability to restructure their processes to meet and adapt to the dynamically changing environment (Ryu and Jung, 2003).

3. LOGISTICS COST INTEGRATION

Nowadays, to provide value advantages in the supply chains companies try to decrease inventory with higher replenishment frequency. However, it may leads to increase in the transportation cost due to longer travel distances. In addition, inventory holding cost and transportation cost are independent to each other; both of them are function in replenishment frequency with inverse and direct relationship respectively.

Therefore, contrast between transportation cost and inventory holding cost has been focused for planning activities. Viau et al. (2007) used Decision Support Systems (DSS) model to integrate inventory control and transportation operation in the spread supply chain by considering delivery frequency and date of delivery to nodes (e.g. Friday and Monday) as variables. Moreover, mathematical models of inventory holding cost and transportation cost are created in order to reduce logistics cost. Qu et al. (1999) developed mathematical model to integrate inventory and transportation policies by considering a central warehouse and several suppliers under stochastic demand during a period time. Hong et al. (2012) presented a model to integrate inventory and transportation for ubiquitous supply chain management and developed mathematical model which demand of products assumed as linear, convex and concave function of price. Chen et al. (2012) used non-linear programing to minimise both inventory cost and transportation cost. They developed a model with one supplier and several retailers and compared the results with traditional approach which was based on Economic Order Quantity (EOQ). Kutanoglu and Lohiya (2008) built inventory model in terms of single-echelon and multi-facility and integrated with both transportation and service responsiveness. They use three alternate modes namely slow, medium and fast in the service parts logistics system. Hong Zhao et al. (2010) developed an algorithm to solve Markov decision process model which was applied to formulate ordering and delivery problems based on vary transportation modes, costs and inventory issues. Pei et al. (2012) used bi-level programming method to establish mathematics model in order to integrate and optimise inventory and transportation cost with probable demand and various products. Swenseth and Godfrey (2002) proposed a method to approximate the actual transportation cost with truckload freight rates into inventory replenishment decisions in order to minimise the total logistics cost. They claimed that the complexity arising from incorporating transportation cost into inventory replenishment policies does not affect the accuracy of decisions. Zhao et al. (2004) introduced the problem of minimising the production, inventory and transportation costs in a two- echelon system model. They made a trade-off among production, inventory and transportation costs and considered both the fixed cost and the variable cost of the vehicles.

There is some research focused on integration of inventory and transportation in order to minimise logistics costs. However, in terms of fractal supply network, there is very few technical research carried out in this area. The focus of this paper is to optimise logistics cost by investigating the different replenishment frequencies on both transportation and inventory holding through fractal supply network.

4. THE PROPOSED MATHEMATICAL MODEL

In order to achieve the lowest total logistics cost through each fractal in the fractal supply network, both inventory holding costs and transportation costs can be integrated to choose the best match and find the optimum amount of replenishment frequency. Through understanding the mathematical equations governing the problem of inventory holding costs (IHC) and transportation costs (T(c)); mathematical model is presented briefly as follows due to space limitation, which will be presented in details during the conference.

$$Min\left(\left\{\sum_{j}^{n} SS_j + DBR \times \left(\frac{\sum_{j=1}^{n} SS_j \sum_{j}^{n} TD_j}{2T}\right) + \frac{\left(\sum_{j=1}^{n} SS_j \sum_{j}^{n} TD_j\right) t}{T}\right\} \times C_{(v)}/P_{(v)} \times \frac{T}{365} \times I_{(cc)\%} + td \times \frac{\sum_{j=1}^{n} SS_j \sum_{j}^{n} TD_j}{DBR \times \mu_d} \times A_{(C)}\right),$$

$$DBR = 1, \ldots, x$$

Where
SS =Safety stock
DBR = Days between replenishment
TD = Total demand of component/product j
j = Index number of different component/product
n= Number of different component/product
T = Time period
t= Transportation time
$C_{(v)}$ = Component value
$P_{(v)}$ = Product value
$I_{(cc)\%}$ =Inventory carrying cost percentage
td =Travel distance
μ_d = Average daily demand
$A_{(c)}$ = Average transportation cost per mile

5. MODEL VERIFICATION AND VALIDATION

The validity of the developed simulation model was evaluated by comparing the performance of the model to the conceptual system (manually calculated). Experiments were carried out, to investigate how robust the proposed model is, the output values obtained from the simulation model were not found significant difference (at most 10.8%) to the estimated values of the conceptual system. Therefore, this increases our confident in the proposed model and can be considered as a valid model for analysis and experimentation and the obtained results should be reliable within this percentage of error. The output values obtained will be presented at the conference.

6. APPLICATON OF THE PROPOSED MODEL

In this study, a simple hypothetical fractal supply network located in England with a core manufacturer (M) located in the Sheffield and deals with just one type of product (K) with value of £100 per product made from different components is considered. Due to long lead times from suppliers to manufacturer, a central supply hub (H) (12.04 miles from core manufacturer) built close to the manufacturer located in Chesterfield. Components are supplied from the following suppliers to Supply Hub (H):

- S_1 (Norwich) deals with a single component (c_1) with a value of £20 (141.2 miles from Supply Hub (H)).
- S_2 (Sunderland) deals with a single component (c_2) with a value of £10 (133.51 miles from Supply Hub (H)).
- S_3 (Swansea) deals with a single component (c_3) with a value of £30 (180.18 miles from Supply Hub (H)).
- S_4 (Southampton) deals with a single component (c_4) with a value of £40 (187.99 miles from Supply Hub (H)).

Moreover, there is a distribution centre (D) (75.19 miles from core manufacturer) dealing with finished product located in in Birmingham with five retailers, including Oxford (R_1) (67.15 miles from distribution centre), Cambridge (R_2) (101.94 miles from distribution centre), Cardiff (R_3) (103.5 miles from distribution centre), Leeds (R_4) (107.55 miles from distribution centre) and Liverpool (R_5) (91.84 miles from distribution centre). The proposed hypothetical fractal supply network is implemented in the Supply Chain Guru Simulation Software within which the proposed mathematical model mentioned in previous section is in-cooperated. Figure 1 displays a snap shot of the GURU model created for the hypothetical supply network.

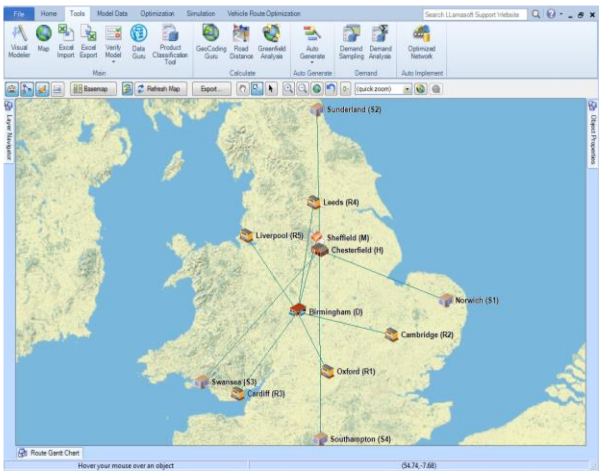


Figure 1: Supply Chain Guru Screen Shot of the Considered Fractal Supply Network

In accordance with fractal theory, each member of the supply network can be a fractal by itself, and also any combination of members can be a fractal as well. Figure 2 displays the composition of the of the considered hypothetical fractal supply network. The upstream stage deal with components (c_1,c_2,c_3 and c_4) and consists of three levels; the manufacturer (M) as top level, the supply hub (H) as middle level and suppliers (S_1,S_2,S_3 and S_4) as bottom level. The downstream stage deal with product (K) also consists of three levels; manufacturer (M) as top level, the distribution centre (D) as middle level and retailers (R_1, R_2, R_3, R_4, and R_5) as bottom level.

In this study, the following compositions of the fractals in the both upstream and downstream stage are assumed and applied in the Supply Chain Guru Simulation Software:

- M in the upstream stage can be considered as a fractal named (Fr-M_1) with one sub fractal (H).
- H can be considered as a fractal named (Fr-H) with four sub fractals (S_1, S_2, S_3 and S_4).
- M in the in the downstream stage can be considered as a fractal named (Fr-M_2) with one sub fractal (D).
- D in the downstream stage can be considered as a fractal named (Fr-D) with five sub fractals (R_1, R_2, R_3, R_4, and R_5).

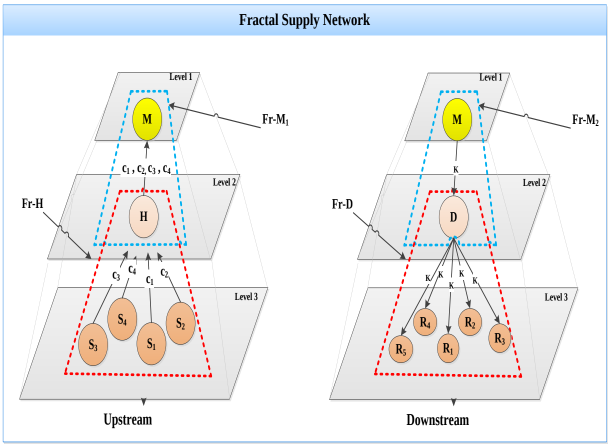


Figure 2: Composition of Fractals in Fractal Supply Network

Retailer's demand of one-month test period for the one type of product (K) has been recorded as shown in Table 1.

Table1: Retailers' Demand of one-month Test Period

	01/12/16	08/12/16	15/12/16	22/12/16	29/12/16
R_1	1000	1000	1000	1000	1000
R_2	N(1000,100)	N(1000, 100)	N(1000, 100)	N(1000, 100)	N(1000, 100)
R_3	N(1000,200)	N(1000, 200)	N(1000, 200)	N(1000, 200)	N(1000, 200)
R_4	N(1000,300)	N(1000, 300)	N(1000, 300)	N(1000, 300)	N(1000, 300)
R_5	N(1000,400)	N(1000, 400)	N(1000, 400)	N(1000, 400)	N(1000, 400)

Moreover, there are some other assumptions as follows:

- The lead time required for all components and product to be replenished from the source sites is assumed to be 1 day.
- The percentage of Inventory carrying cost is assumed to be 12 percent of total value of inventory. In practice, this percentage is identified by senior managers in the company.
- There is a transportation system from a third party with two types of transportation assets (no capacity limitation) to ship components and products from source sites to destination sites, namely; Full truck load (TL) which is assigned to the distance of more than fifty miles with average transportation cost per mile ($A_{(c)}$) of £1 and Less than truck load (LTL) which is assigned to the distance of less than fifty miles with average transportation cost per mile ($A_{(c)}$) of £2.
- Days between replenishment should not be more than 5 days.

With respect to fractal supply network capability each fractal unit as independent unit has ability to improve its performance continuously. Fractals choose and use suitable methods to optimise operation and decision making processes with coordination of the whole system to achieve the goals. Therefore, in this study each fractal investigated different days of replenishment from 1 day to 5 days aiming to minimise its logistics cost and whole network as well.

7. RESULT

As shown in figure 3 the results proved that during the demand of one-month test period for supplying components in the Fr-H, the lowest logistics cost can be achieved with day between replenishment of five days from each supplier (S_1, S_2, S_3 and S_4) to supply hub (H) . Moreover, in terms of Fr-M1, the results showed that during the demand of one-month test period for supplying components from supply hub (H) to Manufacture (M), the lowest logistics cost can be achieved with day between replenishment of 1 day.

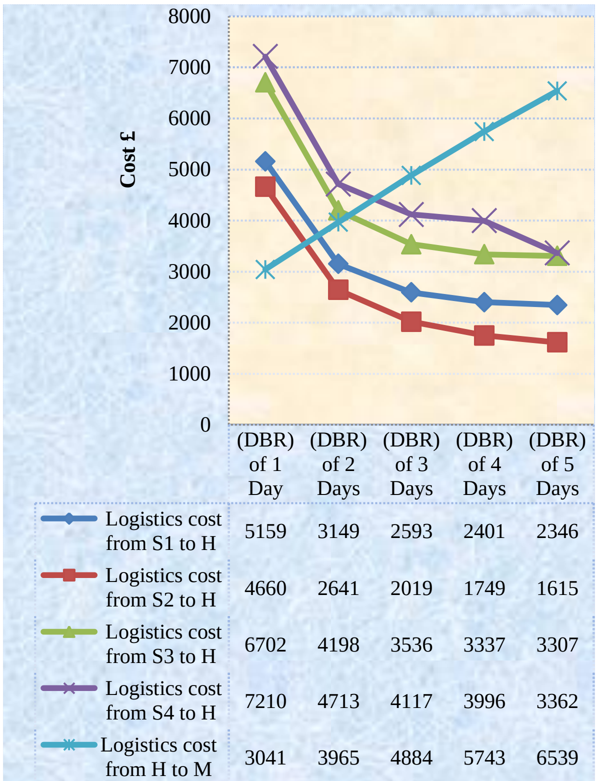
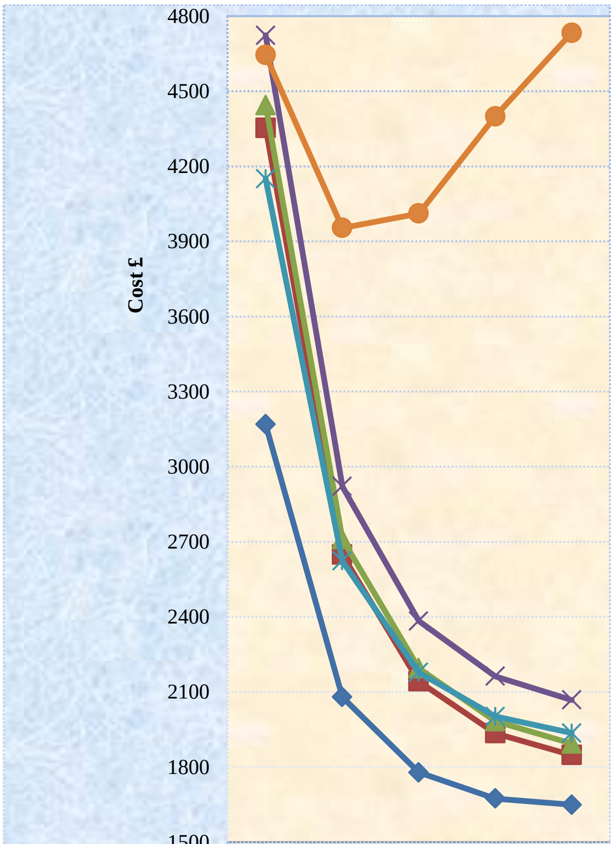


Figure 3: Logistics Cost at different DBR (1 day to 5 days) through Upstream Stage

As shown in figure 4, the results proved that during the demand of one-month test period for distributing finished product (K) from Manufacture (M) to distribution centre (D) in the Fr-M_2, the lowest logistics cost can be achieved with day between replenishment of 2 days.

Finally, in terms of Fr-D, during the demand of one-month test period for supplying finished product (K) from distribution centre (D) to each retailer the lowest logistics cost can be achieved with day between replenishment of five days.



	(DBR) of 1 Day	(DBR) of 2 Days	(DBR) of 3 Days	(DBR) of 4 Days	(DBR) of 5 Days
Logistics time from D to R1	3169	2079	1778	1674	1649
Logistics time from D to R2	4354	2649	2142	1935	1848
Logistics time from D to R3	4445	2710	2194	1983	1893
Logistics time from D to R4	4723	2921	2383	2162	2068
Logistics time from D to R5	4150	2623	2178	2002	1935
Logistics cost from M to D	4645	3954	4012	4400	4734

Figure 4: Logistics Cost at different DBR (1 day to 5 days) through Downstream Stage

8. CONCLUSION

In this paper, a new mathematical model is proposed to measure logistics cost through the fractal supply network which inventory holding cost and transportation cost can be measured and integrated at different sub-fractal of the fractal supply network. The hypothetical fractal supply network located in England which is composited to different fractals is considered and implemented in the Supply Chain Guru Simulation Software within which the proposed mathematical model is in-cooperated. Logistics cost optimised by investigating different days between replenishment (from 1 day to 5 days) through each fractal during the period test of one month to choose the best match of inventory holding cost and transportation cost; in order to minimise the total logistics costs within sub-fractals and finally the whole fractal supply network.

Application of the proposed mathematical model provides a systematic method through which practitioners should be able to decide upon replenishment frequency at different sub-fractal of the network. Moreover, it shows that the proposed fractal supply network and its capabilities have ability to optimise and achieve the lowest logistics cost through the supply network.

9. REFERENCES

Aronsson, H., Ekdahl, B., and Oskarsson, B., 2003. Modern logistik–för ökad lönsamhet. Liber Ekonomi, Malmö.

Attar, M. A., and Kulkarni, M. L., 2014. Fractal manufacturing System–Intelligent control of manufacturing industry. International Journal of Engineering Development and Research, 2(2), 1814-1816.

Borgqvist, F., & Hultkrantz, L., 2005.Mapping logistics costs and flows: A case study within the höganäs group 2004.

Cesca, L. A., 2006. Economic competitiveness in the global textile supply chain: Examination of logistics cost structures.

Chao-yang, Z., Hong-rui, F., and Wei, J., 2011. An model for supply chain logistics cost management based on analytic hierarchy process. In 2011 International Conference on Business Management and Electronic Information, 269 - 273.

Chen, Z., Lee, C., Ip, W., and Ho, G., 2012. Design and evaluation of an integrated inventory and transportation system. Transportation Planning and Technology, 35(4), 491-507.

Fan, X., and Chen, H., 2008. Research on the self-organization model of fractal supply chain. In 2008 4th International Conference on Wireless Communications, Networking and Mobile Computing, 1-4. IEEE.

Gudehus, T., and Kotzab, H., 2009. Logistic Pricing and Marketing. Comprehensive Logistics, 157-184.

He, X., 2010. Research on evaluation model for self-similarity of fractal supply chain. 2010 International Conference On Educational and Information Technology (ICEIT), 279- 281.

hong Zhao, Q., Chen, S., Leung, S. C., and Lai, K., 2010. Integration of inventory and transportation

decisions in a logistics system. Transportation Research Part E: Logistics and Transportation Review(6), 913-925.
Hong, K., Yeo, S. S., Kim, H. J., Chew, E. P., and Lee, C., 2012. Integrated inventory and transportation decision for ubiquitous supply chain management. Journal of Intelligent Manufacturing, 23(4), 977-988.
Kutanoglu, E., and Lohiya, D., 2008. Integrated inventory and transportation mode selection: A service parts logistics system". Transportation Research Part E: Logistics and Transportation Review, 44(5), 665-683.
Leitão, P., and Restivo, F., 1999. A layered approach to distributed manufacturing. Advanced Summer Institute–Life Cycle Approaches to Production Systems: Management, Control and Supervision,
Min, H., Song, H., and Wang, L., 2009. The status and development of logistics cost management: Evidence from mainland china. Benchmarking: An International Journal, 16(5), 657-670.
Monczka, R. M., Petersen, K. J., Handfield, R. B., and Ragatz, G. L., 1998. Success factors in strategic supplier alliances: The buying company perspective. Decision Sciences, 29(3), 553-577.
Pei, Y. M., Ye, C. M., and Liu, L. H., 2012. Inventory-transportation integrated optimization problem. Applied Mechanics and Materials, 178, 2793-2797.
Rushton, A., 2010. The handbook of logistics and distribution management, Kogan Page Publishers.
Ryu, K., and Jung, M., 2003. Agent-based fractal architecture and modelling for developing distributed manufacturing systems. International Journal of Production Research, 41(17), 4233-4255.
Ryu, K., Moon, I., Oh, S., and Jung, M., 2013. A fractal echelon approach for inventory management in supply chain networks. International Journal of Production Economics, 143 (2), 316-326.
Somuyiwa, A., 2010. Analysis of transportation cost in overall logistics cost management of manufacturing companies in southwestern, nigeria. Eur J Sci Res, 44(3), 420-429.
Stock, J. R., and Lambert, D. M., 2001. Strategic logistics management, McGraw-Hill/Irwin Boston, MA.
Swenseth, S. R., and Godfrey, M. R., 2002. Incorporating transportation costs into inventory replenishment decisions. International Journal of Production Economics, 77 (2), 113-130.
Viau, M., Trépanier, M., and Baptiste, P., 2007. Integration of inventory control in spread supply chains. CIRRELT
Wagner, S. M., & Buko, C. 2005. An empirical investigation of knowledge-sharing in networks. Journal of Supply Chain Management, 41(4), 17-31.
Warnecke, H., 1993. The fractal company: A revolution in corporate culture. (berlin: Springer-verlag).
Zhao, Q., Wang, S., Lai, K., and Xia, G., 2004. Model and algorithm of an inventory problem with the consideration of transportation cost. Computers & Industrial Engineering, 46 (2), 389-397.

AUTHORS BIOGRAPHY

Professor Sameh M. Saad, BSc (Honours), MSc, PhD, PGCHE, CEng, MIET, MILT, FHEA, FCILT is the Professor of Enterprise Modelling and Management, Postgraduate Research Coordinator and MSc/MBA Course Leader, in the Department of Engineering, Faculty of Arts, Computing, Engineering and Sciences, Sheffield Hallam University, UK. His research interests and experience include fractal supply chain, modelling and simulation, design and analysis of manufacturing systems, production planning and control, reconfigurable manufacturing systems and next generation of manufacturing systems including fractal and biological manufacturing systems. He has published over 150 articles in various national and international academic journals and conferences, including keynote addresses and a book.

Ramin bahadori is a PhD candidate in the Department of Engineering, Sheffield Hallam University, UK. He received his BSc in Industrial Management from Persian Gulf University, IRAN and MSc degree in Logistics and Supply Chain Management from Sheffield Hallam University, UK in 2010 and 2014 receptively. His research interest is in the field of fractal supply chain, modelling and simulation, logistics capabilities, inventory optimisation, logistics cost optimisation, information system, responsiveness optimisation, supply network integration, communication and collaboration within supply network, and multi-criteria decision-making fuzzy AHP.

REDUCING WORKLOAD IMBALANCE IN PARALLEL ZONE ORDER PICKING SYSTEMS

Sarah Vanheusden[(a)], Teun van Gils[(b)], Katrien Ramaekers[(c)], An Caris[(d)]

[(a),(b),(c),(d)]UHasselt, Research group Logistics, Agoralaan, 3590 Diepenbeek, Belgium

[(a)]sarah.vanheusden@uhasselt.be, [(b)]teun.vangils@uhasselt.be, [(c)]katrien.ramaekers@hasselt.be, [(d)]an.caris@uhasselt.be

ABSTRACT
To stay competitive and preserve high service levels for their customers, the focus of warehouses in today's supply chain is on timely and faster delivery of smaller and more frequent orders. To keep up with competitors, companies accept late orders from customers, which results in additional pressure for order picking operations. Specifically, more orders need to be picked and sorted in shorter and more flexible time windows, which often results in workload peaks during the day. The objective of this study is to balance the workload across the day in parallel zone order picking systems. A real-life case-study demonstrates the value of balancing the workload for European order lines in a large international warehouse system located in Belgium, engaged in the distribution of spare parts. Solving the operational workload imbalance problem results in a more stable order picking process and overall productivity improvements for the total warehouse operations.

Keywords: warehouse planning, manual order picking, workload balancing, integer programming

1. INTRODUCTION

To stay competitive, companies try to minimise logistical costs as they play an important role in the total cost of a product (Rouwenhorst et al. 2000). Warehouses, where products can be stored before the fulfilment of customer orders, play a vital role in the supply chain, and costs can be cut by organizing warehouse operations in an efficient and effective way (Davarzani and Norrman 2015).

To be able to fulfil customer orders, warehouse operations need to satisfy basic requirements such as receiving, storing and retrieving stock keeping units. Sometimes value added activities such as labelling and kitting are performed before the retrieved goods are assembled for shipment. Many design and operation challenges need to be considered and carefully implemented in order to meet capacity, throughput and customer service requirements (Gu et al. 2007).

Of the four main warehouse activities (receiving, storage, order picking and shipping), order picking is the most costly. Up to 50% of the total warehouse operating costs can be attributed to this activity (De Koster et al. 2007). Order picking, where goods are retrieved from storage or buffer areas to fulfil incoming customer orders, tends to be very labour intensive when it is done manually, and very capital intensive when automated warehouse systems are used (Gu et al. 2007).

Although automating the order picking process is possible, the most popular order picking system in practice is still the low-level, picker-to-parts order picking system. About 80% of all order processes are performed manually, because human operators are considered to be more flexible if unexpected changes occur in the process. Despite its popularity in practice, most research efforts have been performed in areas of AS/RS, focusing on high-level picking rather than its manual counterpart (De Koster et al. 2007).

Besides the continuous focus on reducing logistical costs, trends such as shortened product life cycles, e-commerce, greater product variety and point-of-use delivery expose warehouse management to new challenges. To overcome these challenges and simultaneously preserve high service levels, warehouses need to be able to fulfil many small orders for a great variety of stock keeping units (SKUs) (Davarzani and Norrman 2015).

Furthermore, to stay competitive, companies are accepting late orders from customers. This results in extra difficulties for planning order picking operations: more orders need to be picked and sorted in shorter and more flexible time windows. To fit these limited time windows, order picking time needs to be reduced, as this is an integral part of the delivery lead time (De Koster et al. 2007).

Apart from reductions in order picking times, other possibilities exist to keep up with competition and to fulfil imposed service levels. Nowadays the order picking process is expected to be flexible and in the meanwhile customer orders need to be fulfilled in a timely and efficient manner, despite limited time windows. Because of this trend, warehouse managers and supervisors experience difficulties in balancing the workload of the order pickers on a daily basis, resulting in peaks of workload during the day. These workload imbalances result in order picking inefficiencies as order pickers need to cope with high peaks in demand, forced by certain departure deadlines of shipping trucks.

The focus of this paper is on the minimization of the hourly variation of the workload during the day, which is

highly relevant for practitioners. The balancing of workloads results in a more efficient picking process, and will cause higher utilization rates of the available workforce, resulting in a better performance and efficiency of the overall warehouse operations.
The remainder of this paper is organized as follows. Section 2 provides a discussion on related literature. The new operational workload imbalance problem is introduced and described in Section 3. Section 4 is devoted to the results and summarizes managerial implications of this study. Section 5 concludes the paper.

2. LITERATURE REVIEW

To optimize the challenging process of order picking, various planning issues have been identified in the literature: layout design, storage assignment, order batching, zoning, picker routing and to a lesser extent workforce scheduling (De Koster et al. 2007). The zoning problem and the problem of workforce scheduling are most related to the problem of workload imbalance, as both planning problems substantially impact workload peaks. Managing the zoning problem should prevent workload imbalance across order picking zones, whereas workforce scheduling should prevent workload imbalance between order pickers. Related literature, focussing on each of these planning problems, is discussed below.
A well-known tactical option to lift order picking performance to a higher level is the division of the warehouse into different zones. Zone picking assigns the order picker to a dedicated zone. The order picker only picks items of an order that are located in his or her zone (Petersen 2002). Research focussing on zoning is divided into two types of zoning: parallel (or synchronized) zoning and progressive zoning. In synchronised zoning, all zone pickers work on the same batch of orders, while in progressive zoning, a batch of orders is sequentially passed from one zone to the other (Yu and De Koster 2009).
Zoning leads to several advantages. First of all, the picker traverses smaller areas in the warehouse, which leads to travel distance reduction. Furthermore, order pickers become familiar with the item locations in the zone they are assigned to. The biggest disadvantage associated with zoning is the need for consolidation before shipment, because orders have been split during the zoning process (De Koster et al. 2007). Furthermore, labour and equipment resources need to be allocated across the different zones in the warehouse (Gu et al. 2007).
Jane (2000) smoothens a serial pick lane by balancing workloads in such a way that the difference between the number of picks of each order picker is minimized. The effect of adding or deleting storage zones during slack and peak periods is analysed. Jane and Laih (2005) consider a parallel zoned manual order picking system and develop a heuristic algorithm to balance the workload among order pickers by analysing different assignments of products to order picking zones. Despite the valuable contribution of these papers to balance the workload among zones in the long run, these solution methods will be less suitable in an operational context, where daily operations need to be planned and managed.
Another way to safeguard customer service against peaks in workload is efficient scheduling and staffing of the order picking personnel. This personnel planning problem is a commonly formulated research opportunity in warehouse literature. A large number of workforce related studies have been conducted in manufacturing environments (De Bruecker et al. 2015; Xu et al. 2011), but similar studies in warehousing are rather limited (Davarzani and Norrman 2015; Rouwenhorst et al. 2000).
Due to several differences between warehouses and manufacturing environments, the results obtained in both environments cannot be assumed to be equal. Efficient employability of human resources is necessary because of the labour intensive nature of warehousing operations. Warehouses have to deal with strong fluctuations in daily demand and should simultaneously be able to meet fixed deadlines in short time intervals. To face these challenges, warehouses need to be highly flexible (Van Gils et al. 2016).
An important aspect of the personnel scheduling problems is deciding on the number of employees needed to cover the workload. Adaptations in the labour force can be used to cope with fluctuations in demand (Van den Bergh et al. 2013). Temporary workers are often hired in order to capture workload peaks between different days (Grosse et al. 2013). Personnel capacity is an important driver in the service quality companies are able to deliver to their customers (Defraeye and Van Nieuwenhuyse 2016). On the one hand, an insufficient number of workers reduces the service level. On the other hand, planning too many workers will cause unnecessarily high labour costs, congestion in the warehouse, and falling picking efficiency (Van Gils et al. 2016).
Four steps in the personnel planning process have been determined in literature. The first one is demand forecasting. The second step is the determination of staffing requirements to meet certain goals or avoid certain costs over time. Thirdly, shift scheduling is necessary in order to meet the staffing requirements. Shift scheduling results in deciding how many workers are needed in evert shift type. In a fourth step, employees are assigned to shifts, which is called rostering (Defraeye and Van Nieuwenhuyse 2016).
The solution to the problem that is tackled in this paper is most related to the third step in the personnel planning process. Balancing the workload by a minimization of the hourly variation in order lines, will result in a reduction of temporary, more expensive order pickers which were needed to be able to process peaks in workload. Likewise, it will become easier to plan the number of required order pickers for every zone.
To conclude this section, the focus of this paper is on the minimization of the hourly variation of the workload in a parallel zoned manual order picking system. Balancing the workload in an order picking system can be addressed from different perspectives. While most papers that

cover the issue of workload imbalance, start at a strategic or tactical level, the emphasis of this paper will be on the operational level, to avoid peaks in the number of orders to be picked in certain time slots during the day. To the best of our knowledge, we are the first to focus on workload peaks during the day. The objective of this paper is therefore to minimize variations in workloads per time slot by assigning order sets to a single time slot, conducted for every zone. This warehouse planning problem is defined as the operational workload imbalance problem.

3. OPERATIONAL WORKLOAD IMBALANCE PROBLEM

The operational workload imbalance problem will be introduced in section 3.1, in the context of the company used in the case-study. Section 3.2 discusses the mathematical formulation of the new problem.

3.1. Problem Description

The warehouse studied in this paper is a large international B2B warehouse located in Belgium. The warehouse is responsible for the storage of automotive spare parts and the distribution of these parts around the globe. The mission of the company is to maximize the operating time of their sold vehicles by aiming at fast throughput times and reliable deliveries.

The warehouse under consideration is fully manually operated and is divided in several zones, as can be observed in Figure 1. The products have been assigned to the different zones based on their dimensions, weights or demand patterns. This division is necessary because different handling methods are used for products with different dimensions.

Zone one is divided into three parts: A, B and C. Products with the highest demand are located in the A part of zone one, while products with the lowest demand are situated in part C. Products in zone two are characterised by their small size. Products are stored in plastic boxes which contain for example small buttons and screws. The third zone contains products that are heavier than 15 kilograms or contain products that do not fit standard euro pallet measurements. Products that are demanded most of all goods in the warehouse can be found in zone four. Zone five contains all products that are already packed individually for shipment. This study will only consider the zones marked in grey in Figure 1.

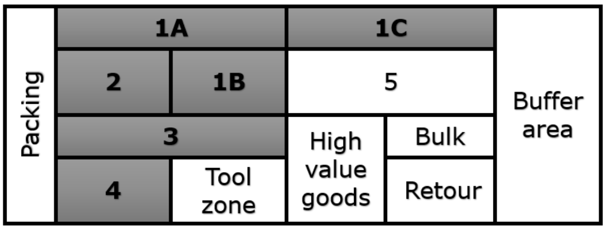


Figure 1: Warehouse Layout

Spare part warehouses are characterized by orders that can be grouped based on their destination. An order set refers to a group of orders with a common destination that is picked in a single zone. Deadlines of customer orders are determined by the shipping destination and resulting schedule of shipping trucks (i.e. shipping schedule). Each shipping truck can consist of multiple order sets (i.e. a single order set for each order picking zone). The assignment of orders to shipping trucks as well as the shipping schedule are assumed to be fixed at the operational level. The fixed shipping schedule often results in workload peaks during the day, as order patterns vary across customers and destinations (e.g. varying number of orders and customers, varying order point and resulting available time to pick orders). The release time of an order set is fixed at the point in time that 95% of the orders belonging to each order set have been send to the warehouse, based on real-life order data of two years.

In this paper, we introduce a new mathematical programming model describing the operational workload imbalance problem in a parallel zoned manual order picking system. The operational workload imbalance problem assumes that the number of order pickers in each shift is equal in each order picker zone.

3.2. Problem Formulation

This section introduces and discusses the new mathematical formulation of the operational workload imbalance problem with the aim of reducing workload imbalance in parallel zone order picking systems. To formulate the problem, following notations are used:

Sets

I Set of time slots with time slot $i \in I$

J Set of shipping trucks with $j \in J$

K Set of pick zones with $k \in K$

Decision variables and Parameters

a_{jk} Average number of order lines for shipping truck j in zone k

t_i Time slot i

Δt_{max} Maximum difference in number of time slots that is allowed for planning order sets of a single shipping truck over different zones.

X_{ijk} Binary variable which is 1 if shipping truck j in zone k is planned in time slot i

$t_{release,\,j}$ Release time for orders of shipping trucks j

$t_{deadline,\,j}$ Order picking deadline orders of shipping trucks j

Max_k Maximum number of order lines in zone k

Min_k Minimum number of order lines in zone k

δ Split order set factor

Subsequently, the objective function and associated constraints are discussed for the operational workload imbalance problem. This study formulates the problem as a mathematical programming problem and aims to solve the problem to optimality using CPLEX. The minimization of the range for workload deviation in every zone on a particular day of the week is considered as objective function. In other words, the difference between the maximum and minimum number of order lines per time slot is minimized for every zone.

$$MIN \sum_{k=1}^{K} (Max_k - Min_k) \quad (1)$$

The model is subject to the following constraints:

$$\sum_{i=1}^{I} t_i X_{ijk} \geq t_{release,j} \quad (2)$$
$$\forall\ k = 1 \dots K, \forall\ j = 1 \dots J$$

$$\sum_{i=1}^{I} t_i X_{ijk} \leq t_{deadline,j} \quad (3)$$
$$\forall\ k = 1 \dots K, \forall\ j = 1 \dots J$$

$$\sum_{i=1}^{I} X_{ijk} = 1 \quad (4)$$
$$\forall\ k = 1 \dots K, \forall\ j = 1 \dots J$$

$$Max_k \geq \sum_{j=1}^{J} a_{jk} X_{ijk} \quad (5)$$
$$\forall\ k = 1 \dots K, \forall\ i = 1 \dots I$$

$$Min_k \geq \sum_{j=1}^{J} a_{jk} X_{ijk} \quad (6)$$
$$\forall\ k = 1 \dots K, \forall\ i = 1 \dots I$$

$$\sum_{i=1}^{I} t_i X_{ijk1} - \sum_{i=1}^{I} t_i X_{ijk2} \leq \Delta t_{max} \quad (7)$$
$$\forall\ j = 1 \dots J,$$
$$\forall\ k_1 = 1 \dots K, \forall\ k_2 = 1 \dots K,$$
$$k_1 \neq k_2$$

Constraints (2) indicate that the release time of an order set needs to be smaller or equal than the time slot that orders will be released. Similarly, constraints (3) indicate that pick deadline of an order set is larger than the scheduled time slot. Assigning each order set to a single time slot is the result of constraints (4). Constraints (5) and (6) define the maximum and minimum number of order lines over all time slots for every zone. Constraints (7) incorporate the allowed difference in time slots for planning order lines of a certain shipping truck over different zones. This difference in time slots cannot exceed a certain parameter Δt_{max}.
Besides aforementioned constraints, the model will take into account an extra parameter δ in case extreme large order sets occur for planning. The split order set factor δ is defined as the fraction of the mean number of order lines per time slot in zone *k*. The split order set factor results in an extra set of constraints:

$$a_{jk} \geq \delta \mu_k \quad (8)$$
$$\forall\ j = 1 \dots J,$$
$$\forall\ k = 1 \dots K$$

By means of the size of δ, the order sets will be split into two if an order set of a shipping truck *j* is greater than δ times the mean number of order lines in zone *k* in order to facilitate balancing over the different time. Furthermore, the split order sets must be planned in consecutive time slots.

4. RESULTS AND DISCUSSION

Section 4.1 is devoted to the experimental design. Section 4.2 describes the results and discusses the findings. Section 4.3 provides some important managerial implications.

4.1. Experimental Design

The operational workload imbalance problem aims at reducing the workload imbalance during the day in a parallel zoned manual order picking system. The factors and their associated factor levels for the experiment of this paper are summarized in Table 1. The first factor in the experiment is Δt_{max}, and is tested at four different levels. The second factor is the split order set factor δ and includes four levels as well. This factorial setting results in a 4 x 4 full factorial design. Each factor level combination is replicated for each day of the working week (Mon – Fri), resulting in 80 observations.

Table 1: Experimental Factor Setting

Factors	Factor levels			
Δt_{max}	1	2	12	25
δ	1	1.25	1.5	∞

The size of Δt_{max} is of practical relevance, as this influences usable space in the staging area of a company. In the most extreme case, Δt_{max} has a value of 25. As the number of time slots is limited to 24, constraints (7) are no longer binding and order sets can be planned, without taking into account the time slot of order sets for the same destination planned in other zones. This can result in overcrowded staging areas when order sets for same destinations originating from different zones have to wait for each other. The smaller the staging area of a company, the better it would be to keep Δt_{max} small, as waiting times for order sets of same destinations will be lower.
The order set factor δ ensures a better balanced solution as large order sets are split in half when they exceed a certain fraction of the average number of order lines per time slot in a zone. Parameter δ takes values from one to infinity. If δ takes the value of one, order sets are split if they are larger than the average order size in the corresponding zone. When δ is set to infinity, no orders will be split, which means that large order sets have to be planned in a single time slot.

4.2. Computational Results

The experimental factor levels are simulated by solving the operational workload imbalance problem using CPLEX with a time limit of six hours for all instances. Considering 80 instances, none are solved to optimality. The optimality gap varies between 0.916% and 37.852% with an average of 10.346%. The objective value ranges from 215.59 to 1,396.32, with an average of 528.26. In the remainder of this section, the effect of Δt_{max} and δ is studied on both the objective function value and the size of the optimality gap.
Figure 2 presents the effect of the different levels of Δt_{max} and δ on the mean objective function value. The graph indicates no existence of an interaction between both factors. For the split order set factor δ, it becomes clear that for $\delta = \infty$, the mean objective function value is

highest for all levels of Δt_{max}. This result can be expected as $\delta = \infty$ means that no order set can be split over multiple time slots. Balancing the workload becomes hard in this situation, as the largest order set defines the maximum peak that cannot be further reduced. The other levels of factor δ result in substantially lower objective function values, because large order sets can be divided over multiple time slots. If $\delta = 1$, which means orders are split in half whenever they are larger than the average number of order lines in a zone, the lowest workload range is reached.

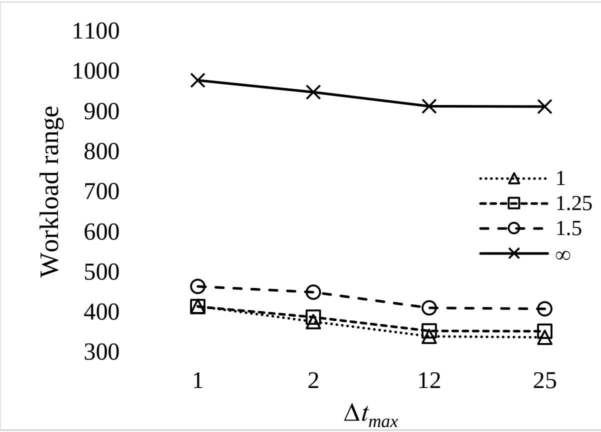


Figure 2: Interaction Plot for Average Workload Range

For the factor of Δt_{max}, a slight downward trend can be observed from Figure 2, indicating that there are more possibilities for reducing the range when constraints (7) are no longer binding.

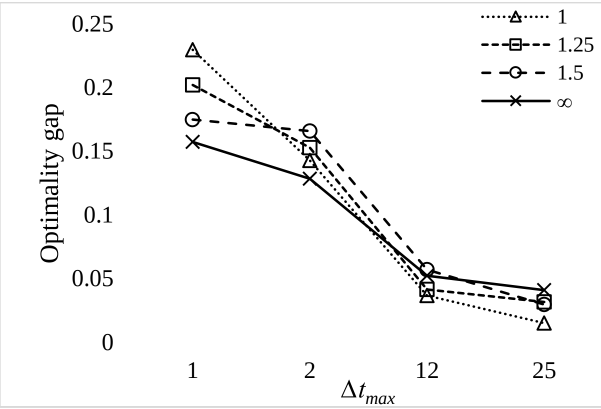


Figure 3: Interaction Plot for Average Optimality Gap

As illustrated in Figure 3, the difference in optimality gap is mainly due to the factor Δt_{max}. Given a specific level of Δt_{max}, different levels of the split order set factor result in only small differences in mean values for the optimality gap. Whenever Δt_{max} has a value of 25, order sets can be planned in all available time slots before their deadline, as the planning does not have to consider the planned order sets for same shipping trucks in the remaining zones. In other words, the planning in each zone is independent, which seems to result in smaller optimality gaps.

If a decision has to be made on the value of Δt_{max}, not only aforementioned results need to be taken into consideration. As already stated, Δt_{max} influences the space that is left in the staging are. The choice will strongly depend on the size of the staging area of the warehouse under consideration. Table 2 illustrates the difference in space utilization in the staging area expressed in number of shipping trucks and corresponding number of order lines for $\Delta t_{max} = 1$ and $\Delta t_{max} = 25$. For every option, the minimum and maximum number of shipping trucks and order lines are calculated over all time slots that occurs on a Monday in the staging area. On average when Δt_{max} is set to 25, place has to be reserved for 2,219.67 extra order lines in comparison to the situation where factor Δt_{max} is fixed at level one.

Table 2: Occupation of the Staging Area

Summary	$\Delta t_{max} = 1$	$\Delta t_{max} = 25$
min # shipping trucks	13	11
max # shipping trucks	48	56
average # shipping trucks	32.88	34.54
min # order lines	1,432.80	3,887.67
max # order lines	8,077.98	11,839.04
average # order lines	4,899.05	7,118.72

4.3. Managerial implications

If peaks in the workload are observed during the day, it is possible that the required order throughput exceeds the capacity of the available order pickers at certain points within their shift. This results in missed departure deadlines and lower customer satisfaction. The operational workload imbalance model developed in this paper tries to minimize this hourly variation of the workload on each day. This is highly relevant for practitioners to construct a more stable order picking process, which ultimately results in more efficient warehouse operations.

This section discusses the practical implications of this research for warehouse managers and supervisors. First of all, the problems of the current pick plan and its deadlines are examined for the warehouse described in Section 3.1. Subsequently, the balanced workload solution calculated by the model is graphically displayed, and its benefits and implications are discussed.

The order picking deadlines for the given shipping schedule of the Belgian warehouse can be observed in Figure 4. As an example, shipping deadlines and corresponding order lines for every order set in zone 1 are shown for a Monday. Time slot one corresponds to the time interval 21 p.m.-22 p.m.

In the current situation, order pickers gradually pick orders that enter the system, with a priority given to order sets with pressing deadlines (i.e. earliest-due-time). As shown in Figure 4, shipping deadlines for order sets are not equally divided over all time slots. No shipping deadlines exist during night (time slot 1 to 6), while more departures pile up during the day. This means more

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

deadlines need to be met and the order picking system is subject to peaks in workload during daily hours.
Every day, a rough estimate is made of the total number of order lines that need to be picked the next working day, and at the same time the total amount of picked order lines for every zone is guessed. If peaks occur in certain time slots, that cannot be covered by the order pickers who are present, warehouse supervisors carry out a last minute assignment of employees of other warehouse activities to the different zones in need. The number of people and the assignment to zones is based on their experience. Using other warehouse employees for covering peaks in order picking workload, results in inefficiencies in the corresponding activities. Sometimes these other activities are delayed or even shut down.

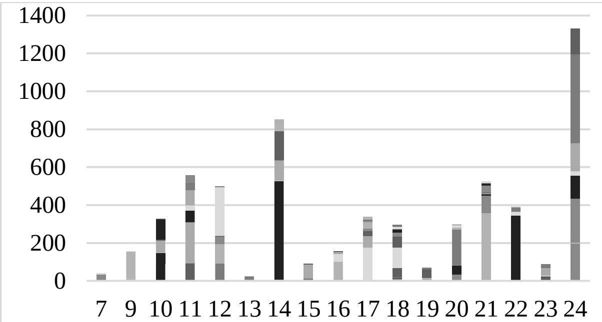


Figure 4: Current Deadlines Belgian Warehouse with each Block Representing a Single Order Set

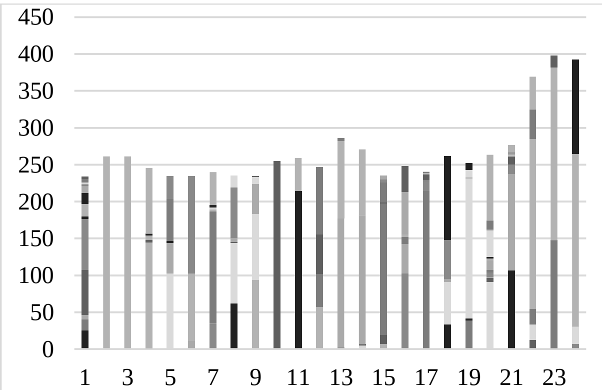


Figure 5: Balanced Planning with each Block Representing a Single Order Set

The operational workload imbalance model developed in this paper provides a solution for abovementioned problems. Figure 5 presents the results of the model with respect to Monday. Factor Δt_{max}, as well as the split order set factor δ are fixed at their second level of the experimental design. These levels are considered as the best fitting values to the real-life warehouse operations of the case-study.
By balancing the workload, as can be observed in Figure 5, the order picking process can be kept under control. In other words, for every time slot, certain goals are set for picking predefined order sets. This way, warehouse supervisors are better prepared and can check at every moment in time if they are on schedule. If not, warehouse supervisors are able to intervene timely, without disturbing other warehouse employees and processes, as is the case in the current situation.
With respect to the balanced planning shown in Figure 5, the graph shows an increased number of order lines in the last three time slots. In order to decrease this imbalance, we proposed to shift the release of a single shipping truck j^* from time slot 22 to time slot 21. This means that the cut-off time for customers who are delivered with shipping truck j^* is one hour prior to the current cut-off time. The operational workload imbalance model is simulated with the new release time of shipping truck j^*. Table 3 shows the results of the simulation in terms of the daily required number of full time equivalents (FTEs). Based on the average productivity, the number of FTEs is currently determined by warehouse supervisors. The minimum and maximum number of FTEs shows the minimum and maximum required number of FTEs resulting from the operational workload imbalance model as a consequence of hourly workload variations. This minimum and maximum value can be seen as an indication of the number of employees that should be shifted from other warehouse activities in order to fulfil all orders before the deadline. By only shifting a single shipping truck, the number of FTEs that should be shifted reduces significantly. For example in Zone 4, the available number of FTEs equals 10.66, while during the peak time slot 16.26 FTEs are required. This peak requirement reduces to 13.12 FTEs in case of shifting the release of shipping truck j^*.

Table 3: Daily Required Number of FTEs

	Zone 1	Zone 2	Zone 3	Zone 4
Mean productivity (in number of order lines per FTE)	33.0	8.5	63.5	38.0
Current situation (number of FTEs)				
Mean	8.12	21.72	1.41	10.66
Minimum	7.09	19.40	1.19	8.83
Maximum	12.06	27.67	2.02	16.26
Improved situation (number of FTEs)				
Mean	8.12	21.72	1.41	10.66
Minimum	7.05	20.31	1.27	9.46
Maximum	11.22	25.78	1.83	13.12

To conclude this section, several practical implications can be summarized for warehouse managers and supervisors to take into account when planning daily order picking operations. If the workload is balanced, warehouse supervisors are better prepared and other warehouse operations are less disturbed. In other words, the order picking process is less depending on individual experiences of warehouse supervisors. A better balanced workload means a better utilization rate of the order pickers in the system. By planning an evenly divided workload during the day, the probability of missing shipping deadlines is smaller, which results in more efficient warehouse operations.

5. CONCLUSIONS

Due to several upcoming trends in warehousing, the process of order picking is expected to keep improving in terms of flexibility, which results in shrinking time windows for order picking. Late customer order acceptance in these limited time windows causes peaks in workload during the day, resulting in extra work pressure for warehouse supervisors as well as order pickers. Until now, only solutions for long-term balancing have been introduced in literature. Practitioners were searching for a solution to balance the workload for every hour of the working day, to take their operational activities to a higher level.

This study formulates the new operational workload imbalance problem as a mathematical programming problem and tries to solve the problem to optimality using CPLEX. CPLEX has proven to be very effective in solving small planning problems (Henn and Wäscher 2012). However, mathematical programming problems can be hard to solve to optimality in reasonable computing times for planning problems of realistic size. This is supported by the results described in Section 4. Of 80 instances, none have been solved to optimality.

The novel mathematical programming model for the workload balancing problem is too complex to provide fast results. Heuristic algorithms, in particular local search based algorithms, can compensate for the risk of large computing times. Future opportunities to solve the workload balancing problem, could be the development of an iterated local search algorithm, as an example of a local search algorithm, to serve as alternative for the exact solution. Iterated local search algorithms have proven to be excellent alternatives to solve complex warehouse planning problems (Henn et al. 2010; Öncan 2015).

The developed model can be used by warehouse managers and supervisors as a simulation tool to plan order sets more accurately during the day, in this way, avoiding peaks in workload. The utilization of order pickers in the system will rise in case of a balanced pick plan. There is a smaller need for workers from other activities or expensive temporary workers to cope with peaks in demand. It is important that effects, such as necessary reserved space in the staging area, are kept in mind by setting model parameters. The developed model can also be used as an advisory tool for warehouse managers to start negotiations in changes in cut-off times for customer order entry and shipping schedules to further reduce workload imbalances.

ACKNOWLEDGMENTS

This work is partially funded by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (research project COMEX, Combinatorial Optimization: Metaheuristics & Exact Methods).

The computational resources and services used in this work were provided by the VSC (Flemish Supercomputer Center), funded by the Research Foundation - Flanders (FWO) and the Flemish Government – department EWI.

REFERENCES

Davarzani H., Norrman A., 2015. Toward a relevant agenda for warehousing research: literature review and practitioners' input. Logistics Research 8.

De Bruecker P., Van den Bergh J., Beliën J., Demeulemeester E., 2015. Workforce planning incorporating skills: State of the art. European Journal of Operational Research 243, 1–16.

De Koster R., Le-Duc T., Roodbergen K.J., 2007. Design and control of warehouse order picking: A literature review. European Journal of Operational Research 182, 481–501.

Defraeye M., Van Nieuwenhuyse I., 2016. Staffing and scheduling under nonstationary demand for service: A literature review. Omega 58, 4–25.

Grosse E.H., Glock C.H., Jaber M.Y., 2013. The effect of worker learning and forgetting on storage reassignment decisions in order picking systems. Computers & Industrial Engineering 66, 653–662.

Gu J., Goetschalckx M., McGinnis L.F., 2007. Research on warehouse operation: A comprehensive review. European Journal of Operational Research 177, 1–21.

Henn S., Koch S., Doerner, K.F., Strauss C., Wäscher G., 2010. Metaheuristics for the Order Batching Problem in Manual Order Picking Systems. Bus Res 3, 82–105.

Henn S., Wäscher G., 2012. Tabu search heuristics for the order batching problem in manual order picking systems. European Journal of Operational Research 222, 484–494.

Jane C.-C., 2000. Storage location assignment in a distribution center. International Journal of Physical Distribution & Logistics Management 30, 55–71.

Jane C.-C., Laih Y.-W., 2005. A clustering algorithm for item assignment in a synchronized zone order picking system. European Journal of Operational Research 166, 489–496.

Öncan T., 2015. MILP formulations and an Iterated Local Search Algorithm with Tabu Thresholding for the Order Batching Problem. European Journal of Operational Research 243, 142–155.

Rouwenhorst B., Reuter B., Stockrahm V., van Houtum G.J., Mantel R.J., Zijm W.H.M., 2000. Warehouse design and control: Framework and literature review. European Journal of Operational Research 122, 515–533.

Van den Bergh J., Beliën J., De Bruecker P., Demeulemeester E., De Boeck L., 2013. Personnel scheduling: A literature review. European Journal of Operational Research 226, 367–385.

Van Gils T., Ramaekers K., Caris A., Cools M., 2016. The use of time series forecasting in zone order

picking systems to predict order pickers' workload. International Journal of Production Research 1–14.
Xu J., Xu X., Xie S.Q., 2011. Recent developments in Dual Resource Constrained (DRC) system research. European Journal of Operational Research 215, 309–318.

AUTHORS BIOGRAPHY

Sarah Vanheusden graduated in 2016 as a Master of Science in Business Engineering with a major in Operations Management and Logistics at Hasselt University, Belgium. In October 2016, she started her PhD focusing on human-system interactions in manual order picking planning problems.

Teun van Gils graduated in 2014 as a Master of Science in Business Engineering with a major in Operations Management and Logistics at Hasselt University, Belgium. In October 2016, he started his PhD focusing on operational order picking planning problems.

Katrien Ramaekers is Assistant Professor in Operations Management and Logistics at the Faculty of Business Economics (BEW) of Hasselt University (Belgium). She graduated as master in Business Engineering at the Limburg University Centre, Belgium, in 2002. She obtained her PhD in Applied Economics in 2007 at Hasselt University. In her PhD she developed a simulation optimization framework for inventory management decision support based on incomplete information. Her research interest goes to the application of Operations Research techniques in the field of operations management and logistics, with a strong focus on simulation (optimization). Current research domains are warehouse operations, healthcare logistics and cost allocation in intermodal barge transport.

An Caris was appointed in 2012 as Assistant Professor at the Faculty of Business Economics (BEW) of Hasselt University. She obtained her PhD in Applied Economics in 2010 and was first a postdoctoral research fellow of the Research Foundation - Flanders (FWO). Her research interest goes to the application of Operations Research (OR) techniques in the field of operations management and logistics. In her PhD thesis she focused on the competitiveness of intermodal transport making use of inland navigation. Currently she studies planning problems in warehouse operations, intermodal rail transport, collaborative logistics and healthcare logistics.

A SIMULATION MODEL FOR ESTIMATING THE CARBON FOOTPRINT OF VEHICLES IN THE TERMINAL OPERATING PROCESSES

Wenhe Yang[(a)], Soemon Takakuwa[(b)]

[(a),(b)]Chuo University, Japan

[(a)] yangwh@indsys.chuo-u.ac.jp, [(b)] takakuwa@indsys.chuo-u.ac.jp

ABSTRACT

Maritime container terminals face increasing transfer loads, causing severe air pollution. Controlling and reducing carbon greenhouse gas emissions has become a social responsibility of the logistics service providers, and it is encouraged by national policies. Nowadays, operational data for the handling equipment in the terminal are typically recorded in daily operation logs kept by the terminal's operating system. In this study, we aimed to construct a model and, using system tracking data, estimate CO_2 emissions from vehicles involved in various operating processes at a terminal yard. The proposed estimation method renders the daily log file visible, representing a potential method for further evaluating port operation efficiency during real-time control from a green terminal perspective.

Keywords: green terminal, carbon footprint estimation, terminal modeling

1. INTRODUCTION

With the rapid increase in the world trade, the volume of the international maritime trade has increased accordingly. Eighty percent of global merchandise trade by volume is carried by sea and handled by ports (UNCTAD 2013). However, increasing transfer loads are causing environmental issues, such as air pollution.

Greenhouse gas emissions, particularly carbon dioxide (CO_2) emissions, have a significant impact on global warming. Freight-related energy consumption and CO_2 emissions grow annually because of increasing transfer loads worldwide (U.S. IEA 2016). Controlling and reducing CO_2 emissions has become an important issue for the country as well as the logistics service providers as it attempts to fulfill its societal responsibility. Therefore, an effective assessment of the carbon footprint has become important and necessary.

A method of estimating the carbon footprint of a container terminal has been attempted by several researchers. Geerlings and Van Duin (2011) presented a bottom-up methodology for estimating CO_2 emissions from container port terminals based on fuel and energy consumption using macro data from the terminal. Yang and Lin (2013) employed a green terminal perspective to compare the performances of four types of cargo handling equipment used in the yard. Veidenheimer (2014) investigated CO_2 emissions of maritime container transport from Asia into the European hinterland through new built German port compared to the other European deepwater ports. The study also addressed measures for CO_2 reduction in maritime door-to-door container transport. Longo et al. (2015) developed a model for evaluating, in terms of throughputs, CO_2 and NO_x emissions beyond the traditional berth and yard operations using an LCA approach. Miodrag et al. (2016) developed a model for evaluating the relationship between crane power consumption and container handling distance. Carbon emissions from container handling equipment during ship loading (LD) and unloading (UL) is usually estimated using these studies. However, few studies discuss the emissions resulting from moving containers within the yard. And, in reality, congestion typically occurs at the yard gate or at entry intersections during rush hours.

Terminal operating systems often utilize information and communication technology such as the Internet, Electronic Data Interchange processing, wireless LANs, radio-frequency identification, etc., to manage container terminals and to control delivery, storage, container processing and handling operations at the container terminal, as well as to manage container documentation in real time (Yang and Takakuwa 2015). Daily operational data from handling equipment at the terminal are recorded by the terminal operating system. Trailer moving information can be extracted from movement information for yard cranes (YCs) and containers.

In this study, we aimed to construct a model for estimating the carbon footprint of container handling during yard operations based on daily operational records of the handling equipment. The method renders daily log files visible, and it represents a method that can further evaluate port operational efficiency in real time from the environment's perspective.

In this paper, section 2 gives the general descriptions of the container handling processes, as well as the terminal operating system. In the section 3, the modeling framework and the carbon footprint calculation method of the trailers is detailed. Section 4 presents the simulation model. Finally, summaries are presented in the Section 5.

2. GENERAL DESCRIPTIONS

2.1. Operational Processes in the Terminal

At a container terminal, operations can be classified as import or export processes, and these two categories employ opposite operation flows (Stahlbock and Voß 2008). The typical process flows of the cargo and information are shown in Figure 1.

Import cargo is usually stocked temporarily in a bonded warehouse near the terminal, and it is there that it is sorted and packed into containers. Export containers ready to be put onto a vessel are carried into the yard before the vessel's arrival. Therefore, export containers are generally gathered approximately one day before vessel arrival, and the logistics service providers can use container information to gather cargo for a given vessel prior to LD.

When the vessel arrives at the berth, import containers are first unloaded onto trailers. Upon an appearance damage-checking process, containers are transferred to the yard storage blocks. Once UL is completed, export containers are transferred from the yard to the quay before being loaded onto the vessel.

The terminal yard is usually divided into an area for export containers (LD area) and an area for import containers (UL area) for efficiently handling cargo. Operations in the LD area include receiving (R), the process whereby an export container is received by the terminal, and LD, the process whereby the container is loaded onto the vessel. Conversely, operations in the UL area include UL, the process whereby container is unloaded from the vessel, and Delivery (D), the process whereby an import container is delivered to the cargo owner. Each of these operations require the use of trucks with trailers, either from outside the yard or owned by the yard. Additionally, shift (S) operations occur in these two areas, and they can be divided into those that occur without a trailer (SS), which is usually referred as re-handling, and those that occur with a trailer (ST), which is usually referred as moving a container under the shift plan. The operation processes at the terminal are supported by the terminal operating system.

2.2. Terminal Operating System

A terminal operating system is a software application that supports a container terminal's planning, scheduling and equipment-control activities (Boer and Saanen, 2008). When a vessel arrives at the berth, containers are unloaded by a gantry crane (GC) onto trailers that are trucked to the yard's storage blocks. Once a container is loaded onto a trailer, information indicating completion of UL is transferred to the system. Shortly thereafter, handling instructions for container storage spots are sent to the YCs. Concurrently, system tracking records time to completion. Other operations inside the yard (S, D, R and LD), and basic information about the container and vessel are also recorded in the system. The information flows as depicted in Figure 1.

Data records can be used to analyze and improve the system, and they are divided into vessel information, yard operation data, and container inventory data. Additionally, in this study, yard operation data is used primarily for extracting moving information for the trailers.

3. MODELING FRAMEWORK

3.1. Model Logic Flow

To extract information about the trailers, the process flows of the YCs and containers must be clarified and analyzed. The flow chart is shown in Figure 2.

The logic flow of the model consists of logic control and calculations.

