THE 15TH INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELLING AND SIMULATION

SEPTEMBER 25-27 2013

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EDITED BY

AGOSTINO G. BRUZZONE

MANFRED GRONALT

YURY MERKURYEV

MIQUEL ANGEL PIERA

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EDITORS

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

MANFRED GRONALT
UNIVERSITY OF NATURAL RESOURCES AND LIFE SCIENCES, AUSTRIA
manfred.gronalt@boku.ac.at

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

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

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Welcome to the 15th International Conference on Harbor, Maritime & Multimodal Logistics Modeling and Simulation, that is a great opportunity for worldwide scientists and experts to share experiences, recent research efforts, studies and applications related to maritime environments, logistics and supply chain management issues. HMS is a traditional event and it has been held successfully worldwide, usually in the surroundings of major international ports such as Genoa (1999) or Marseille (2001), Gioia Tauro (2008), etc.

The tracks, special sessions and workshops, which are part of HMS, provide an excellent overview of recent advances in this field, which can be regarded as an increasingly important factor for the overall economic development both at national and international levels.

Within this framework, Modeling & Simulation has proved to be very effective to support decision making and training. The HMS 2013 conference is an ideal framework for authors that present innovative technologies, new approaches and advanced solutions based on Modeling & Simulation in order to provide a valid support for experts, authorities and operators in maritime and transportation sector to plan effective actions, to optimize supply chain, to improve transportation systems and services or simply to train people.

The success of HMS 2013 is related to the strong efforts of the International Program Committee that, also this year, has worked hard to review and select high quality papers and scientific works. Therefore we appreciate reviewers' work and thank them for their valuable cooperation. Last but not least, a special thank goes to the authors that are the main contributors of HMS's success.

We would like to wish all the conference attendees a pleasant stay in Athens and to have a fruitful and memorable time during the HMS 2013 Conference.

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

Yuri Merkuryev
Riga Technical University, Latvia

Manfred Gronalt
University Of Natural Resources And Life Sciences ATHENS, Austria

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The HMS 2013 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 2013 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

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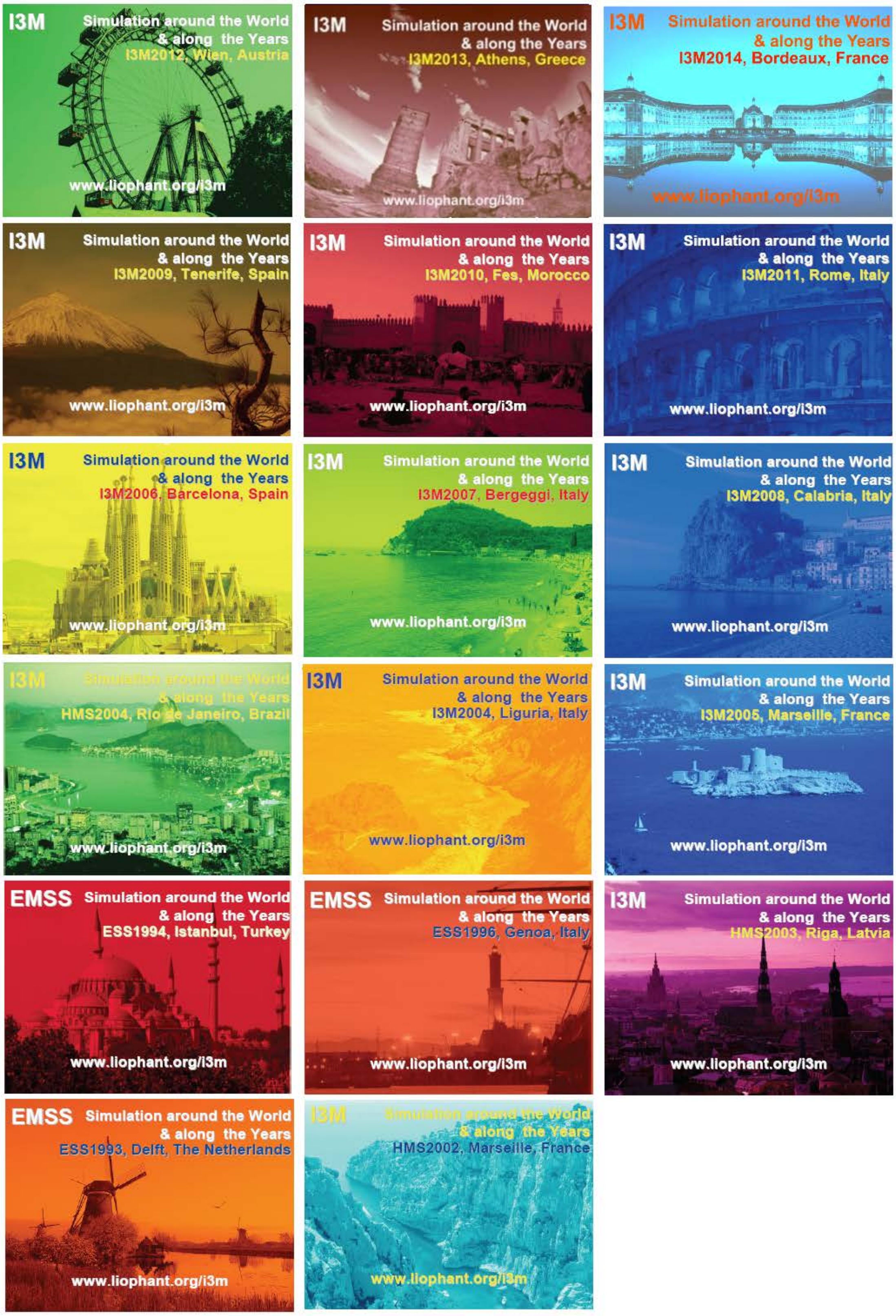

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USE OF MODELLING FOR ASSESSMENT OF LATVIAN ROAD SAFETY AND LOGISTICS COSTS MINIMIZATION

Vitalijs Jurenoks [(a)], Vladimirs Jansons[(b)], Konstantins Didenko[(c)]

[(a)]Riga Technical University, Latvia
[(b)]Riga Technical University, Latvia
[(c)]Riga Technical University, Latvia

[(a)] vitalijs.jurenoks@rtu.lv, [(b)] vladjans@latnet.lv, [(c)]konstantins.didenko@rtu.lv

ABSTRACT
In this article attention is paid to the assessment of the number of accidents on main roads of Latvia, as well as the analysis and evaluation of the cargo insurance premium and modelling of logistics service costs $P^*_{delivery}$, taking into account the most essential risks of the logistics process.
The principal objectives of this research work are:
- to consider an option of modelling for the assessment of Latvian road safety and number of accidents on roads;
- to model the value of the cargo insurance premium P and logistics service costs $P^*_{delivery}$.

Keywords:
Logistics systems, nonparametric modelling, road safety, insurance modelling, cost optimization.

1. THEORETICAL APPROACH TO THE PROBLEM AND SYSTEM DESCRIPTION

Organisation of processes in the sphere of logistics requires optimization of time parameters and costs with regard to cargo transportation. At the same time, a problem arises to establish an agreed amount of price $P_{delivery}$ for the delivery of cargo from the point of dispatch to the point of destination, the insurance premium P for cargo and as result value $P^*_{delivery}$ – logistic service cost. In a general case, the value of $P_{delivery}$ can be presented as a function of a range of variables (factors characterizing the particular cargo and its terms of delivery), namely:

$$P_{deliv} = \Phi\ (KF,\ V,\ W,\ KT,\ FR\ ,\ KR\ ,\ T,\ F_{t_1},\ F_{t_2}\ ,\ M,\ Y). \qquad (1)$$

Corresponding feasible sets for model parameters are defined below:

$$KF \in A_{KF},\ V \in A_V,\ W \in A_W,\ KT \in A_{KT},\ FR \in A_{FR}, \quad KR \in A_{KR},\ T \in A_T,\ F_{t_1}, F_{t_1} \in A_{F_t}, M \in A_M,\ Y \in A_Y. \qquad (2)$$

Feasible sets A_{KF}, A_V, …, A_Y for model parameters depend on the characteristics of the logistics process.

The parameters of the model are follows: KF – type of cargo transported (table 1); V - total volume of cargo carried in containers; W - transportable cargo weight; KT – type of cargo transportation (table 2); FR - types of financial risks (table 3); KR – the type of roads (table 4); T - time of delivery from the consignor to the consignee; F_{t1} - price of 1L of diesel fuel used by transportation vehicles at the moment of signing the contract; F_{t2} - price of 1L of diesel fuel used by transportation vehicles when transporting cargo; M - route which is used for transporting cargo. Y - other factors characterising the particular cargo to be transported and its terms of delivery.

Table 1: Types of Cargo Transported

i	KF_i
1	General Goods
2	Dangerous Goods (hazard risk of cargo, according to the IMO (International Maritime Organization classification)
3	Perishable goods (mostly, consumable goods)
4	Non-standard and heavy cargo
5	Consolidated cargo
6	Transportation of bulk and liquid cargoes
7	Car transportation
8	Live transportation
9	Other types of cargo

The type of equipment used for transportation of cargoes is (V_1 = 20` or $V_2$ = 40` containers). The dimensions of a 20` container are: L = 6m, w = 2.25 m, h = 2.33m. The dimensions of a 40` container are: L = 12m, w = 2.25 m, h = 2.33m; (W_1 – 3 ton container, container loading rate 2,400 kg; W_2 – 5 ton container, container loading rate 4,000 kg; W_3 - 20' container, container loading rate of up to 21,800 kg of packaged unit cargo; W_4 - 40' container, container loading rate of up to 30,000 kg (30 t).

Table 2: Types of Cargo Transportation

i	KT_i
1	Railroad transportation
2	Sea transportation
3	River transportation
4	Road transportation
5	Air transportation

Types of financial risks (FR) are shown in table 3.

Table 3: Types of Financial Risks

i	FR_i
1. Market Risk	Absolute risk, Relative risk, Directional risk (Linear risk exposure), Non Directional risk, Basis risk, Volatility risk.
2. Liquidity Risk	Asset Liquidity risk, Funding Liquidity risk.
3. Credit Risk	Exposure, Recovery rate, Credit event, Sovereign risk, Settlement risk.
4. Operational Risk	Model risk, People risk, Legal risk.

Types of roads (KR_i) to transport goods are shown in table 4.

Table 4: Types of Roads

	Lenght of roads on 1 January 2012, km			
Classification of roads, incl.	Paved roads	Single and gravel roads	No cover	Total
State roads	8,455,688	11,660,644		11,660,644
Main roads	1,650,522			1,650,522
Regional roads	4,188,236	1,127,487		5,315,723
Local roads	2,616,93	10,533,157		13,150,09
Local goverment roads and streets, uncl.	5,643,787	33,039,365		38,683,15
Roads	1,055,61	29.593		30,648,61
Streets	4,588,177	3,446,365		8,034,542
Forest roads		6.216	3.926	10.142
Private roads	500	3		3.5
Total roads and streets	14,599,48	53,916,009	3.926	72,441,48

The scheme of the M_i^{th} route of traffic with the relevant road traffic parameters of every section of the route from point A to point D is presented in figure 1.

Figure 1: Scheme of the M_i^{th} Route of Road Traffic between Points A and D

2. METHODOLOGY OF INVESTIGATION

This paper investigates the possibility of minimizing the function $P^*_{delivery}$ depending on the additional parameters introduced into the model by the authors, namely:

- road conditions, as indicated by the number of traffic accidents on the roads of Latvia;
- modelling of logistic service cost;
- assessment of financial stability of TLS;
- investigation of weak points in TLS;
- amount of the insurance premium.

Methods of investigation are: multistatistical methods of modelling; scanstatistics methods; Monte-Karlo nonparametric statistical methods; financial and actuarial mathematical methods.

The main blocks of modelling of transport logistic process are presented in figure 2.

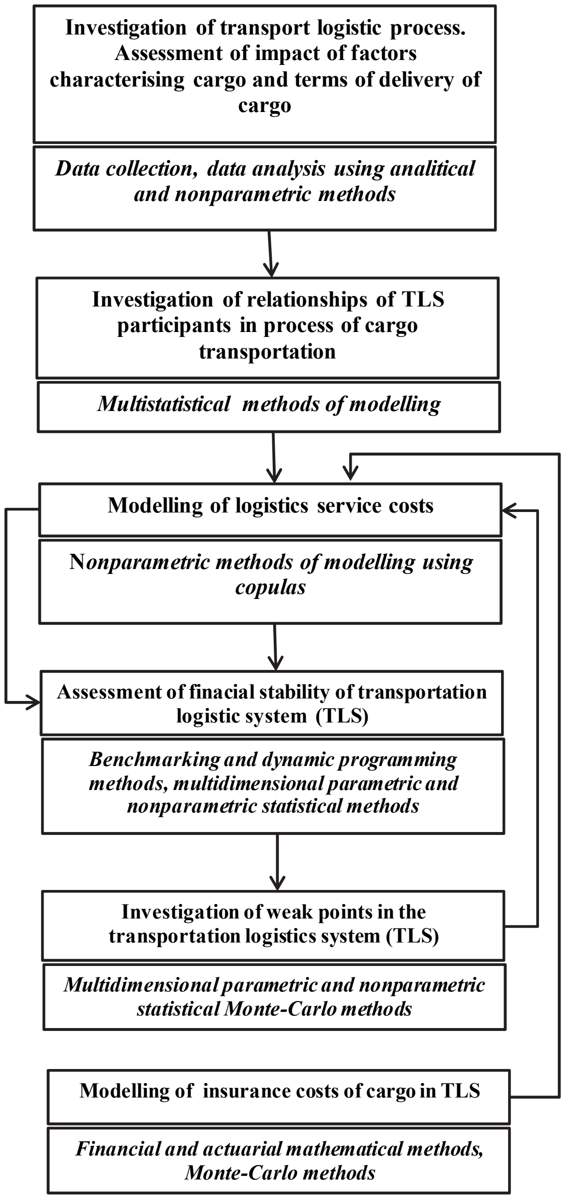

Figure 2: Main Blocks of Modelling of Transport Logistic Process

The scheme of modelling the financial parameters of TLS is presented in figure 3.

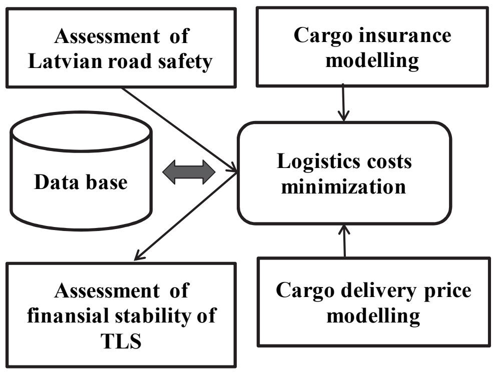

Figure 3: Scheme of Modelling of the Financial Parameters of TLS

3. MODELLING OF LOGISTICS SERVICE COSTS

One of the essential components of the logistic service is cargo insurance. The formula for calculating $P^*_{delivery}$ – logistic service cost can be written as:

$$P^*_{delivery} = P_{delivery} + \ P, \qquad (3)$$

where the value of P - the insurance premium for cargo.

Therefore, it is important to build an economic and mathematical model for calculating the premium P (4) at different parameters of the transportation process.

$$P = F\,(S, DP, H, T, KT, TF, KR, FR, M, F_{t1}, F_{t2}, Y), \qquad (4)$$

where - DP – declared value of the goods carried;
- S – amount of insurance sum for cargo carried, calculated by formula (5):

$$S = k \cdot DP, \qquad 0 < k \le 1, \qquad (5)$$

where k – correction coefficient of sum for cargo insurance;
- T - time of delivery from the consignor to the consignee;
- F_{t1} - price of 1L of diesel fuel used by transportation vehicles at the moment of signing the contract;
- F_{t2} - price of 1L of diesel fuel used by transportation vehicles when transporting cargo;
- H_i - hazard risk of cargo, according to the IMO (International Maritime Organization) classification;
- M_i - route which is used for transporting cargo. The scheme of the M_i^{th} route of traffic with the relevant road traffic parameters of every section of the route from point A to point D is presented in Figure 1.

For the calculation of the insurance premium P, the empirical data and methods of statistical Monte Carlo simulation are used.

The scheme of financial modelling of insurance process is presented in figure 4.

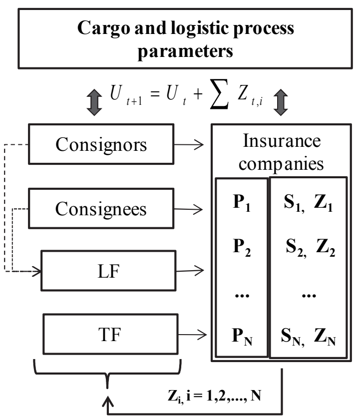

Figure 4: Scheme of Financial Modelling of Insurance Process

In figure 4 are presented parameters: Z_i – insurance indemnity; N – number of insurance objects. For the insurance process, the possibility of performance of insurance obligations is most significant, irrespective of the intensity of the stream of insured events $\{t_j, Z_j\}$ and size of insurance reserve U_{t+1} in time moment t+1.

$$U_{t+1} - \sum_{i=1}^{N} Z_{t,i} > 0. \qquad (6)$$

The insurance process should be financially stable during all the functioning time of the insurance system.

We understand the stability of the insurance process as performance of an inequality (6) during all time T ($0 < t \le T$) of functioning of the insurance process with probability 1-α. To solve the inequality (6), the premium P is calculated based on the parameters of the insurance process (4). Based on the above, the formula for calculating value P (the insurance premium for cargo) can be presented as:

$$P = P_0 + DP(r_T + r_{KT} + r_{TF} + r_{KR} + r_M + r_{FR}), \qquad (7)$$

where P_0 - risk-free component of the premium, which also includes the burden of insurance;
- r_T – risk of exceeding the time of delivery of the goods envisaged in the contract;
- r_{KT} – risk due to the type of cargo transportation;
- r_{TF} – risk due to the type of cargo transported;
- r_{KR} – risk due to the state of the quality of roads along which the goods are transported (estimated by the number of traffic accidents);
- r_M – risk due to the route by which the goods are transported;
- r_{FR} – financial risks.

4. STATISTICAL MODEL OF ACCIDENT NUMBER ON LATVIAN ROADS

For statistical modelling of annual road transport accidents N_a, authors used mathematical model:

$$N_a = \sum_{i=1}^{R} \left[\sum_{j=1}^{M} \alpha (V_{ij})^{\beta_1} (N_{ij})^{\beta_2} + \sum_{j=1}^{M-1} \gamma_{ij} A^R_{c_{ij}} S_{ij} \right], \qquad (8)$$

where α, β_1, β_2 – coefficients for model of road accidents in Latvian cities (towns);
– γ_{ij} – coefficient describing factor risk for the the j^{th} section of the i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1;
- $A^T c_{ij}$ – incidence of road traffic accidents occurring in the j^{th} populated area (town) i=1,2,…,R; j=1,2,…,M;
- N_{ij} – number of population in the j^{th} populated area (town) of the of i^{th} route of traffic i=1,2,…,R; j=1,2,…,M;
- V_{ij} – number of transport vehicles in the j^{th} populated area (town), i=1,2,…,R; j=1,2,…,M;

– λ_{ij} – intensity of road transport vehicle movement in the j^{th} section of the i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1;
- $A^R c_{ij}$ – incidence of road traffic accidents occurring in the j^{th} sector of the of i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1;
- S_{ij} – length of the j^{th} sector of the of i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1;
- R – number of main state routes, R=I, II, …,X.

Using regression tool the model of evaluation of annual damage C_{mod} can be expressed as:

$$C_{mod}(x_1, x_2, x_3) = -71.9 + 0{,}002 \cdot x_1 - 0{,}01 \cdot x_2 + \\ + 0{,}03 \cdot x_3 \, , \qquad (9)$$

where x_1 – number of road transport accidents;
x_2 – number of people killed in road traffic accidents;
x_3 - number of injured victims.

Regression model (9) has a good approximation of real annual losses of economy (annual damage) of Latvia (figure 5).

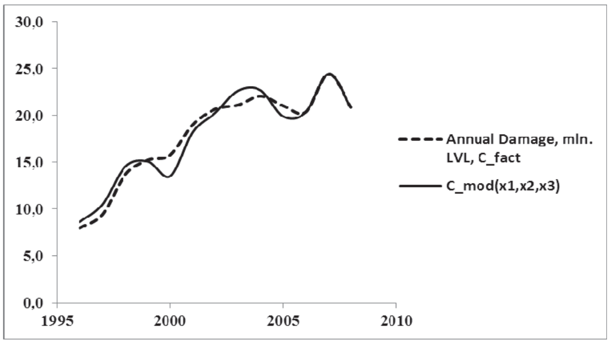

Figure 5: Graphical Illustration of Regression Model of Annual Damage and Real Road Traffic Accidents

5. ASSESSMENT OF SAFETY OF LATVIAN ROADS USING SCAN STATISTICS METHOD

The researchers seek to use scan statistics to monitor future road traffic accident data with the purpose to minimize the number of accident events and reduce the insurance premium paid for cargo. Let us have N events, distributed in the time interval (0, T). Denote S_w maximal number of the events, which is in the time interval with length w (window of fixed length w of time). The maximum cluster S_w is called the scan statistics, from the viewpoint that one scans the time period (0, T) with a window of size w and observes a large number of points. W_k is the shortest period of time containing a fixed number of k events. The interval W_{r+1} is called the minimum r^{th} order gap, or r-scan statistics. The distributions of the statistics S_w and W_k are related. If the shortest window that contains k points is longer than w, then there is no window of length w that contains k or more points:

$$P(W_k > w) = P(S_w < k). \qquad (10)$$

Analysing the statistics of accident events on roads of Latvia, it is seldom possible to get exact analytical solution for distribution of accident events on roads. In this case there exists only one possibility, which is to use computer modelling. In the paper we consider the possibility of using Monte-Carlo method in scan statistics for calculating p-value and testing null hypothesis H_0 (no clusters). Let $S[x, x + w) = S_{x,w}$ denote the number of events in [x, x + w). The scan statistics S_w is defined as shown in (11):

$$S_w = \sup_{0 \le x \le 1-w} S[x, x+w) \, . \qquad (11)$$

This is often suggested as statistics (with an appropriate window length w) for testing the presence of clustering. Indeed, it arises from the generalized likelihood ratio test of uniformity (H_0) against the alternatives (H_1), using density function f(x):

$$\begin{aligned} f(x) &= 1/\{1+(\mu-1)\cdot w\}, \quad 0 \le x < T, \\ &= \mu/\{1+(\mu-1)\cdot w\}, \quad T \le x < T+w, \\ &= 1/\{1+(\mu-1)\cdot w\}, \quad T+w \le x < 1 \end{aligned} \, , \qquad (12)$$

where $\mu > 1$ and T are unknown, but w is known.

In our case, the computer programs model the constant background rate of events and the scenarios of grouped data. The authors compute the scan statistics S_w for continuous data, where it has been assumed that N = n events occur on the time line (0, T). The authors generate uniform samples from this time interval and construct an empirical distribution of Pr ($S_w > k$), where k is the maximum number of events in a subinterval of width w (scanning window). We are interested in finding the value of "k" which shows a small p-value, typically 0.05 or smaller. The modelled p-value can be used for testing the null hypothesis that samples are uniformly distributed against the clustering alternative.

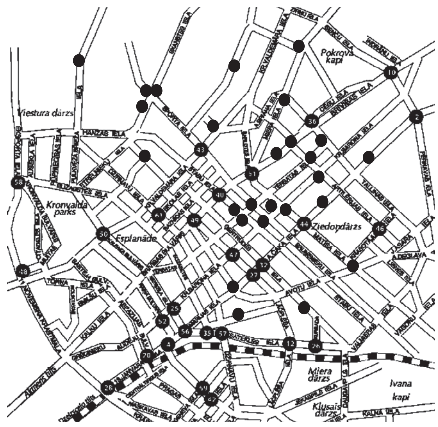

Figure 6: Illustration of Road Accident (Black Spots) in a Small Fragment of One Region of Latvia

In practice, it is essential to investigate the situation, when the number of events in the time interval is not viewed as fixed number N, that has already occurred, but rather as random variable with known probability distribution. We will consider a more popular discrete distribution for Poisson process – Poisson distribution function with an average of λ events per unit time. The illustration of road accident black spots in the fragment of one region of Latvia is shown in figure 6. Having studied the quality of main roads of Latvia, taking into consideration the number of road accident black spots (figure 6), we came to conclusion that, due to this factor, risks r_{KR} may change in the interval (0.01%, 0.04%). The researchers seek to use scan statistics to monitor future road traffic accident data with the purpose to minimize the number of accident events and reduce the insurance premium paid for cargo.

6. PRACTICAL USE OF STATISTICAL MODELLING

Let us consider the example of calculating $P^*_{delivery}$ using the values of model parameters, obtained by simulation (1, 4, 7). Transportation of goods includes the following steps (figure 1):
- transportation of goods by motor transport on US roads from point A to the port of loading the cargo on the ship – to point B (New York port);
- transportation of goods by sea from point B (Port New York) to point C (Riga port (Latvia);
- transportation of goods by motor transport on the roads of Latvia and Russia from point C (Riga port (Latvia) to point D – destination of the consignee in Russia (Moscow).

Types of the main risks and the results of modelling of $P^*_{delivery}$ are shown in table 5.

Table 5: Types of Risks

Cargo delivery route USA (New York) - Latvia (Riga) - Russia (Moscow)	
Cargo delivery main parameters	20' container (max weight 21800 kg)
DP	USD 250 000
P_delivery by sea	USD 4 000
P_delivery by road	USD 2 840
P_0	USD 1 200
r_T	0.009%
r_{KT}	0.006%
r_{TF}	0.07%
r_{KR}^{USA} =	0.006%
r_{KR}^{Latvia} =	0.04%
r_{KR}^{Russia} =	0.05%
r_M	0.02%
r_{FR}	0.01%

$P^*_{delivery}$ =	USD 8 568

Substituting these values into the equation of the model (3, 5, 7), we obtain the value of the $P^*_{delivery}$, taking into account the risk factors (see table 5). As a result, the actual amount of the financial payment made from the account of the logistics firm and other logistics process participants for the technological operation and cargo insurance in the time of realization of logistics process can be calculated, which creates the basis for the assessment of TLS stability in the "risk zones" of TLS participants. By financial stability, we understand the ability of all TLS participants to perform all the financial obligations undertaken with the view of ensuring complete continuous technological process in the terms agreed.

CONCLUSION

In this article attention is paid to the assessment of the safety of main roads of Latvia, as well as the analysis and estimation of the cargo insurance premium and modelling of logistics service costs $P^*_{delivery.}$

The methods used in the study (method of scan statistics, simulation method for assessing the safety of roads and risks of the logistics process, method for modelling the financial risks) allow us in a more complete and accurate way assess the borders of the changes of the logistic service cost.

Road traffic accidents are a growing world social and economic problem. A lot of people killed in traffic accidents are young adults aged between 15 and 44 years (World Report on Road Traffic Injury Prevention). As mentioned above, road traffic injuries cost low-income and middle-income countries between 1% and 3% of their GDP. Road traffic crashes and injuries are preventable. The opportunity of using of statistical modelling for research of road accidents on highways and town's roads of Latvia is presented in this paper.

The application of statistical modelling using Monte Carlo method allows:
- to investigate the safety of Latvian roads;
- to detect road accident black spots on Latvian roads;
- to analyse the dynamics of changes of road accidents taking into consideration the time factor)
- to define economic losses caused by traffic road accidents $C_{Total.}$.
-to model the value of the cargo insurance premium P and logistics service costs $P^*_{delivery}$.
- to set alternative strategies of insurance system performance;
- to manage functioning of insurance system.

Road traffic accidents prevention must be incorporated into the development and management of road infrastructure. The theoretical and practical results obtained as a result of this research can be applied for evaluation of premium values for different scenarios of insurance process in conditions of uncertainty.

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AUTHORS BIOGRAPHIES

VITALIJS JURENOKS was born in Riga, Latvia. In 1976 he graduated from the Faculty of Engineering Economics of Riga Technical University, and for ten years, has worked in an industrial enterprise in Riga. Since 1986, he has been lecturing at Riga Technical University, and in 1987 was awarded the doctoral degree in the science of economics (Dr.oec.). The main field of research pursued is planning, simulation and optimization of economic processes and systems.
E-mail: vitalijs.jurenoks@rtu.lv.

VLADIMIRS JANSONS was born in Daugavpils, Latvia and is a graduate of the University of Latvia, where he studied mathematical science and obtained his degree in 1970. For eight years he has worked in the Computing Centre of the University of Latvia. Since 1978 he has been lecturing at Riga Technical University, where in 1983 he was awarded the doctoral degree in the mathematical science. The main field of research pursued is simulation and optimization of economic systems.
E-mail: vladjans@latnet.lv.

KONSTANTINS DIDENKO was born in Jelgava, Latvia. In 1969 he graduated from the Faculty of Engineering Economics of Riga Technical University. Since 1969 he has been lecturing at Riga Technical University where in 1985 he obtained the doctoral degree in the science of economics. In 2006 he was elected a corresponding member of the Latvian Academy of Sciences. The main field of research pursued is planning and optimization of economic processes and systems.
E-mail: konstantins.didenko@rtu.lv.

THE CAPACITATED VEHICLE ROUTING PROBLEM WITH LOADING CONSTRAINTS

Hanne Pollaris[(a)], Kris Braekers[(a)], An Caris[(a,b)], Gerrit K. Janssens[(a)]

[(a)] Hasselt University, Agoralaan – Gebouw D, BE-3590 Diepenbeek
[(b)]Reseach Foundation Flanders (FWO), Egmontstraat 5, BE-1000 Brussels

hanne.pollaris@uhasselt.be, kris.braekers@uhasselt.be, an.caris@uhasselt.be, gerrit.janssens@uhasselt.be

ABSTRACT

Distributors of goods have to take loading constraints into account to make a realistic planning for their delivery vehicles, while current planning tools generally do not include these constraints. The most common loading problems encountered in the distribution of goods are multi-dimensional packing constraints, unloading sequence constraints, stability constraints and axle weight constraints. This paper combines vehicle routing problems with loading problems. First, an overview of the relevant literature is provided. Second, the paper will shed light on axle weight limits since, to our knowledge, VRPs with axle weight constraints have not yet been considered in literature. A two dimensional VRP with sequence based loading is formulated. This model is used to perform computational experiments on a small network. For each computed vehicle route, the weight on the axles is calculated and compared with legal limits.

Keywords: vehicle routing problem, loading constraints, axle weight, two dimensional VRP

1. INTRODUCTION

The Vehicle Routing Problem (VRP) concerns the distribution of goods between depots and customers (Toth and Vigo 2002). It is the most common studied combinatorial optimization problem in transport and logistics. The goal of the vehicle routing problem is to find a set of routes for a fleet of vehicles where the objective function (e.g. total distance, routing costs) is optimized. Every demand needs to be fulfilled and vehicle capacities need to be respected. The basic version of the VRP is the Capacitated VRP (CVRP). The CVRP considers a homogeneous vehicle fleet with a fixed capacity (in terms of weight or number of items) which delivers goods from a single depot to customer locations. Split deliveries are not allowed. The CVRP can be extended to VRP with time windows (VRPTW) by specifying time windows in which deliveries need to take place. Another variant is the VRP with Pickups and Deliveries (VRPDP) in which orders may be picked up and delivered at customer places. For each order, an origin location (pickup location) and a destination (delivery location) is specified. It is possible to have both deliveries and pickups at a given location. A third common extension of the basic CVRP is the VRP with backhauls (VRPB) in which again pickups and deliveries may be done in one tour, but first all delivery requests need to be performed, and afterwards the empty vehicle may pick up goods at customer locations. (Toth and Vigo 2002)

Many solution methods already exist for the 'classic' VRPs mentioned in the previous paragraph. In real-life, companies are facing several additional constraints that greatly increase the complexity of the problem. Examples of such complicating constraints are maximum route length and duration, time-dependent routing, incompatibilities between goods and vehicles and loading constraints. 'Rich' VRPs are routing problems that take into account some of these additional realistic constraints (Battarra, Monaci and Vigo, 2009). This paper focuses on routing problems combined with loading constraints.