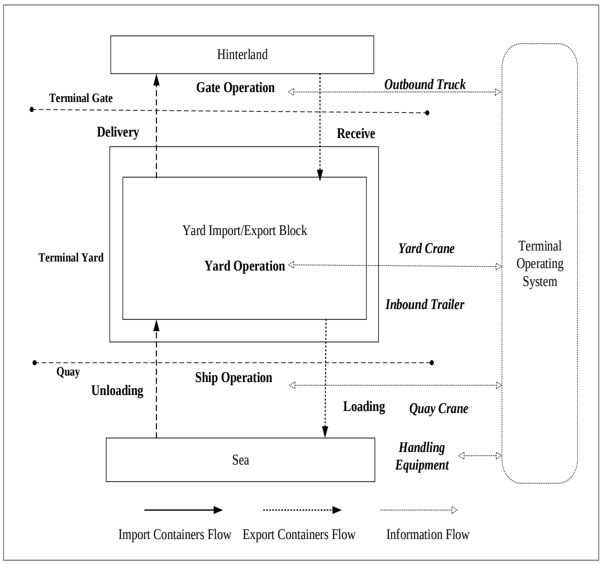


Figure 1: Typical Cargos Flow and the Information Flow in a Terminal

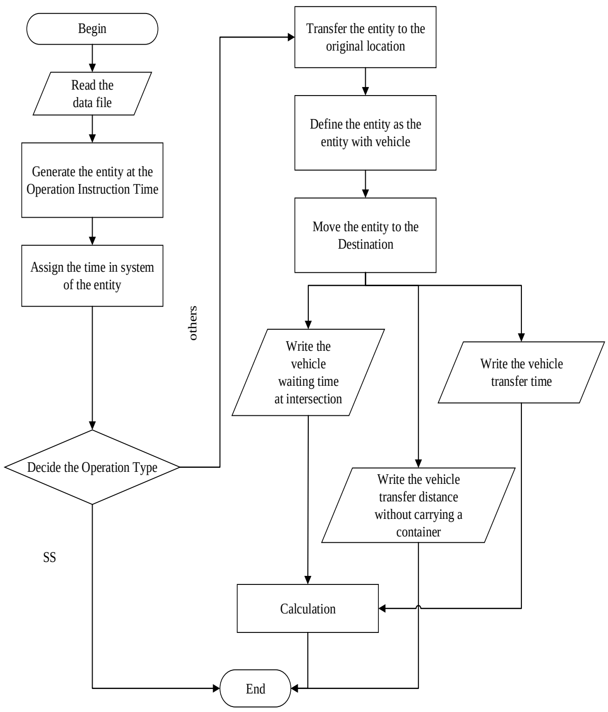


Figure 2: The Flow Chart of the Model

Container handling processes typically use a trailer. The relationships between the origins and destinations are shown in Table 1.

Table 1: Positional Relations of the Operations

Operation Type	Original Position	Destination
UL	GC	Yard Block
LD	Yard Block	GC
R	Gate	Yard Block
D	Yard Block	Gate
ST	Yard Block	Yard Block

Furthermore, trailers are either inbound (LD, UL or S operations) or outbound (R or D operations). During LD and UL, a group of trailers is usually assigned to a given GC so that these operations can be processed quickly. Therefore, these trailers are defined travel one-way distance again without carrying a container.

3.2. Emission Factor

Energy-based and activity-based method are two basic approaches using in carbon auditing. Energy-based method directly apply standardized energy or fuel conversion factors. Activity-based method is based on transport activity data expressed typically in ton kilometers (tkm). For calculation of activity data the weight of carried goods (ton), and distance travelled (km) is needed (Veidenheimer 2014). For this model, both energy based and activity based methods are used for calculation.

We adopted the Japanese standard CO_2 emission factors specified by the Port Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan in 2009.

Trailers used for transporting marine containers are driven primarily by diesel engines filled with diesel fuel. Therefore, the emission factor for diesel fuel, 2.62 t-CO_2/kl, is adopted. Fuel consumption of an idling engine (e.g., when in congestion) is 1.25 l/h.

$$CO_2 \text{ emission volume while idling} = 1.25 \text{ l/h} \times 1/1000 \times 2.62 \text{ t-}CO_2\text{/kl} \times \text{idle time (h)}. \quad (1)$$

$$CO_2 \text{ emission factor (while moving)} = 0.0421 \text{ (l/tkm)} \times 1/1000 \times 2.62 \text{ (t-}CO_2\text{/kl)} = 110 \text{ (g-}CO_2\text{/tkm)}. \quad (2)$$

$$CO_2 \text{ emission volume while moving} = \text{cargo weight (t)} \times \text{transfer distance (km)} \times CO_2 \text{ emission factor (g-}CO_2\text{/tkm)}. \quad (3)$$

$$= 110 \text{ (g-}CO_2\text{/tkm)} \times \text{cargo weight (t)} \times \text{transfer distance (km)} \quad (4)$$

Additionally, these emission factors and the parameters can be adjusted to correspond to the actual situation.

4. SIMULATION MODEL

4.1. Modeling Software

For this simulation, Simio modeling software (Kelton, Smith, and Sturrock 2013) is used for coding. Simio is a simulation-modeling framework based on graphical object-oriented programming. The model is realized using multiple modeling paradigms, including event, process, object, system-dynamics and agent modeling views (Thiesing and Pegden, 2014). 3D animation provided an efficient mechanism for model verification.

4.2. Data and Model

The external data files, such as excel or csv files can be imported into Simio. A data example of the model is shown in Figure 3.

The YC operation data is used as input data. In the demo, a four-hour data set is used for testing.

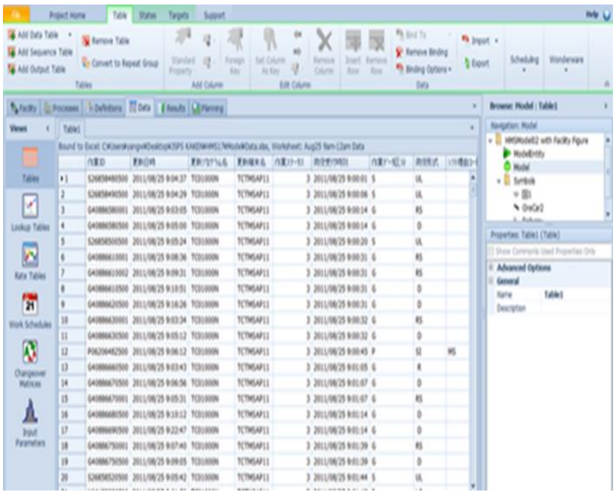


Figure 3: A Data Example of the Model

A very large amount of information is recorded in the system. The items listed below are the primary ones used in the study.

(1) Operation No.;
(2) Container attributes:
Container No.,
Container Size (20 ft or 40 ft)
Container Weight;
(3) Vessel information:
GC No.,
UL Time (in the UL process) from the ship;
(4) Yard crane information:
YC No.,
Operation Area;
(5) Operation information:
Operation Type,
Operation Instruction Time,
Operation Completion Time,
Original Location,
Destination.

The logic flow to build the model is shown in Figure 2. Firstly, the entity (an operation) is generated at the operation instruction time. Secondly, decide if the operation need a trailer by operation type. Then, transfer the entities which are need a trailer from the original location to the destination. The trailer transfer time and the waiting time at intersection are written for further calculation. The travel distance of the trailer without carrying loads is also recorded in the model.
The equation (1) and (4) are used for calculation. Statistics can be collected in real time while the model is running. CO_2 emissions can be obtained from the model interface. The model can be further used for evaluating port operational efficiency from the environmental viewpoint.

5. SUMMARY

In this study, a model for estimating the carbon footprint of trucks operating in the yard was developed. Daily YC operational data recorded in the terminal operating system can be utilized effectively in the model. The modeling framework and the carbon footprint calculation method of the trailers was detailed. Both energy based and activity based methods were used for calculation. The proposed method represents a potential method for evaluating port operations in real time from the green terminal perspective.

ACKNOWLEDGMENTS

This research was supported by the Grant-in-Aid for Scientific Research of Japan Society for the Promotion of Science (JSPS) Grant Number JP17K12984.

REFERENCES

Boer C. A. and Saanen Y., 2008. Controls: emulation to improve the performance of container terminals. Proceedings of the 2008 Winter Simulation Conference, 2639-2647. December 7-10, Miami (Florida, USA).

Geerlings H. and Van Duin R., 2011. A new method for assessing CO2-emissions from container terminals: a promising approach applied in Rotterdam. Journal of Cleaner Production, 19 (6), 657-666.

Kelton W.D., Smith J.S. and Sturrock D.T., 2013. Simio and simulation: modeling, analysis, applications. 3rd ed. Pittsburgh, Pennsylvania: CreateSpace Independent Publishing Platform.

Longo F., Padovano A., Baveja A. and Melamed B. 2015. Challenges and opportunities in implementing green initiatives for port terminals. Proceedings of the International Workshop on Simulation for Energy, Sustainable Development & Environment (SESDE), part of the International Multidisciplinary Modeling and Simulation Multiconference, 38-45.

Miodrag Z., Kaffka J., Clausen U., Munsel L. and Drost S., 2016. Assessment of emissions caused by logistics handling operations in multimodal-terminals. Transportation Research Procedia, 4, 2754-2761.

MLIT, 2009. Calculation method of carbon dioxide emission intensity in the port (Ver 1.0). Available from: http://www.mlit.go.jp/common/ 000043052. pdf [accessed 16 April 2017] (in Japanese).

Stahlbock, R. and Voß, S., 2008. Operations research at container terminals: a literature update, OR Spectrum, 30(1), 1-52.

Thiesing R. M. and Pegden C. D., 2014 Introduction to SIMIO. Proceedings of the 2014 Winter Simulation Conference, 4192-4201. December 7-10, Savannah (Georgia, USA).

United Nations Conference on Trade and Development (UNCTAD), 2013. Review of maritime transport Available from: http://unctad.org/en/Publications Library/rmt2013_en.pdf [accessed 16 April 2017]

U.S. Energy Information Administration (U.S. EIA), 2016. International energy outlook 2016. Available from: https://www.eia.gov/outlooks/ieo/transportation.cfm [accessed 16 Apirl 2017]

Veidenheimer K., 2014. Carbon Dioxide Emission in maritime container transport and comparison of European deepwater ports: CO2 calculation approach, analysis and CO2 reduction measures. Hamburg: Anchor Academic Publishing.

Yang W. and Takakuwa S., 2015. Simulation-based analysis of import cargo-handling operations on a container terminal. Proceedings of the 2015 Winter Simulation Conference, 1960-1971. December 6-9, Huntington Beach (California, USA).

Yang Y.-C. and Lin C.-L., 2013. Performance analysis of cargo-handling equipment from a green container terminal perspective. Transportation Research Part D: Transport and Environment, 23, 9-11.

AUTHORS BIOGRAPHY

WENHE YANG is a Research Associate in the Faculty of Science and Engineering at the Chuo University, Japan. She received her B.Sc. degree in Logistics Engineering from the Tianjin University in 2010, and her M.Sc. and Ph.D. degrees in Economics from the Graduate School of Economics and Business Administration at Nagoya University in 2013 and 2016, respectively. Her research interests include discrete-event simulation, agent-based simulation, and development of applications in manufacturing and logistics systems. Her email address is yangwh@indsys.chuo-u.ac.jp.

SOEMON TAKAKUWA is a Professor at the Chuo University and a Professor Emeritus at Nagoya University in Japan. He received his B.Sc. and M.Sc. degrees in industrial engineering from the Nagoya Institute of Technology in 1975 and the Tokyo Institute of Technology in 1977, respectively. He received a Ph.D. in industrial engineering from the Pennsylvania State University. He also holds a Doctorate of Economics from the Nagoya University and a P.E. in industrial engineering. He is a corresponding member of the

International Academy of Engineering in Russia. His research interests include the optimization of manufacturing and logistics systems, management information systems, and simulation analysis of these systems in the context of hospitals. He has prepared the Japanese editions of *Introduction to Simulation using SIMAN*, *Simulation with ARENA*, and *Simio and Simulation: Modeling, Analysis, Applications*. His email address is takakuwa@indsys.chuo-u.ac.jp.

METHODS AND ALGORITHMS OF SHIP-BUILDING MANUFACTORY OPERATION AND RESOURCES SCHEDULING

Boris Sokolov[(a)], Vyacheslav Zelentsov[(b)], Nikolay Mustafin[(c)], Alexander Kovalev[(d)], Vladimir Kalinin[(e)]

[(a),(b),(c)]SPIIRAS— St. Petersburg Institute of Informatics and Automation, Russian Academy of Sciences,
14th line 39, St. Petersburg, 199178, Russia
[(a),(c)]ITMO University— St. Petersburg National Research University of Information Technologies,
Mechanics and Optics, 13 Gdanovskaya str., St. Petersburg, 197198, Russia
[(d)]The Arsenal Design Bureau named after M.V. Frunze Federal State Unitary Enterprise,
1-3 Komsomola str., St. Petersburg, 195009, Russia
[(e)]Military-space academy named after A.F. Mozhaisky
13 Gdanovskaya str., St. Petersburg, 197198, Russia

[(a)]sokolov_boris@inbox.ru, [(b)]v.a.zelentsov@gmail.com, [(c)] nikolay.mustafin@gmail.com, [(d)]kbarsenal@kbarsenail.ru,
[(e)]kvn112@mail.ru

ABSTRACT
We present a new multiple-model description and algorithms of ship-building manufactory scheduling. This description is represented as a special case of the job shop-scheduling problem with dynamically distributed jobs. The approach is based on a natural dynamic decomposition of the problem and its solution with the help of a modified form of continuous maximum principle coupled with combinatorial optimization.

Keywords: ship-building manufactory, shop-scheduling problem, optimal control, combinatorial optimization

1. INTRODUCTION

Nowadays the development of computer-aided decision-making procedures, as well as procedures of automatic planning and scheduling, for complex technical-organizational systems (CTOS) design, maintenance, and improvement remains a very important problem. In the paper we investigate problems of operation and resources scheduling for ship-building manufactory (SBM) as a possible variant of CTOS. Scheduling, in the broad sense, is a purposeful, organized, and continuous process including examination of SBM elements, analysis of their current state and interaction, forecasting of their development for some period, forming of mission-oriented programs and schedules. Our investigation have shown that the SBM operation and resources scheduling, as a phase of decision-making, has several peculiarities: scheduling is a preliminary designing of organization make-up and functioning mechanism providing goal achievement by a given time; the result of scheduling is a system of interrelated distributed time-phased decisions, while the function of planning is directly connected with the function of control, since designing and keeping of program trajectories use common resources; the process of scheduling permanently approaches the end but never reach it because of two reasons: firstly, revising of decisions lasts until actual actions are performed; secondly, the system and the environment can change during the planning process, therefore it is necessary to correct plans periodically; scheduling is aimed at prevention of erroneous operations and at decrease of unimproved opportunities.

In a general case, planning is concerned with the following groups of tasks (Ackoff., (1978), Chen Z.-L. and Hall NG, (2007), Ivanov D., Sokolov B. (2012, 2013), Werner F. & Sotskov Y (2014)): 1) forming of SBM goals and objectives, i.e., evaluation of preferable states and time for achievement of goals and objectives; 2) determination of means and instruments for goals and objectives achievement; 3) determination of resources and their sources for implementation of plans, as well as development of principles and methods for resources allocation; 4) design of SBM make-up (first of all, development of SBM main structures) and SBM functioning algorithms providing continuity of integrated scheduling and control.

Three planning approaches (concepts, philosophies) emerged by now: satisfactory (incremental), formal, and system (comprehensive) planning. Formal planning concentrates on prediction of situation in terms of mathematical models, satisfactory planning consider SBM reactions to external impacts, system planning supports SBM interaction with the environment. System planning implies problem resolution and redefinition through learning process, rather than problem solving. This lets interpret planning not as discrete operations, but as continuous adaptive process. That was called adaptive planning. A posteriori, current, and a priori information can be used for plan adaptation (adaptation to the “past”, “present”, or “future”).

In this paper, we mainly consider the only one stage of the described technology, namely scheduling of SBM operation and resources scheduling (Ackoff., (1978), Chen Z.-L. and Hall NG, (2007), Ivanov D., Sokolov B. (2012, 2013).

We used a dynamic interpretation of SBM functioning for formal statement of the problem. This approach resulted in essential reduction of a problem dimensionality and in advantages of the proposed combine algorithms because of its connectivity decrease.

We propose to use two methods for optimization of SBM operation and resources scheduling, and for simulation of SBM operation and optimization of resources scheduling execution: local section method (modification of the L.S. Pontryagin maximum principle) and a method of discrete programming.

The dimensionality of SBM scheduling problem is determined by the number of independent paths in a network diagram of SBM operations and by current spatiotemporal, technical, and technological constraints. In its turn, the degree of algorithmic connectivity depends on a dimensionality of the main and the conjugate state vectors (Chen Z.-L., G.L. Vairaktarakis, (2005), Khmelnitsky E., Kogan K., Maimom O. (1997, 2000)., Ye H. and Liu R (2016), Ivanov D., Sokolov B. (2012, 2013)).

2. MODELS, METHODS AND ALGORITHMS OF SHIP-BUILDING MANUFACTORY OPERATION AND RESOURCES SCHEDULING

We propose a multiple-model description of the ship-building manufactory scheduling problem. The multiple-model complex includes a dynamic model of job and resource control in ship-building manufactory and a dynamic model of flow (material, energy, information) control in ship-building manufactory. Let us consider the proposed multiple-model description in more detail.

2.1. The Dynamic model of job and resource control in ship-building manufactory (model M1)

We consider the mathematical model of job and resource control. We denote the job state variable $x_{i\mu}^{(o)}$, where (o) — indicates the relation to jobs (orders). The execution dynamics of the job $D_{\mu}^{(i)}$ can be expressed as (1).

$$\frac{dx_{i\mu}^{(o)}}{dt} = x_{i\mu}^{(o)} = \sum_{j=1}^{n} \varepsilon_{ij}(t) u_{i\mu j}^{(o)} \quad (1)$$

where $\varepsilon_{ij}(t)$ is an element of the preset matrix time function of time-spatial constraints, $u_{i\mu j}^{(o)}(t)$ is a 0–1 assignment control variable.

Let us introduce equation (2) to assess the total resource availability time:

$$x_{j}^{(o)} = \sum_{i=1}^{\bar{n}} \sum_{\substack{\eta=1 \\ \eta \neq i}}^{\bar{n}} \sum_{\mu=1}^{s_i} \sum_{\rho=1}^{p_i} (u_{i\mu j}^{(o)}) \quad (2)$$

Equation (2) represents resource utilization in job execution dynamics. The variable $x_{j}^{(o)}$ characterizes the total employment time of the *j*-supplier. The control actions are constrained as follows:

$$\sum_{i=1}^{\bar{n}} \sum_{\mu=1}^{s_i} u_{i\mu j}^{(o)}(t) \le 1, \forall j; \ \sum_{j=1}^{n} u_{i\mu j}^{(o)}(t) \le 1, \forall i, \forall \mu \quad (3)$$

$$\sum_{j=1}^{n} u_{i\mu j}^{(o)} [\sum_{\alpha \in \Gamma_{i\mu_1}^{-}} (a_{i\alpha}^{(o)} - x_{i\alpha}^{(o)}) + \prod_{\beta \in \Gamma_{i\mu_2}^{-}} (a_{i\beta}^{(o)} - x_{i\beta}^{(o)})] = 0 \quad (4)$$

$$u_{i\mu j}^{(o)}(t) \in \{0,1\}; \quad (5)$$

where $\Gamma_{i\mu_1}^{-}$, $\Gamma_{i\mu_2}^{-}$ are the sets of job numbers which immediately precede the job $D_{\mu}^{(i)}$ subject to accomplishing of all the predecessor jobs or at least one of the jobs correspondingly, and $a_{i\alpha}^{(o)}, a_{i\beta}^{(o)}$ are the planned lot-sizes. Constraint (3) refers to the allocation problem constraint according to the problem statement (i.e., only a single order can be processed at any time by a manufacturer). Constraint (4) determines the precedence relations, moreover this constraint implies the blocking of operation $D_{\mu}^{(i)}$ while the previous operations $D_{\alpha}^{(i)}, D_{\beta}^{(i)}$ are being executed. If $u_{i\mu j}^{(o)}(t) = 1$, all the predecessor jobs of the operation $D_{\mu}^{(i)}$ should be executed. Constraint (4) formalize basic ship-building manufactory technology. Note that these constraints are identical to those in traditional mathematical programming (MP) models.

Corollary 1. The analysis of constraints (4) shows that control $\mathbf{u}(t)$ *is switching on only when the necessary predecessor operations are being executed.* $\sum_{j=1}^{n} u_{i\mu_j}^{(o)} \sum_{\alpha \in \Gamma_{i\mu_1}^{-}} (a_{i\alpha}^{(o)} - x_{i\alpha}^{(o)}(t)) = 0$ *guarantees the total processing of all the predecessor operations, and* $\sum_{j=1}^{n} u_{i\mu_j}^{(o)} \prod_{\beta \in \Gamma_{i\mu_2}^{-}} (a_{i\beta}^{(o)} - x_{i\beta}^{(o)}) = 0$ *of at least one of the predecessor operations.*

According to equation (5), controls contain the values of the *Boolean variables*. In order to assess the results of job execution, we define the following initial and end conditions at the moments $t = T_0$, $t = T_f$:

$$x_{i\mu}^{(o)}(T_0)=0;\ \ x_{i\mu}^{(o)}(T_f)=a_{i\mu}^{(o)}; \tag{6}$$

Conditions (6) reflect the desired end state. The right parts of equations are predetermined at the planning stage subject to the lot-sizes of each job.
According to the problem statement, let us introduce the following performance indicators (7)–(10):

$$J_1^{(o)}=\frac{1}{2}\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}[(a_{i\mu}^{(o)}-x_{i\mu}^{(o)}(T_f))^2] \tag{7}$$

$$J_2^{(o)}=\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}\int_{T_0}^{T_f}\alpha_{i\mu}^{(o)}(\tau)u_{i\mu j}^{(o)}(\tau)d\tau \tag{8}$$

$$J_3^{(o)}=\frac{1}{2}\sum_{j=1}^{n}(T-x_j^{(o)}(T_f))^2 \tag{9}$$

The performance indicator (7) characterizes the accuracy of the end conditions' accomplishment, i.e. the service level of *ship-building manufactory*. The goal function (8) refers to the estimation of a job's execution time with regard to the planned supply terms and reflects the delivery reliability, i.e., the accomplishing the delivery to the fixed due dates. The functions $\alpha_{i\mu}^{(o)}(\tau)$ are assumed to be known, and characterize the fulfilment of time conditions for different jobs and time points, as the penalties increase due to breaking supply terms. The indicator (9) estimates the equal resource utilization in the *ship-building manufactory*.

2.2. The Dynamic model of flow control in ship-building manufactory (model M2)

We consider the mathematical model of flow control in the form of equation (10):

$$\dot{x}_{i\mu j}^{(f)}=u_{i\mu j}^{(f)}\ ,\ \dot{x}_{ij\eta\rho}^{(f)}=u_{ij\eta\rho}^{(f)} \tag{10}$$

We denote the flow state variable $x_{i\mu j}^{(f)}$, where (f) indicates the relation of the variable *x* to flows.
The control actions are constrained by maximal capacities and intensities as follows:

$$\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}u_{i\mu j}^{(f)}(t)\le\tilde{\tilde{R}}_{1j}^{(f)}\ ,\ \sum_{\rho=1}^{p_i}u_{ij\eta\rho}^{(f)}(t)\le\tilde{\tilde{R}}_{1j\eta}^{(f)}\ , \tag{11}$$

$$0\le u_{i\mu j}^{(f)}(t)\le c_{i\mu j}^{(f)}\cdot u_{i\mu j}^{(o)}\ ,\ 0\le u_{ij\eta\rho}^{(f)}(t)\le c_{i\eta\rho j}^{(f)}\cdot u_{i\eta\rho j}^{(o)}\ , \tag{12}$$

where $\tilde{\tilde{R}}_{1j}^{(f)}$ is the total potential intensity of the resource $C^{(j)}$, $\tilde{\tilde{R}}_{1j\eta}^{(f)}$ is the maximal potential channel intensity to deliver products to the customer $\bar{B}^{(\eta)}$ of results of *ship-building manufactory*, $c_{i\mu j}^{(f)}$ is the maximal potential capacity of the resource $C^{(j)}$ for the job $D_\mu^{(i)}$, and $c_{i\eta\rho j}^{(f)}$ is the total potential capacity of the channel delivering the product flow $P_{<s_i,\rho>}^{(j,\eta)}$ of the job $D_\mu^{(i)}$ to the customer $\bar{B}^{(\eta)}$ of results of *ship-building manufactory*.
The end conditions are similar to those in (6) and subject to the units of processing time. The goal functionals of the flow control model are defined in the form of equations (14) and (15):

$$J_1^{(f)}=\frac{1}{2}\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}[(a_{i\mu j}^{(f)}-x_{i\mu}^{(f)}(T_f))^2+ \\ +\sum_{\substack{\eta=1\\ \eta\ne i}}^{\bar{n}}\sum_{\rho=1}^{p_i}(a_{ij\eta\rho}^{(f)}-x_{ij\eta\rho}^{(f)}(T_f))^2] \tag{13}$$

$$J_2^{(f)}=\frac{1}{2}\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}\int_{T_0}^{T_f}\beta_{i\mu}^{(f)}(\tau)u_{i\mu j}^{(f)}(\tau)d\tau\ . \tag{14}$$

The economic meaning of these performance indicators correspond to equations (7) and (8). With the help of the weighting performance indicators, a general performance vector can be denoted as (16):

$$\mathbf{J}(\mathbf{x}(t),\mathbf{u}(t)=\left\|J_1^{(o)},J_2^{(o)},J_3^{(0)},J_1^{(f)},J_2^{(f)}\right\|^{\mathrm{T}}. \tag{15}$$

The partial indicators may be weighted depending on the planning goals and SC strategies. Original methods (Okhtilev M. Y., Sokolov B.V., Yusupov R.M. (2006), Ivanov D., Sokolov B. (2012, 2013)) have been used to transform the vector $\mathbf{J}$ to a scalar form J_G.
The job shop scheduling problem can be formulated as the following problem of OPC: it is necessary to find an allowable control $\mathbf{u}(t)$, $t\in(T_0,T_f]$ that ensures for the model (1)–(2), and (10) meeting the vector constraint functions $\mathbf{q}^{(1)}(\mathbf{x},\mathbf{u})=0$, $\mathbf{q}^{(2)}(\mathbf{x},\mathbf{u})\le 0$ (3)–(5) and (10–11), and guides the dynamic system (i.e., job shop schedule) $\dot{\mathbf{x}}=\boldsymbol{\varphi}(t,\mathbf{x},\mathbf{u})$ from the initial state to the specified final state. If there are several allowable controls (schedules), then the best one (optimal) should be selected in order to maximize (minimize) J_G. In terms of optimal program control (OPC), the program control of job execution is at the same time the job shop schedule. The formulated model is a linear non-stationary finite-dimensional controlled differential system with the convex area of admissible control. Note that the *boundary problem* is a standard OPC problem; see [4-6]. In fact, this model is linear in the state and control variables, and the objective is linear. The transfer of non-linearity to the constraint ensures convexity and allows to use interval constraints.
We propose a method and algorithm of ship-building manufactory which are based on local section method and methods of discrete programming. Scheduling

problems of the considered class are usually solved via methods of discrete programming, but when the dimensionality is high, the optimal solution is not provided and heuristic algorithms are needed. We suggest an original approach, based on integration of models and methods of optimal control theory with methods of bivalent programming, to ship-building manufactory scheduling problems of high dimensionality.

Necessary optimality conditions can be derived from the maximum principle (Athans M., & Falb, P.L(1966)). Consider control system (9).

$$\mathbf{x}(t) = f(t,\mathbf{x}(t),\mathbf{u}(t)),\ t_0 \le t \le t_f,$$
$$\mathbf{x}(t_0) = \mathbf{x}_0,\ \mathbf{u}(t) \in U, \quad (16)$$
$$J = F(\mathbf{x}(t_f)) \to \mathbf{min}$$

Let us introduce a scalar Hamiltonian function H and conjunctive vector system $\psi \in R^n$ in Eq. (17).

$$H(t,\mathbf{x}(t),\mathbf{u}(t),\psi(t)) = \psi^{\mathrm{T}}(t)\mathbf{f}(t,\mathbf{x}(t),\mathbf{u}(t)),$$
$$\psi(t) = -\frac{\partial H}{\partial \mathbf{x}}(t,\mathbf{x}(t),\mathbf{u}(t),\psi(t)), \quad (17)$$

$$\psi(t_f) = -\left.\frac{\partial F(\mathbf{x}(t))}{\partial \mathbf{x}}\right|_{t=t_f}, \quad (18)$$

Conjunctive vector system plays the role of dual models in linear programming. Coefficients of the conjunctive systems can be interpreted as Lagrange multipliers. Under assumptions that $\mathbf{u}(t)$ is optimal control and $\mathbf{x}(t)$ and $\psi(t)$ are the trajectory and conjunctive system satisfying (17) and (18), the function $H(t,\mathbf{x}(t),\mathbf{u}(t),\psi(t))$ reaches its maximum for $\mathbf{x}(t)$ at the point $\mathbf{u}(t)$. Then Eq. (19) holds:

$$\mathbf{u} = \mathbf{u}(t,\mathbf{x}(t),\psi(t)) \quad (19)$$

Subsequently, Eq. (19) is brought into correspondence with (17) and (18). In the result, a two-point boundary problem for a system of ordinary differential equations in regard to $\mathbf{x}(t)$ and $\psi(t)$ is formed. The optimal solution is now bounded by this differential system. Note that Eq. (17)-(19) in general case provide only necessary conditions for optimal solution existence whereas for linear control systems these maximum principles provide both optimality and necessary conditions.

The basic peculiarity of the boundary problem considered is that the initial conditions for the conjunctive variables $\psi(t_0)$ are not given. At the same time, an optimal program control should be calculated subject to the boundary conditions. To obtain the conjunctive system vector, the Krylov–Chernousko method of successive approximations for an optimal program control problem with a free right end which is based on the joint use of a modified successive approximation method has been used (Krylov I.A., & Chernousko F.L. (1972)).

Step 1. An initial solution $\overline{\mathbf{u}}(t),\ t \in (t_0, t_f]$ (a feasible control, in other words, a feasible schedule) is selected and $r=0$.

Step 2. As a result of the dynamic model run, $\mathbf{x}^{(r)}(t)$ is received. Besides, if $t = t_f$ then the record value $J_G = J_G^{(r)}$ can be calculated. Then, the transversality conditions (18) are evaluated.

Step 3. The conjugate system (17) is integrated subject to $\mathbf{u}(t) = \overline{\mathbf{u}}(t)$ and over the interval from $t = t_f$ to $t = t_0$. For the time $t = t_0$, the first approximation $\psi_i^{(r)}(t_0)$ is obtained as a result. Here, the iteration number $r=0$ is completed.

Step 4. From the time point $t = t_0$ onwards, the control $\mathbf{u}^{(r+1)}(t)$ is determined ($r = 0,1,2,...$ denotes the number of the iteration). In this case during the maximization of the Hamiltonian different tasks of mathematical programming should be solved. The dimensionality of these tasks is low, and the problem dimensionality is determined by the number of independent paths in a network diagram of ship-building manufactory operations and by current spatial-temporal, technical, and technological constraints. In parallel with the maximization of the Hamiltonian, the main system of equations and the conjugate one are integrated. The maximization involves the solution of several mathematical programming problems at each time point.

The advantage of method of successive approximations is that it allows to implement needle-shape control variations to the whole area of feasible control actions subject to the given constraint system, i.e., the area of feasible schedules [8]. Another advantage of the method is that the search for an optimal control in each iteration is performed in the class of boundary (e.g., pointwise or relay) functions which correspond to the discrete nature of decision making in scheduling. Note that the method of successive approximations in its initial form does not guarantee the convergence.

3. SOFT-WARE PROTOTYPE

In the paper we present a software prototype of SBM operation and resources scheduling. The software has three modes of operation with regard to scheduling and an additional mode to analyze stability of the schedules. The first mode includes the interactive generation/preparation of the input data. The second mode lies in the evaluation of heuristic and optimal SBM operation and resources scheduling. The following operations can be executed in an interactive regime: • multi-criteria rating, analysis, and the selection of SBM plans and schedules; • the evaluation

of the influence that is exerted by time, economic, technical, and technological constraints upon SBM structure dynamics control; and • the evaluation of a general quality measure for SBM plans and schedules, and the evaluation of particular performance indicators. The third mode provides interactive selection and visualization of SBM schedule and report generation.
The approach proposed in this article was used while carrying out the research work devoted to the investigation and selection of methods and algorithms of solving tasks of integrated and simulation modeling as well as multi-criteria analysis of the manufacturing systems in shipbuilding industry (Aframchuk E.F., Vavilov A.A., Emel'yanov S.V. et al., (1998), Okhtilev M. Y., Sokolov B.V., Yusupov R.M (2010)). Business Process Modelling Notation (BPMN) was used to develop and perform SBM operation and resources scheduling including technological and auxiliary manufacturing processes. In Figure 1 one can find an extract of specified processes description.

A consistent use of simulation and analytical logic-dynamic model on the basis of BPMN application allowed to extend the set of calculated indices of shipbuilding enterprise functioning and to make computation, multi-criteria evaluation and analysis of structure dynamics of a shipbuilding enterprise under different variants of input effect. It is important to emphasize once again that designed special software of ship-building manufactory scheduling using BPMN represents unified modern automation tool for modeling built on service-oriented architecture and web-technologies.

4. CONCLUSIONS

Problems of ship-building manufactory scheduling may be challenged by high complexity, combination of continuous and discrete processes, integrated production and transportation operations as well as dynamics and resulting requirements for adaptability. A possibility to address these issues opens the embedding of OPC into ship-building manufactory scheduling and using its advantages in combination with advantages of mathematical programming (MP). Under the assumption that the introduction of the dynamic aspect of job arrival can have a significant impact on the solution procedure, this study presented a new original model for ship-building manufactory scheduling as OPC of job execution dynamics coupled with combinatorial optimization and based on a natural dynamic decomposition of the scheduling problem and its solution with maximum principle in combination with MP. The proposed substitution lets use fundamental scientific results of the OPC theory in ship-building manufactory scheduling.

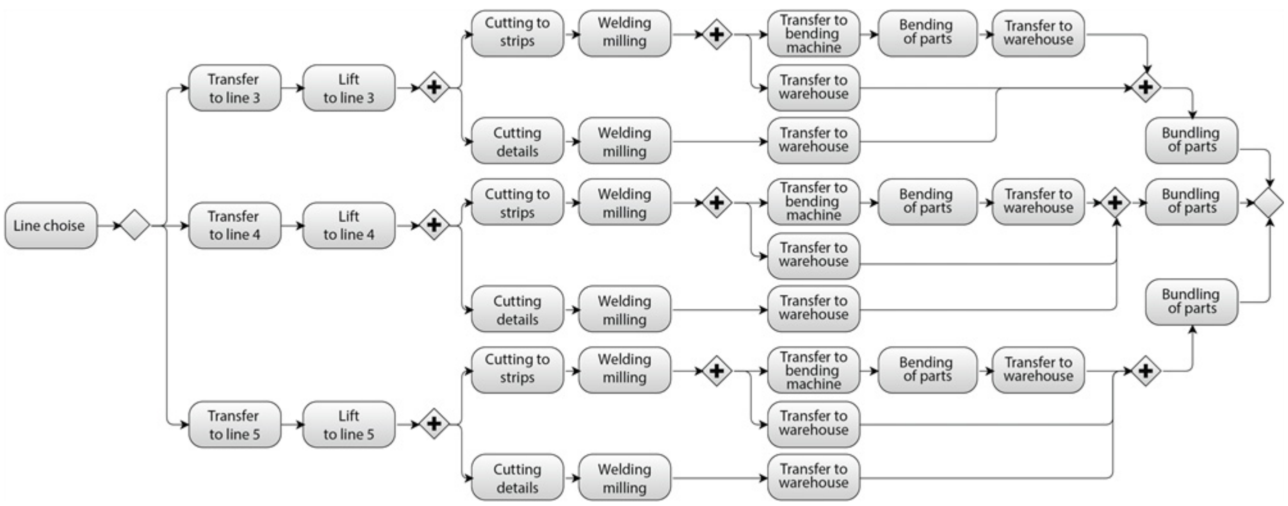


Figure 2: Fragment of ship-building manufactory in BPMN

ACKNOWLEDGMENTS

The research is supported by the Russian Science Foundation (project № 17-11-01254).

REFERENCES

Ackoff R.L., 1978. The Art of Problem Solving. New York: Wiley-Interscience.
Aframchuk E.F., Vavilov A.A., Emel'yanov S.V. et al., 1998. Technology of System Modelling. Emel'yanov S.V. (ed.), Moscow: Mashinostroenie.
Athans M. & Falb P.L., 1966 Optimal control: An introduction to the theory and its applications. New York San Francisco, CA, Sidney, NSW: McGraw-Hill.
Chen Z.-L. and Hall NG, 2007. Supply Chain Scheduling: Conflict and Cooperation in Assembly Systems. In: Operations Research, 55(6), 1072–1089.
Chen Z.-L., G.L. Vairaktarakis, 2005. Integrated scheduling of production and distribution operations. In: Management Sci., 51, 614–628.
Ivanov D., Sokolov B., 2013. Dynamic coordinated scheduling in the supply chain under a process modernization. International Journal of Production Research, 51(9).

Ivanov D., Sokolov B., 2012. Dynamic supply chain scheduling, Journal of Scheduling, 15(2).
Khmelnitsky E., Kogan K., Maimom O., 1997. Maximum principle-based methods for production scheduling with partially sequence-dependent setups. Int J Prod Res, 10(35).
Kogan K., Khmelnitsky E., 2000. Scheduling: control-based theory and polynomial-time algorithms. Dordrecht, Kluwer.
Krylov I.A., & Chernousko F.L. 1972. An algorithm for the method of successive approximations in optimal control problems. Zh. Vychisl. Mat. Mat. Fiz., 12(1).
Okhtilev M. Y., Sokolov B.V., Yusupov R.M., 2006. Intellectual Technology of Complex-Technical-Object Structural-Dynamic Monitoring and Control. Moscow: Nauka.
Werner F. & Sotskov Y., 2014. Sequencing and Scheduling with Inaccurate Data. Nova Publishers.
Ye H. and Liu R., 2016. A multiphase optimal control method for multi-train control and scheduling on railway lines. Transportation Research Part B: Methodological, 93 (Part A).

AUTHORS BIOGRAPHY

BORIS SOKOLOV is a deputy director at the Russian Academy of Science, Saint Petersburg Institute of Informatics and Automation. Professor Sokolov is the author of a new scientific lead: optimal control theory for structure dynamics of complex systems. Re-search interests: basic and applied research in mathematical modelling and mathematical methods in scientific research, optimal control theory, mathematical models and methods of support and decision making in complex organization-technical systems under uncertainties and multicriteria. He is the author and co-author of 9 books on systems and control theory and of more than 450 scientific papers. Professor B. Sokolov supervised more over 90 research and engineering projects. Web-page can be found at `http://litsam.ru`.

VIACHESLAV ZELENTSOV — Doctor of Sciences (Tech), Prof., Chief researcher, Laboratory for Information Technologies in Systems Analysis and Modeling, St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS). Research interests: analyses of systems, reliability theory, mathematical models and methods of decision-making support in complex technical-organizational systems with the use of aerospace data. The number of publications 250, including 3 monograph and 3 textbook. Web-page can be found at http://litsam.ru/index.php/en/2016/06/08/zelentsov-en/.

NIKOLAY MUSTAFIN — PhD, Leading researcher, Laboratory for Computing &Information systems and Programming Technologies, St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS). Research interests: methods and models for complex decision support.

ALEXANDER KOVALEV — Doctor of Sciences (Tech), Prof., Honored scientist of Russian Federation; Leading researcher, Laboratory for Information Technologies in Systems Analysis and Modeling, St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS). Research interests: analyses of systems, reliability theory, mathematical models and methods of decision-making support in complex technical-organizational systems with the use of aerospace data. The number of publications 160. Web-page can be found at http://litsam.ru/.

VLADIMIR KALININ — Dr. Sc.in Technical Science, Prof., Honored Scientists of the Russian Federation; The full member of the Russian academy of astronautics of a name K.E. Tsiolkovsky, Professor of Military-space academy. Research interests – the theory of system researches, space cybernetics and computer science, the theory of optimum control of the dynamic systems, the automated control systems, preparation of the engineering staff and new information-didactic technologies in higher education. Number of scientific publications – 170.

Simulation Study on Dynamic Variable Gate Setting Condition of Container Port

Zijian Guo[(a)], Qi Zhang[(b)], Wenyuan Wang[(c)]

[(a),(b),(c)]Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian, Liaoning 116024
[(a),(b),(c)]State Key Laboratory of Costal and offshore Engineering, Dalian University of Technology, Dalian, Liaoning 116024

[(a)]zjguo@dlut.edu.cn, [(b)]zhangqidlut@163.com, [(c)]wangwenyuan@dlut.edu.cn

ABSTRACT
In order to ease the queuing congestion at container terminal gate and improve the service level of gate, we propose a kind of intelligent gate of which the working direction can be adjusted automatically according to queuing length of In/Out gate. A queuing imbalance coefficient between In/Out gate is developed to be applied as the setting and changing condition of variable gate. We build a variable gate operating system simulation model and offer a case study, based on which we try to find how the variable gate impacts on the service status of the gate and then estimate the critical value used to decide the setting of variable gate and the moment of changing the working direction.
Keywords: container terminal; variable-gates; service level; simulation model

1. INTRODUCTION

Container terminal gate is an indispensable areas where the containers transported into or out the port area must pass through. With the globalization of containerized trade and the large size of container ships, the transportation volume of containers is increasing in the recent decades. As a results, the gate of the container terminal has gradually become a bottleneck as the most crowded area. However, for most of the container terminals, total number of the gate ca not be amplified with respect to the restriction of space and economic conditions. The through capacity fails to meet the requirement with the increasing logistics demand day by day. Thus, how to make full use of the existing gates and improve the through capacity is a very important problem for the operational efficiency of container terminal.

In recent years, the researches on the through capacity and the plan of container terminal gate has been emphasized gradually all over the world. Minh (2014) and Guan and Liu (2009) built a multi-server queue model to analyze the congestion situation of container terminal gates and the waiting cost of container trucks. Boile (2013) proposed a method based on simulation to evaluate the effect of queuing congestion on the efficiency of container terminal operation. Huynh (2014) developed a planning tool used to study the layout of container terminal gate. In addition, a method based on stochastic service system has been proposed by Mai (2007). To calculate the optimal lanes number of the container terminal gate and the stop buffer length. Liu (2011) built a mathematical model to study the optimal scale of the container terminal gate. An optimization model based on simulation was set up by Yu (2007) to determine the optimal scale of container terminal gate meanwhile minimize the cost of gate construction. Meanwhile, as environmental issues have become important for the port planning, Longo and Padovano et al (2015) proposed a solution capable of recreating a port terminal and while take into consideration the main factors affecting sustainability of port operations. In order to adopt green port policy, Simpson (2010) proposed 11 components in the 160-acre Pier S Marine Terminal. In addition, a chassis exchange terminal and information technology were proposed to reduce the truck congestion at gates respectively by Dekker et al (2013) and Masaaki (2003). However, all the researches above didn't consider how to improve the service level of the gate when given the total number of certain container terminal gates.

With the help of simulation tool and the new concept of the imbalance coefficient of In/Out gate queuing introduced in this paper, we build a variable-gate operating system simulation model to simulate the service states of container terminal gate in a state of disequilibrium of the container trucks arriving. It is a new attempt in the field of port planning and construction that study the feasibility of variable gate applied to improve the service level of gate and the critical value used to decide the moment when changing working direction of variable gate. This research can provide a reference for planning and design of large container terminal gate.

2. RELATED CONCEPTS

2.1. Variable gate

The process from arrival to departure of container trucks is a three-level queuing system, as shown in the Figure 1. The container terminal operating system is a stochastic service system. The arrival or departure of the container trucks has a characteristics of randomness. Meanwhile, considering the difference of the service between in and out, the service time is also different. As a result, there is a probable situation in which the traffic pressure has been beyond the capacity in a certain direction of the gate while there is still great redundancy of the through capacity in the other direction.

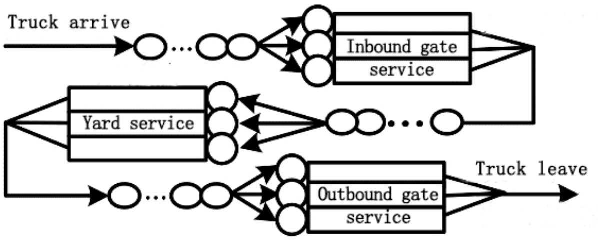


Figure1: Schematic diagram of container truck queuing system

To alleviate the congestion in one direction and improve the service level of the gate on the premise of a certain number of container terminal gates, we propose the concept of variable gate of which the working direction can be changed according to the dynamic requirement of traffic status, referring to the thought of tide lane (Li et al., 2009; Dai et al., 2012) in the field of road traffic. Changing the working direction of some gates, according to the queuing indicators about the truckers entering and leaving the port, can maximizing the through capacity of container terminal gate.

2.2. Imbalance coefficient of In/Out-gate queuing

The queuing status at container terminal gate in the two directions is the decision basis for changing the working direction of the variable gates. To quantitatively describe this condition, we introduce the imbalance coefficient of In/Out-gate queuing which is defined as the ratio of the inbound gate average queuing length and outbound gate average queuing length, denoted by τ.

$$\tau = \frac{\text{In gate average queuing length}}{\text{Out gate average queuing length}}$$

2.3. Critical value of τ used to change direction of the gate

A critical value of τ (denoted as τ^*) is set to determine whether to change the direction of gate. Here is an example. It is assumed that the initial direction of the variable gate is entrance direction. The working mechanism of variable gate is as follows: when $\tau > \tau^*$ which means the queue length at the entrance gate is greater than the one at the exit gate, the variable gate should still be the entrance gate until the queuing congestion of entrance gate is eased and the value τ decreases gradually; when $\tau < \frac{1}{\tau^*}$, which means the queue length at the exit gate is τ^* times greater than that at the entrance gate, the variable gate should be adjusted as an exit gate in order to ease the queuing congestion of the exit gate. The operation is similar to the example to adjust the passage direction of the variable gate dynamically.

If the value of τ^* is too small, the passage direction of the variable gate will be changed frequently, while if the value is defined too large, the sensitivity of the variable gate operation will significantly reduce, which can not fully reflect the role of a variable gate . Therefore, it is necessary to find a reasonable critical value to change the direction of the variable gate.

3. SIMULATION MODEL CONSTRUCTION

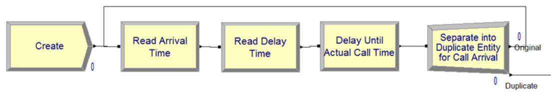
3.1. Operation Process of Container terminal gate

The operation process of the container terminal gate which is not variable is as follows: if the entrance gate is idle, the arriving truck will accept service, else it need to wait until it is idle. Then it drives to the yard waiting to load and unload. After that, the container truck will drive to exit gate. If the exit gate is idle, the truck will accept service and leave the port, else, it will wait until it is idle.

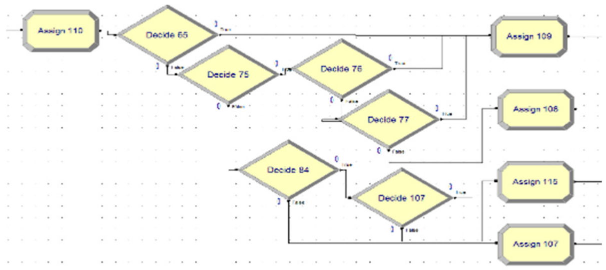
The operation process of the variable gate is similar to the ordinary operation process of the container terminal entrance，excerpt the numbers of entrances or exits are decided by the direction of variable gate at present.

3.2. A Simulation Model of Gate Operation System for Container Terminals with Variable Gate

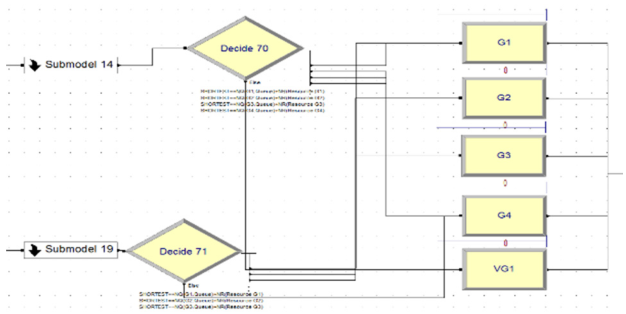
The simulation model mainly includes five sub-models, which are truck entity creation, variable gate working direction decision, entrance gate selection, yard service and exit gate selection. The sub-models are shown in Figure 2.



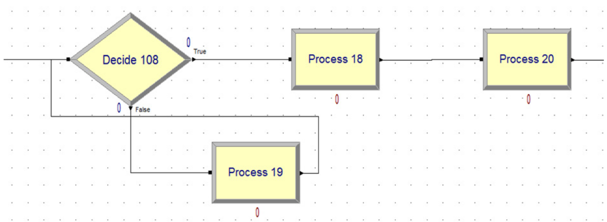
a) sub-model of truck entity creation



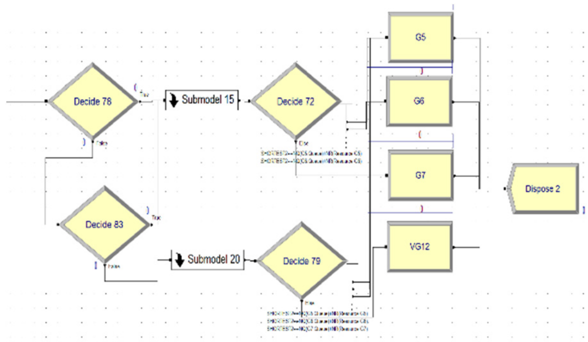
b) sub-model of variable gate working direction decision



c) sub-model of entrance gate selection



d) sub-model of yard service



d) sub-model of exit gate selection

Figure2: Simulation Model of Gate Operation System for Container Terminals

1) Sub-model of truck entity creation. The Create module generates truck entities, reads and inputs values of the interval to port from truck data file, and enters the *Read Arrival Time* module, and then reads the data with the *Read Delay Time* module. At last it arrives to the *Delay Until Actual Call Time* module. This ensures that each truck has one-to-one correspondence with its time parameters. On the one hand, the truck entity can sent back to the *Read Arrival Time* module through the Original exit point, and then obtain the time interval for the next truck from the data file. On the other hand, the module generates a copy truck entity, which can be passed to the model by the *Duplicate* module, completing all remaining model logic.

2) Sub-model of variable gate working direction decision: at first, the current passage direction of the variable gate is judged by *Decide* module and then assigned by the *Assign* module to determine direction of the variable gate after comparing τ with τ^* or comparing τ τ and $\frac{1}{\tau^*}$.

3) Sub-model of entrance gate selection: the truck entity is prepared to enter the port operation through the gate channel. Sub-model is adopted to select the most suitable gate channel. A Nonpooled queuing system is used to decide whether the entrance channel is idle by the *Decided* module. If the entrance channel is idle, then the truck entity chooses to accept the service, else, the truck chooses the entrance channel with the shortest queue length. After then, the truck entity enters to the port through entrance channel, enters yard and accepts yard service.

4) Sub-model of yard service: The truck entity enters the container terminal yard, and then examines whether the loading and unloading machinery is idle by the *Decide* module. After that, the truck entity goes to loading and unloading operation in the yard. Then the truck entity leaves the yard and prepares to enter the exit gate channel.

5) Sub-model of exit gate selection: The main process is the same as the entrance channel selection module of the gate.

4. CASE STUDY

4.1. Overview of the port in the case

There are 10 container berths in the container terminal, of which the design capacity is 8,900 thousands TEU in this case.

4.2. Simulation parameters

1) Arrival time of container trucks

The time when the trucks arriving at the gate of terminal is gotten by practical investigation and taken as the original data. Due to the irregularity of the arrival time in this case, we select the data in one year as the inputs of the model.

2) Service time

The service time of a truck through the In/Out the gate follows a normal distribution. The average service time of a truck through entrance gate is 1.024 minutes, the standard deviation is 0.28. And the average service time of a truck through the exit gate is 0.871 minutes, the standard deviation is 0.16.

3) Number of gates

According to the layout of the terminal, the number of the gates is 10

4.3. Determination of critical value

In order to determine the value of τ^* ($\tau^* > 1$) used to decide whether to change the working direction of the gate, we need to find a reasonable value of τ^* to optimize the queuing indexes, including maximum queuing time, average queuing time, maximum queue length and average queue length. In this study, we simulate the service status of the gate with only one variable gate in the situation in which the value range of τ^* is 1.1~2.3. We obtain the data of the aforementioned indexes. The results of the simulation are shown in Fig. 3.

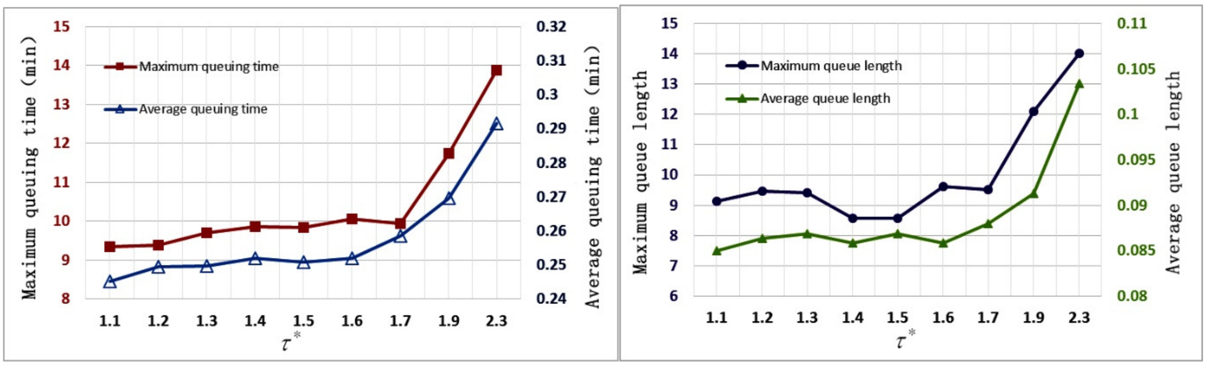


Figure 3: The results of the simulation

As shown in the Fig.3, with the increasing of τ^*, all the queuing indexes of the container trucks in the gate follow the same trend. And it should be noted that τ^* has little effect on the queuing indexes before its value reaches 1.7. It means that, on the premise that the values of maximum queuing length and time change little, we should take the value of τ^* as much as possible when the range is (1/1.7, 1.7), so that the direction change of the variable-gate won't be too frequent. After the value of τ^* reaching 1.7, the queuing indexes increased rapidly. Obviously, when the value of τ^* is sufficiently large, the critical value of the variable gate will never be able to reach in the model. And the variable gate won't change working direction.

Hence, the critical value in this case should be 1.7, which means that we should set variable gates when $\tau < 1/1.7$ or $\tau > 1.7$. In this situation, the judging condition of direction changing from In gate to Out gate is $\tau < 1/1.7$, and the judging condition of changing from Out gate to In gate is $\tau > 1.7$. When the interval of τ is (1/1.7, 1.7), it will keep the previous working direction.

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

4.4. Study of the effect on capacity of variable gate

In order to study the effect on capacity of variable gate of, we make three stimulations. Two of them is without variable gate and considers two combinations of numbers of In gates and Out gates, which are 4 in and 4 out, and 5 in and 3 out. In the other one simulation, the direction of the variable gate is dynamically adjusted according to the queuing index at the entrance and exit gate and the value of τ^* is from 1.1 to 2.3 with variable gate. In the three simulations, we obtain the values of the indexes including maximum queue time, maximum queue length, average queue time and the average queue length of the truck are gained. The results are shown in Fig 4.

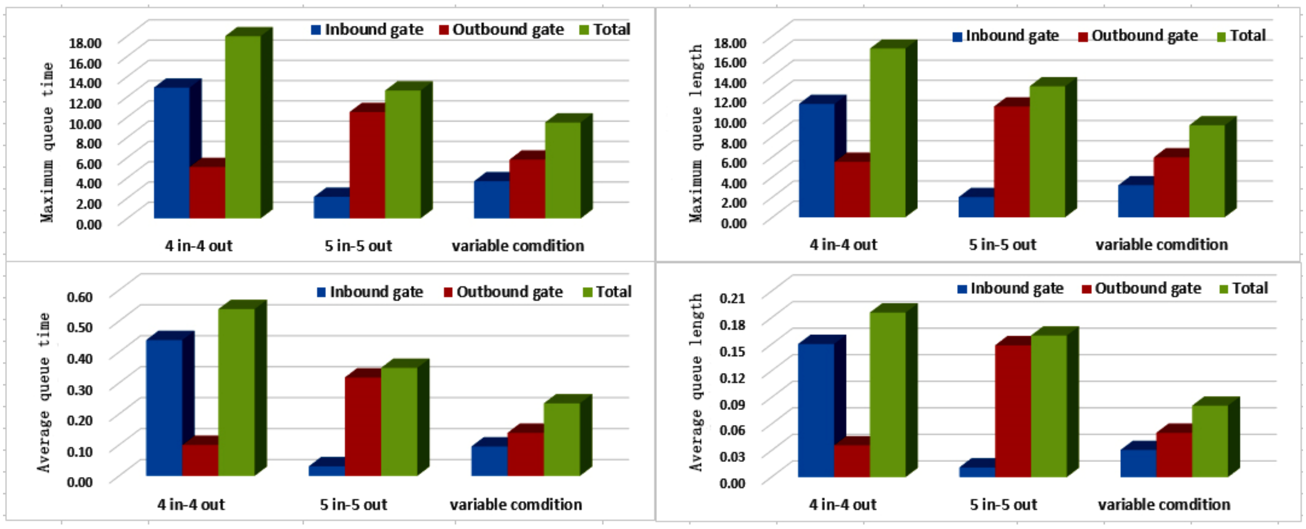


Figure 4: Comparison of the queue index of the port gate

Figure 4 shows that there is a great imbalance between the values of the indexes at entrance and exit gates in the simulations without variable gate. When the variable gate is set, the queuing imbalance is obviously relieved, and the overall queuing index is also significantly decreased, which indicates that the variable gate has a significant effect on easing the queuing phenomenon at the gate channel.

5. CONCLUSION

The research on the efficient and intelligent gate operation and making full use of existing gate resources can not only avoid the wastage caused by the blind expansion of gate, but also can greatly improve the terminal operating efficiency. According to the simulation model of the container terminal gate operating system, the variable gate is proposed as a method of improving the service level of the container gate.

Based on the simulation model with different values of imbalance coefficient, the effect of the variable gate on service status is measured. The critical values τ^* used to determine whether to set variable gates and to change the direction of variable gates is measured. The conclusions are as follows:

1） Setting variable gate has a significant effect on easing the queuing congestion at the entrance and exit gate.

2） The simulation model can be used to determine the critical values of τ used to determine whether to set the variable gate and changing its direction.

3) The application of simulation method can provide an effective tool for ports to scientifically plan and operate the wharf, which has great randomness and uncertainty. The results of this paper can provide a reference for the planning and design of large-scale container terminal gates.

ACKNOWLEDGMENTS

We would like to thank the National Natural Science Foundation of China (Grant No. 51309049 and No.51279026) for supporting this research.

REFERENCES

Boile M., Thefanis S., Golias M., et al., 2013. Gate strategies' impact on marine container terminal access networks. World Conference on Transport Research, July 15-18, Rio de Janeiro, Brazil.

Dai L., Gu J., Yu C., 2012. Simulation study on traffic flow characteristics and setting scheme of tidal lane. Computer and Communications, (01), 15-19.

Dekker R., Van Der Heide S., Van Asperen E., Ypsilantis P., 2013. A chassis exchange terminal to reduce truck congestion at container terminals. Flexible Services and Manufacturing Journal, (25), 528-542.

Guan C., Liu R., 2009. Container terminal gate appointment system optimization. Maritime Economics & Logistics, 11(4), 378-398.

Iwasaki M., Sato T., Oikawa T., 2003. Development of the ITS non-stop gate system for container terminals. Ishikawajima-Harima Giho/IHI Engineering Review, (43), 86-91.

Li L., Qu S., Chen Y., 2009. Variable lane control method. Journal of Jilin University (Engineering and Technology Edition), (S1), 98-103.

Liu C., Ji M., Yu L., 2011. The container terminal operation system through the research ability. Journal of Transportation Systems Engineering and Information Technology, (04), 117-123.

Longo F., Padovano A., Baveja A., Melamed B., 2015. Challenges and opportunities in implementing green initiatives for port terminals. 3rd International Workshop on Simulation for Energy, Sustainable Development and Environment, 138-145. Sept 21-23, Bergeggi, Italia.

Mai Y., Lu C., Tan J., 2007. Application of random service system (queuing theory) in the design of container terminal gate. Port and Waterway Engineering, (05), 39-42.

Minh C. G., Huynh N., 2014. Planning-Level Tool for Assessing and Optimizing Gate Layout for Marine Container Terminals. Transportation Research Record, (2409), 31-39.

Simpson K., Gamette, S., 2010. Design of Pier S marine terminal per the green port policy. Ports 2010: Building on the Past, Respecting the Future - Proceedings of the 12th Triennual International Conference, 1212-1221. April 25-28, Jacksoville, Florida.

Yu Y, Jin C, Huo L., 2007. Research on container yard gate system planning based on Simulation Optimization. Journal of System Simulation, (13), 3080-3084.

BUNCHING INDEX FOR BULK CARGO PORTS

Hai-Yan Xu [a], Xiuju Fu [b], Ruthu Shree Ragavan [c], Lee Jek Suen [d] , Xiao Feng Yin[e], Rick Siow Mong Goh[f]

[a],[b],[e],[f] Computing Science, Institute of High Performance Computing, Singapore
[c],[d] Jurong Port Pte Ltd, Singapore

[a] xuh@ihpc.a-star.edu.sg, [b] fuxj@ihpc.a-star.edu.sg, [c] ruthu@jp.com.sg
[d] jeksuen@jp.com.sg, [e] yinxf@ihpc.a-star.edu.sg, [f] gohsm@ihpc.a-star.edu.sg

ABSTRACT

In this study, we propose a novel Bunching Index (BI) model to derive a useful parameter for quantifying instantaneous information of congestion degree of ports based on number of vessels waiting for berths, waiting time and vessels size. Further analysis based on the data of port calls, port processes, and cargo demands from a general and bulk cargo port in Southeast Asia shows that the proposed bunching index well reflects the impact of vessel bunching at ports. It is found that bunching index is significantly correlated to certain types of port processes, cargo storage balance, and number of trucking trips for the cargo with time lags. Our study demonstrates that bunching index can be used for predicting time-ahead bunching, detecting the impact of bunching and factors affecting operations, and evaluating the effectiveness of counter measures for reducing bunching. We believe that bunching index can be used for other ports to detect hidden patterns and provide insights for improving port operation efficiency and optimizing resource utilization.

Keywords: bunching, bulk cargo ports, port operation efficiency, Berth on arrival rate

1. INTRODUCTION

Port congestion happens when the number of vessels waiting for berthing is accumulated to a certain level that exceeds the port capacity and the affected vessels have to wait longer than expected. Considering the detrimental impact of port congestion on port operator, shipping agents, and consignees, many researchers have studied possible factors that cause port congestion, cost associated with port congestion, and the ways to avoid and eliminate port congestion (Gidado 2015; Naudé 2016; Pani 2013).

Port congestion related studies could be more effective only when the severity of port congestion at any given time can be properly quantified. From the literature, the quantification of the degree of port congestion may be measured from different perspectives. One is from the view of ports, such as congestion index defined by Abe and Wilson (2011), i.e., the ratio of throughput handled in the port to the whole capacity of the port, which can also be considered as ports utilization rate. High value of this index implies high possibility of congestion. Berth on Arrival (BoA) rate, the percentage of vessels berthed within a certain time window since arrival, is usually used at ports, representing the performance of berthing at a port over a certain time period (Dai et al. 2004; Huang et al. 2008; Yang, Zhang, and Lam 2013). Lower BoA represents that the percentage of vessels not berthed within the specific time window is higher at ports. It also implies higher possibility of a long queue waiting for berths.

However, both congestion index and BoA cannot provide timely information for port berthing status and ignores the evaluation of berthing service from the view of vessel owners and consignees, i.e., the volumes of cargo on the vessels coupling the waiting duration matter, which is related to the demurrage cost occurred and the potential cost of cargo shortage due to the delayed unloading schedule, and affects vessels' next schedule etc.

The second one is from the view of ports' customers, i.e., shipping companies and consignees. UNCTAD (1976) proposed average waiting time to represent port congestion. This index cannot reflect the impact of the number of waiting vessels. If average waiting time is same, more waiting vessels implies a more severe congestion. Naudé (2016) improved the index by considering both average waiting time and number of waited vessels. Two indices are not convenient to be used to quantify the impact of the congestion situation and the vessel DWT are not reflected either.

It is obvious that port congestion at the moment is not properly quantified to reflect the real-time severity of congestion and the factors that concern various stakeholders. In this paper a novel Bunching Index (BI) model is proposed to derive a composite parameter for quantifying instantaneous information of congestion degree of ports based on the number of waiting vessels, waiting time and vessels size. The association between the proposed index and port operation parameters, and cargo demands is investigated based on the data of port calls from a general and bulk cargo port in Southeast Asia. We found that BI is significantly correlated to some port operations, cargo storage balance, and number of trucking trips for the cargo with time lags.

The rest of this paper is organized as follows: the details of the bunching index is formulated in Section 2; the influence of bunching index to other port loading/unloading processes is explored in Section 3; the study and discussions of factors that could affect bunching index is presented in Section 4; conclusions and further study directions are discussed in Section 5.

2. BUNCHING INDEX DEFINITION AND FORMULATION

2.1. Definition of bunching index in general and bulk cargo port

Bunching index is a concept that can be generally found to define regularity assessment in scheduled transportation system (Daganzo 1997), such as flight traffic (Dravecka 2006), bus transport (Li, Yang, and Ma 2013) and container liners. Different from scheduled transportation system where vehicles/vessels/planes are scheduled to arrive regularly, the berthing of vessels at general and bulk cargo port is usually irregular, i.e., vessels arrive with FCFS (first come and first served) mode. As such, bunching of vessels for berthing is expected, especially when there is higher throughput and limited number of berths available. Hence, bunching index for general and bulk cargo port is important to reflect the degree of port congestion.

Upon defining bunching index for general and bulk cargo port, we have the following considerations:

1. Vessels' waiting time threshold. Only vessels whose waiting time exceeds the threshold are accounted in bunching index calculation. This threshold can be changed according to different ports' regulation. Usually, it can be set the same as the threshold adopted for calculating BoA rate. For example, a 1-day time window is used in this study.
2. Accumulative effect of the number of waiting vessels and their waiting time. The longer the vessels wait and the more the vessels at port, the higher the bunching index is. As different vessels contribute differently to bunching index, bunching index is defined as the product of all vessels' contributions. We further assume that congestion severity increases exponentially as the increase of waiting time.
3. Impact of vessel size. Here vessel size is its deadweight. We choose deadweight instead of vessel throughput as deadweight directly links with the demurrage fee. The contribution of each vessel to bunching index is a power with the base of a function of vessel size. To avoid a too high and obtain a reasonable bunching index, the function of vessel size is defined as the sum of one and standardized vessel size, which is the ratio of vessel size divided by its maximum possible value of vessel size at the port. Here, maximum possible value is the biggest vessel deadweight at the port in history.

Let t denote current time, w_i denote the deadweight of vessel i, $t_i(t)$ denote waiting time of vessel i until time t, t_0 denote BoA threshold, the bunching index at time t is defined as

$$B(t) = \prod_{i \in \Omega_t} l_i(t) \qquad \text{Eq. 1}$$

where

$$l_i(t) = l(w_i, t_i) = (1 + g(w_i))^{f(t_i(t))}$$

Ω_t is the set of all vessels at the port at time t; $l_i(t)$ is the contribution of vessel i to bunching index; $g(w_i)$ reflects the impact of vessel's deadweight, and it is in (0, 1) with $g(w_i)=\alpha w_i/W$, α is an adjustment parameter, $W=max\{w_i|i\in\Omega\}$, Ω is the set of all vessels at the port in history; $f(t_i)$ is to reflect the impact of vessel's waiting time, $f(t_i)=max\{0, t_i-t_0\}$. It implies that $B(t)$ is 1, if there is no bunching at time t; $B(t) > 1$ if bunching presents.

2.2. Application of bunching index to a general cargo port

To check the reasonability and effectiveness of the proposed bunching index, we compared bunching index with the number of vessels at port and vessels' waiting time based on port calls data from a general and bulk cargo port in Southeast Asia. The data from April 2011 until June 2015 is used to verify the bunching index. Figure 1 depicts the time series of bunching index, number of vessels and waiting time calculated upon each vessel arriving at berth.

Figure 1: Bunching index, number of vessels and waiting time from April 2011 until June 2015 calculated upon each vessel arriving at berth. First panel: bunching index obtained based on Eq. 1; Second panel: number of vessels at port; third panel: waiting time before a vessel arriving at berth. BOA rate is calculated at annual basis.

From the Figure 1, it is clear that the bunching index reaches its highest point in 2013, when exceptional long waiting time erupts and the BoA rate is the lowest among all studied years. The bunching index is closely related to the BoA as the same threshold is used for both bunching index and BoA calculation. On the other hand, the number of vessels in the queue does not significantly affect bunching index. It is because the bunching index gives allowance for the vessel to be waiting in the queue. It affects the bunching index only when queuing time is longer than expected. Meanwhile, it also indicates that the fluctuation of the number of vessels is not the only factor affecting congestion degree and it works together with the duration of waiting time. It will be further discussed in Section 4.

3. HOW DOES BUNCHING INDEX AFFECT PORT PROCESSING

In this section, we explore how does bunching index associate with port operations through the port calls data from the general and bulk cargo port in Southeast Asia. We investigate the impact of bunching index on all non-working hour components for cement cargo unloading, including gantry (gantry moving and positioning), lubricant, trimming (trimming and cleaning of vessel cargo hole), silo stoppage (unloading stoppage due to silo capacity limitation), rain, port breakdown, others by consignee (others stoppage caused by consignee) and others by port (other stoppage caused by port).

Among all the non-working hour components, gantry and trimming are found having significant relationship to the bunching index after controlling other factors, such as cargo throughput, shipping agent, cargo type, net-working hour and non-working hour components other than the interested component using port stay data from April 2011 until June 2015 (see **Table 1**).

Table 1: Significant impact of bunching index on non-working hour components

Non-working hour components	Bunching index coefficient	p-value
Gantry (day)	1.449e-02	0.01430
Trimming (day)	-1.900e-02	0.01496

For net-working hour (NWH), we found that the impact of bunching index on NWH is not significant after controlling the effect of port and cargo relevant factors and non-working components. On the other hand, if we associate bunching index with NWH without controlling other factors, significant relationship between bunching index and NWH is detected. It implies that NWH might be affected by port of loading and/or cargo relevant factors (e.g., the type of cargos).

4. WHICH FACTORS CAN AFFECT BUNCHING INDEX

We further explore the factors that could affect or indicate bunching index through the cement vessel port calls data from the port. High cement demand implies high volume of cement and more vessels required by cement consignees, which would trigger possible high bunching index. The number of daily cement trucks passing through the port gates may reflect cement demand. To remove the periodic fluctuation of the number of cement trucks, a monthly moving average is used. The cross-correlation between cement trucks and daily maximum bunching index from August 2013 to August 2015 is calculated (see **Figure 2**). It is detected that cement trucks number 28 days ago has highest correlation coefficient with the current bunching index.

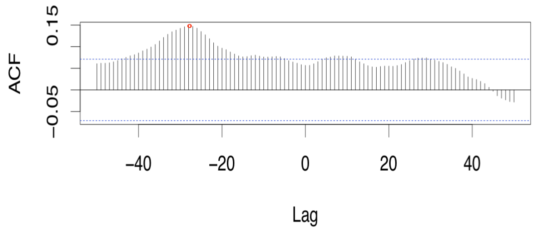


Figure 2: Cross-correlation between cement trucks (monthly moving average) and daily maximum bunching index

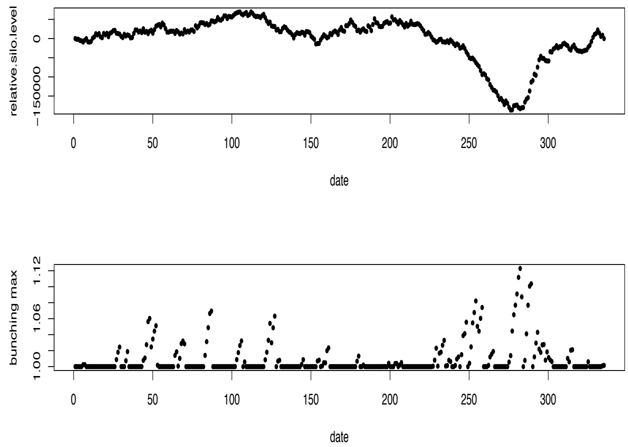


Figure 3: Estimated relative silo level and bunching index from April 2014 to February 2015

Silo balance can be another factor to reflect cement demand and also a more direct indicator to bunching index compared with the number of trucks running in the port's yard. Figure 3 illustrates the comparison of time series of estimated relative silo level and bunching index from April 2014 to February 2015. Furthermore, the cross-correlation between estimated relative silo level and daily maximum bunching index from April 2014 to February 2015 is calculated and depicted in **Figure 4**. Compared with the correlation between truck number and bunching index, higher correlation coefficient is detected between relative silo level and bunching index. It is detected that relative silo level one day ago has highest correlation coefficient with current bunching index.

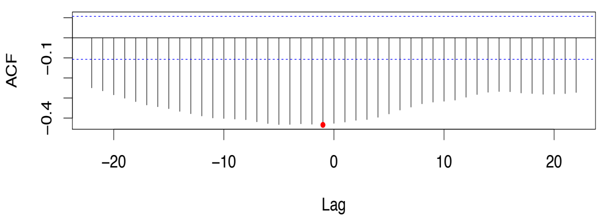


Figure 4: Cross-correlation between silo balance and daily maximum bunching index

5. CONCLUSIONS AND FUTURE WORK

In this paper, we propose a novel bunching index that takes into consideration the number of waiting vessels, vessel sizes and their waiting time. As a useful parameter for port and port efficiency study, the association between BI and other port operation parameters is indeed detected in this study. Significant relationship is found between bunching index and non-working hour components in port operation: gantry and trimming after controlling other factors. More specifically, higher bunching index associates longer gantry time and shorter trimming time. Silo balance and number of cement trucks entering into port have lagged effect on bunching index. Silo balance one day ago has highest negative correlation to bunching index, while number of trucks one month ago has the highest positive correlation to bunching index considering all lags.

Our study demonstrates that bunching index can be used for predicting time-ahead bunching, detecting the impact of bunching and factors affecting operations, and evaluating the effectiveness of counter measures for reducing bunching. It suggests that advanced booking is one option to reduce bunching besides increasing port resources. We believe that BI can be used for other ports to detect hidden patterns and provide insights for improving port operation efficiency and optimizing resource utilization. The BI can also be extended to include other relevant factors, such as cargo size, to better reflect the significance of vessels affected. A version II BI might be realized in the near future that is able to be used not only in bulk cargo terminal but in general and container cargo terminals.

REFERENCES

Abe K., Wilson S.J., 2011. Investing in Port Infrastructure to Lower Trade Costs in East Asia, Journal of East Asian Economic Integration. Vol. 15, pp. 3-32.

Daganzo F.C., 1997. Scheduled transportation systems, Fundamentals of Transportation and Traffic Operations, pp.285 – 321.

Dai J., Lin W., Moorthy R., Teo C.-P., 2004. Berth allocation planning optimization in container terminal. Unpublished manuscript. Available from: https://people.orie.cornell.edu/jdai/publications/daiLinMoorthyTeo08.pdf [accessed 1 June 2017]

Dravecka L., 2006. Operational feasibility of traffic synchronisation in central Europe – results, in 25th Congress of the International Council of the Aeronautical Sciences. Hamburg, Germany: ICAS.

Gidado, U., 2015. Consequences of port congestion on logistics and supply chain in African ports. Developing Country Studies. 5(6): 160–167.

Huang S.Y., Hsu W.J., Chen C., Ye R., Nautiyal S., 2008. Capacity analysis of container terminals using simulation techniques, International Journal of Computer Applications in Technology, 4(32), pp. 246-253

Li F., Yang D., Ma, K., 2013. Bus Rapid Transit (BRT) Bunching Analysis with Massive GPS Data. Fourth International Conference on Transportation Engineering, October 19-20, Chengdu, China

Naudé J., 2016. A Multi-Phase Model to Forecast Congestion at Brazilian Grain Ports: a Case Study at the Port of Paranagua, Thesis (Master). Stellenbosch University.

Pani C., 2013. Managing vessel arrival uncertainty in container terminals: a machine learning approach. Thesis (PhD). University of Cagliari, University of Antwerp.

UNCTAD, 1976. Port performance indicators. United nations Conference on Trade and Development. New York, US.

Yang D., Zhang A., Lam J.S.L., 2013. Impacts of port productivity and service level on liner shipping operating cost and schedule reliability. International Forum on Shipping, Ports and Airports (IFSPA). Trade, Supply Chain Activities and Transport: Contemporary Logistics and Maritime Issues.

AUTHORS BIOGRAPHY

Dr. Hai-Yan XU is a research scientist with the Institute of High Performance Computing, Singapore. She received her B.S. (1999) in Mathematics, M.S. (2002) and Ph.D. (2005) in Statistics from Shanghai Normal University, China. She has published more than 20 papers in peer-reviewed conferences and journals such as PLOS Neglected Tropical Diseases, PLOS One, IEEE Transactions on Reliability, IIE Transactions, Computational Statistics & Data Analysis, and The International Journal of Advanced Manufacturing Technology. Her research interests include applied statistics and probability, longitudinal data analysis, discrete time series analysis, accelerated life and degradation testing, optimal design, and large-scale data analysis with applications in maritime port, logistics and supply chain, public health, manufactury, and city planning.

Dr. Xiuju FU is Senior Scientist in Department of Computing Science at Institute of High Performance Computing, A-STAR. She received her bachelor and master degrees in Beijing Institute of Technology in 1995 and 1999, respectively. And she received her Ph.D. in Information System, School of EEE, Nanyang Technological University, 2003. Her research areas are in intelligent modelling and simulation based on data analysis, modeling/simulation and optimization techniques, with the applications in maritime port and transportation, logistics and supply chain, and public health.

Ms. Ruthu Shree Ragavan is an Assistant Manager, Strategic Planning Office at Jurong Port Pte Ltd. During her 6 years in the port industry, she has also served in Operational and Customer Service roles. She majored in International Transportation and Logistics Management and received her Master of Business Administration (2011) from Indian Maritime University, India

Mr. Lee Jek Suen is an Assistant Vice President, Strategic Planning Office at Jurong Port Pte Ltd. He received his B.A Oxon (1996) in Politics, Philosophy & Economics from the Oxford University (UK), and MSc International Relations (1997) from the London School of Economics (UK). Over the past decade, besides Strategic Planning, he has served in Business Development and Operational roles in Singapore, China, other ASEAN as well as African ports.

Dr. Xiao Feng YIN is Scientist for the Institute of High Performance Computing, A*STAR Singapore. He received both his PhD and his Master's degrees from Nanyang Technological University (NTU), Singapore. His research interests include maritime, logistics and supply chain optimization, planning and scheduling, knowledge discovery and artificial intelligence.

Dr. Rick Siow Mong GOH is the Director of the Computing Science (CS) Department at the A*STAR's Institute of High Performance Computing (IHPC). At IHPC, he leads a team of more than 60 scientists in performing world-leading scientific research, developing technology to commercialization, and engaging and collaborating with industry. The research focus areas include high performance computing (HPC), distributed computing, artificial intelligence, and complex systems. His expertise is in discrete event simulation, parallel and distributed computing, and performance optimization and tuning of applications on large-scale computing platforms. Dr. Goh received his Ph.D. in Electrical and Computer Engineering from the National University of Singapore. More details on Rick can be found at: http://www.a-star.edu.sg/ihpc/People/tid/2/Rick-Goh-Siow-Mong.aspx

A BRANCH-AND-BOUND ALGORITHM FOR THE BLOCK RELOCATION PROBLEM TO MINIMIZE TOTAL CRANE OPERATION TIME

Y. Inaoka[(a)], S. Tanaka[(b)]

[(a),(b)] Kyoto University

[(a)]inaoka@rotary.kyoto-u.ac.jp, [(b)] tanaka@kuee.kyoto-u.ac.jp

ABSTRACT
Containers transferred to a sea port are stacked and stored in container yards of a container terminal. In order to retrieve a container on which other containers are stacked by a crane, these interfering containers should be relocated to some places beforehand, where they may cause further relocations. The aim of the block (container) relocation problem is to retrieve all blocks in a specified order with such unproductive relocation being minimized. Most of existing studies on this problem aim to minimize the total number of relocations. However, it is more desirable from a practical point of view to consider actual crane operation time. In this research, we propose a branch-and-bound algorithm for the block relocation problem to minimize total crane operation time. Its effectiveness is examined by computational experiments.

Keywords: container terminal, block relocation problem, branch-and-bound algorithm, total crane operation time

1. INTRODUCTION

Container transport plays an important role in the global logistics system. Containers transferred to a sea port by vessels or trucks are stored temporarily in a container terminal. Due to limitation of space, they are in general piled up in container yards as Figure 1. Containers are then transferred to their next destinations from there. Since this order is determined by their departure time, destinations, weight, contents and so on, it in general does not coincide with the stacked order. Therefore, relocation or reshuffling inevitably occurs to retrieve a container stacked in a lower tier by a crane. Such relocated containers may interfere another container if they are stacked on it, meaning that a careful and intelligent decision of relocations can improve the throughput of container handling in a container terminal. For the purpose of reducing unproductive relocations, the container relocation problem, which is also known as the block relocation problem, has been studied in the literature. Its objective is to retrieve stacked containers (blocks) in a specified order with the least effort. For the sake of generality, this problem is referred to as the block relocation problem (BRP), and a container as a block accordingly. Most of previous studies on this problem aim to minimize the total number of relocations. To the best of the authors' knowledge, studies that try to minimize crane operation time are limited in spite of its practical importance. Lee and Lee (2010) proposed a heuristic algorithm for the BRP where horizontal travel time of a block is considered. Ünlüyurt and Aydın (2012) also treated the BRP with horizontal travel time, and proposed a branch-and-bound algorithm as well as heuristic ones. Lin et al. (2015) further considered

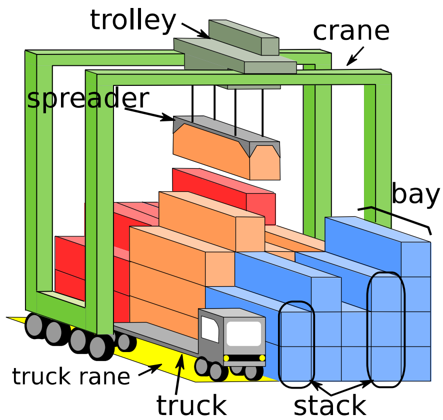


Figure 1: Container Yard

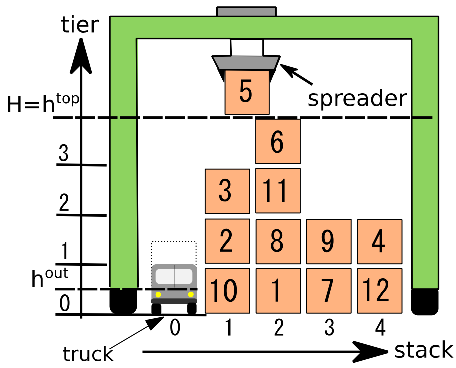


Figure 2: Blocks in the Target Bay

vertical travel time and constructed a heuristic algorithm. They also treated a crane capable of handling multiple blocks at a time. Recently, Schwarze and Voß (2016) solved the problem with horizontal and vertical travel time using the ILP (integer linear programming) formulation by Zehendner et al. (2015), which was originally proposed to minimize the total number of relocations. However, the size of instances that can be solved to optimality is still restrictive. The purpose of this study is to construct an efficient branch-and-bound algorithm for the BRP to minimize total crane operation time where not only horizontal travel time but also vertical travel time is taken into account. For this purpose, we will propose dominance properties for suppression of unnecessary nodes and two types of lower bound of the objective value for bounding. The effectiveness of the algorithm will be demonstrated by numerical experiments.

2. PROBLEM DESCRIPTION

In this section, we will provide an explicit description of the BRP considered in this study. Suppose that blocks (containers) are stored in a container yard as illustrated in Figure 1. A single row of blocks is called a bay, and a bay is composed of stacks where blocks are piled up vertically. A gantry crane is used to move blocks. Since the travel time of the crane across bays is time-consuming, we concentrate on a single bay and consider retrieving all blocks therein (Figure. 2).

The stacks in the bay are numbered as stack 1, stack 2, stack S. N blocks of the same size are stored in the bay, which are numbered as block 1, block 2, …, block N. Due to the height of the crane, the maximum number of blocks in each stack is limited to H. The slot in the h-th tier of stack s is denoted by (s, h), where the ground level is $h = 0$. We are to retrieve all the blocks from the bay in the ascending order of block numbers. To do this, the blocks should be moved onto the bed of a truck at $(0, h^{\text{out}})$ one by one. The crane can access only topmost blocks, so that the crane performs the following two operations.

- Relocation: A block on the top of a stack is moved to the top of another stack that does not reach the height limit.
- Retrieval: The block with the smallest number (target block) is moved to the bed of the truck if it is on the top of a stack.

Our objective is to minimize the total crane operation time. Here, we make the following assumption.

Only blocks above the target block can be relocated.

The BRP with this assumption is often referred to as the restricted BRP in the literature.

When the crane relocates a block, it moves the spreader horizontally to the stack where the block is placed. Next, it winds the spreader down onto the block, and grasps the block. Then the crane winds them up together, moves them horizontally to the destination stack, winds them down, and releases the block. We assume that the spreader can move horizontally only along the h^{top}–th tier. In addition, the initial position of the spreader is assumed to be $(0, h^{\text{out}})$. The detailed crane operation time is summarized in Table 1. It follows from Table 1 that when the initial position of the spreader is $(0, h^{\text{out}})$, the time necessary for retrieving a block from (s, h) is given by

Table 1: Crane Operation Time

t_{sg}[s]	The block grasp time
t_{sr}[s]	The block release time
t_{t} [s/stack]	The trolley speed for horizontal move
t_{hu} [s/tier]	The hoisting speed (unloaded)
t_{hl}[s/tier]	The hoisting speed (loaded)

$$t_{\text{s}} + 2t_{\text{t}}s + t_{\text{h}}\,(2h^{\text{top}} - h - h^{\text{out}}), \quad (1)$$

where $t_{\text{s}} = t_{\text{sr}} + t_{\text{sg}}$ and $t_{\text{h}} = t_{\text{hu}} + t_{\text{hl}}$. If, before retrieving the block from (s, h), n blocks on it are relocated from $(s, h + k)$ to $(s^{\text{d}}_k, h^{\text{d}}_k)$, $(k = 1, 2, \dots, n)$, respectively, the total crane operation time becomes:

$$t_{\text{s}} + 2t_{\text{t}}s + t_{\text{h}}(2h^{\text{top}} - h - h^{\text{out}}) + \sum_{k=1}^{n}\{t_{\text{s}} + 2t_{\text{t}}|s^{\text{d}}_k - s| + t_{\text{h}}(2h^{\text{top}} - h^{\text{d}}_k - h - k)\}. \quad (2)$$

Suppose that block i $(i = 1, 2, \dots, N)$ is retrieved from (s_i, h_i), which causes M relocations from $(s^{\text{s}}_k, h^{\text{s}}_k)$ to $(s^{\text{d}}_k, h^{\text{d}}_k)$ $(k = 1, 2, \dots, M)$. Noting that every block is relocated from the stack where the current target block is placed as in (2), we can see that the total crane operation time is given by

$$\sum_{k=1}^{M}\{t_{\text{s}} + 2t_{\text{t}}|s^{\text{d}}_k - s^{\text{s}}_k| + t_{\text{h}}(2h^{\text{top}} - h^{\text{s}}_k - h^{\text{d}}_k)\} + \sum_{i=1}^{N}\{t_{\text{s}} + 2t_{\text{t}}s_i + t_{\text{h}}\,(2h^{\text{top}} - h_i - h^{\text{out}})\}. \quad (3)$$

This equation provides the objective function of the BRP that should be minimized. If we ignore the horizontal and vertical travel times by setting $t_{\text{t}} = t_{\text{h}} = 0$, (3) reduces to $t_{\text{s}}(M + N)$, so that the problem becomes equivalent to the problem of minimizing M, the total number of relocations.

3. BRANCH-AND-BOUND ALGORITHM

To solve the BRP explained in the preceding section to optimality, we apply a branch-and-bound algorithm. Since a solution of the BRP can be expressed by a sequence of relocations by assuming that blocks are retrieved as soon as they become retrievable, the algorithm searches for an optimal sequence of relocations. Subproblems are generated by fixing the sequence from the start one by one. Thus, a node at depth k in the search tree represents a bay configuration obtained by applying k relocations (and retrieving as many blocks as possible). The search tree is traversed in the depth-first manner. The initial solution is calculated by a constructive heuristic PR4 by Zhu et al. (2012) for simplicity, although it aims to minimize the total number of relocations.

4. DOMINANCE OF COLUMNS

We will derive two dominance properties, which are employed to suppress generation of unnecessary nodes in the search tree of the branch-and-bound algorithm. A (partial) sequence of relocations is said to dominate another sequence of relocations if the former yields at least as good a solution as the latter. Here, we show that the same bay configuration is obtained by two sequences of relocations under some conditions. Then, the one with a longer crane operation time is dominated by the other, so that the former can be forbidden in the search tree.

Let us denote by C_0 the bay configuration obtained by retrieving as many blocks as possible from the initial configuration without any relocation. Let us also denote by a triplet $(i, s^{\mathrm{s}}, s^{\mathrm{d}})$ the relocation of block i from stack s^{s} to stack s^{d}. In the following, we prove two theorems that provide conditions for a sequence of relocations $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}})$, $(i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \dots, (i_n, s_n^{\mathrm{s}}, s_n^{\mathrm{d}})$ to be dominated by another sequence when applied to C_0. Throughout this section, the bay configuration obtained by applying $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}}), \dots, (i_k, s_k^{\mathrm{s}}, s_k^{\mathrm{d}})$ to C_0 (and retrieving all retrievable blocks) is denoted by C_k. Furthermore, the number of blocks and the smallest block number in stack s of a bay configuration C are denoted by $N_s(C)$ and $Q_s(C)$, respectively. The stack where the target block is placed is referred to as the target stack: it is given by $\operatorname{argmin}_{1 \le s \le S} Q_s(C)$.

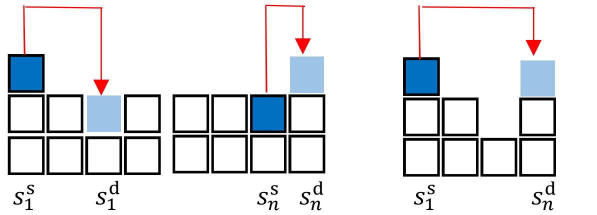
4.1. Transitivity of two relocations

The first dominance property concerns transitivity of two relocations. If some block is relocated from stack s_1 to stack s_2 and then stack s_2 to stack s_3, these two relocations can be combined into one relocation from stack s_1 to stack s_3 without increasing the total crane operation time (Figure 3) as long as it does not affect block retrieval.

Theorem 1

The sequence $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}}), (i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \dots, (i_n, s_n^{\mathrm{s}}, s_n^{\mathrm{d}})$ for C_0 is dominated by a sequence $(i_1, s_1^{\mathrm{s}}, s_n^{\mathrm{d}}), (i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \dots, (i_{n-1}, s_{n-1}^{\mathrm{s}}, s_{n-1}^{\mathrm{d}})$, if all the following conditions are satisfied:

1. $i_n = i_1$.
2. $\{s_1^{\mathrm{d}}, s_n^{\mathrm{d}}\} \cap \{s_2^{\mathrm{s}}, s_2^{\mathrm{d}}, \dots, s_{n-1}^{\mathrm{s}}, s_{n-1}^{\mathrm{d}}\} = \emptyset$.
3. $N_{s_n^{\mathrm{d}}}(C_0) = N_{s_n^{\mathrm{d}}}(C_{n-1})$.



(a)Transitive Relocations (b) Combined Relocation

Figure 3: Combining Two Transitive Relocations into One

Proof. Condition 2 ensures that no block is relocated from or to stack s_1^{d} by the sequence $(i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \dots, (i_{n-1}, s_{n-1}^{\mathrm{s}}, s_{n-1}^{\mathrm{d}})$. Moreover, condition 1 implies that block i_1 is not retrieved by this sequence, so that $s_n^{\mathrm{s}} = s_1^{\mathrm{d}}$ holds. Furthermore, stack s_1^{d} is not the target block in $C_0, C_1, \dots, C_{n-1}$ because no block is relocated from there by this sequence. It follows that this stack becomes the target block for the first time after relocation $(i_{n-1}, s_{n-1}^{\mathrm{s}}, s_{n-1}^{\mathrm{d}})$. Now, assume that block i_1 is relocated from s_1^{s} not to stack s_1^{d} but to stack s_n^{d}. From conditions 2 and 3, it does not make block i_1 interfere any retrieval from stack s_n^{d}. Let us denote by $\hat{C}_{n-1}$ the block configuration obtained by sequence $(i_1, s_1^{\mathrm{s}}, s_n^{\mathrm{d}})$, $(i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \dots, (i_{n-1}, s_{n-1}^{\mathrm{s}}, s_{n-1}^{\mathrm{d}})$ for C_0. Then, the differences between C_{n-1} and $\hat{C}_{n-1}$ are:

(a) block i_1 is on the top of stack s_1^{d} in C_{n-1}, while it is on the top of stack s_n^{d}, unless it is already retrieved in $\hat{C}_{n-1}$,

(b) some block may be retrieved from stack s_1^{d} in $\hat{C}_{n-1}$, which may cause further retrieval.

The retrieval from stack s_1^{d} in (b), which is interfered by block i_1 in C_{n-1}, should be after relocation $(i_{n-1}, s_{n-1}^{\mathrm{s}}, s_{n-1}^{\mathrm{d}})$ because this stack does not become the target stack until then. Therefore, this retrieval should also be enabled by relocating block i_1 to stack s_n^{d} in C_{n-1}. In other words, the block should be retrieved in C_n. If, as in (a), block i_1 is already retrieved in $\hat{C}_{n-1}$, it should be caused by the retrieval from s_1^{d} in (b) because otherwise, block i_1 should already be retrieved also in C_{n-1}. Hence, relocating it from s_n^{s} in C_{n-1} makes it retrievable. From these observations, $\hat{C}_{n-1}$ and C_n are exactly the same. Since it is obvious that the crane operation time of sequence $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}})$, $(i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \dots, (i_n, s_n^{\mathrm{s}}, s_n^{\mathrm{d}})$ is not shorter than that of sequence $(i_1, s_1^{\mathrm{s}}, s_n^{\mathrm{d}})$, $(i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}})$, $\dots, (i_{n-1}, s_{n-1}^{\mathrm{s}}, s_{n-1}^{\mathrm{d}})$, the former is dominated by the latter.

4.2. Dominance on retrieval

The second dominance properties covers the situation when a block is retrieved regardless of which stack it is relocated to. In such a case, the destination stack with a shorter crane operation time is preferred (Figure 4).

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

Theorem 2
The sequence $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}}), (i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \ldots, (i_n, s_n^{\mathrm{s}}, s_n^{\mathrm{d}})$ for C_0 is dominated by a sequence $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}'}), (i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \ldots, (i_n, s_n^{\mathrm{s}}, s_n^{\mathrm{d}})$, if all the following conditions are satisfied:

1. $i_1 \in C_{n-1} \wedge i_1 \notin C_n$.
2. $\{s_1^{\mathrm{d}}, s_1^{\mathrm{d}'}\} \cap \{s_1^{\mathrm{s}}, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}, \ldots, s_n^{\mathrm{s}}, s_n^{\mathrm{d}}\} = \emptyset$.
3. $Q_{s_1^{\mathrm{d}'}}(C_0) > i_1$.
4. $N_{s_1^{\mathrm{d}'}}(C_0) < H$.
5. $N_{s_1^{\mathrm{d}'}}(C_0) \geq N_{s_1^{\mathrm{d}}}(C_0)$.
6. $s_1^{\mathrm{d}'} < s_1^{\mathrm{d}}$.

Proof. From condition 1, block i_1 is retrieved after the relocation of block i_n. Block i_1 stays on the top of stack s_1^{d} in $C_1, \ldots, C_{n-1}$ from condition 2. Since conditions 2 and 3 claim that stack $s_1^{\mathrm{d}'}$ is unchanged before block i_1 is retrieved, this block does not interfere any retrieval even if it is relocated not to s_1^{d} but to $s_1^{\mathrm{d}'}$, whose feasibility is guaranteed by condition 4. In addition, this relocation does not enable any retrieval from stack s_1^{d} before that of block i_1 because block i_1 is retrieved before the blocks in stack s_1^{d} in C_0 from condition 1, meaning that it never interferes their retrieval. Therefore, sequence $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}'}), (i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \ldots, (i_n, s_n^{\mathrm{s}}, s_n^{\mathrm{d}})$ yields exactly the same configuration as C_n. The total crane operation time of this sequence is not longer than that of sequence $(i_1, s_1^{\mathrm{s}}, s_1^{\mathrm{d}}), (i_2, s_2^{\mathrm{s}}, s_2^{\mathrm{d}}), \ldots, (i_n, s_n^{\mathrm{s}}, s_n^{\mathrm{d}})$ due to conditions 5 and 6: stack $s_1^{\mathrm{d}'}$ is nearer from the truck than stack s_1^{d}, and the former is at least as tall as the latter.

5. LOWER BOUND COMPUTATION

In this section, we will propose two types of lower bound of the objective value, which are employed in the branch-and-bound algorithm. Hereafter, a block below which a block with a smaller number is placed is referred to as a blocking block. Every blocking block should be relocated at least once.

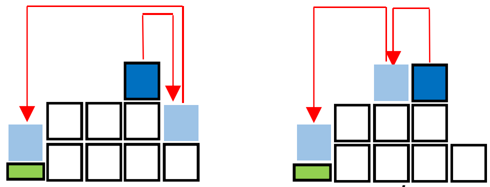
5.1. LB-A

Let us consider a bay configuration C where n blocks are placed at $(s_1, h_1), (s_2, h_2), \ldots, (s_n, h_n)$. If all these blocks can be retrieved without any relocations, the total crane operation time is, as the second term of (3), given by

$$\sum_{i=1}^{n} \{t_{\mathrm{s}} + 2t_{\mathrm{t}} s_i + t_{\mathrm{h}}(2h^{\mathrm{top}} - h_i - h^{\mathrm{out}})\}. \quad (4)$$

If the block placed at (s_i, h_i) is relocated to (s_i', h_i') from where it is retrieved, the increase of the total crane operation time from (4) is:

$$t_{\mathrm{s}} + 2t_{\mathrm{t}}(|s_i' - s_i| + s_i' - s_i) + 2t_{\mathrm{h}}(h^{\mathrm{top}} - h_i'). \ (5)$$



(a) Longer Operation Time (b) Shorter Operation Time
Figure 4: Difference of Retrieval due to Preceding Relocation

The second term of (5) takes a minimum value 0 at $s_i' < s_i$ if $s_i > 1$, and $4t_{\mathrm{t}}$ at $s_i' = 2$ if $s_i = 1$. The minimum of the third term is achieved by relocating the block to the tallest stack and is given by $2t_{\mathrm{h}}(h^{\mathrm{top}} - h^{\mathrm{max}})$, where $h^{\mathrm{max}} = \max_{\substack{1 \leq s \leq S \\ N_s(C) < H}} N_s(C)$. Taking into account the increase of the stack height from h^{max} to $h^{\mathrm{max}} + 1$ after this relocation, we obtain the following lower bound of the total crane operation time for C:

$$\sum_{i=1}^{n} \{t_{\mathrm{s}} + 2t_{\mathrm{t}} s_i + t_{\mathrm{h}}(2h^{\mathrm{top}} - h_i - h^{\mathrm{out}})\} + t_{\mathrm{t}} m_1$$
$$+ \sum_{i=1}^{m} [t_{\mathrm{s}} + t_{\mathrm{h}}\{h^{\mathrm{top}} - \max(h^{\mathrm{max}} + i - 1, H - 1)\}]. \ (6)$$

Here, m denotes the total number of relocations and m_1 that from stack 1. We choose m_1 as the number of blocking blocks in stack 1, and m as a lower bound of the total number of relocations. We refer to this lower bound as LB-A1 and LB-A2 when m is chosen as the total number of blocking blocks (the lower bound by Kim and Hong (2006)), and the lower bound by Tanaka and Takii (2016), respectively.

5.2. LB-B

To derive another lower bound LB-B, we start from (5) as LB-A, which provides the increase of the total crane operation time caused by a relocation. Unlike LB-A, we further take into consideration the situation when this block becomes a blocking block again and thus should be relocated once more. Let (s_i'', h_i'') be the destination slot of this relocation. Then, the total crane operation time further increases by

$$t_{\mathrm{s}} + 2t_{\mathrm{t}}(|s_i'' - s_i'| + s_i'' - s_i') + 2t_{\mathrm{h}}(h^{\mathrm{top}} - h_i''). \ (7)$$

A lower bound of this increase is computed as that of (5) in LB-A, except for that h_i'' is chosen simply as $H - 1$. Thus it is given by $t_{\mathrm{s}} + 2t_{\mathrm{h}}(h^{\mathrm{top}} - H + 1)$ if $s_i' \neq 1$, and $t_{\mathrm{s}} + 4t_{\mathrm{t}} + 2t_{\mathrm{h}}(h^{\mathrm{top}} - H + 1)$ if $s_i' = 1$. In summary, a lower bound of the increase caused by relocating a block is provided as follows.

1. If the block does not become a blocking block: (5).

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

Table 2: Three Types of Crane Specification in the Literature

Setting	t_s[s]	t_t[s/stack]	t_h[s/stack]
1	30	1.2	0
2	5	1	0
3	0	1.2	7.77

1 (Lee and Lee, 2010)
2 (Ünlüyurt and Aydın, 2012)
3 (Lin et al, 2015)

2. If the block becomes a blocking block after the relocation:

If $s_i' \neq 1$,

$$2t_s + 2t_t(|s_i' - s_i| + s_i' - s_i) + 2t_h(2h^{top} - h_i' - H + 1). \quad (8)$$

If $s_i' = 1$,

$$2t_s + 2t_t(|s_i' - s_i| + s_i' - s_i + 2) + 2t_h(2h^{top} - h_i' - H + 1). \quad (9)$$

To obtain LB-B for C, we compute this lower bound for every blocking block and add them to (4). Inspired by the lower bound of the total number of relocations proposed by Zhu et al. (2012), the destination stack s_i' in (5), (8) and (9) is determined in the following manner. First, we relocate the topmost block above the target block, and its destination is determined so as to minimize the lower bound of the increase given by (5), (8) or (9). It is done by computing (5), (8) or (9) for every candidate stack whose height is less than H. Then, this block is removed from the bay, and the destination stack of the second topmost block (the topmost block in the current bay configuration) is determined in the same way. After the destination stacks of all blocking blocks above the target block are determined, the target block itself is removed as well, and the new target block in the current bay configuration is identified. Then, the destination stacks of blocking blocks above it are determined. This procedure is repeated until the destination stacks of all blocking blocks are determined. With regard to the height h_i' of the destination stack, we should consider the influence of removed blocking blocks that in practice are relocated to some stacks. Let b be the number of blocks removed so far in the above procedure (it includes removed target blocks). Without loss of generality, the target block is block 1 in C, and block c in the current block configuration. Then, the number of ignored blocks is given by $b - (c - 1)$. Therefore, h_i' is assumed to be the current height of the destination stack plus $b - (c - 1)$ (the maximum is $H - 1$).

6. COMPUTATIONAL EXPERIMENTS

We applied the proposed algorithm to the set of benchmark instances used in Caserta et al. (2011) in order to examine its effectiveness. This benchmark set is composed of 40 randomly generated instances for each combination of S and T, where T is the number of blocks in each stack (the total number of blocks is ST). The stack height limit H was set to $T + 2$. As the specification of the crane, we considered three settings in the literature, which are summarized in Table 2. In every setting, h^{top} and h^{out} were chosen as $h^{top} = H$ and $h^{out} = 0.5$, respectively. The computation was conducted using a desktop computer with an Intel Core i7-6700K CPU (4.00GHz) and 64GB RAM. The time limit for one instance was set to 1800s.

Table 3: Computational Results under Setting 1

T	S	LB-A1		LB-A2		LB-B	
		opt	time[s]	opt	time	Opt	Time
3	3	40	0.00	40	0.00	40	0.00
	4	40	0.00	40	0.00	40	0.00
	5	40	0.00	40	0.00	40	0.00
	6	40	0.00	40	0.00	40	0.00
	7	40	0.00	40	0.00	40	0.00
	8	40	0.00	40	0.00	40	0.00
4	4	40	0.00	40	0.00	40	0.00
	5	40	0.00	40	0.00	40	0.00
	6	40	0.01	40	0.01	40	0.00
	7	40	0.05	40	0.05	40	0.02
5	4	40	0.00	40	0.00	40	0.00
	5	40	0.14	40	0.01	40	0.02
	6	40	1.88	40	0.28	40	0.39
	7	40	49.31	40	11.73	40	9.28
	8	37	74.64	39	56.11	39	34.01
	9	29	302.03	32	404.13	37	141.73
	10	20	511.13	16	203.59	27	220.53

Table 4: Computational Results under Setting 2

T	S	LB-A1		LB-A2		LB-B	
		opt	time[s]	opt	time	Opt	time
3	3	40	0.00	40	0.00	40	0.00
	4	40	0.00	40	0.00	40	0.00
	5	40	0.00	40	0.00	40	0.00
	6	40	0.00	40	0.00	40	0.00
	7	40	0.00	40	0.00	40	0.00
	8	40	0.00	40	0.01	40	0.00
4	4	40	0.00	40	0.00	40	0.00
	5	40	0.00	40	0.01	40	0.00
	6	40	0.03	40	0.06	40	0.01
	7	40	0.42	40	0.91	40	0.04
5	4	40	0.00	40	0.00	40	0.00
	5	40	0.38	40	0.35	40	0.04
	6	40	16.49	40	29.35	40	0.71
	7	37	128.17	36	67.49	40	64.49
	8	27	225.70	25	332.92	38	65.95
	9	14	538.09	14	675.19	26	106.93
	10	6	511.48	4	304.39	14	366.22

Table 5: Computational Results under Setting 3

T	S	LB-A1		LB-A2		LB-B	
		opt	time[s]	opt	Time	Opt	Time
3	3	40	0.00	40	0.00	40	0.00
	4	40	0.00	40	0.00	40	0.00
	5	40	0.01	40	0.01	40	0.00
	6	40	0.69	40	2.20	40	0.34
	7	40	2.73	40	8.21	40	1.13
	8	40	60.64	39	105.65	40	21.26
4	4	40	0.01	40	0.02	40	0.01
	5	40	1.80	40	5.46	40	1.29
	6	39	170.40	33	134.64	40	88.36
	7	17	430.01	11	498.18	22	402.28
5	4	40	0.59	40	1.77	40	0.51
	5	29	234.27	25	344.92	31	210.05
	6	4	863.87	2	1507.20	4	515.74

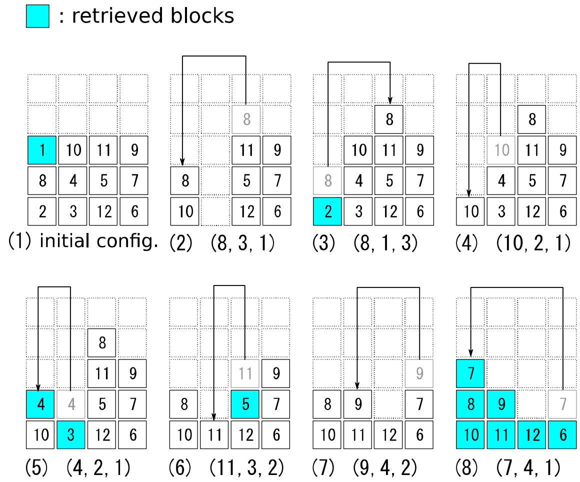
The computational results are summarized in Tables 3-5 for settings 1-3, respectively. In the tables, 'opt' denotes the number of instances out of 40 solved to optimality within the time limit, and 'time' the average CPU time in seconds over instances solved to optimality.

LB-A2 is not smaller than LB-A1 because the lower bound of the total number of relocations by Tanaka and Takii (2016) used in LB-A2 always dominates the total number of blocking blocks used in LB-A1. On the other hand, the former takes a longer computation time than the latter. Therefore, it depends on the crane specification which lower bound yields a better result.

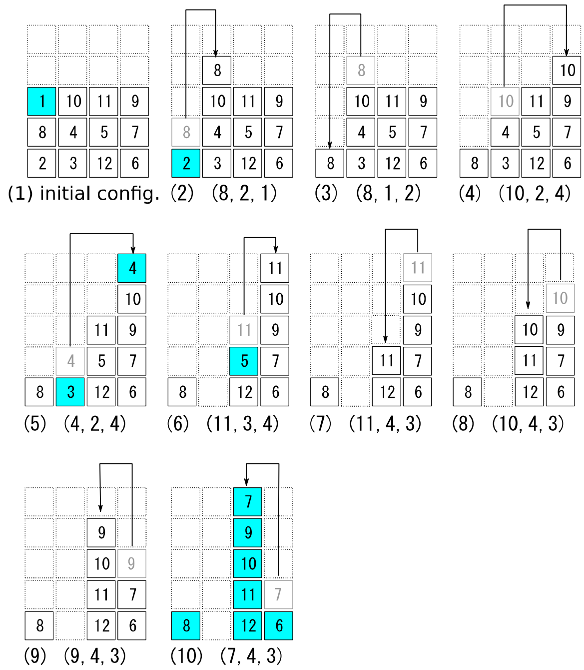
Indeed, the algorithm with LB-A2 is faster than that with LB-A1 under setting 1, whereas the converse is true under settings 2 and 3. It will be because the impact of the number of relocations on the objective value is smaller in setting 1 than in settings 2 and 3. Among the three types of lower bound, LB-B yields the best results under all the settings. Although it requires a longer computation time than LB-A1, its tightness seems to contribute to improving the efficiency of the algorithm further.

Schwarze and Voß, (2016) solved the same instances under settings 1 and 3 using an ILP formulation for the BRP to minimize the total number of relocations in Zehendner et al. (2015). Although a direct comparison is not possible due to differences in CPUs (their CPU is slower than ours), they failed in solving to optimality within a time limit of 3,600s in a multi-thread environment, six instances with $(T, S) = (5, 5)$ under setting 1, and three instances and one instance with $(T, S) = (4, 6)$ and $(5, 4)$, respectively, under setting 3. Because all these instances were solved to optimality by the proposed algorithm with LB-B, it seems that our algorithm outperforms their approach.

Next, we examine the effect of the crane specifications on a solution. Figure 5 provides optimal solutions of the same instance under different settings. In this example,



(a) Setting 1 and 2



(b) Setting 3

Figure 5: An Example of Solutions under Different Crane Specification

settings 1 and 2 yield the same solution (a), whereas a difficult solution (b) is obtained under setting 3. We should also note that solution (a) also minimizes the total number of relocations. We can observe from this figure that in solution (b), the right most two stacks are more likely to be used, although they are far from the truck. It is due to the fact that the hoisting time (vertical travel time) is relatively large compared to the trolley time (horizontal travel time) under setting 3, so that taller stacks are preferred in order to reduce the hoisting time. In solution (b), the total number of relocations increases by 2 from the optimal value. However, it does not affect the total crane operation time directly because $t_s = 0$ is assumed under setting 3.

7. CONCLUSION

In this study we proposed a branch-and-bound algorithm for the block relocation problem to minimize the total crane operation time. For this purpose, we proposed dominance properties and two types of lower bound. Numerical experiments showed that the algorithm is capable of solving benchmark instances efficiently although its performance depends highly on the crane specification. In the three types of settings considered in this study, the crane travel speed (trolley speed and hoisting speed) linearly depends on the travel distance. However, it is not the case in practice due to acceleration and deceleration. Hence it will be necessary to extend the proposed lower bounds for such situations. In real-world container yards, it is often the case that 5 or 6 containers are piled up in each stack. Since instances of this size is still hard to solve for the proposed algorithm, constructing good heuristic algorithms is also an important future research topic.

This work was supported by JSPS KAKENHI Grant Number JP 15K01187.

8. REFERENCES

Caserta M. and Voß S., 2011. Applying the corridor method to a blocks relocation problem. OR Spectrum, 33, 915-929.

Kim K. H. and Hong G.-P., 2006. A heuristic rule for relocating blocks. Computers & Operations Research, 33, 940-954.

Lee Y. and Lee Y. J., 2010. A heuristics for retrieving containers from a yard. Computers & Operations Research, 37, 1139-1147.

Lin D.-Y. et al., 2015. The container retrieval problem with respect to relocation. Transportation Research Part C, 52, 132-143.

Schwarze S. and Voß S., 2016. Analysis of alternative objectives for the blocks relocation problem, working paper.

Tanaka S. and Takii K., 2016. A faster branch-and-bound algorithm for the block relocation problem. IEEE Transactions on Automaton Science and Engineering, 13, 415-422.

Ünlüyurt T. and Aydın C., 2012. Improved rehandling strategies for the container retrieval process. Journal of Advanced Transportation, 46, 378-393.

Zehendner E. et al., 2015. An improved mathematical formulation for the blocks relocation problem. European Journal of Operational Research, 245, 181-190.

Zhu W., Qin H., Lim A. and Zhang H., 2012. Iterative deepening A* algorithms for the container relocation problem. IEEE Transactions on Automation Science and Engineering, 9, 710-722.

TRUCK GATE SIMULATION FOR INLAND TERMINALS

Jana Vögl[(a)], Manfred Gronalt[(b)]

[(a),(b)] University of Natural Resources and Life Sciences, Vienna, Institute of Production and Logistics

[(a)]jana.voegl@boku.ac.at, [(b)]manfred.gronalt@boku.ac.at

1. INTRODUCTION

Inland terminals are often characterized by the dominance of rail and road based freight and transhipment between those modes. While various other authors have looked in detail on processes of terminal operation, including terminals at sea ports as well as inland rail-road terminals, the stage just before trucks which are delivering or picking up intermodal transport units (ITUs) such as containers, swap bodies or reefer containers, enter the terminal is commonly ignored. This is especially true for inland rail-road terminals. In practice, however, carriers sending their trucks to a terminal have to wait before they can pick up and/or drop of ITUs. This waiting time is costly for costumers and not desired. Additionally, truck waiting is often linked to exhaust emissions as trucks are idling while waiting. Thus, long waiting times for carriers, which often result from poor gate operations and transfer point assignment, are causing problems for operators of inland terminals as well as for the local and global environment.

Therefore, in this ongoing research, we focus on the possibilities to organize trucks waiting for empty transhipment points in different ways using real data from several Austrian terminals. We develop an agent based discrete event simulation model, which investigates alternative options to organize truck arrivals and gate policies. The simulation aims to find alternatives which reduce the dwell time of trucks, transhipping goods at the terminal, especially focusing on the waiting time before those vehicles enter the terminal. After a literature review we present the problem description, the tentative structure of the simulation model (incl. simulation input and output data) and a short conclusion.

2. RELATED LITERATURE

There is a lack of interest in the interface between road traffic and terminals, especially regarding inland terminals but also concerning port terminals. This is surprising as there is already some research pointing to the importance of this topic. For example, Benna and Gronalt (2008) investigate hinterland terminals by presenting a simulation based tool for the planning and design of these terminals. They show that the reduction of total waiting times for trucks is a key goal for rail-road terminals and that the average waiting time of truck delivering and picking up containers is a critical factor for customer satisfaction. Similarly, Rizzoli, Fornara, and Gambardella (2002) who present a simulation model which represents the flow of ITUs within and between intermodal inland terminals based on the discrete event simulation paradigm, point out the importance of modelling the processes of arrival and departure of trucks and trains at the terminal gate in rail/road terminals as ITU dwell time is shorter in this terminals. However, they clearly state that they are not researching processes or activities beyond the terminal gates, although they do explicitly model the gate itself. Instead they are referring the reader to both traffic simulation and simulation/optimization of the rail network to be used to "model the 'interfaces' of the terminal with the external world".

Huynh and Vidal (2010) focus on truck turn times, and thus the inner workings of the terminal, to reduce waiting time for trucks at the gate. The authors point out the high costs for drayage trucks in proportion to total transport costs which according to them make up 25% to 40% of total transportation costs. These authors, however, also argue in an additional vein as they discuss the emissions produced by idling trucks which are waiting for entrance into the terminal.

This focus on related environmental issues can also be found in Longo et al. (2015). The work considers green initiatives for port terminals. The authors develop a decision support system which simulates various green practices with several configurations in order to evaluate the different solution scenarios. In addition, they list and categorize green practices in ports. One category is named "practices for the reduction of emission by parked vehicles", under this heading the authors list "Gate policies for incoming trucks" as best practice example for this category which impacts direct and indirect emissions as well as fuel and electrical consumption. Gate processes are further classified as Process-centric practices as opposed to technological-centric and relationship-centric practices.

Suggestions regarding the economic and environmental importance of gate processes and congestion can, e.g., be found in the work of Iwasaki et al. (2003), Simpson and Gamette (2010) or Motono et al. (2016).

Simpson and Gamette (2010) present the design of the first terminal which is planned after the Port of Long Beach has committed itself to a strict Green Port Policy.

The authors present a number of environmentally friendly design elements such as shore-to-ship power for container ships. However, it is worth highlighting that one of the elements of the newly planned container terminal is the implementation of efficient gate systems and effective truck circulation. This is done in order to reduce truck idling and thus, emissions as well as waiting time.
Iwasaki et al. (2003) present a non-stop terminal gate system for Japanese container terminals which eliminates the need for paperwork by using ITS Technology. Their work shows that this system improves efficiency and reduces environmental impacts when it was tested at the Shimizu port container terminal.
Motono et al. (2016) consider the reasons for landside gate congestion as well as different measures to decrease this problem. They find three categories of measures to decrease congestion; First: controlling the arrival rate of trucks, e.g., by shifting arrivals to other modes or using an appointment system, or by extending the opening hours, Second: increasing the number of the gate lanes dynamically; Third: improve gate service rate by increasing the automatization or by eliminating trucks which have documents that are not correct.
A very different solution to the issue of truck congestion in container terminals is provided by Dekker et al. (2012) which is especially designed to mitigate peak hour gate congestion. They introduce a chassis exchange terminal. This is an additional terminal, where trucks do not have to load or unload ITUs but rather switch their chassis (trailer) against another one. The chassis are then loaded or unloaded during off peak times at the required container terminal. These authors again argue that gate congestion has more than one problem, they point to the emission problem caused by idling trucks while waiting as well as to the problem of waiting time itself, stating that this can amount to more than two hours. Their idea for a chassis exchange terminal is that turnaround time is much shorter as switching chassis faster than loading and/or unloading, additionally smoothing out the demand on traditional terminals and thus, reducing waiting times there as well. This is, however, also a problem for the idea of a chassis terminal, as transport companies might not be willing to bear additional costs for the terminal and the chassis respectively the rental system behind them as well as the transfers to and from the chassis terminal when waiting times at traditional terminals are reduced.

Nevertheless, few have tackled “the interfaces of the terminal with the external world” as described by Fornara and Gambardella (2002) so far. While this is especially true for inland rail-road terminals, it also applies for port terminals. This is reflected for example in a recent review paper on ports and container terminals including more than 200 publications by Dragovic, Tzannatos, and Park (2017). The authors visualize the port system and its main subsystems and although they do mention the shore-side link, it is, unlike the anchorage-ship-berth link, not regarded as one of the main subsystems of the port system. However, there are some papers on the gate congestion problem for ports existing. Most of this work is focusing on systems for booking appointments or time windows which are often referred to as truck appointment systems (e.g., Gracia, González-Ramírez, and Mar-Ortiz 2016; Chen and Jiang 2016; Guan and Liu 2009).
Guan and Liu (2009) use a multiserver queuing model for the analysis of gate congestion at marine container terminals. They additionally develop an optimization model to minimize total gate waiting costs, from which they derive different measures to mitigate gate congestion, from which a truck appointment system is seen as most suitable.
These results are confirmed by Gracia, González-Ramírez, and Mar-Ortiz (2016) who address gate congestion and how it can be reduced by truck appointment systems by analysing a case study of a Chilean port terminal using a simulation model. The results of this work indicate benefits of implementing a truck appointment system with regard to gate congestion reduction.
Chen and Jiang (2016) use optimization to tackle the problem of gate congestion at marine terminals. They present a framework to assign time windows to manage truck arrivals, which are dependent on vessels, as well as three strategies for optimizing these time windows.
To the best of our knowledge only Zeng, Cheng, and Guo (2014) look at gate congestion of railway container terminals, using queueing modelling. Additionally, Ballis and Golias (2002) include truck dwell times into their criteria for acceptance of a rail-road terminal design. They evaluate different designs and only accept those which serve 95% of arriving trucks within 20 minutes (Ballis and Golias 2002).
Thus, so far there is little research done on the interfaces pointed out by Rizzoli, Fornara, and Gambardella in 2002.