A survey conducted by the authors among several Belgian logistics service providers pointed out that they are faced with important loading problems in their route planning. The most common loading problems that are encountered by distributors are multi-dimensional packing constraints, unloading sequence constraints, stability constraints, load-bearing strength constraints and axle weight constraints. Multi-dimensional packing constraints include that items cannot overlap and should be completely enclosed by the vehicle. In a three-dimensional problem, the three dimensions (length, width and height) of the vehicle are taken into account to check this constraint. In a one dimensional or two dimensional problem respectively a single or two dimensions of the vehicle are taken into account. The unloading sequence constraint ensures that when arriving at a customer, no items belonging to customers served later on the route block the removal of the items of the current customer. In a one dimensional problem this constraint can be referred to as a Last-In-First-Out (LIFO) constraint. Stability constraints guarantee vertical as well as horizontal stability of the cargo in the vehicle. When items are stacked on top of each other in the vehicle, the items have to be supported by other items or by the floor to ensure the vertical stability of the cargo. Vertical stability constraints specify the minimum supporting area of each item (for example as a percentage of the base area of the item). Horizontal stability of the cargo refers to the support of the lateral sides of the items in the vehicle to avoid the items from moving around in the vehicle. The load-bearing strength of an item is the maximum pressure that can be applied on this item (Junqueira et al. 2012). This is taken into account to prevent items to be damaged because of the pressure of other items that are placed above them. Fragile items can be defined as items that cannot bear much pressure. This may imply that no item can be placed upon fragile items or that only other fragile items can be placed upon them. Not only the total weight of the load inside the vehicle is of importance, but also the distribution of the weight of that load over the axles of the vehicle is an important issue. Axle weight limits impose a great challenge for transportation companies. Transporters face high fines when violating these limits, while current planning programs do not incorporate axle weight constraints. Legislation about axle weight limits varies by country (for an overview of the axle weight limits in Europe, the reader is referred to the International Transport Forum). The axle weight is the total weight that is being placed on the axles of a truck or a trailer. This is illustrated in figure 1. When item *j* is placed onto a vehicle, the weight of the item is divided over the axles of the truck and the axles of the trailer. F_K^j represents the weight of the items of customer *j* placed on the axles of the truck. F_A^j represents the weight of the items of customer *j* on the axles of the trailer.

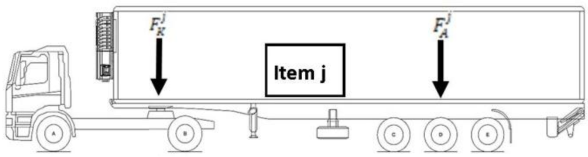

Figure 1: Axle weight truck and trailer

The main goal of the paper is to demonstrate it is necessary to take axle weight constraints into account in a VRP model. In section 2, an overview of the literature concerning VRPs combined with loading constraints is provided. A two dimensional CVRP is formulated in section 3. In section 4, the model is used to perform computational experiments on a small network. For each computed vehicle route, the weight on the axles is calculated and compared with legal limits. In the last section, conclusions and future research opportunities are discussed.

2. LITERATURE STUDY

The combination of VRP and loading problems is a fairly recent domain of research. The two problems are separately already NP hard and very difficult to solve (Iori and Martello 2010). Combining these problems is therefore very challenging but leads to a better overall logistic solution. Papers dealing with VRP with loading problems may be placed in following categories based on the type of routing problem and the loading characteristics that are dealt with: VRP and 2D loading, VRP and 3D loading, multiple pile VRP, multi-compartments VRP and PDPs with loading constraints. We will focus in this article on the general VRPs in which all items are picked up at the depot and afterwards delivered to the customers. We will therefore not go into detail about the PDPs. For a detailed overview of literature on this topic up to 2010 the reader is referred to Iori and Martello (2010).

2.1. VRP with 2D loading constraints

In the two-dimensional VRP, the demand of customers and the vehicle measurements are expressed in two dimensions.

Iori, Salazar-Gonzales and Vigo (2007) are the first to address a two dimensional vehicle routing problem. They develop an exact method to solve the problem that takes into account sequence based loading, fixed orientation constraints and a maximum weight capacity. Total routing costs are minimized with a branch-and-bound method. Gendreau et al. (2008) develop a Tabu Search (TS) method to solve the same problem heuristically. Fuellerer et al. (2009) employ an Ant Colony Optimisation (ACO) method for a similar problem, with a small alteration in the loading constraints. The items are allowed to rotate 90° on the horizontal plane in their model. Zachariadis, Tarantilis and Kiranoudis (2009) develop a Guided Tabu Search method which is a combination of Guided Local Search and TS to solve the 2L-CVRP formulated by Iori et al. (2007). Duhamel et al. (2011) address the 2L-CVRP without sequence based loading by using a Greedy Randomized Adaptive Search Procedure (GRASP) in an Evolutionary Local Search (ELS) framework. Leung et al. (2013) develop a Simulated Annealing (SA) model to solve the 2L-CVRP with heterogeneous fleet. The packing constraints that are considered in this model are the same as in Iori et al. (2007). The vehicles have different weight capacities and different measurements. Currently, this is the only multi-dimensional CVRP in which a heterogeneous fleet is considered.

2.2. VRP with 3D loading constraints

In the 3L-CVRP, the three dimensions of the vehicle are taken into account and customer demands consist of three-dimensional items as well. Since the height dimension is considered, additional loading constraints concerning load bearing strength and stability of the cargo can be specified.

Gendreau et al. (2006) are the first to tackle the three-dimensional Capacitated Vehicle Routing Problem (3L-CVRP). They develop a TS method to solve the problem with the objective to minimize total route length. Their model takes into account sequence-based loading, the weight capacity of the vehicle, fragility and stability constraints and a fixed vertical orientation of the items in the vehicles (it is allowed to rotate the items 90° on the width-length plane).

Several papers take into account the same loading constraints as Gendreau et al. (2006) to solve the 3L-

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CVRP (e.g. Ren, Tian, and Sawaragi 2011; Ruan et al. 2013; Bortfeldt and Homberger 2013).

Moura (2008) develops a multi-objective genetic algorithm to solve the 3L-CVRP with time windows (3L-VRPTW). The model takes into account sequence based loading, orientation constraints and stability constraints. The presented problem has three objectives: minimisation of the number vehicles, minimisation of the total distance travelled and maximisation of the volume utilisation. In 2009, Moura and Oliveira develop a sequential and a hierarchical approach to solve the 3L-VRPTW. The objective is to minimise the number of vehicles and total route time. The hierarchical approach, takes into account sequence based loading, orientation constraints and stability constraints. In the sequential approach, container loading and vehicle routes are planned simultaneously. The unloading sequence constraint is relaxed in this solution approach.

Massen, Deville and Van Hentenryck (2012) develop a column generation method for vehicle routing problems with black box feasibility (VRPBB). In the VRPBB, the routes of the basic VRP need to satisfy a number of unknown constraints. A black box algorithm is used to verify the feasibility of a route. Their approach is tested on the 3L-CVRP as well as on the multiple pile-VRP.

Junqueira, Oliveira and Morabito (2012) are the first to propose an exact method to solve the 3L-CVRP. They take into account sequence based loading, orientation constraints and stability constraints. The authors introduce multi-drop constraints that take into account the unloading pattern. By specifying a reach length of the worker or forklift, they avoid that items that are placed on top of other items cannot be reached. They propose an integer linear programming model to solve problems of moderate size.

2.3. Multiple pile VRP

The multiple pile vehicle routing problem (MP-VRP) is introduced by Doerner et al. (2007). They develop a TS method and an ACO heuristic to solve a real-world transportation problem regarding the transport of wooden chipboards. A distinction is made between small chipboards and large chipboards. For every order, chipboards of the same type are grouped into a unique item, which is placed onto a single pallet. The vehicle is divided into three piles in which the pallets can be stacked. The pallets containing large chipboards can extend over multiple piles. The other pallets can be placed into a single pile. An example of a loading plan of a multiple-pile vehicle can be found in figure 2.

Because of this specific configuration of pallets placed into multiple piles, the original three dimensional problem can be reduced to a one dimensional one. In the model of Doerner et al. (2007), sequence based loading is taken into account and a homogeneous vehicle fleet is assumed.

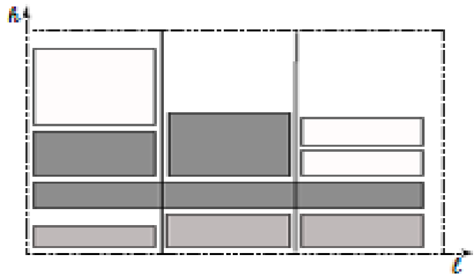

Figure 2: Example of a Multiple Pile Vehicle (Massen, et al., 2012)

Tricoire et al. (2011) develop a combination of Variable Neighbourhood search and branch-and-cut to solve the MP-VRP exactly for small-size instances and heuristically for large-size instances. In both solutions, sequence-based loading is taken into account. Massen et al. (2012) test a column generation method for vehicle routing problems with black box feasibility (VRPBB) on the MP-VRP. They take into account sequence based loading and assume a homogeneous fleet.

2.4. Multi-compartments VRP

The multi-compartments VRP is related to the multiple pile VRP. Vehicles with multiple compartments allow the transport of inhomogeneous products in the same vehicle, but in different compartments. The compartments are not always compatible with every type of product and certain product pairs cannot be loaded together into the same compartments. Vehicle routing problems with compartments are encountered in several industries like the distribution of petrol (e.g. Brown and Graves 1981; Cornillier et al. 2012), the distribution of food (e.g. Chajakis and Guignard 2003) and waste collection (e.g. Muyldermans and Pang 2010).

3. PROBLEM FORMULATION

We start with an investigation of a classic two dimensional CVRP with sequence based loading, whereas in further research the conclusions may be tested in more complex VRPs. Multiple homogenous vehicles are considered. Vehicle capacity is expressed both in weight capacity (Q^k) (maximum 30 tonnes) as in maximum length L_i and width W_i of the loading space (10 m and 2 m respectively). The demand of the customers consists of pallets of 1x1 meters. Pallets cannot be placed on top of each other, but can be placed beside each other in the vehicle. In total 20 pallets can be placed inside each vehicle.

Consider a complete directed graph $G = (V, E)$, where V is the set of vertices corresponding to the begin depot (node *1*), end depot (node *n*) and the customers (node *2 … n-1*). E is the set of edges where each edge has an associated transport cost c_{ij}, for $(i, j) \in E$. Let K be the set of identical vehicles. Each customer i has a demand of m_i pallets. The total weight in kilograms of the pallets ordered by each customer i is expressed as w_i. Stages are incorporated into the model in order to know in which sequence the locations are visited. This way, we can calculate the axle weights in a next step. This notation is also used by Junqueira et al. (2012). The routing decision variables d_{ij}^{kt} of the model are defined as:

$$d_{ij}^{kt} = \begin{cases} 1, & \text{if vehicle } k \text{ goes directly from node } i \\ & \text{to node } j \text{ in stage } t; \\ 0, & \text{otherwise}. \end{cases}$$

The vehicle routing model may be formulated as follows:

$$Min \sum_{k\in K} \sum_{(i,j)\in E} \sum_{t\in T} c_{ij} * d_{ij}^{kt} \quad (1)$$

Subject to

$$\sum_{k\in K} \sum_{i\in V} \sum_{t\in T} d_{ij}^{kt} = 1 \quad \forall j \in V \; with \; 1 < j < n \quad (2)$$

$$\sum_{k\in K} \sum_{j\in V} \sum_{t\in T} d_{ij}^{kt} = 1 \quad \forall i \in V \; with \; 1 < i < n \quad (3)$$

$$\sum_{i\in V} \sum_{j\in V} d_{ij}^{kt} \leq 1 \quad \forall k \in K, t \in T \quad (4)$$

$$\sum_{i\in V} \sum_{j\in V} d_{ij}^{kt} \geq \sum_{i\in V} \sum_{j\in V} d_{ij}^{k,t+1} \quad \forall k \in K, t \in T \quad (5)$$

$$\sum_{i\in V} \sum_{j\in V} \sum_{t\in T} (d_{ij}^{kt} * w_i) \leq Q^k \quad \forall k \in K \quad (6)$$

$$\sum_{i\in V} \sum_{j\in V} \sum_{t\in T} (d_{ij}^{kt} * m_i) \leq 2 * L_k \quad \forall k \in K \quad (7)$$

$$\sum_{j\in V} d_{ji}^{kt} = \sum_{j\in V} d_{ij}^{kt+1} \quad \forall k \in K, \forall t \in T, \forall i \in V, 1 < i < n \quad (8)$$

$$d_{ij}^{kt} \in \{0,1\} \quad \forall i,j \in V, k \in K, t \in T \quad (9)$$

The objective function (1) aims to minimize the total cost for the vehicles to visit all customers. Constraints (2) and (3) ensure that each customer is visited exactly once. Constraint (4) ensures that each vehicle can only visit a single arc per stage while constraint (5) does not allow a vehicle to visit a customer in stage *t* when the vehicle has not visited a customer in stage *t-1*. Constraint (6) prevents the total weight of the load to exceed the weight capacity of the vehicle. Constraint (7) limits the amount of pallets per vehicle to the length of the vehicle multiplied by two, since two pallets can be placed beside each other in the vehicle. Constraint (8) eliminates the possibility of subtours.

4. COMPUTATIONAL RESULTS

The model formulated in the previous section is used to perform computational experiments on a small network. This network consists of ten nodes: the begin depot (node 1), the customers (nodes 2 to 9) and the end depot (node 10). The demand of the customers (node 2 to 9) is $D_C = (8, 4, 2, 6, 4, 6, 8, 10)$. To define the bound of the amount of stages, we computed the amount of stages required when the customers with the smallest amount of items would be carried in the same vehicle. Maximum four customers can be serviced by the same vehicle, namely customers 2, 3, 4 and 5. The total amount of pallets of these customers is 16, which is below the maximum capacity of 20 pallets. This means that a maximum bound of 6 stages (the begin and end depot are also taken into account) can be set. The model is solved with Cplex 12.5 on a personal laptop.

The model solution contains three vehicle routes. For each vehicle route, the axle weight of the pallets of customer j on the trailer (F_A^j) and on the truck (F_K^j) is calculated with equations (10) and (11) respectively. In figure 3, the parameters in the equations are graphically represented. Parameter f represents the distance from the beginning of the trailer to the center of gravity of the item. Parameter c denotes the distance from the beginning of the trailer to the coupling (which is the link between the truck and the trailer). The final parameter, d, represents the distance between the coupling and the middle axes of the trailer. For our calculations we use 1,67 m for parameter *c* and 7,8 m for parameter *d*.

$$F_A^j = \frac{(f-c)*w_j}{d} \quad \forall j \in V \quad (10)$$

$$F_K^j = w_j - F_A^j \quad \forall j \in V \quad (11)$$

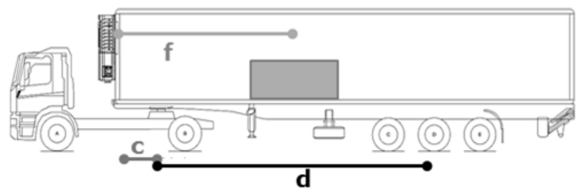

Figure 3: Truck (with two axles) and trailer (with tridem axles)

According to Belgian legislation, the maximum total weight on the two axles of this truck is 22 tonnes. The empty truck weighs 8 tonnes, therefore the maximum weight of the load on the axles of the truck is 14 tonnes (or 14000 kg), as stated in constraint (12).

$$\sum_{i\in V} \sum_{j\in V} \sum_{t\in T} (d_{ij}^{kt} * F_K^j) \leq 14000 \quad \forall k \in K \quad (12)$$

Belgian legislation limits the maximum weight of the trailer with tridem axles to 30 tonnes. The empty trailer weighs 14 tonnes. The weight of the load on the axles of the trailer is therefore limited to 16 tonnes (or 16000 kg), as stated in constraint (13).

$$\sum_{i\in V} \sum_{j\in V} \sum_{t\in T} (d_{ij}^{kt} * F_A^j) \leq 16000 \quad \forall k \in K \quad (13)$$

The weight capacity of the vehicle is 30 tonnes. This equals the sum of the axle weight limits of the truck and trailer. We can therefore conclude that if the loading is optimally divided over the axles of the vehicle, the weight of the load can amount to 30 tonnes.

Tables 1, 2 and 3 present the calculation of the axle weight on the truck and the trailer of the vehicle from respectively the first, second and third route. In the first column, the customer nodes that are visited in the route are identified. The second column presents the customer demand divided by two, which equals the total loading meters required by customer j. To ensure ease of computation, we assumed that the customer demand is even. This constraint can easily be relaxed. In the third column f_j, the distance from the beginning of the trailer to the center of gravity of the pallets of customer j, is presented. It is assumed that the center of gravity of each pallet is in the middle of the pallet. In the next column the weight of the pallets in kilograms of each customer j is presented. In the fifth column the weight of the items of customer j on the axles of the trailer is calculated. In the last column the weight of the items of customer j on the axles of the truck is presented. In the last row the sum of the loading meters, weight of the pallets, axle weight on trailer and axle weight on the truck for each route is presented.

From table 1 can be concluded that while the total weight in the vehicle (18 tonnes) is still far below vehicle capacity (30 tonnes) and while length capacity of the vehicle is also respected (<10 m), there is a violation of the axle weight constraint of the truck since this exceeds 14 tonnes. Similar results can be drawn from tables 2 and 3. In this example the axle weight limit of the truck is in each vehicle violated. However – although not illustrated in this example – it is also possible that the axle weight limit of the trailer is violated, or (in the ideal case) that both limits are respected.

Route 1 (1-5-8-3-10)					
Node (j)	$m_j/2$	f_j	w_j	F_A^j	F_K^j
5	3	1,5	9200	-200	9400
8	4	5	8500	3628	4871
3	2	8	5156	5288	-132
Total	7		17700	3428	**14271**

Table 1: Axle weight calculation trailer (F_A) and truck (F_K) vehicle route 1

Route 2 (1-9-7-10)					
Node (j)	$m_j/2$	f_j	w_j	F_A^j	F_K^j
9	5	2,5	19150	2038	17112
7	3	6,5	10250	8542	1708
Total	8		29400	10579	**18821**

Table 2: Axle weight calculation trailer (F_A) and truck (F_K) vehicle route 2

Route 3 (1-2-6-4-10)					
Node (j)	$m_j/2$	f_j	w_j	F_A^j	F_K^j
2	4	2	5000	211	4788
6	2	5	14020	5985	8034
4	1	6,5	9000	7500	1500
Total	7		28020	13697	**14323**

Table 3: Axle weight calculation trailer (F_A) and truck (F_K) vehicle route 3

CONCLUSIONS AND FUTURE RESEARCH

This paper shows the need of integrating axle weight constraints into VRP models. While research has been done about VRP combined with loading constraints, the literature is still silent about axle weight limits. Axle weight has become however an increasingly important issue for transportation companies. Transporters are faced with high fines when violating these limits, while current planning programs do not incorporate these constraints. Future research can integrate axle weight constraints into the model. This can include taking into account axle weight constraints when the vehicle is fully loaded and axle weight increases when items are dropped off at customer places. Subsequently, a heuristic method can be developed to solve the integrated problem in an acceptable time frame. Lastly, other realistic constraints such as time windows and three dimensional loading can be added to the model.

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AN INTEGRATED RESOURCE-BASED APPROACH TO PORT AND TERMINAL SIMULATION MODELING

Constantin Semyonov[(a)]

[(a)]Department of Organization of Transportations, Baltic Fishing Fleet State Academy, Kaliningrad, Russia

[(a)]mail3cms@yandex.ru

ABSTRACT
The accuracy of simulation model significantly increases when not only the processes, but also the factors that have on them great influence are taken into account. Many of them is considered as resources necessary for the functioning of the particular process and characterized by power, balance and deficit. Resources are an integral part of most practically useful simulation models, where they largely determine the course of the different processes. This paper describes an integrated method of accounting, analysis and distribution of resources among the active terminal processes implemented in a specialized simulation software BaltInLog PortInvest developed by the author. Resource model presented in the paper may contribute in efficiency and accuracy of terminals and ports simulation as it is based on reduction of the uncertainty of the processes, taking into account the actual conditions of their occurrence. These conditions are largely determined by the resources of the terminal.

Keywords: port and terminal simulation, resources, resource management, simulation software.

1. INTRODUCTION

Simulation is one of the most useful tools in port management which, if implemented properly, can result in significant economic benefits (Law and Kelton 2000). But the development of efficient and accurate simulation model of port or terminal is not an easy task. As each model reflects real activity the latter should be thoroughly studied and decomposed into basic processes such as cargo handling, stowage, warehousing etc.

To take into account all distinctive features of these processes and to get total control over program code the author developed a specialised software in Visual Studio environment using C++ language. Usage of general-purpose software such as ARENA, AnyLogic and others (a good brief review is presented by Park, N.K., Dragović, B., Zrnić, N., Moon, D. S. H. (2012)) is also a good practice as they have sufficient functionality for most basic port models.

The software should simulate port processes in close interrelation with factors which determine their commencement, existence and termination. Some of them are referred to as resources, whose role in simulation models was discussed in several papers. Legato and Trunfio (2007) presented a theoretical framework for holistic simulation model where resources are objects with several states. They also introduced resource managers necessary for complex system model. A similar entity (resource allocation module) is described in another papers (Rizzoli, Gambardella, Zaffalon, and Mastrolilli 1999; Gambardella, Rizzoli, and Zaffalon 1998). Arango, Cortés, Muñuzuri and Onieva (2011), Cortés et al. (2007) described a real port model with several types of resources allocated upon ship's arrival and during cargo handling operations. Authors of another paper (Legato and Mazza, 2001) focused on particular types of resources such as cranes and berth length. Agerchou et al. (2004) provided some general recommendations on resource management.

When resources are insufficient the process is suspended or its productivity decreases. In real systems, such as ports, the purpose of resource management is to distribute the resources in a way that maximizes the entire system efficiency. To achieve this it's necessary to define the key performance indicators (or a single indicator) and estimate them for apparently effective distribution methods and policies.

If the evaluation of these methods is effected by simulation the indicators are estimated according to results of statistical processing of the model outputs. This is a common approach and it is also used in our software.

As most ports are commercial enterprises the efficiency evaluation is based on costs and income. Zaffalon, Rizzoli, Gambardella, and Mastrolini (1998) recommended the same approach. BaltInLog PortInvest also calculates net present value (NPV) which is useful when implementation of resource management system requires significant investments, for example, in case of sophisticated ERP system installation.

There is often a direct connection between resource allocation and port costs. Expenses are often proportional to the quantity of resources used (this is an acceptable assumption for basic models), but in some cases the actual dependence may be far from linear. Moreover, usage of some resources (for example, length of railway segment for cargo handling operations) don't cause any expenses. Nevertheless the connection persists as insufficiency of railway length will prevent cargo handling and result in downtime and, eventually, in economic penalties. To assess this losses we primarily estimate cost of delays per hour and input it to our program.

The revenues depend on the flows of different cargoes going through the port but they are mainly subject to external factors such as port location towards transport routes. But to obtain these revenues port should be able to handle all this cargo. The resource distribution and management system, in its turn, should ensure smooth and efficient running of all handling processes to prevent the loss of revenue. Our model is not intended for estimation of all consequences of inefficient and slow cargo handling as some of them may result in after-effects which can be hardly described by means of simulation. For instance, port congestion prevent some clients from sending cargoes to it that results in overall decrease of cargo flow. Instead the costs of delays in our simulation model is slightly higher than ones stipulated in the agreements.

Thus the resources and resource management are paramount factors of port cost-effectiveness and determinants of its competitiveness.

2. A CLASSIFICATION OF PORT RESOURCES AND THEIR VIRTUAL REPRESENTATION

Researchers consider resource allocation one of the major problems of container terminal (Zaffalon et al. 1998). However this applies also to other types of terminals. Besides, optimising resource management policy on the whole is a much more challenging task.

In such a case simulation is a suitable and effective tool but to apply it we should define what resources should be included in model considering its accuracy and complexity.

Currently our software allows to simulate the following resources:

1. storage capacity;
2. cargo handling equipment;
3. port workers;
4. length of railway segments intended for cargo handling operations;
5. length of berth;
6. maximum number of truck simultaneously loaded and unloaded at terminal.

To deal with more complex tasks the program should contain algorithms for the simulation of additional resources such as:

- finance;
- quay capacity;
- cargo handling equipment service life;
- information used in decision-making etc.

But the way how the model receives and processes resource data is more important. Despite the complexity of modern simulation models the interaction between virtual processes and resources is not the same as between real ones. To reduce the difference with moderate burden on CPU the models should contain and compute convenient data structures that also determined by the nature of processes of port or terminal.

When cargo handling operation is to commence terminal provides a set of equipment and labour determined by modes of transport, type of cargo and other factors. Each set has its own productivity and includes particular quantity of each resource. In fact, this set is an essential element of cargo handling technology. Simulation environment operating with resource sets instead of separate resources would have better performance, but the labour and machinery management policy reduces to choice of the best resource set.

The implementation of labour and equipment sets allows to significantly simplify the problem of optimising management of this kind of resources. We can surely get only a few effective combinations of labour and equipment for each handling process, and the program will be selecting the most suitable set dynamically during runtime.

To guide the program a priority of each set can be specified. Each time it select the set with the highest priority provided all its resources are available. Besides, each set has a rate of cargo handling. But in real conditions the speed of handling is not constant. Many circumstances may affect it. Namely, breach of equipment, rain, wind, defects of cargo etc. To take that into account the rate is multiplied by a random value whose mean is near 1. To find the optimal set the model should be run several times when one of the suitable sets has the highest priority. Then output data on costs and income should be analysed.

Obviously, each set for particular cargo handling process should contain similar types of resources. But to maintain high handling rate, the ratio between quantities of resource types in each set should be approximately equal. This condition limits the quantity of resource sets for each process which differ only in overall amount of resources and, therefore, in cargo handling rate. But the latter is not proportional to the former as high concentration of equipment and workers may create congestions which slow down the speed of loading and discharging. Small equipment number in set don't seem to be reasonable too as it increases the total duration of transport stay in port. Unfortunately, the optimal set cannot be found by direct algebraic solution as it depends on many factors, but simulation is very helpful in this case.

3. SETTING THE SIMULATION ENVIRONMENT

BaltInLog PortInvest provides a simple interface for adjusting sets of labour and equipment for each type of cargo handling operation (fig. 1).

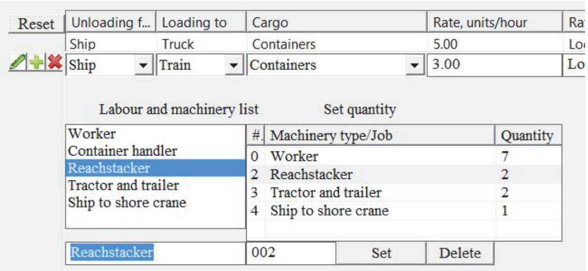

Figure 1: Labour and equipment set adjustment

Total quantity, costs and other parameters of equipment and workers is input through another part of program interface (fig. 2). The costs allow to evaluate economic efficiency of resource management policies. "Running cost/hour" is a value added to expenses for each hour when a resource is involved in cargo handling process. "Maintenance cost/month" are added every time even if a resource is idle.

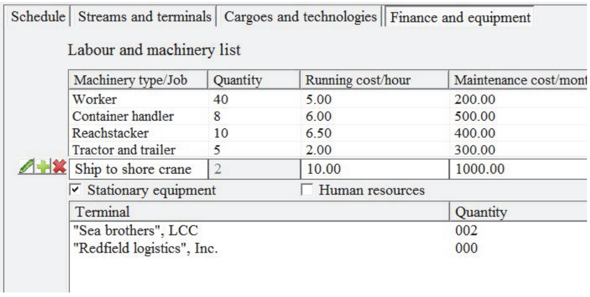

Figure 2: Parameters of workers and equipment

Some resources belong to particular terminal and cannot be used by the others. Namely, length of berth, railways, storage and cargo handling areas capacity which are set as terminal properties (fig. 3). Equipment can be terminal bound as well (for instance, cranes move only within a berth). It is marked by enabling "Stationary equipment" checkbox (fig. 2). The quantity of such equipment is specified for each terminal separately. For workers we should enable "Human resources" checkbox to make the program separate them from equipment in the final report (fig. 4).

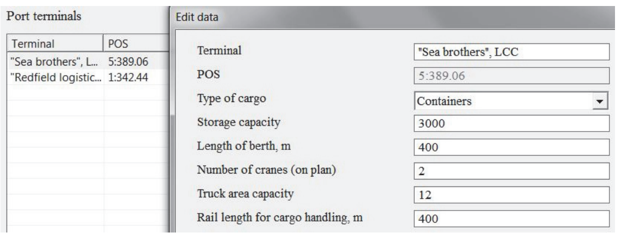

Figure 3: Terminal properties

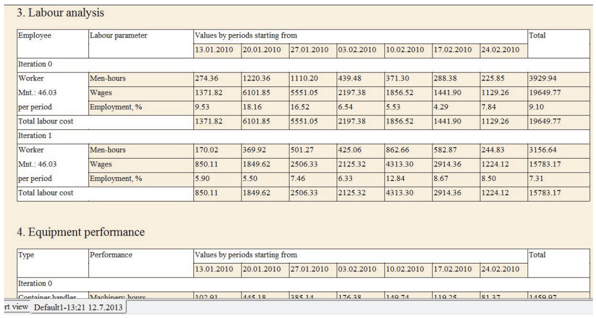

Figure 4: Separate report on labour and equipment

Each resource management policy in simulation model must have an algorithm which ensures proper distribution of resources among active processes. If a process lacks resources, it is eventually cancelled, delayed, suspended or slowed down. In the last case, there must be a clear rule for calculating the duration of the slowed process. If the minimum resource set is unavailable cargo handling is suspended. The cancellation of loading and discharging is not typical for ports and terminals as it would break the entire supply chain and result in significant losses for clients.

But insufficiency of other resources prevents cargo handling as well. For instance, while almost all berth is occupied with vessels an incoming ship cannot be loaded of discharged.

To simulate the real circumstances of vessel arrivals BaltInLog PortInvest contains the algorithm:

```
if((vessel length + gaps < free berth length) and
(amount of cargo < free storage space)) then
    check available resource sets
    if(no sets available) then
      add vessel to queue
    else commence cargo handling
else add vessel to queue
```

With minor changes the algorithm is used in similar cases. For truck and train arrivals berth length is replaced with areas for truck loading/discharging and length of railway for cargo handling respectively. If cargo is not unloaded to storage areas (directly to any mode of transport) there is no check for free storage space.

The algorithm places ships in queue, and on release of any resources the checks are made again to find out whether it is possible to commence cargo handling.

The report system of the simulation environment provides all information required for analysis of simulations. This output data also includes indicators of economic feasibility and performance, namely, NPV costs, revenue, berth utilization, labour and equipment employment etc. Testing the resource management policies we don't take into account any investments. Therefore net revenue may be considered as main indicator of policy effectiveness provided the same amount of cargo goes through port in each experiment.

This amount forms cargo stream which must be specified before simulation experiment in respective table (fig. 5). To specify the stream user should input modes of transport, their capacity and its usage (ratio of amount of cargo in each ship/truck/wagon to its capacity). Fields with "f(x)" buttons may be filled with function description, which may include fixed and random numbers, operators and variables (time, length of queue, free storage capacity etc.). The variables provide enhanced control over the model. For instance, season fluctuation may be easily simulated by using time as argument for sine or cosine.

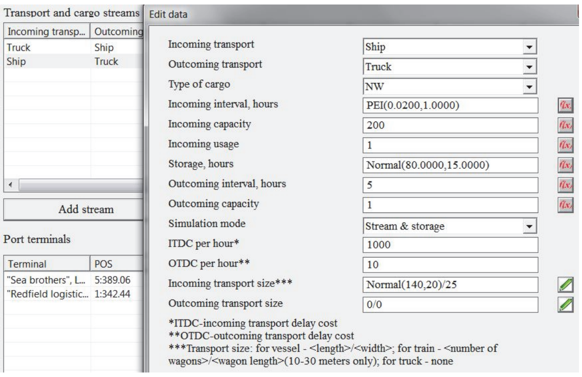

Fig. 5: Transport and cargo streams setting

After setting all necessary properties the user can launch simulation experiment and find out which resource distribution policy is the most effective.

The simulation described below in this paper is effected for a model of typical container terminal, but the method is also suitable for many other types of terminals.

4. TESTING THE RESOURCE MANAGEMENT POLICIES

The resource management policies are tested in a model of container terminal where feeder container ships are discharged. The cargo is transferred to stowage area and stored till the arrival of trucks.

A simple Poisson ship stream is simulated with parameters corresponding to 3 ship calls per day. The average vessel load is 300 containers with deviation of 50.

The labour and equipment sets used in simulation are shown in table 1. There are 3 levels of labour and equipment concentration for each direction, i.e. the amount of resources (proportional to multiplier) with approximately the same ratio between quantity of resource types. Table 2 shows priority of the sets for different resource management policies tested by simulation.

Other resources such as length of berth and railway, storage and truck area capacity are adjusted in a way that they are sufficient during the simulations.

Table 1: Resource sets for different types of cargo handling processes

Process type*	Quantity of resources					Handling speed, containers/ hour
	Worker	Container handler	Reachstacker	Ship-to-shore crane	Tractor and trailer	
S-W x1	9	2	2	1	2	32
S-W x2	18	4	4	2	4	56
S-W x3	27	6	6	3	6	80
W-T x1	2	2	0	0	0	30
W-T x2	4	4	0	0	0	56
W-T x3	6	6	0	0	0	80

*S-W: ship-warehouse; W-T: warehouse-truck; xN - multiplier.

Table 2: Resource set priorities for tested resource management policies

Process type	Resource management policy by labour and equipment concentration		
	High	Medium	Low
S-W x1	1	1	1
S-W x2	2	2	0
S-W x3	3	0	0
W-T x1	1	1	1
W-T x2	2	2	0
W-T x3	3	0	0

This is a simple scenario intended for demonstration but in practice we can use more advanced settings. Two-directional container handling (loading and discharging of the same vessel), non-stationary transport stream with aftereffect and other conditions can be simulated with the same software.

As described above the evaluation of resource management policies is based on output economic data. To get the proper results we should set respective inputs such as average payment for each handled container, cost of resources, penalties for transport downtime and average total fixed expenses of the port.