3. PROBLEM DESCRIPTION

Trucks delivering or collecting ITUs from rail-road terminals usually enter the terminal via truck gates where export ITUs are checked regarding possible damages on the outside, this can be done manually by a checker or (partly) automated, e.g., by using a ‘fotogate’ where pictures are taken of the ITUs when the vehicle carrying it passes. These pictures can then be interpreted either by personnel or in future possibly fully automated by software applications. In addition, labels, seals and temperature might need to be checked. Before entering the terminal all vehicles whether they are delivering or picking up an ITU also have to provide data to the terminal, e.g., which ITU they are picking up and the associated documents. This process differs and might also be (partly) automated, e.g., through prior document provision via an online platform. In a next step the transfer point is determined. This process might start after all checks have been completed successfully. However, because the process of determining the transfer point can take some time it often starts as soon as possible, i.e. the driver has registered its vehicle and provided the relevant data. The exact process varies from terminal to terminal. It depends among other things on the local circumstances, e.g., the availability of space. In addition to variations in the sequence, delays might occur at any given point in the process. For example a delay might be caused by wrong or incomplete documents as described in Motono et al. (2016), by mistakes made by the driver (user) when self-service check in counters are used. When the transfer point is determined, its location is given to the truck driver. This can be done manually by a staff member but also via a computer gate where the driver receives his or her transfer point after typing in a specific number. The driver then moves his or her vehicle there and waits for the transfer to take place as soon as the transfer point is idle. After the truck arrives at the transfer point the transhipment takes place, e.g., a crane puts an ITU onto or picks up an ITU from the truck. The crane or other terminal equipment can only tranship a given number of ITUs at a time. Its capacity therefore limits the throughput of ITUs and affects the trucks dwell time, delays at the gate also occur due to limited capacity within the gate itself. The process described above is illustrated in a simplified way in Figure 1. Poor organization at the gates and transfer point assignment causes congestion before and at rail-road terminals and thus, long dwell times for trucks.

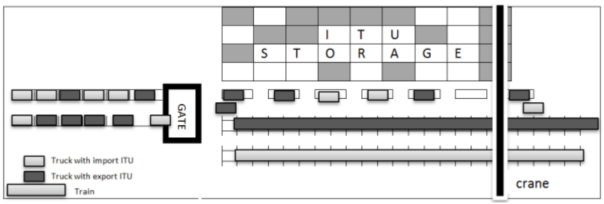


Figure 1: Terminal system

4. THE SIMULATION

4.1. Developing the simulation model

The goal of the simulation is to support terminals and carriers by researching different possibilities how truck movement respectively operations into the terminal is organized. In contrast to existing models, we have widened the scope to include not only the trucks that are entering but also those waiting for entrance (or are still to arrive). As this is a first attempt to include this at an inland rail-road terminal, we decided not to focus on the inner works of the terminal (Benna and Gronalt 2008) as this has been modelled before, but to keep this part of the simulation as simple as possible. This simplicity is also an advantage as in so doing it is easier to adapt the simulation model to different terminal situations.

4.2. Simulation components

The simulation is set up as an agent based discrete event simulation. An individual agent-based model may be defined as a model "in which the agents in the model are represented individually and have diverse characteristics" (Macal 2016) while the term discrete event simulation is according to Borshchev (2013) "used for the modelling method that represents the system as a process" and is therefore also referred to as process simulation in which entities are traversed through queue and delays. Thus, the entities (vehicles, ITUs, cranes) in our simulation are modelled as agents with diverse characteristics (e.g., capacities or types) waiting in queues and traversing through delays. The presented simulation model consists of two main parts. The first one is the part we want to focus our research on, this is the journey of a truck from before the terminal gate, waiting for a transfer point to transhipment and exiting the terminal under different pre-gate regimes. The second part is necessary to simulate adjacent processes at the terminal; it contains the transhipment of ITUs (rail-rail, rail-truck, truck-rail, storage-rail/truck, and rail/truck-storage) by terminal equipment (e.g., a crane) as well as the arrival and departure of trains.

4.2.1. Set up of part 1: truck arrival and lane assignment

In a first attempt, we look at different numbers of First in First-Out (FIFO) queues for arriving trucks which are assigned randomly and according to the truck's import/export status (picking up or delivering ITUs). This strategy is used due to the reason that the work of Gracia, González-Ramírez, and Mar-Ortiz (2016) who, in addition to looking at the implementation of a truck booking system, also implement a variety of lane segmentation strategies in their model for their Chilenian case study port, i.e. five lanes for all vehicles, five lanes split up into two lanes for refer, two lanes for empty and dry containers and one lane without segmentation indicates that an appropriate approach for lane segmentation can be sufficient to reduce congestion at terminal gates. The development of alternative options, i.e. regarding the number of lanes (and gates) and lane segmentation but also the sequence of processes, is a key part of this ongoing research. However, in our first setting trucks wait in queues until one transfer point is idle. We especially focus on these transfer points for trucks which have to be empty for the next truck to use it as they directly influence the waiting and therefore the total dwell times of trucks. When transhipment has been completed the truck leaves the transfer point and subsequently the terminal, thereby freeing the transfer point for following trucks.

4.2.2. Set up of part 2: terminal process interactions

As soon as a truck is assigned an idle transfer point it also interacts with other terminal processes. These have to be modelled to make sure waiting times for and at transfer points are reasonable. This is important as they are the basis for experiments on part 1 components. A simplified overview of the processes is presented in Figure 2 and Figure 3.

In case of export trucks the ITU (to be delivered) claims a spot in the terminals equipment's job list. To start with, we consider one and two cranes with a list of transhipment-jobs, as terminal equipment. When the ITUs request is at the top of the cranes job list, the crane tranships it either to a train (if available) or to storage.

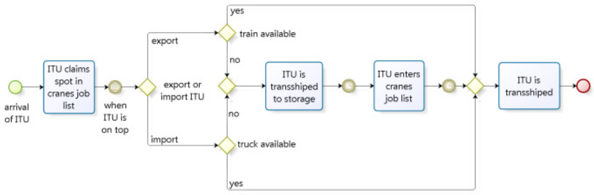


Figure 2: ITU process

In case of an import truck (picking up an ITU) the vehicle informs the terminal equipment (crane) that transhipment is now possible and requested. The next available container on the cranes job list needing pick up by a truck is now assigned to the waiting truck. In case the trucks pick-up capacity is greater than one, i.e. the vehicle needs to pick up more than one ITU, the process is repeated until the truck is loaded with the requested number of ITUs.
Import trucks may be loaded from storage or directly from trains. To include this we also model arriving trains in a very simple form. Trains arrive according to a given arrival pattern. Each train has a given number of spaces for ITUs (capacity) of which a given number are occupied by export ITUs. ITUs on arriving trains proceed as ITUs on arriving trucks, placing a request for transhipment in the job list of the terminal equipment. In a first step this list is FIFO, we do, however, also consider priority based approaches.

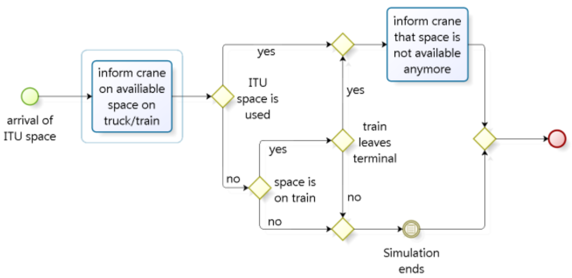


Figure 3: ITU space process (empty trucks and trains)

In accordance with the process for import trucks, empty ITU spaces on trains inform the terminal equipment that they are ready to receive ITUs which need to be transferred onto trains. In order to stop ITUs from being re-shipped to their arrival train from storage this is forbidden in the model. The terminal equipment tries to tranship ITUs from trains and trucks onto trucks or trains, depending on the vehicle type requested by the ITU. If this is not possible ITUs are transhipped to storage. Once stored ITUs are looked in storage for a given time and can only be transhipped to a vehicle after this time has passed.
Regarding the assumptions of the presented simulation, an average time is assumed for each transhipment regardless of the destination, i.e. storage, train or truck of the ITU. We further assume a given distribution of dwell times of ITUs in storage, thus, in case an ITU is not directly transhipped onto a vehicle (train or truck) it stays in storage for a given time until it is again allowed to be transhipped. The storage area itself is, in the first setting, assumed to be unlimited and ITUs are not stored according to any system. Additionally, as the presented model focusses on gate congestion by trucks, no gate processes are modelled for arriving trains, as they are assumed to be non-existent. The same approach is used for gate out processes of leaving trains or trucks.

4.3. Simulation input data

We use two kinds of input data. Input data for part 1 defines the alternative "pre-gate" regimes. These input scenarios are developed by the authors building, e.g., on the work of Gracia, González-Ramírez, and Mar-Ortiz (2016). They include variations of the number of truck waiting lanes and thus gates, the priority system and the segmentation of these lanes including the use of priority lanes, as well as the information available to the (waiting) trucks and the availability of an online booking system. Input data for part 1 also includes truck arrival patterns and the number of available transfer points, here real data from several Austrian terminals is used.
Input data for part 2 are parameters regarding the operation of the modelled terminal and the arrival of the ITUs at the terminal by train. For this input we mainly use available data from Austrian terminals, this includes average dwell times of ITUs in storage, average times for transhipment of single ITUs, arrival patterns of trains as well as numbers of and probabilities for (occupied) ITU spaces on trains, probabilities of ITUs being transhipped from rail to rail, from rail to road and from road to rail while transhipment to storage is an intermediate step in case direct transhipment is not possible. Except for the number of transfer points terminal layout is not included, this could, however, be part of future research.

4.4. Simulation Output

The performance indicator we are interested in primarily is the total dwell time of trucks from arriving at/close to the terminal until exiting the terminal depending on the "pre-gate" regime. We additionally, measure the time the trucks in the simulation model wait until they enter the terminal, and how this time is distributed between different types of trucks, i.e. export and import trucks. However, a simulation model also allows for a greater understanding of the modelled system. Thus, in line with a renowned quote by Huntington, Weyant and Sweeney (1982) the aim of the presented simulation model is also the "modelling for insights, not numbers".

5. CONCLUSION

The goal of the agent-based discrete event simulation model presented in this paper is to provide a starting point in the research of the interface between the road system and the rail-road terminal. We compare different pre-gate regimes regarding their influence on total truck dwell times as well as pre-gate waiting times at inland rail-road terminals. These dwell and waiting times present an important cost factor for carriers and thus terminal customers and are also relevant regarding resource and space management at terminals. In addition, especially pre-gate truck waiting times, which are often times when trucks are idling, present not only an economical but also an environmental burden due to the locally and globally harmful emissions produced by the vehicles engines. As this is research in progress a conclusion cannot yet be drawn. It is clear however, that, this research promises interesting results especially because the topic has been mostly neglected so far or rather the issue was researched separately; before and after the terminal gate.

Further work might focus on the extension of the presented simulation framework. It can therefore include, various additional characteristics such as differentiations between types of ITUs or between regular customers of the terminal and those arriving for the first time. In addition, terminal design could be included to a greater extend within the simulation model. Greater detail could also be added to the assignment of ITUs to vehicles and on entrance processes of trains.

ACKNOWLEDGMENTS

This research is part of the HubHarmony project arising from the ER-NET Transport III (ENT III), which received funding from the following national/regional funding agencies: Austrian Research Promotion Agency (Austria), NCBR – National Centre for Research and Development (Poland) and IWT – Agency for Innovation by Science and Technology (Flanders), funded from the European Union's Seventh Framework Programme for research, technological development and demonstration.

REFERENCES

Ballis A., Golias J., 2002. Comparative evaluation of existing and innovative rail-road freight transport terminals. Transportation Research Part A: Policy and Practice: 36:7:593-611.

Benna T., Gronalt M., 2008. Generic simulation for rail-road container terminals. Proceedings of the 40th Conference on Winter Simulation SESSION: Logistics, transportation and distribution: Container operations, 2656-2660. DEC 6-12, Miami Florida.

Borshchev A., 2013. The big book of simulation modeling: multimethod modeling with AnyLogic 6. AnyLogic North America.

Chen G., Jiang, L., 2016. Managing customer arrivals with time windows: a case of truck arrivals at a congested container terminal, Annals of Operations Research 244:2: 349-365.

Dekker R., van der Heide S., van Asperen E., Ypsilantis P., 2013. A chassis exchange terminal to reduce truck congestion at container terminals. Flexible Services and Manufacturing Journal 25:4:528-542.

Dragović B., Tzannatos E., Park N.K., 2017. Simulation modelling in ports and container terminals: literature overview and analysis by research field, application area and tool. Flexible Services and Manufacturing Journal 29:1:4-34.

Gracia M.D., González-Ramírez R.G., Mar-Ortiz J., 2016. The impact of lanes segmentation and booking levels on a container terminal gate congestion. Flexible Services and Manufacturing Journal article in press:1-30.

Guan C.Q., Liu R., 2009. Modeling gate congestion of marine container terminals, truck waiting cost, and optimization. Transportation Research Record 2100:58-67.

Huntington H.G., Weyant J.P., Sweeney J.L., 1982. Modeling for insights, not numbers: the experiences of the energy modeling forum. Omega 10:5:449-462.

Huynh N. and Vidal J.M., 2010. An agent-based approach to modeling yard cranes at seaport container terminals. 10 Proceedings of the 2010 Spring Simulation Multiconference, April 11-15, 2010, Orlando, Florida.

Iwasaki M., Sato T., Oikawa T., Isojima Y., Matsunaga T., 2003. Development of the ITS Non-Stop Gate System for Container Terminals. ISHIKAWAJIMA HARIMA ENGINEERING REVIEW 43:3:86-91.

Longo F., Padovano A., Baveja A., Melamed B., 2015. Challenges and opportunities in implementing green initiatives for port terminals. 3rd International Workshop on Simulation for Energy, Sustainable Development and Environment, SESDE 2015., 21-23 September 2015, Bergeggi, Italy.

Macal C.M., 2016. Everything you need to know about agent-based modelling and simulation. Journal of Simulation 10:2:144-156.

Motono I., Furuichi M., Ninomiya T., Suzuki S., Fuse M., 2016. Insightful observations on trailer queues at landside container terminal gates: What generates congestion at the gates? Research in Transportation Business & Management 19:118-131.

Rizzoli A.E., Fornara N., Gambardella L.M., 2002. A simulation tool for combined rail/road transport in intermodal terminals. Mathematics and Computers in Simulation 59:1-3:57-71.

Simpson K. and Gamette S., 2010. Design of Pier S Marine Terminal per the Green Port Policy. Ports 2010: Building on the Past, Respecting the Future Proceedings of the 12th Triannual International

Conference,1212-1221. 25-28 April, 2010, Jacksonville, Florida, USA.
Zeng M., Cheng W,. Guo P., 2014. A Transient Queuing Model for Analyzing and Optimizing Gate Congestion of Railway Container Terminals. Mathematical Problems in Engineering, 2014.

AUTHORS BIOGRAPHY

Jana Vögl studied Environmental Management at the University of Natural Resources and Life Sciences, Vienna. Since 2015 she is project assistant at the Institute of Production and Logistics. Since 2016 she works on the project HubHarmony (Harmonization benchmark for inland multimodal hubs - Future links for sustainability).

Manfred Gronalt is professor at the University of Natural Resources and Life Sciences, Vienna and Head of the Institute of Production and Logistics. His expertise and research interests include computer-aided simulation, logistics and operations research and production management. Dr. Gronalt has published numerous journal articles, book chapters, and conference papers. He is also a member of the Austrian Society for Operations Research (ÖGOR).

FORECAST MODELS AND HIERARCHICAL COMBINED DISCRETE-RATE/DISCRETE-EVENT SIMULATION MODELS FOR PARCEL SERVICE NETWORKS

Sebastian Lang[(a)], Tobias Reggelin[(b)], Horst Manner-Romberg[(c)]

[(a),(b)]Otto-von-Guericke-University, Magdeburg
[(c)]MRU GmbH

[(a)]sebastian.lang@ovgu.de, [(b)]tobias.reggelin@ovgu.de, [(c)]info@m-r-u.de

ABSTRACT
Parcel service providers act in a fast changing market. The annual number of dispatch orders increased continuously in the past years, because of the tremendous popularity of e-commerce. At the same time, customers are expecting shorter delivery periods and lower prices for shipment services caused by the entrance of new competitors, the intersection of potential customers of courier, express and parcel delivery service providers and the increasing service quality advertised by e-commerce market leaders. In the consequence, parcel service providers need efficient tools to keep in pace with this development. This paper presents two simulation models, which enable the user to forecast future dispatch quantities and to evaluate the performance of their delivery network in consideration of different levels of detail.

Keywords: parcel service providers, forecasting, delivery networks, regression analysis, continuous simulation, discrete simulation, hierarchical simulation

1. INTRODUCTION

Driven by the increasing popularity of e-commerce, the German courier, express, and parcel (CEP) industry grows rapidly. From the year 2000 until 2015, the number of dispatch orders increased by 74 %. In the same period of time, the revenue of the CEP industry grew by 73 %. Parcel service companies benefit the most from this development. With a revenue of EUR 9.4 billion in 2015 and a share of 54 % in the revenue of the German CEP industry, the parcel service providers are the most significant participants of the CEP market. (BIEK 2016)
A decline of this development is not expected in the near future. The current trend even indicates an increasing growth of the demand for parcel shipments, due to the further expected strong growth of e-commerce. Figure 1 shows the impact of e-commerce on the annual number of parcel shipments in Germany. As illustrated, business-to-customer (B2C) shipments generate more than a half of the revenue of parcel dispatches and are mainly represented by e-commerce sales. Compared to the year 2014, the number of B2C shipments in 2015 increased by 10.1 %. (BIEK 2016, Bevh 2016)
Overall, approximately 170 million additional parcels were shipped in 2015 (BIEK 2016).

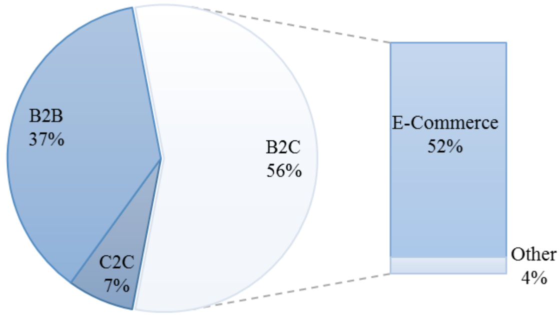


Figure 1: Distribution of the revenue by parcel dispatches according to the type of dispatch order

Parcel service companies are facing the challenge to maintain a high service level and to guarantee the lead time customers are used to, despite of rising shipment volumes and increasing utilization of their production systems. To cope with this challenge, the delivery service providers are forced to invest continuously in their supply network. Hereby, determining the correct amount and subject of investment is a difficult task. In terms of the amount of investment, parcel service companies should, on the one hand, pursue the goal to minimize their investments in order to avoid the waste of capital and the risk of opportunity costs. On the other hand, the parcel service companies are also facing the risk of under-investment which could result in an overload of their systems, in a decreasing delivery performance and in short-term investments which are commonly more cost-intensive than early planned investments. To avoid those risks, one solution approach is to forecast the future demand of parcel shipments to estimate the right point of time and the right amount of investment.
The necessary investment sum depends not only on the future system load, but also on the current capacities of the delivery network. A detailed knowledge about the capabilities of the resources inside a logistics network is essential to identify future bottlenecks and therefore potential subjects of investment. Compared to analytical or static models, discrete simulation models obtain great benefits for analyzing parcel service networks, because

they are able to consider the high complexity and dynamic behavior of such systems by implementing them on any required level of detail.

This paper presents an example for a holistic solution concept to support parcel service providers in preparing their logistics networks for future requirements. The approach integrates a continuous regression model to forecast dispatch quantities and a hierarchical discrete simulation model to evaluate the performance of an exemplary parcel delivery network.

2. RELATED WORK

The following research has been done on modeling and simulation related to the CEP industry.

BIEK (2016) publishes a forecast of dispatch orders in Germany until the year 2020. In contrast to the mathematical approach of the forecast model presented in this paper, the authors based their estimations mainly on surveys and expectations of industry insiders.

Clausen et al (2015) describe a discrete event simulation model of a transshipment terminal, which is linked to a mathematical optimization. The optimization algorithm improve the parcel transshipment operations by searching the best allocation of resources.

Fedorko, Weiszer and Borzecky (2012) present a simulation model of the process of package sorting at a courier service.

Larsen (2003) creates a discrete-event simulation model for the postal industry to analyze the performance of postal networks. He presents an extensive tool to evaluate a postal logistic chain. The modeling of the postal processes with the discrete-event paradigm is not clearly described.

White et al. (2001) present an object-oriented paradigm for simulating postal distribution centers. They describe how discrete-event simulation is an established tool for the design and management of large-scale mail sortation and distribution systems.

Cornett and Miller (1996) describe a model of the aircraft operations at the United Parcel Service Louisville Air Park, which allows the user to evaluate the processes in dependence on flexible input data.

Dowlaty and Loo (1996) applies Monte-Carlo simulation to calculate the number of bags needed to operate a large package delivery.

Swip and Lee (1991) present the application of an integrated modeling tool on the reload process of a United Parcel Service.

Tuan and Nee (1969) present a simulation tool, which evaluates the relative merits of alternative nonpriority mail processing, handling, and transportation plans.

Most of the papers only describe isolated simulation models that focus on a single transfer point of a parcel or postal network.

3. FORECAST MODEL FOR DISPATCH QUANTITIES

The forecast model presented in this paper estimates the future demand of parcel shipments based on linear and nonlinear regression. To do so, the model is connected to a linear regression algorithm and to a Gauß-Newton algorithm for nonlinear regression. The algorithms generate and update the formulas in the model, in dependence on the given input data. Additionally, the model offers the possibility to analyze different development scenarios and to perform sensitivity analyzes. The forecast model was created in three steps:

1. Investigation of potential influencing variables for the annual dispatch quantity
2. Performing of multiple regression analyzes to quantify the influence of each variable
3. Implementation of the continuous simulation model

The following sections contain detailed descriptions to every work package.

3.1. Identification of Influential Variables for the Dispatch Quantity

In the first step, the authors identified economic figures, for which they suspect a potentially influence on the development of the annual demand for parcel shipments. The investigated datasets are also evaluated according to their:

- Reliability – the used datasets should originate from a objective source
- Quantity – the greater the amount of data in each set is, the meaningful results can be achieved
- Resolution – the regression analyzes can only be applied for datasets, which are completely associable with each other

In consequence of the research, the author team selected the history datasets of the economical figures illustrated in figure 2 for a further regression analysis. The chosen datasets fulfill all requirements, set up at the beginning of this section.

In terms of the postulated influence on the dispatch quantity, it is reasonable to assume a relation between the population development and the annual number of shipped parcels, expecting that every inhabitant could be

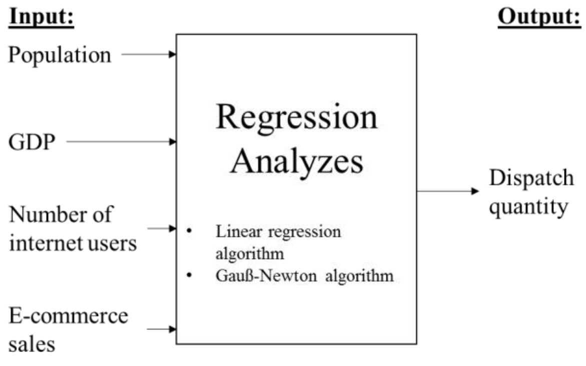


Figure 2: Economical figures with an assumed influence on the dispatch quantity

a potential customer for a delivery service provider. It is also obvious to consider an impact of the GDP on the dispatch quantity, because the GDP is a good indicator for the purchasing power of an economy. For both, the number of internet users and the e-commerce sales, an influence on the dispatch quantity is undeniable, knowing that e-commerce is the main driver of the fast growing parcel market.

To ensure the reliability of each dataset, the authors only consulted data from trustworthy sources. The history data about the German population and GDP come from Destatis (2017), further known as the federal statistical office of Germany. The forecast of the population development until the year 2060 originates from Destatis (2015). The author team referred to a study of PwC (2017) to receive forecast data about the GDP. The number of internet users in the years of 2001 until 2015 were calculated based on the surveys of Destatis (2017) and Initiative D21 (2016). Since no appropriate estimation for the development of the number of internet users in Germany could be found, it was necessary to generate the needed forecast data with a regression analysis, which is further described in the next section. The historical data of e-commerce sales were provides by MRU (2015) – a management consultancy firm with a strong focus on the CEP industry. The corresponding forecast data are based on trend scenarios of GfK (2015) and IFH (2014).

The data quantities of the sets are very disparate. While the population data extend back to the year of 1950, historical data about the GDP are only available until 1970. For the number of internet users and the e-commerce sales, the amount of data points is even smaller, because the internet is a comparatively new technology. Past data of the number of internet users in Germany exists only until 1997 and data about e-commerce sales could be only detected for the years since 2006. Meeting the requirement of an equal resolution and size of all datasets, the authors decided to consider only data since 2006 to determine the influence of the chosen economical figures on the dispatch quantity.

3.2. Quantification of the Influences using Regression Analyzes

Before a functional correlation could be evaluated between the selected input datasets and the dispatch quantity, it was essential to visual assess the datasets, which kind of correlations are worthwhile to check. This was done by comparing each dataset with the dispatch quantity one by one in a scatterplot. As an example, figure 3 shows the scatterplot of the comparison between the past dispatch quantity data and the corresponding past GDP data.

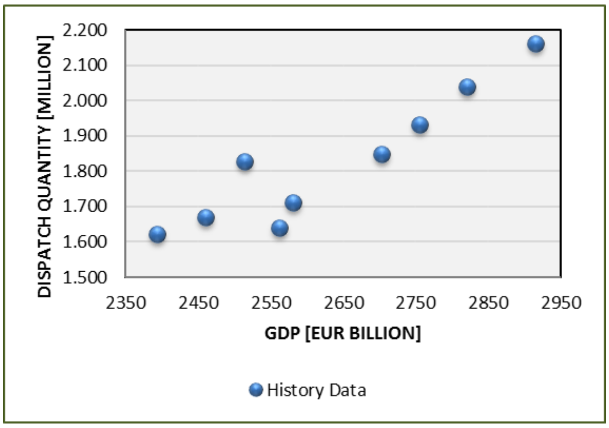


Figure 3: Pre-analysis for functional correlation between dispatch quantity and GDP history data

Based on the optical evaluation, several parameterized objective function were modeled to describe the influence of each dataset on the dispatch quantity. Remaining with the example illustrated in figure 3, the modelers assumed a linear or quadratic correlation between the annual dispatch quantity and the GDP.

To verify the assumptions, two regression algorithm were developed in C#. The linear regression algorithm fits a polynomial function for datasets, for which a linear, quadratic or cubical correlation is assumed. To do so, the algorithm tries to find the (polynomial) function, which obtains the minimal sum of squared distances to the data points. Detailed descriptions of this method are, for instance, given in Bingham and Fry (2010), Weisberg (2005) and Yan and Gang Su (2009). Besides the sum of the square distances, the algorithm also considers the mean forecast error to indicate data-overfitting. The mean forecast error is defined as the sum of distances between each history data point and the corresponding value from the regression (Andres and Spiwoks 2000). For the compared dispatch quantity and GDP data in figure 3, the linear regression algorithm approximate a polynomial function of the 2nd degree, which can be interpreted as a combined linear and quadratic correlation between both sets.

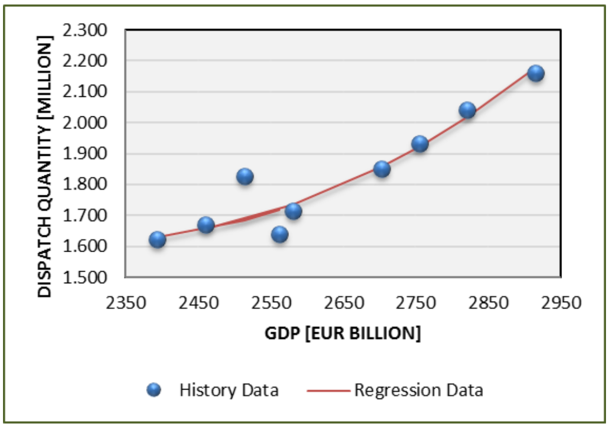


Figure 4: Fitted function of the linear regression algorithm for dispatch quantity and GDP data

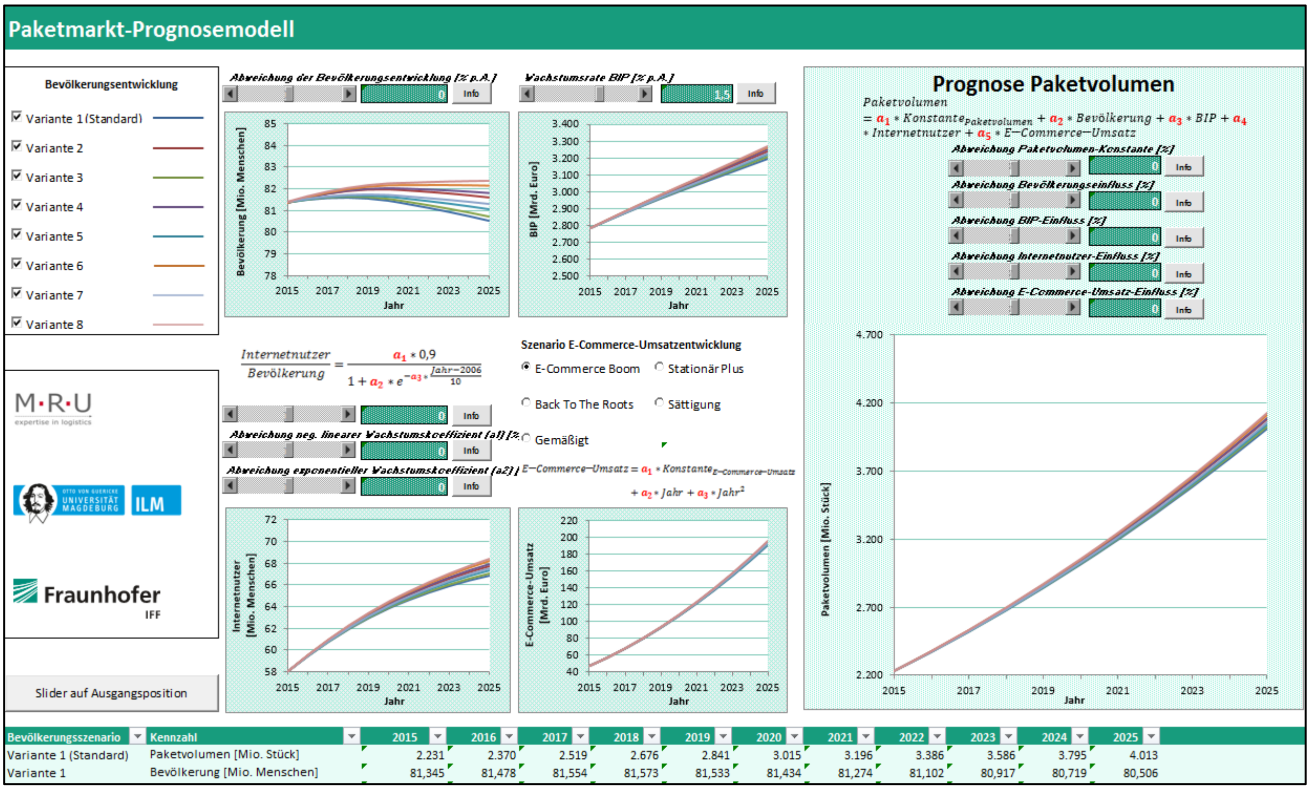


Figure 5: Screenshot of the implemented forecast model in Microsoft Excel

The second regression algorithm which was implemented is the Gauß-Newton algorithm. This method was applied if a nonlinear correlation between datasets were supposed. Hereby, the nonlinear problem is approximated by a finite number of linear problems using Taylor expansion. More precisely, similar to the linear regression the Gauß-Newton algorithm searches the coefficients of a nonlinear function, in order to minimize the sum of square distances of each data point to consider. For further information about this method, please refer to Argyros and Hilout (2013), Damen and Reusken (2008) and Deuflhard (2004). Like for the linear regression algorithm the mean forecast error is additionally calculated to identify data-overfitting.

As discussed in section 2.1, it was necessary to generate forecast data for the number of internet users. In a preceding analysis, the history data of the number of internet users were also inspected for a potential correlation within the values. The authors assumed for this dataset a dependence to the population, which correlates to a sigmoid function in. As illustrated in figure 5, the authors used the history data of the internet users within the Gauß-Newton algorithm to fit a sigmoid function, which considers also a forward projection for forecasting. In general, sigmoid functions have an upper bound, to which they converge. It is clear that the number of internet users is limited by the number of inhabitants in Germany. For the presented function in figure 5, the authors assumed, that the number of internet users can not exceed 95 % of the population.

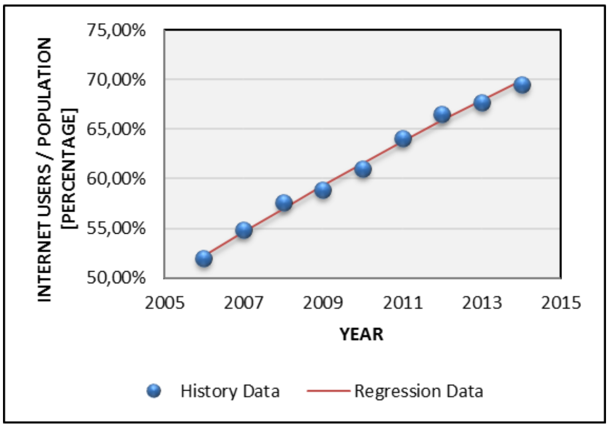


Figure 6: Fitted sigmoid function of the Gauß-Newton algorithm for the number of internet users

In the end of the regression analysis, the quantified influences of the four economical figures were summarized in one forecasting function:

$$Q_D = a_1 * C_D + a_2 * P + a_3 * GDP + a_4 * IN + a_5 * ECS \quad (1)$$

Whereby the variables are declared as followed:

- Q_D: Dispatch quantity
- C_D: Constant of dispatch quantity
- P: Population
- GDP: Gross domestic product
- IN: Number of internet users
- ECS: E-commerce sales

- $a_1,\ldots,a_4$: Parameters of the influence variables from the regression analysis

3.3. Implementation of the Forecast Model

The resulting forecast model is a VBA based tool, implemented in Microsoft Excel. The tool visualizes forecasts of future dispatch quantities until the year 2025. The model enables to incorporate in-depth knowledge, by manipulating the parameters of the influence variables with scrollbars and edit fields. Furthermore, the user is able to choose between eight scenarios of population development as well between five scenarios of e-commerce sales to improve the accuracy of the forecast results. Beside a graphical output in plot charts, the user can achieve a deeper insight into the forecast by analyzing the numerical result values in tables. Figure 5 on the previous page gives an impression of the implemented model.

3.4. Validation of the Forecast Model

To evaluate the accuracy of the model results, the authors compared the fitted functions with the corresponding data sets from the past. Of particular importance is the fitting accuracy of the dispatch quantity, because the function is influenced by all other economical figures. Therefore, the dispatch quantity is the best indicator to evaluate briefly the fitting quality of all functions. Figure 7 compares the dispatch quantity data from the regression with the real dispatch quantities of the past years.

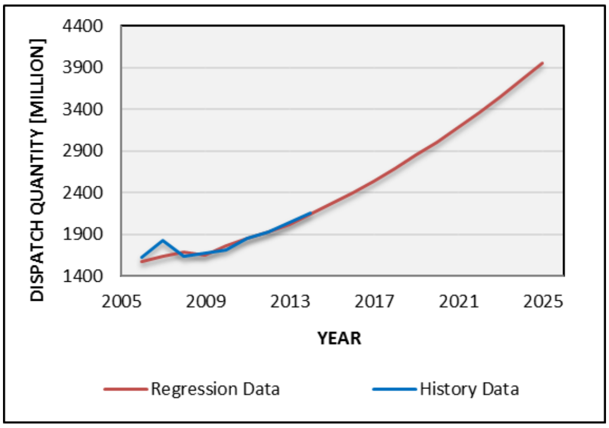


Figure 7: Comparison of dispatch quantity regression data and real history data

With a coefficient of determination of approximately 0.9, the fitting accuracy of the regression is more than satisfying.

4. IMPLEMENTATION OF A PARCEL SERVICE NETWORK AS HIERARCHICAL MESOSCOPIC SIMULATION MODEL

After the generation of forecast data, the user can check if its parcel service network is able to process the estimated dispatch quantities according to the customized service level requirements. To give an instance, the delivery network of a parcel service provider was implemented as simulation model.

Because of the plenty number of locations and their processes inside, it is a challenge to define the right level of detail for the simulation model. In General, the choice of the level of detail is a central question in modeling and simulation (Balci 1989). Finding the right level of detail is even for experienced simulation engineers not a trivial task. A high level of detail leads to a time consuming creating phase and a long simulation run time. A low level of detail involves the risk of modeling system components inaccurately, which can lead to invalid simulation results or reduce the adjustability of system parameters (Wenzel et al. 2008).

In order to resolve this problem, the parcel service network is implemented as hierarchical mesoscopic simulation model. The following descriptions summarize the previous work of Erichsen et al. (2015).

4.1. Mesoscopic Simulation

Primarily, the exemplary parcel service network is implemented as mesoscopic simulation model. The mesoscopic simulation approach detailed described by Reggelin (2011) and Reggelin and Tolujew (2011) is settled between continuous and discrete-event simulation in terms of level of detail, required modeling effort and computational time. Looking on the plenty number of locations within the parcel service network, the mesoscopic simulation approach represents a good compromise to consider, on the one hand, the operations within the network on an expedient level of detail and to receive, on the other hand, simulation results in a tolerable period of time. Hereby, a mesoscopic abstraction and aggregation is achived through the modeling of intra logistics processes as discrete flow rates, while transport processes are still modeled with flow objects.

Krahl (2009) as well as Damiron and Nastasi (2008) describe the simulation paradigm of modeling processes through piecewise constant flow rates as discrete-rate simulation. For instance, the simulation software ExtendSim 9 has a discrete-rate library to create these type of models. The authors use also this software to model the parcel service network.

No longer considering single parcels for processes within the locations of the network, the mesoscopic simulation model calculates experiments in a significant smaller computational time compared to purely object-based models. Furthermore, the mesoscopic simulation model depicts operations more accurate than continuous simulation models, because the control of processes and resources is event-driven, by which the point of times of necessary adjustments can be precise calculated.

4.2. Hierarchical Model Structure

In course of simulation experiments, the analyst may indicates a node of the network as bottleneck, but cannot exactly identify the cause of the underperformance, because the mesoscopic view limits the possibilities for

analyzes. In this case, a microscopic view on the processes of the location would be desirable.
The model of Erichsen et al. (2015) meet exactly this requirement by implementing the parcel service network as a model with a hierarchical structure.
More precisely, locations to be analyzed in more detail are implemented another time as additional sub-models considering a higher level of detail. Through switches in the main model, the user is able to manually change the hierarchy and therefore the level of detail. For superficial experiments to receive quick impression of the network performance, the lower level of detail is used. That leads to a fast run time of the simulation model. Only for detailed analyses, the user applies the higher level of detail for simulation experiments. Figure 7 illustrates this concept on the example of a hub.

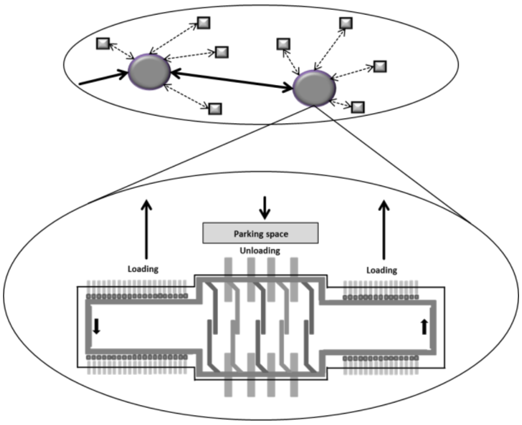


Figure 8: Hub hierarchies

To demonstrate the differences between the less detailed and high detailed sub-models, figure 8 and figure 9 presents the implemented processes of a hub in both sub-models.

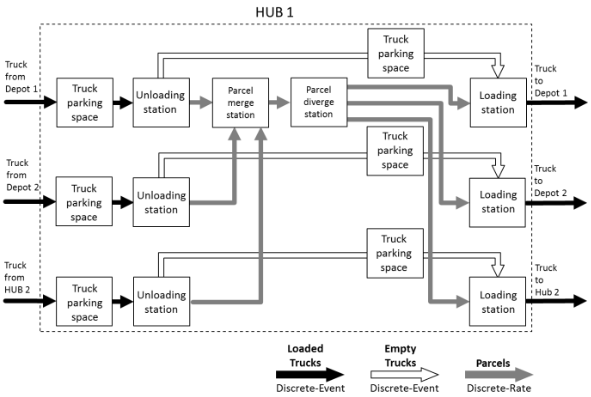


Figure 9: Conceptual model of the mesoscopic hub

Compared to the mesoscopic standard model, the most striking difference of the more detailed hub is the consideration of internal transports within the hub as single processes. Therefore, a more complex control is implemented, which navigates the parcels to the respective outputs of the hub. This allows, for instance, to identify congestions on conveyors or in buffer areas.

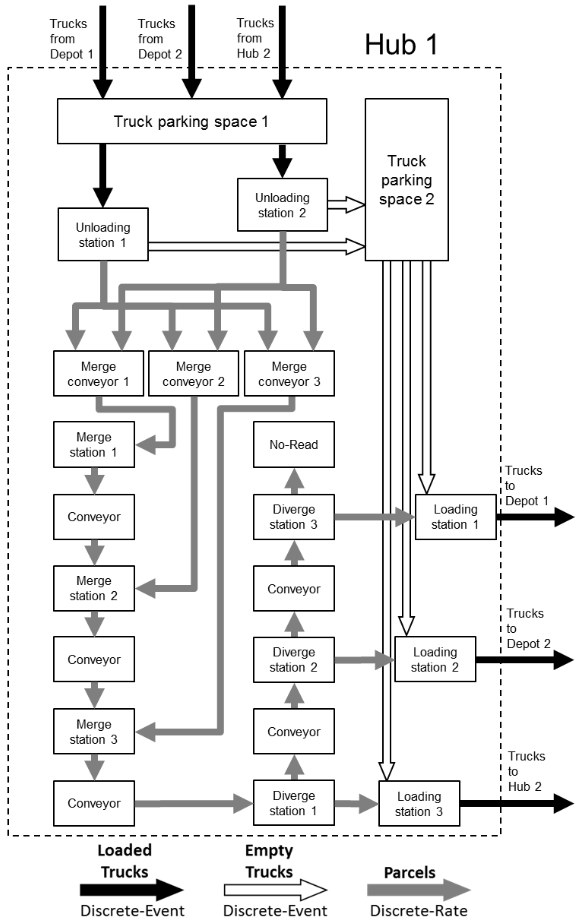


Figure 10: Conceptual model of the microscopic hub

In General, the model enables to determine for instance:

- The throughput time of single parcels
- The utilization of hubs and depots of the network
- The required number of trucks to ship the incoming parcels in time

The KPI's are calculated in order of several input parameters, which can be adjusted by the user. For instance, these are:

- Speed of parcel sorter
- Length of parcel sorter
- Capacity and speed of feeding lines
- Capacity of the trucks
- Speed of trucks
- Rate to load trucks
- Rate to unload trucks
- Quantity of trucks on transport relations
- Length of the transport relations

4.3. Validation of the Hierarchical Mesoscopic Simulation Model

The validation process consists of two steps. In the first step, the functionality of the microscopic submodels

were evaluated by considering them as separate models. In simulation experiments, dispatch quantities labeled with specific destinations were sent to each model. By checking if all parcels has left the models through the expected sink and in the expected time, the hierarchical components of the simulation model were successful validated.
In the second step, the accuracy of the complete simulation model was evaluated, considering the mesoscopic parcel network and the microscopic submodels of some network nodes. Hereby, several simulation experiments has been done, in which parcel shipments has been processed on a pure mesoscopic level or in a mix of mesoscopic and microscopic processes. Like in the first step of the validation, the authors evaluated the quality of the results on the throughput time and on the accuracy of the routing of parcels through the network.

5. SUMMARY

This paper described a suggestion for a holistic solution approach to deal with the issues of a fast developing and high dynamic parcel service market. The approach consists of a continuous and a discrete simulation model. On the first level, the user applies the continuous simulation model to create a customized forecast of future shipment demands. Hereby, the model estimates dispatch quantities until the year 2025 based on linear and nonlinear regression.
On the second level, the forecast data are used in a hierarchical mesoscopic simulation model to evaluate the future reliability of a parcel service network. Despite of the large and complex structure of the network, the model enables fast analyses through a mesoscopic rate based implementation of intra logistics processes. Due to its hierarchical structure, the model allows also detailed analyzes by switching to a higher level of detail for specific locations within the network.
In this way, analysts are able to identify the correct point of time to invest and the right subject and amount of investment to ensure a sufficient capability of the delivery network for future shipment service demands.

REFERENCES

Andres P., Spiwoks M., 2000. Prognosegütemaße. State of the Art der statistischen Ex-post-Beurteilung von Prognosen. 1st ed. Darmstadt: Sonderforschung ökonomischen. und juristischen Institutionenanalyse.

Argyros I.K., Hilout S., 2013. Computational Methods in Nonlinear Analysis. Efficient Algorithms, Fixed Point Theory and Applications. 1st ed. Singapore: World Scientific Publishing Co. Pte. Ltd.

BIEK, 2016. Kurier-Express-Paketdienste. Wachstumsmarkt & Beschäftigungsmotor. KEP-Studie 2016. Berlin: Bundesverband Paket und Expresslogistik e. V. Available from: www.biek.de/index.php/studien.html?file=tl_files/biek/downloads/papiere/BIEK_KEP-Studie_2016.pdf [accessed 2 May 2017]

Balci O., 1989. How to assess the acceptability and credibility of simulation results. In: MacNair E.A., Musselmann K.J., Heidelberger P. (Hrsg) Proceedings of the 1989 Winter Simulation Conference, Washington (USA). IEE, Piscataway, pp. 62-72

Bingham N.H., Fry J.M., 2010. Regression. Linear Models in Statistics. 1st ed. London: Springer

Bevh, 2016. Interaktiver Handel in Deutschland. Ergebnisse 2016. Berlin: Bundesverband E-Commerce und Versandhandel e.V. Available from: https://www.bevh.org/uploads/media/Auszug_aus_der_bevh-Studie_Interaktiver_Handel__in_Deutschland_2016_.pdf [accessed 2 May 2017]

Clausen U, Dieckmann D., Baudach J., Kaffka, J., Pöting M, 2015. Improving Parcel Transshipment Operations – Impact of Different Objective Functions in a Combined Simulation and Optimization Approach. In: Yilmaz L., Chan W.K.V., Moon I., Roeder T.M.K., Macal C., Rossetti M.D. (Eds.) Proceedings of the 2015 Winter Simulation Conference

Cornett K., Miller A., 1996. An Aircraft Operations Simulation Model for the United Parcel Service Louisville Air Park. In: Charnes J.M., Morrice D.J., Brunner D.T., Swain J. J. (Eds.) Proceedings of the 1996 Winter Simulation Conference, pp. 1341–1346

Damen W, Reusken A., 2008. Numerik für Ingenieure und Naturwissenschaftler. 2nd ed. Berlin: Springer

Damiron C., Nastasi A., 2008. Discrete Rate Simulation Using Linear Programming. In: Mason S.J., Hill R.R., Moench L, Rose O., Jefferson T., Fowler J.W. (Eds.) Proceedings of the 2008 Winter Simulation Conference, pp. 333-338

Destatis, 2017. GENESIS-Online Datenbank. Wiesbaden: Statistisches Bundesamt. Available from: https://www-genesis.destatis.de/genesis/online [accessed 3 May 2017]

Destatis, 2015. Bevölkerung Deutschlands bis 2060. 13. koordinierte Bevölkerungsvorausberechnung. Wiesbaden: Statistisches Bundesamt. Available from: https://www.destatis.de/DE/Publikationen/Thematisch/Bevoelkerung/VorausberechnungBevoelkerung/BevoelkerungDeutschland2060Presse5124204159004.pdf?__blob=publicationFile [accessed 3 May 2017]

Deuflhard P., 2011. Newton Methods for Nonlinear Problems. Affine Invariance and Adaptive Algorithms. 3rd ed. Berlin: Springer

Dowlaty Z., Loo C., 1996. Derivation of the Initial Stock of Bags – A Monte-Carlo Approach. In: Charnes J.M., Morrice D.J., Brunner D.T., Swain J. J. (Eds.) Proceedings of the 1996 Winter Simulation Conference, pp. 1479–1482

Erichsen B., Reggelin T., Lang S., Manner-Romberg H., 2015. Hierarchical Mesoscopic Simulation Models of Parcel Service Provider Networks. In: Merkuryev Y., Del Rio D., Bruzzone A. (Eds.) 17th International Conference on Harbor, Maritime and Multimodal Logistics Modelling and Simulation, HMS 2015, pp. 73–78.

Fedorko G., Weiszer M., Borzecky M., 2012. The Shipments Flow Simulation in Courier Company. Carpathian Logistics Congress 2012

GfK 2015: E-Commerce: Wachstum ohne Grenzen? Online-Anteile der Sortimente – heute und morgen. Bruchsal: GfK GeoMarketing GmbH. Available from: http://www.gfk-geomarketing.de/fileadmin/gfkgeomarketing/de/beratung/20150723_GfK-eCommerce-Studie_fin.pdf [accessed 3 May 2017]

IFH 2014: Branchenfokus PBS-Artikel. Köln: IFH Institut für Handelsforschung GmbH. Available from: https://www.ifhshop.de/studien/branchen-insights/42/branchenfokus-pbs-artikel?number=

Initiative D21, 2016. D21-Digital-Index. Jährliches Lagebild zur Digitalen Gesellschaft. Berlin: Initiative D21 e. V. Available from: http://initiatived21.de/app/uploads/2017/01/studie-d21-digital-index-2016.pdf [accessed 3 May 2017]

Krahl D., 2009. ExtendSim Advanced Technology: Discrete Rate Simulation. In: Rossetti M.D., Hill R.R., Johansson B., Dunkin A., Ingalls R.G. (Eds.) Proceedings of the 2009 Winter Simulation Conference, pp. 333-338

Larsen N.E., 2003. Simulation – A Key Tool to accelerate and add Confidence to Postal Network Configuration. In: Chick, S., Sanchez, P. J., Ferrin, D., Morrice, D. J. (Eds.) Proceedings of the 2003 Winter Simulation Conference, pp. 1585–1592

MRU, 2015, E-commerce sales data for the years 2006 until 2015. Hamburg: MRU. Data are not accessible to the public. Please send your request on: http://www.m-r-u.de/de/kontakt/ [accessed 3 May 2017]

PwC, 2017. The Long View. How will the global economic order change by 2050? London: PricewaterhouseCoopers LLP. Available from: https://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf [accessed 3 May 2017]

Reggelin T., 2011. Mesoskopische Modellierung und Simulation logistischer Flusssysteme, Otto-von-Guericke-Universität Magdeburg

Reggelin T., Tolujew J., 2011. A Mesoscopic Approach to Modeling and Simulation of Logistics Processes. In: Jain S., Creasey R.R., Himmelspach J., White K.P., Fu M. (Eds.) Proceedings of the 2011 Winter Simulation Conference,IEEE, Piscataway, pp. 1513-1523

Swip, T. M., Heungsoon, F. L., 1991. Application of an integrated Modeling Tool. In: Nelson B.L., Kelton W.D., Gordon M.C. (Eds.) Proceedings of the 1991 Winter Simulation Conference, pp. 786–791

Tuan P.L., Nee D.S., 1969. MASS-A Mail Service Simulation. In: Proceedings of the 1969 Winter Simulation Conference, pp. 382–395

Wenzel P., Weiß M., Collisi-Böhmer S., Pitsch H., Rose O., 2011. Qualitätskriterien für die Simulation in Produktion und Logistik, Springer-Verlag Berlin Heidelberg

Weisberg S., 2005. Applied Linear Regression. 3rd ed. Hoboken, New Jersey: John Wiley & Sons, Inc.

White K.P., Barney B., Keller S., Schwieters R., Villasenor J., Terry W.S., Fairbrother R.G., Saxton R.D., 2001. An Object-Oriented Paradigm for Simulating Postal Distribution Centers. In: Peters B.A., Smith J.S., Medeiros D.J., Rohrer M.W. (Eds.) Proceedings of the 2001 Winter Simulation Conference, pp. 1007–1012

Yan X. and Gang Su X., 2009. Linear Regression Analysis. Theory and Computing. 1st ed. Singapore: World Scientific Publishing Co. Pte. Ltd.

AUTHORS BIOGRAPHY

Sebastian Lang is a student of the master's program industrial engineering and logistics at the Otto-von-Guericke University in Magdeburg. He holds a master's degree in mechanical engineering with focus on production technologies and a bachelor's degree in industrial engineering in logistics. His research interests include simulation modeling and mathematical optimization of production and logistics systems.

Tobias Reggelin is a research and project manager at Otto von Guericke University Magdeburg and the Fraunhofer Institute for Factory Operation and Automation IFF Magdeburg. He received a doctoral degree in engineering from Otto von Guericke University Magdeburg. He holds a diploma degree in industrial engineering in logistics from Otto von Guericke University Magdeburg and a master's degree in Engineering Management from Rose-Hulman Institute of Technology in Terre Haute, IN. His research interests include modeling and simulation of production and logistics systems, the development and application of new modeling and simulation methodologies and the development and use of logistics management games for teaching and training.

PORT COMPETITIVENESS EVALUATION BY FUZZY LOGIC OF MAJOR PORT IN ASIA

Veerachai Gosasang [a], **Jiravich Klomperee** [b], **Pitinoot Kotcharat** [c]

[(a),(b),(c)] Port Authority of Thailand

[a] veerag1968@hotmail.com, [b] jiravich.k@gmail.com, [c] pitonoot.k@gmail.com

ABSTRACT

Port competitiveness measurement should be considered of operational efficiency and effectiveness. This paper is to investigate the characteristics of port competitiveness and develop Fuzzy model. This model is primarily for qualitative analysis, but this study invites quantitative indicators. It concurrently takes efficiency and effectiveness indicators into consideration. Fuzzy logic evaluates port competitiveness classification by partial order based on five grades. This paper takes major port in ASEAN's countries such as Myanmar, Cambodia, Malaysia, Singapore, Vietnam, Indonesia, Philippines, Brunei Darussalam and Thailand. It confirms the method is stable and effective in practical applications.

Keywords: port competitiveness, fuzzy, classification model

1 .INTRODUCTION

International trade is a key indicator for economic progress in the ASEAN's country. The success of the strategic export in the country to stimulate economic growth, which promotes the growth of commerce to increase the production of containers in the following countries such as Myanmar, Cambodia, Malaysia, Singapore, Vietnam, Indonesia, Philippines, Brunei Darussalam and Thailand.

In maritime transport, the ASEAN port network consists of 47 ports established in nine ASEAN countries, the mainstay of the ASEAN Port Network Developing berths is another important milestone in the physical infrastructure as shipping movements are important to trade. Maritime transport is the most cost-competitive mode of trade compared to highway, rail or air.

Obstacles to achieving effective and low-cost of maritime transport barriers in the region include a variety of port facilities, quality and port efficiency, as well as poor gateway access to land transport. In ASEAN, Singapore and Malaysia, Port Klang has the most potential port. The rest of port gateways are very different in their ability to manage the cargo throughout. The geographical profile of Southeast Asia means that shipping lanes are keys to achieving an effective supply chain network. It has the potential to make it possible for ASEAN to take advantage of and benefit from the shipping industry due to its strategic location in the major shipping lanes around the world. Southeast Asia remains an important hub for shipping because of its outstanding location and modern port infrastructure.

A port's business is a part of maritime transportation. This business is the key factor for promoting economic growth, macroeconomics and giving access to international markets. Containerization is one of the most important factors in ASEAN's economy.

According to Table 1, Singapore and Malaysia are performing far better than the other ports.

Table 1. Top container port in ASEAN in 2015

Rank	Port	Country	Container Throughput
1	Singapore	Singapore	30,922,300
2	Port Klang	Malaysia	11,890,000
3	Laem Chabang	Thailand	6,780,000
4	Tanjung Perak	Indonesia	3,120,683
5	Bangkok	Thailand	1,559,000
6	Penang	Malaysia	1,265,712
7	Hai Phong	Vietnam	1,003,000
8	Cebu	Philippines	829,146
9	Yangon	Myanmar	721,428
10	PAS	Cambodia	333,904
11	Muara	Brunei Darussalam	106,168

The paper of port competitiveness has been an important topic over recent years, and, with the effects that ports are suffering from the recent crisis, it is only gaining importance. This is true in the context of containerized goods.

The purpose of this research is to study the characteristics of port competitiveness and to develop fuzzy logic model. This method is useful for mathematical applications. Therefore, in this paper we try to address the issue of competitiveness, the criteria that determine it and evaluate the strengths and weaknesses of the ports. In the analysis, the focus will be on selected ports of ASEAN's countries. Mainly the case of containers will be analyzed, as this sector features the strongest worldwide changes.

The structure of this paper is organized as follows: Section 2 reviews the relevant literature; Section 3 presents the research methodology; Section 4 presents the results and gives a discussion of the results; and Section 5 provides some conclusions.

2 .LITERATURE REVIEW

This section is devoted to the various Fuzzy logic)Part 1(Port competitiveness)Part 2(.

2.1. Fuzzy logic

Fuzzy logic was thought to be a better way for sorting and manipulating data. But it has proven to be a great option for many control systems, from imitation of human control logic. It can be made into a small handheld product to a computerized control system. Use unclear language, but it is more meaningful to manipulate input data than human operators. It is very effective and forgiving in operation and input, and usually works when used initially with little or no customization.

The basic idea of fuzzy logic has been established by L. Zadeh (1965) and J. A. Goguen (1968). The purpose of such logic is to do the "approximate reason" we use in everyday life is by accepting the terms "big", "near", "slow", which is ambiguous. These statements are interpreted by the concept of "Fuzzy subset", which is a generic function with a value in the complete mesh. False logic program is a very promiscuous chapter of ambiguous logic, which aims to create intelligent database systems with "flexible" answers.

2.2. Port Competitiveness

Port competitiveness is defined as the ability of a port and its vicinity in the creation of value-added. Port competitiveness evaluation shall take efficiency and effectiveness indices into consideration. The analysis of port competitive advantage can be classified into full order and partial order two types. Some distinguished researches opt to cluster analysis, while others use full order. In fact, full order ranking for comparing the improvement of port competitiveness is not necessarily pertinent to decision makers, if port's ranking varies by marginal difference.

The previous papers of port competitiveness are as follows: Hoffman, P.)1985(and Tongzon, J.L., *(*1995*)* investigated port performance by meaning of ship, berth or terminal indicators, while Miyajima and Kwak)1989(examined container cargo competition among Japanese ports.

Dowd, T.J. and Leschine, T.M.)1990(and Robinson, D.,)1999(extended to include production factors or productivity indicators to assess ports productivity.

Murphy, P. R. et al.)1992(developed a framework for classifying existing transportation choice research by using two dimensions: the decision)s(being researched and the respondent's role)s(in the decision process.

Heaver)1995(presented the idea of improving competitiveness, but did not carry it further to include evaluation.

Prescott and Grant)1998(were pioneers by reviewing those competitiveness researches and presenting characteristics of twenty-one evaluation approaches. While, Oral)1993(classified analysis approaches in two categories:)1(descriptive approach, and)2(analytical approach, and applied linear programming on strategies and competitiveness evaluation of glass industry.

Malchow and Kanafani)2001(aims to capitalize on the factors that contribute to their competitiveness in order to extend their captive hinterland. At the same time, they will try to erode those of their competitors.

Yap, W. Y., et al. T.)2006(analyzed a game-theoretic approach was applied by Anderson et al. to competition between Busan and Shanghai. In South Korea, it was emphasized by Yap et al that Busan appeared to face a greater threat from Kwangyang for increasing its transshipment traffic.

Ding, J. F.)2009b(evaluated key capabilities and core competence for port of Keelung for more loyal customers in order to enhance their competitive-ness, and sustain their competitive advantage.

Brooks, M. R., et al. Pallis)2011(examined how users evaluate port effectiveness and identify those constructs relevant to that evaluation. The study concludes that the evaluation criteria influencing users' perceptions of satisfaction, competitiveness, and service delivery effectiveness are different, and so while the determinants of these constructs have considerable overlap, they are different constructs.

Chou, C. C.)2010(attempted to fill this gap in current literature by establishing an integrated quantitative and qualitative fuzzy multiple criteria decision-making model for dealing with both objective crisp data and subjective fuzzy ratings.

Yuen, C. A., et al.)2012(., they explored the relative importance of factors that determine container port competitiveness from the users' perspective. Three groups of port users – shipping liners, forwarders and shippers are considered in them work.

Liang, G. S., et al. (2012), he applied the fuzzy quality function deployment approach to evaluate solutions of the service quality for international port logistics centers in Taiwan, 34 attributes with 11 feasible solutions of the service quality of customer requirements are measured by employing the house-of-quality matrices.

Customer satisfaction must be enhanced in order to gain and retain loyal customers. In order to maintain customer satisfaction, greater customer values must be created and provided to increase favorable behavioral intentions *(*Yang et al., 2013*)*. In order to enhance these behavioral intentions, port competitiveness can be enhanced by providing an efficient service system.

3. Research Methodology

This section focuses on the process for the qualification of key factors of port competitiveness and fuzzy logic.

In order to develop the research to meet the objectives of the study, the research methodology used or each step for conducting the research needs to be built up and clarified. The factors found from previous papers, which have influence on port competitiveness ranking between in ASEAN port.

From the previous papers and the Delphi method, this thesis applies economic factors for port competitiveness in ASEAN port, as follows: Throughput (TEUs)/Berth,Throughput(TEU)/m,Throughput(TEU)/QC, total TEUs, Berth length, Number of Berth, Number of Ship to Shore Gantry Crane and Terminal Area.

Fuzzy sets are mathematical ways to make decisions under ambiguity or ambiguity. It is similar to human thought, invented by Zadeh in 1965, which relies on fuzzy sets to indicate uncertainty, (Zadeh, L. A.,1965(.