The results of the simulations are shown in table 3. Economic outputs accounted in custom currency units (1 is approximately equal to one million euro). The experiment lasted 5 months of model time.

Table 3: The results of resource management policies simulation

Indicator		Tested policy		
		High	Medium	Low
Total income		5,95	6,17	5,77
Total expenses		2,21	2,96	2,77
Net revenue		3,74	3,21	3,00
NPV		3,64	3,12	2,92
Average utilisati-on, %	berth	4,70	7,41	11,48
	labour	21,21	19,72	17,50
	equip-ment	21,40	19,64	17,46
	storage	57,71	47,82	44,68

The fists management policy proved to be the most effective. Despite the decrease of cargo handling speed due to overconcentration of labour and equipment the reduction of transport dwell time allowed to cut the costs.

We should also pay attention to the fact that we changed only the priorities of resource sets in the experiment, but it resulted in the significant changes of all parameters in table 3. It demonstrates the sensitivity of a terminal to management decisions related to resource distribution.

5. COCLUSIONS

The result of the above experiment don't lead to any general rule for resource management optimisation. The optimal policy is determined by the properties of port and terminal such as berth length, cost of resources, storage area size etc. If they change need of additional analysis eventually arises.

If the area of port is relatively small high concentration of labour and equipment may result in severe performance losses. In such a case even distribution of resources is recommended. On the other hand, if berth is short individual vessels should be discharged and loaded in short period that makes effective high labour and equipment concentration.

The approach presented in the paper may serve as a basis for further research aimed to solving more complex problems of resource management using advanced simulation models. Thorough analysis of factors that define the optimal resource management policies would lead to development of the practices which may significantly improve port and terminal performance.

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MODELLING OF INTERMODAL NETWORKS

Karl Etlinger[(a)], Edith Schindlbacher[(b)], Manfred Gronalt[(c)]

[(a,b,c)]Institute of Production and Logistics, University of Natural Resources and Life Sciences, Vienna
Feistmantelstraße 4, 1180 Vienna, Austria

[(a)]karl.etlinger@boku.ac.at, [(b)]edith.schindlbacher@boku.ac.at, [(c)]manfred.gronalt@boku.ac.at

ABSTRACT
This work presents an approach to support intermodal network planning and evaluation by providing a framework of methods for terminal location planning and operational network design. Therefore a mixed integer linear programming model is introduced to optimize the network structure and determine the locations for operating intermodal terminals as well as the type of terminal to be established.
This optimization approach is supposed to be combined with simulation techniques in order to provide a comprehensive planning and evaluation approach for intermodal transportation networks.
Within our work the developed methods and models are also implemented for a case study with test data based on major European transport corridors and future priority axes for freight transportation in Central and Eastern European (CEE) countries.

Keywords: intermodal transportation network, transportation corridor, hub location planning, network optimization

1. INTRODUCTION

Various studies come to the conclusion that the volumes of container traffic will continue to rise steadily after the short stagnation in 2009 caused by the economic crises (Seidelmann 2010). Therefore it is not only inevitable that the expansion of transportation infrastructure continues, but also that the infrastructure in new regions, especially in the CEE countries, is further developed and better connected to main European transport routes. Hence initiatives like RailNetEurope (RNE) and Ten-T (Trans-European Networks) for the development of transportation infrastructure have been launched. RNE is an association of European rail infrastructure managers and allocation bodies that aims at harmonizing conditions and procedures in the field of international rail infrastructure management. The focus of Trans-European Networks, a program of the European Commission, is the further development and expansion of the trans-European transportation corridors. Figure 1 depicts the growth of transportation volumes comparing the actual volumes of 2007 and the volumes forecasted for 2020 in twenty-foot equivalent units (TEU) (UIC 2010).

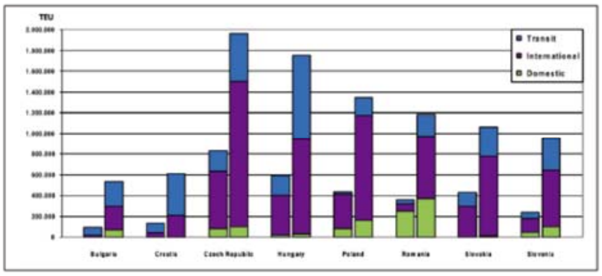

Figure 1: Comparison Of Transportation Volumes 2007 And 2020 (UIC 2010)

As a consequence of this development the experts of the International Union of Railways (UIC) expect the emergence of substantial bottlenecks in the rail infrastructure as well as terminal capacities by 2015 (Seidelmann 2010).

The emerging challenge is the timely planning of the expansion of transportation infrastructure and the introduction of efficient operational concepts for terminals as well as railways in intermodal transport (European Commission 2005).

When developing a method framework for the planning and evaluation of intermodal transport networks one faces a twofold problem. On the one hand there are long term decisions at a strategic level to be made but on the other hand, at the same time one has to deal with short term decisions at a tactical and operational level.

At the strategic level, decisions are found on a very long term, typically 10 to 20 years. This includes the location of terminals, network configurations and the design and layout of the terminals. Typically these are decisions where a large amount of capital is fixed for a long time and which are difficult to change retroactively (Macharis and Bontekoning 2004).

In general, when dealing with hub location problems, the concern is how to locate hub facilities and allocate demand nodes to these hubs in order to route the occurring traffic from an origin to a destination node within the network. Since optimal allocations are affected by hub locations and vice versa it is important not to deal with these two problems separately, as sometimes did in literature, but consider them together in the process of designing a hub network (Alumur and Kara 2008).

Macharis and Bontekoning (2004) state that operational research (OR) has focused mostly on uni-modal transport problems and that intermodal freight transport is only just starting to be researched seriously. Since intermodal transport systems are more complex compared to mono-modal ones, there is a need for the development of different OR techniques for intermodal freight transport research.

Caris et al. (2013) give an overview of new research themes in different areas concerning the development of decision support systems in intermodal transport.

At the tactical level the network operator has to determine which services will be offered and hence the corresponding service schedules have to be fixed. Secondly he has to decide which production model should be used i.e. how to operate the trains. This includes decisions like frequency of service, train length etc. (Macharis and Bontekoning 2004).

Even when focusing only on the tactical and operational levels, due to the complexity of intermodal transportation systems, a majority of the work in this field only deals with a certain aspect of the system and specific problem statements. So there are particular models for the calculation of the modal split based on costs for rail- and road traffic (Floden 2007) or models for the detailed simulation of the processes taking place at intermodal terminals as well as simulation models of those terminals (Gronalt et al. 2012). Rizzoli et al. (2002) and Gambardella et al. (2002) combine an agent based simulation model and a discrete event simulation for planning the flow of loading units between inland container terminals. Schindlbacher and Gronalt (2010) present an approach for the use of auction mechanisms to coordinate container flows in intermodal freight transportation networks whereas Bierwirth et al. (2012) focus on the transport service selection in intermodal rail/road distribution networks.

The authors propose a method framework for the planning and evaluation of intermodal rail/road transportation networks in order to support the decision processes necessitated by the aforementioned future development of transportation infrastructure. The goal is to provide an integrated approach that considers the strategic as well as the tactical and operational planning levels in one comprehensive approach that allows for interdependencies of the different planning perspectives.

2. MATERIAL AND METHODS

To track the problem at hand, we use two different methods to deal with the complexity of intermodal transportation networks.

For the long term planning of the intermodal network design at the strategic level, which is the main focus of this work, we develop an optimization model for the terminal location planning problem in order to create the basic network topology.

At the tactical and operational levels we approach the short term planning by developing a multi-agent simulation model which builds on the results of the terminal location optimization.

To design our transportation network we start by dividing the analyzed geographical area into smaller regions. Those regions are the origin and destination regions for the intermodal loading units in our model. We then identify a number of potential hub locations in the considered geographical area. Depending on the aim of the analysis the selection of those potential hub locations can be influenced by existing infrastructure, population density, regional economic power, geographic structure etc.

For real data analysis the granularity of the origin and destination regions is mainly determined by the availability of the required data on freight transportation volumes. Since it makes no sense to subdivide into areas for which there is no data available, the granularity of the regions is determined by the level of detail of the available data.

We now build a transportation network consisting of terminals and rail links connecting the terminals within the geographical area.

This is the basis for the routing of freight traffic in the network at the aggregated strategic level. At this level only aggregated transportation volumes such as yearly data are considered.

The disaggregation follows in the detailed planning of single train connections and terminal services at the tactical and operational levels.

2.1. Hub location planning

To solve the hub location planning problem, we modify and extend the well-known single allocation hub location problem (see Alumur and Kara (2008) for an overview of hub location problems) as presented in Alumur et al. (2009) and formulate a mixed integer linear programming model to approach our task at hand.

The optimization model creates the basic topology of the analyzed transportation network. The network consists of a set of nodes as well as arcs connecting the nodes in the network. The nodes can be divided into supply/demand nodes and hub-nodes. Supply/demand nodes represent the origin and destination regions of the analyzed transportation network and therefore are the starting- and endpoints for the flows of loading units in the network. They will be denoted as non-hub nodes subsequently. In our model we consider different types of hub nodes as introduced by Clausen and Sender (2011). These nodes represent different types of terminals, like gateway and feeder terminals which differ in their capacity, fixed operating costs as well as transshipment costs. They can also be distinguished by the number of connecting links they can have with the network.

The decision at which nodes a terminal should be established and what type of terminal it should be is based on the estimated volume of loading units that have to be handled by the network and the costs of transportation services as well as terminal operations.

The model chooses nodes out of a given pool of potential hub location nodes and determines the type of terminal that should be placed at those nodes in order to minimize the overall network costs while ensuring that all traffic can be handled and is transported from its origin to the assigned destination.

In the model formulation we emphasize model flexibility and the possibility to quickly adapt the model to a variety of problems, even though this means an increased level of complexity. Therefore, we relax the assumption that the hub network is a complete network with a link between every pair of hubs, as it is made in many other works in the area of hub location problems (Alumur and Kara 2008), and allow for complete as well as incomplete network structures in our model solutions.

The model also can be quickly adopted for either capacitated or uncapacitated problem statements as well as the inclusion or exclusion of fixed costs.

2.1.1. Mathematical model

For the mathematical formulation of our hub location problem we define a graph $G = (N, A)$ where N is the set of nodes and A the set of arcs of the graph. Let H be the set of potential hub locations such that $H \subseteq N$ with h hubs. Arcs that connect two hubs will be referred to as hub-links hereafter.

In order to present the mathematical formulation we define the following parameters:

p	number of hubs to be established
q	number of hub-links with $q \in \left\{p-1, \dots, \frac{(p-1)p}{2}\right\}$
c_{ij}	distance between nodes $i \in N$ and $j \in N$
c_{ij}^{truck}	transportation costs for one unit of flow between nodes $i \in N$ and $j \in N$ when carried by truck
c_{ij}^{train}	transportation costs for one unit of flow between nodes $i \in N$ and $j \in N$ when carried by train
w_{ij}	given flow from node $i \in N$ to node $j \in N$
O_i	total flow originating at node $i \in N$
D_j	total flow bound for node $j \in N$
$\bar{\Gamma}_k^c$	capacity of a hub of type $c \in L$ at node $k \in H$ where $L = \{1, \dots, c\}$ is the set of hub types
Θ_{kl}	capacity of a hub-link connecting hubs $k \in H$ and hub $l \in H$
F_{kl}	minimum flow required to establish a hub-link between hub $k \in H$ and hub $l \in H$
a^c	maximum number of hub-links that can be connected to a hub of type $c \in L$
$\overline{Ch}_k^c$	cost for a hub of type $c \in L$ at node $k \in H$
Cl_{kl}	cost of installing a hub-link between hubs $k \in H$ and $l \in H$
$\overline{cch}_k^c$	cost for cargo handling at hub $k \in H$ with capacity level $c \in L$

Decision variables:

$$x_{ik} = \begin{cases} 1, & \text{if node } i \in N \text{ is allocated to hub } k \in H \\ 0, & \text{otherwise} \end{cases}$$

$$y_{kl} = \begin{cases} 1, & \text{if a link is established between } k \in H \text{ and } l \in H \\ 0, & \text{otherwise} \end{cases}$$

f_{kl}^i flow from node $i \in N$ to hub $l \in H$ via hub $k \in H$

$$g_k^c = \begin{cases} 1, & \text{if node } k \in H \text{ is a hub of hub type } c \in L \\ 0, & \text{otherwise} \end{cases}$$

The model formulation is given as follows:

$$\min \sum_{i\in N} \sum_{\substack{k\in H:\\ k\neq i}} c_{ik}^{truck} O_i x_{ik} + \sum_{i\in N} \sum_{\substack{k\in H:\\ k\neq i}} c_{ki}^{truck} D_i x_{ik} \tag{1a}$$

$$+ \sum_{k\in H} \sum_{l\in H} \sum_{i\in N} c_{kl}^{train} f_{kl}^i \tag{1b}$$

$$+ \sum_{k\in H} \sum_{c\in L} \overline{Ch}_k^c \, g_k^c \tag{1c}$$

$$+ \sum_{i\in N} \sum_{k\in H} \sum_{\substack{l\in H:\\ l\neq k}} \sum_{c\in L} f_{lk}^i \overline{cch}_k^c g_k^c + \sum_{i\in N} \sum_{k\in H} \sum_{c\in L} O_i x_{ik} g_k^c \overline{cch}_k^c \tag{1d}$$

$$\sum_{k\in H} \sum_{c\in L} ld1_k^c \overline{cch}_k^c + \sum_{i\in N} \sum_{k\in H} \sum_{c\in L} O_i ld2_{ik}^c \overline{cch}_k^c \tag{1e}$$

subject to:

$$\sum_{k\in H} x_{kk} = p \tag{2}$$

$$\sum_{k\in H} \sum_{l\in H: k<l} y_{kl} = q \tag{3}$$

$$\sum_{k\in H} x_{ik} = 1 \qquad \forall\ i \in N \tag{4}$$

$$x_{ik} \le x_{kk} \qquad \forall\ i \in N, k \in H \tag{5}$$

$$y_{kl} \le x_{kk} \qquad \forall\ k, l \in H: k < l \tag{6}$$

$$y_{kl} \le x_{ll} \qquad \forall\ k, l \in H: k < l \tag{7}$$

$$\sum_{l\in H: l\neq k} f_{lk}^{it} + O_i^t x_{ik} = \sum_{l\in H: l\neq k} f_{kl}^{it} + \sum_{j\in N} w_{ij}^t x_{jk} \qquad \forall\ k \in H, i \in N \tag{8}$$

$$f_{kl}^i + f_{lk}^i \le O_i y_{kl} \qquad \forall\ k, l \in H: k < l, i \in N \tag{9}$$

$$f_{kl}^i \ge 0 \qquad \forall\ k, l \in H: k \neq l, i \in N \tag{10}$$

$$\sum_{i\in N} f_{kl}^{it} \le \Theta_{kl} \qquad \forall\ k, l \in H: k \neq l \tag{11}$$

$$\sum_{i\in N} f_{kl}^i \ge F_{kl}(y_{kl} + y_{lk}) \qquad \forall\ k, l \in H: k \neq l \tag{12}$$

$$\sum_{i\in N, k\in H: k\neq l} f_{kl}^i \le \sum_{i\in N} D_i x_{il} - \sum_{u,z\in N: u\neq z} w_{uz} x_{ul} x_{zl} + \left(\left(\sum_{\substack{m\in H:\\ l<m}} y_{lm} + \sum_{\substack{e\in H:\\ e<k}} y_{el} \right) - 1 \right) n + (x_{ll}(-n) + n) \qquad \forall\ l \in H \tag{13}$$

$$\sum_{i\in N, l\in H: l\neq k} f^i_{lk} \le \sum_{i\in N} D_i x_{ik} - \sum_{u,z\in N: u\neq z} w_{uz}\, ld3_{uzk} + \left(\left(\sum_{m\in H:k<m} y_{km} + \sum_{e\in H:e<k} y_{ek}\right) - 1\right) * \sum_{i\in N} D_i + \left(x_{kk} * (-1 * \sum_{i\in N} D_i) + \sum_{i\in N} D_i\right) \quad \forall\ k \in H \qquad (14)$$

$$\sum_{c\in L} g^c_k = x_{kk} \quad \forall\ k\in H \qquad (15)$$

$$\sum_{i\in N} O^t_i x_{ik} \le \sum_{c\in L} \bar{\Gamma}^c_k g^c_k \quad \forall\ k\in H \qquad (16)$$

$$\sum_{l\in H} (y_{kl} + y_{lk}) \le g^c_k * a + n \sum_{s\in L: s\neq c} g^s_k \quad \forall\ k\in H, c = m \qquad (17)$$

$$0 \le ld1^c_k \le \sum_{i\in N} O_i g^c_k \quad \forall\ k\in H, c\in L \qquad (18)$$

$$0 \le \sum_{i\in N}\sum_{l\in H: l\neq k} \left(f^i_{lk}\right) - ld1^c_k \le \sum_{i\in N} O_i (1 - g^c_k) \quad \forall\ k\in H, c\in L \qquad (19)$$

$$ld2^c_{ik} \le x_{ik} \quad \forall\ i\in N, k\in H, c\in L \qquad (20)$$

$$ld2^c_{ik} \le g^c_k \quad \forall\ i\in N, k\in H, c\in L \qquad (21)$$

$$ld2^c_{ik} \ge x_{ik} + g^c_k - 1 \quad \forall\ i\in N, k\in H, c\in L \qquad (22)$$

$$ld3_{ijk} \le x_{ik} \quad \forall\ i,j\in N, k\in H \qquad (23)$$

$$ld3_{ijk} \le x_{jk} \quad \forall\ i,j\in N, k\in H \qquad (24)$$

$$ld3_{ijk} \ge x_{ik} + x_{jk} - 1 \quad \forall\ i,j\in N, k\in H: i\neq j \qquad (25)$$

$$x_{ik} \in \{0,1\} \quad \forall\ i\in N, k\in H \qquad (26)$$

$$y_{kl} \in \{0,1\} \quad \forall\ k,l\in H: k<l \qquad (27)$$

$$f^i_{kl} \in \mathbb{Z}^+ \quad \forall\ k,l\in H, i\in N \qquad (28)$$

$$g^c_k \in \{0,1\} \quad \forall\ c\in L, k\in H \qquad (29)$$

$$ld1^c_k \in \mathbb{Z}^+ \quad \forall\ k\in H, c\in L \qquad (30)$$

$$ld2^c_{ik} \in \{0,1\} \quad \forall\ i\in N, k\in H, c\in L \qquad (31)$$

$$ld3_{ijk} \in \{0,1\} \quad \forall\ i,j\in N, k\in H: i\neq j \qquad (32)$$

There are three types of flows that form the origin-destination flows within the network. O_i is the collection move respectively the aggregated flow from the origin node i to the first hub. The aggregated flow from the last hub to the destination node j is denoted by D_j. If the flow is routed from one hub to another on a hub-link, this results in a positive f^i_{kl} flow where i is the node of origin and the flow is routed to hub l via hub k (see figure 2).

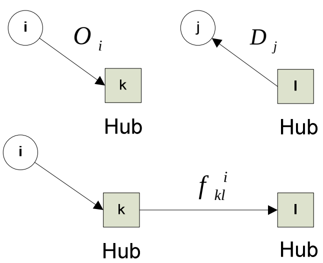

Figure 2: Types Of Flows

Depending on the structure of the network and whether the origin or destination node is a non-hub node or a hub node, an origin-destination flow can be either only one of those flow types or consist of subsequent flows of different types. Please note, that an origin-destination flow can be routed via multiple hubs and therefore can consist of multiple f-flows but includes at most one O- and at most one D-flow.

Since in our model we require, that every origin-destination flow of the given transportation volumes W is being operated, the flows from the origin node to the first hub and the according flows from the last hub to the destination node can be calculated by $O_i = \sum_{j\epsilon N} w_{ij}$ and $D_j = \sum_{i\epsilon N} w_{ij}$ respectively (Alumur et al. 2009).

The goal of the model is to determine where in the network to establish hubs and what type of terminal should be installed in order to handle all given flows at minimum overall costs. Therefore the model also has to allocate every non-hub node to a hub and route the flows through the network in a cost optimal way.

The objective function minimizes the overall system costs which consist of transportation costs as well as fixed operating and variable cargo handling costs at the terminals.

In the first term of the objective function (1a) the costs of the road transportation from the origin nodes to the associated hubs are calculated. This is followed by the costs for delivering a flow from the last hub to the destination node by truck. (1b) evaluates the costs of routing a flow from hub to hub within the railway system. (1c) regards for the fixed costs that arise when a hub of a certain type is being operated at node k. In (1d) the costs that are caused by handling flow at a hub are considered. As one can see (1d) is nonlinear and can therefore make the model hard to solve. So in (1e) a linearized version of (1d) is proposed where $ld1^c_k$ is the linearization of $f^i_{lk} g^c_k$ and $ld2^c_{ik} = x_{ik} g^c_k$. The constraints for these linearizations are given in constraints (18) through (22).

In order to model the transportation costs we use distance-dependent cost functions for road and for rail transport based on the distance matrix C which result in costs of c^{truck}_{ij} and c^{train}_{ij} for the shipment of one unit of flow from node i to node j on a direct connection with the according mode of transportation. In case such cost functions are not available one can simply substitute c^{truck}_{ij} and c^{train}_{ij} with c_{ij} and add a discount factor α to the last term of (1a) as it is widely used in the literature in order to factor in the economies of scale associated with flows between hubs.

We do not consider costs for establishing hub-links since we assume that the transportation network is planned within an already existing railway network and therefore it is not necessary to include those costs. However, if desired this can easily be done by extending the objective function with the term

$$+\sum_{k\in H}\sum_{l\in H: l>k} Cl_{kl}\, y_{kl} \qquad (1e)$$

where Cl_{kl} are the costs for maintaining a hub-link between hubs at nodes k and l.

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ISBN 978-88-97999-24-9; Bruzzone, Gronalt, Merkuryev, Piera Eds.

Constraint (2) allows to fix the number of hubs that should be operated in the system. As does constraint (3) for the according hub-links whereby this number has to be somewhere between $\mathrm{p}-1$, which is the minimum number of hub-links required to connect all hubs, and $\frac{(\mathrm{p}-1)\mathrm{p}}{2}$ which would provide a complete graph for all hub nodes. In order to let the model determine the number of hubs to be established one can simply leave out (2). The same applies to the number of hub-links and (3). Another obvious possibility would be to let the model determine the optimal number of hubs, but predetermine the connections between the hubs in a way that all hubs are connected with the minimum number of hub-links so that the graph of hubs takes the form of a spanning tree. This can be achieved by including

$$\sum_{k \in H} \sum_{l \in H} y_{kl} = \sum_{k \in H} x_{kk} - 1 \tag{33}$$

into the model.

Constraint (4) makes sure that the single allocation condition is met and every non-hub node is allocated to exactly one hub. Additionally (5) ensures that non-hub nodes are only allocated to hub nodes. Constraints (6) and (7) guarantee that hub-links can only be established between actual hubs and not between non-hub nodes. (8) is the flow conservation constraint and makes sure, that every flow that enters a hub is routed further through the system, except for flows that are designated for the node of the hub. For strictly non-negative $\mathrm{f}_{\mathrm{kl}}^{\mathrm{i}}$-flows and in order to ensure that they are only positive if nodes k and l are hubs (10) and (9) are added to the model.

Constraint (11) offers the possibility to limit the maximum amount of flow that can be routed over a specific hub-link to a certain capacity Θ. However, since in the context of train operations the track capacity usually is not a limiting factor, it can be included or left out as needed. In contrast to (11), constraint (12) serves the purpose of limiting hub-link operations to connections that exceed a certain amount of flow. This constraint can be motivated by the fact, that in reality it is not feasible to establish train routes where there is not enough cargo traffic to operate a minimum number of trains per week. Subsidiary to that, (13) prevents the model to send flow back and forth a hub-link in order to push the volume of flow over the minimum flow requirements threshold where n can be any big number that is known to exceed the actual flow. Since (13) is a non-linear constraint which can cause difficulties when solving the model, (14) provides a linearized version of the constraint where $ld3_{ijk} = x_{ik}x_{jk}$. Linearization constraints are given in (23)-(25).

The following two constraints present the possibility to include different hub types in the model which can be differentiated according to their flow capacity as well as their fixed operating costs and the cost for transshipping units of flow. (15) limits every hub to exactly one hub type out of the subset $L = \{1, \dots, c\}$ of possible types of hubs. That the capacity of a hub of a certain size is not exceeded is ensured via (16). Through (17) different types of hubs can be further differentiated by limiting the number of hub-links that can be connected to a hub of type $c \in L$ to a fixed number of a.

Finally constraints (26) through (32) are non-negativity and binary conditions.

3. CASE STUDY

In this case study we apply our model to a test scenario that is based on the situation in the CEE - area. Therefore the model is implemented in the solver software Xpress, using the programming language Mosel.

For the case study we use real world data to build a simplified model that resembles the conditions of a transportation network in this area in terms of terminal sizes and costs as well as transportation volumes and distances plus costs for rail and road based transportation.

As data basis for the flow volumes we use yearly freight transportation data of the CEE region on a NUTS2 regional level. The data regarding costs and capacities of terminals are based on the information of experts involved in intermodal transportation and terminal operations. For modeling the intermodal transportation costs we use distance-dependent cost functions where the costs per km decrease with increasing transport distance. The cost function for train-based transport starts at 80 per cent of the costs for road transportation and includes a higher cost degression. To be eligible for the establishment of a hub-link, we require a minimum amount of aggregated flow on a hub-hub connection, roughly corresponding to one block train per week operating on the hub-link. In order to create our network area, we generate 20 random nodes on a coordinate system to resemble the actual CEE region and calculate the resulting distances between these nodes. We also choose ten nodes to be potential hub locations.

The resulting map of nodes looks as depicted in figure 3. Colored nodes indicate that the node is marked as potential hub location.

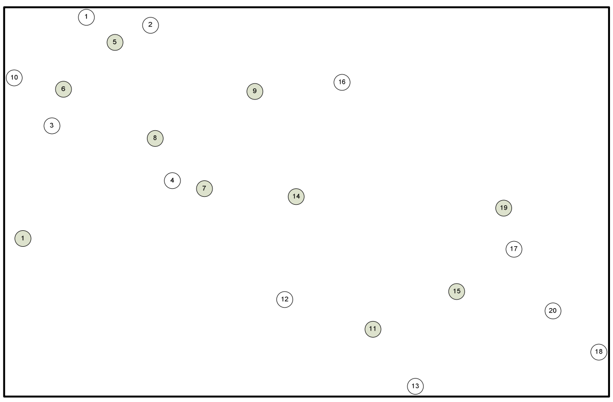

Figure 3: Map Of Nodes

Solving the optimization model leads to a network of seven hubs that are connected with eight hub-links. Figure 4 shows the resulting network where rectangular nodes indicate hubs and red lines mark hub-links. In the optimal solution out of the three possible terminal types, only medium and small capacity hubs are used. Medium sized hubs are located at the nodes 5, 6, 7 and 14 whereas at nodes 8, 9 and 19 small hubs are established. The fact, that there are no large hubs placed into the network leads to the conclusion that the operation of a larger amount of smaller hubs is favored over the possibility to use fewer hubs with higher capacity. This can be explained by the fact that in our network the transportation costs outweigh the costs of terminal operations by far. In the optimal configuration of the network, terminal related costs account for 10% of the overall costs while the other 90% are shipment costs. So it is hardly surprising that the savings in shipment costs that come with a larger amount of hubs and thus a reduced mileage for truck shipments lead to a relatively high number of hubs in the network. Especially since we focus on the operation of the network and thus do not consider investment costs for the installation of a hub.

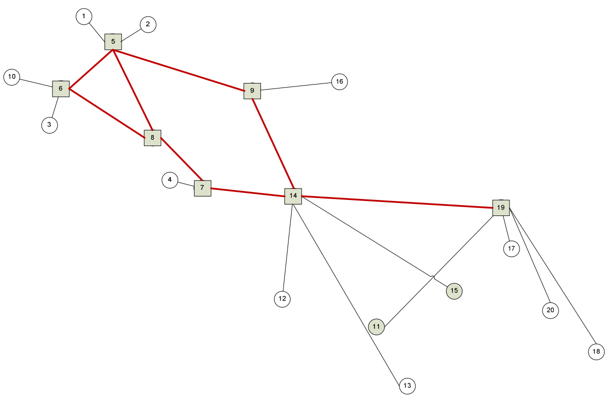

Figure 4: Solution 1 Of The Hub Location Problem

Varying the costs for transportation shows, that the network design is sensitive to the cost ratio of rail and road haulage. The higher the cost advantage of train transportation, the higher is the tendency to include additional hubs and hub-links to exploit those cost advantages.

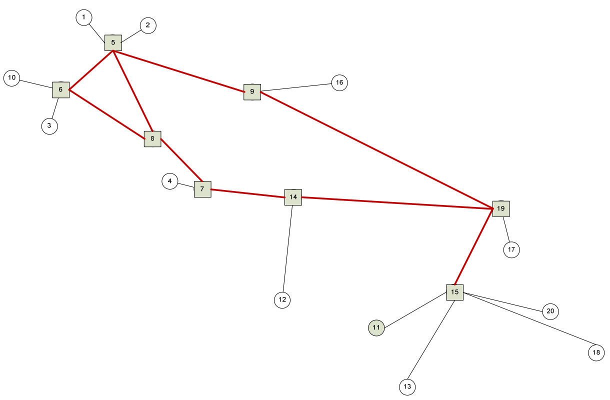

Figure 5: Solution 2 With Decreased Train Costs

A reduction of the cost ratio from 80% to 60% results in the inclusion of an additional hub at node 15 (see figure 5) whereas an increase to 90% leads to the subtraction of the hub at node 9 (see figure 6).

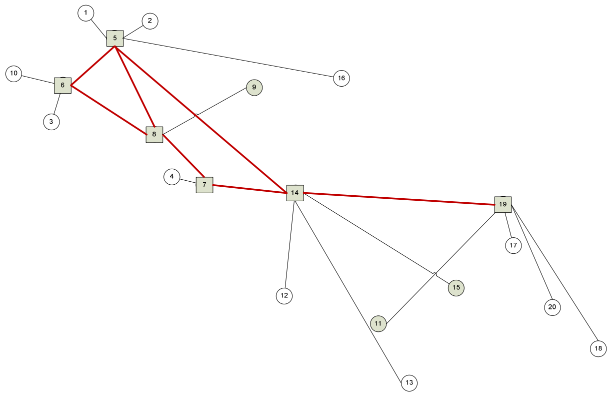

Figure 6: Solution 3 With Increased Train Costs

In a next step we restrict the model in the number of hub-links that can be established so that the resulting graph of hubs is a spanning tree. The underlying assumption is that the potential hub nodes are consecutively located along the main routes of the railway network and therefore cannot be bypassed via hub-links that connect other hubs in a more direct way.

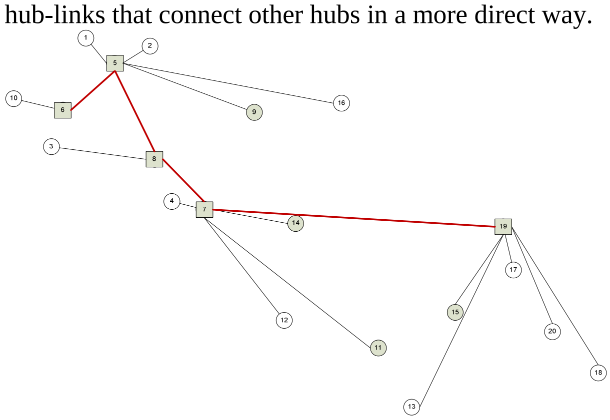

Figure 7: Solution 4 With Limited Hub Connectivity

Compared to the initial solution network this change results in the removal of two hubs (at nodes 9 and 14) from the model solution as shown in figure 7. This result is consistent with the previous findings. Since the possibility of saving shipment costs by directly linking hubs in order to shorten the transportation distances is limited now, it becomes less beneficial to operate a large hub network. So in this solution there is a terminal of the highest available capacity placed at node 5 and four medium sized terminals are operated at nodes 6, 7, 8 and 19. There are no small terminals established in the network any more.

Table 1: Relative Network Costs

	Relative Network Costs			
cost factor	Solution 1	Solution 2	Solution 3	Solution 4
overall costs relativ to Solution 1	**100,0%**	**84,1%**	**104,5%**	**107,4%**
prehaulage	15,7%	12,8%	17,9%	17,6%
train tansport	61,1%	62,4%	57,0%	60,7%
posthaulage	13,7%	12,7%	16,0%	14,2%
transportation	**90,5%**	**88,0%**	**91,0%**	**92,6%**
fixed operating costs	6,2%	8,0%	6,1%	4,7%
transshippment	3,3%	4,1%	3,0%	2,8%
terminal operations	**9,5%**	**12,0%**	**9,0%**	**7,4%**

Table 1 compares the overall network costs of the presented solution networks relative to the initial solution 1. Additionally the shares of the different cost factors in the respective network costs are listed. One can see that the restrictions for the establishment of hub-link connections result in a seven per cent increase in total network costs while the shares of the cost factors are relatively constant.