The fuzzy sets allow the membership level to be determined in the degree of membership is between 0 and 1. Unlike classical sets, there are only two sets of values: 0 means no member in the set, and 1 refers to a set member. The membership level configuration of the interested variables depends on the membership function. Commonly used member functions are many, but here are two types of functions, triangles and trapezoids.

Triangles functions comprised with 3 parameters {a b c} as shown in equation 1 and figure 1:

$$f(x;a,b,c)=\begin{cases}0, & x<a\\ (x-a)/(b-a), & a\le x<b\\ (c-x)/(c-b), & b\le x\le c\\ 0, & x>c\end{cases} \qquad)1($$

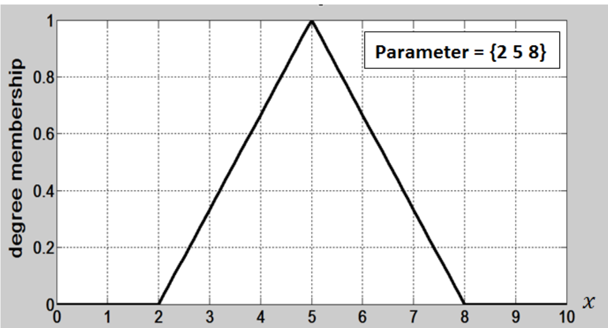


Figure 1. Triangular membership function

Trapezoidal functions comprised with 4 parameters {a b c d} as shown in equation 2 and figure 2:

$$f(x;a,b,c,d)=\begin{cases}0, & x<a\\ (x-a)/(b-a), & a\le x<b\\ 1, & b\le x<c\\ (d-x)/(d-c), & c\le x<d\\ 0, & d\le x\end{cases} \qquad)2($$

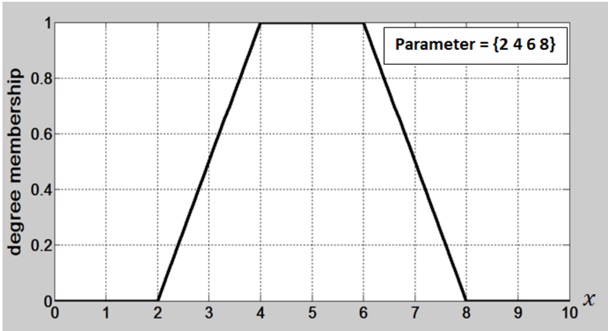


Figure 2. Trapezoidal membership functions

The choice of type of membership function depends on the characteristics of the variables and the needs of the users. In addition, fuzzy sets can be used with language variables to denote quality or quantity, such as' low ',' medium, '' good. The operations in fuzzy set are similar to the general set of union, interactions and complement, μ are the subsets of the possible members of the set of the universe (universe of discourse). x is the members of the set in μ, $\underset{\sim}{A}$ and $\underset{\sim}{B}$ are the internal members of the set.

Union or OR operation is shown as in equation 3

$$\mu_{\underset{\sim}{A}\cup\underset{\sim}{B}}(x)=\{x: x\in\underset{\sim}{A}\ \text{Or}\ x\in\underset{\sim}{B}\},\quad \max(\mu_{\underset{\sim}{A}}(x),\mu_{\underset{\sim}{\mathbf{B}}}(x)) \qquad)3($$

Intersection or AND operation is shown as in equation 4

$$\mu_{\underset{\sim}{A}\cap\underset{\sim}{B}}(x)=\{x: x\in\underset{\sim}{A}\ \text{And}\ x\in\underset{\sim}{B}\},\quad \min(\mu_{\underset{\sim}{A}}(x),\mu_{\underset{\sim}{\mathbf{B}}}(x)) \qquad (4)$$

Complement is shown as in equation 5

$$\mu_{\bar{\underset{\sim}{A}}}(x)=1-\mu_{\underset{\sim}{A}}(x) \qquad (5)$$

4 .THE RESULTS AND DISCUSSION

This section presents the results of fuzzy logic to evaluate port competitiveness in ASEAN's.

Countries and finally, gives the discussion of the results.

4.1 Fuzzy set grading

The fuzzy set will look similar to the baseline method. But to be different, fuzzy sets use the principle of infinite or vague sets to evaluate. The method of class performance in this way starts with the evaluator having to determine the type of membership function. To calculate the weight membership function, the membership weight in the set is based on scores in Table 2. In this research, each members are detail the following grades.

X = raw score
F = the evaluation result (fail)
D = the evaluation result (very poor)
D^+ = the evaluation result (poor)
C = the evaluation result (fair)
C^+ = the evaluation result (fairly good)
B = the evaluation result (good)
B^+ = the evaluation result (very good)
A = the evaluation result (excellence)

Table 2. Criteria for Score Factor Grading

level of assessment	grade level	
	grade	**score**
Excellence	A	80.00 – 100.00
very good	B+	75.00 – 79.99
Good	B	70.00 – 74.99
fairly good	C+	65.00 – 69.99
Fair	C	60.00 – 64.99
Poor	D+	55.00 – 59.99
very poor	D	50.00 – 54.99
Fail	F	0.00 – 49.99

The details of some grades are shown as follows.

Evaluation of Grade F, Use the trapezoidal member function as Equation 6, following as,

$$\text{function } F\,(x;0,0,45,50) = \begin{cases} \text{If } 0 \le x \le 45 \text{ Then } 1\ (True) \\ \text{If } 45 < x < 50 \text{ Then } (50-x)/(50-45) \\ \text{If } 50 \le x \text{ Then } 0\ (False) \end{cases} \quad (6)$$

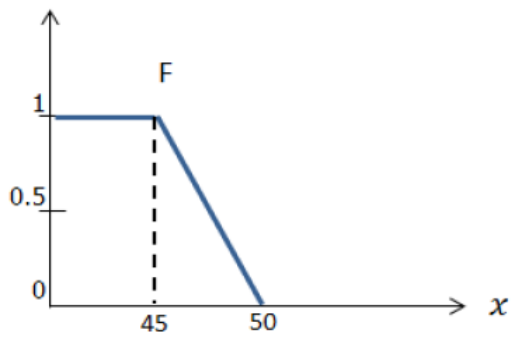


Figure 3. Membership function of function F

Figure 3 shows the membership function of function F.

Evaluation of Grade D, Use the triangle member function as Equation 7, following as,

$$\text{function } D\,(x;45,50,55) = \begin{cases} \text{If } x \le 45 \text{ Then } 0\ (False) \\ \text{If } 45 < x < 50 \text{ Then } (x-45)/(50-45) \\ \text{If } 50 \le x < 55 \text{ Then } (55-x)/(55-50) \\ \text{If } 55 \le x \text{ Then } 0\ (False) \end{cases} \quad (7)$$

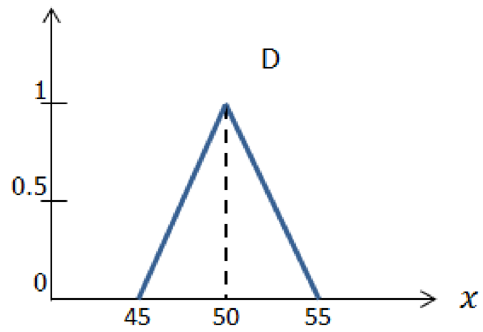


Figure 4. Membership function of function D

Figure 4 shows the membership function of function D.

Evaluation of Grade B^+ Use the triangle member function as Equation 8, following as,

$$\text{function } B+\,(x;70,75,80) = \begin{cases} \text{if } x \le 70 \text{ Then } 0\ (False) \\ \text{if } 70 < x < 75 \text{ Then } (x-70)/(75-70) \\ \text{if } 75 \le x < 80 \text{ Then } (80-x)/(80-75) \\ \text{if } 80 \le x \text{ Then } 0\ (False) \end{cases} \quad (8)$$

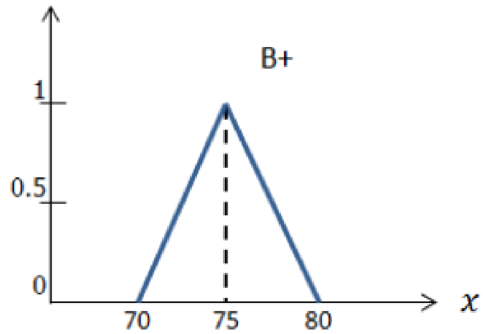


Figure 5. Membership function of function B^+

Figure 5 shows the membership function of function B^+

Evaluation of Grade **A**. Use the trapezoidal member function as Equation 15, following as,

$$\text{Function A}\,(x;75,80,100,100) = \begin{cases} \text{if } 80 \le x \le 100 \text{ Then } 1\ (True) \\ \text{if } 75 < x < 80 \text{ Then } (80-x)/(80-75) \\ \text{if } x \le 75 \text{ Then } 0\ (False) \end{cases} \quad (9)$$

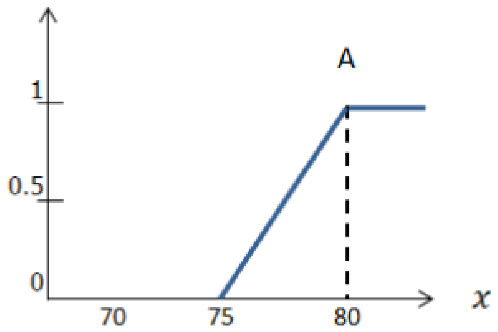


Figure 6. Membership function of function A

Figure 6 shows the membership function of function A.

When the membership function of all 8 grades is written together under the same axis, the graph is shown in Figure 7.

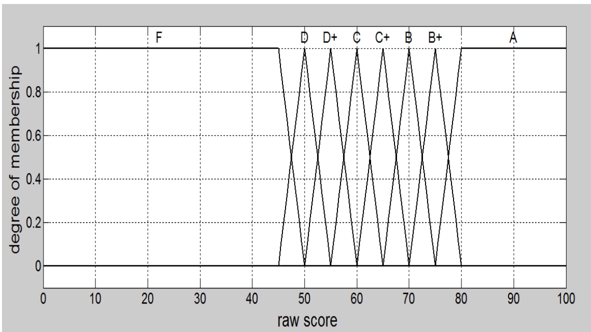


Figure 7. Condition check on all criteria.

4.2 Result

Based on the results of the study, the raw scores and data from 11 ports in ASEAN's Countries were evaluated by fuzzy sets. The factors are both of port performance and port facilities. The detail of port performance are number of container throughput per birth, number of container per berth length, number of container throughput per number of Ship to Shore Gantry Crane and number of container throughput, while port facilities are berth length, number of berth, number of Ship to Shore Gantry Crane and terminal area. The grade-based assessment results for each method can be shown in Table 3.

Table 3. Membership weight in each grade for Container throughput per Shore Side Gantry Crane

Port	Score	weight Membership Function								Fuzzy Set Grading
		F	D	D+	C	C+	B	B+	A	
Singapore	88.73	0	0	0	0	0	0	0	1	A
Port Klang	100	0	0	0	0	0	0	0	1	A
Laem Chabang	85.61	0	0	0	0	0	0	0	1	A
Tanjung Priok	64.09	0	0	0	0.2	0.8	0	0	0	C+
Bangkok	59.89	0	0.1	0.9	0	0	0	0	0	C
Penang	52.01	0	0.4	0.6	0	0	0	0	0	D+
Haipong	32.81	1	0	0	0	0	0	0	0	F
Yangon	32.61	1	0	0	0	0	0	0	0	F
Cebu	58.61	0	0	0.2	0.8	0	0	0	0	C
PAS	75.32	0	0	0	0	0	0	1	0	B+
Muara	29.66	1	0	0	0	0	0	1	0	F

Table 3 evaluates only Container throughput per Shore Side Gantry Crane, not only the evaluated this factor and the other factors also evaluated. The result are presented in table 4.

Table 4. Ranking of Port Competitiveness in ASEAN's Countries

Rank	Port	Country	Container	Port C
1	Singapore	Singapore	30,922,300	1
2	Port Klang	Malaysia	11,890,000	2
3	Laem Chabang	Thailand	6,780,000	3
4	Tanjung Perak	Indonesia	3,120,683	4
5	Bangkok	Thailand	1,559,000	5
6	Penang	Malaysia	1,265,712	6
7	Hai Phong	Vietnam	1,003,000	7
8	Yangon	Myanmar	721,428	8
9	Cebu	Philippines	829,146	9
10	PAS	Cambodia	333,904	10
11	Muara	Brunei Darussalam	106,168	11

5. CONCLUSIONS

This article states that the competitiveness of ports and its drivers has been greatly affected by significant changes in the maritime industry. So the original explores the nature of "Port Competitiveness" by conducting a systematic literature review of international journals. Port performance and port infrastructure are used in this article. The results are shown that Port of Singapore is the most competitiveness in ASEAN's Countries, Port Klang and Laem Chabang are respectively.

In Southeast Asia, the Singapore Port will continue to be a leading port in the region due to its existence and excellent service. However, by establishing other regional hubs, their dominance will continue to decline.

Singapore ports are facing increasing competition from Tanjung Pelepas Port, but also to other ports in the region, such as the Port Klang, Laem Chabang Port and Tanjung Priok Port.

A review of previous studies focusing on key container ports in ASEAN, port competition is expected to increase with the development of new ports and the upgrading of existing facilities. In a competitive environment, most of these ports ASEAN are needed to develop and expand facilities in response to the increase in container cargo.

The evaluation methods used by the researcher were the fuzzy set. Based on the results of the research, it can be seen that when comparing a fuzzy set with the others method, it is found that the fuzzy set evaluation allows for flexibility at the level of the range.

Therefore, the result is more accuracy, which will benefit for port officers to develop as a tool for measuring and evaluating the factors for port competitiveness that can help reduce the ambiguity of evaluators in decision making and is also easy to apply.

However, the fuzzy set also has limitations in determining the appropriate membership function for adoption. It may be necessary to use retrospective data that have been evaluated and assist in determining the membership function in the set.

The others factor such as Key economic growth drivers, quality and cost are adopted in the future research.

REFERENCES

Brooks, M. R., T. Schellinck and A. A. Pallis (2011). A systematic approach for evaluating port effectiveness. Maritime Policy and Management 38(3), 315-334.

Chou, C. C. (2010). An integrated quantitative and qualitative FMCDM model for location choices. Soft Computing 14 (7), 757-771.

Ding, J. F. (2009b). Evaluating key capabilities and core competence for port of Keelung. International Journal of Information and Management Sci-ences 20(2), 269-290.

Dowd, T.J. and Leschine, T.M., "Container Terminal Productivity: A Perspective," Maritime Policy and Management, Vol. 17, No. 2, pp. 125-133)1990(.

J.A. Goguen (1968), Categories of Fuzzy Sets: Applications of Non-cantorian Set Theory, Ph.D. Thesis, University of California Berkeley, Dept. of Math.

Heaver, T.D., "The Implications of Increased Competition among Ports for Policy and Management," Maritime Policy and Management, Vol. 22, No. 2, pp. 125-133)1995(.

Hoffman, P., "Performance Indicators and Productivity," Port Management Textbook Containerization, Bremen)1985(.

Liang, G. S., J. F. Ding and C. L. Pan (2012). Applying fuzzy quality function deployment to evaluate solutions of the service quality for international port logistics centers in Taiwan. Journal of Engineering for the Maritime Environment 226(4), 387-396.

Malchow, M., Kanafani, A., 2001. A disaggregate analysis of factors influencing port selection. Maritime Policy & Management 28, 265–277.

Miyajima, M. and Kwak, K.S., "Interport Competition in Container Cargo," Maritime Policy and Management, Vol. 16, No. 1, pp. 47-55)1989(.

Murphy, P. R., J. M. Daley and D. R. Dalenberg (1992). Port selection criteria: An application of a transportation research framework. Logistics and Transportation Review 28(3), 237-255.

Oral, M., "A Methodology for Competitiveness Analysis and Strategy Formulation in Glass Industry," European Journal of Operational Research, Vol. 68, No. 1, pp. 9-22)1993(.

Prescott, J.E. and Grant, J.H., "A Manager's Guide for Evaluating Competitive Analysis Techniques," Interfaces, Vol. 18, No. 3, pp. 10-22)1988(.

Robinson, D., "Measurement of Port Productivity and Container Terminal Design, A Cargo System Report," IIR Publications, London)1999(.

Tongzon, J.L., "Determinants of Port Performance and Efficiency," Transportation Research A, Vol. 29A, No. 3, pp. 245-252)1995(.

Yang, W. S., G. S. Liang and J. F. Ding (2013). Identifying solutions for adding service value to international port logistics centers in Taiwan. Maritime Economics and Logistics 15(4), 395-415.

Yap, W. Y., Lam, J. S. J. and NOTTEMBOOM, T. (2006) "Developments in Container Port Competition in East Asia". Transport Reviews, Vol.26 No.2, pp.167-188, Taylor & Francis

Yuen, C. A., A. Zhang and W. Cheung (2012). Port competitiveness from the users' perspective: An analysis of major container ports in China and its neighboring countries. Research in Transportation Economics 35, 34-40.

Zadeh (1965), "Fuzzy Set", Information and Control, Vol.8 pp.338-353.

AUTHORS BIOGRAPHY

Veerachai Gosasang, Ph.d., he works at Bangkok Port, Port Authority of Thailand, his position is Director of Mechanical Handling Equipment Division.

Jiravich Klomperee, he works at Policy and Planning Department, Port Authority of Thailand, his position is Director of Research and Organization Development Division.

Pitinoot Kotcharat, she works at Policy and Planning Department, Port Authority of Thailand, her position is Chief of International Affairs Section.

SIMULATION-BASED TRAINING MODULES FOR INDEPENDENT TRAINING OF EMPLOYEES IN THE AUTOMOTIVE INDUSTRY

Alexander Friedrichs[(a)], Tobias Reggelin[(b)], Sebastian Lang[(c)], Toralf Wunder[(d)]

[(a),(b),(c)]Otto-von-Guericke-University, Magdeburg

[(a)]Alexander.Friedrichs@st.ovgu.de, [(b)]Tobias.Reggelin@ovgu.de, [(c)]Sebastian.Lang@ovgu.de, [(d)]Toralf.Wunder@gmail.com

ABSTRACT

The goal this work is to describe the conception and implementation of a simulation-based training environment, which is supposed to be used to train employees in the field of automotive logistics by the principle of cause and effect. Today's jobs are shifting away from executive positions to rather service-orientated jobs and thus change quickly. This leads employees to adjust their skills and knowledge to the demands of the job market. The focus of training concept is put on the characteristics of andragogy, self-directed learning, as well as "on the job training", all based on the constructivism' learning approach. Aside from the theoretical principles of learning, practical examples of (simulation-based) training concepts are analyzed. Content-wise the training module is based on the standard processes of the internal logistics in the automotive industry. The implementation is done with the discrete-event simulation software "Plant Simulation".

Keywords: simulation-based training, internal logistics in the automotive industry, employee training

1. LITERATURE REVIEW

A high extend of simulation based training programs exist in the field of medicine. More than 86% of medicine students are using simulation as a part of education within their studies (Passiment 2011). Concerning logistics, most of the training programs are developed for students or in the context of employees' professional development (usually commercial programs). Examples for the former can be found in (Siddiqui Khan and Akhtar 2008, Mustafee and Katsaliaki 2010). Nowadays employee training is also been executed by mobile learning, in the form of tasks that can be conducted of the cell phone of the employee (Witt et al. 2011).

General learning theory divides learning concepts into behaviorism and constructivism, while the letter means that learning contents should not be reduced to very basics tasks but be left in their original complexity (Ziltener 2005). Based on that concept, learning is generated within the learning process (defining one's own theory and then trying to prove it) and not in form of an objective result. For every individual there are different styles of effective learning (Staemmler 2005) and different reasons for why to learn. Since the training environment of this work is specified on training employees, it is supposed to vary from the teaching process of children or in school. Differences in how to teach children and grown-ups are essential (Knowles Holton and Sawnson 2005). There are evidences for adults mainly having subjective intentions to learn, in contrast to children who usually learn because they are advised to. For that reason, keeping up adults motivation is of highest importance and can only be guaranteed by taking into account their own experiences, as well as their situation of life (see figure 1).

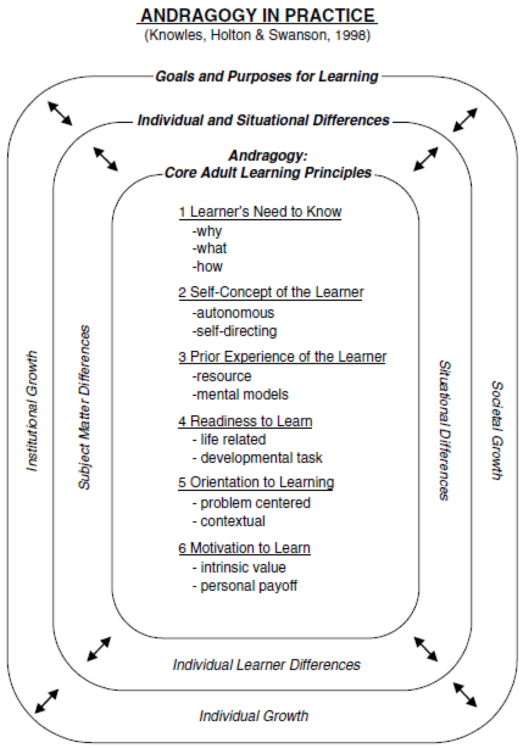


Figure 1: Andragogy in Practice (Knowles et al. 2005)

In contrast to other fields of simulation, like virtual and augmented reality, the developed learning environment is designed for employees in planning or management departments. When teaching with VR and AR, usually operative tasks, for instance picking and packing, are being taught where the main principle of teaching is the visual presentation. Material flow simulation is rarely used to implement 3D-visualized models, as its focus lies on transforming input data to quantitative results. Still the graphic demonstration of a simulation run is not ignored since the acceptance of teaching individual is heavily depending on them to understand what content they are taught and the relation to their daily business.

2. STANDARD PROCESSES OF THE INTERNAL LOGISTICS IN THE AUTOMOTIVE INDUSTRY

The process of the internal logistics starts with the receiving department at the receipt of goods and ends in sending the products to each of their customers at the outgoing goods department. In between these stages the products (purchased material) run through checking areas, warehouse operations (i.e. picking and packing), warehouses and assembly logistics, before it is mounted to complete vehicles. All included processes are associated to procurement, production logistics as well as distribution departments. (Klug 2010, Laffert 2000)

As the first differentiation from other departments related to logistics, procurement department can clearly be distinguished from fields like purchasing department. Main tasks of purchasing department are to select suppliers and to analyze their performance, while procurement has to work with the selected suppliers. Its primary function lies on supplying the plant with goods and organizing and executing the receipt of goods. Operative contents within the receipt of goods are accepting and unloading of deliveries and transporting them to further steps like checking areas or buffering places.

Any logistics inside the assembly hall can be clustered as assembly logistics. Its focus is aimed on adequately supplying the assembly line with goods of the right quality at the right time. In addition to that any tasks regarding supermarkets, where “Carsets” or sequences are arranged, belong to assembly logistics. “Carsets” contain a certain amount of parts that will all be mounted into one car, while a sequence is a sorted amount of one part family for the next n cars. Both are used to decrease the area needed close to the assembly line just as improving the mounting process for the worker.

Preparing the completed cars for their department and sending them out to the customer are the major functions of distribution logistics. In that sense, preparing means physically arranging the cars for the upcoming transports, like putting plastic foils above them to reduce weather influences or to fasten them into prefabricated pallets. Since deliveries can include more than one mode of transport it might also be necessary to install transshipment devices.

Further details regarding the standard processes of the automotive logistics will be described in the implementation of the model.

3. CONCEPTION

In general the conception is based on the assumptions of the learning theory and some practical examples regarding efficient training of employees. Requirements for successful learning environments which are being taking into consideration and defined measurements on how to encounter them are as follow:

Table 1: Requirements of adult learning and how to encounter them

Requirement	Measurement
Take into account the learners knowledge and experience.	Implementing processes comparable to the standard processes of the users’ job.
Relate the learning contents to the learners’ situation in life.	Developing learning scenarios that treat characteristic problems of his daily job or the neighboring departments.
Do not just give the learner information to read or view but let him act himself.	This Requirement is already accounted by using simulation as the learning method
Do not judge about the learners’ performance. Let him reflect himself about his progression within the learning process.	The simulation run does not finish by showing a subjective score based on the developers opinion. Instead objective key figures are presented and can be reflected by the learner based on his on view.
Use interaction between the learner and the simulation model as a replacement for the non-existing teacher to keep up the motivation.	Dialogue boxes are used the create communication and interaction between the user and simulation model.

The standard processes which are also the foundation of the simulation model were already presented in chapter 2. Characteristic problems of the related logistics departments are the basis for the implemented learning scenarios. These function not just to present learning content but also to provide a basic understanding of how the underlying simulation model works and what processes and interdependencies exist.

The knowledge which can be gained by the training program is based on the concept of cause and effect, where causes are exclusively parameters that can be changed by the user and influence the system’s behavior (effects). As mentioned before, the targeted learning process of the learning environment is heavily characterized by constructivism and thus is not targeting on just bringing up print or video material for the user to watch and then try to replicate. The learning process of the presented environment depends on successive changing of parameters (act) and watching as well as reflecting the results afterwards. Results are illustrated by visualizing the simulation run and simultaneously showing the most important key figures within diagrams. At the end of every simulation run these key figures are reviewed in dialogue boxes to give the user an overview of the performance of the last run. Reflecting the results into perceptions is what makes the learning process and thus the main task of the user.

Additionally an introduction dialogue will be presented when opening the simulation model. That dialogue is supposed to give the user essential information about the training program. In general, the interaction of the user and the model is of high importance, because this leads, guides and limits the learning process. Any kind of interaction is implemented in dialogue window elements which open up every time the user needs to get some information.

To increase the user acceptance of the learning program it is supposed to be user friendly. When working with adult learners these need to know what they are learning and why they need to learn. While it is very hard to work on that “why”-part, not knowing the individuals to teach and developing a “teacher-less”, self-directed learning environment, the main goal of the concept is to treat with the “what”-question. Therefore the concept is heavily content-driven and focuses primarily on the implemented processes, the learning content and how both is presented in the simulation model.

4. IMPLEMENTATION OF THE MODEL

As described in the abstract, “Plant Simulation” was used as the tool to implement the simulation model. It is among the standard software for simulating material-flow processes in the automotive industry (Mayer and Pöge 2010). Plant simulation allows the implementation of discrete event simulation models and therefore is able to reconstruct most of the logistic processes of the automotive industry in accurate fashion while maintaining a high grade of abstraction to keep up a low computational cost.

The first thing to view for the user is the introduction, which is supposed to provide basic information about the content of the learning program and how to work with the model. It is displayed in a dialogue box (figure 1) and appears every time the model file is opened. If needed it can also be opened by clicking the button in the upper left corner of the user interface (see figure 3). In addition to that, the introduction dialogue allows the user to navigate between the different areas of the plant so that first impressions of the related logistics and production steps can be obtained. These areas are described more precise within the instructions dialogue.

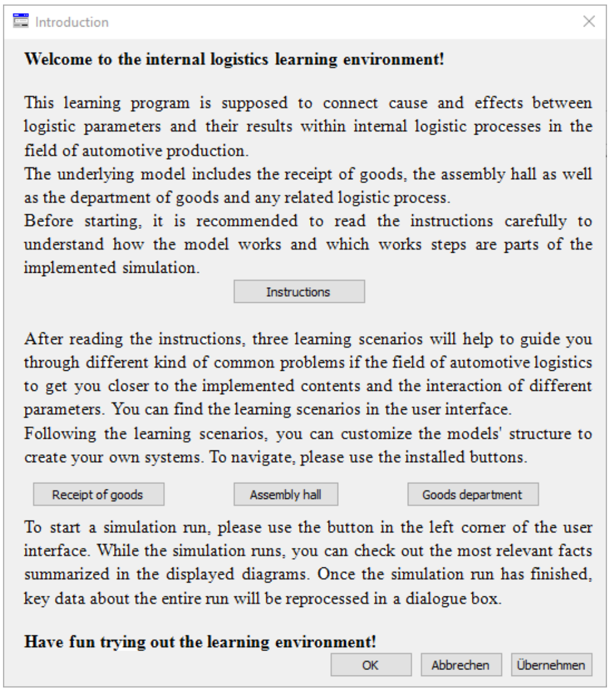


Figure 2: Introduction dialogue in Plant Simulation

In general, the entire coordination and navigation of the user is taking place in the user interface. A user friendly environment was highly prioritized in this work, as it may decrease possible rejection of users regarding simulation models. Most of the interaction is realized by buttons and dialogue boxes.
Next to the navigation, results of the ongoing simulation run are displayed in preinstalled diagrams, which are showing live data of key figures.

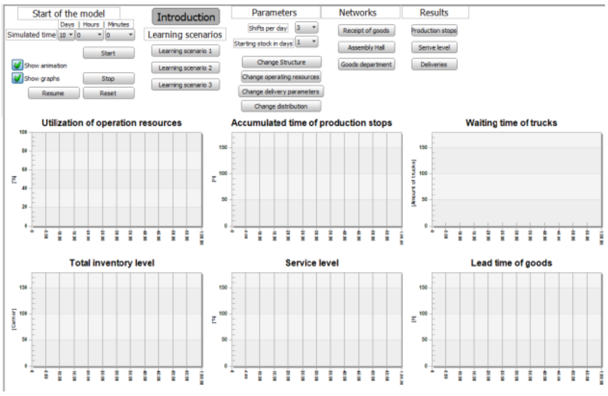


Figure 3: User interface in Plant Simulation

The user interface allows the user to:

- Open the introduction and instruction
- Start, stop and resume the simulation
- Change the parameters and the structure
- Start the learning scenarios

- Navigate between the areas of the plant
- Watch the key figures in both diagrams and tables

To get in touch with how the model works, three learning scenarios are developed. In these scenarios common problems of the related logistic departments are treated. Therefore problematic states are implemented which need to be solves by the user. The difficulty increases from one to another and while it is rather obvious what needs to be changed in the first scenario, the user needs to develop a deeper understanding of the underlying system to fix the problems of the later scenarios. After the simulation run of a learning scenario has finished, the results will be presented in a dialogue box (figure 5). This dialogue box also contains a button that leads the user to the box to change the related parameters (figure 6).

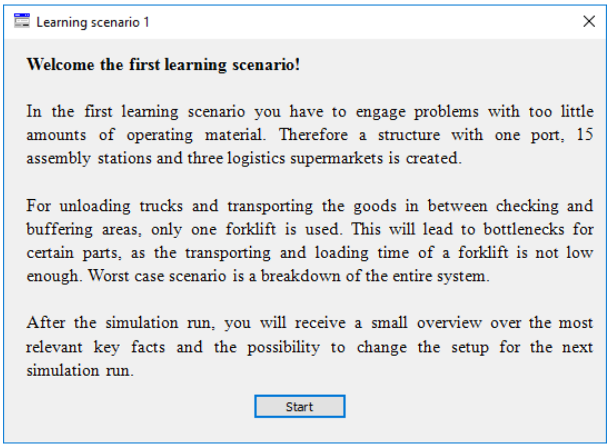


Figure 4: Dialogue window of the first learning scenario in Plant Simulation

Figure 4 shows the text of the first learning scenario. The text itself just provides some basic information as the more detailed information about the modeled production system should already be gathered by studying the instructions. With clicking the "start"-button in this dialogue, the model will change the structure to the setup of the first learning scenario and afterwards run the simulation for a simulation time of 10 days, which is enough to cause the system to collapse. Once the simulation has finished, results will be summarized inside another dialogue box and it is left to the user to reflect the performance of the last run.

The next step is to change the related parameters in a fashion that solves the occurring problems (see figure 6). Finding out the changes that need to be made is part of the learning process and relies on the principle of constructivism. The user can change the parameters and run the simulation as often as he wants and figure out how the changes affect the systems' performance.

As long as a user is working on the learning scenarios, he is limited to change the parameters concerned. Structural adaptations are not allowed at that point in time as those go in hand with high investment costs and thus are not the first answer to logistical problems.

Outside of the learning scenarios it is possible to change the entire structure and mostly every procedural parameter, however processes themselves cannot be changed as the implementation of a self-learning model was not part of this work.

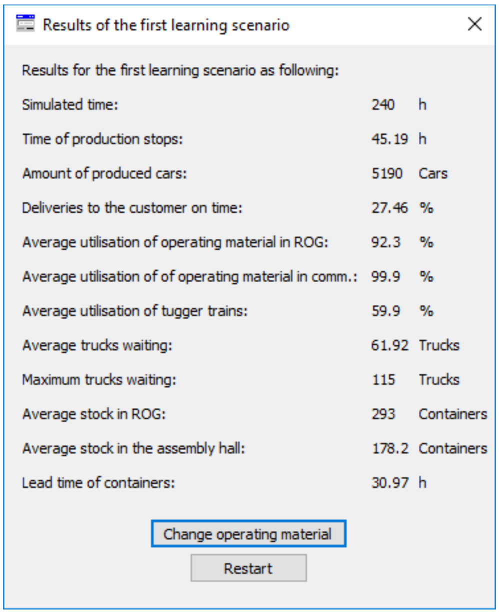


Figure 5: Exemplary results of a simulation run in Plant Simulation

Clicking the "Change operating material"-button will lead to the following window. As seen in figure 6, some of the parameters are colored in grey meaning they cannot be changed in that scenario. Regarding the other variables, the user is free to change the numbers and restart the simulation with the new setup. Parameters concerning the assembly or the general structure of the model can be found in different dialogues, but as these are irrelevant to fixing the problematic situation of the first learning scenario they are locked at that time.

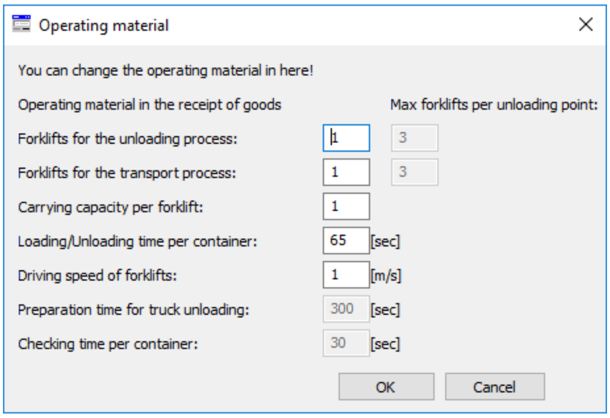


Figure 6: Parameter changing dialogue for operating material in extracts in Plant Simulation

The presented diagrams are showing the live status of the current simulation run. Key figures of production stops, service level, lead time, utilization, waiting time and stock level were chosen to provide enough information to deduce the performance of the current run. These key figures are the most important parameters of logistic systems, still the user is free to find other defining numbers of his performance by clicking at the implemented material flow elements. As a consequence, more experienced users can evaluate their performance in a more precise fashion and in this way progress faster in their learning. At the end of each run, key figures are compressed into average and maximum values, as those are otherwise very hard to identify out of the presented diagrams.

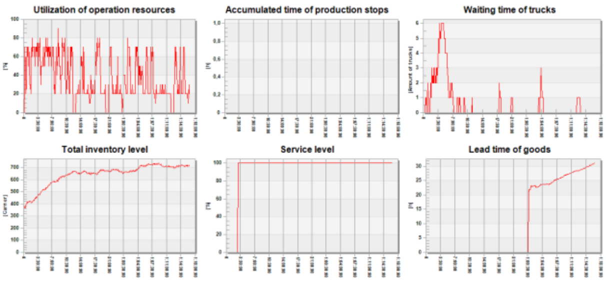


Figure 7: Exemplary diagrams of key figures in Plant Simulation

The simulation model was implemented by separating the plant layout into the receipt of goods, the assembly hall and the goods department, each being represented by one network in plant simulation. Parameters are not just including quantities and capacities of resources, but also the structure of the plant. Therefore the "automatic model construction" is used, which allows users or trainers to configure the layout to their own needs before running the simulation.

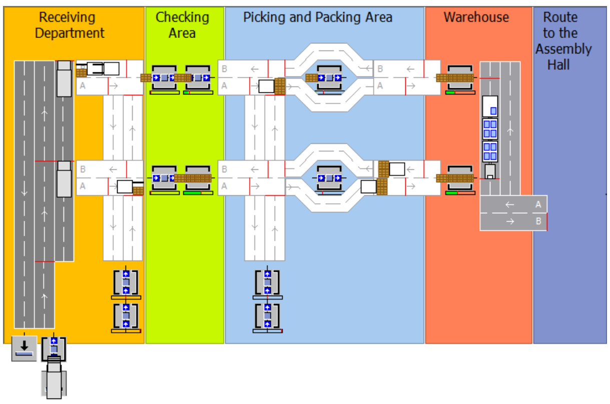


Figure 8: The receipt of goods in Plant Simulation

Figure 8 presents an example of the implemented network of the receipt of goods during a simulation run. Colors divide different parts of the network and different kinds of transportation units have different icons as well. On the left side of the picture the trucks (grey icons) are being emptied by forklifts (white icons). Next to that process, the unloaded goods (large load carriers, brown icons) are checked in regard to their quality and usability inside the checking area. In the picking and packing area the delivered good are prepared for either being stocked or delivered right into the assembly hall. On the right side of the picture one tugger train is taking out small load carriers (blue icons) of the warehouse to deliver them into the assembly hall.

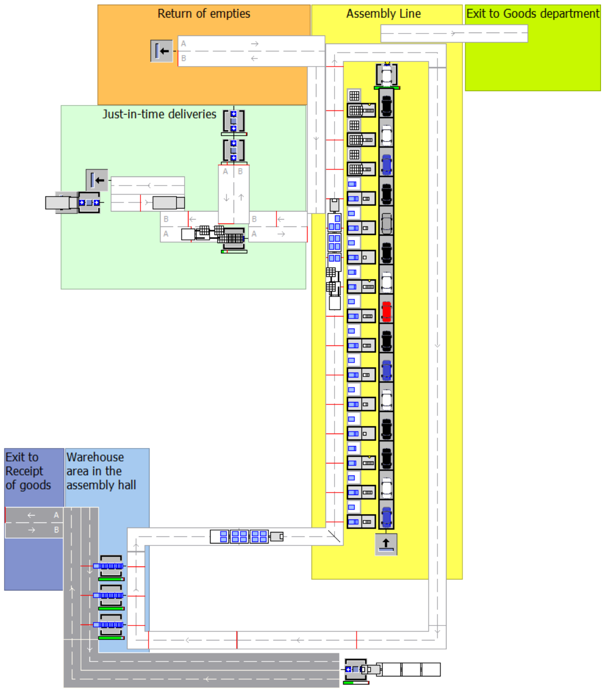


Figure 9: The assembly hall in Plant Simulation

The assembly hall during production is shown in figure 9. Similar to the receipt of goods, different colors represent various working areas. The production line is centered in the middle of the picture. Purchased parts are delivered to small buffer places close to the assembly line, where they are mounted into painted car bodies. At the end of the assembly line, cars are finished, filled with mediums and from there driven to the goods department. Deliveries to the assembly buffers are taken out of the warehouses (light blue area) by tugger trains or supplied directly to the assembly hall (Just-in-time area) and then brought the assembly line by use of forklifts.

After exiting the assembly hall cars will enter the goods department. Before carrying them out to the customers either by ship, train or truck they need to be prepared for the upcoming transport. Depending on the mode of transport, packaging material is used to guarantee the prevention of any damage during the transport. The three modes of transport in action are shown in figure 10.

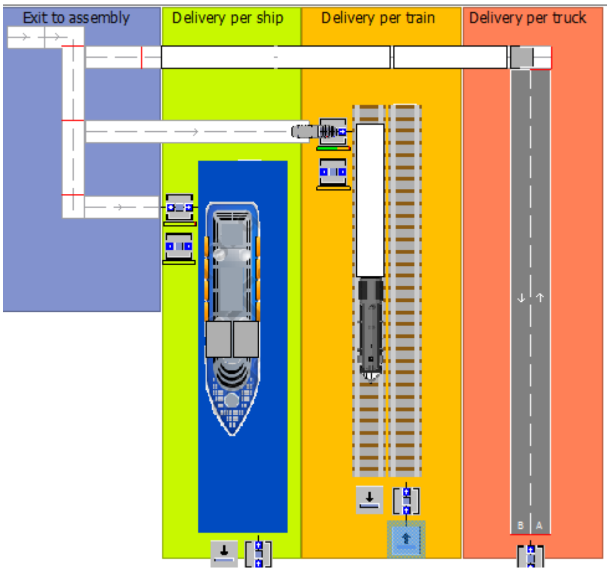


Figure 10: The goods department in Plant Simulation

As displayed, the visualization is an important factor, since it increases the learning effectiveness by maintaining the learner's attention and the imprinting process of the simulated contents (Ewleszyn 2011). The graphic elements and diagrams can be disabled in the users interface to increase the speed of the simulation run if needed.

5. RESULTS

The models functionality was tested by using 20 sets of different random number streams for every of the three learning scenarios. It appears that the results between every run differ but all go into the same direction. For example, production stops will income in every run but their timing depends on the moment of certain deliveries and the production program of the assembly. With fixing the "broken" parameters these production stops disappear which reveals the concept of cause and effect inside the implemented processes.

This enables users to gain knowledge about the underlying logistic processes, understanding of the elements' interdependencies and experience about characteristic problems of their working environment.

The verification of the model was done by using the methods of sensitivity analysis, monitoring certain situations within simulation runs and the internal validity which was already proven with the interdependencies between parameters and results.

Another goal of this work was to meet the theoretical requirements for effective self-directed learning. These goals were met by using simulation as the training method and dialogue boxes to "interact" with the user.

For further prospects, the learning environment should be tested by employees within the automotive logistics. That was not part of this work, but is essential regarding the acceptance of a simulation based learning program. In addition to that a web or browser-based approach needs to be evolved, like running the simulation model inside the browser to further decrease possible reservations towards the simulation software.

REFERENCES

Arnold, D., 2006. Intralogistik – Potentiale, Perspektiven, Prognosen. Springer Verlag Berlin Heidelberg, p.84

Ewleszyn, M., 2011. Auswirkungen von Medien auf Schulleistungen am Beispiel von Bildschirmmedien. In: R. Arnold. Pädagogische Materialien: Hochschulschriften. 12th ed., p.19

Klug, F., 2010. Logistikmanagement in der Automobilindustrie – Grundlagen der Logistik im Automobilbau. Springer Verlag Berlin Heidelberg, 183-204

Knowles, M., Holton III, E., Swanson, R., 2005. The Adult Learner. Elsevier Butterworth-Heinemann, San Diego, 7th ed., 4, 61-69

Laffert, J., 2000. Informations- und Materialflüsse in internationalen Logistiksystemen der Volkswagen AG. Kassel University Press GmbH, Kassel, 41-48

Mayer, G., Pöge, C., 2010. Auf dem Weg zum Standard – Von der Idee zur Umsetzung des VDA Automotive Bausteinkastens. In: G. Zülch, P. Stock. Integrationsaspekte der Simulation: Technik, Organisation und Personal. KIT Scientific Publishing, Karlsruhe, p.29

Mustafee, N., Katsaliaki, K., 2010. The Blood Supply Game. Proceedings of the Winter Simulation Conference, 327-338

Passiment, M., Sacks, H., Huang, G., 2011. Medical Simulation in Medical Education – Results of an AAMC Survey. Association of American Model Colleges, p.1

Siddiqui, A., Khan, M., Akhtar, S., 2008. Supply Chain Simulator: A scenario-based educational tool to enhance student learning. Department of Systems Engineering, King Fahd University of Petroleum and Minerals, Dhahran, 252-261

Staemmler, M., 2005. Lernstile und interaktive Lernprogramme. Deutscher Universitäts-Verlag, GWV Fachverlage GmbH, Wiesbaden, 1st ed., p.51

Witt, C., Ganguin, S., Kuszpa, M., Mengel, S., 2011. Mobile Learning in the process of work: Participation, knowledge and experience for professional development. In: N. Pachler, C. Pimmer, J. Seipold. Work-Based Mobile Learning – Concepts and Cases. Peter Lang AG, International Academic Publishers, Bern, 152-154

Ziltener, A., 2005. Gestaltung mediengestützter Lernumgebungen. Hochschule für Wirtschafts- Rechts- und Sozialwissenschaften St. Gallen, 18-24

A DECISION SUPPORT TOOL FOR STRATEGIC CONFLICT MANAGEMENT THROUGH ASSIGNMENT OF CALCULATED TAKE-OFF TIMES

Nina Schefers[(a)], Juan José Ramos González [(b)], Pau Folch[(c)]

[(a),(b)] Department of Logistics and Aeronautics, Universitat Autònoma de Barcelona, Spain
[(c)] Department of Research and Innovation, Aslogic, Spain

[(a)] NinaRebecca.Schefers@uab.cat, [(b)] JuanJose.Ramos@uab.cat
[(c)] pfolch@aslogic.es

ABSTRACT
Collaborative Decision Making (CDM) is part of the "Single European Sky" program for optimizing airspace and airport operations. It emphasizes the coordination of processes, the sharing of accurate information among agents and the improvement of real-time data exchange between airports and the Air Traffic Flow Management (ATFM) network. This enhanced cognitive decision making process supports the global performance ambitions for air traffic optimization. In this paper, an advanced tool is presented that enhances the design of Decision Support Tools (DST) by identifying concurrence events at network level to readjust the aircraft take-off times within their assigned nominal Calculated-Take-Off Time (CTOT) margins on ground. The overall goal is to reduce the probability of separation minima infringement. The tool is capable to identify concurrence events at 3D level and to filter the tightest concurrence events for each pair of aircraft. Furthermore, an efficient analysis method based on graph theory to cluster the detected concurrence events is presented to ensure an efficient conflict resolution.

Keywords: Air Transportation, Decision Support Tools, Conflict Detection, Air Traffic Management, Graph

1. INTRODUCTION

According to the Single European Sky program SESAR, one of the elements in the European air transport value chain that should be improved and innovated is the Air Traffic Management (ATM) due to its limitations in capacity and its costs. The key areas of European air traffic performance optimization lay in environmental sustainability, capacity improvement, cost efficiency, operational efficiency, safety and security. To support these global key performance areas, the ATM sector has defined focus areas to introduce changes and implement optimization techniques. The areas include an optimized ATM network services, high-performing airport operations, advanced air traffic services and improved aviation infrastructure. (Sesar 2015)

In this paper, we address all ATM key performance areas and propose an innovative CDM methodology to improve the ATM performance based on the concept of Trajectory Based Operations (TBO) using Reference Business Trajectories (RBT). The approach focuses on improving the air traffic dynamic demand capacity balance by using means of the prompt identification of concurrence events at network level and by readjusting the take-off times within the assigned nominal Calculated-Take-Off-Time (CTOT) margins of [-5, 10] minutes. This way, the amount of Air Traffic Control (ATC) interventions could be minimized by rearranging the departing sequence of aircraft at the involved airports. The approach can be considered as a short-term Air Traffic Flow and Capacity Management (ATFCM) measure, applied at local level and reducing traffic peaks for the whole European airspace.

The objectives and benefits of this approach are aligned with the Single European Sky ATM Research Programme (SESAR) and can be summarized as follows:

1. Reduction of the probability of separation minima infringement: The approach is based on RBTs that provide an excellent source of information to identify long time in advance situations in which 2 or more aircraft could require ATC directives to maintain the required separation minima. Applying the mitigation mechanism, robust clearances at hotspots for a certain rate of predicted conflicts could be achieved. This way we create a robust traffic in which a reduced amount of ATC interventions is considered as part of the solution.
2. Enhancement of Airport Collaborative Decision Making (A-CDM) processes: The tool, presented in this paper, will contribute to a smooth integration of the different DSTs implemented at airport level in the ATM system, in which information about turnaround and taxi-out delays could be used for a better use of airspace resources.
3. To improve Air traffic Navigation Service Provider (ANSP) predictive workload: The TBO mapping tool presented in this paper provides more accurate traffic information in terms of the management of the flight position in which task load at sector level could be estimated at micro-level.

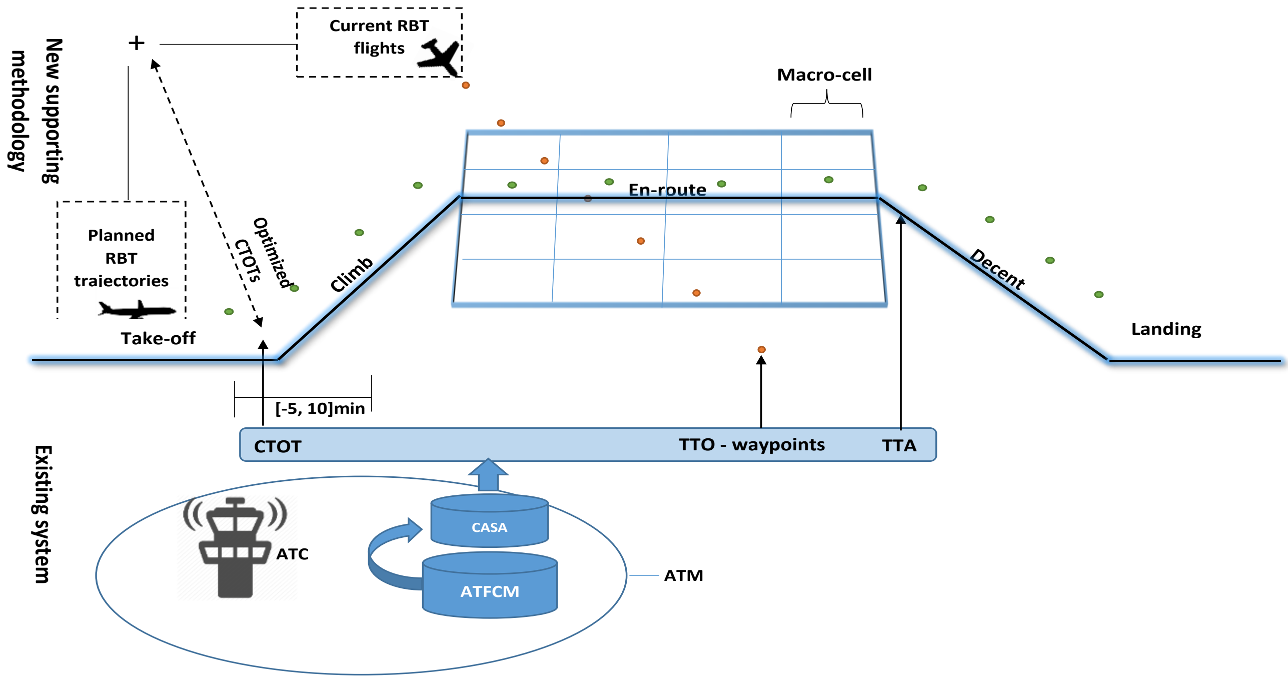


Figure 1: Aeronautical background in context of the used methodology

1.1. Aeronautical background

Europe has some of the busiest airspace in the world, compiled from 44 member states united in the European Civil Aviation Conference (ECAC) region. To safely operate the demand, any Airspace User that intents to depart from, arrive at or overfly one of the ECAC member states must submit a flight plan that must be approved in advance. Once the flight plan has been approved, its term changes to Reference Business Trajectory (RBT) and the aircraft is authorized to proceed in accordance with the agreed RBT consisting of predefined conflict free segments.

In Europe, an Air Traffic Flow and Capacity Management (ATFCM) service has been established to use the given capacity to the maximum extent possible keeping in mind the guiding principles safety, continuity and expeditious for the flow of air traffic. Information can be retrieved from the System Wide Information Management (SWIM) platform, an advanced technology program designed to facilitate greater sharing of ATM system information, such as airport operational status, weather information, flight data, and airspace restrictions.

Integrated in the ATFCM service is the Computer Assisted Slot Allocation (CASA) system that operates under the "First-Planned, First-Serve" policy. As it can be seen in Figure 1, the CASA system calculates the estimated Time to Overfly (TTO) for each point of entry in each sector and provides the Calculated-Take-Off-Time (CTOT) that must be followed within a slot window. (Cook 2007)

Attempting to improve the slot situation, new information processes and systems are under development to meet the current European capacity demands. The goal hereby is to improve the flight planning process and the supporting systems to create shorter routes, reduce emissions, reduce delays and improve the connectivity of trajectories. Thus, the ATFCM adherence measured at its efficiency and safety level can be revealed to decrease the overload of ATC workload in dense sectors.

To draw a connection between ATFCM and ATC as two components of the ATM, the concept of TBO was introduced. Short Term ATFCM Measures (STAM) tools and functionalities that smooth sector workloads by reducing traffic peaks through e.g. short-term application of minor ground delays [-5,10] minutes, rely on this TBO framework. The result is a synchronization of the trajectory prediction ensuring consistency between the trajectory and generic constrains that originate various ATM components and the various regions that shape this trajectory. Furthermore, it fosters the ground delay approach over the en-route delay approach since studies have reveal that holding aircraft on the ground contributes to less fuel consumption, less emissions and represents one of the simplest ways to leverage ATC workload as stated in (Barnier & Allignol 2008) and (Envisa 2017).

By empowering the concept of TBO as a flexible synchronization mechanism towards an efficient and competitive ATM service, a precise description of an aircraft path in space and time can be retrieved. Under this approach, airspace users should fly precise 4-

dimensional trajectory (4DT) paths, previously agreed upon with the network manager and in consistency with the agreed RBT.

In this paper, an advanced tool is presented that is compatible with the above described ATM tools and services to support the SESAR optimization objectives. The proposed algorithm allows the analysis of en-route trajectory interactions and can detect overlapping time windows to identify concurrence events between two or more aircraft on a 3D level (including different flight levels), see chapter 3. The approach is based on the idea to map the European airspace onto a grid and to identify "collective micro-cells" whose initial 2D concepts were studied in (Nosedal et al. 2014) and (Barnier & Allignol 2012). Furthermore, the computational efficiency and assurance of compatible conflict resolutions is of great importance. Therefore, an innovative methodology based on graph theory is proposed in chapter 4 to cluster the identified concurrence events into independent sub-graphs. This could support a mitigation tool to find fast and robust scheduling solutions measured by the amount of reduction ATC interventions.

2. CONFLICT DETECTION METHODOLOGY

The conflict detection is composed of two processes. First, the calculation of "overlap times" of aircraft within one microcell and second, the filtering of the tightest concurrence events, see chapter 2. Later, a graph theory based analysis is applied to cluster the hotspots of the detected concurrence events and to provide a robust set of data to a mitigation tool to reschedule the CTOTs of the detected aircraft, see chapter 3.

2.1. 3D Conflict detection

To detect the different ''collective microregions'' throughout the entire European airspace, each en-route trajectory is initially projected onto a discrete grid (square microcells of 6NM ground size) spanning longitudes of -20 to 30 degrees and latitudes of 0 to 80 degrees, representing the European airspace as presented in (Nosedal et al. 2014; Schefers et al. 2017).

After the initial mapping, microcells (cells of 6NM x 6NM ground size) with an occupancy rate equal or greater than two aircraft simultaneously are identified, as described in Figure 2. Then, for each aircraft pair, the "clearance time'' or ''overlap time'' is computed and the entry and exit times are stored to identify the aircraft that share one "microregion" as it can be seen in Figure 3.

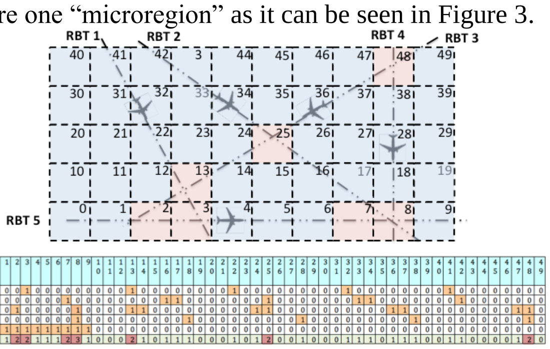


Figure 2: Occupancy rate matrix

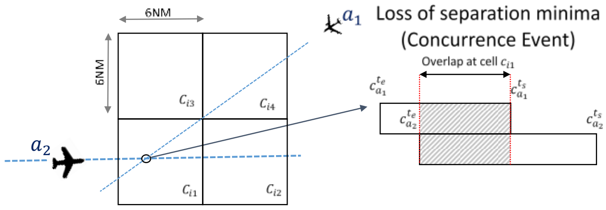


Figure 3: Conflict detection

To avoid missing concurrence events in neighbouring cells, a neighbourhood analysis is performed using a shifting process. To improve the reliability of the concurrence event identification, the original microcell will be shifted by 0,1 degree up, then 0,1 degree to the right, then 0,1 degree sown and back to its original position.

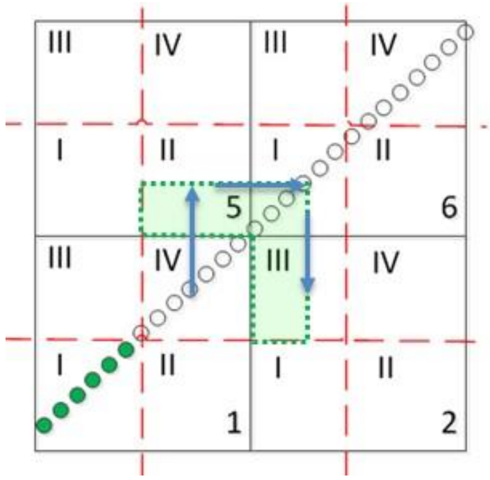


Figure 4: Neighborhood Analysis

The above presented approach described a 2D concurrence event detection approach. This article extends the 2D concurrence event detection approach and introduces a 3D concurrence event detection method. Therefore, the different flight levels must be integrated to achieve a multi-level mapping. The world's airspace is divided into three-dimensional segments that have been divided into different classes that are fundamentally defined by the International Civil Aviation Organization (ICAO)(Alphaaditya n.d.).

The approach that has been developed represents a rather conservative but safe method. Considering an aircraft a_i that changes its flight level from flight level FL_i to FL_{i+1}, the trajectory will be represented on both flight levels during the climbing manoeuvre, see Figure 5. If now an aircraft a_j causes a concurrent event during the climbing process of a_i in FL_i it might happen that a_i is already about to approach FL_{i+1} and no real conflict exists. On the other hand, this approach can be considered as very safe which is a primary objective in aeronautics.

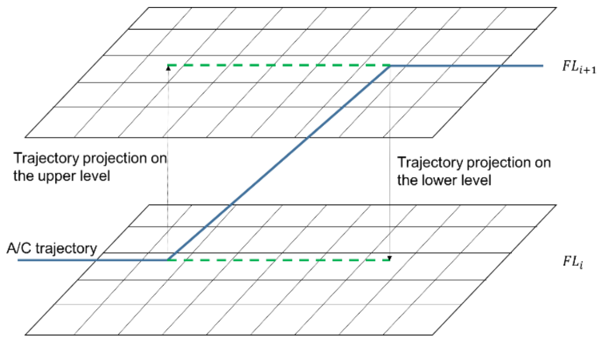


Figure 5: 3D Multi-flight level mapping

After computing all microcells with an occupancy rate of 2 or more aircraft, the output of the detection process is a list of all concurrence events, with all pairwise conflicts. The detection algorithm has $O(n \times m)$ complexity.

2.2. Filtering process

In the previous chapter it was mentioned that the entry and exit times of aircraft into a cell are stored. Now, these values are retrieved to calculate the temporal looseness of aircraft in one particular cell. As mentioned in (Nosedal et al. 2014) the temporal looseness H of two aircraft can be calculated by determining the minimum value of the exit time of the two aircraft and subtract the maximum entry time from this value.

$$H = \min_{t_j}\left(t_{j_x}; t_{j_y}\right) - \max_{t_i}(t_{i_x}; t_{i_y}) \qquad (1)$$

In Equation 1, Min is a function that determines the minimum exit time t_j of two aircraft t_{j_x} and t_{j_y} in one cell. Max is a function that determines the maximum entry time t_i of two aircraft t_{i_x} and t_{i_y} in one cell.

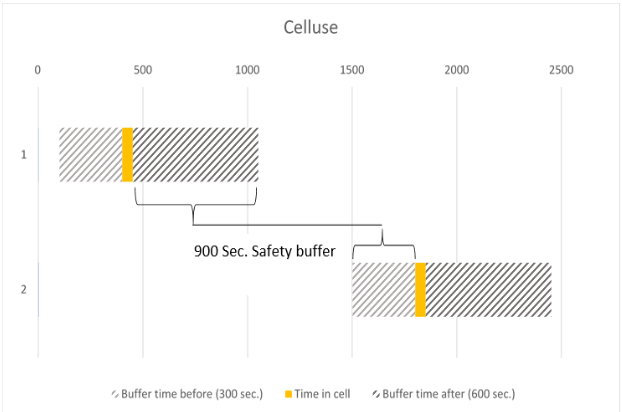


Figure 6: Celluse of one Microcell. X-Axis: Time in sec. Y-Axis: Aircraft

The detected concurrence events are filtered for each pair of aircraft. The result after the filtering process are tightest potential concurrence events for each pair of aircraft. Since the domain for rescheduling the CTOT is restricted to [-5,10]min, the greatest value is 15min (900sec). Therefore, the list of tightest potential occurrence events can be cut by all values exceeding this timeframe because their spatial separation is so great that even a maximum CTOT shift (900 sec.) would not have any effect to endanger the safety separation, see Figure 6.

The idea behind this process is to focus on the endangered pair of aircraft that could lose separation minima. Furthermore, this process makes it feasible to develop a conflict detection methodology, capable to outperform present NP-Hard algorithms (mainly pairwise oriented) and new Polynomial algorithms such as SDS (Spatial Data Structure) with a performance sensible to scalability problems.