4. CONCLUSIONS AND FURTHER RESEARCH

The results of our case study indicate that the model solutions are not very robust in terms of changes in the cost structure of road and railroad transportation as well as restrictions for the establishment of hub-links. So when planning an actual network it should be ensured that the used data as well as the modeling of these elements are as close to the real world situation as possible.

A general limitation of the presented approach lies in the static nature of the optimization and the use of aggregated data which makes it impossible to consider the variability of freight volumes and the implications for terminal capacities and train connections during peak and off-peak periods.

As the presented approach therefore only constitutes the first step in an integrated planning and evaluation framework, further research will mainly focus on the planning of the operational network design, including concepts for terminal operations and train production concepts, and their detailed assessment. Thus, for the completion of the overall process an agent based simulation model will be used for a comprehensive analysis of the networks designed according to the presented method. In other words, after the network topology is fixed and the transportation volumes are allocated to the different terminals in the network by optimization a multi-agent simulation model is applied for the evaluation at the tactical and operational levels.

Therefore we model the processes that take place at an intermodal terminal and the railway system that connects the terminals by using simulation techniques. Hereby we focus on processes that are specific to intermodal terminals like the handling of intermodal loading units and train dispatching. With the simulation tool, one can test different concepts of terminal operations as well as train production concepts and determine the correspondent performance measures like transshipment capacities and cycle times for train dispatching.

Hence the simulation model supplements the static results of the hub location optimization with dynamic performance parameters. The simulation enables the evaluation of capacity limits of the terminal network and allows to analyze the effects of different train production concepts. If this evaluation of the intermodal transportation system exposes flaws induced by the network topology or network operation concepts, the preceding steps of optimization and design can be repeated in feedback loops within the whole method framework.

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MANAGEMENT OF DANGEROUS GOODS IN CONTAINER TERMINAL WITH MAS MODEL

Mansoriya Hamidou*, Dominique Fournier*, Eric Sanlaville*, Frédéric Serin*

* Litis Laboratory - University of Le Havre, France

(*mansoriya.hamidou, *dominique.fournier, *eric.sanlaville, *frederic.serin)@univ-lehavre.fr

ABSTRACT

In a container terminal, many operations occur within the storage area: containers import, containers export and containers shifting. All these operations require the respect of many rules and even laws in order to guarantee the port safety and to prevent risks, especially when hazardous material is concerned. In this paper, we propose a hybrid architecture, using a Cellular Automaton and a Multi-Agent System to handle the dangerous container storage problem. It is an optimization problem since the aim is to improve the container terminal configuration, that is, the way hazardous containers are dispatched through the terminal to improve its security. In our model, we consider containers as agents, in order to use a Multi-Agent System for the decision aid software, and a Cellular Automaton for modelling the terminal itself. To validate our approach many tests have been performed and the results show the relevance of our model.

Keywords: container terminal, dangerous container, multi-agents system, security

1. INTRODUCTION

This paper proposes a dynamic technique to manage the storage of containerized dangerous goods in a terminal. This work aims at maintaining the safety of a terminal during all the handling operations that can be executed in such areas.

More precisely, our research is about stacking activities and dangerous containers storage in a port terminal. The problem is: how to position hazardous containers in compliance with physical constraints and regulations? The International Maritime Dangerous Goods (IMDG) Code, available on IMO web site (International Maritime Dangerous Goods 2013), classifies dangerous goods into 9 main classes (**Table 1**). Their stockpiling must respect regulation and separation rules for each class. Our aim is to maintain a safe configuration of the terminal. The management of handling equipment is outside the scope of this paper. Methods for the scheduling of Straddle Carrier (SC) missions, and the subsequent routing, are investigated in other papers, see (Lesauvage, Balev and Guinand 2011) and (Balev, et al. 2009).

In the following, we first present more precisely our problem and some related works. Then, our multi-agents hybrid architecture and the behaviours of our agents are presented. Thereafter our tests and results are discussed.

2. PROBLEM DESCRIPTION AND LITERATURE

In this section, we will describe the problem of dangerous container storage: first we define the storage area structure we use. Then dangerous goods' classes are determined with examples of security rules. After that, we explain the objective of our work.

2.1. Problem Description

2.1.1. Storage Area Structure

A container terminal is a part of a port where containers are stored and handled. The storage area (yard) is divided in blocks. On each block containers are arranged in rows and slots (piles of at most 4 containers high); see **Figure 1**.

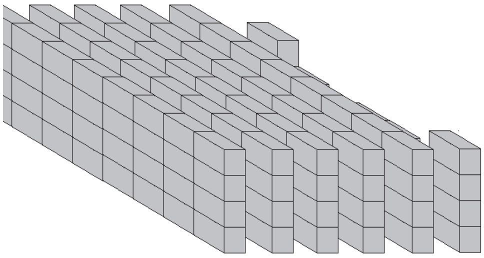
Spaces between two rows allow the handling equipment circulation. Handling equipment is required for terminal management. It transfers containers within terminal and tranship them. Common types of handling equipment are chassis based transporter, straddle carriers, quay crane, rubber tired gantry crane and rail mounted gantry crane (Stahlbock and Voss 2008).

In a terminal, there are three main activities concerning containers:

- **Unloading:** containers are discharged from a ship or other transport mode like trucks or train, to be transferred to the storage area using handling equipment.
- **Staking:** containers are stored on the area dedicated to them, respecting physical constraints and regulations.
- **Loading:** containers leave storage area and are loaded to be transported on train or ship.

This paper focuses on the stacking activities, and the storage area where containers are moved by Straddle Carriers. When a container is moved from one place to another, within the terminal, we talk about a "movement".

Figure 1 Storage Area Structure



2.1.2. Dangerous Containers

Containers are boxes which contain goods. These goods can be dangerous and are then called hazardous materials or *dangerous* goods. This means articles or materials potentially dangerous for people or environment. It includes items of common use, such as aerosol cans, perfumes, and paints (Dangerous goods definition).

The nine IMDG classes of dangerous goods are listed in the following table:

Table 1 IMDG Classes

Class #	Dangerous Goods
1	Explosives
2	Gases
3	Flammable liquids
4	Flammable solids; substances liable to spontaneous combustion; substances which, in contact with water, emit flammable gases
5	Oxidizing substances and organic peroxides
6	Toxic and infectious substances
7	Radioactive material
8	Corrosive substances
9	Miscellaneous dangerous substances and articles

Storage constraints exist for each class. The containers of a particular class cannot be stored next to another, or must be separated from them by a fixed distance. An example of separation rules is cited below, see (IDIT 2013).

Flammable liquids containers (class 3) must be separated by:

- Distance F from explosives (class 1). F equals to

  $F=4.8\times Q^{13}$

  where:

  F is a separation distance in meters; and

  Q is the explosive net weight in kilograms.
- 30 meters from gases (class 2).
- 7 meters from radioactive.
- etc.

2.1.3. Objective

To explain the objective of this work, we use an example.

N Containers of different types T_1, T_2,.. T_r are packed together on one terminal. For simplicity, it shall be supposed in that presentation that the terminal is composed of one unique block of n rows. According to its type and the typology presented before, the well-being of one container can be evaluated. For instance, considering a dangerous container of radioactive type as in previous section, its well-being depends on the number of containers of any dangerous type present in its neighbourhood (defined in terms of Euclidean distance). Generalizing this observation, it is easy to derive a well-being value for each container of the terminal, which can be normalized according to all container types. The total well-being value of a whole terminal configuration can be computed as the worse of the well-being values of all containers it contains (an alternative criterion is the sum of well-beings). This is also called fitness function in section 3.

Consider now some initial terminal configuration, associated with its well-being value. The problem consists in changing the configuration through a sequence of transfers (moves of a container from one place to another) so as to optimize the total well-being by minimizing movements number. This optimization problem is not simple to solve because of the different types of containers, and the special dimension of the problem. It is also clear that the optimal configuration does not depend on the initial configuration, but only on the number of containers of each type. Finding this optimal configuration is a problem of placing objects in a three-dimensional environment, so as to allot each type at best with a minimum number of movements.

2.2. Literature

As far as we know, there is no work specially dedicated to the storage of containers with dangerous goods in a terminal, excepted in (Salido, Rodriguez-Molins and Barber 2011). They resolved both allocation berth problem and container stacking problem by a set of Artificial Intelligence based heuristics. In the container stacking problem, the objective was the minimization of number of relocation. In this paper, dangerous containers were considered but the constraint was: two dangerous containers must maintain a minimum security distance, but different existing classes and rules of dangerous containers were not been considered.

However, many research papers use agent-based approach to simulate or solve transport logistics problems (Davidsson, et al. 2005). Some of them study the container terminal management problem using Multi-Agent System and their aims focus on various aspects of terminal planning and management (Rebollo, et al. 2000), (Henesey, Wernstedt et Davidsson 2003) and (Thurston and Hu 2002).

In (Kefi, et al. 2007), a MAS approach was used for storing containers respecting their departure time. The authors use two kinds of agents (Container Agents and Interface Agent) in order to optimize the container storage area on a port terminal; their goal was to reduce the transportation cost within the terminal.

All these works reinforce our idea to use a MAS approach to model the management of a port terminal

and to solve our problem. Moreover, (Kefi, et al. 2007) used such architecture to perform container storage optimization which has a spatial aspect like our problem.
Other papers used Operational Research techniques to solve container storage problem in a terminal. (Kim and Hong 2006) proposed two methods for determining the relocation of containers: a branch-and-bound algorithm and a decision rule, but it was limited to only 6 stacks by 5 containers high (5 tiers).
In (Kim and Lee 2006), constraint satisfaction technique was used for space allocation to export containers. The objective was the maximization of the equipment efficiency.

The spatial aspect also appears in works on cellular automata (Wolfram 2002). Cellular automata are in particular used by geographers and economists to model the evolution of a population inside a given space (Schelling 1978). As we shall see later, we use a similar model (see section 3.2.2).

3. PROBLEM MODELING

In this section, we define Cellular Automata and show the similarity between the block structure and the Cellular Automata architecture. Then, multi-agent systems are defined and described in the container terminal context. Finally, we detail the adopted strategies and the agents' behaviours.

3.1. Hybrid Approach

3.1.1. Cellular Automaton structure

A container terminal is a set of three-dimension cubic cells arranged in rows. These properties inspire us to introduce, by similarity of structure, the notion of 3D Cellular Automaton (CA).

A Cellular Automaton is a complex and dynamic system. It is a collection of cells on a grid. Each cell has a "state" among a finite set of states, and evolves through a number of discrete time steps according to a set of rules based on the states of neighboring cells. The grid can be in any finite number of dimensions (Wolfram 2002). If state updates occur synchronously, we speak about synchronous cellular automata, i.e. the states of every cell in the model are updated together. In contrast, in an asynchronous cellular automaton cells are updated individually and independently, in such a way that the new state of a cell affects the calculation of states in neighbor cells.

Thus, each cell of our cellular automaton corresponds to a container place on terminal. It can be free or occupied. The neighbourhood of each cell depends on the container class and its separation rules, it is defined in terms of Euclidean distance, but a transition function is not simple to be expressed. It will correspond to agents' decisions.

3.1.2. Multi-Agent System Model

A Multi-Agent System is a set of physical or virtual autonomous entities, located on an environment. They can coordinate, communicate, negotiate and interact with each other, using their resources and skills, in order to fulfil common and individual goals (Weiss 1999). Our project aims to avoid a coordination center and consequently to introduce local and neighbourhood consideration to proceed the placing of hazardous items.

As dynamic and complex systems, requiring many decision makers with different objectives, dangerous containers storage problem is suitable for distributed solving techniques. The specification of mobility attached to our agents engaged us to use situated agents in the grid and to precise that elements are not fixed in a definitive cell into the CA. Nevertheless, the agents come in, come out, and move into the CA.

The aim is to satisfy container objectives, that is why container centred model is developed. Consequently, containers are considered as agents and they attempt to reach their goals. Each agent has to be placed in a cell, in which its safety rules are respected. They also contribute to reach the global objective.

Container agents have to execute two processes. The first one is the negotiation phase; the second one is the movement phase. The negotiation phase is composed by the following tasks:
First, each agent computes its well-being. We can restrict the number of partners (containers) interacting in the negotiation phase. Candidates are chosen according to their well-being. The next step consists in finding a destination for elected agent(s); the chosen container can be selected before this step or after to consider the well-being enhancement.
Among the strategies intervening to decide the winner of the negotiation, the moving cost can be considered. It depends on the distance.

After that, the agent selected to be moved will execute the movement process. In this process, container searches a new place better than its current position, and moves using resources.
The "search new place" task can be in the first process or the second process. It depends on the strategy chosen and the agent situation.

This model allows us to test various strategies for dangerous container placement or displacement on a terminal. These strategies depend on processes execution of agents.

To summary our model, first we structure these objects using the CA architecture, secondly, we introduce agent based modelling to add communication protocols and behaviours.

3.2. CA and MAS Application: Strategies

To solve the dangerous container storage problem, many strategies are implemented using the Cellular Automata and Multi-Agent System approach.

First, some terms definition, useful for describing strategies, are remained. Then two strategies are detailed

3.2.1. Notations

- *Neighbourhood*: The neighbourhood of container agent A is a set of containers. These containers are separated from A by a known distance. For example, a radioactive container R neighbourhood is a set of containers which are located within a radius of 6 meters from the container R.

- *Fitness*: the function fit(A) is used to denote the fitness of the container A. It measures its well-being. It is equal to the number of violated rules of container A.

- *Weighted fitness*: the function $fit_w(A)$ is used to denote the weighted fitness of container A. It is equal to the fitness multiplied by a factor between 0 and 1. This factor depends on the neighbourhood size of the container agent A. The weighted fitness is used to choose candidates agent containers.

- *Configuration*: exact location of each type of container in the block. *An Undesirable configuration* is a configuration in which some security rules are not respected.

3.2.2. Schelling Strategy

This strategy was inspired by Schelling's segregation model (Schelling 1978). This model was proposed by Thomas Schelling in 70's. It is a Cellular Automaton used to study racial segregation mechanism inside an urban area. A cell of the automaton is an accommodation (flat or house). Its state is the group of its inhabitant, or empty. The inhabitant decides to leave if the percentage of foreigners (relatively to his group) in its neighbourhood exceeds a given threshold. He then moves to any free accommodation. Under very weak initial conditions and a high tolerant threshold, segregation appears between the different groups of inhabitants.

We use a similar model, where inhabitants are replaced by containers. In this strategy, each container agent interacts with its neighbours, and computes its fitness, then its weighted fitness. Agents with weighted fitness equals to the maximum value of weighted fitness of all agents in the block, move randomly within the terminal. Many agents can be moved in the same time. They choose randomly an empty cell. This strategy is repeated until all security rules are respected, or until the movements becomes too high.

If a container agent is selected to be moved (i.e. his weighted fitness equals to the maximum weighted fitness in the block) and is not on the top of the stack, then this agent asks the agents above to be moved. They also move randomly, from the highest to the lowest.

Advantages

- Even if agents move to random places, like Shelling's segregation model, this strategy often find a solution.

Disadvantages

- The number of movements is very high.
- Some movements are useless.
- Maximal fitness value of all container agents varies considerably between two configurations (after one strategy run).

3.2.3. Cognitive Agent Based Strategy (CABS)

Unlike the previous strategy where container agents are reactive, in this one, agents are cognitive. They anticipate before acting. Only one container moves in the same time.

First, all agents compute their fitness, and their weighted fitness. Then they compare their weighted fitness. The ten agents that have the worst (the ten maximum values) weighted fitness compose "the candidates set". According to strategy steps, this set will be reduced until it contains only one element: the agent to be moved.

Hereafter, step run by candidate agents (agents that are members of "candidate set"):

a) Search place in the block: agents search places; they begin by the nearest empty cells. The best place with the best fitness for each agent is saved in its memory. Each agents stop searching when it finds a place which respects all its security rules.
b) Compute utility value: this value measures fitness improving. It is equal to the difference between the current fitness and the future potential fitness of the agent container. Each candidate agent computes its utility.
c) Reduce candidates set: agents having utility equals to the biggest utility of all candidate agents are retained in the "candidates set". The others are deleted from this set. More over the best utility value must be positive or zero, otherwise the strategy running stops. At this level, candidates set cardinality can be one or more.
d) Candidate agents compare fitness of all neighbour agents, and save on its memory the maximum value called "neighbourhoods' maximum fitness". The agents having the neighbourhoods' maximum fitness value equal to the highest one, are kept in the candidates set, the others are removed.
e) If "candidates set" has more than one element, then one container agent is chosen randomly to be the final candidate.
f) The final candidate moves. If one or more containers are placed just above it, they have to be moved. So, they search the best existing places in the terminal without comparing with the current places, and without taking into account the place chosen by the final candidate (so they can take its chosen place).

Neutral containers (i.e. containers that don't store dangerous goods) have always a fitness equals to zero. When they are ordered to be moved they chose the nearest empty cell.

The program stops if all security rules are respected in the block, or all candidate agents don't find a place that improves or stabilises their fitness.

Advantages

- Agents anticipate: before moving, agents search places. Then they compare their fitness improving before they decide which one will be moved.
- A container agent does not move until it improves its fitness or stabilizes it.
- Movement number is strongly reduced comparing with Schelling Strategy

Disadvantages

- Anticipation is efficient only if the final candidate container is on top of the stack.
- Risk of getting movement cycles: after *x* movements, the block turns back in a previous configuration and same container(s) move(s) indefinitely.
- The strategy can fall in a local minimum: it can be possible that none of agents container within the candidates set finds a new cell improving or stabilizing its fitness. In this case, the program stops without finding a solution.

4. TESTS AND RESULTS

To estimate the efficiency of these strategies, tests were executed. To simplify the model, only five types of containers are considered, with realistic separation rules:

- T1: Highly dangerous containers
- T2: containers storing flammable material
- T3: containers storing oxidizing material
- T4: food containers
- T5: neutral containers

The **Table 2** below shows these classes with their separation rules:

Table 2 Separation Rules

Types	T1	T2	T3	T4	T5
T1	X	20m	20m	VN	X
T2	20m	X	6m	VN	X
T3	20m	6m	X	VN	X
T4	VN	VN	VN	X	X

Significance of the table:

- *l* m: it means that there must be a separation of *l* meters between two container types. For example a flammable container (T2) must be stored away from highly dangerous containers (T1) for at least 20 meters and away from oxidizing containers (T3) for at least 6 meters.
- VN is the Von Neumann neighbourhood: a food container cannot be close to a dangerous one.
- X: no constraints.

The solution is implemented with Repast Simphony (Repast Simphony). It is an open source toolkit for agent-based modelling and simulation.

In the following, we present a selection of tests and their results. Remember that, the optimization begins from an initial random configuration, in which many security rules are violated. The purpose is to obtain a final configuration where the number of violated rules is minimum or zero if it is possible, with a minimum of movements. In this first phase, the dynamic of containers terminal is not taken into account: during simulation, there is no arrival or departure to or from the terminal.

4.1. Schelling vs. CABS

To compare the two strategies defined in section 3.2, we consider one block with the five previously defined container types. The block is composed of 10 rows; each row is composed of 10 container stacks, and each stack is at most four containers high. So, the block contains 400 cells.

75% of cells are occupied by containers. The average percentage of dangerous containers is about 10% of the global traffic. In our tests, the percentage is increased to 15% to verify the robustness of our approach. Food containers (T4) represent 20% and the rest (65%) are neutral containers (T5). Hereafter a recapitulative of the block properties:

Dimensions : 10x10x4
Filling : 75%
%T1 : 1%
%T2 : 7%
%T3 : 7%
%T4 : 20%

Tests were done on 1000 instances. Results are expressed on the table above:

Table 3 Schelling vs. CABS

Strategies		Schelling	CABS
Number of movements	Min	277	62
	Max	8906	130
	Avg	703,43	92,61
% success		95,40 %	99,70%

Min, **Max** and **Avg**, are respectively the minimum, maximum and the average of the number of movements, in case the optimal solution was found.
% success is the percentage of optimal solutions found by the strategy among solutions.

During tests, the program is stopped if the solution is found or if the number of movements reaches 10000 movements for Schelling strategy and 1000 movements for CABS.

Among 1000 CABS runs, the program stopped without finding a solution in 3 cases. In these 3 cases the program reached the limit number of movements

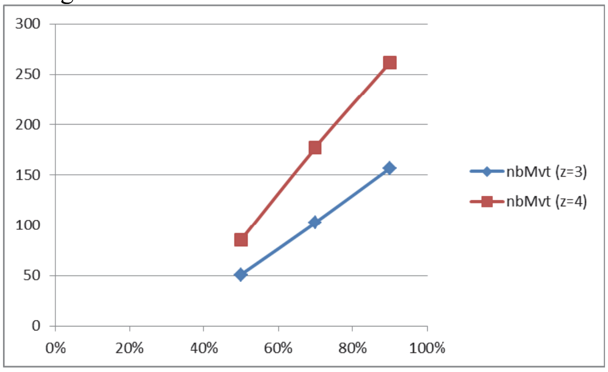
(1000 movements), and movement cycles were observed.

To avoid cycles in CABS, some modifications were done: when an agent container moves, it keeps temporarily in memory the last places occupied. When a container searches for a new place, it checks its list of memorized places, and avoids them.

4.2. Block Filling Variation

In these tests of CAB Strategy, we try to vary the parameter of the block filling (50%, 70% and 90%), and observe how the strategy is efficient.

Figure 2 Number of Movements When The Block Filling Varies



The rate success in the six cases is 100%.
We observe that when the filling percentage increases to high values, the number of movements increases no more than linearly.

4.3. Dimension Block Variation

Now we vary the block dimension: the number of rows (X) and the stack high (Z). The other parameters remain unchanged and are kept as before.

Table 4 Test Results: Block Dimensions Variation

	X=10		X=20		X=40	
Z	***nbMvt***	***Success***	***nbMvt***	***Success***	***nbMvt***	***Success***
2	23,87	99,9 %	50,56	100 %	103,35	100 %
3	51,27	100 %	103,24	100 %	213,56	100 %
4	91,49	99,8 %	177,07	100 %	355,74	100 %

nbMvt: is the average number of movements.
Time: is the average time of run in seconds.

These tests show that the number of movements is linearly proportional to the number of containers.

4.4. T1 Percentage Variation

Here the percentage of T1 containers is allowed to vary. The block dimensions are 10x10x3 and the percentages of T2, T3 and T4 remain unchanged (7%, 7% and 20% respectively).

The results show that from 0 to 3% (6 containers) of T1 containers, almost always an optimal solution is found, and the number of movements increases.
From 4% to 11%, the percentage of success decreases rapidly, from 91% to 1%, until no solution is found for 12%, which corresponds to 27 T1 containers. Note that the number of movements is then non increasing.

Figure 3 The Percentage of Success When T1 Containers Varies

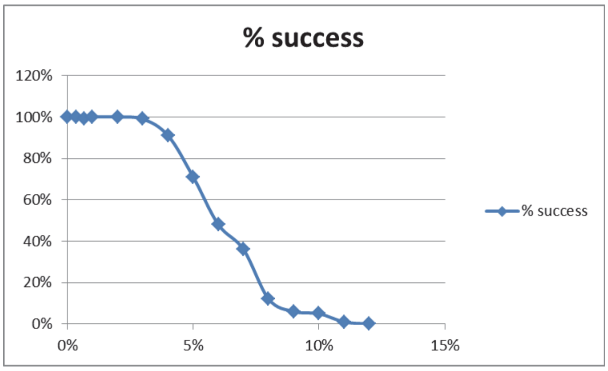
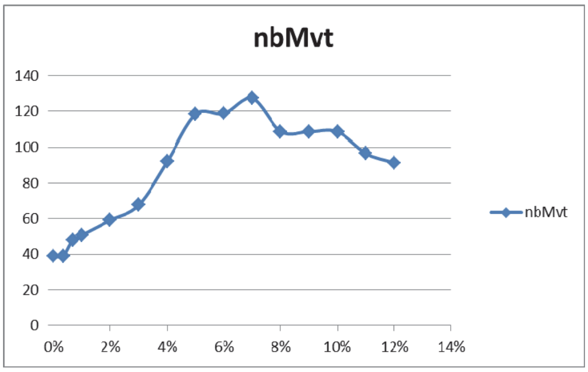


Figure 4 The Number of Movements When T1 Containers Varies



4.5. Tests Conclusion

Our decentralized multi-agents model is an efficient way to solve the problem of dangerous container storage when the parameters (percentage of dangerous containers) are realistic. It is efficient even if the initial configuration is created randomly, which is making things more difficult.

In a second step, the model will include the dynamics of the terminal.

5. CONCLUSION

The presented framework permits to study different situations. We have tested our container centred approach modelling. The obtained results permit to validate the model and the simulation compared to the ground truth. Complementary test are being realized to take into account the dynamic arrivals and departures of containers.

After validating the behaviour of our intelligent agents, we have introduced some extreme values considering the density of dangerous containers. The results show the existence of a threshold; beyond this threshold our model has difficulties to reach an optimal solution. Nevertheless, these unsuccessful configurations are quite unrealistic.

Now, our model invites us to test specific agent behaviours using the centred container approach. This consists in modifying each intelligent agent to introduce different perceptions of the environment and to change the rules of positioning and fitness computing. So, this modelling permits the practical modularity and flexibility, allowing to test and to adapt strategies to the dynamic context of a container terminal.

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A NEW ROBOTIZED VEHICLE FOR URBAN FREIGHT TRANSPORT

Aiko Dinale[a], Rezia Molfino[b], Penghui Huang[c], Matteo Zoppi[d]

[(a), (b), (c), (d)]Department of Mechanical Engineering, University of Genova, Italy

[(a)]dinale@dimec.unige.it, [(b)]molfino@dimec.unige.it, [(c)]penghui.huang@gmail.com, [(d)]zoppi@dimec.unige.it

ABSTRACT
In recent years, the research in the field of urban area delivery drew the attention of the scientific world. Many problems arise from the lack of a well-defined urban logistic, aimed at an efficient parcels distribution. Also technological issues arise; the current technology does not satisfy the needs of this specific context, in particular for what it concerns the vehicles and the transportation process.
In this research we present the FURBOT vehicle result of the FURBOT (Freight Urban RoBOTic) project, funded within the Seventh Framework Programme of the European Union, which aim is to develop a new vehicle to improve the urban freight transport. The vehicle represents an integration between a mobile robot, a van and a forklift. The new vehicle design is presented.

Keywords: electric vehicle, urban freight delivery, robotized freight handling, sustainable transport

1. INTRODUCTION

Freight transport is a critical issue for urban areas: the European population is mainly concentrated in cities and therefore the bulk of industrial production is dispatched to these areas. Moreover, the demand for freight transport is growing at a fast rate due to changes in industry logistics and consumer purchasing patterns.

Also the consuming behaviours have changed rapidly in the past years and they have transformed the way people travel for shopping. Surveys show that home deliveries are not marginal anymore. As a result, the scope of urban freight ranges from large trucks delivering full loads to single destinations, through to courier vans that visit many destinations, picking up and delivering many separate consignments.

These urban freight movements cause problems within cities, as the BESTUFS (Best Urban Freight Solutions) European network underlines (BESTUFS 2008). The main ones are related to:

- the lack of suitable infrastructure for deliveries (ramps, areas for loading and unloading, reserved parking spaces, etc.),
- noise emissions,
- conflicts with other users during delivery operations (loading and unloading),
- access of goods vehicles to pedestrian zones or historic centres,
- environmental pollution.

Therefore, it is clear that the modern reality requires a change of paradigm for goods delivery. Thus, it is necessary to carefully analyse the needs of the next generation of freight.

A sustainable freights transport has to fulfil all the following objectives (Behrends 2008):

- ensure the accessibility offered by the transport system to all categories of inhabitants, commuters, visitors and businesses;
- reduce air pollution, greenhouse gas emissions, noise to levels without negative impacts on the health of the citizens or nature;
- improve the resources, the energy-efficiency and the cost-effectiveness of the transportation of goods, taking into account the external costs;
- contribute to the enhancement of the attractiveness and quality of the urban environment, by avoiding accidents, minimizing the use of land and without compromising the mobility of citizens.

2. STATE OF THE ART

The urban freight transport is a research field that started to become active in recent years. In fact, due to the continuous development of the commercial activities in the urban areas, it is necessary to improve the freight transport systems currently in use in order to achieve better results in terms of efficiency and quality of life. Also the European Union is trying to promote this topic through appropriate research programme, offering specific calls for urban clean transport.

FIDEUS (Freight Transport System for Urban Shipment and Delivery) is a project of the 6th Framework Programme which focuses on the concept of “cooperative transport” (Bruning 2011, Burzio 2006). Three classes of vehicles have been proposed: a lorry used for long distance transport of a big amount of parcels; a van to transport a smaller amount of goods from the storehouse to the neighbourhood of the city centre; a micro-carrier which is an uni-axial transport unit that can be used both as a part of a multiple trailer vehicle or as a hand-guided transport unit. This last element is used to travel from the van to the collection place, usually located in the pedestrian area (/low-traffic area).

On the other hand, CityLog (Sustainability and efficiency of city logistics) is a project of the 7th Framework Programme which exploits the idea of “modularity”. The especially designed container, named BentoBox, plays a key role in the delivery logistic (Dell’Amico 2011). The delivery of the parcel is decoupled between the couriers, who transport the goods up to the collection area, and the customers, who pick up the parcel by himself. In order to optimize this process, the BentoBoxes are installed in an area of the city centre that is easily accessible by public transport and by foot. CityLog has been conceived in parallel to another EU-funded project, CITY MOVE (City Multi-role Optimized VEhicle). The latter focuses on innovative vehicle technologies and it is meant to be a complementary work to CityLog.

CITY MOVE proposes a vehicle based on hybrid powertrain architecture in order to improve the efficiency, decrease the environmental impact and increase the safety (Aimo Boot 2010). Great attention has been paid to the latest technology in freight transport in order to accelerate the introduction of such product in the market.

A different aspect of the urban traffic has been studied by INRIA (Institut National de Recherche en Informatique et en Automatique). They proposed Cybercars, a family of new vehicles especially designed to achieve a more effective organisation of urban transport (INRIA 2006). The idea is to extend the advantages of a car in a public context, like in a car sharing system, and going beyond offering a doot-to-door service. One product of this family is CityMobil, an autonomous vehicle for passengers and goods, funded by the 6th Framework Programme (Bouraoui 2011, Nashashibi 2012).

The main difficulty of all these systems is related to the integration with the existing urban environment. In fact, the objective is to realise an aid for the urban transport which must be accepted by the deliverers, customers and also pedestrians.

During the development process it is necessary to organise field tests in order to collect opinions directly from the end-user. In addition, asking for the support of municipalities and public authorities is going to help the introduction of these new products from a logistic point of view.

3. VEHICLE REQUIREMENTS

In this research, we propose and analyse a new concept architecture of a light duty fully electrical vehicle for efficient urban freight transport, namely FURBOT (Freight Urban RoBOTic vehicle). The strong points of FURBOT are:

- small size - the reduced size of FURBOT will make easier the delivery of the goods in pedestrian and historical centre, where roads are usually narrow.
- zero emission and zero noise - FURBOT is an electrical vehicle, so it is environmentally cleaner and also less noisy. Due to the low noise level, off-peak and night-time deliveries can be performed.
- intelligent behaviour - FURBOT is endowed with proprioceptive and exteroceptive sensors which allow to understand the internal state of the vehicle and the environment surrounding it. Furthermore, the control system allows the driver to choose among different control modes. Each control mode is designed in order to help the user during his task. For instance, the driving might be fully manual or assisted, according to the situation. The loading and unloading operation will be automatized to reduce the labour that the user should perform.
- multi-functional - FURBOT is an integration of a mobile robot, a van and a forklift. It is able to perform various tasks as robot; it transports pallets as van; and it loads and unloads pallets as forklift.
- transport optimization - fleet management is studied by UDC (Urban Delivery Centre), taking into account the freight transport demand, the road network with the passenger traffic flows and the governance measures. Then the shortest route will be sent to each FURBOT, so that the total trip travelled by all vehicles will be optimized.
- intuitive HMI - FURBOT will be easy to drive thanks to the intuitive HMI and driving assistant.

These characteristics make FURBOT suitable for a sustainable urban freight transport.

In what it follows, particular attention will be given to the vehicle design, Human Machine Interface and the control system logic.

4. VEHICLE DESIGN

4.1. Design methodology

The development of the new concept FURBOT vehicle requires the use of application-oriented design tools obtained by integrating specific design modules with traditional functional and structural general purpose modelling packages. The aim is to study all the main life-cycle design aspects in a simultaneous way and to develop a modular scalable architecture with a set of software and hardware modules re-usable for different vehicles and a new service-oriented infrastructure. Attention is paid from the beginning to the in-use (easy maintenance, energy efficiency, safety, ergonomics, wellbeing of users) and post-use (modules reuse, disassembly, recycling) phases.

Modularity, intelligent mass reduction, suitable manufacturing processes, off the shelf components, and recyclable materials use, have driven the cost oriented design-production process. All the design activities, throughout their development, have been made transparent to and discussed by researchers, freight delivery companies, municipalities and users in order to achieve solutions jointly agreed. The points of view of end-users, such as urban transport service managers and city public authorities, are considered vital for reducing the risk of wrong decisions and ensuring the success of the chosen solution in terms of both life-cycle cost and user satisfaction.