3. CONFLICT DETECTION ANALYSIS

In order to provide a robust set of data for the mitigation tool capable to reschedule the initial CTOTs, this paper proposes an efficient analysis to identify those trajectories that will reduce the maximum clearance in order to provide a more robust departure coordination solution. The analysis is based upon Adjacency Matrix properties and Depth-first search (DFS) algorithm, connecting components are extracted from the initial graph in order to be processed independently. Such a formulation based on graphs allows representing in single manner concurrence and coupling interdependencies between detected pairwise conflicts obtained from the mapping and filtering tools as it can be seen in Figure 7.

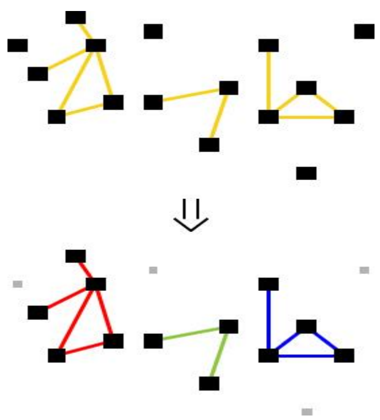


Figure 7: Graph representation of coupled concurrence events

This section is organized as follows: chapter 3.1 will introduce the preliminary definitions needed to understand the graph theory that was applied to analyze the conflict interdependencies. Chapter 3.2 describes methods of graph representations. Finally, chapter 3.3 explains the concept for the analysis of conflict interdependency based on graph theory.

3.1. Preliminary definitions for graph theory

A graph $G(V, E)$ is a triple consisting of a vertex set $V(G)$, an edge set $E(G)$, and a relation that associates with each edge two vertices called its endpoints (not necessarily distinct) see Figure 8.

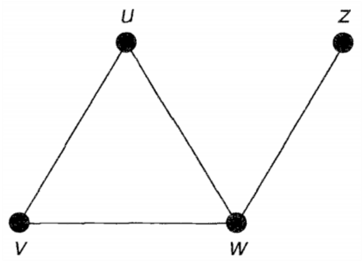


Figure 8: Simple graph

For our purposes, all graphs will be finite graphs where $V(G)$ and $E(G)$ are finite sets. However, this definition does not exclude the possibility that two endpoints of an edge are the same vertex (which is called a loop) and we may have multiple edges. A simple graph $G(V, E)$ is a graph having no loops or multiple edges.

For a graph G, we denote, with $\nu_G = |V(G)|$ and $\varepsilon_G = |E(G)|$. The number of the vertices ν_G is called the order of G, and ε_G is the size of G. Vertices u and v are adjacent or neighbours if $uv \in G$, and u and v are then incident with such an edge, see Figure 9. Similarly, two edges $e_1 = uv$ and $e_2 = uw$ having a common endpoint are adjacent with each other.

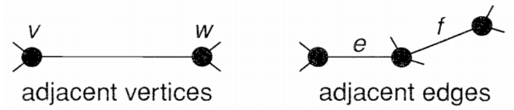


Figure 9: Adjacency in vertex and edges

For our purposes, we need to introduce also the concept of connectedness. Two graphs can be combined to make a larger graph. If the two graphs are $G_1 = (V(G_1), E(G_1))$ and $G_2 = (V(G_2), E(G_2))$, where $V(G_1)$ and $V(G_2)$ are disjoint, then their union $G_1 \cup G_2$ is the graph with vertex set $V(G_1) \cup V(G_2)$ and edge family $E(G_1) \cup E(G_2)$.

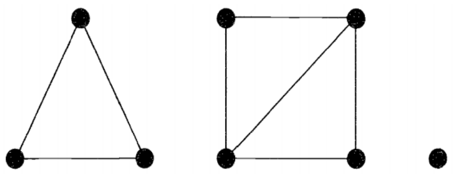


Figure 10: Disconnected graph with three components

A graph is connected if it cannot be expressed as the union of two graphs and disconnected otherwise. More formally, a graph G is connected if for every $u, v \in V(G)$ there exists a u, v-path in G. Otherwise G is disconnected. The maximal connected subgraphs of G are called its components. (Trudeau & Trudeau 1993)

Finally, in a formal way, the degree of a vertex v of G can be defined as follow: Let $v \in G$ be a vertex a graph G. The neighborhood of v is the set:

$$N_G(v) = \{u \in G \mid vu \in G\} \quad (2)$$

The degree of v is the cardinality of its neighborhood:

$$d_G(v) = |N_G\ (v)| \quad (3)$$

If $d_G(v) = 0$, then v is said to be isolated in G, and if $d_G(v) = 1$, then v is a leaf of the graph. The minimum degree and the maximum degree of G are defined as:

$$\delta(G) = \min\{d_G(v) \mid v \in G\} \quad (4)$$

and

$$\Delta(G) = \max\{d_G(v) \mid v \in G\}$$

3.2. Graph representations

The two main graph representations used in graph problems are the adjacency list and the adjacency matrix. An adjacency list is a list of lists. Each list corresponds to a vertex u and contains a list of edges uv that originate from u (the neighborhood of u). Thus, an adjacency list takes up $O(V + E)$ space.
An adjacency matrix is a $|V| \times |V|$ matrix of bits where element (i, j) is 1 if and only if the edge $v_i v_j$ is in E, and 0 otherwise. Thus, an adjacency matrix takes up $O(|V|^2)$ storage (note that the constant factor here is small since each entry in the matrix is just a bit).

The worst-case storage of an adjacency list is when the graph is dense, i.e. $E = (|V|^2\ )$. This gives us the same space complexity as the adjacency matrix representation. The $O(|V| + |E|)$ space complexity for the general case is usually more desirable, however. Furthermore, adjacency lists give you the set of adjacent vertices to a given vertex quicker than an adjacency matrix $O(neighbors)$ for the former vs. $O(|V|)$ for the latter.

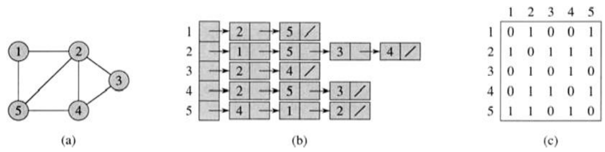


Figure 11: Two representations of an undirected graph. $(\boldsymbol{a})$ An undirected graph G having five vertices and seven edges. $(\boldsymbol{b})$ An adjacency-list representation of G. $(\boldsymbol{c})$ The adjacency-matrix representation of G.

One of the most fundamental problems in graph theory is graph traversal (also known as graph search). This problem refers to the process of visiting (checking and/or updating) each vertex in a graph. There are two standards of traversing all vertices/edges in a graph in a systematic way: Depth-First Search (DFS) and Breadth-First search (BFS).

The main idea of the Depth-First Search algorithm is to make a path as long as possible, and then go back (backtrack) to add branches also as long as possible. A complete DFS ends when we traverse back to the root and we have visited every vertex or when we have found the desired edge/vertex. During the search DFS divides the edges of *G* into tree edges and back edges. Obviously, the tree edges form a spanning tree of *G*, also known as a DFS-tree. (Chartrand & Zhang 2006)(Gibbons 1985)

3.3. Formulation for conflict interdependencies

A set of pairwise concurrence events between aircraft is produced by mapping and filtering tools as described in chapter 2. The final output of these tools is a set of pairwise potential concurrence events. This list is made by the following information:

1. An identification number of the cell where the potential concurrence events occurs.
2. The Flight Level where the concurrence event is detected.
3. Identification numbers of the two involved aircraft.
4. The times t_s and t_e of the two aircraft.
5. And two Boolean values that describes if the involved aircraft will take off before the time window analyzed or not. This information will be used in the mitigation phase in order to detect in which aircraft we are able to do a shifting in its CTOT and in which not.

The process to detect potential concurrence events analyses a scenario that can contain potential conflicts between more than two aircraft. However, the obtained pairwise list of potential conflicts does not represent intuitively the real state space of the processed scenario. Hence, we need new formulation able to correct this issue and, at the same time represent efficiently possible interdependencies between these listed pairwise potential conflicts.

Therefore, the potential concurrence events detected in one cell at the same flight level will form a node or vertex of a graph and its edges will represent the interdependencies between potential conflicts.

More formally, the nodes of graph $G(V,E)$ will be constructed in the following way:

1. By using the output list aforementioned, the potential conflicts are grouped by cells and by flight level. This way, clusters of potential conflicts that share physical location in the space are formed. Notice that the cell fixes the Cartesian coordinates x and y, and Flight Level (FL) fixes the last coordinate z, which represents the altitude.
2. Once the clusters are made, we must distinguish which pairwise conflicts really form a unique potential concurrence event using time information. This step is conceptually important because it transforms the spatial representation of the potential conflicts induced by the grid to an adimensional representation.
   To distinguish between potential conflicts in a cluster we use the following criterion:
   a) Create an empty list L, and add to it the earliest potential conflict in the cluster.
   b) Search in the cluster if there is another pairwise potential conflict that involves one of the aircraft in the earlier conflict, let be a_i the shared aircraft (AC), and check that the times t_e and t_s of a_i are the same in the two conflicts. Repeat this step until no more pairwise conflicts are found.
   c) Add all conflicts found in step b) in L, ordering them by earlier t_e.
   d) Repeat b) and c) considering this time the earlier element of L not used yet. Repeat until all elements in L has been cheeked.
   e) Construct using list L an ordered list of AC by its t_e.

   By regrouping the elements in the output list the potential concurrence events that really occurs in the analyzed scenario independently of the number of AC involved can be reconstructed. (see Figure 12).

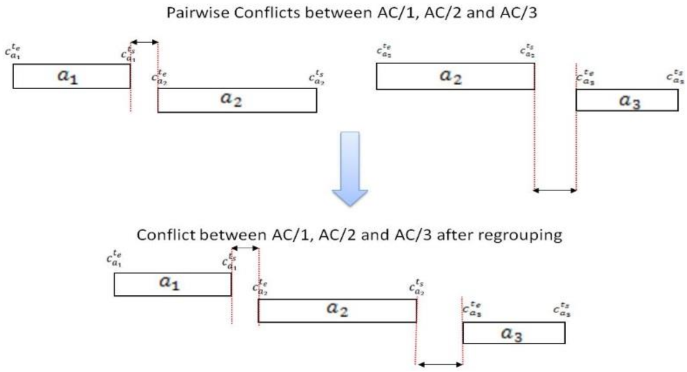


Figure 12: Regrouping two pairwise conflicts to form one conflict node

All the nodes in graph *G* are outputs of this procedure, thus, one node which represent one potential conflict could involve more than one aircraft. Furthermore, two different nodes may represent two potential concurrence events in the same cell, but involving different aircraft in different time.

Remembering, the main objective of the tool is to enhance the airspace demand-capacity balance by trying to reduce the number of potential concurrence events en-route. Towards this goal, concurrence interdependencies between aircraft trajectories are identified at the network level, and are removed by rescheduling take-off times in such a way that target times of arrival are preserved within a one-minute margin. Then, the interdependencies between potential conflicts are in some sense the repercussions that the rescheduling takes-off times could produce later at en-route phase.

To construct *G*, we need to define also the edge set $E(G)$. As aforementioned, the edges in *G* must represent the interdependencies between potential concurrence events and the rescheduling takes-off times. Hence, edges must be related to RBTs of the aircraft involved in the nodes of G.

Formally, we add to $E(G)$ an edge uv if and only if there are at least one aircraft which is involved in node u and in node v. That is an edge $uv \in E(G)$ if and only if u and v shares an aircraft.

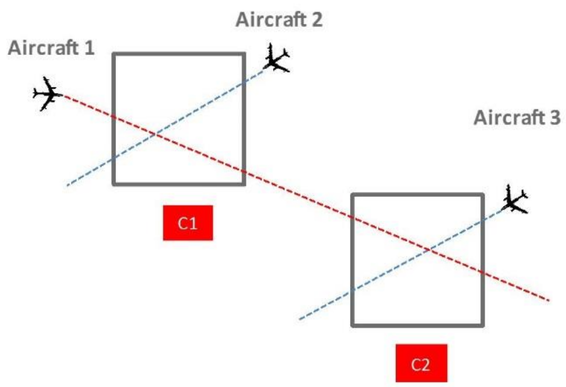


Figure 13: Two potential conflicts shearing aircraft 1.

Figure 13 shows two potential concurrence events that occur in different cells. Let be u the node of G that represents the potential conflict listed in cell c_1 and v the node for the conflict in c_2. Then, we must add to $E(G)$ the edge uv because u and v shares Aircraft 1.

The idea behind this is to remove by rescheduling take-off times the potential concurrence event encoded in u considering the modified CTOT of Aircraft 1 that may result in a reduction of the clearance H in v and vice-versa. In case where u and v represent only potential conflicts which means that there is a positive clearance H in both cases, a rescheduling take-off in Aircraft 1 may remove one potential conflict but, producing at same time a real conflict later on.

This formulation based on graphs allows representing real conflicts and their interdependencies, and visualize complex situations. For example, the connection of nodes v and w by a vw-path of length greater than 1 means that the potential conflicts in v and w even they do not share any aircraft there is interdependence between them which is given by some intermediate nodes that we must consider when rescheduling take-off times.

Once the formulation has been presented along this section we will then introduce a couple of definitions regarding the nature of the interdependencies.

The presented approach induces some differences between the elements listed in the output of the mapping and filtering tools. To be more precisely, we will differentiate between interdependencies that relate aircraft inside a node of G and those that relate conflicts by edges in G:

- Concurrent interdependencies are those which appear between aircraft that are in the same node in G. That is, potential concurrence events between two or more aircraft result in a concurrent interdependence between these aircraft. This definition induces to introduce a criterion or metric to measure the hardness of that interdependence.
- If there exist in G a uv-path between two nodes u and v each one encoding a potential conflict then, there is and interdependence between them. Since the resolution of one of them propagate some restrictions in the time stamp domains for the resolution of the other one. We namely this kind of interdependencies coupling interdependence.

Concurrent interdependencies must be removed from the system as much as possible but considering the existence of the coupling interdependencies. It is possible to expand these concepts by introducing criterions or metrics that help us describe the degree of these interdependencies. For the concurrent interdependencies, we introduce the saturation concept which refers to the trade-off between cell occupancy and cell capability. That is, we define the level of saturation as a metric to indicate how occupied is a cell in terms of its capability.

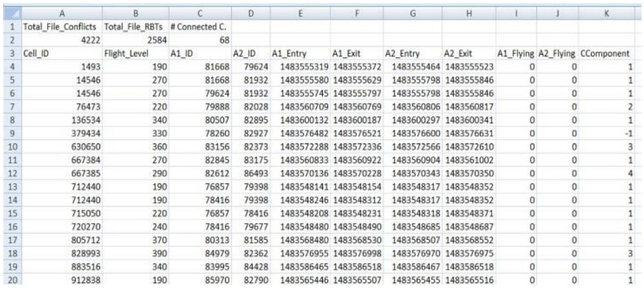
Finally, we introduce one more concept which is the coupling level that describes how much the propagation of one resolution between concurrent interdependencies may affect future resolutions. This metric deals with concepts like tight interdependence which appears in scenarios where the coupling interdependencies between the concurrent ones produce a complex over-constrained system where solutions maybe strongly relegated or even removed.

4. APPLICATION AND EXPERIMENTAL RESULTS

The model was applied to DDR2 data obtained from one day of traffic. The scenario is composed of a set of 2584 real 4D trajectories in the European airspace that reveals 4222 conflicts. In this work, we assumed TBO without uncertainties. In this context, the trajectories were discretized at each second, and each position was specified in terms of geographic coordinates and a time stamp.

Figure 7 at the beginning of this chapter showed graphically the idea of identifying connected components in G. In this way, the whole system is partitioned in independent sub problems of less size. This allows the mitigation tool, read more in (Schefers et al. 2017), to work faster and in a parallelizable way.

The way we carried out the partitioning of G is to modify the Depth-First Search algorithm to be able to extract the connected components of G. This minor modification is based on the idea of colouring each visited node of one connected component using the same colour and changing it each time the DFS starts to visit another non visited node. At the end of the DFS phase we obtain which node belongs to each connected component and the number of components that *G* has.



	A	B	C	D	E	F	G	H	I	J	K
1	Total_File_Conflicts	Total_File_RBTs	# Connected C.								
2	4222	2584	68								
3	Cell_ID	Flight_Level	A1_ID	A2_ID	A1_Entry	A1_Exit	A2_Entry	A2_Exit	A1_Flying	A2_Flying	CComponent
4	1493	190	81668	79624	1483555319	1483555372	1483555464	1483555523	0	0	1
5	14546	270	81668	81932	1483555580	1483555629	1483555798	1483555846	0	0	1
6	14546	270	79624	81932	1483555745	1483555797	1483555798	1483555846	0	0	1
7	76473	220	79888	82028	1483560709	1483560769	1483560806	1483560817	0	0	2
8	136534	340	80507	82895	1483600132	1483600187	1483600297	1483600341	0	0	1
9	379434	330	78260	82927	1483576482	1483576521	1483576600	1483576631	0	0	-1
10	630650	360	83156	82373	1483572288	1483572336	1483572566	1483572610	0	0	3
11	667384	270	82845	83175	1483560833	1483560922	1483560904	1483561002	0	0	1
12	667385	290	82612	86493	1483570136	1483570228	1483570343	1483570350	0	0	4
13	712440	190	76857	79398	1483548141	1483548154	1483548317	1483548352	0	0	1
14	712440	190	78416	79398	1483548246	1483548312	1483548317	1483548352	0	0	1
15	715050	220	76857	78416	1483548208	1483548231	1483548318	1483548371	0	0	1
16	720270	240	78416	79677	1483548480	1483548490	1483548685	1483548687	0	0	1
17	805712	370	80313	81585	1483568480	1483568530	1483568507	1483568552	0	0	1
18	828993	390	84979	82362	1483576955	1483576998	1483576970	1483576975	0	0	3
19	883516	340	83995	84428	1483586465	1483586518	1483586467	1483586518	0	0	1
20	912838	190	85970	82790	1483565446	1483565507	1483565455	1483565516	0	0	1

Figure 14: Output of the analytic tool

The output of the analytic tool has one more column than the data list created in the mapping phase. That column determines in which component belongs each pairwise conflict and can be seen in column K in Figure 14. If the potential conflict is an isolated node in *G* the value is set to -1.

4.1. Experiments

The mitigation of the conflicts is tested by a Constraint Programming model (read more in has been implemented with the ILOG Optimization Suite (IBM 2015). The optimization goal introduced in the mitigation tool which is formulated by the means of Constraint Programming is set up in a way that the solution searches to maximize the minimum clearance. This way, the minimum distance between two aircraft that take part in a concurrence event is maximized as much as possible. The idea behind this is to provide a set of safe trajectories that reduce the possibility of an ATC intervention. The following results were obtained:

As it can be seen in Figure 15, there are in total 68 subgraphs. The proportion of the amounts of relating components in *G* show that most subgraphs consists of one isolated node in G, followed by 24 subgraphs composed of 2 nodes and 10 subgraphs composed by either 3 or 5 nodes. Subgraphs that are constructed out of more than 5 relating components and up to 30 related components only occur once or twice in the data series. Finally, there is one subgraph that has the most components which is subgraph 1 with 3721 nodes, see Figure 16.

First, the set of data was analyzed without making use of the in chapter 3 described analysis tool. The result of solving the 4222 conflicts achieve the maximum minimum clearance of 2 seconds.

In a second experiment, the data output of the analysis tool that can be seen in Figure 14 was applied. In the data, it can be seen which pairwise conflicts belong to each subgraph and the number of connected component that the graph has. The results that were achieved can be seen in Table 1:

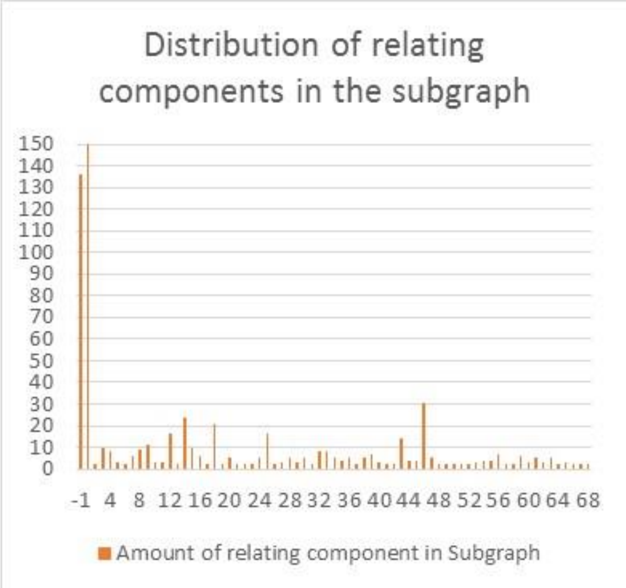


Figure 15: Amount of relating components for each subgraph in *G*

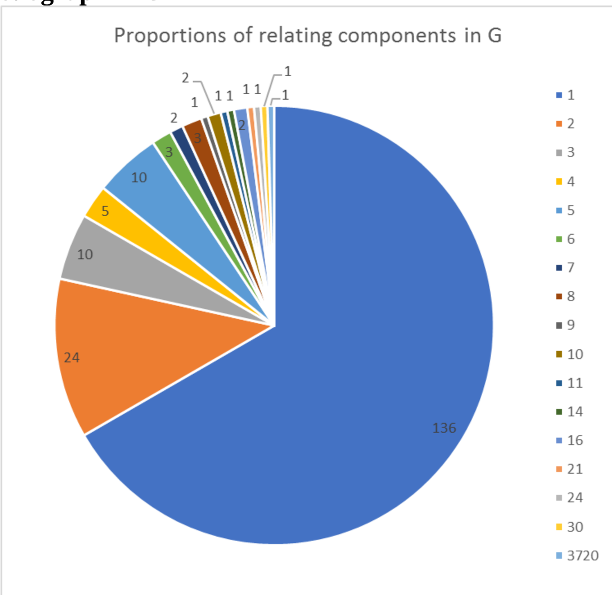


Figure 16: Proportion of distribution of relating components in *G*

Connecting Components	Max. Min. Clearance in sec.	Running Time
3721	2	00:09:26:65
30	119	00:00:06:39
24	147	00:03:05:12
21	21147	00:03:06:02
16	16144	00:00:06:62
14	14280	00:00:07:64
11	11420	00:00:06:13
10	10537	00:00:10:14
9	362	00:00:05:85
8	389	00:00:05:66
7	478	00:00:05:87

ISBN 978-88-97999-87-4; Bottani, Bruzzone, Longo, Merkuryev, and Piera Eds.

6	729	00:00:08:37
5	328	00:03:04:62
4	322	00:00:05:75
3	1176	00:00:05:46
2	1525	00:00:04:87
Without analysis tool	2	00:15:49:80

Table 1: Results of the experiments

Solving the subgraph with 3720 connecting components also achieves a maximum minimum clearance time of 2 seconds. This is no improvement with respect to the first experiment, however, there are still 501 pairwise conflicts remaining distributed among different subgraphs. Solving the second biggest subgraph combined of 30 nodes already achieves a clearance time of 119 seconds. The biggest clearance time of 1525 seconds was achieved in a subgraph with 2 nodes.

4.2. Solution Analysis

There is a significant improvement in both, achieved clearance times and running time using the analysis tool based on graph theory. As it can be seen in Figure 17, the bottleneck of the maximum minimum clearance time lays in the subgraph with 3721 nodes. All other subgraphs achieved a great improvement in their clearance time.

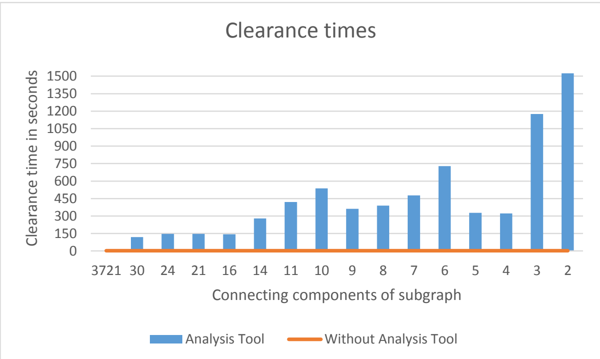


Figure 17: Clearance times

By dividing the whole problem into sub problems using graph theory, the clearance times within the sub problems can be significantly improved.

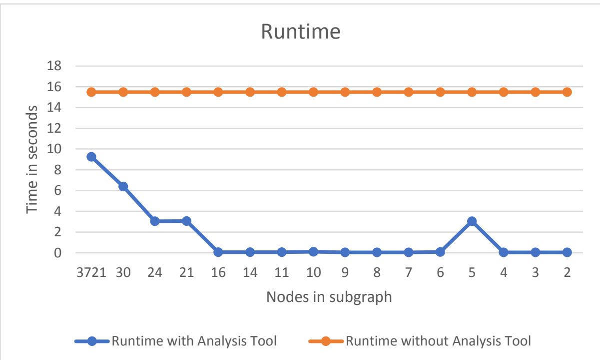


Figure 18: Runtime

Furthermore, the runtime of each sub problem can be drastically improved as it can be seen in Figure 18. While executing the whole problem continuously takes 15 minutes and 49 seconds, the runtime can be improved to 9 minutes and 26 seconds for solving the subgraph with 3721 nodes and subgraphs with only 2 nodes which represent the second biggest type of subgraph in the problem (see Figure 16) could be solved within 4 seconds.

5. CONCLUSION AND FUTURE RESEARCH

In this work a powerful analysis tool is presented based on graph theory. The model was applied on DDR2 traffic data and has been able to highly improve the maximum minimum clearance time of aircraft.

The analysis tool translates pairwise potential concurrent events described by using 4 dimensional coordinates into a planar representation allowing its visualization. This simplification is itself a useful tool to graphically analyses the whole system, since the information encoded in the mapping output list is presented now as an interdependence graph.

Furthermore, the graph representation allows identifying concurrent and coupling interdependencies, discarding useless information such as in which cell potential concurrence events take place.

Moreover, finding connected components reduce the problem size respecting all the identified interdependencies. The partitioning of the system does not eliminate or add any solution, being the solution space after partitioning the problem the same as before. Furthermore, this partitioning on the mitigation phase allows finding better solutions in less time.

Finally, induced metrics such as the saturation level and the coupling level can be extracted from the intrinsic information encoded in the graph representation and used later by the mitigation tool. That is, saturation level will be a function of the number of aircraft occupying in a particular cell, in other words, this level will be the size of the potential conflict encoded by the node. The coupling level of one aircraft, which will be used as a weight in the objective function of the constraint programming model for the resolution phase, will be a function of the degree of the nodes where it passes and its path length.

Regarding future research, up to now, two different research topics that require further developed/ discussion were identified. First, the objective function of the mitigation tool, on which the output of the analysis based on graph theory is based, could be optimized. There should be found a metric that defines and calculates the weight distribution that can be used for the objective function and therefore guides the search. This parameter depends on the characteristics of the graph theory as for example the degree of the node, the size of the connected component, the length, the saturation level etc.

Furthermore, a criterion should be defined that clearly states how aircraft that cause a certain level of tightness are treated and delegated. As an example, either, special rules like relaxing the aircraft' domain could be applied for an aircraft that is imperiling the clearance or the identified aircraft could be delegated to ATC.

6. ACRONYMS

AC	Aircraft
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
AU	Airspace User
BFS	Breadth-First search
CASA	Computer Assisted Slot Allocation
CP	Constraint Programming
CSP	Constraint Satisfaction Problems
CTOT	Calculated-Take-Off Time
DFS	Depth-First Search algorithm
DST	Decision Support Tool
ECAC	European Civil Aviation Conference
FL	Flight Level
JSSP	Job Shop Scheduling Problem
TBO	Trajectory Based Operation
TTA	Target Time of Arrival
TTO	Time-To-Overfly
RBT	Reference Business Trajectory
STAM	Short Term ATFCM Measures
SWIM	System Wide Information Management
4DT	4-dimensional trajectories

ACKNOWLEDGMENTS

This research is supported by the European Union' s Horizon 2020 research and innovation program. The Project related to this research is PARTAKE "Cooperative departures for a competitive ATM network service" with Grant Agreement No. 699307. Opinions expressed in this paper reflect author's views only.

REFERENCES

Alphaaditya, Airspace classification - AviationKnowledge. Available at: http://aviationknowledge.wikidot.com/aviation:airspace-classification [Accessed July 14, 2017].

Barnier, N. & Allignol, C., 2008. Deconfliction with constraint programming. , p.pp xxxx. Available at: https://hal-enac.archives-ouvertes.fr/hal-00938416 [Accessed May 15, 2017].

Barnier, N. & Allignol, C., 2012. Trajectory deconfliction with constraint programming. , 27(3), pp.291–307. Available at: https://hal-enac.archives-ouvertes.fr/hal-00935206/document [Accessed April 23, 2017].

Chartrand, G. & Zhang, P., 2006. *Introduction to graph theory*, Tata McGraw-Hill Pub. Co.

Cook, A., 2007. *European air traffic management : principles, practice and research*, Available at: https://books.google.es/books/about/European_Air_Traffic_Management.html?id=vQ9LG6TWl9oC&redir_esc=y [Accessed May 11, 2017].

Envisa, 2017. Environmental Costs and Benefits of Ground Delay - Envisa - Aviation & Environmental Solutions. Available at: http://www.env-isa.com/en/expertise/environmental-costs-and-benefits-of-ground-delay-2/ [Accessed May 15, 2017].

Gibbons, A. (Alan M.., 1985. *Algorithmic graph theory*, Cambridge University Press.

IBM, 2015. *IBM ILOG CPLEX Optimization Studio OPL Language User's Manual*,

Nosedal, J. et al., 2014. An efficient algorithm for smoothing airspace congestion by fine-tuning take-off times. *Transportation Research Part C: Emerging Technologies*, 44, pp.171–184.

Schefers, N. et al., 2017. Causal Analysis of Airline Trajectory Preferences to Improve Airspace Capacity. *Procedia Computer Science*, 104, pp.321–328. Available at: http://www.sciencedirect.com/science/article/pii/S1877050917301424 [Accessed June 7, 2017].

Sesar, 2015. THE ROADMAP FOR DELIVERING HIGH PERFORMING AVIATION FOR EUROPE European ATM Master Plan. , Edition 20. Available at: http://ec.europa.eu/transport/modes/air/sesar/doc/eu-atm-master-plan-2015.pdf [Accessed July 18, 2016].

Trudeau, R.J. & Trudeau, R.J., 1993. *Introduction to graph theory*, Dover Pub. Available at: https://books.google.co.uk/books/about/Introduction_to_Graph_Theory.html?id=8nYH5OYEW24C&redir_esc=y [Accessed July 14, 2017].

APPLICATION OF DISCRETE-RATE BASED MESOSCOPIC SIMULATION MODELS FOR PRODUCTION AND LOGISTICS PLANNING

Tobias Reggelin[(a)], Christian Schauf[(b)], Sebastian Lang[(c)], David Weigert[(d)]

[(a),(c),(d)]Otto von Guericke University Magdeburg
[(b)]Volkswagen AG

[(a)]tobias.reggelin@ovgu.de, [(b)]christian.schauf@volkswagen.de, [(c)]sebastian.lang@ovgu.de
[(d)]david.weigert@ovgu.de

ABSTRACT
The paper describes and analyzes the application of mesoscopic discrete-rate based simulation models for production and logistics planning tasks in comparison with microscopic discrete-event simulation models. Mesoscopic models represent logistics flow processes on an aggregated level through piecewise constant flow rates by applying the discrete-rate simulation paradigm instead of modeling individual flow objects. This leads to a fast model creation and computation.

Keywords: Discrete Rate Simulation, Mesoscopic Simulation, Production and Logistics Planning

1. INTRODUCTION

The principles and tools of discrete-event simulation (Schriber and Brunner 2008; Banks 2005; Law and Kelton 2007; Kosturiak and Gregor 1995) are utilized to implement discrete models. Discrete-event simulation models are widely used for simulation modeling in manufacturing and logistics and state of the art in production planning and logistics planning in the automotive industry (Huber and Wenzel 2011). Production and logistics planners prefer to use discrete-event models since most of the logistics processes are discrete (Scholz-Reiter et al. 2007).
The term discrete-event modeling stands "for the modeling approach based on the concept of entities, resources and block charts describing entity flow and resource sharing" (Borshchev and Filippov 2004). Since discrete-event models are able to represent workstations, technical resources, carriers and units of goods as individual objects, they can depict production and logistics systems with a high level of detail and are also referred to as microscopic models (Borshchev and Filippov 2004, Pierreval et al. 2007). Models in this class can be very complicated and slow and their creation and implementation can be time and labor consuming (Pierreval et al. 2007; Law and Kelton 2007; Kosturiak and Gregor 1995; Huber and Dangelmaier 2009; Scholz-Reiter et al. 2008).
Plant Simulation is the standard tool in the German automotive industry for the development and application of discrete-event simulation models. A survey in a German automotive OEM with 29 participating production planners (Schauf 2016) shows that 96.6 % of the production planners consider the application of simulation models in the production planning process as 'absolutely necessary', 'very important' or 'important'. Only 3.4 % of the production planners answered that simulation modeling is not important for production planning. Production planners see the following requirements in the given order as most important for a simulation model to fulfil:

1. high quality of results,
2. quick provision of results,
3. transparency,
4. easy configuration of the simulation tool and simulation model, and
5. usability of tools and models for a production planner.

The reality though differs from the requirements and wishes of the production planners. Simulation projects to support production planning projects in the automotive industry often take quite a long time.
More than 60% of the simulation projects require more than a month and 30 % of the simulation projects even take more than six months (Schauf 2016). This contradicts the requirement of the production planners for a quick provision of the simulation results.
Problem formulation, system analysis, data collection and validation, conceptual modeling and model implementation together can require up to 85 % of the total time of a simulation project. Conducting and analyzing experiments often take less than 20 % of the total time of a simulation project. (Schauf 2016, Huber and Wenzel 2011)
One reason for long lasting simulation projects could be the application of discrete-event simulation models. Discrete-event models with a lot of entities flowing through the model or models with a too high level of detail can be associated with a high effort for modeling and computation of the model. (cf. Kuhn and Rabe 1998; Law and Kelton 2007; Feldmann and Reinhart 2000; Scholz-Reiter et al. 2008; Kosturiak and Gregor 1995).

A feasible approach to reduce the time for a simulation project is to apply simulation models with less level of detail. Reggelin (2011) and Reggelin and Tolujew (2011) describe a mesoscopic simulation approach to solve planning tasks in production and logistics systems which is based on the discrete-rate simulation paradigm (Krahl 2009, Damiron and Nastasi 2008).

A lower level of detail usually goes along with less accurate simulation results. The survey of Schauf (2016) asked the production planners which margin of error they are willing to accept, see Figure 1. The willingness to accept errors decreases with an increasing duration of a simulation project. Production planners are ready to accept errors of 5 % for simulation project which take less than a week. In simulation projects with a duration of more than six months they are willing to accept an error of about 1.5 %. These results could mean that production planners would accept to work with models which have not such a high level of detail but are capable of providing simulation results faster.

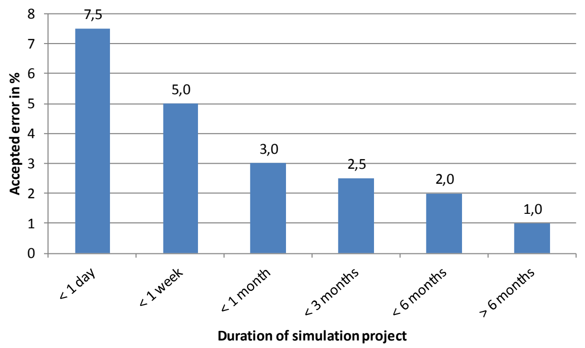


Figure 1: Accepted Errors by Production Planners in a Simulation Project (Schauf 2016)

Standard discrete-event simulation tools only support the creation of aggregated simulation models to a small degree. Simulation tools like ExtendSim (Damiron and Krahl 2014) and AnyLogic (Jain and Lechevalier 2016) easily allow the implementation of simulation models with different simulation paradigms within one model, like the combination of discrete-event elements and discrete-rate elements in ExtendSim in order to solve planning tasks in manufacturing and logistics.

However, simulation projects in the German automotive industry do not very often apply the simulation tools ExtendSim or AnyLogic. They mainly use the discrete-event simulation tool Plant Simulation. This is due to the fact that the material flow blocks of Plant Simulation allow for a very good representation of material flows in a manufacturing and logistics environment. Furthermore, the VDA Automotive Toolkit (Mayer and Pöge 2010) provides pre-build modeling blocks for the typical production and logistics processes in the body shop, paint shop, assembly and logistics in an automotive factory.

This paper describes and evaluates the application of a mesoscopic simulation approach based on the discrete-rate simulation paradigm for typical planning tasks in production and logistics systems, implemented with the simulation software ExtendSim. The modeling and computational effort and the accuracy of results of the mesoscopic discrete-rate based simulation models will be compared with discrete-event models for the same problem.

2. MESOSCOPIC MODELING AND SIMULATION APPROACH

The mesoscopic simulation approach proposed by the authors of this paper is situated between continuous and discrete-event approaches in terms of level of modeling detail and required modeling and simulation effort (Reggelin 2011). It supports quick and effective execution of analysis and planning tasks related to manufacturing and logistics networks. The principles of mesoscopic simulation models to describe processes in logistics and production networks have been derived from the actual development of several mesoscopic models (Hennies et al. 2014; Hennies et al. 2012; Tolujew et al. 2010; Schenk et al. 2009; Savrasov and Tolujew 2008; Tolujew and Alcala 2004).

Even when the term mesoscopic is not explicitly applied, a mesoscopic view often already exists from the start of production and logistics flow system modeling and simulation. Many practical production and logistics analysis and planning problems like capacity planning, dimensioning or throughput analysis describe performance requirements, resources and performance results in an aggregated form that corresponds to a mesoscopic view, see Figure 2.

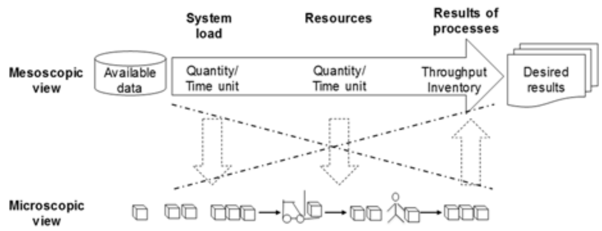


Figure 2: Mesoscopic and Microscopic Simulation Modeling Views

The basic idea of the mesoscopic approach is the direct and fast transformation of mesoscopic input data (performance requirements and resources) into mesoscopic performance results without the detour of object based event-driven process modeling. In order to fulfill the requirement of a quick provision of simulation results mesoscopic models employ a flow based approach for the direct computation on a mesoscopic aggregation level.

Mesoscopic models represent flow processes in production and logistics systems through piecewise constant flow rates. This assumption is valid since logistics flows do not change continuously over time. The control of resources is not carried out continuously but only at certain points of time like changes of shifts, falling below or exceeding inventory thresholds. The resulting linearity of the cumulative flows facilitates event scheduling and the use of mathematical formulas

for recalculating the system‘s state variables at every simulation time step.
The simulation time step is variable and the step size depends on the occurrence of scheduled events. This leads to a high computational performance. The principles of event-based computation of linear continuous processes are employed in the discrete-rate simulation paradigm implemented in the simulation software ExtendSim (Krahl 2009, Damiron and Nastasi 2008) and the hybrid simulation approach described by Kouikoglou and Phillis (2001).
However, a pure linear continuous representation of logistics flow processes is too abstract and aggregated for many analysis and planning tasks in production and logistics systems. Therefore, the mesoscopic modeling and simulation approach applied in this paper expands the event-based computation of linear continuous flow processes as described below. A more detailed description of the mesoscopic modeling and simulation approach can be found in Reggelin (2011) and in Reggelin and Tolujew (2011).

2.1. Mesoscopic Product Model

Since one single variable reproduces the flow between two nodes of a network structure in a flow-based model, a flow’s individual segments are neither identifiable nor traceable. Therefore, a mesoscopic model may employ different product types in parallel through all nodes and edges of the logistics network and in order to differentiate between flow objects with different characteristics. Features like resource consumption and required routes through the logistics network distinguish the individual product types from one another. Every product type is assigned to its own channel at the model’s components.
Furthermore, so-called product portions are introduced in order to sequentially differentiate a flow of a product type. Their number is specified during the conceptual modeling phase. Certain quantities of products, e.g. lot size, cargo size, number of goods in a shipment or number of people in a group, may be modeled as product portions. Thus, the path of individual product portions that may be spatially distributed throughout the network can be tracked and relevant events that may occur along this path can be captured.

2.2. Mesoscopic Process Model

In addition to piece-wise continuous flows (discrete-rate modeling), a mesoscopic model may employ impulse-like flows (object-based discrete-event modeling) to represent the flow of objects through a production or logistics system in order to increase the level of detail. Impulse-like flows allow to represent bundled movement of objects like bundled transports or the movement of production batches.

2.3. Mesoscopic Modeling Components

The mesoscopic model components allow to model the basic functions of a production and logistics system: transformation, storage and transportation. A mesoscopic model may employ the basic components of source, sink, funnel and delay to represent a material flow structure. Flows may be additionally modified with the components of assembly and disassembly. Multichannel funnels are a mesoscopic model‘s main components because they properly represent the processes of parallel or sequential processing and storage of several product types and product portions in a real area of operations. The use of a multichannel funnel as a mesoscopic model’s main component facilitates a straightforward modeling.

3. TYPICAL PLANNING TASKS IN PRODUCTION AND LOGISTICS SUPPORTED BY SIMULATION MODELING

Schauf (2016) also asked which tasks do production planners already solve or would like to solve with the help of simulation models in the future. The results are grouped into the typical applications of simulation modeling of systems in materials handling, logistics and production according to (VDI 2014) and depicted in Table 1. Furthermore, Table 1 shows whether or not mesoscopic discrete-rate based simulation models seem to be suitable to solve these analysis tasks.
Mesoscopic simulation models seem to be a possible choice for most of the typical planning tasks which planners already solve with the help of simulation modeling. However, they are not capable solving tasks that relate to the analysis of order sequences due to the fact that discrete-rate models cannot represent individual flow objects in a simulation model. Schauf (2016) analyzes more detailed the suitability of the mesoscopic simulation approach for typical tasks of a production planner.
Even when almost 97 % of the asked production planers stated that simulation modeling is ‘absolutely necessary’, ‘very important’ or ‘important’ (see section above), the application and planned application of simulation modeling seems to fall behind this figure. One reason as already mentioned above could be the gap between the desired quick provision of results and the often long durations of a simulation project. The next section describes which advantages the use of mesoscopic discrete-rate based simulation models can have in terms of duration of a simulation study by applying the approach for three typical tasks of a production planner.

4. APPLICATION AND EVELUATION OF MESOSCOPIC SIMULATION MODELS

This section compares the application of mesoscopic discrete-rate based simulation models with discrete-event simulation models in terms of duration of a simulation study and deviation in results by applying these two modeling paradigms for three typical tasks of a production planner:

1. Determination of the number of load handling devices for a an assembly line
2. Verifying the throughput of a final assembly

3. Verifying performance of the goods receiving processes of an assembly plant.

Table 1: Fields of Analysis in Production and Logistics Planning and Use of Simulation Models

	Already use simulation modeling	Plan to use simulation modeling in the future	Mesoscopic discrete rate based simulation model suitable?
Order sequences	8 %	14 %	no
Throughput	15 %	11%	yes
Management Strategies	11 %	18 %	yes
Verifying function and performance	11 %	18 %	partly
Dimensioning	30 %	18 %	partly
Performance limits	2 %	4 %	yes
Bottlenecks	5 %	4 %	partly
Examination of variants	9 %	7 %	party

The authors chose ExtendSim to implement the mesoscopic simulation models, since ExtendSim facilitates combining discrete-rate model elements and discrete-event model elements by using the Rate library and the Item library within one model. Furthermore, the Rate library supports a close modeling of the mesoscopic modeling elements described in the section before.

4.1. Determination of the Number of Load Handling Devices for an Assembly Line

A typical task for a production and logistics planner is to determine the required number of resources for a process. Already 30 % of the asked production planners use simulation modelling for this task, see Table 1. In this example, the planner has to determine the number of load handling devices that need to be provided for a total of five sections of an assembly line. Figure 3 depicts the mesoscopic discrete-rate based simulation model to solve this task. The model mainly comprises the blue Rate Library blocks and the yellow Value Library blocks.

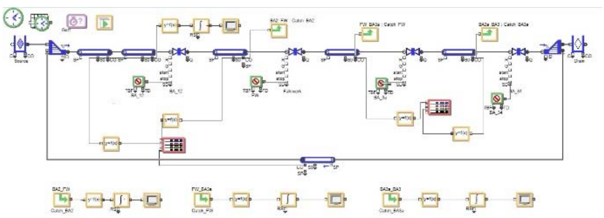


Figure 3: Mesoscopic Simulation Model in ExtendSim based on Rate Library and Value Library Blocks for Determining the Number of Load Handling Devices for an Assembly line

The model was compared to a discrete-event model implemented with the Plant Simulation VDA toolkit. Table 2 shows the comparison of results and simulation run time. The deviation of the results of the mesoscopic simulation model compared to the discrete-event model is about 1 % and lies within the accepted margin of error of the interviewed production planners (see Figure 1). The use of the discrete-rate based model leads to an enormous reduction of simulation runtime. Furthermore, the modeling effort for the discrete-rate based model is also lower than for the discrete-event model. That implicates that mesoscopic discrete-rate based simulation models could be a good alternative for a production planner to get quick planning results in a sufficient quality.

Table 2: Comparison of Simulation Effort and Results for the Microscopic and Mesoscopic Simulation Model

	Number of required load handling devices	Deviation of result	Duration of a simulation run
Microscopic discrete-event model with VDA toolkit in Plant Simulation	417	0 %	720 minutes
Mesoscopic discrete-rate model with own toolkit in ExtendSim	421	1 %	1 minute

4.2. Verifying the Throughput of a Final Assembly

For the same assembly line that was analyzed in the section before, the task of the production planner was to verify that the final assembly can guarantee a throughput of 60 products per hour. For this tasks the simulation model shown in Figure 3 was modified to solve this task and then compared to a discrete-event model implemented with the Plant Simulation VDA toolkit. Table 3 shows the results of the comparison.

Table 3: Comparison of Simulation Effort and Results for the Microscopic and Mesoscopic Simulation Model

	Output per hour	Deviation of result	Duration of a simulation run
Microscopic discrete-event model with VDA toolkit in Plant Simulation	60.02	0 %	103 minutes
Mesoscopic discrete-rate model with own toolkit in ExtendSim	60.14	0.2 %	0.04 minutes

The comparison shows that margin of error with about 0.2 % lies within the accepted margin of error of the interviewed production planners (see Figure 1) and the use of a mesoscopic discrete-rate based simulation model gains a huge reduction in simulation runtime and also helps to reduce the time required for building the model.

4.3. Verifying Performance of the Goods Receiving Processes of an Assembly Plant

The task of the planer was to verify that the throughput of the receiving process of an assembly plant meets the required performance. Figure 4 shows the main processes of the goods receiving department. Between 6:00 a.m. and 11:30 p.m., one to three trucks arrive at the goods receiving department every half an hour and will be allocated to one of the three unloading gates. The number of loading units on each truck depends on the type of loaded products. A truck has loaded one loading unit up to 90 loading units. After the quality check, the loading unit have to be transported by forklifts to sort lanes. The storage process can only be started, if all loading units of a truck are sorted in the corresponding sort lanes.

Figure 4: Goods Receiving Process of an Assembly Plant

The main challenge for mesoscopicly modeling the logistics processes is to determine which processes can be aggregated to the discrete-rate paradigm in a reasonable way (transforming single process durations into flow rates) and which processes need to be modeled object-based with the discrete-event simulation paradigm. Figure 5 presents the conceptual mesoscopic simulation model with a combination of discrete-rate and discrete-event processes.

The created entities in process stage I represent arriving trucks in the goods receiving department. Every entity has an attribute, which represents the number of loaded units on the truck. After going through one of the three preparation processes, entities move into the corresponding interchange block, which symbolizes a gate for unloading. In the gate, the attribute of the entity is transformed into a discrete-rate stock to model the unloading process. The unloading work cycles with a forklift are aggregated to a rate process by taking into account the process times for all work cycles to unload one truck, depending on the current number of allocated forklifts to the process, the speed, loading capacity, loading and unloading time of each forklift, the average stacking time for each loading unit, the distance between gate and buffer zone, and the number of loading units in the truck. After a truck is unloaded, it goes through the follow-up process, before it leaves the system and unblocks the gate for the following trucks.

For the quality check, the discrete-rate stock in the buffer area will be retransformed into an attribute of a discrete-event entity. The reason for this is that in the real system a restriction exists, which postulates that loading units of a truck load are only allowed to be sorted, if all of them pass the quality check. Therefore it is possible to save more computational and modelling effort, if only one entity is processed instead of applying a complex rate equation.

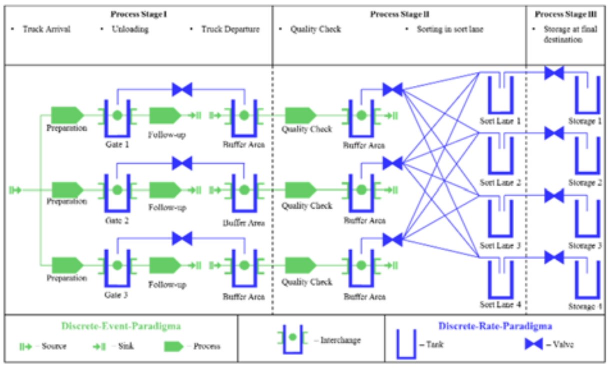


Figure 5: Conceptual Mesoscopic Simulation Model with Discrete-rate and Discrete-event Processes in the ExtendSim Notation

The runtime of the mesoscopic model is nearly 87 % lower (see Table 4) compared to the microscopic model. In terms of the queue length in front of the gates and the daily system throughput of loading units, there are only slight deviations between the mesoscopic and microscopic simulation models.

Table 4: Comparison of the Simulation Results of the Mesoscopic and Microscopic Model

	Throughput (loading units/day)	Max. queue length in front of gates (trucks)	Duration of a simulation run
Microscopic discrete-event model with VDA toolkit in Plant Simulation	3,445	3	201 seconds
Mesoscopic discrete-rate model in ExtendSim	3,464	3	27 seconds

5. CONCLUSION

The results of the simulation experiments show that mesoscopic simulation models based on the discrete-rate simulation paradigm are capable to support planning tasks in production and logistics systems. For several typical planning tasks, their results differ only slightly from the results of a discrete-event simulation model. The results deviation stays within a margin that is accepted by production planners.

Mesoscopic simulation models can save enormous amounts of modeling and computational time compared to discrete-event models and thus comply with the requirements of production planners to receive simulation results within a short period of time.

REFERENCES

Banks, J., J. S. Carson, B. L. Nelson, and D. M. Nicol. 2005. Discrete-Event System Simulation. 4rd ed. Upper Saddle River, New Jersey: Prentice-Hall, Inc.

Borshchev, A., and A. Filippov. 2004. "From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools". In Proceedings of the 22nd International Conference of the System Dynamics Society, edited by M. Kennedy, G. W. Winch, R. S. Langer, J. I. Rowe, and J. M. Yanni. Oxford.

Damiron, C., and D. Krahl. 2014. "A Global Approach for Discrete Rate Simulation". In Proceedings of the 2014 Winter Simulation Conference, edited by A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, 2966–2977. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Damiron, C., and A. Nastasi. 2008. "Discrete Rate Simulation Using Linear Programming". In Proceedings of the 2008 Winter Simulation Conference, edited by S. J. Mason, R. R. Hill, L. Moench, O. Rose, T. Jefferson, and J. W. Fowler, 740–749. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Feldmann, K., and G. Reinhart. 2000. Simulationsbasierte Planungssysteme für Organisation und Produktion. 1st ed. Berlin: Springer.

Hennies, T., T. Reggelin, and J. Tolujew. 2012. "Mesoscopic Supply Chain Simulation". In Proceedings of the international Conference on Harbour, Maritime and Multimodal Logistics Modelling and Simulation, edited by A. G. Bruzzone, M. Gronalt, Y. Merkuryev, M. A. Piera, and W. Talley, 85–90. Vienna: International Multidisciplinary Modeling and Simulation Multiconference, I3M.

Hennies, T., T. Reggelin, J. Tolujew, and P.-A. Piccut. 2014. "Mesoscopic supply chain simulation". In Journal of computational science 5 (3), 463–470. Amsterdam: Elsevier.

Huber, D., and W. Dangelmaier. 2009. "Controlled Simplification of Material Flow Simulation Models". In Proceedings of the 2009 Winter Simulation Conference, edited by M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin, and R. G. Ingalls, 839–850. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Huber, L., and S. Wenzel. 2011. "Trends und Handlungsbedarfe der Ablaufsimulation in der Automobilindustrie". In: Industrie Management 27 (5), 27–30. Berlin: GITO-Verlag.

Jain, S., and D. Lechevalier. 2016. "Standards based Generation of a Virtual Factory Model". In Proceedings of the 2016 Winter Simulation Conference, edited by T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, 2762–2773. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Kosturiak, J., and M. Gregor. 1995. Simulation von Produktionssystemen. 1st ed. Wien: Springer.

Krahl, D. 2009. "ExtendSim Advanced Technology: Discrete Rate Simulation". In Proceedings of the 2009 Winter Simulation Conference, edited by M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin, and R. G. Ingalls, 333–338. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Kuhn, A., and M. Rabe. 1998. Simulation in Produktion und Logistik, 1st ed. Berlin: Springer.

Kouikoglou, V. S., and Y. A. Phillis. 2001. Hybrid simulation models of production networks. New York: Kluwer Academic Plenum Publishers.

Law, A. M., and W. D. Kelton. 2007. Simulation Modeling and Analysis. 4rd ed. Boston: McGraw-Hill, Inc.

Mayer, G., and C. Pöge. 2010. "Auf dem Weg zum Standard – Von der Idee zur Umsetzung des VDA Automotive Bausteinkastens". In Integrationsaspekte der Simulation: Technik, Organisation und Personal, 29-36. Karlsruhe: KIT Scientific Publishing.

Pierreval, H., R. Bruniaux, and C. Caux. 2007. "A Continuous Simulation Approach for Supply Chains in the Automotive Industry". In Simulation Modelling Practice and Theory 15 (2), 185–198. Amsterdam: Elsevier.

Reggelin, T. 2011. "Mesoskopische Modellierung und Simulation Logistischer Flusssysteme". Ph.D. thesis, Institute of Logistics and Material Handling Systems, Otto-von-Guericke-Universität, Magdeburg, Saxony-Anhalt.

Reggelin, T., and J. Tolujew. 2011. "A Mesoscopic Approach to Modeling and Simulation of Logistics Processes". In Proceedings of the 2011 Winter Simulation Conference, edited by S. Jain, R. R. Creasey, J. Himmelspach, K. P. White, and M. Fu, 1508–1518. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Savrasov, M., and J. Tolujew. 2008. "Mesoscopic Approach to Modeling a Traffic System". In: International Conference Modelling of Business, Industrial and Transport Systems, edited by E. Kopytov, H. Pranevicius, E. Zavadskas, and I. Yatskiv, 147–151. Riga: Transport and Telecommunication Institute.

Schauf, C. 2016. "Anforderungen von Produktionsplanern an die Simulation – Discrete-Rate Simulation als Ergänzung zur ereignisdiskreten Simulation in der Produktionsplanung?". In Schenk, M. (Hrsg.) 21. Magdeburger Logistiktage »Logistik neu denken und gestalten«, edited by M. Schenk, 141–148. Magdeburg: Fraunhofer IFF.

Schenk, M., J. Tolujew, and T. Reggelin. 2009. “Mesoscopic modeling and simulation of logistics networks”. In IFAC Proceedings Volumes 42 (4), 582-587. Amsterdam: Elsevier.

Scholz-Reiter, B., F. Wirth, M. Freitag, S. Dashkovskiy, J. Jagalski, C. de Beer, and B. Rüffer. 2007. “Mathematical Models of Autonomous Logistic Processes”. In Understanding Autonomous Cooperation and Control in Logistics – The Impact of Autonomy on Mananagement, Information, Communication and Material Flow, edited by M. Hülsmann, and K. Windt, 121–138. Berlin: Springer.

Scholz-Reiter, B., C. de Beer, M. Freitag, T. Hamann, H. Rekersbrink, and J. T. Tervo. 2008. “Dynamik logistischer Systeme”. In Beiträge zu einer Theorie der Logistik, edited by P. Nyhuis, 109–138. Berlin: Springer.

Schriber, T. J., and D. T. Brunner. 2008. “Inside Discrete-Event Simulation Software: How it Works and Why it Matters”. In Proceedings of the 2008 Winter Simulation Conference, edited by S. J. Mason, R. R. Hill, L. Moench, O. Rose, T. Jefferson, and J. W. Fowler, 182–192. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Tolujew, J., and F. Alcala. 2004. “A Mesoscopic Approach to Modeling and Simulation of Pedestrian Flows”. In Proceedings of the 18th European Simulation Multiconference, edited by G. Horton, 123–128. Ghent: SCS International.

Tolujew, J., T. Reggelin, and A. Kaiser. 2010. “Discrete Rate Simulation als grundlegendes Paradigma bei der Entwicklung von mesoskopischen Flussmodellen“ In Integrationsaspekte der Simulation: Technik, Organisation und Personal. Karlsruhe : KIT Scientific Publ., 437-444. (ASIM-Mitteilung; AM 131).

VDI 3633- Blatt 1. 2014. Simulation von Logistik-, Materialfluss- und Produktionssystemen – Blatt 1: Grundlagen. Berlin: Beuth Verlag.

RAILWAY PLANNING: AN INTEGRATED APPROACH USING DISCRETE EVENT SIMULATION

Carlos Henrique Fernandes de Faria[(a)], Marta Monteiro da Costa Cruz[(b]

[(a)]Federal University of Minas Gerais
[(b)]Federal University of Espirito Santo

[(a)]chfaria86@hotmail.com, [(b)]marta.cruz@ufes.br

ABSTRACT
In this paper, a discrete event simulator of a heavy haul railway, developed as an integrated tool for supporting operational, tactical and strategic planning, is presented. For operational planning, a better scenario for maintenance tracks, using the same stoppage time, is defined. For tactical planning, the capacity of two-track circulation lines is analyzed, considering real capacity for the year of 2016. Finally, an increase in railway capacity utilization is planned, considering a scenario with a higher number of cars with duplicated rail lines for strategic planning. The simulation tool was previously verified and validated with real data presenting an error inferior to 5% in results for all planning areas.

Keywords: Capacity; Railway; Simulation; Planning

1. INTRODUCTION

The proposed research deals with discrete event simulation in the three scopes of planning in a supply chain: strategic, tactical and operational. It is important to note that many complex systems have already been detailed and studied only with the use of discrete event simulation. For example, the dependencies between the performance of the supply chain and the ruptures of the stock were analyzed (Cigolini 2014). Another example is the study of logistic chains of iron ore and general cargo with modeling starting with the design of the product in the cargo terminals, the transportation via modal rail and the unloading in the port for ship loading (Faria 2015).

Other issues, however, can be solved through robust optimizations with multiple applications. First is the tactical planning of the supply chain (Almeida 2015). Another is the operational planning of iron ore mining (Pinto 2001). Moreover, there are the mathematical models assigned as independent sub-systems within an integrated system to determine optimal levels of inventory and costs and investments (Tsai 2013). There are also some studies that evaluate the supply chain in a centralized and decentralized way through the so-called "interactive agents" (Macal and North 2014).

The simulation, although not aimed at optimizing the obtained results, is able to represent in detail a real system, identifying problems, bottlenecks and deficiencies through the evaluation of scenarios based on deterministic or stochastic parameters (Banks 2014).

Heavy haul railways carry large volumes of loads and seek to use the maximum available capacity of the rail system to obtain scale economy. This type of rail is typically used for commodities such as minerals, coal, among others.

A railway can be characterized as a closed circuit in order to connect the load source and destination, which is usually a port or an industry, and is composed by multi-locomotive heavy haul trains (Zhuan and Xia 2008). A closed loop system is the interaction between a (open loop) system and a controller that checks and supervises the deviation of a variable from a target. Its scheme is defined as a multiple open loop with memory, repeatedly implementing control measures, computing each time based on the current traffic state and the actions taken in the past (Corman and Quaglietta 2015).

Railway capacity is frequently evaluated. At a given moment, however, its capacity may be resized and aligned to long term demand analysis. Heavy haul railways are capital intensive systems which require robust methods that simultaneously encompass interactions on operational, tactical and strategic levels.

The current study describes an innovative method for strategic capacity of railway planning, considering tactical and operational decisions. A discrete event simulation model was developed, encompassing general features of such systems. To demonstrate its functionality, the model was used to support strategic capacity planning on heavy haul railways of Vale (a multinational corporation engaged in mining and logistics) located in different continents: Vitória-Minas, Carajás (South America) and Nacala (Africa). An in depth a case study conducted on the Vitória-Minas Railway (VMR) railway is described.