In order to address all main risk issues from the very beginning of the project development, an extensive use of computer simulation, digital mock-ups and virtual reality testing is adopted, to provide the complete characterization of the vehicle in different urban scenarios; this allowed the testing, at the design phase, of alternative competing architectures and the selection of those which improve the overall system performances against manufacturing cost. The computer simulation, moreover, offers, during the vehicle use phase, an important aid for the work management and tasks allotment.

To guide the design, a set of specialized tools and procedures have been exploited. During the definition of the design rules, both state-of-the-art packages for CAE and codes purposely written to solve particular aspects were used, allowing: parametric design by 3D CAD packages; kinematics and dynamics analysis and simulation; resort to digital mock-ups and to virtual reality testing; models tuning with purposely developed blocks (using C, Matlab, Maple, Simulink codes, etc.); to deepen the relational frame and to deal more precisely the reference kineto-dynamics and statics outputs.

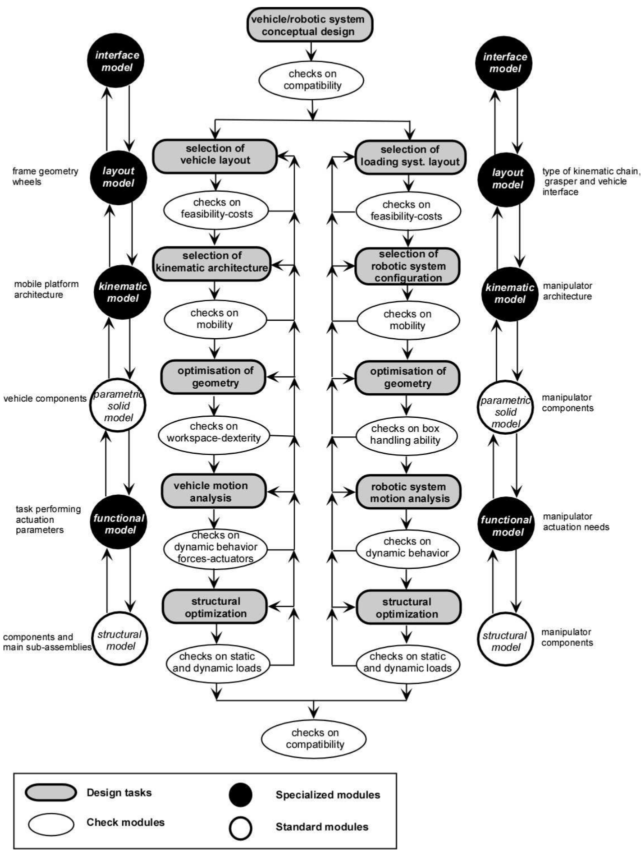

Figure 1: Scheme of the mechanical design process

The vehicle design process is sketched in Fig. 1. The design processes of the vehicle chassis and on board handling system are parallel but integrated at each progress step in order to achieve harmonic solutions.

4.2. Vehicle architecture

4.2.1. Mobile platform

The mobile platform is designed with the aim to tightly envelop the maximum freight volume consisting of two Euro pallet or dedicated boxes (800x1200 mm). The freight weight is supported by a minimalist network of welded stainless steel tubes with square and rectangular section, Fig. 2. The material used for the frame is stainless steel due to the mechanical performance that allows the creation of robust and light frames. The manufacturability and weldability of the material were also considered. Static and dynamic analyses were performed for optimizing the frame cage.

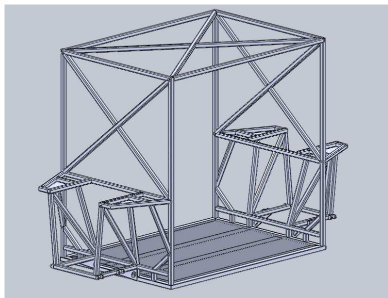

Figure 2: FURBOT frame early solution

The suspension of the vehicle is constituted by a McPherson strut with a telescopic dumper. It allows reduced transversal dimensions and high distance between the lower and the upper attachments, resulting in a reduction of the stress applied to the body. The suspension is integrated with a lifting hydraulic cylinder that allows to move vertically the entire chassis, making possible to shift from the driving configuration to the loading/unloading one and vice-versa, Fig. 3.

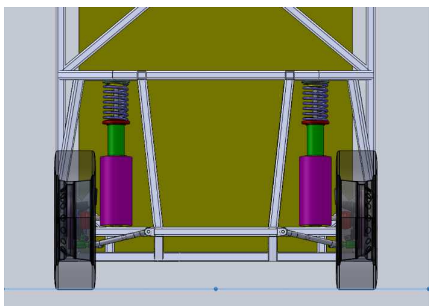

Figure 3: FURBOT chassis configuration

The steering wheels are placed in the front part of the vehicle, while the traction wheels are located in the rear part. Two electric motors are mounted near to the wheels, due to the lack of in-wheel motors with suitable diameter and power available in the market.

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The batteries, electronics and service devices are hosted in the rear part of the vehicle.

Ergonomics and life cycle paradigms guided the vehicle chassis and body design. On the upright part of the vehicle a solar panel of 2 square meters is positioned.

4.2.2. Freight handling device

The final design of the FURBOT vehicle will allow the movement of the two Euro Pallets, Fig. 4. The handling system has been designed in order to realize the loading and the unloading operations on the right side of the vehicle. The loading bed space determines heavily the length of the vehicle.

The handling system will be within the loading bed space of the vehicle, Fig. 5. The devices needed to develop the handling system must be designed in order to simplify as more as possible the loading/unloading operations. The interface between the frame of the vehicle and the handling devices must be simple and robust.

The weight of the handling system must be as less as possible in order to achieve the main target of the project to limit the weight of the entire vehicle and consequently the energy consumption of all its devices. At the same time, a simple mechanism to load and unload the freights guarantees these targets.

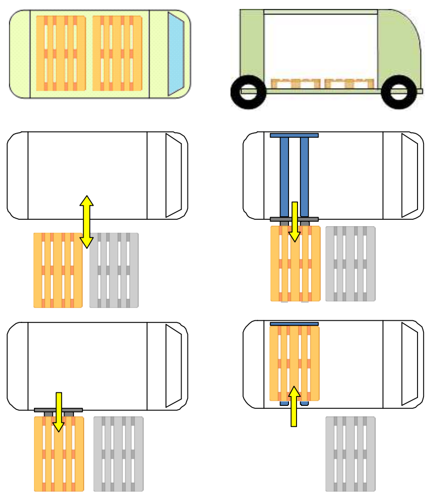

Figure 4: Robotic handling device – loading phase

The handling device is developed in order to move pallets from the ground (or a step) to the vehicle platform's level. This feature plays an important role from the urban logistic point of view; the pallet can be left in any free area of the city, without modifying the urban environment in order to make dedicated collection area.

The loading/unloading movement can be assured through a system that realized at most 2 DoF: vertical and transversal displacement.

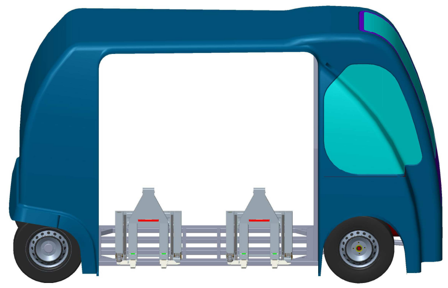

Figure 5: Robotic handling device on FURBOT

5. HMI AND CONTROL SYSTEM

5.1. Human Machine Interface (HMI)

The HMI is designed in order to be easily used by a not specialized user; it is intuitive and training is not necessary. The main components of the HMI are:

- a tablet - it is used to provide general information to the driver. It will display a map and the itinerary that FURBOT has to follow in order to satisfy the list of missions to be dispatched. Furthermore the tablet is used to monitor the vehicle state such as battery, position, velocity, etc.
- a joystick - FURBOT processes the speed and the direction of motion desired by the driver, reading the inclination and the orientation of the joystick.
- a set of buttons - they allow to choose among the possible control modes offered by the FURBOT's control system.
- an emergency leverage - in case of dangerous situation, the driver can use this leverage as emergency brake. When it is activated, the electronic control unit is switched off and FURBOT stops.

5.2. Control System Logic with Control Modes

As mentioned before, in order to improve driver's experience of FURBOT and simplify driver's job, several control modes are developed to deal with different situations during the whole process of delivery. These control modes are: manual driving, assisted driving, automatic loading and automatic unloading. The first two are used when FURBOT transports pallets, and the other two are designed to implement fully automatic loading and unloading operations of pallets. For each control mode, we will choose suitable sensors to provide required measurements.

Manual driving is the basic driving control mode. When it is on, the driver is fully in charge of the whole vehicle just like the drivers of normal trucks. No extra assistance will be provided to the driver and the locomotion of FURBOT is based on the input from joystick, which is controlled directly by the driver.

Assisted driving is an advanced driving control mode. When it is selected, three functions are activated in order to manoeuvre FURBOT more easily and prevent any dangerous situations. These functions are obstacle avoidance, adaptive speed control and parking assistance.

The obstacle avoidance function detects obstacles in front of and behind FURBOT. We define two levels of safety distance: when any obstacle reaches the first level, FURBOT will slow down giving sound alarms to catch driver's attention; when an obstacle reaches the second level, FURBOT stops itself, and then driver can only move FURBOT away from the obstacle. To detect the obstacles, two laser range finders are mounted on the front and the rear part of FURBOT.

The adaptive speed control function helps the driver to control the speed of FURBOT according to the maximum velocity (40 km/h) or according to the speed of vehicle in front of it.

The parking assistance function gives driver visual or sound alarms during parking, when the vehicle is approaching a not desirable configuration. Here rear laser range finder and rear camera information will be combined together.

Automatic loading simplifies the driver's work: instead of lifting pallet by manpower, FURBOT will load the chosen pallet automatically and this process is triggered by a button. The whole loading process consists of three main steps. First, the pallet is detected and recognized using computer vision methods. Then the position of the pallet with respect to FURBOT will be calculated. The images are acquired by a camera mounted on the operating side of FURBOT, where by operating side we mean the side of the vehicle where the loading and unloading is performed. Then, after the pallet's position is identified, FURBOT adjusts his position in order to be close and parallel to the pallet. The precision of this step is crucial: the fork-system must be correctly aligned with the pallet slots; a misalignment will compromise the whole loading operation. Finally, the pallet is lifted up onto FURBOT by the fork-system. When the operation is completed, the driver will be informed by the HMI whether the task has been accomplished correctly or not.

Automatic unloading helps the driver to pick one pallet from chassis of FURBOT and leave it on the ground automatically, without any manpower. This process is also triggered by a button and when the process is done, a message will be displayed on the tablet.

In Fig. 6 it is possible to see in details where the sensors are going to be placed. In particular four different sensing zones are defined. The lasers are mounted in the front and the rear part of the vehicle in order to cover zone 1 and 3, intended for obstacle avoidance and parking. The laser mounted in the front will have a bigger range distance compared to the one mounted on the rear part, since it has to detect frontal collision which results to be more dangerous. In order to provide a visual feedback to the driver, two cameras are mounted: one on the operating side of FURBOT and the other one on the rear part. These two cameras are used to monitor the loading/unloading process (zone 2) and the parking (zone 4). As it can be seen from Fig. 6, zone 3 and zone 4 are partially overlapping, so both the information from the camera and the laser are processed in order to perform the parking.

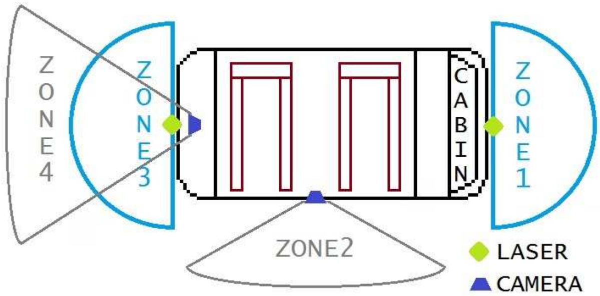

Figure 6: Sensor configuration on FURBOT

6. CONCLUSIONS

In this research a new robotized vehicle for urban freight transport has been presented. FURBOT aims to be an innovative solution in the field of delivery from different point of view. The vehicle architecture has been designed in order to get the best compromise between the load capacity and the size of the vehicle itself. A dedicated handling system has been proposed in order to improve the loading/unloading time and reduce the human effort during this task. The driver's experience is enhanced by an intuitive HMI and a set of control modes. Field tests are planned with the collaboration of the municipality of Barreiro, Portugal.

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AUTHORS BIOGRAPHY

Aiko Dinale received the B.E. degree in 2010 in computer engineering from University of Genova, Italy. She received the M.E. degree in 2012 in robotics engineering jointly from Ecole Centrale de Nantes, France and University of Genova, Italy as Erasmus Mundus scholarship holder for the European Master on Advanced Robotics (EMARO). She is currently a Ph.D. student at University of Genova.

Her research interests include robotics, intelligent vehicles, and motion control.

Rezia Molfino, full professor at the University of Genoa, head of DIME–PMARlab, president of SIRI (Italian Association of Robotics and Automation), president of IIS Italian Welding Institute; National Co-ordinator at IFR (International Federation of Robotics). Research interest in robotics and intelligent automation: new mechatronic architectures, kinematic and dynamic modelling and simulation; manipulation and grasping; climbing and security robots. IAS, CLAWAR, Euron, IEEE member. Coordinator of FURBOT project.

Penghui Huang obtained his B.E. degree in 2010 in automation engineering from Xi'an Jiaotong University, China. He is currently doing his Master degree in the European Master on Advanced Robotics (EMARO) hold by three institutes: Ecole Centrale de Nantes in France, University of Genova in Italy and Warsaw University of Technology in Poland. He will graduate in Sept. 2013 from EMARO and receive two Master degrees from University of Genova and Warsaw University of Technology separately.

His research interests include bio-inspired robotics and intelligent vehicles, especially for what concerns the sensing systems.

Matteo Zoppi, PhD, Researcher at the DIME–PMARlab of the University of Genova. Research interests: - Synthesis, analysis, modelling and design of robotic systems with special expertise in methods for the analysis of mechanisms with parallel and complex architecture for robotics; - Development and design of task oriented robots including mobile robots for industrial and service applications;- Design of MEMS robotic systems creative synthesis of complex 3D mechanisms and life-cycle oriented design of mechatronic systems. Involved in many European Projects and Networks (FURBOT, PICAV, EURON, CLAWAR, OSNET). ASME and IEEE member.

SIMULATION ASSISTED DESIGN OF INDUCTORS IN POWER ELECTRONICS SYSTEMS

D. Hofinger [a], H. Weinzierl [b], M. Jungwirth [c]

[a], [b], [c] University of Applied Sciences Upper Austria, Campus Wels,
Stelzhamerstrasse 23, 4600 Wels, Austria

[a] Daniel.Hofinger@fh-wels.at, [b]Heinz.Weinzierl@fh-wels.at, [c]Mario.Jungwirth@fh-wels.at

ABSTRACT

Inductors are main components in power electronics systems, e.g. switching mode power supplies used in grid-connected inverters for photovoltaic systems. Inductive components mainly contribute to losses, therefore there is a big potential to increase the overall efficiency. In addition to the electric requirements due to the system architecture, energy effciency and thermal behavior are the main aspects for an optimal inductor design. To achieve this it requires an accurate prediction of the occurring electromagnetical and thermal effects and their mutual interactions. The design procedure is a rather complex task and the result is highly dependent on the experience of the design engineer. To reduce the time to market and in order to standardize the design process, a computer aided design tool was developed. The aim is an accurately and fast prediction of the inductors physical behavior and the optimization of all significant design parameters.

Keywords: power electronics systems, inductors, energy efficiency, model-based design, optimization

1. INTRODUCTION

A main aspect in the design of switching mode power supplies is to increase the operating frequency and to reduce the size of the inductive components, e.g. transformer and variable chokes, and therefore decrease the energy density and the overall size of the product. As a consequence high frequency effects like eddy currents inside the conductor and increased core losses due to non-sinusoidal current waveforms become the major challenge to achieve an effective design of the required inductive components.

2. MODELING PROCESS OF MECHATRONIC MULTIDOMAIN SYSTEMS

For an optimal design of power electronics systems the coupling of several physical domains has to be taken into consideration. Energy efficient designs mostly depend on multiple physical effects and their mutual coupling, as shown in figure 1. Therefore, the design process of mechatronic systems is a rather complex and time-consuming challenge which also needs a lot of experience.

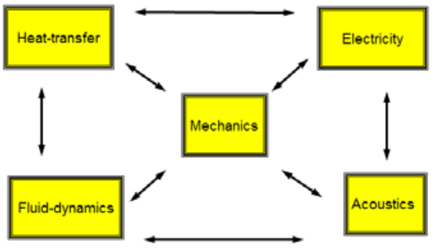

Figure 1: Mutual coupling of physical domains

Finding an optimum system configuration in a short time is a particular challenge to the engineer. There are a lot of parameters that need to be optimized in an early stage of the design process. In this situation a computer aided (automated) design tool could help to speed-up the design process (see figure 2, green line).

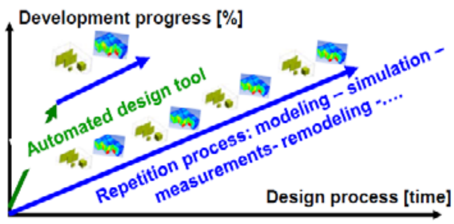

Figure 2: Automated design tool

3. INDUCTIVE POWER ELECTRONIC COMPONENTS

In figure 3 a typical topology of a switching mode power supply being part of power electronics system is shown.

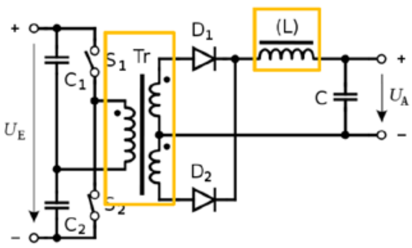

Figure 3: Topology of a switching mode power supply with inductive components

In the Push-Pull converter topology depicted in figure 3, there is a lot of potential for optimization, e.g. capacitors, power electronics semiconductors, noise-filters and inductive components.

As a matter of fact, inductive components mainly contribute to losses and therefore there is a great potential to increase the overall energy efficiency. The requirements to optimize inductive components are:

- Taking into account electromagnetic and thermal effects
- Understand the power loss mechanisms in the inductor winding and the magnetic core
- Consider the mutual interactions of physical effects

4. POWER LOSS MECHANISMS

In the design of high frequency inductive components, e.g. output choke, performing multi-field simulations of electro-magnetically, thermal and possibly structural field interaction is inevitable. For an optimal design of such devices one has to understand the mechanisms of losses within the device and the interaction with electrically connected components.

A main element in the design of chokes is the calculation of the heat losses, due to transformation of part of the electric energy into thermal energy and to determine the resulting temperature-rise of the choke. In practice energy is dissipated due to the resistance of the windings (known as winding or copper losses) and due to magnetic effects mainly attributable to the core (known as core or iron losses). Figure 4 shows the total losses occurring inside an inductor and how they are calculated. It is split up into losses occurring inside the winding and the magnetic core:

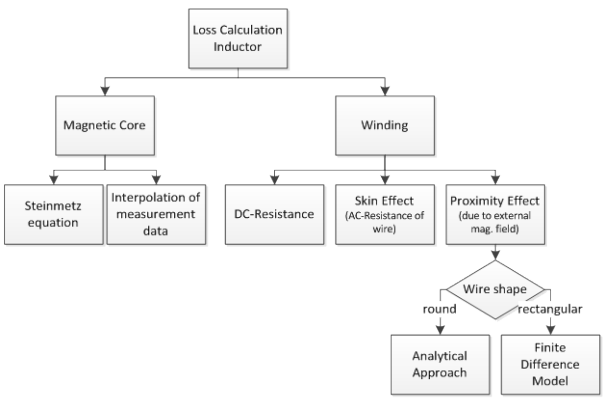

Figure 4: Inductor loss calculation

4.1. Core Losses

Ferromagnetic materials used in chokes typically are magnetically soft and preferable have a low coercive field strength and low power losses. Commonly used materials are based on iron, cobalt and nickel and its alloys and can be divided into polycrystalline and amorphous materials. The proper selection of the magnetic material depends on both the magnetic characteristics like saturation flux density and power loss and more important price. Most of the data is provided by the manufacturers or can be calculated using formulas describing measurement data.

Core or iron losses can be split into hysteresis- and eddy current losses. Hysteresis losses are related to the energy loss in each alternating-cycle of the magnetic field in the core. Whereas induced eddy currents cause resistive heating in the magnetic core. The main parameters of core losses are the magnetic flux density B, the operating frequency f and the temperature T. A well-known and frequently used analytical method calculating core losses is the equation of Steinmetz (Eq. 1) (Reinert 2000).

$$P_v = c_m f^{\alpha} B^{\beta} g(T) \qquad (1)$$

The parameters c_m, α, β and temperature polynomial g(T) are provided in datasheets or are identified through fitting characteristic curves. The Steinmetz equation is valid for sinusoidal current waveforms without dc-bias. A method to calculate core losses for arbitrary current waveforms is presented in (Albach 1996). To consider the influence of dc-bias measurement data of 3F3 Ferrite material presented in (Brockmeyer 1996) is normalized on the saturation flux density and used for all other ferrite materials in the calculation routine.

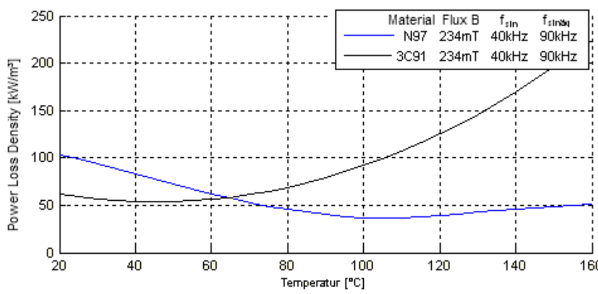

Figure 5: core losses of ferrit material N97 & 3C91

Figure 5 shows the power loss density of the two different ferrite materials N97 (Epcos) and 3C91 (Ferroxcube), excited with the same flux density. The material 3C91 has its power loss minimum at around 50°C whereas the material N97 is best used at 105°C.

4.2. Winding Losses

Winding losses occur because of the electric current flowing throw the windings of the inductor. Winding losses can be split up into regular dc-losses and ac-losses cause by induced eddy-currents (see figure 4 and 7). The determination of dc-losses is rather easy. They results from the dc-resistance of the wire and the rms-value of the current flowing throw it.

The alternating current produces a time varying magnetic field, which again induces eddy currents that

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try to oppose the magnetic field. If those eddy currents occur inside the wire itself, they oppose the original current and therefore increase its ac-resistance. This is calls skin-effect, and can be calculated for round wires using Bessel-functions (Albach 2000).

The increase of ac-resistance because of eddy currents induced by currents flowing in nearby wires and by the fringing field of air gaps is called proximity-effect.

Skin- and proximity-effect depend on the frequency of the current flowing and the conductivity of the wires. Proximity-effect usually is considerable larger than skin-effect and in most cases can’t be neglected in the design process. To calculate the losses for alternating currents two different approaches are used depending on the type of cross-section of the wire.

Round wires structures:
The winding losses for round winding structures are determined using a two- dimensional analytical calculation procedure as described in (Albach 2000). First the magnetic field inside the winding window due to the air gaps is calculated. To reduce the calculation area only to the winding window we replace the air gaps by linear current loads, which produce the same field inside the winding window as the fringing flux of the air gaps. Figure 6 shows a cross-section of a typical EE-core configuration.

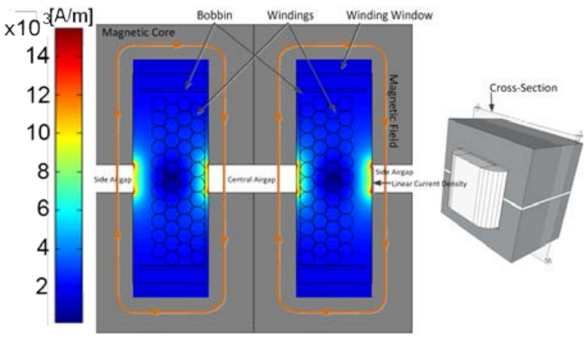

Figure 6: magnetic field strength of 1st harmonic inside winding window of typical EE-core configuration

The following steps lead to the proximity losses in each wire:

1. Express the external field strength on the wire boundary as function of radius r and angle φ (transformation of coordinates)
2. Transform field strength into Fourier series
3. Solve boundary value problem of Helmholtz equation for a current carrying conductor with arbitrary distribution on its boundary to find field strength and current density distribution inside the conductor
4. Calculate power loss by means of the Poynting vector

The detailed calculation procedure is described in (Albach 2000). Figure 7 shows the ratio between ac-losses and dc-losses. The influence of the air gap on the wires next to it leads to a significant increase of total power loss inside the winding.

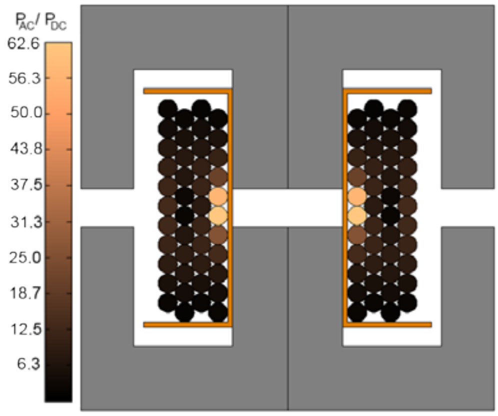

Figure 7: Ratio between AC-losses and DC-losses

Rectangular wire structures:
The field problem arising from rectangular wires is solved using a finite difference model. The finite difference method is convenient, because calculation domain requires a regular quad-mesh discretization, which is good applicable for rectangular wires but not for round wires. If the general formulation of the finite difference method with variable step size is used, a grid as shown in figure 8 is generated.

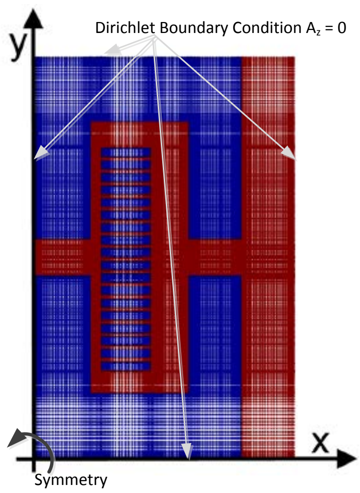

Figure 8: mesh of a typical EE-core configuration for FDM-model

The partial differential equation being solved is the Maxwell’s amperes law for the time-harmonic case:

$$j\omega\sigma A_z + \nabla \times \mu_0^{-1}\mu_r^{-1} \nabla \times A_z = J^e_z \qquad (2)$$

with ω as the angular frequency, σ as the electrical conductivity, μ_0 as the permeability of vacuum, μ_r as the relative permeability and j as the imaginary unit. The external current density J^e_z is the source for the magnetic field and has to be chosen so that the total current (sum of induced currents and external current) in every wire is the net current flowing through all wires. The resulting linear equation system in form of

$$A\,x = b \qquad (3)$$

where x is the unknown vector potential A_z, A is the coefficient matrix and b is the source vector. Since the coefficient matrix is sparse and band, the equation system is solved with an iterative solver using the quasi-minimal residual method and an incomplete LU-preconditioner. The magnetic field strength results from the magnetic potential

$$\nabla \times A_z = B = \mu_0 \mu_r H \qquad (4)$$

The induced current density is calculated by

$$j\omega\sigma\, A_z = J_{ind} \qquad (5)$$

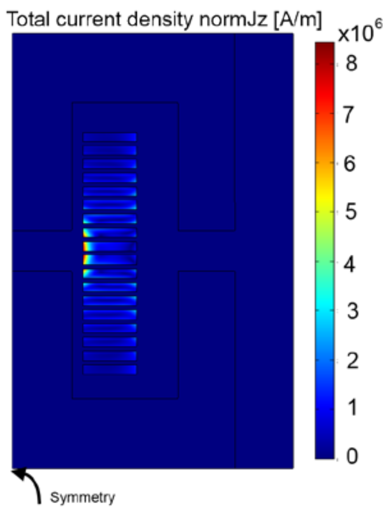

Figure 9: Total current density of EE-core configuration

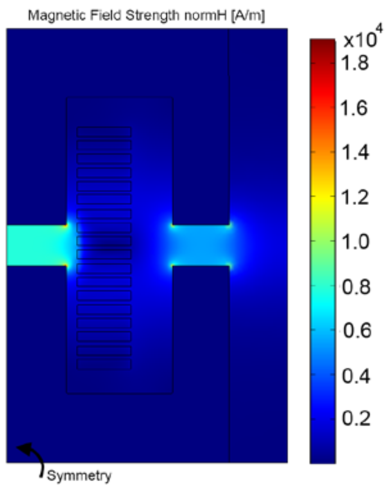

Figure 10: Magnetic field strength of EE-core configuration

Figure 9 shows the resulting total current density distribution inside the wires. The calculated field strength is shown in figure 10.

5. THERMAL MODELING

Optimum heat transfer in electronic enclosures, done by conduction, radiation and convection is of particular interest in the design process of power electronics in general. Especially in the design of inductive components e.g. chokes, a main element is the calculation of the heat losses, due to transformation of part of the electric energy into thermal energy and to determine the resulting temperature- rise of the choke. The losses depend on the magnetic flux density *B*, the frequency *f* and the Temperature *T* as shown in Eq. 1. These effects do interact with each other and it is necessary to solve the coupled equations iteratively as explained in chapter 6. Even the thermal calculation itself is to be solved iteratively, because of the temperature dependent heat transfer coefficients and material properties.

In addition to selecting one of the three possible mounting positions displayed in Figure 12, the following calculation-options can be chosen in the 'Choke calculator' design tool:

- Natural Convection
- Natural Convection and Radiation
- Forced Convection
- Forced Convection and Radiation
- Manual Input of Heat Transfer Coefficients

To balance the heat fluxes, a network of thermal resistances was generated as shown in Figure 11 for 'E-core shapes' and in Figure 13 for 'U-cores shapes' for example.

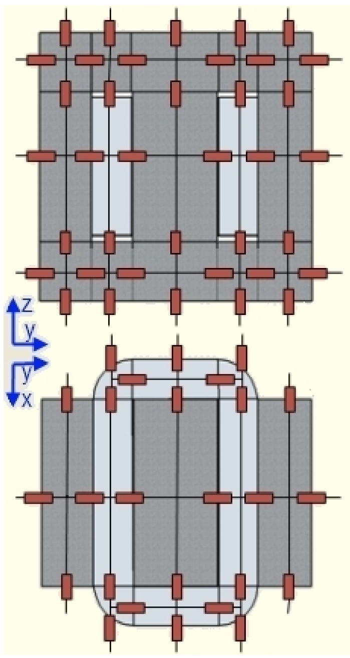

Figure 11: Network of thermal resistances ('E-core')

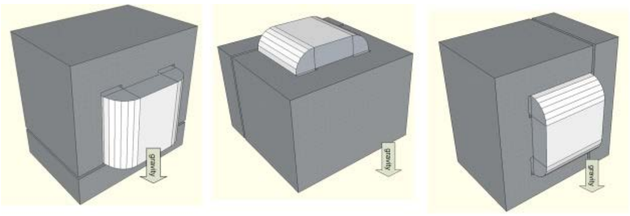

Figure 12: Mounting positions

The thermal resistances are calculated, using empirical equations given in (VDI 2006). So the thermal model of the ‘E-core shapes’ has an accuracy of 21 temperature- nodes and the model of the ‘U-cores shape’ consists of 26 nodes.

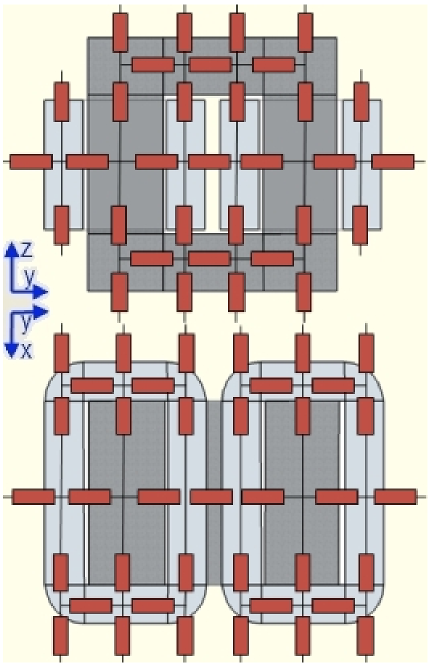

Figure 13: Network of thermal resistances (‘U-core’)

In Figure 14, the circuit diagram of these network models with n- Temperature nodes is shown. This model leads to a system of equations, generated by the node potential method. Then the set of equations is solved iteratively because of the temperature dependency of the thermal resistors.

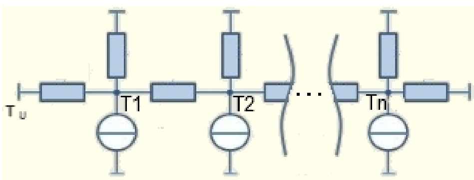

Figure 14: Circuit diagram of the thermal network model

Even when the radiation model is selected, the solution is converged in less than half a minute and show good agreement as verified e.g. in (Jungwirth 2011).

6. AUTOMATED DESIGN TOOL

To reduce the time to market and in order to standardize the design process, a computer aided design tool was developed. The tool named “Choke calculator” is programmed in MATLAB with a user friendly graphical user interface (GUI). The workflow of the modeling process and the schematic design of the tool are shown in Figure 15.

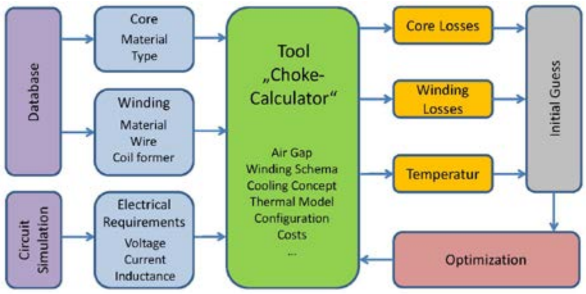

Figure 15: Workflow of the modeling process

The tool is characterized by low computing time and minimal effort in geometry modeling because of its connection to a component database. A ‘Microsoft Access’ database contains the required data of core materials, coil formers and winding materials of relevant suppliers and can be extended in any order. The construction of the database, taking into account various data formats of individual suppliers, can already be seen as a first step towards standardization. The communication to MATLAB is programmed by SQL-statements.

Figure 16 shows a flowchart of the calculation tool. The green frame marks the Electromagnetic calculation, coupled to the Thermal calculation, shown in the yellow section.

Traditionally, the design of inductors has been based on sinusoidal current waveforms operating at low frequencies. In modern switching power supplies a movement towards higher power density continues. Therefore non-sinusoidal excitation and high frequency skin and proximity effects must be considered as described in chapter 4.

The design of an inductor usually begins with the specification of the desired inductance value and the maximal required current flowing throw it. Depending on the application variable current waveforms can be chosen.

The next step is a preselecting of an appropriate core. A selection of a manufacturer, the core-material, the core-shape and the core-type is possible. The dependency of the core-losses on the temperature can be plotted and a comparison of the different types can easy be done.

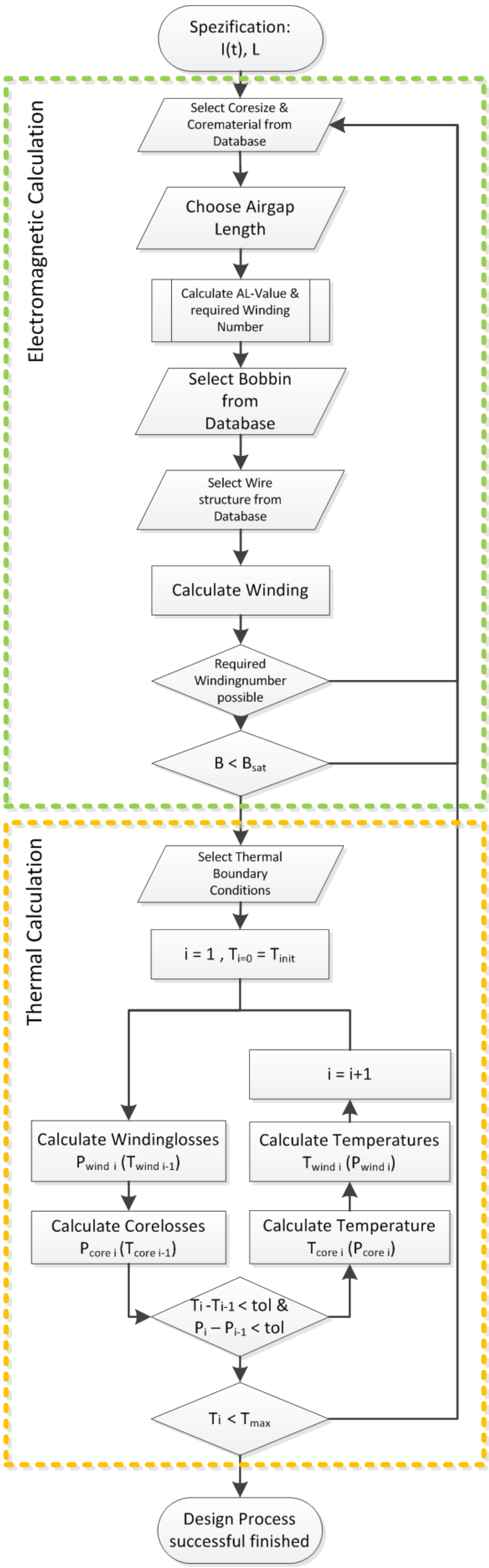

Figure 16: Flowchart of the design tool

To obtain the desired inductance value, chokes usually require air gaps to define the resistance of the magnetic circuit so it stores the correct amount of magnetic energy. To do so the size of the air gaps is varied and corresponding required winding numbers are computed.

A small air gap has the advantage that only a few turns are required to obtain the desired inductance, however, the low magnetic resistance results in a large magnetic flux. As a consequence the core might saturate and the iron loss increase. On the other hand a large air gap requires more turns, which is spatially limited by size of the winding window. So the right choice of air gap size and winding number is a tradeoff between magnitude of the magnetic flux and core losses on the one side and copper losses on the other side.

For the thermal calculation, the boundary conditions have to be defined, as described in chapter 5. After initializing by a starting temperature, the core losses and winding losses can be calculated. Then a new temperature distribution can be determined for the calculated losses of the actual iteration step. The next iteration loop can be started, where the temperature dependent losses will be calculated using the values from the previous step and so on. The iteration process is continued until the changes in temperature and power dissipation are smaller than a specified tolerance.

The GUI of the design tool is intuitive to use and subdivided into the following six major steps

- Specification
- Selection of the core
- Selection of the winding
- Electromagnetically calculation
- Thermal calculation
- Post processing

Figure 17, shows for example the visualization of the winding calculation.

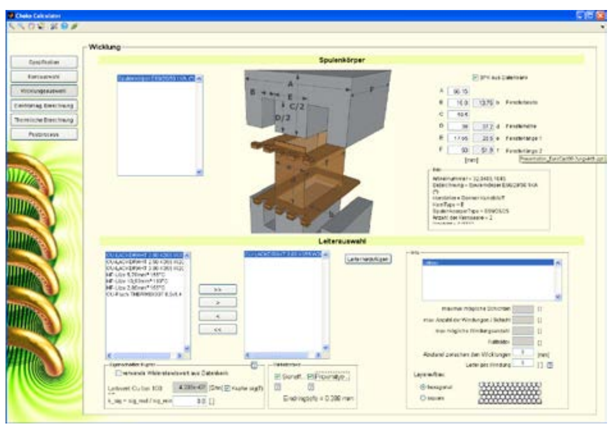

Figure 17: GUI of the design tool

7. VERIFICATION STUDY

In order to describe the benefit of the easy-to-use design tool, a typical workflow from specifications to optimal results is presented.

A choke as shown in figure 18 should be optimized.

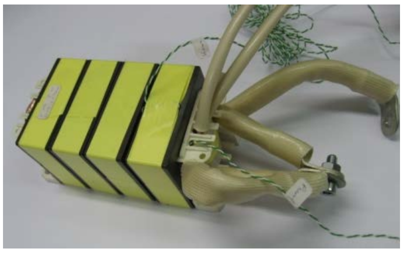

Fig 18: Original choke to be optimized (courtesy of Fronius International GmbH)

Firstly, the following specifications are given:

- required inductance L=180µH
- DC-current 10A / ripple-current 12A (see figure 19 for current wave-forms)
- Switching frequency f=40kHz

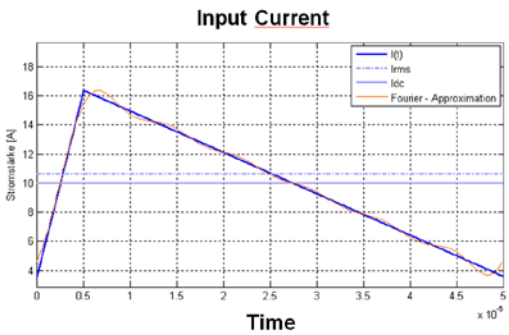

Fig 19: Input current (10A DC/12A ripple)

After setting the specifications one has to define the core-type, the type of wire and some parameter variations, e.g. variation of the air-gap (1mm to 5mm).

The calculation results are shown in figure 20. Therein, for each variation of the airgap calculations on the losses (core and winding losses), magentic flux density and suitable winding turns are shown. The optimal result is indicated by the red line:

- Inductance L=195µH

  @ 2mm airgap and N=23 winding turns

- Losses:
  - P_{rms}=1,2W
  - P_{prox}=3,2W
  - P_{skin}=0,1W
  - P_{core}=0,8W

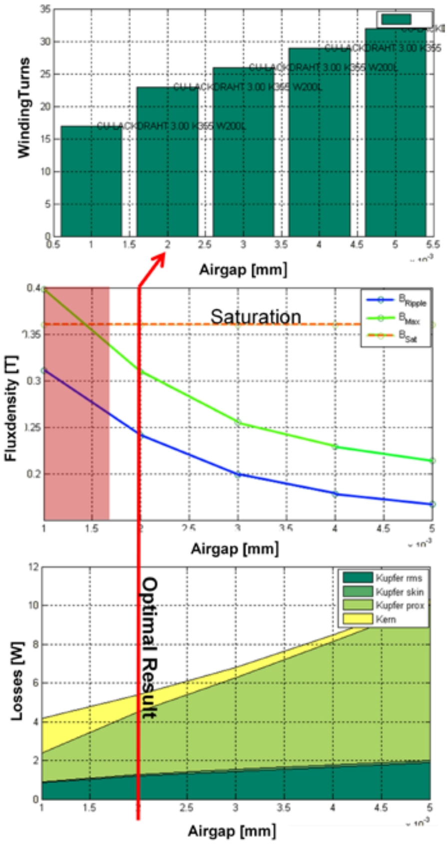

Fig 20: Optimal result of verification study (red line)

8. CONCLUSIONS AND FURTHER PROSPECTS

An automated design tool based on physical effects and material parameters for inductive components in power electronics systems was presented and verified. This tool could be very useful giving the engineer an initial guess in the early design process.

As a next step the design tool could be extended to optimize a complete switching mode power converter with capacitors, semiconductors and noise-models in the different mode of operations.

ACKNOWLEDGMENTS

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AUTHORS BIOGRAPHY

Hofinger, Daniel J. was born in Vöcklabruck, Austria in 1980. He received the diploma degree in Sensors and Micro-Systems engineering from the University of Applied Sciences in Wels, Upper-Austria in 2006. He is currently working in the field of numerical simulations at the Research Center of the University of Applied Sciences in Wels.

Weinzierl, Heinz was born in Grieskirchen, Austria in 1969. He recieved the diploma degree in automation engineering from FH OÖ – University of Applied Sciences Upper Austria in 2005, where he is currently pursuing his master degree in mechanical engineering. Since 2009 he has worked as a Research Associate at the University of Applied Sciences Upper Austria in the areas of multiphysics simulation.

Jungwirth, Mario P. was born in Linz, Austria in 1970. He received the diploma degree in Mechatronics and his PhD from the Johannes Kepler University in Linz, Austria in 1997 and 2001, respectively. He has a working experience of more than 15 years in the field of modeling and simulation of multi-domain systems. Currently he is the head of the degree program Mechatronics and Business at the University of Applied Sciences in Wels, Upper Austria. He is also member of IEEE and OVE Austria.

AN OPTIMIZATION METHODOLOGY FOR THE CONSOLIDATION OF URBAN FREIGHT BOXES

Elvezia M. Cepolina [(a)], Alessandro Farina [(b)]

[(a) (b)]Department of Civil and Industrial Engineering, University of Pisa, Italy

[(a)] elvezia.cepolina@dic.unipi.it, [(b)] alessandro.farina@dic.unipi.it

ABSTRACT
The paper refers to an innovative urban freight distribution scheme. Packages are firstly delivered to urban distribution centers (UDCs) on the border of urban areas. Packages should therefore be delivered from the UDC to receivers within the urban area. Each package is characterized by an address and dimensions. FURBOT boxes are consolidated in the UDC with these packages. Each box is addressed to a temporary unloading bay and it is delivered there by a FURBOT vehicle. A virtual key and the actual address of the box will be communicated to all the receivers, allowing them to collect their packages from the box in a given time window. The paper concerns a methodology for the box consolidation which minimizes the overall distance travelled by receivers, taking into account the box capacity and the maximum walking distance the receivers accept to collect their packages. A fuzzy k-means clustering algorithm has been adopted.

Keywords: LBL urban freight boxes, LBL freight consolidation, optimization

1. INTRODUCTION

This paper concerns freight distribution in urban areas. Freight is addressed to receivers that could be commercial activities or consumers.

As it concerns *freight directed to commercial activities*, its transport depends on the production system. The *decentralization of production* (e.g. importing the semi-finished products from countries with cheaper human resources to those with higher technology to assemble the final goods) gives an international nature to the freight transport. Moreover, the *increasing value of delivered products* requires rapid transportation because companies want to reduce the interest costs bound up in store and inventories. There is the need to *reduce store costs* since store areas in urban centers are expensive. In fact, the dimension of commercial activities in urban areas is small and often commercial activities have not a store area or if they have one, it is small. This leads to the Just-In-Time (JIT) delivery principle, which involves *more frequent delivery* of materials at the right time and at the right place in the production process.

As it concerns *freight directed to consumers*, this is the result of on-line shopping. E-commerce enables businesses to sell their products and services directly to the consumers without establishing a physical point of sale. While some products can be delivered digitally to households (for example, newspapers, airline tickets and music CDs), most products purchased online ultimately must be transported to the end-users in the physical world. The receivers are often single people, especially students and time-poor professionals, who purchase products online but are not normally at home at daytime to accept deliveries. An efficient, rapid and reliable delivery system is essential for gaining customer loyalty online and consequently obtaining profitability (Park and Regan 2004). Home delivery is therefore increasingly becoming a key element in e-commerce. The logistical requirements of supply chains that extend to each customer's address may stimulate greater complexity in distribution systems management, potentially causing higher costs in carriers' fleet operations. More frequent home-based local deliveries will likely add to traffic congestion and environmental problems in urban areas, making it more difficult for carriers to meet customer demands.

Nowadays, the trends of urban freight transport towards to deliver "Just-in-time" and "door-to-door". The operation of freight transport changes to have more trips but fewer loads in order to increase the efficiency differently. Without improvement, the transport costs will increase hugely to satisfy the current requirements. (Tseng et al. 2005). The impact of freight transport in urban centers is that, usually among the total urban traffic, 20-30% is composed of freight vehicles (Dablanc 2007; Cepolina et al. 2012). Freight vehicles are responsible for 30-50% of total emissions of PM10. Moreover, because the deliveries in urban areas consist on small quantity of freight to each receiver, the level of load is always very low and also several empty trips are performed. It is calculated that in Italy, the average load factor of 30% of vans in urban areas is less than 25%, of 50% of vans is less than 50% (Di Bugno et al. 2008).

These problems will become even more critical in the next future since on one hand urbanization will bring more consumers in urban areas; and on the other hand home deliveries will increase since e-commerce trend is growing despite the crisis. In Europe the total e-commerce revenue in 2012 was 305 billion euros and the 43% of the European population buys habitually on line products and services (Source: Eurostat). In Italy 12 million people were web shoppers in 2012. Between 2011 and 2012 we had a 15% increase in the number of online orders and this growth is expected to continue. In 2012, 35.5 million orders (services + products) have been done on the web (excluding train tickets, couponing and phone top-ups). Among orders, we are interested only in products because they need to be delivered as packages: these are 48.5% of the orders, equal to 17.2 million orders (source: osservatori.net). Each on-line order consists of 1.1-1.2 packages: in Italy therefore e-commerce moves 76000 packages each day. Although e-commerce still accounts for a very small market share compared to conventional retail business, the online shopping market is growing very fast.

Cooperative freight systems are the ways which could be expected to solve urban freight transport problems. Cooperative freight systems integrate the resources of the cooperating companies to optimize the economic benefits. The main benefits of the techniques are (1) properly increasing delivery trip loads; (2) reducing unnecessary trips, as well as pollution and costs; (3) reducing service area overlaps; (4) increasing service quality and company profits (Tseng et al. 2005). Cooperative freight systems need logistic platforms (*UDC - Urban Distribution Centre*) close to the city centre, within the freight village area. The goods are reorganized in the freight village before being delivered to the urban areas. This system can reduce the required number of vehicles used for delivery and handling.

The paper concerns the delivery system from the UDC to the receivers in urban areas (i.e. the last mile distribution problem). The paper has been structured in the following way. The first section describe the FURBOT freight delivery system in urban areas and it describes alternative systems proposed in the literature. Afterwards, the FURBOT box characteristics are described. Then, the mathematical formulation of the clustering of packages in the boxes is provided and a fuzzy k-means clustering algorithm to solve it is presented. Finally, the application of the algorithm to a trial case study is exposed. Conclusions follow.

2. THE FURBOT FREIGHT TRANSPORT SYSTEM

The paper refers to the last mile delivery problem; the proposed transport system is based on the belief that pick-up points play an important role in the physical distribution of goods since they solve the problem of the receivers not being at home at the time of delivery and contribute in reducing the impact of freight transport on urban pollution and congestion. The concept of local pick-up points is described in Browne at al. (1997).

Freight is firstly delivered from the production/ consolidation sites to urban distribution centers (UDCs) on the border of urban areas. A set of packages should therefore be delivered every day from the UDC to receivers within the urban area. Each package is characterized by an address (consumer's home address or commercial activity address) and its dimensions.

Every day, in the UDC these packages are clustered, according to their addresses, in a given number of boxes (FURBOT boxes) and an unloading bay is assigned to each box, according to the addresses of the packages assigned to it. FURBOT boxes are then consolidated in the UDC with these packages. Each box is addressed to the unloading bay, resulting from the clustering process, in the urban area and it is delivered there by a FURBOT vehicle. A virtual key and the actual address of the box unloading bay will be communicated to all the receivers, allowing them to collect their packages from the box in a given time window. The paper concerns a methodology for clustering process which minimizes the overall distance travelled by receivers, taking into account the box capacity and the maximum walking distance the receivers accept to collect their packages.

The FURBOT vehicle is small in size and it is able to move two FURBOT boxes, it is ecologically friendly and allows the automatic unloading of the boxes in the bays. This operation saves time and operative costs related to personnel. Since the unloading bay is occupied by the box only if there is freight addressed to its location, also the land occupation is minimized and the bay can be allocated to different uses, like parking, when not required. The high loading factor of the FURBOT box will lead to a decrease in the number of trips for freight distribution in urban areas and its impact on pollution. A representation of the FURBOT vehicle is provided in figure 1

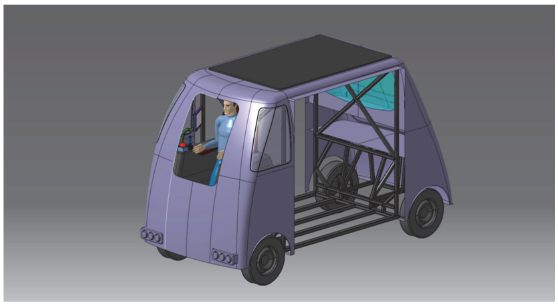

Figure 1: A Design of the FURBOT Vehicle

Some solutions, close to the FURBOT freight delivery system that adopt delivering to pick-up points, have been proposed in literature and will be shortly described in the following.

Packstation is a system that is meant to reduce the number of home deliveries, and it is destined to private customers and businesses. It has been introduced initially in Germany and afterwards developed also in Austria, Finland and Latvia. It is a service run by DHL Parcel Germany and it provides automated booths for self-service collection of parcels and oversize letters as well as self-service dispatch of parcels 24 hours a day, seven days a week. The structure is fixed, parcels can be accessed by customers through a touch screen. The pack station can be used for both: the delivery of packages to customers, who have a code to access their packages; and by customers to send their packages, avoiding queues at post offices. Using pack stations is free of charge both for private and business customers, however prior registration is required for collection of parcels.

A major market for pack station is the increasing number of people, who purchase products online but are not normally at home at daytime to accept deliveries, or who do not have the time to deposit parcels at the post office during normal opening hours.

If a customer wishes to pick up a delivery at a pack station, he just has to specify the identifier number of the pack station (e.g. pack station 124) where he desires to collect the package. Number and location of a pack station can be looked up online prior to receiving a delivery. If a parcel or letter is addressed to a pack station, it is delivered directly to the specified booth. If the destination is full, the parcel is diverted to the nearest booth with free compartments or to the nearest post office. It is also diverted to the post office if it is too large to fit into the compartments.

Since January 2004, DHL has offered in-house pack stations for large businesses. This service is especially attractive for businesses whose employees frequently receive private parcels at their work address.

Loading and unloading of a pack station is performed manually by an operator. A representation of the pack station is provided in figure 2.

Figure 2: A Pack Station

The BentoBox has been developed within the project CityLog (www.city-log.eu). It is composed of a fixed docking station, and six removable modular trolleys. Trolleys are consolidated at the UDC. A representation of a BentoBox is provided in figure 3.

The six trolleys have been made with different arrangements of compartments to allow the reception of several types of parcels. From a 1m79 height, 75 cm width and 63 cm depth, each trolley weighs about 50 kg. Accommodating 6 trolleys, the docking station has a touchscreen HMI to allow clients to retrieve their packages. A GRPS connection ensures the transmission of information with the central computer. For a 500 kg weight, the docking station measures 5m20 (width) x 82cm (depth) x 1m84 (height).

A new loading unit has been proposed within the project CityLog to accommodate the trolleys: it is a small cubic container, with a side of 2.1 metres and provided with retractile legs, in order to allow automatic loading and unloading, as shown in figure 4.

Figure 3: The BentoBox.

Figure 4: The Load Unit. BentoBoxes are Placed Here

The BentoBox trolleys are loaded into the loading unit in the UDC and unloaded at the docking station. At the UDC three loading units are accommodated into a freight bus to perform the penetration trip in the urban area. The freight bus on one side is smaller than a truck and on the other side is big enough to reduce the number of circulating freight vehicles. At some specific places around the oldest part of the city, the unit is unloaded from the freight bus and loaded into a light vehicle, called delivery van, to perform the last part of the trip. Thanks to the loading unit facilities, the transshipment is performed without the need of any building or special facility, but, as shown in figures 5 and 6, only some road space is needed.

The BentoBox by now has not been applied yet on the field as a facility for wide scale urban freight delivery. It has been tested only within the project CityLog, to three trial case studies: Berlin city centre, a major retail in Lyon, and Torino Lingotto.

The main differences between Packstation, BentoBox and the FURBOT delivery systems are herewith summarized.

1. The number and the localizations of the FURBOT boxes are not fixed in the urban area and they depend on the current daily freight transport demand. The impact of the FURBOT boxes on the land occupation is therefore minimized, as the boxes are only where they are required. Conversely, the number and the localizations of the Bentobox docking stations and of the Packstations are fixed for a given urban area and do not depend on the current freight demand.
2. The consolidation of the FURBOT box and of the Bentobox trolleys are performed in the UDC, therefore operative costs are minimized. Conversely the consolidation of the Packstation is performed manually in loco by an operator that transfers packages from a van,

temporarily parked on the road, to the Packstation.
3. The unloading of the FURBOT box in the temporary unloading bay is automatic. The unloading of the Bentobox unloading unit is again automatic but the BentoBox trolleys should be manually moved from the unloading unit to the docking station.
4. In the FURBOT delivery systems, packages are addressed to the receiver's addresses (home address or commercial activity address) and receivers are informed about the actual location of their packages only after the FURBOT box consolidation. Conversely, in the Packstation and in the Betobox systems, packages are addressed to fixed bays (Bentobox docking station locations and the Packstation locations), according with the receiver requests. In these last two cases the clustering of packages in the boxes does not take place whilst it is a critical issue in the FURBOT delivery system and this paper focuses on it.

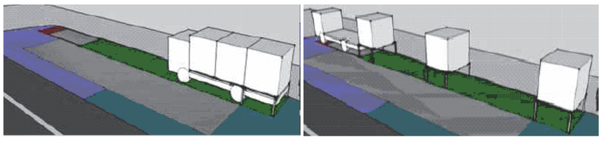

Figure 5: Using its Air Suspension, the Freight Bus Unloads the Loading Units

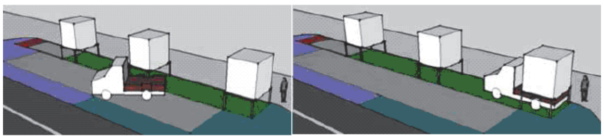

Figure 6: The Delivery Van Uses its Actuators to Load a Load Unit.

3. THE FURBOT BOX

The FURBOT box footprint has the euro-pallet dimension (120 cm long and 80 cm wide). The FURBOT box is 170 cm high. The bottom part of the box has the euro-pallet design in order to be operated with the standard movement and handling tools (loader forks, etc).

We have 2 typologies of FURBOT boxes: LBL (Less than full Box Load) and FBL (Full Box Load). We define FBL box as a box that contains packages for only one receiver while LBL box is a box that contains packages for several receivers. The FBL box can accommodate an euro pallet. In the paper we focus only on LBL boxes.

The internal space of LBL boxes is divided into modular parcels. Each parcel can accommodate packages for a given receiver. The box is accessible by receivers from two sides, and it is divided in two parts through a vertical set. This configuration on one hand allows storing a much greater number of packages, and on the other hand it allows the box to be accessed by two persons simultaneously. The two sides of the box are identical. The design of the FURBOT LBL box is provided in figure 7. The box capacity is equal to 1.102 m^3. There are three standard parcels:

- Type A: 0.0783 m^3, i.e. 56x37x46 cm
- Type B: 0.0426 m^3, i.e. 36x37x32 cm
- Type C: 0.0275 m^3, i.e. 46.5x37x13 cm

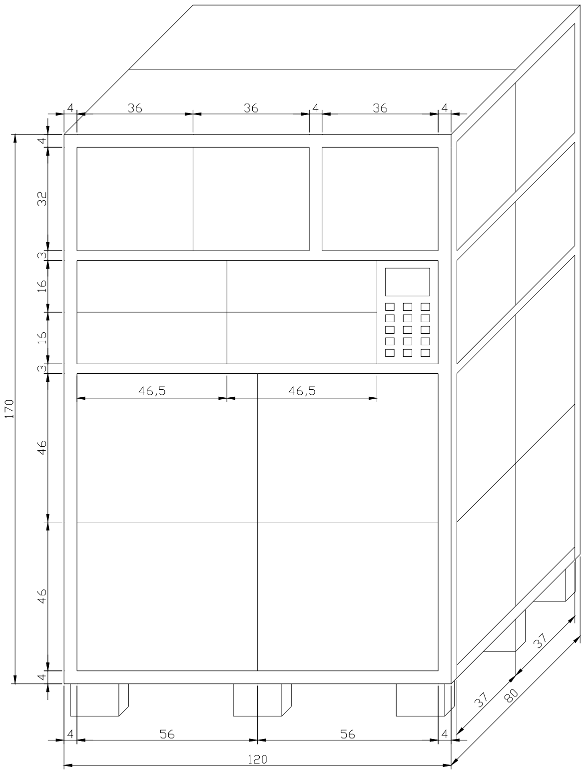

Figure 7: The Design of the FURBOT LBL Box

However, since internal sets are removable, parcels of different dimensions could be configured.

The standard parcel dimensions have been assessed according the dimensions of packages commonly delivered to commercial activities and consumers (e-commerce). Surveys on the field have been performed.

4. THE PACKAGES CLUSTERING IN THE FURBOT BOXES AND ITS MATHEMATICAL FORMULATION

The problem we face is the daily clustering of the packages at the UDC into a given number of LBL boxes. To each cluster, and therefore to each LBL box, an address is assigned, which is the "centre" position of the addresses of the packages within the cluster. Among all the possible clusters we select the ones that minimize the distances the receivers have to walk to collect their packages (and therefore the distances from the addresses of the packages to the cluster centre). The cluster centre will be the unloading bay of the box.

We have other constraints to our problem, one is related to the box capacity and another is related to the maximum distance the receivers can walk (in order to collect their packages in the box). In the literature one of the optimization problems closer to the problem we face is the k-means clustering problem with size constraints (Zhu et al. 2010).

Simple k-means clustering is a method of cluster analysis which aims to partition *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean. The problem is computationally difficult (NP-hard); however, there are efficient heuristic algorithms that are commonly employed and converge quickly to a local optimum.

The simple k-means clustering does not work properly as we have a constraint on both the box capacity and the maximum allowed walking distance. Actually the simple k-means clustering always assigns each object to the closest box and therefore when some boxes have reached their capacity, the remaining objects must be assigned to other boxes, which may entail far more than the maximum walking distance allowed.

As a result, fuzzy k-means clustering has been adopted. In fuzzy clustering, each item has a degree of membership to each cluster (u_{ij} is the degree of membership of item *i* to cluster *j*), rather than belonging completely to only one cluster. The degree of membership of item *i* to cluster *j* is inversely proportional to the distance of the item *i* to the centre of cluster *j* .

The fuzzy clustering can be formalized as follows:

$$\min f = \sum_{i=1}^{N} \sum_{j=1}^{nLBL} u_{ij}^{m} \left\| x_i - c_j \right\|^2 \tag{1}$$

Where:
x_i = address of package *i*,
c_j = position of the centre of cluster *j*,
m = parameter of fuzziness,
N = number of receivers,
nLBL = number of LBL boxes (i.e. number of clusters).

In the faced problem the independent variables are the degrees of membership u_{ij}: we need to assess the u_{ij} values that minimize the cost function. To solve the problem, an iterative algorithm has been adopted.

As starting point, the initial values for the degrees of membership $u_{ij}^{(0)}$ of the item *i* to the cluster *j* at the 0 iteration (initialization step) have been assessed assuming the positions of the cluster centers uniformly distributed in the area.

At the generic *k* iteration, the degrees of membership $u_{ij}^{(k)}$ and the positions $c_j^{(k)}$ of cluster centers are updated according to eq. 2 and 3 (Klawonn and Hoeppner 2006; Hoeppner and Klawonn 2008).

$$c_j^{(k)} = \frac{\sum_{i=1}^{N} u_{ij}^{(k-1)^m} \cdot x_i}{\sum_{i=1}^{N} u_{ij}^{(k-1)^m}} \tag{2}$$

$$u_{ij}^{(k)} = \frac{1}{\sum_{b=1}^{nLBL} \left(\frac{\left\| x_i - c^{(k)}{}_j \right\|}{\left\| x_i - c^{(k)}{}_b \right\|} \right)^{\frac{2}{m-1}}} \tag{3}$$

At each iteration k, the algorithm updates a matrix $\mathbf{U}^{(k)}$ whose columns refer to the clusters, whose rows refer to the items and whose generic element is $u_{ij}^{(k)}$.

The fuzzy clustering algorithm stops when for each item *i* and for each cluster *j* the degree of membership is no longer updated relevantly from an iteration to the following:

$$\max_{\forall i,j} \left| u_{ij}^{(k)} - u_{ij}^{(k-1)} \right| < \varepsilon \tag{4}$$

The fuzzy clustering algorithm does not provide a problem solution since it does not provide clusters but a matrix **U**. Moreover constraints have not yet been taken into account in the algorithm.

A distance matrix **D** is now assessed. The columns refer to the clusters and the rows refer to the items. The generic element d_{ij} is the distance of the item *i* from the center of cluster *j*, c_j.

For each element *ij* in the **D** matrix whose value d_{ij} exceeds 450m (maximum allowed walking distance), the related element in the **U** matrix (u_{ij}) is set equal to 0. A new matrix **U*** is therefore assessed and it satisfies the constraint (eq. 5) on the maximum distance.

New values for c_j are assessed, according to equation 2 and **U***.

$$\max_{i,j} \left\| x_i - c_j \right\| < 450 \text{ m} \tag{5}$$

Clusters should be now assessed from **U***. The item *i* with the highest u_{ij}^{*} is assigned to cluster *j* if cluster *j* has enough space (and then eq. 6 is satisfied) :

$$\sum_{p=1}^{N} w_p y_{pj} \le K_j \tag{6}$$

Where:

$$y_{pj} = \begin{cases} 1 \text{ if the item } p \text{ has been assigned to the box } j \\ 0 \text{ otherwise} \end{cases}$$

w_p = volume of the item *p*,
K_j = capacity of the box *j* = 1.102 m^3

If the constraint is satisfied, the $\mathbf{U}^*$ matrix is modified: u_{ij}^{**}=1 and $u_{iz}^{**} = 0 \ \forall z \neq j$.

If the constraint is not satisfied, u_{ij}^{**} is set equal to 0. The resulting $\mathbf{U}^{**}$ matrix satisfies also the capacity constraints.

If the elements u_{ij}^{**}= 0 or u_{ij}^{**}=1, the clusters are definitely assessed.

If there is a row *i* for which $u_{ij}^{**} = 0 \, \forall j$ (this means that there is not space for item *i* in any of the boxes that satisfy the maximum distance constraint) it is necessary to modify the clusters already assessed.

We need to remove an item *q* from a box *b* and to substitute it with the item *i*. *b* are all the boxes for which $u_{ib}^* > 0$, i.e. which respect the distance constraints. Among these *b* boxes, the box *bb* and the item *q* are selected if $u_{q,bb}^{**}=1$ and u_{qj}^* is maximum $\forall j \neq bb$ and $\forall j$ capable to contain the item *q*.