The Vitória-Minas Railway (VMR) is one of the world's major heavy haul railways, with one of the world's highest productivity levels. Spanning 905 kilometers in total length, this system connects the iron ore mines in the state of Minas Gerais to the Port of Tubarão in the state of Espírito Santo, Brazil. The VMR also transports coal, general cargo and passengers. The

VMR has a two-way track railway, a denominated trunk line, and four single-track branches. Studies and analyses have been conducted using mathematical or analytical models with limited scope. However, they do not encompass the global effect of the logistics chain.
Using concepts described in Crainic and Laporte (1997) a discrete event simulation model was developed using Arena®. The model represents the closed-loop iron ore rail transportation and enables the analysis of important variables when facing an increase in capacity transportation in VMR. In addition, the model includes operational and tactical decisions. It enables short-term analysis, such as the daily maintenance of the railway, port facilities and loading terminal operations and medium-term planning issues such as rail capacity.
This paper is organized as follows: in section 2 the literature of strategic, tactical and operational planning on heavy haul railways is revisited. Then, in section 3 the developed methodology using discrete event simulation is described. In section 4 a case study is presented on VMR. The results are presented in section 5, preceding the conclusion.

2. METHODS

Simulation studies in the railway sector are not new, since the use of this technique provides great security in supporting investment decisions, which are usually substantial.
Extensive literature is available on models and algorithms for railway simulations. The use of discrete event simulation in railway dynamics is a widespread tool. Currently there are many others that can be used in this area. Here the most relevant works for our research and those used to develop the VMR simulator are presented. The research conducted by some authors (Cordeau et. al. 1998), (Crainic and Laporte 1997) (Fogliatti et al. 2007) (Kamrani et al. 2014) brings a comprehensive review of major studies related to optimization, sequencing and planning, with main focus on railways.
The use of simulation to support investment decisions has been used since the 90s in North American and European railways companies, where the railways have great influence (Lewellen and Tumay 1998) and (Hooghiemstra and Teunisse 1998). The evolution of simulation software has increased since then. It can be noticed that there is a group of specialized software for railways like SIMPROCESS (Swegles 1997) (Dalal and Jensen 2001), RailSys (Anand and Anayi 2010), SIMUL8 (Marinov 2009) (Wales 2015), SIMONE (Middelkoop and Bouwman 2011), OpenTrack (Nash and Huerlimann 2004) and ROMA (Corman and Quaglietta 2015). In addition, general software is used for rail purposes. Arena software has been used for many different applications but also in rails (Bontekoning 2006) (Faria 2016) (Fioroni et. al. 2008) (Meireles 2010). Although Arena is not a specific package for railways, it has a variety of features that allow its use in different railway analyses or in specific studies in rail yards (Sinay et. al. 2008) (Abbot and Marinov 2014) (Ricci 2016) or in studies of other areas (Pinto 2015) (Ceciliano 2007). However, such studies of rail yards are conducted with a high level of abstraction, since their activities are operational and require a careful study of processes involving the system to determine its routine work.
Joborn et al. (2004) divides planning into three levels: strategic (long term), tactical (medium term) and operational (short term). The developed simulator is a tool aimed to support decisions in these three areas of planning.
The analysis carried out in each of these levels can be summarized as described below:

- Strategic analysis: some indicators provided by the simulator served as guidelines for the long-run planning sector. The objective is to plot strategic plans such as: viewing track network projects; expanding, doubling or tripling stretches; insertion of new dumpers in the discharge at the port or new loading silos in the mines and location of facilities (terminals, workshops, among others); the acquisition of resources, such as locomotives and wagons; improved asset productivity; and even pricing policies.
- Tactical analysis: at this level, the specifics of policies and operational assumptions are generally updated on a monthly basis and with a one-year horizon maximum. The simulator makes it possible to establish the efficient allocation and use of resources to enable better system performance, since it details the premises used.
- Operational analysis: in the short-run planning, the simulator is able to quickly and accurately respond “what if?” everyday questions. In other words, it is possible to test the effects of transportation of iron ore, passengers or general cargo on the supply chain, when, for instance, there is a scheduled maintenance in the port and in mining equipment, or when there is a railway accident, or an unscheduled interdiction on railway, among others.

For the case study in question, a computer model of the chain logistics from the loading terminals or mines to the port (Tubarão Port) was built. These points were interconnected by the railway (VMR). The methodology for developing simulation projects for discrete events that was used is found in Banks et al. (2000). The concept of developed templates (Abbott and Marinov 2014) was also used, applying the tool: Software Arena.

3. CASE STUDY

VMR is a heavy haul railway with a daily distribution of close to 106 trains. For this cargo volume, it is necessary to have train schedule management in order to reduce as many delays as possible on the railway line in maneuver yards, loading terminals and unloading trains. As shown by Crainic and Laporte (1997), rail planning must encompass three main levels: strategic (long term), tactical (medium term) and operational (short term). All of these have planning levels of specific goals according to modelling analyses, however, there is a limitation when it comes to the formulations of interconnected models. For example, a strategic location model will hardly offer responses to the required volume for a daily train schedule.

Due to the progress in simulation models, these merging models are becoming increasingly possible to be built. The simulator presented here has the feature of simultaneously joining these three levels considering the operation of the railroad as a whole.

The conceptual model developed based on the diagram is shown in Figure 1.

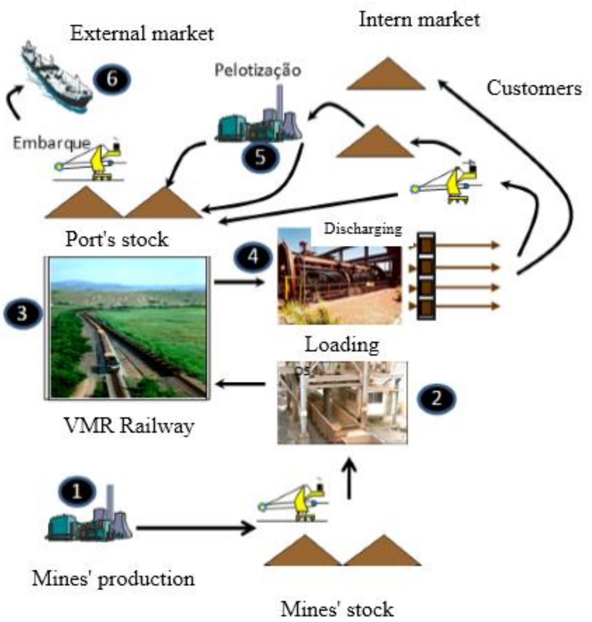


Figure 1: Scope of the implemented model

Regarding the distribution of empty lots that leave Port of Tubarão heading for the mines, their allocation was based on the availability and performance of the loading points. This allocation is performed at the OCC and is based on mine schedules. An algorithm was required to best represent these distributions. Its development may be summarized as follows: the step 1, the loading points request the loading of iron ore for external and internal markets and the step 2, a decision-making algorithm is used to analyze the distribution based on six sequential priority evaluations:

- Evaluation 1 (Distribution on the branch line): As previously mentioned, the VMR contains four branch lines where the loading points are concentrated. The algorithm determines which branch line has the greatest delay in relation to the schedule and allocates a distribution to balance the service percentage.
- Evaluation 2 (Maximum amount allocated by loading stretch): The algorithm determines the maximum amount of lots each branch line is capable of receiving.
- Evaluation 3 (Maximum queues per loading point): The algorithm determines the maximum number of empty lots that can be allocated to a given loading point.
- Evaluation 4 (Preventive and corrective maintenance): Preventive and corrective maintenance limits the receiving of empty lots on the branch lines in evaluations 2 and 3.
- Evaluation 5 (Assessment of the loading point): The lots are distributed as a function of the service percentage at the most-delayed loading point (summing the external and internal markets).
- Evaluation 6 (Identification of loads headed for internal or external markets from the loading point): The algorithm follows the same logic by evaluating the service percentage in following the schedule and by assigning priority to the internal market and to whichever destination is the most delayed.

4. ANALYSIS AND RESULTS

As previously mentioned, there were several planning analysis at three levels: operational (short term), tactical (medium term) and strategic (long term) using the discrete event simulator developed. The goal is to justify the importance of applying this tool to support decision-making in different areas.

An important process while developing a simulation model is the calibration and acceptance of the developed models (Marinov 2009). Those can be obtained by two distinguished ways: by the comparison between real and achieved results or by using analytical techniques when not possible to get operational data.

All analyses described below were performed using an Intel® Core ™ i7-5600U CPU@2.60 GHz computer with 4.00 GB (RAM) on a 64-bit operational system. Furthermore, the size of the simulation has spin duration of one year, with a number of 50 replicates and warm-up set to ten days. On average, the processing time of these simulation rounds are close to ten minutes.

4.1. The operational planning:

The simulator is capable of responding fast and accurately to "what if" questions. It is possible to test the effects of the iron ore on the logistic chain when, for instance, a port or a machine has planned maintenance, or some railway accident happens. It is also possible to test the best way to dissipate a "blister effect" caused by an event or by the increase of unavailable wagons in the system.

One of the objects of analysis of the model developed in the short-term is daily maintenance planning. The planning of preventive maintenance of a permanent route is essential to eliminate and avoid errors or alterations that could affect the performance of the rail network.

Thus, the developed mesh simulator is able to assist the operational planning area, or short-term view, considering the frequency of trains circulating in determined stretches, with their peculiarities, such as the best time and duration of permanent way maintenance tracks, with regard to the impacts on capacity and average transit time.

For this purpose, a VMR mesh section divided into single and double stretches, called BH Branch, is analyzed. It can be seen in the following Figure 2:

Figure 2: BH Branch layout

For this analysis, the hypothetical frequency of iron ore, passenger and general cargo trains were inserted. The impact on the transit time variables and maximum capacity of BH Extension was found by varying the pathway where maintenance could be performed, but values for monthly total stoppage time, i.e were kept the same.

- Scenario 1: four weekly track maintenances with duration of six hours.
- Scenario 2: three weekly track maintenances with duration of eight hours.
- Scenario 3: two weekly track maintenances with duration of twelve hours.

The detailed information about the results obtained from the scenarios described above is presented in the following Table 1 and Table 2:

Table 1: Single Line Table Caption

Variable (average)	Weekly tracks maintenances		
	Scenario 1	Scenario 2	Scenario 3
Lots/day: iron ore	24,64	24,38	24,31
Trains/day: iron ore	11,40	11,31	11,27
Cycle: iron ore	8,14	8,23	8,34

Table 2: Average trains/day pairs (iron ore, general cargo and passengers) – BH Branch with maintenances

Local	Weekly tracks maintenances		
	Scenario 1	Scenario 2	Scenario 3
Yard VP8	24,76	24,61	24,61
Stretch VP8_VP7A	24,76	24,61	24,61
Yard VP7A	24,76	24,61	24,61
Stretch VP7A_VP7	21,69	21,55	21,59
Yard VP7	18,62	18,48	18,56
Stretch VP7_VP6	18,62	18,48	18,57
Yard VP6	18,62	18,48	18,57
Stretch VP6_VP5	17,82	17,68	17,73
Yard VP5	17,01	16,87	16,90
Stretch VP5_VP4	17,01	16,87	16,90
Yard VP4	17,01	13,24	13,29
Stretch VP4_VP3	13,32	13,24	13,29
Yard VP3	13,32	13,24	13,29
Stretch VP3_VP2	13,32	13,24	13,29
Yard VP2	13,32	13,24	13,29

According to these outputs, it is possible to conclude that the performance of four weekly permanent road track maintenances, each one lasting 6 hours, allows a greater implementation of the volume of iron ore with a smaller cycle. Besides, it brings a larger railway capacity in pairs of trains per day.

Yet, analyzing the main indicators (average lots/day and average cycle of iron ore), there were statistical parameters to validate the data of completed replication and considering a 90% confidence interval, these are stable and representative, Table 3 and Table 4.

Table 3: Analysis of statistical parameters of the variable “average lots/day” of iron ore

Parameter	Weekly tracks maintenances		
	Scenario 1	Scenario 2	Scenario 3
Lower Control Limit	25,56	25,56	25,30
Upper Control Limit	23,74	23,21	23,32
Standard deviation	1,03	1,33	1,12
Average	24,65	24,38	24,31
Error	3,70%	4,83%	4,08%

Table 4: Analysis of statistical parameters of the variable "cycle" of iron ore

Parameter	Weekly tracks maintenances		
	Scenario 1	Scenario 2	Scenario 3
Lower control limit	8,35	8,45	8,54
Upper control limit	7,94	8,00	8,13
Standard deviation	0,24	0,26	0,23
Average	8,14	8,23	8,34
Error	2,58%	2,76%	2,48%

4.2. Tactical planning

The annual budget cycle is performed based on the results of the scenario generated by the simulator. Some pointers are given with high details, such as the cycles at the loading points, the Port cycle and the equipment's indicators (physical availability, utilization and effective rate). These pointers will be practical guidelines for the medium term planning sector to use them for more effective use of available resources.

One of the applications of the simulator in medium term decisions is by defining railway capacity. This is analyzed by the current operating characteristics such as the transit time, the definition of permanent line track maintenances, the unavailability of the network, the licensing times for trains, among others. To demonstrate the applicability of the simulator at the tactical level, an analysis of the division capacity of single parts and duplicate parts will be performed.

4.2.1. Analysis of the capacity of two-track circulation lines

For this analysis, a random section where the railway is doubled was selected to verify the dynamic capacity generated by the simulator when setting up the operating efficiency factor (k). It was emphasized that all data inputs were obtained using National Land Transport Agency ANTT Network Statement (ANTT 2016). The capacity results obtained by simulation were compared to ANTT Network Statement in order to verify the adherence of the model.

The following analysis includes the evaluation of the Resplendor railway section. For these capacity analyses of the two-track lines the following parameters are used as simulation assumptions, Table 5:

Table 5: Simulation assumptions of two-track lines analyses

Variable	Values	Unit
Number of replications	100	unit.
Duration of replications	30	day
Statistical distribution: iron ore train starting	Normal (32,4)	minute
Statistical distribution: general cargo train starting	Normal (2.18,0.22)	hour
Statistical distribution: passenger train starting	Uniform (1)	day

The Table 6 presents the main data obtained from the simulation model. Considering a 95% confidence interval, it is noted that the simulated outputs of the variable railway capacity present an accuracy of 0.53, a standard deviation of 0.41 and an error 1.31% margin. That is, such parameters indicate a proper statistical variability of the results of this simulation model.

Table 6: Outputs simulation – Resplendor railway section

Variable	Simulated outputs	Unit
Annual capacity	209,32	millions of tons
Total empty trains	1.177,98	unit
Total loaded trains	1.196,23	unit
Trains/day	40,57	pair
Operational efficiency	63,03	%
Coefficient *k*	96,15	%
Transit time: empty trains	2,60	hour
Transit time: loaded trains	2,69	hour
Speed of empty trains	25,97	km/h
Speed of loaded trains	25,09	km/h

4.3. The strategic planning

According to Crainic (1997), to increase long-term volume within 5 to 10 years, investments will be necessary in order to expand system capacity. These can be the need of duplicating or triplicating the existing lines, a new car dumper to the Port, a new silo at the loading station, or an alternative to improve productivity such as increased number of wagons for trains and increased average weight at the loading station, among many other possible alternatives. Besides, some indicators given by simulated outputs such as the total cycle, the Port unloading cycle and needed GDE lots will be the guidelines for the long term planning sector to siege the need of multiannual rolling stock. The simulator also provides the average

queue generated with the system, therefore making it easier to verify possible bottleneck points as well as critical points. Using this, investment possibilities must be proposed by the analyst based on generated outputs and global links at the logistic chain.
To analyze the VMR logistics chain, rounds of simulations were held in order to verify the impacts on the main rail indicators. This was compared by changing the number of wagons for the transport of ore and by altering assumptions related to the Port of Tubarão.

4.3.1. The impact of the change in the number of cars on the system

In this item, the impact of the change in the number of freight wagons for the transport of iron ore in VMR is verified by the main indicators which are calculated in the simulation model.
The below Figure 3 presents the impact of the increase in the number of GDE's wagons (horizontal axis), responsible for transporting iron ore, in compliance with the volume and wagons cycle (time for the wagon to complete a full cycle: Port - Mine - Port).
These indicators are fundamental for the design of rolling stock, mainly in the strategic horizon or long-term. In the simulation model, a "target" volume is inserted (red line in Figure 2), i.e. the volume (relative to an interval of four months) that is expected to be completed during replication scenarios (number of GDE's wagons: "X axis").

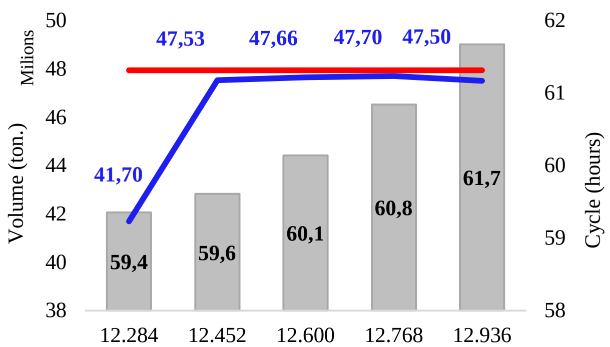


Figure 2: Volume influence of the system cycle

This analysis verifies that for the variable "volume" (blue line in the graph), the more wagons inserted in the railway, the closer the line gets to "target" volume, but the wagons cycle inceases (gray bars in Figure 2).
However, it must be noted that from the scenario of 12.768 wagons, even when more wagons are inserted, the volume doesn't change. The same does not occur with wagon cycle, which increases considerably over the scenarios.
Thus, one can conclude that the bottleneck to achieve the "target" volume is not the shortage of rolling stock. Therefore, 12.768 GDE's wagons would be the ideal number to carry out the transportation of iron ore, once it reaches 99.5% by volume. This type of analysis is essential to assist the strategic areas in verifying the amount of assets required for the implementation of the long-term projected volume.

4.3.2. Increased capacity with the duplication of single parts

The increase of transportation demand over the years may result in a rail capacity deficit and thus disable the growth in transported volume. Therefore, the long-term planning area is responsible for envisioning increasing capacity over the years.
It is said that some investment projects are strategic, such as the expansion of patios where long trains are not able to make the crossing with other trains. The construction of new crossing yards at points where there is a "bottleneck" in the rail network improves the permanent path, allowing an increase in speed and, consequently, reduces the transit time between consecutive sections. Doubling single portions is also an alternative for increasing railway capacity.
A comparison analysis was carried out to estimate what would be the ability to increase the BH Branch stretch to duplicate it fully (Hypothetical scenario) at the expense of current installed capacity, as shown in Table 7 and Table 8.

Table 7: Comparison of Current scenario versus BH branch duplicated scenario

Variable (average)	Current scenario	Hypothetical scenario
Lots/day: iron ore	24,64	26,20
Trains/day: iron ore	11,40	12,16
Cycle: iron ore	8,14	8,88

Table 8: Comparison of Current scenario versus BH branch duplicated scenario: average trains/day pairs (iron ore, general cargo and passengers):

Local	Current scenario	Hypothetical scenario
Yard VP8	24,76	31,40
Stretch VP8_VP7A	24,76	31,40
Yard VP7A	24,76	31,40
Stretch VP7A_VP7	21,69	27,47
Yard VP7	18,62	23,54
Stretch VP7_VP6	18,62	23,54
Yard VP6	18,62	23,54
Stretch VP6_VP5	17,82	23,26
Yard VP5	17,01	22,99
Stretch VP5_VP4	17,01	22,99
Yard VP4	17,01	19,18
Stretch VP4_VP3	13,32	19,18
Yard VP3	13,32	19,18
Stretch VP3_VP2	13,32	19,18
Yard VP2	13,32	19,18

It is inferred that an analysis with high investment expenditure, such as a duplication of rail segments, must be better analyzed. The balance point where spending on investment is equal to the obtained revenue is called break-even.

In this example, the breakeven point occurs where the cost of the project is equal to the increasing cost of train cycles due to increased stopped train time (stopped trains in a queue in backyards of intersections or stopped trains queue in the crossing yards that give access to the BH Branch) by not carrying out the duplication.

5. CONCLUSIONS

This paper presents a simulator developed to analyze the behavior of a heavy haul railway considering strategic, tactical and operational planning levels. The goal of a highly efficient heavy haul railway is to maximize the use of loading points and to follow the schedules to meet demand while taking into account the entire integrated logistics chain: mine, railway and port. Thus, the long-term planning department has a robust tool that allows for the analysis of new expansion projects. The short-term planning department has a tool to address the various logistical issues that arise daily.

The high sensitivity of the system to various sources of interference in train circulation, including their scheduled and corrective stops, bottlenecks and queues require modelling algorithms that can properly represent these behaviors.

The algorithm developed to direct the trains was observed to be highly adequate in its goal to maximize occupation at the loading points in order to fulfil the pending requests at these locations. The algorithm automatically reduces the capacity at a point where preventive or corrective maintenance is being performed and adjusts by providing other points with greater demand and where no maintenance is being performed.

By achieving the primary objective of this study, the long-term planning departments will have a tool to assess the demands of new expansion projects, and the short-term planning departments will also be able to address the many “What if?” questions that arise daily.

The various tests of this model in its current development phase allow for its use in many applications:

- Determining the adequate number of railcars to achieve a given transportation volume;
- Identifying potential bottlenecks in the face of increased transport volume;
- Evaluating the impact of projects to improve the loading, unloading, and train assembly and disassembly terminals;
- Assessing the impact of projects to increase the network circulation capacity (e.g., duplication, triplication, inclusion of new crossings);
- Assessing the impacts of scheduled maintenance programs of loading and unloading equipment and railroad tracks;
- Assessing the impact on engineering projects to decrease the duration of corrective maintenance of loading and unloading equipment and railroad tracks;
- Determining the adequate percentages of two-lot and three-lot trains going uphill and downhill because having additional three-lot trains in loading, unloading, assembly and disassembly yards leads to an increase in the residence time at these yards. In turn, the train trips will be faster as a result of less-intense traffic in the network. Therefore, the simulator is capable of determining, based on the many simulation runs, the best configuration of the percentage of these trains under the simulated scenario conditions.

ACKNOWLEDGMENTS

To FAPES for financial support.

REFERENCES

Abbot D. and Marinov M., 2015. An Event Based Simulation Model to evaluate the Design of a Rail Interchange Yard, which provides Service to High Speed and Conventional Railways. Simulation Modelling Practice and Theory, pp. 15-39.

Almeida J., 2015. Otimização do planejamento tático da cadeia de suprimentos: formulações e métodos. PhD thesis. Universidade Federal de Minas Gerais.

Anand N. and Anayi M., 2010. Improving punctuality of train traffic on western main line of Swedish railway network: simulation approach. ASME Rail Transportation Division Fall Conference, pp. 15-24. October 20-21, Fort Worth, TX, USA.

ANTT, 2016. National Land Transport Agency, Network Statement. Available from: http://www.antt.gov.br/ [accessed 15 February 2016].

Banks J., Carson II J., Nelson B. and Nicol D., 2014. Discrete-Event system Simulation. Pearson Education Limited.

Banks J., 2000. Introduction to Simulation. Proceedings of the Winter Simulation Conference, pp.9-16. December 10-13, Orlando, FL, USA.

Bontekoning Y., 2006. Hub exchange operations in intermodal hub and spoke networks. The Netherlands, Delft University Press.

Ceciliano W. R. A., 2007. Aplicação de um método de simulação-otimização na cadeia produtiva de minérios de ferro. Master’s thesis. Universidade de São Paulo.

Cigolini R., Pero M., Rossi T. and Sianesi A., 2014. Linking supply chain configuration to supply chain performance: A discrete event simulation model. Simulation Modelling Practice and Theory, v.40, pp.1-11.

Cordeau J.; Toth F. and Vigo P., 1998. A survey of optimization models for train routing and scheduling, Transportation Science v.32, n.4, pp.380-404.
Corman F. and Quaglietta E., 2015. Closing the loop in real-time railway control: Framework design and impacts on operations, Transportation Research. Part C. v.54, pp.15-39.
Crainic T. and Laporte G., 1997. Planning models for freight transportation, European Journal of Operational Research, n.97, pp.409-438.
Dalal M. and Jensen L. P. A., 2001. Simulation Modeling at Union Pacific Railroad. Proceedings of the Winter Simulation Conference, pp.1048-1055. December 9-12, Arlington, VA, USA.
Faria C.H.F. and Cruz M.M.C., 2015. Simulation modelling of Vitoria-Minas closed loop rail network. Transport Problems, v.10, pp.125-139.
Faria C. H. F., 2016. Análise do planejamento ferroviário: uma abordagem utilizando simulação de eventos discretos. Master's thesis. Universidade Federal do Espírito Santo.
Fioroni M.M., Franzese L.A.G., Bianchi T.J., Ezawa L., Pinto L.R. and Miranda G. Jr., 2008. Concurrent simulation and optimization models for mining planning. Proceedings of Winter Simulation Conference, pp.759-767. December 7-10, Miami, FL, USA.
Fioroni M. M., Botter R. C., Pompermayer F. M. and Franzese L. A. G., 2004. Estudo Estratégico da Infra-estrutura do Pátio Ferroviário de Tubarão através de Simulação. Proceedings of the XVIII Anpet, pp.969-979. Florianópolis, Brazil.
Fogliatti M.C. and Mattos N.M.C., 2007. Teoria de Filas. Rio de Janeiro, Brazil. Ed. Interciência.
Hooghiemstra J. S. and Teunisse M. J. G., 2008. The use of Simulation in the Planning of the Dutch Railway Services. Proceedings of the Winter Simulation Conference, pp.1139-1145. December 7-10, Washington DC, EUA.
Joborn M., Crainic T.G., Gendreau M., Holmberg K. and Lundgren J.T., 2004. Economies of Scale in Empty Freight Car Distribution in Scheduled Railways. Transportation Science, n.2, v.38, pp. 121-134.
Kamrani M., Abadi S.M.H.E. and Golroudbary S.R., 2014. Traffic simulation of two adjacent unsignalized T-junctions during rush hours using Arena software. Simulation Modelling Practice and Theory, v.49, pp.167-179.
Lewellen M. and Tumay K., 1998. Network Simulation of a Major Railroad. Proceedings of the Winter Simulation Conference, pp.1135-1138. December 13-16, Washington DC, EUA.
Macal C. M. and North M. J., 2014. Introductory tutorial: Agent-based modeling and simulation. Proceedings of the Winter Simulation Conference, pp.1451-1464. December 7-10, Savannah, GA, USA.
Marinov M. and Viegas J., 2009. A simulation modelling methodology for evaluating flat shunted yard operations. Simulation Modelling Practice and Theory 2009, v.17, n.6, pp.1106-1129.
Marinov M. and Viegas J., 2011. A mesoscopic simulation modelling methodology for analyzing and evaluating freight train operations in a rail network. Simulation Modelling Practice and Theory 2011, v.19, pp.516-539.
Meireles R.P.L., 2010. Modelagem e simulação da malha ferroviária em circuito fechado da Estrada de Ferro Vitória a Minas. Master's thesis. Federal University of Espírito Santo, Vitória, Brazil.
Middelkoop D. and Bouwman, M, 2011. SIMONE: large Scale Train Network Simulations, Proceedings of the Winter Simulation Conference, pp.1042-1047. December 09-12, Arlington, VA, E.U.A.
Middelkoop D., Meijer S.; Steneker J.; Sehic E. and Mazzarello M., 2012. Simulation backbone for gaming simulation in railways, Proceedings of the Winter Simulation Conference, pp.3262-3274. December 09-12, Berlim, Germany.
Nash A. and D. Huerlimann, 2004. Railroad simulation using Open Track. 9th International conference on computer aided design, manufacture and operation in the railway and other advanced transit systems. May 17-19, Dresden, Germany.
Pinto L.R. and Merschmann L.H.C., 2001. Planejamento operacional da lavra de mina usando modelos matemáticos. Rem: Revista Escola de Minas, v.54(3), pp.211-214.
Pinto L.R., Silva P. and Young T., 2015. A generic method to develop simulation models for ambulance systems. Simulation Modelling Practice and Theory, v.5, pp.170-183.
Ricci S., Capodilupo L. and Tombesi E., 2016. Discrete Events Simulation of intermodal terminals operation: Modelling techniques and achievable results. Proceedings of the Third International Conference on Railway Technology, pp.1-13. Stirlingshire, Scotland.
Sinay M.C.F., Filho A.S.F. and Oliveira G.D., 2008. Railroad yard logistic to improve capacity. International Conference on Industrial Logistics. March 9-15, Tel Aviv, Israel.
Swegles S., 1997. Business Process Modeling with SIMPROCESS. Proceedings of the Winter Simulation Conference, pp.606-610. December 7-10, Atlanta, GA, USA.
Tsai S.C. and Zheng Y.X., 2013. A simulation optimization approach for a two-echelon inventory system with service level constraints. European Journal of Operational Research, v.229 (2), pp.364-374.
Wales J. and Marinov M., 2015. Analysis of delays and delay mitigation on a metropolitan rail network-using event based simulation. Simulation Modelling Practice and Theory, v.52, pp.52-77.

Woroniuk C. and Marinov M., 2013. Simulation modelling to analyses the current level of utilization of sections along a rail route. Journal of Transport Literature, v.7, n.2, pp.235-252.
Zhuan X. and Xia X., 2008. Speed regulation with measured output feedback in the control of heavy haul trains. Automatica, v.44, pp.1-6.

AUTHORS BIOGRAPHY

Full-time Professor at the Federal University of Espírito Santo, Brazil, professor of the production engineering undergraduate course and permanent professor of the graduate course in civil engineering, in the area of transportation concentration. She has experience in the area of Transport Engineering, with emphasis on cargo transportation, mainly in the following subjects: simulation, rail transportation, logistics, ports and data envelopment analysis. Civil Engineer from the State University of Rio de Janeiro (1991), Master's degree in Transport Engineering from the Federal University of Rio de Janeiro (1993) and PhD in Transport Engineering from the Federal University of Rio de Janeiro (1997).

Senior engineer in the VLI Company and undergraduate professor of Production Engineering at the University Center of Belo Horizonte. He has worked at Vale Company to develop simulation and optimization models to evaluate long-term logistics capabilities planning in the integrated chain (terminals, railways and ports). He has experience in mathematical modeling, optimization, simulation, supply chain planning and logistics. PhD student at Federal University of Minas Gerais, Brazil. Master’s degree in Civil Engineering with emphasis in Transportation at Federal University of Espírito Santo, Brazil (2016). Specialist in Strategic Logistics and Transportation Systems (2012) and graduated in Production Engineering (2006), both at Federal University of Minas Gerais, Brazil.

INTERMODAL LOGISTICS: SUPPORTING PLANNING AND SCHEDULING SERVICES OF FREIGHT FORWARDER

Francesco Longo[(a)], Letizia Nicoletti[(b)], Antonio Padovano[(c)], Agostino Bruzzone[(d)], Adriano O. Solis[(e)], Beatrice Zaccaro[(f)]

[(a) (c)(f)]DIMEG, University of Calabria, Italy
[(b)]CAL-TEK Srl
[(d)]DIME, University of Genoa, Italy
[(e)]York University, Canada

[(a)]f.longo@unical.it, [(b)]l.nicoletti@cal-tek.eu, [(c)]antonio.padovano@unical.it, [(d)]agostino@itim.unige.it
[(d)]asolis@yorku.ca, [(e)]beatrice.zaccaro@msc-les.org

ABSTRACT
Over the years the shipping sector has gained a fundamental role when talking about Global Trade. This paper presents a simulation platform for intermodal container shipping operations mainly devoted to support freight forwarders operations. The simulator is able to recreate long haul import and export container intermodal shipments with pick-up and delivery points on a world map. Input data for the simulations are available from two different databases, namely the Web Database able to retrieve data directly from the web and the Historical Database that makes use of historical data and time series collected by the forwarders companies operating long haul containers shipments in the port of Gioia Tauro, Italy. As part of the simulation, a number of different Key Performance Indicators are included and can be used to support expeditions planning, scheduling and scenarios comparison.

Keywords: long range container shipments, intermodal transportation, forecasting, planning, Simulation

1. INTRODUCTION

The container shipping sector is one of the most dynamic sectors inextricably connected to harbor business operations as well as to land transportation, due to its intermodal nature. A crucial development during the last twenty years was the increasing containerization rate with the aim of increasing the efficiency of shipping and cargo handling. Nowadays, international shipping can be regarded as a sophisticated network of scheduled services that transports goods from anywhere in the world to anywhere in the world and it is able to connects countries, markets, businesses and people, allowing them to buy and sell goods on a global scale. In such a context, seaports play a crucial role in the countries national economies by serving or driving import-export trade. They also influence viability, prospective and propensities for growth of regions. Today, the liner shipping industry transports goods representing approximately one-third of the total value of the Global Trade (Rajkovic et al. 2015). The latter depends mostly on the maritime network; its understanding in terms of services planning, scheduling, alternatives, etc. is a value added for: (i) those who require it (cargo owners, logistics service providers, forwarders companies), (ii) those who enable and shape it (shipping lines, port authorities), (iii) and those who regulate it (policy makers, regulators and governments), (Viljoen and Joubert, 2016). Focusing more on trade flows, Ducruet (2013) adds a commodity perspective to describe the diversity of maritime flows in the global network. The results show a strong influence of goods types on the specialization of maritime traffic at ports and on routes. This research is a first step in coupling the study of the global maritime network with the trade dynamics.

However, despite its average continuous growth, the global maritime industry, and the container shipping industry in particular, has become increasingly more volatile in the past decade (also due to the economic crises). Sudden changes in the world trade patterns and uncertain growth have resulted in a mismatch of demand and supply of container capacity (Neylan, 2015). Cost cutting and efficiency have become an imperative for the survival of container shipping companies as well as for all the other entities involved (e.g. logistics service providers, forwarders companies, etc.). To absorb capacity and ensure a more balanced use of their assets, shippers are deliberately slowing down their ships, so that more of them can be deployed on one service while maintaining the schedule of port calls. This is the so called slow-steaming and, while it was considered a drastic intervention a few years ago, it is now a common practice (causing, as side positive effect, environmental impacts reduction). Furthermore, shipping companies are able to plan and schedule their services in the most cost-efficient way. In fact, shippers may decide to discontinue a service due to profitability or to change it in favor of ports selection efficiencies or cargo volumes; or alliances may be formed to consolidate specific market segments. Luo and Fan (2010) investigates how ship-owners take decisions and invest their money according to the company dimensions, growth rate of demand, ships dimensions, possibility of ship replacement (new ship or second-hand ship) and ship speed. Basically, this research work quantitatively outlines the current ship-owners behaviors and preferences. However, these are not the only factors taken into account when talking about the liner shipping industry. Song and Dong (2013) proposed a design for a maritime service line operating on long distance taking into account routes structure, deployment of ships and repositioning of empty containers with the objective of minimizing the total cost incurred a liner long-haul service route, while Bruzzone et al. (2002) propose the use of simulation based optimization for the fleet management.

A survey of the current state of the art reveals that there are a number of research works in this area, mostly related to intermodal transportation. SteadieSeifi et al. (2014) reports an updated review of the state of the art (from 2005 to 2014) while previous review can be found in Crainic and Kim (2007), Christiansen et al. (2007) and Bektaş and Crainic (2008). From the analysis of the review articles, it is also clear that, among others, simulation and optimization are among the most powerful and user methodologies to face planning and scheduling problems in supply chains (Bruzzone, 2002).

1.1 Contribution of this article

Similar problems to those outlined in the previous section, are also faced by freight forwarders; indeed, while freight forwarders do not move directly containers or goods, they are required to deal with carriers and shipping companies. Therefore, they continuously face strategic problems mostly related to delays during the shipment (e.g. customs & border protection controls), uncertainty in delivery times, unforeseen transshipment, bad weather conditions, etc.

This article reports the results of research project carried out by the Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES, a simulation lab of University of Calabria, Italy) in collaboration with some Italian freight forwarders operating in the Gioia Tauro Harbor area, Italy. The main goal of the research project was the definition, design, development and testing of a simulation platform for long-range intermodal container shipments. The simulation platform has to be regarded as a tool for strategic planning issues that can be encountered by freight forwarders in long range intermodal container transportation, including problems in direct shipping, transshipment, services scheduling and uncertainty problems along the entire shipment. To this end, the simulation platform allows the forwarder to carry out stochastic simulations including:

- any desired pick-up and delivery points on a global scale,
- the entire shipment process (pre-haul for the container picking, long-haul and post-haul until the delivery to the final destination)
- two different databases for input data (web database and historical database)
- a set of Key performance Indicators to increase the reliability and the service level provided to the final customers.

The article is organized as follows: section 2 describes the conceptual models and the design of the two databases for input data. Section 3 presents the simulation platform architecture. Section 4 describes how the simulation platform has been implemented together with its main features, functionalities and Key Performance Indicators. Finally, section 5 summarizes the main results and conclusions.

2. ABSTRACTING THE LONG RANGE CONTAINER SHIPPING PROCESS

Long range intermodal container shipments have to be regarded as real-world complex processes; the main aim of this section is to abstract such complexity in a way that can be understood and successively implemented as a part of a simulation model. As mentioned in section 1, this research work was developed in cooperation with the forwarder companies operating in the Gioia Tauro harbor area, Italy. These companies mostly operate import and export long range intermodal container shipments. The figure 1 depicts a flow chart representing the export process (intended as a long range container shipment with its final destination somewhere outside Italy), while figure 2 depicts a flow chart representing the import process (intended as a long range container shipment with its final destination somewhere in Italy).

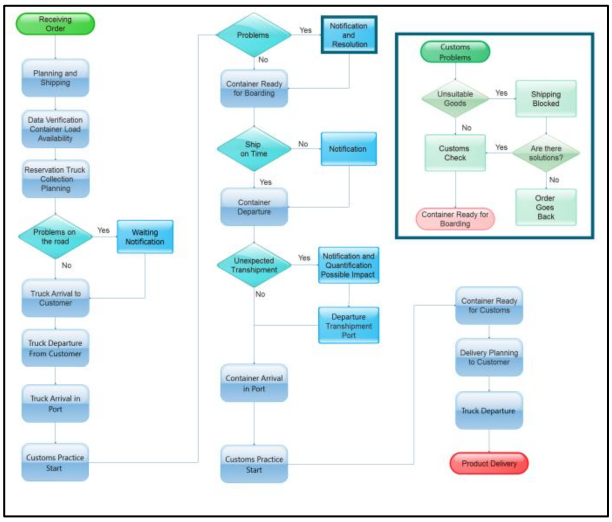


Figure 1 – Export Process Flowchart

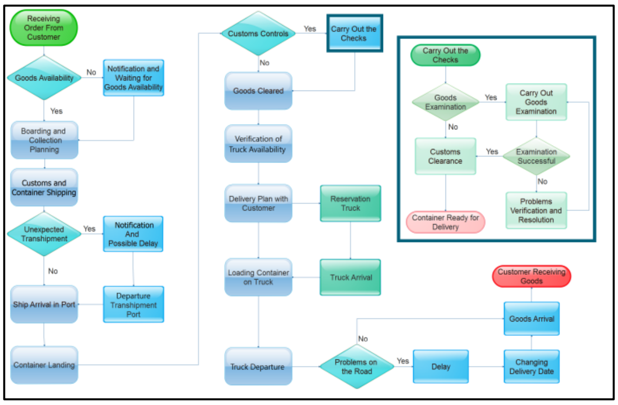


Figure 2 – Import Process Flowchart

While the figures 1 and 2 clearly explain the forwarders activities in planning, scheduling and executing a long range expedition, they do not provide any insight about quantitative data needed to simulate the import and the export process.

2.1 Data Collection and Analysis

A quick look to the flow charts clearly shows that most of the times and events related to the activities depicted in the flow charts can be regarded as stochastic variables. To this end, particular attention has been given to data collection that represents a preparatory phase in the probability distributions determination, through statistical techniques.

The approach used to model the input data was to determine theoretical distributions rather than empirical distributions. The following operational procedure has been adopted and applied to determine the theoretical distributions suitable to represent the available data samples:

- verification of the data independence (all the data observations are probabilistically independent of one other)
- determination of candidate distributions families
- estimation of distribution parameters
- verification of the representativeness of the theoretical distributions identified

As far as the verification of the data independence is concerned, a correlation coefficient $\widehat{\rho_J}$ is calculated according to equation 1:

$$\widehat{\rho_J} = \frac{\sum_{i=1}^{n-j}(X_i-\overline{X_n})(X_{i+J}-\overline{X_n})}{(n-j)s_n^2} \quad (1)$$

Where X_i represent the generic observation, n is the total number of observations, $j = 1 \ldots, n-1$ is a generic distance between two observations (in order to check all the possible combinations) and $\overline{X_n}$, $s_n{}^2$ represent observations mean and variance values.

In addition to the value of $\widehat{\rho_J}$ (absence of correlation means $\widehat{\rho_J} = 0$ or $\widehat{\rho_J} \sim 0$), the independence requirement can be easily evaluated by plotting the $\widehat{\rho_J}$ value against the j value or the $(X_i, X_{i+1}), i = 1,2, \ldots n-1$ points (dispersion plot). The figure 3 shows an example of correlation coefficient for a road transit time, from the pick-up location to the nearest selected port for the expedition. Specifically, the data refer to a pick-up location in Naples (Italy) and a road transit toward the port of Gioia Tauro (Italy) for an export long-range container shipment, while figure 4 shows the dispersion plot for the same variable. The independence of the observations can be observed by the random distribution of the points and the absence of traceable patterns and polynomial functions.

The preliminary determination of candidate distributions families is done according to the summary statistics (mean, variance, Skewness, etc.).

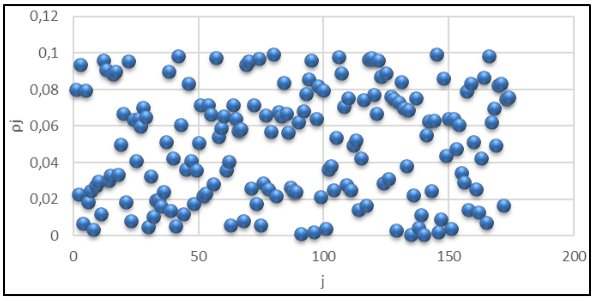


Figure 3 - Correlation coefficient trend for a road transit time

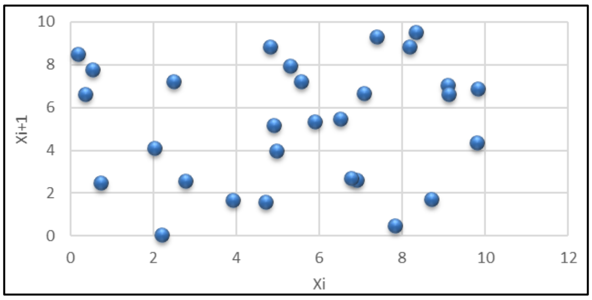


Figure 4 - Dispersion plot for a road transit time

Summary statistics together with histograms and a-priori knowledge (e.g. inter-arrival times are usually distributed according to exponential distribution) provide help in selecting the "most promising" distributions. The figure 5 shows a comparison between a histogram coming from a data sample and a probability distribution. Eventually, the final distribution selection is done according to goodness of fit test (e.g. Chi-Square, Anderson-Darling, etc.).

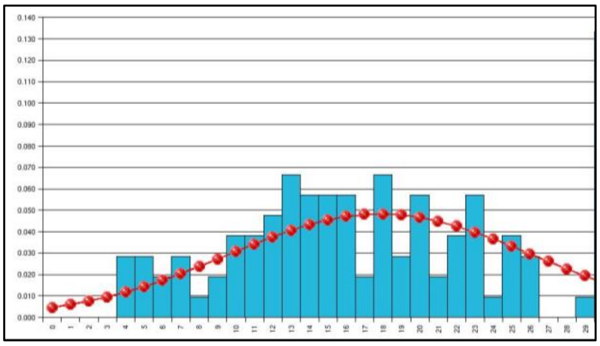


Figure 5 - Comparison between histogram and probability density function

2.2 Web Database and Historical Database

All the input data has been organized in two main databases:

- The web database;
- The historical database.

The web database collects data retrieved directly from the web. While data regarding road transportation can be easily retrieved from Google Map®, Open Street Map or similar platforms, port-to-port transportation times (sea times) can be retrieved by using online services and platforms (e.g. SeaRates); usually such services provide the user with multiple options (and data) as there could be more liners operating on the same route (on the selected departure dates) and more ships belonging to the same liner.

The historical database collects all the data provided by the forwarders companies operating in the port of Gioia Tauro and includes all the long-range container shipments they operated along the last 10 years. It is worth mentioning that both databases can be used to carry out simulations, however there are two major differences:

- by using the web database, the user can select any pick-up and delivery point on a world scale, while, by using the historical database, the pick-up and delivery points can be only those already served by the forwarders in the past. To this end, the web database offers the possibility to carry-out what if analysis investigating new business opportunities, providing customers with more accurate estimates on new routes.
- According to forwarders experts opinions (forwarders can be regarded as Subject Matter Experts), historical data (and therefore simulation results) are more reliable as they are able to reflect more accurately the shipment times.

3. SIMULATION MODEL ARCHITECTURE

The simulation architecture was conceived according to a three-level approach, MVC (Model-Controller-View), as shown in Figure 6. This approach was particularly used to respect two of the project requirements: (i) the simulation should be able to work on mobile devices (e.g. tablet and smartphone), (ii) the simulation should be able to work online over the internet.

The MVC architecture allows a separation among the simulation model and its logics including input data (implemented as part of the Model), the interpretation of all the commands received by the user, the simulation views updates and the correct formulation of the query to access the input data (implemented as part of the Controller) and the presentation of the simulation functionalities and results to the user (implemented as part of the View).

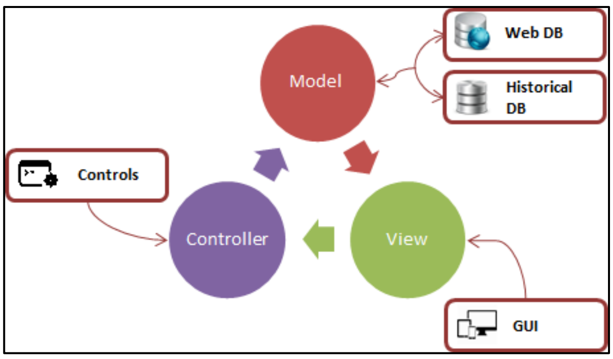


Figure 6 – MVC Simulation Architecture

3.1 Technological and Operational Architecture View

The simulation architecture was then developed according to a Server-Client logic by using the Laravel (version 5) framework. This is a PHP framework, oriented to MVC architecture and object-oriented programming. Laravel was used jointly with other programming languages and software tools: namely CSS 3, HTML 5, JQuery and Bootstrap for the Desktop client development (when the simulation is used online through a desktop computer), Android for the Mobile Client Development (when the simulation is used online from Android mobile devices). The technology view of the architecture is shown in figure 7.

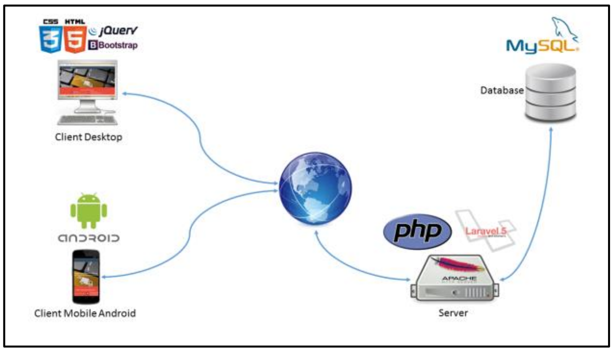


Figure 7 – Technological view of the MVC simulation architecture

From a conceptual point of view, the architecture operating diagram is shown in Figure 8. At the beginning of the simulation the user is required to select the operating mode (web Database or Historical Database), after he is required to insert information about the routes and start the simulation; in the end simulation results and KPIs are visualized.

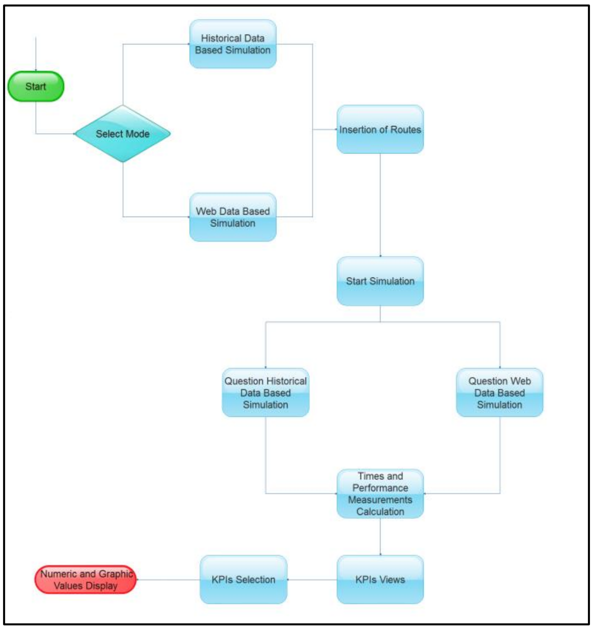


Figure 8 – Architecture Operating Diagram

4. RUNNING THE SIMULATION

The execution of the simulation can be done by a standard web browser by using a desktop PC or a mobile device. This modeling and coding effort have been carried out with the aim of allowing users to avoid obstacles that are typical of non-service-oriented software and to come up with a Simulation as a Service (SaS) solution. Figure 9 shows the simulation model homepage allows the user to choose between two options: Web Data Simulation e Historical Data Simulation.

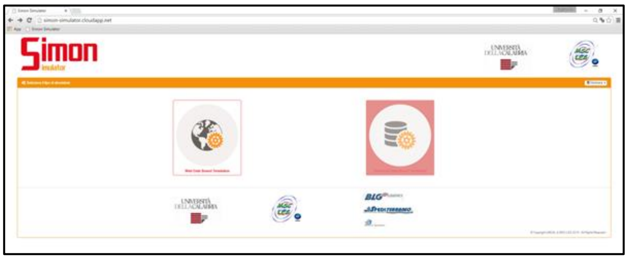


Figure 8 – Simulation model homepage

The user is then required to insert information about the routes that consists in specifying the following information:

- Departure city;
- Port of departure;
- Port of arrival;
- Arrival city;

Routes information can be directly typed in or can be pinned directly on the map as shown in figure 9.

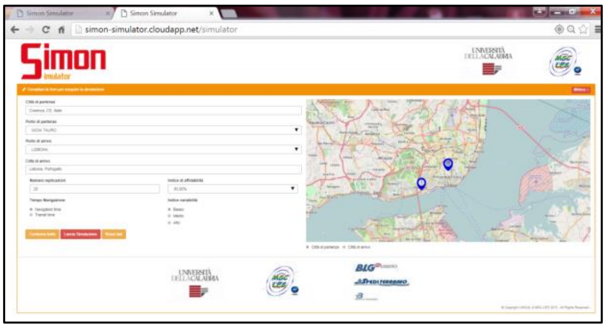


Figure 8 – Routes information, map and simulation commands

The user can change at any time the data entered or possibly decide to reset all fields by selecting the Data Reset button. Other parameters to be provided in input to launch the simulation are:

- *Confidence Interval*, used to determine the reliability of the simulation results (e.g. 95%, 99%, etc.).
- *Replication Number* determines the number of replication for each simulation run.
- *Variability Index*, a parameter used to increase or decrease the stochastic variability affecting sea transportation times.

During the simulation, an animation is displayed on the map that is intended to show the shipment path.

4.1 Key Performance Indicators

Once the simulation is completed, a number of buttons become available in the output window, to allow the user accessing the simulation results available in terms of KPIs (Key Performance Indicators). The following KPIs can be calculated as part of the historical based simulation:

- average shipping time per customer, liner and commodity (respectively KPI1, KPI2 and KPI3): the average value of the total shipping time for a given customer, liner and commodity;
- average sea transit time per customer, liner and commodity (KPI4, KPI5 and KPI6): the average value of the sea transit time for a given customer, liner and commodity.
- average road transit time from the pick-up point to the port (KPI7): calculated as difference between the delivery time at the port and the pick-up time at the point of origin;
- average road transit time from the port to the delivery point (KPI8): calculated as difference between the delivery time at destination and the pick-up time at the port.
- average lateness (KPI9): the average value of the advance or delay compared to the estimated delivery time;
- average waiting time in the terminal area per commodity (KPI10)
- average customs and border protection clearance time per commodity and per liner (KPI11 and KPI12).

For the web based simulation the following KPIs can be calculated:

- average shipping time (KPI1): the average value of the total shipping time;
- average sea transit-time (KPI2): the average value of the sea transportation time;
- average road transit time from the pick-up point to the port (KPI7): calculated as difference between the delivery time at the port and the pick-up time at the point of origin;
- average road transit time from the port to the delivery point (KPI8): calculated as difference between the delivery time at destination and the pick-up time at the port.
- average waiting time in the terminal area (KPI10)
- average customs and border protection clearance time (KPI11).

As the input data for the web based simulation are retrieved on line, a reduced set of KPIs are available from the web based simulation (e.g. it is not possible to carry-out simulation for specific commodities, customers or liners).

4.1 Example of Simulation Results

The following section presents the use of the simulation for two different intermodal (road-sea) shipments. Table 1 reports the details of the two shipments.

Table 1: details about two intermodal shipments

ID	City of Origin	Port of Origin	Port of Destination	City of Destination
1	Cosenza, Italy	Gioia Tauro, Italy	Lisbon, Portugal	Lisbon, Portugal
2	Livorno, Italy	Genoa, Italy	Istanbul, Turkey	Istanbul, Turkey

The shipment ID 1 has been simulated by using the web based simulation while the shipment ID 2 has been simulated by using the historical based simulation. As far as the simulation results for the shipment ID 1 are concerned, the user can easily access the results by using the results view, as shown in figure 9. In particular, figure 9 shows the simulation results (the main view is on the KPI1, however all the KPIs are included). The figure is split in 3 parts: (i) the graph including the KPI1 (shipping time) along all the simulation replications; (ii) the KPI1 confidence interval plot; (iii) a pie charts including the values of all the others KPIs (2, 7, 8, 10, 11). It is also possible to access the main view for the KPIs 2, 7, 8, 10, 11 that will show (in a similar way) the KPIs values along all the replications and the related confidence intervals.

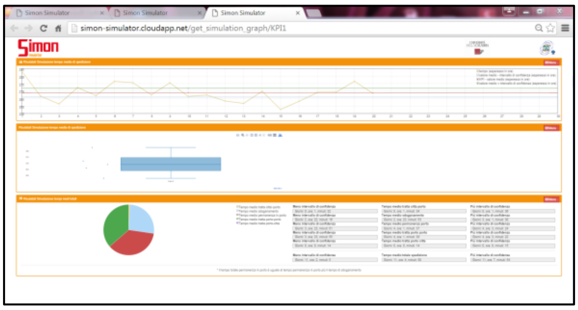


Figure 9 – Simulation results for shipment 1

As far as the simulation results for the shipment ID 2 are concerned, the results are shown in figure 10. In addition to the pie chart and numerical values (in terms of average values and related confidence intervals) of the KPIs 1, 2, 7, 8, 10 and 11, in the lower part of the screen, the user can access all the KPIs selecting a specific commodity, liner or customer.

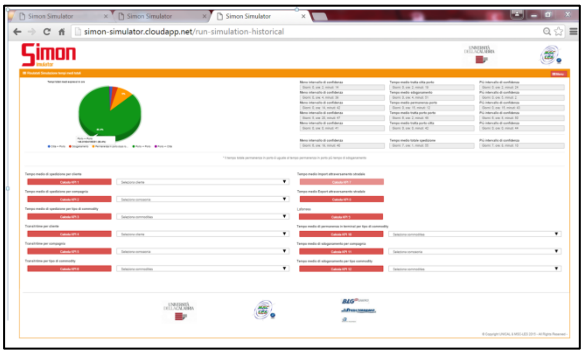


Figure 10 – Simulation results for shipment 2

Many other simulations (long range shipments) have been executed, mainly to carry out validation activities by using (as reference) the historical data provided by the forwarder companies.

5. CONCLUSIONS

The paper presents the results of a research project developed at MSC-LES lab of University of Calabria. The project was devoted to conceive, design and develop a simulation service to support strategic planning and scheduling of forwarders companies operating in the Harbor area of Gioia Tauro, Italy. The authors have conceived a MVC architecture able to work over the internet (providing the simulation as a service) and on mobile devices. This has mainly required the use and adaption of web technologies and software for simulation purposes. The simulation comes with a dedicated Graphic Interface that allows user executing simulations and accessing results (multiple KPIs). The authors have also executed preliminary simulation experiments to show the potentials of the services and to carry out validation activities.

ACKNOWLEDGEMENTS

The research presented in this paper is part of the SIMON project co-financed by the European Union, the Italian Government and Calabria Region under the program POR/FESR Calabria 2007/2013, Asse I, “Ricerca Scientifica, Innovazione Tecnologica e Società dell’informazione”.

REFERENCES

Banks J., 1998. Handbook of Simulation. J. Wiley & Sons New York.

Bektaş T., Crainic T. (2008). A brief overview of intermodal transportation. In G. Taylor (Ed.), Logistics Engineering Handbook (pp. 1–16).

Bartholdi, J. I., Jarumaneeroj, P., and Ramudhin, A. (2014). A new connectivity index for container ports. *Technical report, The Supply Chain & Logistics Institute*, Georgia Institute of Technology.

Bruzzone A., (2002). Introduction to the Special Issue: Supply Chain Management. Simulation, vol. 78, no. 5, pp. 283-284.

Bruzzone A., Orsoni A., Mosca R., Revetria R. (2002). AI-based optimization for fleet management in maritime logistics. Winter Simulation Conference Proceedings, pp. 1174.

Christiansen M., Fagerholt K., Nygreen B., Ronen D. (2007). Maritime transportation. In C. Barnhart, & G. Laporte (Eds.), Transportation. Handbooks in operations research and management science (Vol. 14, pp. 189–284).

Crainic T., Kim, K. (2007). Intermodal transportation. In C. Barnhart, & G. Laporte (Eds.), Transportation. Handbooks in operations research and management science (Vol. 14, pp. 467–537).

Ducruet, C. (2013). Network diversity and maritime ows. Journal of Transport Geography, 30:77-88.

Efficiency of Asian Container Ports." African Journal of Business Management 5 (4): 1397-407.
Gardiner N., Drewry Maritime Research (2014a). Container Forecaster 2Q14.
Gardiner N., Drewry Maritime Research (2014b). Container Forecaster 4Q14.
Luo, M., and Fan, L. (2010). "Determinants of Container Ship Investment Decision and Ship Choice", In Proceedings of the International Forum on Shipping, Ports and Airports (IFSPA), pp. 449-461
Munisamy, S., and Singh, G. 2011. "Benchmarking the
Neylan P., Drewry Maritime Research (2015). Container Forecaster 2Q15.
Rajkovic R., Zrnic N., Stakic D., Mahnic B., 2015, A crucial development during last twenty years is the increasing degree of containerization which makes shipping and handling of cargo far more efficient, *Logistics & Sustainable Transport*, Vol. 6, No. 1, November 2015, 34–40 doi: 10.1515/jlst-2015-0009.
Song, D.P. and Dong, J.X. (2013) Long-haul liner service route design with ship deployment and empty container repositioning. Transportation Research Part B, 55(2013), 188–211.
SteadieSeifi M., Dellaert N.P., Nuijten W., Van Woensel T., Raoufi R.., (2014). Multimodal freight transportation planning: A literature review. European Journal of Operational Research, Volume 233, Issue 1, 16 February 2014, Pages 1-15
Viljoen N. M., Joubert, J. W., 2016, The vulnerability of the global container shipping network to targeted link disruption, *Physica A: Statistical Mechanics and its Applications*, Volume 462, 15 November 2016, Pages 396-409.

BIOGRAPHIES

Francesco Longo is Director of the Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES), a laboratory operating at the Department of Mechanical, Energy and Management Engineering of University of Calabria. He has published more than 200 scientific papers in international conferences and journals, and has participated as speaker and chairman in a broad range of international conferences. His research activities focus on innovative ways to use simulation paradigms (discrete event, agent based, distributed, etc.) and serious games to achieve new scientific advances in various application areas including Industry, Logistics, Defense and Cultural Heritage. He has also served as General Chair and Program Chair for the most prominent international conferences in the area of Modeling and Simulation (EMSS, SCS, I3M, etc.)

Letizia Nicoletti was CEO of Cal-tek Srl from 2012 to 2014 and she is currently Senior Manager at CAL-TEK. She obtained her Bachelor Degree in Management Engineering, Summa cum Laude, her Master Degree in Management Engineering, Summa cum Laude as well as her PhD in Mechanical Engineering from University of Calabria, Italy. She has followed as Scientific Responsible many research projects in different areas including logistics and distribution, Defense and Cultural Heritage. Her skills include requirements definition and development, conceptual modelling, model simplification, data collection and analysis, representing unpredictable variability and selecting statistical distributions, models and software coding, experimentation, verification and validation, serious games development, visualization, simulation software.

A**ntonio Padovano** is currently conducting research in the area of Modeling & Simulation with applications in Industry and Logistics at MSC-LES University of Calabria. Since 2014, he carried out several work experiences travelling in Europe and United States (e.g. he spent 3 months at Rutgers University, USA). He is expert in discrete event simulation and in developing simulation solutions as a service. He has been supporting the organization of the International Multidisciplinary Modeling & Simulation Multiconference since 2014.