5. THE CASE STUDY

The overall methodology has been applied to a trial and illustrative case of study. A squared urban area having dimensions of 1 km x 1 km has been taken into account. The overall area is flat.

The road network is formed by parallel and perpendicular roads 50 meters distant each other. It is represented by a network of links and nodes. Links represent 10 meter long road sections. Nodes represent the midpoint of each road section. All the nodes have the same probability to be extracted as addresses for packages.

The daily freight transport demand consists of 100 packages. Their addresses have been randomly extracted from the nodes list and corresponds to the small dots in the figure 8 and 9. The typologies of the generated packages are: 40 of type A, 40 of type C and 20 of type B. Given this freight transport demand, we hypothesized two scenarios.

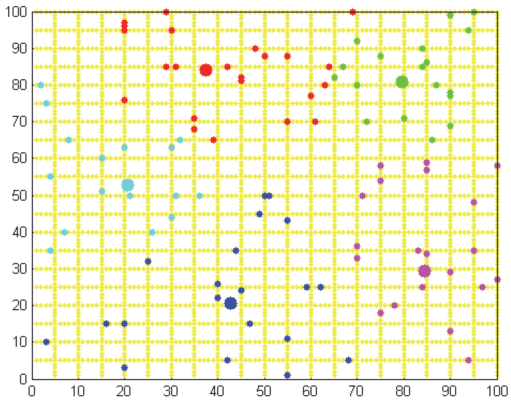

Figure 8: The Cluster of Packages in the Case of 5 LBL Boxes

In a first scenario we assumed 5 LBL boxes and the clusters of packages provided by the algorithm are shown in figure 8: all packages belonging to the same cluster are displayed in the same color; the big dot corresponds to the location of the centre of the cluster its color refers to. The maximum distance travelled by receivers results of 416 m, the average distance travelled by receivers results of 166 m and the LBL box load factors are: 0.96; 0.82; 0.98; 1.0; 0.86 (the average value is 0.92). In a second scenario we assumed 6 LBL boxes and the clusters of packages provided by the algorithm are shown in figure 9. The maximum distance travelled by receivers results of 414 m, the average distance travelled by receivers results of 148 m and the LBL box load factors are: 0.92; 0.70; 0.63; 0.85; 0.76; 0.75 (the average value is 0.77).

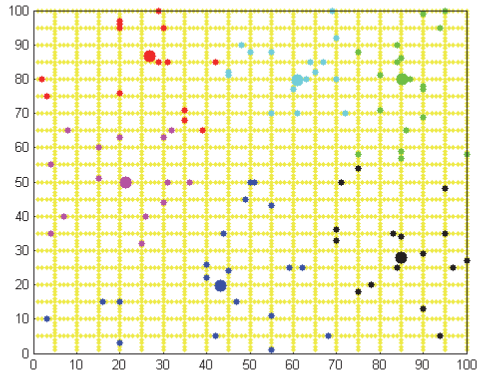

Figure 9: The Cluster of Packages in the Case of 6 LBL Boxes

6. CONCLUSIONS

From the simulation outputs it results that 5 LBL boxes are enough to satisfy the freight transport demand with good performance in terms of maximum and average distances travelled by receivers (the increase in the performance due to an additional LBL box is negligible).

The algorithm assumes a continuum space therefore the locations of the cluster centers could be any point in the area. A off line check should be performed on the locations of the cluster centers because each urban area has a list of possible places that can be used as unloading bays. These places should be accessible from the FURBOT vehicle and the receivers and the impact of the FURBOT box temporarily places there on pedestrian flows and vehicular flows should be minimum.

In the presented case of study the freight transport demand refers only to e-commerce. It could be interesting to analyze the performance of the proposed urban freight transport system in the case we consider also deliveries to commercial activities and therefore a huge increase in the freight transport demand.

In the presented case of study the area is completely trial. It could be interesting to apply the overall procedure to a real urban area.

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AUTHORS BIOGRAPHY

Elvezia M. Cepolina, PhD, assistant professor at the University of Pisa. She is professor of Transport Planning at the University of Pisa and of Transport Design at the University of Genoa. She has been research fellow at the University College London, UK.
Elvezia is the person in charge of scientific and technical/technological aspects in the following European projects for the University of Pisa: FURBOT, Freight Urban RoBOTic vehicle (FP7-SST-2011-RTD-1); PICAV, Personal Intelligent City Accessible Vehicle System (FP7-SST-2008-RTD-1). Elvezia has been Overseas Scientist in the project SPIRAL Scientific Pedestrian Interaction Research in an Accessibility Laboratory, International Joint Project - 2004/R3-EU Europe (ESEP), founded by Royal Society, UK.
Elvezia is author of many papers on international journals and international conference proceedings.
Elvezia is a member of the SIDT (Italian Society of Transport Professors).

Alessandro Farina received the M.Sc. degree in Civil Engineering from the University of Bologna, Italy, in 2009, and the Ph.D. degree from the University of Pisa, in 2012. He is currently a research associated at the University of Pisa. His research interests include car sharing systems, transport logistic and maritime transport.

RESOURCE ALLOCATION IN MESOSCOPIC LOGISTICS NETWORKS SIMULATION

Til Hennies[(a)] , Yvonne Boersch[(b)], Juri Tolujew[(c)], Tobias Reggelin[(d)]

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

[(a)]til.hennies@iff.fraunhofer.de, [(b)]yvonne.boersch@iff.fraunhofer.de, [(c)]juri.tolujew@iff.fraunhofer.de,
[(d)]tobias.reggelin@iff.fraunhofer.de,

ABSTRACT

Resource allocation in supply chains is an as essential as complex topic due to the impact it has on the performance of the entire system. Effective resource allocations take into consideration the multitude of different objectives, the heterogeneity of resources and jobs and the dynamically changing system states and resource attributes. Simulation of these strategies is a powerful way in order to test, analyze and evaluate different strategies under changing external influences. In supply chains, quick simulation algorithms are necessary for effective decision making which is supported through the mesoscopic simulation approach. This paper provides a classification of resources and jobs within supply chains, the definition and mesoscopic formalization of possible resource allocation strategies and combinations of these and an example application of a four stage supply chain.

Keywords: Resource allocation, supply chain, mesoscopic simulation

1. INTRODUCTION

The objectives of effective resource allocation are manifold and include the reduction of lead times and waiting times of logistical flow objects, a maximization of throughputs and the minimization of the utilization degree amplitude of different resources. Effective resource management directly translates into better process management and a resulting quality increase for the customer. One of the main objectives of process simulation is the identification, planning and control of most appropriate strategies of resource allocation. Considering the heterogeneity of resources and jobs, inherent conditions of resource utilization and dynamically changing attributes, the modeling of resource allocation strategies becomes a non-trivial task.

This paper deals with the topic of resource allocation in supply chains and applies it to the concept of mesoscopic simulation that has already been presented in past HMS conferences (Hennies, Reggelin and Tolujew 2012). The mesoscopic modeling and simulation approach is based on the replication of logistical flows on an aggregated level in order to allow for quick model creation and calculation. While resource allocation strategies in discrete-event simulation models are realized only algorithmically, in macroscopic system dynamics and in mesoscopic simulation models these can also be described analytically. This paper presents the formalization of different resource allocation strategies in mesoscopic simulation models. This enables supply chain managers to quickly model and test generic strategies and combinations of these in order to make decisions of resource allocations in the respective supply chain.

2. RESOURCES AND JOBS IN LOGISTICS NETWORKS

Supply chains are globalized and intertwined logistics networks with multiple different resources and jobs. An effective allocation of resources and jobs is one of the key measures to increase the system's performance. However, due to the complexity of resources and jobs this decision is rather complicated. A classification of resources and jobs and the definition of objectives and priorities make up the basis for strategic allocation of resources and jobs.

The term *resource* describes the totality of means of production or services and the multitude of different resources can be classified in material and immaterial resources (Schuster 2012). This first differentiation, however, is too crude for resource allocation problems in production and logistics networks, because there can be found very diverse resources from operating equipment and aids to means of transport, stock and human resources. These resource types have very different characteristics that are predetermining the application areas and the possible jobs to be executed. Therefore, it is essential to develop an appropriate classification in a more specific sense and consider all relevant attributes with the respective characteristics that come into play when strategies for resource allocations have to be selected.

In the context of resource allocation problems in supply chains many attributes besides the already mentioned *appearance* (material/immaterial) need to be considered. The *mobility* of resources describes the ability of resources of being relocated and significantly determines the material flow wherefore it has impacts on the allocation decision. The *flexibility* determines the application area of resources and the *autonomy* of resources describes an inherent requirement of further resources in order to being operated. The *availability* may be dependent of further conditions or circumstances and makes up another factor for effective allocation strategies. Resource *costs* can be operating or investment costs and also highly affect the decision about utilization and job allocation. The *degree of automation* is similar to the autonomy of resources, but has further impacts on the flexibility and correctness of the job execution, wherefore it should be considered separately. The attribute *property* refers to the actual owner of the resources – if these are the organization's own or lent resources. *Renewability* describes the possibility to reproduce the resource or not and has impacts on the decision of utilization and application area. Similarly, the *lifetime* and *substitutability* of resources are further factors that play a role for these decisions and finally, the *condition* of a resource can be different with certain effects on repairs and maintenance requirements which should therefore be considered.

The different characteristics corresponding to each of the described attributes are listed in below morphology in Table 1.

Table 1: Morphology of resource attributes

Attribute	**Characteristics**		
Appearance	Physical/material		Virtual/immaterial
Mobility	Stationary	Moveable	Locally independent
Flexibility	Job-specific		Universal
Autonomy	Active		Passive
Availability	Completely		Partially
Costs	Low	Medium	High
Degree of automation	Computerized	Semi-autonomous	Human
Property	Internal		External
Renewability	Completely	Partially	Not
Lifetime	Short-term	Medium-term	Long-term
Substitutability	Completely	Partially	Not
Condition	Technical		Organizational

Based on these different characteristics, each resource in a supply chain can be precisely described in multiple dimensions and afterwards clustered in groups based on the relevant attributes for distinct purposes such as simulations. Relevant resources for supply chains can be subsumed into the following categories:

- *Human resources*: Important for allocation, processing and monitoring of jobs, goods and services e.g. scheduler, dispatcher, operator and driver
- *Means of transport*: Devices for the purpose of goods carriage e.g. truck, forklift and conveyor
- *Operating aids*: Required for stabilization of the manufacturing process e.g. fuel, energy, coolants and lubricants
- *Operating equipment*: Technical facilities of the manufacturing process (e.g. machinery and tools) and loading, transport and storage equipment (e.g. container, swap body)
- *Organizational resources*: Organization (planning, implementation, monitoring and control) of operational processes e.g. work instructions, policies, manuals and forms
- *Space/surface*: Available limited area for the manufacturing process e.g. premises, factory, warehouse and office building
- *Stock*: Secure the continuous manufacturing process e.g. raw material, (semi-finished) products, finished goods, product components
- *Technological resource*: Development of new production and information technologies e.g. innovative project ideas, patents and licenses

Similarly, jobs have application-specific and context-sensitive definitions. Generally spoken, jobs are complex business objects which include confirmed requests to buy, sell, deliver, or receive goods or services under specified conditions (Schönsleben 2011). In a more abstract sense, the term *job* in a supply chain covers all tasks within the order fulfillment process that require resources and time to be executed – from the customer's inquiry to delivery of a product to the customer.

This broad definition of jobs in a supply chain implies very different characteristics of these in regards to different dimensions. The *production strategy* is defined through the order decoupling point and determines the triggering of a production job. The *complexity* of a job refers to the expertise requirements of the job and the repetition rate which affects the allocation decision. The *flexibility* describes the possibility to execute one job with different resources or not. The *flexibility of the due* date is important for the scheduling process. *Lot Sizes* refer to the number of jobs that are treated as one single group within the process. The *predictability* of jobs highly depends on the demand variability and has impacts on the production strategy and the triggering of jobs. The job *priority* depends on the customer and must be taken into consideration when allocating jobs to resources. The *repetition rate* describes the frequency of the same job and may have effects on the selection of the resources for this job. Jobs can be *triggered* through different events related to demands, forecasts or consumption. The *value of an order* is another important criterion for the allocation of resources to jobs and vice versa. The developed morphology of these characteristics is illustrated in Table 2.

Table 2: Morphology of jobs attributes

Attribute	Characteristics			
Production Strategy	Make-to-stock	Make-to-order	Engineer-to-order	Assemble-to-order
Complexity	Standard job		Customer-specific job	
Flexibility	Resource-specific		Universal	
Flexibility of due date	No	Low	Completely	
Lot size	Single piece	Small series	Mass production	Without lots
Predictability	Ad hoc		Regular	
Priority	Rush order	Standard delivery time	Fixed day of delivery	
Repetition rate	No	Seldom	Frequently	
Triggering off	Demand	Forecast	Consumption	
Value of order	Small order	Standard order	Large order	

3. RESOURCE ALLOCATION STRATEGIES AND MODELS

The identified complexity of resources and jobs in supply chains makes up a broad spectrum of situations and scenarios in the supply chain where resources allocation strategies must be selected and implemented. When looking at one attribute of jobs and resources only, namely the flexibility, there arise four different scenarios that must be taken into consideration for effective resource allocation as exemplary illustrated in Table 3.

Table 3: Flexibility of supply chain resources and jobs and resulting scenarios

Flexibility	Resources are job-specific	Resources are universal
Jobs are resource-specific	One resource type executes one type of jobs, each job can be executed by one resource type	One resource type executes different types of jobs, each job can be executed by one resource type
Jobs are universal	One resource type executes one type of jobs, each job can be executed by different resource types	One resource type executes different types of jobs, each job can be executed by different resource types

The resulting scenarios define the potential strategies that can be applied within one situation. If one resource type executes one type of jobs and each job can be executed by one resource type, the only possible strategy is an explicit allocation of job “A” to resource “A” and job “B” to resource “B”. Contrarily, if one resource type executes different types of jobs and each job can be executed by different resource types, there arise many more potential strategies that need to be compared with regards to different objectives. These objectives can be manifold and the different possible strategies must be tested, analyzed and evaluated. Potential objectives include the following:

- Reduction of waiting times
- Reduction of lead times
- Reduction of utilization degree amplitude
- Reduction of resource movements
- Increase of throughputs
- Increase of utilization rates
- Increase of delivery reliability

This described complexity of resource allocation strategies in supply chains is also reflected in the corresponding models that aim at exploring this topic in more detail. It can be differentiated between *state-based* and *model-based* allocation models. While state-based allocation models are based on stationary snap-shots of the system state and adjust dynamically to changing system states, model-based allocations follow an initial prediction of future system states and therewith do not react to dynamically changing systems. Also, one differentiates between *preemptive* and *non-preemptive* strategies depending on whether jobs are allowed and able to change resources after beginning of processing or not. (Gomoluch and Schroeder 2003)

Many research publications in this field are also dedicated to the development of agent-based or market-oriented resource allocations that allow independent agents to decide which resources to use. (Kelton et al. 2010; Abramson et al. 2002; Chavez et al. 1997) However, as this is a decentralized and local decision-making process, it is a game-theoretical approach rather than strategic supply chain planning and therefore not part of this paper.

The discrete-event simulation, the most used simulation approach in modeling of production and logistics, realizes resource allocation through algorithms and verification of logical conditions. Conventional resource allocation strategies for disposition are methods like *Round-Robin*, *Weighted Round-Robin*, *First-In-First-Out*, *Last-In-First-Out* or *Fixed-Priority*. Within discrete-event simulations, at the moment of the event occurrence an algorithmic verification of resource allocation rules is executed and according to the defined strategy the allocation is realized. The discrete-event simulation software *Tecnomatix Plant Simulation* offers the user so-called resource objects for the implementation of resource allocation strategies, the *Broker* and the *Exporter*. The Exporter assorts several homogeneous resources to one group with a total capacity for job execution, but the allocation is not done individually. Also, one can control the strategy based on the definition of input behavior at each work station where defined strategies can be used from a drop-down menu which are, however, not dynamically adjustable. (Siemens PLMS Inc. 2010)

In macroscopic System Dynamics simulation, resource allocation rules can be expressed analytically and this is already implemented as standard solution in the simulation tool Vensim from the firm Ventana Inc. By utilizing the function *Allocate by Priority* the user can define resource allocation strategies in competitive situations (see Eq. 1). (Ventana Systems Inc. 2012)

$$allocation[subscript] = ALLOCATE\ BY\ PRIORITY(\,request[subscript], priority[subscript], size, width, supply) \quad (1)$$

4. RESOURCE ALLOCATION IN MESOSCOPIC SIMULATION MODELS

The concept of mesoscopic simulation has been developed at the Otto von Guericke University Magdeburg and is presented in (Reggelin 2011a), (Reggelin 2011b), (Schenk et al. 2009) and (Schenk et al. 2010).

Main structural elements in mesoscopic simulation models are multichannel funnels for the replication of processes at resources. Also, there are multichannel delays for replication of planned deferments like transportation and waiting times and product classes for differentiation between distinct groups of flow objects. Funnels allow for an analytical description of resource allocations in mesoscopic simulation, because these elements are also completely analytically defined.

The mesoscopic simulation therefore introduces the variable of limiting performance μ *[number of jobs/ time unit]* of the funnel and for each channel μ^i that enables one to control the output flow λ_{out} *[number of jobs/ time unit]* leaving the funnel (λ^i_{out} for each channel). If the input flow of product 1 λ^1_{in} exceeds the limiting performance of μ^1 inventory S^1 is built up within the funnel. The limiting performance μ can be split between different product types in order to replicate resource allocation strategies. These strategies interpret jobs as products and the total number of waiting jobs in front of the resource as inventories. The allocation strategies developed are different prioritization rules that split a total limiting performance between different job types. Each strategy can be formalized through the mathematical definition of the limiting performance for each product type.

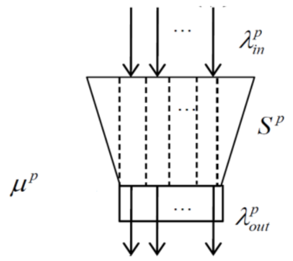

Figure 1: Multichannel Funnel in mesoscopic simulation

The topic of resource allocation has not been explicitly focused on in previous publications on mesoscopic simulation, but it is essential for effective supply chain simulation as one of the primary reasons to execute or simulate processes is to be able to reason about, forecast, and plan the best utilization of available resources. This paper presents several different strategies of resource allocation for multichannel funnels in mesoscopic simulation models. These strategies consider external factors of the situation, multivariate objectives and characteristics of jobs and resources and accordingly control the limiting performance of each channel of the funnel. Therewith, mesoscopic resource allocation strategies are centrally planned and controlled, state-based and non-preemptive. In contrast to system dynamics models, however, mesoscopic simulation models do not continuously execute new resource allocations but only at decision points with distinct events taking place when impulses or changes of the flow rates occur.

The concept of mesoscopic simulation has been implemented in the simulation software MesoSim. The resource allocation strategies have been modeled and selected results are shown in the following. In each situation, there are always two different job types to be executed by one resource with a limited capacity that needs to be split between the different jobs. The diagrams show stock developments of job 1 (black line) and job 2 (red line) under the application of different allocation strategies. General strategies of resource-job-allocations can be based on the following approaches.

Explicitly: The most trivial solution is an explicit allocation where each resource executes one job type only. Each resource can be modeled as a separate funnel or in one multichannel funnel. In the first case the limiting performance of each channel equals the limiting performance of the funnel $\mu\,(i) = \mu$. In the second case, for an allocation of fixed proportions of resource capacity to different job types, the limiting performance of the funnel μ equals the sum of limiting performances of each job type μ^i in accordance with the capacity of the modeled resource.

$$\mu \;=\; \sum_{i=1}^{n-1} \mu\,(i)$$

This allocation reflects inflexible resource utilization without any sharing possibilities. It is only suitable for continuous and stable inflows of jobs.

Uniformly distributed: For this strategy each resource executes the same proportions of different job types. Therefore, the limiting performance of the funnel μ is split into equal proportions for each job type.

$$\mu(i) = \frac{\mu}{n}$$

Independently of demands and stock developments the output rates remain constant over time. This allocation strategy is therefore only suitable for very stable and frequent job types with high predictability and continuity.

Arrival-proportional: This allocation rule suggests that each resource executes jobs according to the proportion of arrivals of jobs. Therewith, the limiting performance for each job type is defined as:

$$\mu(i) = \frac{\Lambda(i)_{in}}{\sum_{j=1}^{n} \Lambda(j)_{in}} \mu$$

This strategy incorporates the number of different jobs to be executed by the resource and is therefore suited for less frequent jobs. It is a push strategy to assure balanced workloads at preceding stages. As illustrated in Figure 2, despite different input flows (green and blue line) of the two job types the stock developments are constant because of an adjustment of resource capacities for the execution of jobs.

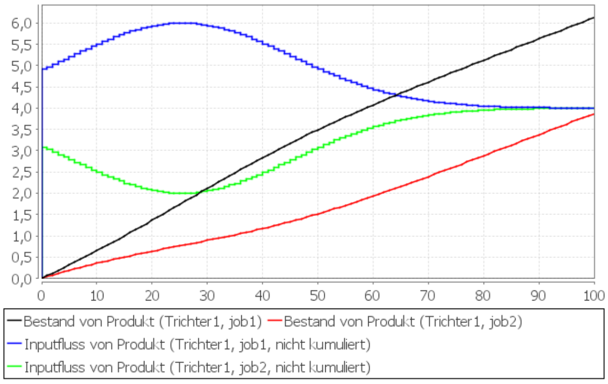

Figure 2: Inflow (green and blue) and stock development (black and red) under arrival-proportional strategy

This strategy, however, does not incorporate actual inventories that are also affected through beginning inventories or impulse-like increases and decreases, which can be seen in Figure 3, where an impulse like increase is triggered without any adjustments of the limiting performance. The additional waiting jobs are not taken into account for this strategy.

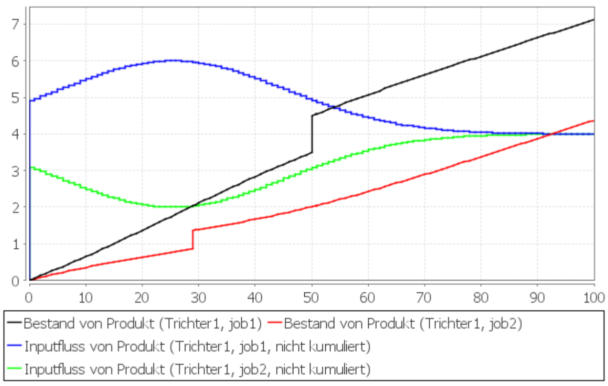

Figure 3: Inflow (green and blue) and stock development (black and red) under arrival-proportional strategy with impulse-like increase

Stock-proportional: This strategy assigns different jobs to one resource according to the proportion of inventory levels in front of the resource. If the limiting performance is adjusted based on current stock levels, impulse-like changes and beginning inventories are taken into consideration and the stock developments of different job types are balanced. The objective is to maintain moderate stock levels of products and accordingly assign the capacities. It does not look at successor operations. This strategy results in developments as shown in Figure 4 and may be applied to assure continuous realization of each job type.

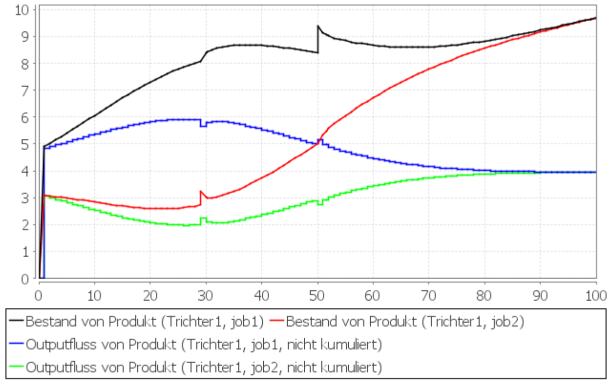

Figure 4: Outflow (green and blue) and stock development (black and red) under stock-proportional strategy with impulse-like increase

Stock-development-proportional: Each resource executes jobs to maintain similar stock developments of different job types. The resulting inventory levels of different jobs run in parallel independently of arriving jobs. The strategy aims at maintaining the same pace of inventory changes of different product types as can be seen in Figure 5. This strategy is suitable to assign resources to jobs from equally important customers with different ordering volumes.

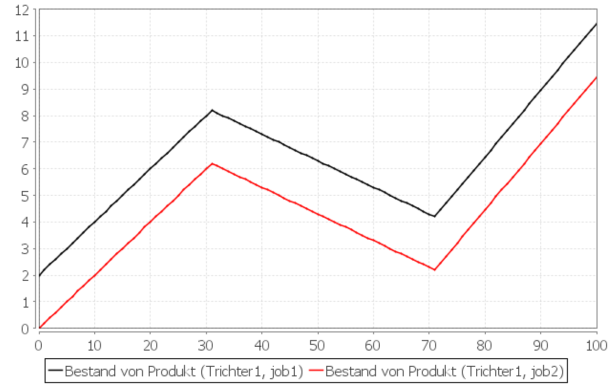

Figure 5: Stock developments (black and red) under stock-development-proportional strategy

Demand-proportional: In this strategy each resource executes jobs according to the proportion of demands. Demands can be defined at the sinks of the system where customers are replicated. If the demand rates at sinks are defined as d^p, the resulting limiting performance is calculated as:

$$\mu(i) = \frac{d(i)}{\sum_{j=1}^{n} d(j)} * \mu$$

Depending on the different demands over time the resource capacities are controlled. An example for this strategy would be the higher prioritization of a lead buyer compared to followers.

Absolute priorities: each resource executes jobs according to absolute job priorities. As long as there are highest priority jobs waiting in front of a resource, the resource capacity is completely dedicated to this job before executing the others. The resulting limiting performance for the product type of the currently highest priority jobs equals the limiting performance of the funnel and therewith the total capacity of the resource.

Relative priorities: This strategy suggests that each resource executes jobs according to previously defined relative priorities of different jobs. If the priority of a product is defined as p^i, the resulting limiting performance for each job is:

$$\mu(i) = \frac{p(i)}{\sum_{j=1}^{n} p(j)} * \mu$$

Relative priorities are equivalent to a fixed proportional assignment of resource capacities to the different job types. This prioritization can also be changed over time, which can be seen in Figure 6 that shows the prioritization of two job types over time and the resulting stock developments. The relative priority of job 1 (black line) is at the beginning higher than the one of job 2 (red line) while at time step 30 this situation turns the other way around. The entire time both jobs are executed, but with different resource capacities.

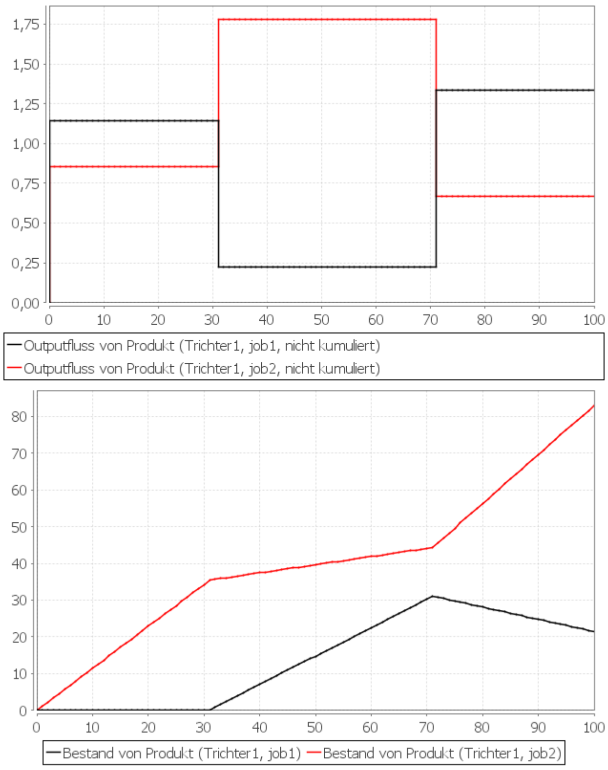

Figure 6: Stock developments (black and red) under relative priorities strategy

Arrival order: Following this strategy, each resource executes jobs according to the arrival order (FIFO, LIFO, etc.). This case is just another example of priorities and therefore not explicitly mentioned here.

Waiting time proportional: This strategy balances waiting times in front of resources which is applicable to jobs that include perishable goods for example. The jobs with longest waiting times in front of the machine are executed next.

Remaining time proportional: This strategy prioritizes jobs according to the remaining time until delivery to customer. Each resource assigns its capacities according to the urgency of the order.

5. APPLICATION EXAMPLE

In logistics networks, these strategies must be defined for several resources separately and the combination ultimately defines the performance of the system. The application example within this paper is an abstract supply chain of several stages that compares a push strategy with a pull strategy. The supplier delivers raw materials to the first production stage where semi-finished goods are produced. In the next stage goods are finished and in the last step they are customized for the delivery to the customer. Two different products are produced and supplies are subject to variability. The objective is the quick satisfaction of customer demands within the supply chain. External conditions for both strategies are the same and they run in parallel so that a direct comparison can be made. The structure of the modeled supply chain is shown in Figure 7.

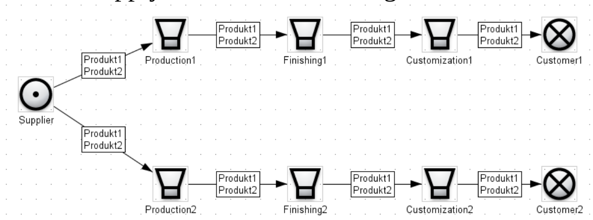

Figure 7: Structure of supply chain application example

The push strategy applies a combination of the arrival-proportional and stock-proportional resource allocations strategies and the particular elements react on the predecessor operations. More specifically, the production element applies the arrival-proportional resource allocation, the finishing element the stock-proportional allocation and the customization element only passes on the demanded products to the customer, if available. The pull strategy contrarily applies demand proportional strategies that are focused on successor operations. The customization element executes jobs according to demands coming from the customer and accordingly allocates resource capacities. The finishing and production elements apply the exact same proportion of resource allocations in order to fill up outflowing product types at the successor's inventory.

Three scenarios have been tested that are differing in the respective replenishment variability coming from the supplier. Within the first scenario, the replenishment variability of both products is very low, in the second scenario it is high for product 1 and in the third scenario for both products. This replenishment uncertainty represents unreliability and unpredictability of resupplies in the supply chain.

The study aims at exploring the effects of these different allocation strategies of every stage of the supply chain on the objective of customer satisfaction. Therefore, the stock developments at the customization stage are compared in order to uncover stock-outs as indicators of the inability to deliver to the customer. The following diagrams show the stock developments of the customization elements for the two product types as a result of different resource allocation strategies under three scenarios. The first diagram always shows the inputs from the supplier (to illustrate the variability), the second one the stock developments at the customization element applying the push-strategy and the third one the corresponding element using the pull strategy.

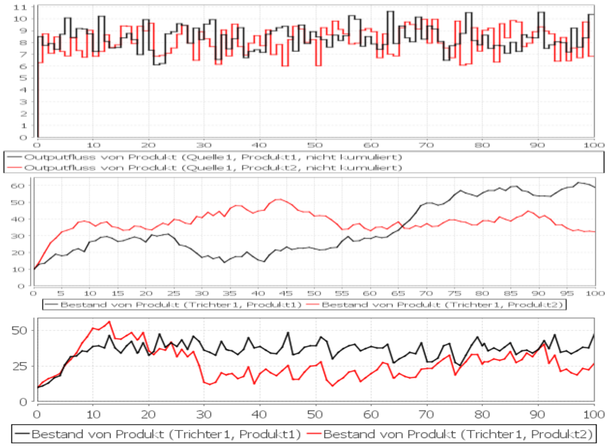

Figure 8: Supplier inputs and stock developments at final SC-stage under push and pull strategy and low replenishment variability

The first scenario (see Fig. 8) shows that both strategies are able to handle the low degree of supply uncertainty for both products and allocate resources effectively to ensure satisfaction of customer demands. The second scenario (see Fig. 9) has a higher replenishment variability for one product (black) that for the other (red). While the push-strategy only leads to few stock-outs and is mostly able to adjust to this variability coming from the supply side, the pull strategy results in several stock-outs at the last stage. This occurs, because the resources have been allocated based on demands only without taking actual available materials into account and this results into wastage of available resources.