Agostino Bruzzone is Full Professor of at the University of Genoa. He is President of Simulation Team, Director of the International Master Program MIPET, member of the BoD of the Society for Modeling and Simulation International, Director of M&S Net, Senior Lecturer within the PhD program on Modeling&Simulation. He also served as M&S Responsible in NATO STO CMRE, Director of the McLeod Institute of Simulation Science, Vice-President of the Board of MIMOS (Movimento Italiano di Simulazione) He was involved in research projects in cooperation among EDA, Italian and French MoD, NATO M&S CoE. He has published over 200 journal and conference papers. E-mail: agostino@itim.unige.it

Adriano O. Solis is an Associate Professor of Logistics Management and currently Director in the School of Administrative Studies, York University, Canada. After receiving his BS, MS and MBA degrees from the University of the Philippines, he joined the Philippine operations of Philips Electronics and became a Vice-President and Division Manager. He later received his PhD in Management Science from the University of Alabama. He was previously an Associate Professor of Operations and Supply Chain Management at the University of Texas at El Paso.

Beatrice Zaccaro is currently a master degree student in Mechanical Engineering at University of Calabria, Italy. Her research interests includes Modeling & Simulation with applications in Logistics and Safety & Security in industrial plants.

AGILE SOLUTIONS & DATA ANALITICS
FOR LOGISTICS PROVIDERS BASED ON SIMULATION

Agostino G. Bruzzone [(a)], Marina Massei [(b)], Matteo Agresta [(c)],
Kirill Sinelshchikov [(d)], Riccardo di Matteo [(e)]

[(a) (b)] Simulation Team, DIME University of Genoa,
[(c) (d)] Simulation Team, Liophant Simulation,
[(e)] Simulation Team, SIM4Future

[(a)] agostino.bruzzone@simulationteam.com, [(b)] marina.massei@simulationteam.com,
[(c)] matteo.agresta@simulationteam.com, [(c)] kirill.sinelshchikov@simulationteam.com,
[(e)] riccardo.dimatteo@simulationteam.com

[(a) (b) (c) (d) (e)] www.simulationteam.com

ABSTRACT
The current advances are enabling the development of new solutions in data analytics and decision making in many fields; it is quite interesting to analyze the impact of this approach on logistics providers; this paper proposes examples of these challenges in this context as well as an example of a *simulation based solution* able to interconnect the different information sources and to fuse the data in order to analyze the logistics processes and support decisions. The proposed solution is based on web services and web application that are adopting the MSaaS concept (Modeling & Simulation as a Service) by using stochastic models.

Keywords: Logistics, Smart Planning, MSaaS, Stochastic Simulation, Web Application

1 INTRODUCTION

Logistics is a quite challenging framework having to deal with multiple requests operating in different frameworks in contact with real world and being subjected to very quick changing boundary conditions; sometime it is said that logistics is a function in industry that is quartered by other major company functions.

In facts logistics providers are usually acting on a very competitive market for supporting industries and business sectors (e.g. Retail) in order to guarantee supply chain operations and quality (Blackwell 1997; Chopra et al. 2001; Bolstorff et al. 2003; Bruzzone et al. 2004; Wenjing et al. 2010). The companies take care of external and/or internal services such as truck transportation services and warehouse operations and they need to adapt to the expectations and requests of different customers (Bang-Ning Hwang et al. 2013) also taking into account reverse logistics (Longo, 2014). So, as happen for all service providers, the logistics operators need to quickly adapt processes, procedures and rates to market evolution taking also into account technological and demand changes. From this point of view the evolutions in ICT sector and infrastructures is a very important enabler in this sector, providing great opportunities to improve the service and react dynamically to change requests (Perakovic et al. 2017).

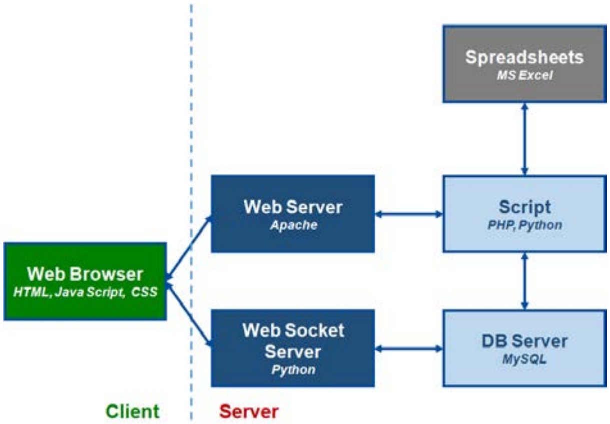


Fig.1- MSaaS Architecture and ALLONS Components

For sure data analytics is a very popular subject, therefore to success in this area it is necessary not only to collect and analyze data, but also to make them consistent and usable to represent correctly the different components of the logistics processes. In addition today there is a big issue in letting the users and decision makers evolving in adopting innovative models and solutions in data analytics, so support in terms of education and training in this area is very fundamental.

In facts, the evolution of logistics processes along recent years has been strongly influenced by enabling technologies including mobile solutions, IoT and cloud techniques; from other point of view the market situation required logistics providers to adapt increasing responsiveness, flexibility and efficiency as well as to cover new markets (Voss et al.2017).

So, this paper proposes an approach based on Modeling and Simulation (M&S) that use stochastic simulation and web application to provide easy and immediate access to models able to correlate the available data and to improve the analysis capabilities devoted to support logistics decisions. The use of mobile solutions and web applications allows to extend the opportunities for education and training (Massei et al. 2010; Lukosch et al. 2016); so the first proposed use is intended for Education and Training adopting multiple platforms such as smart phones and interactive virtual exercise classes.

In general this approach is applying to the MSaaS concept that allows to provide simulation to users as a web service directly integrated with the different Systems) and databases (Siegfried et al. 2014).

2 DATA ANALYTICS IN LOGISTICS

Today "data analytics" is a very popular subject and, in some occasion, it turns also into a buzz word quite fashionable respect traditional "data analysis" (Bryman & Hardy 2009; Kadel 2010); therefore it could be improper to simplify just accepting this point of view considering that the reality is much more articulated and complex: the modern ICT (Information and Communication Technology) & IoT (Internet of Things) systems, the networks and web services structure have been evolved enormously regarding a decade ago (Press 2016). This means that many new opportunities emerge in data processing: for instance, even if the information on the basic cartography has been already available way since decades (e.g. GIS), today the Database is much richer and extended, at very low cost, with many additional data sets, kept "fresh" and immediately accessible (e.g. traffic jams, access regulation, public transportation connections, other level of details); these considerations are worth practically for all various sources of data (e.g. traffic monitoring, vehicle tracking, consumptions, company costs, etc.) and services (Bruzzone et al. 2004; Davenport et al. 2012; Kitchin 2014; Amini et al. 2017,). The direct and economic accesses to this enormous amount of data represent an very big potential to develop an effective understanding of company reality including capability to evaluate dynamically the process efficiency, the values over chain, the customer behaviors, the real operational costs and times, etc. (Zhao et al. 2017). From this point of view, these data are very valuable, therefore they often result pretty hard to be computed and analyzed due to the high level of details and the size of the dataset. For instance, in the analysis of a truck company as in the case we are investigating, it could be very interesting to correlated the consumptions and operational costs with the waiting times at customer pick and drop off sites to identify most profitable services; therefore this analysis requires to be able to define each single truck mission exploded in its subcomponents considering that often it includes multi customers combining and overlapping the relative services (Johansson et al. 2014). This simple example points out the necessity to process a large amount of data (many missions), to fuse different detailed data source (e.g. travelling time, invoice records, site locations, shipping documents), to develop models to create new records (e.g. algorithms to distribute refueling costs over multiple missions, criteria to attribute mission delay among served customers, etc.). The conceptual complexity as well as data dimension require to develop and/or access multiple algorithms, methodologies as well as software solutions. Therefore, considering that often the data are incomplete, inconsistent and require to correlated database characterized by different granularities, it results evident the necessity to develop articulated models able to identify and process the raw data and to fuse them for being usable in the analysis (Castanedo 2013).

Today, it is possible to address these challenges thanks to solutions that allow to access and interoperate with different databases, web sources and services, physical devices, for instance mobile, in a way that was mostly inconceivable just few years ago (Liew et al. 2015).

So it turns evident that the "Data Analytics" is much more than a buzz word, representing a pretty new computational capability enabled by modern technologies and data sources (Cooper 2012); indeed this research is focused on this aspect in relation to logistics providers. In facts the main objectives include the development of models, algorithms and procedures devoted to be able to practically support decision making and planning in complex scenarios dealing with logistics companies. Indeed the modern MIS (Management of Information Systems) and web services guarantee a quite effective and efficient access and extraction to databases, supporting quick elaboration of the information for finalizing analysis devoted to support operational management and strategic decisions (Longo 2013; Hu & Sheng 2014). In this research, these concepts are addressed pragmatically using a real case study to validate and verify the proposed approach; in facts the problem addressed is related to a company that expanded largely within one year: from just 60 trucks addressing a single service on a single district to a fleet tree times large operating over different logistics sectors in a much more wide area.

3 LOGISTICS VS. TRANSPORTATION

It is not rare in several context to register a quite high degree of confusion between the logistics and transportation concepts respect expert's definitions (Kasilingam 1998); sometime this is due to historical reasons related to Institutional approach; for instance in some Countries the Institution in charge to define Strategies in Logistics is a National Department dealing with new infrastructure constructions so it address the problem without a common picture combining the different element of supply chains and combining cargo and passage flows (Maggi & Mariotti 2012). In any case, it is evident that transportation is usually a main component of logistics, therefore it is also clear that the supply chain operations are not limited to these activities. Logistics require not only to move something from Point A to Point B, but also to determine: When it have to be moved, How to move it, How to Load and Unload on vectors, the Synchronization of potentially different vectors to plan a set of multi modal transportations (e.g. heavy haul, railways, ships, barges, air transportation), etc. (Christopher 2016)

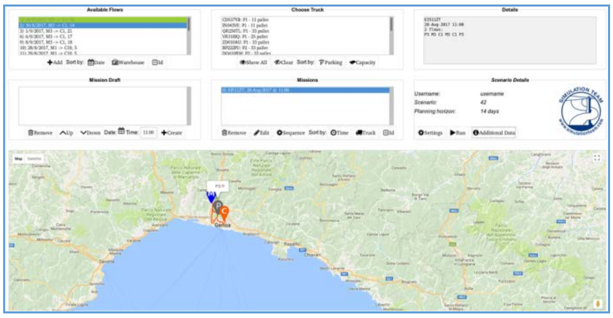


Fig.2- ALLONS Simulator Interface

In facts, the confusion between Logistics and Transportation concepts is a potential sources of problems, especially at High Level (e.g. National Departments), considering that strategic investments going to renew and expand transportation infrastructures could miss the real logistics needs.
For instance, in Italy there is a case where a new large port was constructed from *tabula rasa* in South Italy on a place almost disconnected from other networks interconnecting the Country and Europe (e.g. no effective connection both on railways and highways) just to serve an hypothetical new steel production facility planned for this site and expected to be the largest in Europe (Gironda 2011).
This new port was totally isolated in terms of logistics and even the steel production plant was planned without a view about the global supply chain for steel, resulting in canceling the plant project and dismissing the new port. After several years a very convenient bid allowed to resume the ghost port, assigning almost for free it to private operators that used it for creating a new Container and Ro-Ro Terminal devoted to serve as transshipment facility; obviously the new use was quite successful for the private operator due to the free availability of the basic infrastructure and considering that the transshipment was emerging in logistics context; vice versa, considering the huge initial investments, the low margins and fall-out of this kind of logistics operations, it is evident that the public investment strategy resulted completely wrong and ineffective in terms of overall country development as well as return of investments. The error was due to many aspects, but for sure improper models and data analysis have been in used in such case; in facts, the analyses show that for an European port, it is almost impossible to be profitable without a strong interconnection with global logistics (Adolf & Liu 2014); if the port is not well connected, it could survive by turning into a mere exchange point providing transshipment services (Notteboom 2004).
Therefore these solutions that could be able to attract large logistics flows, have to face very harsh competition with strategic facilities, often more convenient for basic geographical reasons.
For instance considering that the European imports are around 37% and over fifty percent over Sea almost all arriving from East Suez Channel (7.5% of world ocean traffic) excluding Cape route usually dealing with very large bulk cargo (WSC 2007; Eurostat 2016 & 2017; Schuler 2016). So under this global conditions, the Port Said and Tangier ports, corresponding to the two forced gateways (Suez and Gibraltar) to access Europe from this route have a very challenging advantage respect almost any other port for transshipment operations, reducing further marginality of potential competitors in this sector (Yetkili et al. 2015; Benhayoun 2017).
To succeed in this context it is necessary to have a view related to the whole supply chain and logistics networks and not to get lost in single node or specific transportation service (Bruzzone 2002). Obviously these main considerations are true also for logistics companies dealing with inland transportations, considering the necessity to serve logistics nodes in the network interconnected with other elements (e.g. ports, rail terminals etc.) even if from the single company point of view the business is limited just to trucks.
In the proposed case related to North Italy Region, within South Europe, the main issue is not to determine the most convenient path between two towns such as Genoa to La Spezia (in this case there is only one in practice) or between Savona to Milan (in this case may be just two are suitable); vice versa the real question is to define the frequency of the service (e.g. daily, each other day, two times per week, etc.), to define when to carry the transportation (e.g. Monday & Wednesday vs. Tuesday and Thursday), to choose the vector solution (e.g. a big tractor-trailer once per week or two medium size lorries two times), to decide to cross a Distribution Center or to use direct service. These are the real issues to be addressed in terms of logistics and it is important to outline that this does not diminish the importance of Operational Management techniques and simulation, but it is evident that the problems where to apply these methods are quite different from classical shortest path or TSP (Travelling Salesman Problem) and pretty challenging adding usually time to space in terms of investigation range for finding the “optimal solution” (Ayers 2001; Donati et al. 2008). The dimension of the problem as well as the nature of the constraints and resources usually make it very hard to finalize an optimization by simplified approaches introducing the necessity to develop heuristics and to use simulation for “optimization” (Monks 1996; Gousty 1997; Bruzzone 2002). Therefore another very important aspect in this sense is related to the nature of logistics processes that are dealing with external environment (e.g. delays at source and destination, general traffic, weather conditions, equipment failures and problems, etc.). Indeed it could be also considered the impact of safety regulations and issues, especially when fresh good or hazardous material transportation is concerned (Fabiano et al. 2005; Bruzzone et al.2014b). In this context stochastic factors are very important, so it could happen that there is not a “optimal solution”, but several alternatives characterized by different statistical KPI (key performance indexes) with specific risks and opportunities levels. So the optimization concept in these problems is very specific and it requires to move

away from traditional linear programming or theoretical analysis that does not consider these confidence bands and related risks. In addition to the above issues to be addressed, obviously there are many other ones dealing with the logistics demand (Pendyala et al. 2000); for instance a very crucial point is to identify the customers to be included into a mission, the sequence to adopt in serving multi-pick and/or multi-drop locations, the way to use personnel in loading/unloading, the equipment selection and use mode (Livernash & Heuer 2003).

Based on these consideration it is evident that dealing with logistics means to address a much more complex problem respect the basic transportation A to B. In this sector there are many constraints to be considered including technical aspects (e.g. vector capability to maintain temperature for refeer cargo considering number and duration of drop-offs), infrastructures (e.g. truck accessibility respect road network), temporal windows (e.g. urban access timeframe, customer timetable for accessing facilities), traffic (e.g. crossing urban areas out of rush time), costs (e.g. fees and costs of the service), legal regulations (e.g. maximum active work time for drivers, number and duration of rest stops, HACCP constraints), quality (e.g. service level, timely, responsiveness, reliability). Indeed the goal of this research is to develop solutions able to support management and process control as well as strategic decision making within logistics companies operating truck fleets based on the dynamic data and information.

4 SIMULATION AS A SERVICE

The MSaaS (Modeling & Simulation as a Service) foundations are quite consolidated despite the recent fortune of this acronym deriving from evolution of Cloud business, therefore it is evident that the adoption on innovative architecture and environments is usually required for properly addressing Service Oriented Architecture (Tsai et al. 2007). In facts MSaaS concept turned popular with the diffusion of Cloud approach as a way to provide these services in effective, flexible, efficient and maintainable (Cayirci 2013). In this sense the adoption of MSaaS is supported by adoption of standards and guidelines supporting reusability and interoperability as well as by creating an effective VV&A support for the models and simulators (Balci et al. 2009; NMSG 2016); in facts by this approach it becomes possible to develop M&S Services for specific applications and domain and to carry out the simulation within distributed environments and it could be interesting to combine it with MS2G Paradigm (Bruzzone et al.2014a).

5 AGILE SIMULATION SOLUTION

As anticipated, delivery of goods is one of main parts of economy and delivery planning is one of its key aspects. In the past, the planning was performed mostly manually, therefore today the planning software is pretty diffused to improve the logistics process control, reduce costs and offer to customers better quality of service. In facts the motivation of this R&D (Research and Development) activities is originated by the need to create a new platform independent simulator supporting multiple purposes from Education and Training of logistics planners into data analytics and to directly provide logistics planning services and operation supervision; obviously this application serves as first step in developing useful decision support systems for logistics providers. ALLONS have a big potential as decisions support serving for completing a priori analysis on new logistics solutions and could provide Reference Baselines to be used during setup, ramp up and production times to verify if the expected results are achieved as well as best corrective actions and improvement opportunities (Fawcett & Cooper 1998)

The simulator proposed hereafter, titled ALLONS (Agile Lean Logistics Network Simulator) and its architecture have been developed specifically to get benefits from advances in web services and new ICT solutions in order to be able to address the current needs of logistics providers that are looking for reliable, intuitive, economic and flexible solutions. In this sense the simulation is by itself the fundamental enabler to develop agility within logistics acting on multiple streams. For instance in many Countries as in Italy there is a great need to diffuse a scientific approach to management and logistics based on techniques and methodologies that are just partially mastered (or even known) by many managers and operators in this area (Bruzzone et al. 2007). The opportunity to provide a framework to support Education & Training of concepts, criteria, methodologies by experiencing them directly into a synthetic environment is very interesting for these companies. ALLONS simulator is in use with students from engineering classes and professional courses for experimenting and evaluating his potential for Educations and Training (E&T). In addition, the proposed simulator could be easily integrated with open data coming from multiple sources in order to turn easily into a decision support systems for planners and executives in logistics companies; this capabilities could enhance the competitiveness especially for small and medium size companies and the authors are testing and validating this approach in enterprises that operates from few dozens of trucks to hundreds. As anticipated, ALLONS is based on web technologies and allows to provide simulation as a service; in facts, ALLONS is enabled to operate on LAMP server (Linux, Apache, MySQL, PHP) and server-side Python modules to execute simulation, indeed it contains Apache Web Server, DB MySQL, PHP scripts and simulator written in Python. The database includes multiple data, such as customers (e.g. id, company name, address, coordinates, delivery contract type, cluster, delivery hours, accessibility constraints, statistical data on the demand etc.), fleet (e.g. truck register plate, capacity, speed on highway and normal road, consumption, reference parking, maintenance, assurance & depreciation costs, etc.), logistics nodes and warehouses (e.g. id, address, coordinates, etc.), parking locations (e.g. id, address, coordinates, etc.) and routes (e.g. total distance and route steps obtained from Google Directions API), etc.. PHP is used for server-side scripting and it supports main activities such as database connections. Currently an Apache Web Server guarantees communication between client and server through HTTP (Hypertext Transfer Protocol), being designed to operate also on secure networks. ALLONS Client include planning capabilities and it is implemented in JavaScript with additional libraries such as jQuery which is executed in web browsers, while the GUI (Graphic User Interface) is designed in HTML: (Hypertext Markup Language) and CSS (Cascading Style Sheets) to guarantee immediate and extensive reusability over multiple platforms and Operating Systems. Hence, ALLONS is platform independent and is supposed to be capable to run in all modern web browsers, furthermore CSS performs resize and change of position of interface elements based on screen resolution of user's device allowing ALLONS to run on any platform and devices. This is very important to make the simulator able to be used with different screen size, from smart phones, tablet as well as on regular personal computer with big screen. Connection between clients and server is managed by Apache web server, while data exchange between client and PHP scripts, which are required for data acquisition from central database and some auxiliary calculations, is performed using AJAX (Asynchronous JavaScript and XML). This architecture allows ALLONS to carry out operation supervision and planning operating remotely just using the network. Therefore to improve reliability in distributed use, several information about terrain, costs, routing are downloaded on the client at the scenario creation in order to be able to continue to conduct planning and simulation even in case web network failure, obviously without the capability to upload on the server the solutions until the connection is back on. To complete the planning, the users are enabled to select the logistics flows to be processed as well as the vector (e.g. truck), timetable (e.g. time and date of departure from initial parking) and the AIM (Artificial Intelligence Module) of ALLONS performs a preliminary check on the logistics constraints (e.g. delivery time, time windows, access constraints, etc.). These data are necessary to create the different missions that compose the whole planning; each mission include the path of the truck from original parking to each logistics node required to complete the pickups and each customer for dropoff as well as to return back. As anticipated, during the mission creation, ALLONS verifies mission consistency by checking several aspects such as:

- o Truck capacity to carry the quantities corresponding to the selected flows
- o ETA (Estimated Time Arrival) to logistics platform and customers is consistent with their time table
- o Preliminary estimation on delivery costs.

After all preliminary checks and computations, ALLONS carries out the simulation on the whole planning or on a subset including stochastic factors and replicating the experiments to measure the confidence band on the Key Performance Indexes (KPIs). ALLONS includes among the different KPIs: mission duration, mission costs, delays, vector saturation, service level, respect of the different constraints, etc.

$$SLa(t,s) = \frac{\sum_{i=1}^{n} |Fpa_{de}(t,i) - Fpa_{dr}(t,i)| \cdot Ap(i,s)}{Dt'^{(t,s)}}$$

$$SLc(t,c) = \frac{\sum_{i=1}^{n} |Fpc_{de}(t,i,c) - Fpc_{dr}(t,i,c)|}{Dt'(t,c)}$$

$$Fpa_{de}(t,i) = \int_{t_{low}(t)}^{t} de_i(x)dx$$

$$Fpa_{dr}(t,i) = \sum_{k=1}^{Nm} \sum_{j=1}^{m_k} do(i,k,j) \int_{t_{low}(t)}^{t} do_{k,j}(x)dx$$

$$Fpc_{de}(t,i,c) = Cpe(i,c) \int_{t_{low}(t)}^{t} de_i(x)dx$$

$$Fpc_{dr}(t,i,c) = \sum_{k=1}^{Nm} \sum_{j=1}^{m_k} Cpd(j,k,c) do(i,k,j) \int_{t_{low}(t)}^{t} do_{k,j}(x)dx$$

$$t_{low}(t) = \begin{cases} t \le t_0 & t_0 \\ t > t_0 & t \end{cases}$$

$$Ap(i,s) = \begin{cases} l_i \in s & +1 \\ l_i \notin s & 0 \end{cases}$$

$$do(i,k,j) = \begin{cases} l_i = des(k,j) & +1 \\ l_i \ne des(k,j) & 0 \end{cases}$$

$$Dt(t,s) = \sum_{i=1}^{n} Ap(i,s) \int_{t_{low}(t)}^{t} de_i(x)dx$$

$$Dt'(t,s) = \begin{cases} Dt(t,s) = 0 & +1 \\ Dt(t,s) \ne 0 & Dt(t,s) \end{cases}$$

SL(t,s)	Service Level at t time over s area
t	time
t_0	time at simulation start
t_{low}	low value of time window used to computer SL
Δt	time window amplitude (usually set equal to t)
n	number of the demand elements
m_k	number of drop offs of the k-th mission
Nm	Number of missions
$de_i(x)$	i-th demand at x time
$do_{k,j}(x)$	j-th dropoff of k-th mission at x time
des(k,j)	location nof the j-th dropoff of the k-th mission
Cpe(i,c)	check [0,1] if the i-th demand belongs to c-th customer
Cpd(j,k,c)	check [0,1] if the j-th dropoff of the k-th mission is addressing the c-th customer
do(i,k,j)	check about the fact the j-th dropoff of k-th mission addresses i-th demand

s	Subset of the overall region
l_i	Location of i-th demand
Fp(t,i)	Demand Satisfaction at t time over i-th demand
Ap(i,s)	Presence of i-th demand within s area
Dt(x,s)	Overall Demand over s area at x time
Dt'(x,s)	Corrected Overall Demand on s area at x time

To perform open tests of interface's usability and planner's functionality the authors created a public available database inspired to real cases.

For E&T applications the logistics flows are generated based on the statistical data related to customer demands by using Park-Miller PRNG (pseudo-random number generator) at the start of the session; indeed the scenario generator uses the customer data available in central database and creates the flow by considering the statistical momentum of the statistical distribution used for representing the logistics demand in terms of pallets ordered; in addition the generator could change service model (e.g. same day logistics service vs. 2 day lead time) and other parameters (e.g. peaks on weeks, average quantities).

ALLONS provides all data to conduct design of experiments and other analysis techniques (Montgomery 2008). This approach guarantees also the possibility to reproduce the same scenario multiple time keeping active the stochastic elements for crowdsourcing purposes based on collaborative and competition within a large community of people involved in using the simulation to find an "optimal solutions" (Mascagni 2016); in this way it is possible to generate a sequence of value that allows to reproduce the scenarios and validate potential choices from the users and customers in comparative mode. It's important to mention that all complex procedures like generation of flows are server-side, leaving for a browser only parts required to provide communication with server and implement user interface; this approach guarantees confidentiality of the inner models and parameter tuning in case of business applications.

The core of ALLONS is the simulation engine which allows to simulate the partial and complete planning considering the stochastic nature of flows, transportation and logistics operations; the simulation engine estimate the results of the execution on planned missions and evaluate KPIs and related risks. In facts to make the scenario even more realistic, the simulator creates stochastic events, for example driver could 'decide' to make a long break otherwise several short because his fatigue is increasing during work time. Another important aspect of functionality is intelligent correction of missions, for example if during loading at a warehouse the amount of pallets to be elaborated in current mission is higher than truck's capacity, mission is reprogrammed. It means that quantity of pallets which must be delivered is reduced reprogramming flows beginning from the last one in sequence, otherwise entire flow could be excluded from the mission. Mission planning horizon could be very long, for example several weeks, so to reduce calculation time and load of server discreet-event simulation is used. However results must be visualized in scaled real-time, so additional module for visualization is required.

So the ALLONS proposes the results of simulation in log window as text and on map updating them using timer.

Hence one hour or delivery is visualized always in the same amount of time, for example in 10 seconds.

To execute simulation in server and visualize results in browser real-time full-duplex data exchange must be provided; however due to limitations of HTTP(s) this task could not be performed using web-server only and additional communication protocol must be introduced. In presented case, this problem has been solved by using web-socket server.

This choice is due by the fact that modern browsers have native support of this technology and mainstream high-level programming languages could use web-socket modules and libraries to support it. Due the fact that simulator is developed in Python, most documented and supported technologies, such as Autobahn implementation of the protocol and Twisted networking engine, have been adopted. However the protocol itself allows to integrate into project additional modules in Python, Java, C++ and most of popular high-level programming languages.

As mentioned this communication protocol allows to operate in real-time; so by this approach users are enabled to interact with simulation during the execution and receive and visualize dynamically its results as soon as they are available, further improving ALLONS responsiveness.

6 CONCLUSIONS

As mentioned, ALLONS could be used not only for commercial delivery planning, but also for educational purposes; in facts by activating the auxiliary module it's possible to produce self assessment and evaluation of the planning as well as additional result of simulation. The planner provides a comprehensive analysis of the performance evaluating, among the others: percentage of flows successfully satisfied, fuel consumption and costs, early arrivals, delays in deliveries, truck overloads and other factors which affect customer satisfactory.

After simulation results these results are in databases, allowing the instructor, as well as the trainee, to compare efficiency of planning before and after training course.

The same stochastic scenario generation features permits to create exercises for large classes required to compete in finding best solution on a specific automatically generated case studies as well as to learn to collaborate to find a global solution by applying crowdsourcing (Brabham 2009).

In business use, the simulation results represent the crucial element to reconstruct partial data and obtain reference values for KPIs about future planning to be used to control the logistics processes and to obtain a competitive advantage.

REFERENCES

Adolf, K. N., & Liu, J. J. (2014) "Logistics, Supply Chain and Port Evolution", Port-Focal Logistics & Global Supply Chains, Palgrave Macmillan, UK

Amini, S., Gerostathopoulos, I., & Prehofer, C. (2017). "Big data analytics architecture for real-time traffic control", Proc. of *5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, pp. 710-715

Ayers J.B. (2001) "Handbook of Supply Chain Management", CRC Press Boca Raton, USA

Balci O., Castilla I., Longo F., Massei M. (2009) "Modeling and Applied Simulation", La Laguna University Press, ISBN 978-84-692-5417-2

Bang-Ning Hwang, Mei-Hua Chen (2013) "Key selection criteria for third party logistics in the IC manufacturing industry", Proc. of IEEE Service Operations Logistics, and Informatics, Dongguan, China, September 28-30

Benhayoun J. (2017) "Expansion on the Horizon", Port Strategy, May 5

Blackwell R.D. (1997) "From mind to Market: Reinventing the Retail Supply Chain", Harper Business, NYC

Bolstorff P.,Rosenbaum R. (2003) "Supply Chain Excellence", Amacom, NYC

Brabham, D. C. (2009) "Crowdsourcing the public participation process for planning projects", Planning Theory, 8(3), 242-262.

Bruzzone A.G., Massei M., Agresta M., Poggi S., Camponeschi F., Camponeschi M. (2014a) "Addressing strategic challenges on mega cities through MS2G", Proceedings of MAS2014, Bordeaux, France, September

Bruzzone, A. G., Longo, F., Massei, M., Nicoletti, L., & Agresta, M. (2014b) "Safety and security in fresh good supply chain", International journal of food engineering, 10(4), 545-556

Bruzzone, A. G., Bocca, E., & Poggi, S. (2007) "Proposal for an innovative approach for modelling goods flows in retail stores", Proc. of I3M, Bergeggi, Italy, September

Bruzzone A.G., Simeoni S., Bocca E. (2004) "Intelligent Management of a Logistics Platform for Fresh Goods", Proc. of SCI2004, Orlando, July

Bruzzone A.G. (2002) "Web Integrated Logistics and Artificial Intelligence Application for Creating Smart Logistics Networks", Proceeding of SCI2002, Orlando, July

Bryman, A., & Hardy, M. A. (2009) "*Handbook of data analysis*", Sage

Castanedo, F. (2013). A review of data fusion techniques. *The Scientific World Journal*, *2013*.

Cayirci E. (2013) "Modeling and Simulation as a Cloud Service: A Survey",Proc.of Winter Simulation, Washington DC

Christopher, M. (2016) "Logistics & supply chain management", Pearson, UK

Chopra, S., Meindl, P. (2001) "Supply Chain Management", Prentice Hall, NJ

Cooper, A. (2012) "What is Analytics?", CETIS Analytics Series, 1(5), 1-10

Davenport, T. H., Barth, P., & Bean, R. (2012). How big data is different. *MIT Sloan Management Review*, *54*(1), 43.

Donati, A. V., Montemanni, R., Casagrande, N., Rizzoli, A. E., & Gambardella, L. M. (2008) "Time dependent vehicle routing problem with a multi ant colony system", European Journal of Operational Research, 185(3), 1174-1191

Eurostat (2017) "Intra-EU Trade in Goods - Recent Trends", Technical Report, Bruxelles, January 2017

Eurostat (2016) "Half of EU Trade in goods is carried by Sea", News Release, 184/2016, September 28

Fabiano, B., Currò, F., Reverberi, A.P., Pastorino, R. (2005) "Dangerous good transportation by road: from risk analysis to emergency planning", Journal of Loss Prevention in the Process Industries, 18, (4-6), 403-413

Fawcett, S. E., & Cooper, M. B. (1998) "Logistics performance measurement and customer success" Industrial Marketing Management, 27(4), 341-357

Gironda, C. (2011) "Gioia Tauro: not city, not port. What strategies of development", Portus Plus, 2011

Gousty Yvon (1997) "Le Genie Industriel", Presse Universitaire Paris

Hu, Z. H., & Sheng, Z. H. (2014) "A decision support system for public logistics information service management and optimization", *Decision Support Systems*, *59*, 219-229.

Johansson, O., Pearce, D., & Maddison, D. (2014). *Blueprint 5: True costs of road transport*, Routledge, Vol.5

Kadel, R. (2010) "Data-Driven Decision Making--Not Just a Buzz Word" Learning & leading with technology, 37(7), 18-21

Kasilingam, R. G. (1998) "Logistics and transportation", Kluwer Academic Publishers

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. GeoJournal, 79(1), 1-14

Liew, C. S., Wah, T. Y., Shuja, J., & Daghighi, B. (2015) "Mining personal data using smartphones and wearable devices: A survey", *Sensors*, *15*(2), 4430-4469

Livernash T., Heuer, J.(2003)"Web Based Load Planning & Optimization",Flow Logistics,200,1-17

Longo F (2013) "On the short period production planning in industrial plants: a real case study", Int.Journal of Simulation & Process Modelling, vol. 8, p. 17-28.

Longo F., (2014). Testing the behaviour of different inventory control policies in case of extended reverse logistics by using simulation. International Journal of Simulation and Process Modelling, vol. 9, no. 3, pp. 167-180.

Lukosch, H., Kurapati, S., Bekebrede, G., Tiemersma, S., Groen, D., van Veen, L., & Verbraeck, A. (2016) "Design Considerations for Building a Scalable Digital Version of a Multi-player Educational Board Game for a MOOC in Logistics and Transportation", in Games and Learning Alliance, Springer, pp. 167-176

Maggi, E., & Mariotti, I. (2012) "Globalisation and the rise of Logistics FDI", Foreign Investment: Types, Methods and Impacts, Nova Science Pub., NY

Mascagni, M. (2016) "*Reproducibility in Stochastic Simulation"*, Doctoral dissertation, Old Dominion University, Norfolk

Massei, M., Tremori, A. (2010) "Mobile training solutions based on ST_VP: an HLA virtual simulation for training and virtual prototyping within ports", Proc. of Int. Workshop on Applied M&S , St.Petersburg, Russia, May

Monks J., (1996) "Operation Management", McGraw Hill, NYC

Montgomery D.C. (2000) "Design and Analysis of Experiments", John Wiley & Sons, New York

NMSG (2016) "Modelling and Simulation as a Service (MSaaS) Rapid deployment of interoperable and credible simulation environments", NATO STO NMSG-136 Technical Report, Buxell

Notteboom, T. E. (2004) "Container shipping and ports: an overview", Review of Network Economics, 3(2)

Pendyala, R., Shankar, V., & McCullough, R. (2000) "Freight travel demand modeling: synthesis of approaches and

development of a framework", Transportation Research Record: Journal of the Transportation Research Board, (1725), 9-16
Perakovic D., Perisa M., Sente R.S. (2017) "New Challenges of ICT usage in Transport And Logistics", Proc. of 6th Int. Conf on Transport and Logistics, TIL
Press G. (2016) "Internet Of Things By The Numbers: What New Surveys Found", Forbes, Sept. 2
Schuler M. (2016) "Suez Canal Fires Back: Vast Majority of Ships Not Taking Cape of Good Hope Route", GCaptain, March 10
Siegfried, R., van den Berg, T., Cramp, A., & Huiskamp, W. (2014) "M&S as a Service: Expectations and Challenges",Proc. of Fall SIW, Orlando, FL, pp. 248-257
Tsai W.T., Zhibin Cao, Xiao Wei, Ray Paul, Qian Huang, Xin Sun (2007) "Modeling and Simulation in Service-Oriented Software Development", Simulation, Vol.83, n.1, pp.7-32, January 1
Voss, S., Sebastian, H. J., & Pahl, J. (2017) "Introduction to Intelligent Decision Support and Big Data for Logistics and Supply Chain Management Minitrack", Proceedings of the 50th Hawaii International Conference on System Sciences
Wenjing Li, Chunyu Xia (2010) "The Impact of Logistics Mode on Retailer's Logistics Performance Measurement System", Proc. of Int.Conf. on Management oand Service Science, Wuhan, China, August 24-26
World Shipping Council (2007) "The Suez Canal - A vital shortcut for global commerce", Technical Report, Washington DC
Yetkili, E., Dogan Ertugrul, Baltaouglu S., Salihoglu I. (2015) "Economic Analysis of Container Transhipment in the Eastern Mediterranean Region", Int.Journal of Environmental and Geoinformatics, 3 (1), 12-21
Zhao, R., Liu, Y., Zhang, N., & Huang, T. (2017) "An optimization model for green supply chain management by using a Big Data Analytic Approach", *Journal of Cleaner Production*, *142*, 1085-1097

SIMULATION AND VISUALIZATION TO SUPPORT MATERIAL FLOW PLANNING IN A METAL CONSTRUCTION COMPANY

Gaby Neumann[(a)], Thomas Masurat[(b)]

[(a),(b)]Technical University of Applied Sciences Wildau, Germany

[(a)]gaby.neumann@th-wildau.de, [(b)]thomas.masurat@th-wildau.de

ABSTRACT
This paper describes application of simulation and visualization techniques to support factory restructuring, material flow planning, and warehouse design in a family-owned metal construction company. Particular challenges lay in dynamically changing market situation at both customer and supplier sides, space-consuming dimension of the materials to be handled, and ill-structured information base for order management, production planning and control, and inventory management. This project is used as example for more generally discussing current situation of Digital Factory implementation especially in small and medium-sized enterprises. In the end, the paper concludes on barriers eventually hindering a consistent application of this comprehensive concept and underlines specific advantages from using simulation and visualization in the given context.

Keywords: Digital Factory, material flow planning, logistics simulation, 3D visualization

1. INTRODUCTION

A small family-owned metal construction company employs about 10 manufacturing workers and 3 logistics workers. They produce about 1,400 customer-specific metal constructions of different design, size and features according to the make-to-order principle. Final assembly and usage of the aluminium constructions in the building is done by company-own assembly workers directly on the construction site. Because of the close link to the construction sector and the dependency on the overall progress in the construction that is strongly influenced by external conditions and other parameters, delivery and assembly deadlines are highly dynamic and hardly predictable in nature. This might lead to a delay in being called to the construction site or to an earlier demand for using the aluminium construction in the building. Because of this, but also due to large-scale seasonal variations hardly to be predicted the company needs to be flexible and reactive in fulfilling customer orders.

Production is characterized by a high vertical range of manufacture with a manufacturing step from the middle of the product engineering process being outsourced. Production steps are organized in technologically sound manner and do not show any capacitive bottlenecks. In contrast to this, material flows and the link to the warehouse have not been treated well. This results in a high degree of non-transparency in material staging and a large percentage of idle performance mainly in storing, retrieving and restoring not to be quantified so far.

However, the project’s exceptionality does not only come from constraints described above and the strong market dependency with regard to customer orders and procurement policy. On top an enterprise of this size and from this industrial sector typically lacks access to simulation and visualization as methods to accompany planning and development. Only CAD is regularly used for designing customer-specific constructions. This strongly product-focused approach is symptomatic; neither product process organization nor its systemic tool-based support gain the same amount of attention. Chances from pervasively applying models, methods and tools to represent, analyse and provide information on a factory in its entirety of product and production process are not understood. Instead they are seen as unrealistic and straining after effect.

This observation leads to the question for why the Digital Factory concept still is not applied in practice in large scale more than one and a half decades after first discussions on this topic arose. After briefly presenting the concept’s background and state-of-the-art (Section 2), this question is going to be addressed in Section 3 of this paper in both ways in the context of small and medium sized enterprises (SME) in general and with regard to the company under investigation in particular. Section 4 explains application of simulation and visualization in the project presented above, discusses effects resulting from applying those methods, and indicates limitation of their use. The paper concludes with a reflection on barriers hindering pervasive implementation of the Digital Factory concept particularly in an SME and derives recommendations for action to overcome them (Section 5).

2. THE DIGITAL FACTORY CONCEPT

Digital Factory is a phenomenon having its background in computer-aided and computer-integrated technologies and advanced virtual reality (VR) technologies. It entitles the virtual environment for the lifecycle design of manufacturing processes and manufacturing systems using simulation and VR technologies to optimize performance, productivity, timing, costs, and ergonomics (Gregor and Medvecky 2010). According to the respective guideline by VDI (2008, p. 3) "Digital Factory is the generic term for a comprehensive network of digital models, methods and tools – including simulation and 3D-visualisation – integrated by a continuous data management system. Its aim is the holistic planning, evaluation and ongoing improvement of all the main structures, processes and resources of the real factory in conjunction with the product." This concept is illustrated by Figure 1.

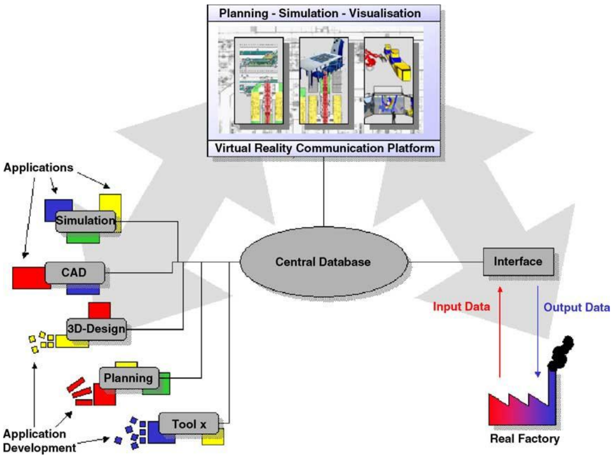


Figure 1: The Vision of the Digital Factory (Bracht and Masurat 2005, p. 327)

All computer-aided tools necessary for planning new products and production plants as well as for factory operation are interlinked through a central database. The entire factory is is represented in a consistent VR model which can be applied continuously all the way from the product idea to the final dismantling of the production plant and buildings. Those digital models form the basis for interdisciplinary cooperation among various experts from product design to inspection of new or modified factory. (Bracht and Masurat 2005)
Consequently, integration is one of the main pre-conditions for implementing the Digital Factory concept. According to Delmia (2010) there are three main elements to be integrated:

- *digital product* with its static and dynamic properties;
- *digital production planning*;
- *digital production* with the possibility of utilizing planning data for growing effectiveness of enterprise processes.

VDI (2008) integrates the following processes in the Digital Factory concept:

- *product* development, test, and optimization;
- *production process* development and optimization;
- *plant* design and improvement;
- *operative production* planning and control.

Plant design and optimization focuses on the optimization of material flow, resource utilization and logistics of all levels of plant planning from global production networks through local plants down to specific lines in order to improve production layout, assure machines and equipment being at the right place, have sufficient materials handling equipment available, optimize buffer dimensions, keep product handling at minimum etc. (Kühn 2006) Here, main focus is put on modelling and simulation techniques as they enable dynamic analysis to ensure that plant design problems and waste are discovered before the company ramps-up for production.
Even though simulation and visualisation play a major role in the Digital Factory concept, the integrative approach in terms of both elements covered and processes supported differentiates the Digital Factory from related concepts like the Virtual Factory or the Smart factory.
The *Virtual Factory* concept dating back to the 1990s is a major driver for the move towards integrating VR and discrete event simulation (DES). Jain et al. (2001) define the *Virtual Factory* concept as an "integrated simulation model of major subsystems in a factory that considers the factory as a whole and provides an advanced decision support capability." In this concept DES is a core component of a holistic model of the factory where DES enables an integrated view encompassing all major subsystems to be formed (Turner et al. 2016). Later concepts also address interoperability of the Virtual Factory at data level, service level, and process level. However, The Virtual Factory is, and should be, "a VR representation" for a factory, with 3-D environments and visualization essential for understanding and knowledge share (Jain and Shao 2014).
The *Smart Factory* is strongly related to Industry 4.0 – the fourth industrial revolution. Production and administrative processes are meshed with each other via IT systems in order to optimize the use and capacity of machines and lines. This way agile production systems are created responding to fast changing consumer markets. The factory can be modified and expanded at will, combines all components from different manufacturers and enables them to take on context-related tasks autonomously (James 2012). Therefore, Turner et al. (2016) see the Smart Factory as practical implementation of the Virtual Factory concept – enabling next generation factories being able to produce customized and small-lot products efficiently and profitably (Wang et al. 2016).
Comparing the concepts introduced so far their different focusses become obvious. Whereas the Smart Factory allows for semi-autonomous decision making in physical factory operation, the Virtual Factory aids the

decision-making process by means of simulation and 3D visualization. The Digital Factory spans from product development to plant design and production planning and control, i.e. it supports planning and development alongside the entire product life cycle including related resources and their operation to prepare physical (even smart) factory operation. The Digital Factory is a planning tool in its widest sense.

At the beginning of the new Millennium Digital Factory as a vision got a boost. Research and development activities focussed on how to implement its concepts, methods and tools into practice inside and across companies and industrial sectors. In Germany, this development was mainly driven by large enterprises, first of all from the car manufacturing sector, as they were absolutely sure about tremendous advantages from letting this vision come to life. Today, we can state the Digital Factory being well established in those enterprises with the Smart Factory still being a vision for future even there (Strehlitz 2016). Application examples from other countries and industrial sector, e.g. from the aerospace industry (Caggiano et al. 2015) or tricanter production (Kyncl et al. 2017), support this situation analysis on Digital Factory implementation. In contrast to this, current situation of Digital Factory implementation is very much different when looking into small and medium-sized enterprises (SMEs).

3. DIGITAL FACTORY IN AN SME CONTEXT

Answering the question for the current level of practical implementation of the Digital Factory concept in SMEs is challenging as those companies do not report in wide scale about how they apply Digital Factory methods and tools.

Bierschenk et al. (2004) run a survey to get a glimpse on the current state of the Digitial Factory in SMEs. As result it became clear that SMEs do not follow large companies in implementing the Digital Factory concept. High costs (64%) and unclear benefits (73%) were identified as main barriers, even though SMEs already saw the enormous potential in terms of savings and increasing competitiveness.

Bracht and Masurat (2005) warned about the particular importance of integrating the fundamental idea of the Digital Factory into the supply chain for gaining competitive advantage. SMEs need to keep up with modern planning procedures for dimensioning their storage and distribution concepts or deriving new organizational structures. This will result in enormous savings in time and costs. However, the efforts necessary for implementation have in part been underestimated and are still underestimated. Especially costs for purchasing suitable software tools are still relatively high. Whereas large enterprises are able to handle those costs, for SMEs they form a large obstacle causing disproportionately high investments.

Five years later, Bracht and Reichert (2010) renewed this message and predicted an increased need for implementing digital methods not only in product development, but also in process, production, and factory planning. For ensuring their own survival in a globalized world SMEs face the inescapable necessity of introducing the Digital Factory.

However, Schallow et al. (2014) still report about lacking implementation of the Digital Factory in SMEs. According to their survey about 45% of participating SMEs even see “Digital Factory” as a buzzword only. Authors conclude that the majority of digital tools available at the market are not suitable for SMEs. This statement first of all refers to tools supporting factory planning, e.g. process simulation or 3D layout planning. Here, costs for purchasing tools and qualifying employees in using them does not pay back to an SME. On top, frequency of planning tasks is rather small making it more difficult to create a sufficient experience base with employees. In contrast to this, the degree of integration of digital tools in product development and production is already quite high. This strong focus on “digital islands” reported by about 94% of SMEs in the study goes in line with media or software disruption. About 88% of the companies criticize a lack of standards regarding interfaces and data (Schallow et al. 2014). Comprehensiveness as required by VDI (2008) obviously does not exist in SMEs.

Similar findings result from analysing more than 200 student projects run with companies when preparing Bachelor or Master thesis at the Technical University of Applied Sciences in Wildau. About 20% of all projects were run with OEMs, but just five projects were allocated in the Digital Factory context, mainly for 3D planning or simulation of robot behaviour and transformation processes. None of these five thesis projects was run in an SME which confirms the weak picture about the reality of Digital Factory in those companies. SMEs usually point on missing tools and doubt about a substantial need for them within the specific company context. Planning problems are seen as simple enough to solve them without support by digital tools. For eventually appearing planning mistakes that could have been avoided e.g. by use of simulation it is almost impossible to specify resulting additional costs. Because of these difficulties in giving proof of economic benefit they also do not see any economic advantage in implementing the Digital Factory concept or even introduce digital tools for planning support in their processes. Instead SMEs look for methods and tools helping them in better managing daily production and reducing order lead-time, production costs or capital lockup.

The general state-of-implementation of the Digital Factory concept in SMEs as elaborated so far now forms the starting point for discussion in the context of a project run with a family-owned metal construction company. Here, as in many other companies, clear advantages from digital product development are well known. Computer-Aided Design (CAD) techniques are taken for granted to have detailed technical drawings directly created by the designer of customer-specific aluminium constructions and also to share them with others in a company-wide collaboration approach. In contrast to this neither Enterprise Resource Planning (ERP) nor Production Scheduling and Control (PSC) systems are used in this company to digitally support the company's business processes. Simulation and visualization techniques are fully unknown creating a lot of scepticism towards their use in the project. Therefore, apart from solving the initial problems concerning factory layout, material flows and warehouse capacity, major challenges throughout the entire project consisted in introducing simulation and visualization at all, raising awareness on the required database, and building trust in results from their application.

4. SIMULATION AND VISUALIZATION SUPPORT IN A COMPANY PROJECT

The presented project aimed at supporting warehouse planning and material flow-oriented factory re-engineering. In order to determine weak points and identify potential for improvement, the project started with comprehensively analysing the current situation of production process, material flows, inventory and the factory as a whole. From this, various fields requiring action got derived. The warehouse was overcrowded with many materials being stored on floor space in front of the cantilever racks and between workstations. Material flows were quite complex and non-directed; many materials were moved forth and back just passing the warehouse without any storing necessity (see Figure 2). In contrast to this, the production process run smoothly with all workstations showing quite some spare capacity. Because of this, situation analysis resulted in expressing the urgent need for clearing material flows by re-locating workstations and warehouse, i.e. improving factory layout. Furthermore, the company was told to introduce accompanying measures like definition of standard processes or unlinking warehouse management from a particular person.

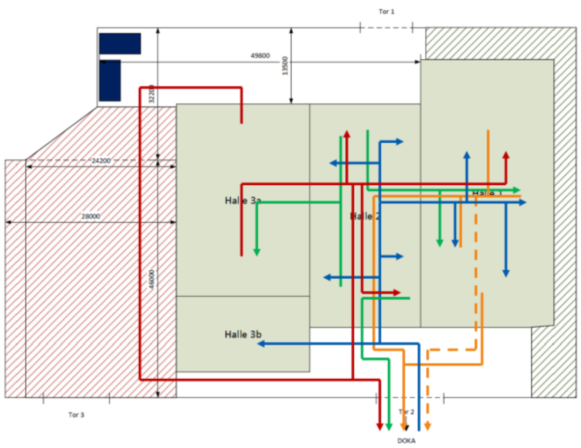


Figure 2: Initial Material Flows

To support factory and warehouse planning as well as layout re-design application of simulation and 3D visualization techniques were suggested. This was not caused by process complexity inside the factory, but much more by the unclear situation in terms of available data. Despite of tremendous efforts in the analysing phase, it was practically impossible to get reliable data on storage/retrieval activities in the warehouse, inventory level per material, warehouse refilling processes including related purchasing decisions, manufacturing order management etc. On top of this unclear in-house situation there are various external influences hardly to predict, like customer behaviour or development of the aluminium market.

Against this background simulation experiments should help in comparing layout variants according to material flow efforts needed to assure a given production output. In the context of warehouse planning inventory development over time should be investigated in order to derive required warehouse capacity, the needed buffer space or additional floor space to provide workstations with material, and determine appropriate purchasing behaviour. Due to missing process data extreme situations were planned to be simulated to analyse their impacts on system performance. However, in the end not even this quite rough analysis of the factory was possible by use of simulation since minimum simulation database was not existing and could not be estimated at meaningful level. As a consequence, developed factory layout variants were compared in an analytical way and by means of static visualization only (see Figure 3). To eventually make simulation possible in future (and to move company management into the 21st Century) the company got a long list of what urgently needs to be done in order to set up information flows and data management of standard level in production companies.

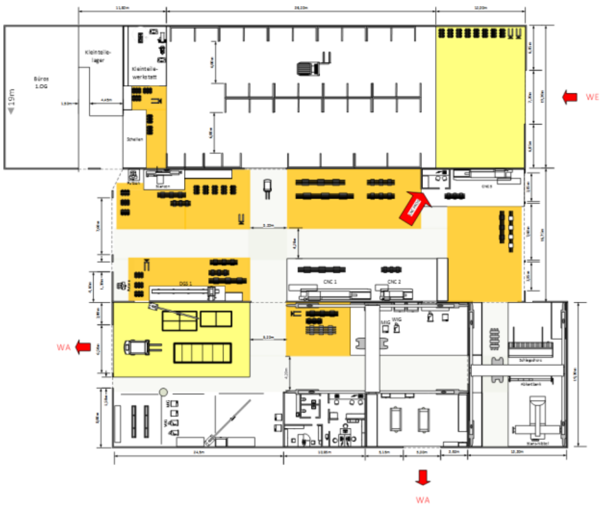


Figure 3: Layout after Re-design

3D visualization aimed to virtually analyse handling operations for large-size materials and semi-products in an environment with narrow aisles and gate of limiting size. For this, the chosen layout (see Figure 3) was represented in a dynamic VR model with all materials handling equipment operating according to their technical characteristics (see Figure 4). Here, simple tests for collision using geometric covers gave proof of the proposal's functionality. Furthermore, the 3D model clearly illustrated the well-structured design of the factory and the dynamic VR scene with its possibility to fly over or walk through became the decisive tool to immediately get production workers and logisticians convinced about the usefulness of the proposed changes. In the end, even the very sceptic company owner agreed on the need for change when seeing his new factory in a close-to-real way.

Figure 4: VR Scene of the Factory after Re-design

With this the project demonstrated the powerfulness of digital support in different planning stages. Of course, this is no news to the scientific community nor to large companies with own simulation and visualization departments having implemented the Digital Factory concept already. For a small company like the one under investigation this finding forms a huge step towards a paradigm shift. Additionally this project is a good example for reminding of the need to question if a problem is worth to be simulated. Because of the confusing, ill-structured initial situation in the factory simulation seemed to have been needed. In the end it turned out that to some extent simulation became obsolete in the problem solving process due to the use of appropriate software for (static) visualization and after re-structuring the factory following a logistics-oriented design. Nevertheless, simulation still would have been (and is) on the agenda for answering all questions related to dynamic forecasting and system performance analysis. In the course of the project the company understood the general importance of a sufficient database and looks for further digital planning and scheduling support by means of simulation once a reliable simulation database has been created.

5. CONCLUSIONS

The presented project is a simple example for applying the Digital Factory concept in a small enterprise from a traditionally rather innovation-hesitant industrial sector. Due to an almost completely missing simulation database purposeful simulation model-building and simulation-based experimentation were impossible. Even though this created quite some extra challenges to the project, the company – after many discussions – learned significant lessons from this. In the end, a solution to the initial problems was proposed on the basis of which the company completely re-organised and re-designed factory layout, processes, material flows, and warehouse solution. Visualization models helped in presenting problems and ideas during project evolution, but even more important they finally were the clue to convince the company owner of the solution's functionality, effectiveness and future-orientation. Whereas all proposals got implemented by now, the project also initiated additional change. Processes are going to be standardized; preconditions for an up-to-date and comprehensive data management are on the way to enable order tracking, stock monitoring, and procurement management. Last but not least, the company after all is strongly interested in applying simulation methodology for system performance limit determination and further process optimization.

This example, at a first glance, seams to put the Digital Factory concept into question rather than supporting the need and usefulness of its implementation. At a closer look it demonstrates the opposite. Even a small family-owned enterprise far away from a high-technology business lacks digital support in adjusting the factory and its processes to current and future needs.

The digital factory concept is an integrated approach to enhance the product and production engineering processes. Simulation is a very important key technology in the overall concept and can be applied in virtual models on various planning levels and stages to improve the product and process planning. Pre-condition for properly applying simulation technology in this context is a sound simulation data base.

According to the vision presented in this paper, nowadays an integrated concept of digital validation should form the methodological basis of all factory and material flow planning activities in large-scale industrial enterprises and company groups at least. However, to expect something similar with regard to SMEs seems to be illusionary. Here, an ongoing learning process is still needed to introduce certain aspects and specific parts of the Digital Factory concept fitting the particular needs and opportunities of the company.

Latest surveys on the potential future of the Digital Factory give a quite optimistic outlook. According to Geissbauer et al. (2017), for example,

- 91% of industrial companies are investing in creating Digital Factories in the heart of Europe,
- 98% of industrial companies expect to increase efficiency with digital technologies,
- 90% of industrial companies believe that digitization offers them more opportunities than risks.

As digitization does not only refer to the Digital Factory concept supporting planning processes, but also to the Smart Factory idea leading to the next evolutionary step in factory operation, another boost in integrating digital tools also in SMEs is to be expected in the coming years.

REFERENCES

Bierschenk S., Kuhlmann T., Ritter A. (2004). *Stand der Digitalen Fabrik bei kleinen und mittelständischen Unternehmen*. Stuttgart: IRB Verlag.

Bracht U., Masurat T., 2005. The Digital Factory between vision and reality. *Computers in Industry* 56 (2005), 325–333.

Bracht U., Reichert J., 2010. Digitale Fabrik – auch KMU sind aufgefordert künftig ihre Fabriken in 3D-CAD zu planen. *Industrie Management* 26 (2010) 2, 65-68.

Caggiano A., Caiazzo F., Teti R., 2015. Digital factory approach for flexible and efficient manufacturing systems in the aerospace industry. *Procedia CIRP* 37 (2015) 122-127. 7-9 April 2015, Sydney, Australia.

Delmia, 2010. *Solutions Portfolio*. Paris: DELMIA.

Geissbauer R., Schrauf S., Berttram P., Cheraghi, F. (2017). *Digital Factories 2020: Shaping the future of manufacturing*. PwC.

Gregor M., Medvecky S., 2010. Digital factory – theory and practice. In: Dudas L., eds., *Engineering the Future*. InTech. Available from: www.intechopen.com/books/engineering-the-future/digital-factory-theory-and-practice [accessed 31 July 2017]

Jain S., Choong N.F., Aye K.M., Luo M., 2001. Virtual factory: An integrated approach to manufacturing systems modeling. *International Journal of Operations & Production Management*, vol. 21, nos. 5/6, 594–608.

Jain S., Shao, G., 2014. Virtual factory revisited for manufacturing data analytics. *Proceedings of the 2014 Winter Simulation Conference*, 887–898. 07 Dec – 10 Dec 2014, Savannah, GA, USA.

James T., 2012. Smart Special – Smart Factories. *E&T Engineering and Technology*, publ. June 18, 2012. Available from: https://eandt.theiet.org/content/articles/2012/06/smart-special-smart-factories/ [accessed 31 July 2017]

Kühn W., 2006. Digital Factory – simulation enhancing the product and production engineering process. *Proceedings of the 2006 Winter Simulation Conference*, 1899-1906. 03 Dec - 06 Dec 2006, Monterey, CA, USA.

Kyncl J., Kellner T., Kubis R., 2017. Tricanter production process optimization by digital factory simulation tools. *Manufacturing Technology*, vol. 17, issue 1, 49-53.

Schallow J., Ludevig J., Schmidt M., Deuse J., Marczinski G., 2014. Zukunftsperspektiven der Digitalen Fabrik: Verständnis, Umsetzungsstand und Entwicklungsmöglichkeiten der digitalen Produktionsplanung. *wt Werkstattstechnik online*, 104 (2014) 3, 139-145.

Strehlitz M., 2016. Digitale Fabrik und Industrie 4.0: Verbindung zweier Welten. *AUTOMOBIL PRODUKTION*, publ. 07 June 2016. Available from: https://www.automobil-produktion.de/iot-by-sap/iot-by-sap/verbindung-zweier-welten-365.html [accessed 31 July 2017]

Turner C.J., Hutabarat W., Oyekan J., Tiwari A., 2016. Discrete Event Simulation and Virtual Reality Use in Industry: New Opportunities and Future Trends. *IEEE Transactions on Human-Machine Systems*, vol. 46, no. 6, 882-894.

VDI, 2008. Digital Factory - Fundamentals. *VDI 4499 part 1*, Düsseldorf: German Association of Engineers (VDI).

Wang S., Wan J., Li D., Zhang C., 2016. Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks*, vol. 2016, article ID 3159805, 10 pages.

AUTHORS' BIOGRAPHIES

Gaby Neumann holds a professorship in Engineering Logistics at the Technical University of Applied Sciences Wildau. She received a Diploma in Materials Handling Technology from the Otto-von-Guericke-University of Technology in Magdeburg and a PhD in Logistics from the University of Magdeburg for her dissertation on "Knowledge-Based Support for the Planner of Crane-Operated Materials Flow Solutions". Between December 2002 and June 2009 she was Junior Professor in Logistics Knowledge Management at the Faculty of Mechanical Engineering there. Since 1991 she also has been working as part-time consultant in materials handling simulation, logistics planning and specification of professional competences in certain fields of logistics. Her current activities and research interests are linked amongst others to fields like problem solving, knowledge management and technology-based competence-building in logistics simulation. She has been or is being involved in a couple of research and company projects in these fields. Gaby Neumann has widely published and regularly presents related research papers at national and international conferences.

Thomas Masurat holds a professorship in Production Organization and Factory Planning at the Technical University of Applied Sciences Wildau. He received a Diploma in Mechanical Engineering from the Technical University Clausthal and a PhD from this university for his dissertation on "New organisational structures for an integrated product and process engineering in the context of a Digital Factory". From 2006 to 2010 he was team manager with Airbus CIMPA in Hamburg. As part of his scientific work he was member of "Digital Factory" expert committees within the German Association of Engineers (VDI). Thomas Masurat regularly has been or is being involved or runs various research and company projects related to factory planning and organization.

AUTHORS' INDEX