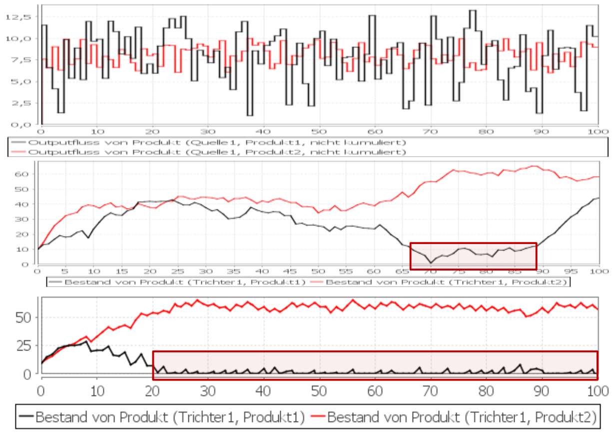

Figure 9: Supplier inputs and stock developments at final SC-stage under push and pull strategy and high replenishment variability for one product

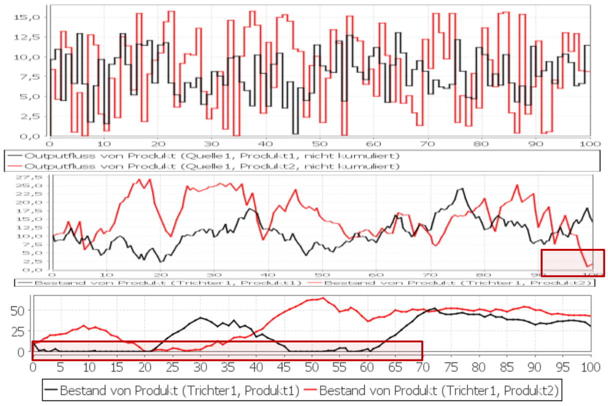

Figure 10: Supplier inputs and stock developments at final SC-stage under push and pull strategy and high replenishment variability

In the last scenario (see Fig. 10), the push strategy enables one to avoid any stock-out situation using the same resource capacities like the pull strategy that results into several stock-out situations. These are the by far better results due to the focus on the supply side in a situation where supply uncertainties are very high. The results of the study imply a direct relationship between the variability of resupplies and the advantageousness of a push or pull strategy in terms of resource allocation. While the pull strategy in this example is well-suited for stable replenishments, with increasing variability the system's performance is higher under an application of the push strategy. This study only considers customer satisfaction as objective and does not incorporate costs or other objectives that will need to be included in further research. It shows, however, the simple implementation of different resource allocation strategies in mesoscopic simulation models and the flexible adjustment to more complicated supply chains.

6. CONCLUSION

The complexity of resource allocations in supply chains is very high due to the different characteristics of jobs and supply chains and the resulting scenarios that complicate decision making in these situations. In order to facilitate an analysis and decrease the complexity, this paper provides a classification scheme for resources and jobs in logistics networks and supply chains and a description of resulting decision scenarios. Based on these analyses, different modeling techniques have been presented as well as the respective implementation of resource allocation strategies within the simulation models. The suitability of the mesoscopic simulation approach for supply chains necessitates a simple realization of different resource allocation strategies. These can be analytically described, because the corresponding mesoscopic simulation elements - multichannel funnels - are also completely analytically described. Different prioritization rules have been presented and their implementation using the software MesoSim has been shown. A model of several stages has been developed to test and analyze different combinations of these strategies. The example illustrates the straight-forward replication of the desired allocation strategies in the mesoscopic simulation model and software MesoSim. Further research will be dedicated to the combination of different strategies within one system to enable supply chain managers to quickly test and analyze different resource allocation strategies for their supply chains and how the mesoscopic simulation models support the decision making process.

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AUTHORS BIOGRAPHY

Til Hennies is a project manager at the Institute of Logistics and Material Handling Systems at Otto-von-Guericke-University Magdeburg and Fraunhofer Institute for Factory Operation and Automation IFF. He holds a degree in industrial engineering and management from Otto-von-Guericke University Magdeburg and a Master's degree in Engineering Management from the Rose-Hulman Institute of Technology, IN, USA. His main research and work interests are logistics system modeling and simulation.

Yvonne Boersch is a Master student at the Otto-von-Guericke-University Magdeburg and graduate research assistant at the Fraunhofer Institute for Factory Operation and Automation IFF. She received a Bachelor's degree in industrial engineering and management logistic from Otto-von-Guericke University Magdeburg.

Juri Tolujew was a lecturer and then assistant professor at the Technical University of Riga from 1976 to 2001. Since 2001, he has been a Research Manager at the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg. He earned his Habilitation in Simulation Technology from Otto-von Guericke-University Magdeburg in 2001. Since 2005, he has also been a member of the faculty of the Institute of Logistics and Material Handling Systems at Otto-von-Guericke University Magdeburg. His main research and teaching interests are the mathematical modeling and simulation of logistics systems and networks.

Tobias Reggelin is a project manager at the Fraunhofer Institute for Factory Operation and Automation IFF and Otto-von-Guericke University Magdeburg. His main research and work interests are logistics system modeling and simulation and the development and conduction of logistics management games. Tobias Reggelin received a doctoral degree in engineering from Otto-von-University Magdeburg. Furthermore, he holds a diploma degree in industrial engineering and management from Otto-von-Guericke University Magdeburg and a master's degree in Engineering Management from Rose-Hulman Institute of Technology in Terre Haute, IN.

SIMULATION MODELING OF SCHEMES OF CARGO TRUCKING BETWEEN EUROPEAN UNION AND CUSTOMS UNION OF RUSSIA, BELARUS AND KAZAKHSTAN

Eugene Kopytov[(a)], Dmitry Abramov[(b)], Mihails Savrasovs[(c)]

Transport and Telecommunication Institute, 1 Lomonosova str., Riga, Latvia

[(a)] kopitov@tsi.lv, [(b)] dmitry.abramov@inbox.lv, [(c)] savrasovs.m@tsi.lv,

ABSTRACT

In the paper existing and proposed schemes of freight transportations by motor transport from European Union to the Customs Union of Russia, Belarus and Kazakhstan are considered. In order to test out proposed transportations approaches, two simulation models are constructed using AnyLogic software. Both models are based on discrete-event simulation paradigm. Validation of models was carried out on the basis of animation and experts' assessment. Comparison of the considered transportation schemes basing on the criteria of efficiency (total costs, time for delivery, required number of trucks, and average container turnover) is executed.

Keywords: freight transportation, regulation of transportation, border crossing, simulation model, AnyLogic package

1. INTRODUCTION

The last decades are characterized by the intensive growth of volumes of the interstate freight transportations, which are carried out by motor transport. The important place in these volumes is taken by freight transportations between EU countries and the countries of the Customs Union (CU) of Russia, Belarus and Kazakhstan. Figure 1 shows that trade of goods between EU and Russia, the biggest country of CU, has increased a lot since year 2000. Moreover, export of goods to Russia exceeds import almost twice.

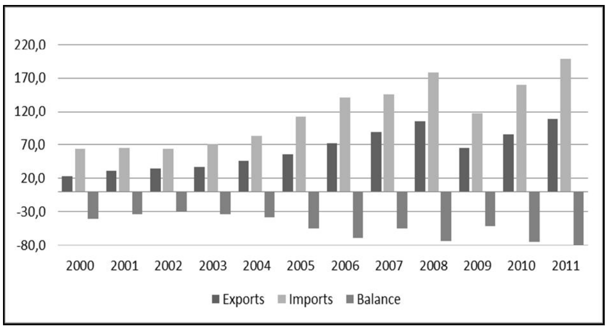

Figure 1: Trade between EU countries and Russia. Eur bil

As can be seen on Figure 2, main import volumes from Russia to EU come for minerals which are usually delivered by sea transport and pipelines.

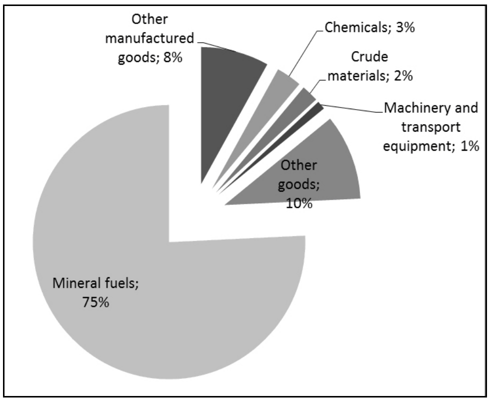

Figure 2: Import from Russia to EU in 2010

Opposite, talking about export to Russia, main volumes go to ready products (see Figure 3), which in particular are delivered by road transport. This leads to constant increase of number of trucks, delivering goods over the borders of EU and CU.

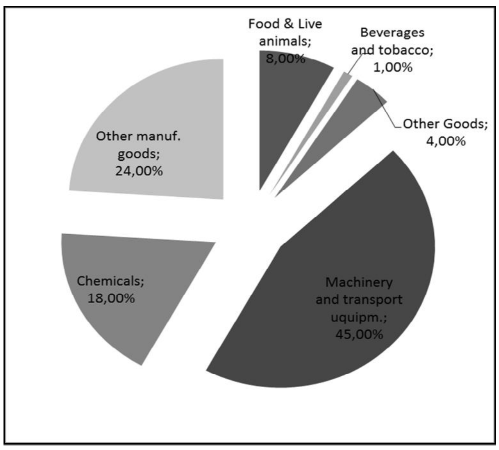

Figure 3: Export to Russia from EU in 2010 year.

The analysis of processes of freight transportations between EU and CU countries has revealed a number of problems demanding the fast decisions. Among them there is a problem of improvement of freight transportations by motor transport through the border of EU and CU, which is investigated in the present article.

Choice of the best cargo transportation scheme demands an estimation of effectiveness of proposed alternatives. While absence of statistics for a new transportation schemes, the estimation can be achieved by simulation modeling. Today simulation models are widely used when solving different tasks of cargo transportation (for instance, see McLean and Biles 2008; Parola and Sciomachen 2005; Rizzoli, Fornara and Gambardella 2002). These models have shown its effectiveness. Thus, simulation modeling method is a basic tool of the presented research.

2. REGULATION OF FREIGHT TRANSPORTATIONS BETWEEN EU AND CU COUNTRIES

Road transportation between EU and CU has number of regulations. The main are agreements between two unions and bilateral agreements between the countries of CU and EU. Basing on these agreements, countries of the CU exchange with each EU country by special permissions for freight transportation between separate countries. There are two types of permissions: reusable and disposable. Generally transportations are carried out on the basis of the disposable permissions, operating between the concrete EU country and the country of CU. Their number exceeds the volume of the given-out reusable permissions many times, which mainly also allow to transport goods from 3-rd countries. Such permissions play a role of the regulator of transport quantity of definite country transporting goods between EU and the CU. Nearly every year the problem of shortage of number of these permissions is observed. The policy of the certain countries, including Russia, is directed to strengthening positions of its transportation companies on these routes. This affects the activity of transportation industry, accompanying and dependent industries, such as warehousing, customs and broker services, production, realization, etc. Year 2011, when there was a conflict between Russia and Poland which have the largest fleets of trucks in the countries of EU and CU, was especially indicative in this respect. The parties couldn't agree for the number of permissions, which are given out for year 2011, during a long time. The conflict lasted till April 2011 and led to decrease in deliveries of goods from EU to Russia.

Another regulation comes from usage of TIR Carnets, which are emitted by local associations of carriers on behalf of IRU (The International Road Transport Union). “TIR” stands for Transports Internationaux Routiers (International Road Transport) and is an international customs transit system (IRU homepage 2013). TIR is an international system allowing goods to travel across one or more international border with minimal customs involvement. TIR is the only universal transit system that allows the goods to transit from a country of origin to a country of destination in sealed load compartments with customs control recognition along the supply chain. This minimizes administrative and financial burdens and customs duties and taxes that may become due are covered by an international guarantee.

These regulations lead to the limitations of transport companies on the market. Companies, which are working on the local market of definite countries, cannot easily access international transportations. In peak seasons, when cargo volumes are growing along with demand for transportation services, cargo owners are suffering higher transportation rates, lack of free trucks, delays in deliveries, penalties and other issues. On the opposite side, the increase of trucks in such obstacles will not lead to the desired effect as during low periods trucks will just stand without cargoes.

The task of improvement of the situation should be looked for in increase of effectiveness of cross-border cargo transportations. In terms of this task authors suggest to look into the conception of customs clearance and customs control of goods in the places closely located to the border of Customs union. This conception was introduced in Russia in 2008 (Federal Customs Service of Russian Federation). According to this concept construction of the large Customs and Logistic Terminals (CLT) within reach of the border is carried out, where customs clearance of goods and possible transfer of cleared cargo to the Russian carrier is being done. In the latter case it is necessary to use a single trailer (a body, a container platform, etc.) for trucks of the different countries which exchange trailers directly on the terminal. This conception is among main priorities of the Customs Authorities of Russia and has long-terms development plans till year 2020.

Implementation of this freight transportation scheme should give the following main advantages:

- Avoid transportation basing on the TIR system;
- Switch to transportation mode when transport registered in this specific territory is working inside each Union, except special transportations; in this case necessity for registration of permissions disappears as in most cases foreign transport doesn't drive on the territory of each Union;
- Improve control after customs payments;
- Eliminate mass transportations of transit goods over the territory of CU, which will allow to reduce the volume of the illicit goods going on the markets of the countries of CU significantly;
- Decrease of lines at the borders;
- Improvement of border infrastructure and working conditions for the drivers;
- Quicker, easier and more transparent border crossing and customs clearance procedures.

Evaluating of effectiveness of the proposed conception is the main goal of present research.

3. FREIGHT TRANSPORTATION SCHEMES BY MOTOR TRANSPORT FROM EU TO CU

Let us consider two schemes of freight transportation by motor transport from EU to the CU: existing and proposed (perspective) schemes, on the example of containers' transportation.

The existing transportation scheme **(ETS)** is the standard scheme which is performed in most cases for containers moving from different ports like Riga (Latvia), Kotka (Finland), Klaipeda (Lithuania) and Tallinn (Estonia) to countries of Customs Union. To illustrate this scheme let us consider transportation of goods in containers from Riga to Moscow.

According to standard scheme, cargo in container is arriving to the port of Riga. After unloading from vessel and passing all required customs formalities it is being loaded onto truck and delivered to the border of Latvia and Russia, which in fact is external border of European Union and Customs Union. After waiting in the line and passing customs border formalities, which can take more than one day, the truck with container is moving further to the customs terminal for customs clearance of transported goods. After performing the customs clearance, which usually takes about one day, the truck is moving to the warehouse of consignee for unloading. After unloading, which usually takes about half a day up to whole day, truck with empty container is moving back to port of Riga for dropping off the empty container.

The considered transportation scheme involves several processes (Kopytov and Abramov 2011) which are described by a graph shown in the Figure 4. The arcs of the graph correspond to the processes and the vertices denote the start and the end of each process. Description of this graph (ETS) is presented in Table 1.

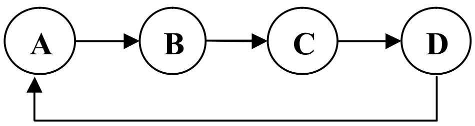

Figure 4: Existing cargo transportation scheme

Table 1: Description of ETS graph

Arc	Process
A-B	Delivery of container from port of Riga to LV-RU border for checking by customs
B-C	Delivery of container from border to customs terminal in Russia
C-D	Delivery of container from customs terminal to warehouse for unloading
D-A	Delivery of empty container from warehouse back to port of Riga

In order to perform such transportation, trucking company has to meet the following requirements:

- Company must have special permits for cross-border delivery;
- Company should have either admission to TIR Carnet system or should present special guarantees for customs authorities for payment of taxes in case of loss, steal or damage the cargo.

Such conditions limit the number of trucks which perform international carriage of goods. In peak season this become a problem for the owners of cargo as demand for transportation services can exceed the offer. Another problem of this scheme, which emerges from time to time, is crossing the border between two Unions. Capacity of border crossing point is limited and during peak seasons big lines can emerge on the borders. For example, in separate months of year 2007 lines on the border between Latvia (LV) and Russia (RU) reached 2000 trucks.

Proposed transportation scheme **(PTS).** In this respect a new approach to the transportation of goods, which is based on the concept proposed by Russia (see previous section), which is considering moving major customs clearance points to the borders, could become a good alternative. This approach is shown in Figure 5 and described in Table 2. The main idea here is that customs clearance of goods is being performed at the terminals, which are located directly at the borders and are like extensions of the border itself. This means that when truck is coming to the terminal, passing physical border line, it is still in neutral zone between two states. On this terminal all required actions for customs clearance can be performed.

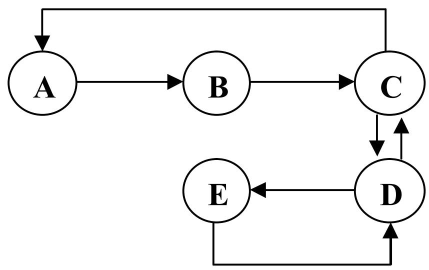

Figure 5. Proposed transportation scheme

Table 2: Description of PTS graph

Arc	Process
A-B	Delivery of container from port of Riga to LV-RU border by LV truck
B-C	Delivery of container from LV-RU border to border customs terminal by LV truck
C-D	Exchange of container with cleared goods between LV and RU trucks
D-E	Delivery of container to warehouse for unloading by RU truck
E-D	Delivery of empty container to border terminal by RU truck
D-C	Exchange of empty container with cleared goods between RU and LV trucks
C-A	Delivery of empty container back to port of Riga by LV truck

According to this scheme, cargo in container is arriving to the port of Riga. After unloading from vessel and passing all required customs formalities it is being loaded onto Latvian truck and delivered to the border of Latvia and Russia. After passing the border, which in this case takes several hours, the truck is going to the border terminal for customs clearance. After goods are cleared, the trailer with container is being changed from LV truck to RU truck and further delivered to the warehouse for unloading. After unloading the empty container is delivered to the border terminal by RU truck, thereafter trailer with empty container is being changed from RU truck to LV truck. On the final stage LV truck deliver the empty container to port of Riga for dropping off. The advantages of this scheme are the following:

- No special permits for cross-border delivery are required;
- No TIR Carnet admission is required (is not used);
- Border terminal adds capacity to the border crossing points;
- Enlarges the amount of transport units, which can perform transportations in order to avoid lack of transport during peak seasons.

4. SIMULATION MODEL DEVELOPMENT

4.1. AnyLogic Simulation Software

As the model development tool AnyLogic simulation software was used (Emrich, Suslov and Florian 2007). AnyLogic software was developed and currently supported by AnyLogic company (earlier XJ Technologies). AnyLogic software first time was presented in Winter Simulation Conference 2000. Science this time AnyLogic become widely used software both by academic and business institutions. There are number of advantages, which make this tool suitable for development of the simulation models. These advantages could be enumerated:

- AnyLogic supports all the most common simulation methodologies (System Dynamics, Discrete Event, Agent Based modeling) and creates so called hybrid models (a number of simulation approaches are combined in one model);
- AnyLogic is implemented on base of the object-oriented model design paradigm;
- As the built-in language AnyLogic uses JAVA programming language;
- AnyLogic provides optimization build-in functionality, which is based on Java OptQuest™ optimizer from OptTek, Inc;
- AnyLogic allows to transform model into stand-alone JAVA application or JAVA applet;
- AnyLogic has a number of preinstalled libraries which cover all application areas (even such specific like traffic flow simulation, pedestrian flow simulation, etc.);
- Ability to construct 2D and 3D animation of the model;
- An extensive statistical distribution function set.

All the mentioned above advantages provides flexibility during construction and experimentation with the model.

4.2. General Issues of Models Development

In order to test out proposed earlier transportation schemes, two models were constructed by using AnyLogic simulation software. Both models are based on discrete-event simulation paradigm (Borshchev and Filippov 2004).

The simulation models were developed in three stages:

1. Development of the ETS model which describes the existing technology, when container is loaded onto truck at the seaport, delivered to the place of customs clearance on the territory of CU, following which it is delivered to an unloading place.
2. Development of the PTS model, which assumes usage of CLT located at the LV-RU border (from Russian side). According to this scheme containers are delivered from port to the border terminal by Latvian truck, thereafter a customs clearance of cargo is performed. Then cleared goods in the same container are taken out of the terminal by Russian truck, which in turn brings the empty container on the terminal. In this way containers are exchanged at the terminal.
3. Development of graphic presentation of the model.

Before detailed description of the constructed models a general parameters of the modeling should be provided (valid for both models):

- The time units in models are minutes;
- Simulation is based on real calendar. In order to develop more representative models a real calendar was used (with weekends and national holidays);
- Simulation period is 6 months.

Both models have a big number of input parameters which were obtained from following sources: official statistical data, real observations, estimations provided by experts. All the input data could be divided on following categories, presented and described in Table 3

Both models have two types of entities implemented as JAVA Classes, the first one is *Container* and the second one is *Vehicle*, both are described in Table 4.

Table 3: Model Parameters Groups

Group	Description
Transportation time	Time spend to perform a transportation from one geographical point to another (at example from Riga to Latvia-Russia border)
Service time	Time spend to provide a service by different service providers along transportation route (at example time spend on custom clearance)
Schedule	Schedule for service providers, which includes working hours, working days of week, national holidays (at example working hours for service provided by port of Riga in order to take out the container)
Quantity of resources	The quantity of the resources provided by service providers. (at example number of transportation vehicles or number of unloading gates in warehouse)
Costs	Different kind of costs which are summarized in total logistics expenditures during simulation
Other	All the parameters which are not included in the mentioned above categories like: • Quantity of containers coming for transportation; • The interarrival time between containers

Table 4: Entities in models

Entity	Parameter	Type	Description
Container	ID	Int	Internal identifier of the container
	inPortTime	Double	Time when container entered to the seaport
	inTranTime	Double	Time when container started to be transported
Vehicle	ID	Int	Internal identifier of the vehicle
	inBlockTime	Double	Parameter used to estimate delay time in different blocks
	onBoardCont	Container	A container which is on board of vehicle

4.3. Model of "Existing Transportation Scheme"

The first (base) model presents the first case of transportation organization: transferring of container by one vehicle. The general view of the ETS model is presented in Figure 6.

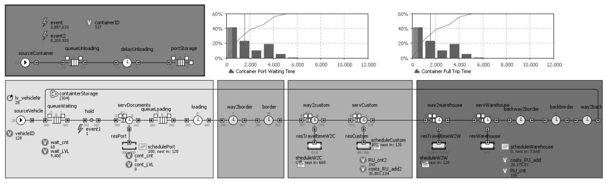

Figure 6: The general view of the ETS model

The description of the model shown in Figure 6 could be given part by part with additional comments on most important issues.

The first part (see Figure 7) of the model simulates incoming process of the containers into port of Riga. Here standard blocks of AnyLogic are used. The issues which must be pointed out, that containers at the end are staked in queue block (*portStorage*), which represent a port storage place. The containers are stored in queue (*portStorage*) till the moment, when a vehicle for transportation will be available.

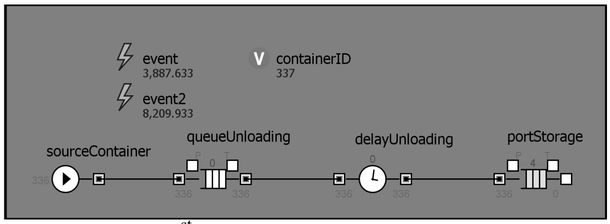

Figure 7: The 1st part of the model (Container Arrival)

The second part (see Figure 8) of the model describes loading process. In time zero a quantity (provided as parameter *lv_vehicleNr*) of vehicles are generated as entities. They are waiting in block queue (*queueWaiting*) till the time, when a container will be checked in event object (*event1*) every time unit, and in case of availability sets hold object (*hold*) in false available for transportation.

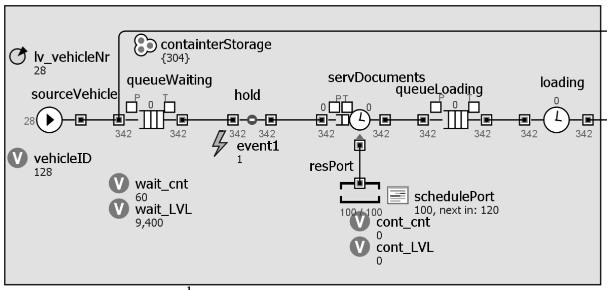

Figure 8: The 2nd part of the model (Operations in Port)

Further a service (*servDocuments*) block is used to simulate registration of documents for container transportation. Here a schedule (*shedulePort*) is used which takes into account working hours and working days. Next two blocks (*queueLoading*, *loading*) are used to simulate loading process of container into vehicle. Also must be noted, that vehicles coming back from the trip are going to the block *queueWaiting* and put empty container into *containerStorage* array.

The third and fourth parts of the model (see Figure 9) present time spend to drive and pass border (Latvia-Russia) and drive and pass customs. All these operations are simulated by using standard AnyLogic blocks. It must be noted that during driving it is taken into account, that driver will not drive by night (it is described by schedule blocks *sheduleW2C*). The custom operates also by schedule (*sheduleCustom*).

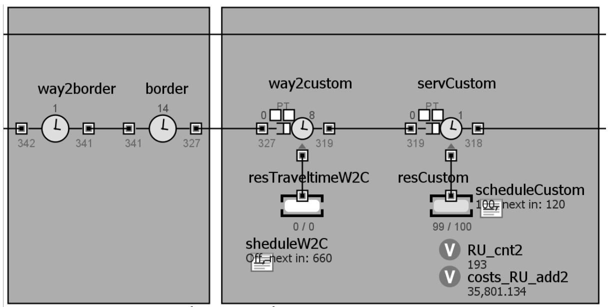

Figure 9: The 3rd and 4th parts of the model (way and operations to border and custom)

The fifth part of the model (see Figure 10) represents operations related to the way to warehouse, unloading in warehouse, and way back to Riga (including border passing). Here must be noted that warehouse is working according to the schedule provided in *sheduleWarehouse* blocks and the number of unloading gates is limited to 5.

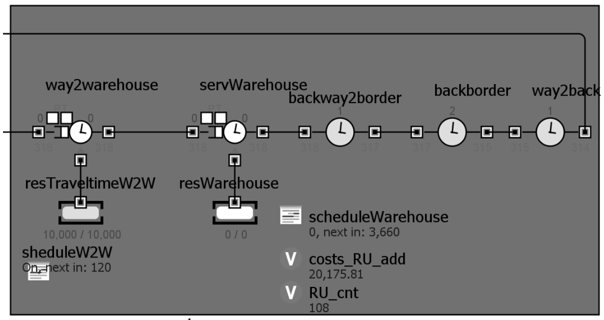

Figure 10: The 5th part of the model (unloading and way back)

During container transferring different addendums of logistics expenditures are calculated, which include transferring costs and additional costs (like: container delay in port storage, additional costs related to custom passing, costs related with unloading process).

4.4. Model of "Proposed Transportation Scheme"

The second model represents the logic described earlier: transferring of container is done by country and customs service is provided in border. The general view of the ETS model is presented in Figure 11. This model is extension of previously described base model; that is why special attention will be put to the parts which significantly differs.

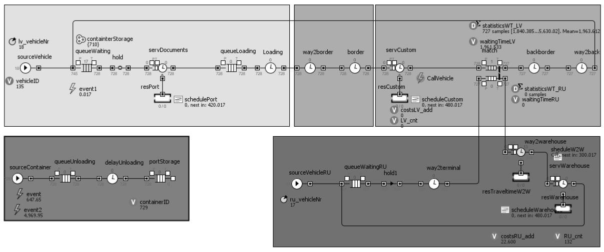

Figure 11: The general view of the PTS model

There is no difference between first, second and third part of the base and PTS model, so no additional description is required. The difference appears in the fourth part of the PTS model which is orientated on passing custom. The fourth part of the model is presented in Figure 12 in more details.

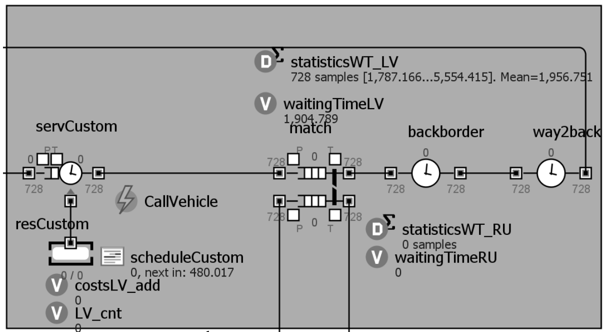

Figure 12: The 4th part of the PTS model (way and operations to border and custom)

As could be seen in Figure 12, after passing the border vehicle with container must complete the customs clearance (block *servCustom*). On entering *servCustom* block new instance of dynamic event block *CallVehicle* will be created. This action is required in order to synchronize the movement between vehicles in Latvia and in Russia. After 900 minutes the request to send a vehicle (from Russian side) will be executed. The next block *match* is very important as it organizes the synchronization between vehicles from Latvian and Russian side. Having vehicles from Latvian and Russian side, it is possible to do exchange of the containers and continue transportation process (vehicles from Latvian side drive to the border and back to Riga, vehicles from Russian side drive to warehouse).

The last part of the PTS model is focused on delivering of full container to warehouse. The detailed representation of this part of the model can be seen in Figure 13. It must be noted, that here, like in the ETS model, a parameter *ru_vehicleNr* is used in order to provide number of vehicles operating from Russian side. These vehicles as entities are generated in the simulation beginning by block *sourceVehicleRU*. Vehicles are waiting in block *queueWaitingRU* till the time they will be called (see the description of 4th part of the model), next they spend some time to reach the border (block *way2terminal*).

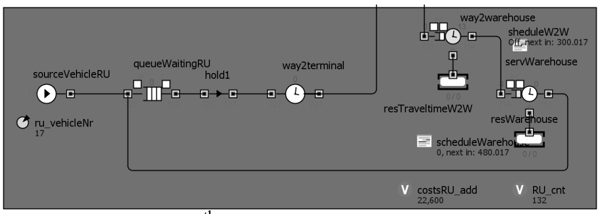

Figure 13: The 5th part of the PTS model (way to warehouse and unloading)

After exchange of containers vehicle performs transportation to the warehouse and unloading. During both procedures working hours and working days are taken into account by schedule objects (*scheduleW2W* and *sheduleWarehouse*). Next, after unloading vehicles drive back to the waiting queue (*queueWaitingRU*).

4.5. Calibration and Validation

In order to be sure, that developed base (ETS) model is valid; the validation and calibration procedure was executed. As the main validation parameter a mean container trip time (a time from the moment when container started to be transported till the moment the empty container will be back) was used. The value of parameter was estimated during 10 runs of the model and after calibration of parameters results were accepted by experts as credible. During calibration mainly driving times between different geographical points were adjusted.

The main tasks, which are fulfilled by the created models, are the following:

1. To define quantity of trucks required for delivery of containers from port of Riga to final destination in Russia;
2. To define costs for transportation of one container;
3. To define transportation time;
4. Basing on 3 criteria: transportation costs, number of required trucks and transportation time – to compare ETS and PTS models.

5. SIMULATIONS RESULTS

5.1. Existing transportation scheme

This is the current solution for delivery of containers from Riga to Moscow via customs terminal. The truck is going from Riga via border, and then moving to customs terminal and to unloading. This is direct scheme when truck in loading the container at terminal and goes directly to unloading place via two major points: border and customs terminal. No reloading or changing trucks are supposed.

The first step of the model is to find a minimum quantity of trucks for delivery of containers from port of Riga to the final destination in Moscow. Major criterion is processing of all incoming containers, so that no containers are left at seaport.

After performing 10 experiments changing quantity of trucks, it was determined that 28 trucks are required for handling all incoming containers (see Table 5).

Table 5: Quantity of trucks and unprocessed containers for ETS

No of experiment	Quantity of trucks	Quantity of unprocessed containers
0	15	325
1	18	249
2	20	198
3	23	124
4	25	74
5	26	49
6	27	25
7	28	0
8	28	0
9	28	0

The next step for the ETS model is to determine total costs for transportations of all containers during simulation period basing on the results, obtained on previous step (quantity of trucks is 28). In order to reach the objective, 10 realizations have been done

The results are shown in Table 6. Obtaining these results gives possibility to calculate mean and standard deviation of total transportation costs during 6 months, and cost for transportation of one container. From the obtained results we can see that mean and deviation of costs values is small and 10 realizations is enough for calculation.

Table 6: Total costs for transportation for ETS

No of realization	Quantity of delivered containers	Total costs for transportation, EUR
1	700	1 254 254
2	700	1 272 502
3	700	1 278 485
4	700	1 273 039
5	700	1 271 849
6	700	1 273 277
7	700	1 274 748
8	700	1 257 403
9	700	1 270 742
10	700	1 273 639
Mean		1 269 994
Standard deviation		7 779
Costs for transportation of one container		1 814

5.2. Proposed transportation scheme

This is the proposed transportation scheme, when there are two “rings” and customs procedure between these rings. One ring is about 350 km from port of Riga to LV-RU border. Second ring is about 800 km from border terminal to warehouse in Moscow. At the terminal exchange of trailers between Russian truck head and Latvian truck head is performed.

The first step of the PTS model is to find a required quantity of truck heads from each side, so that all containers are taken out of port of Riga to the final destination in Moscow. Major criterion is processing of all incoming containers, so that no containers are left at seaport.

After performing 10 experiments, it was determined that 14 truck heads from Latvian side, 17 truck heads from Russian side and 31 trailers for exchange are required for handling all incoming containers. Summarized results are presented in Table 7.

Table 7: Quantity of truck heads and unprocessed containers for PTS

No of experiment	Quantity of truck heads in LV	Quantity of truck heads in RU	Quantity of unprocessed containers
0	11	11	158
1	11	12	145
2	11	13	145
3	12	13	92
4	12	15	92
5	13	15	39
6	13	17	39
7	14	17	0
8	14	17	0
9	14	17	0

The next step for the PTS model is to determine total costs for transportations of all containers during simulation period basing on the results, obtained on previous step. In order to reach the objective, 10 realization have been done (see Table 6). Obtaining results gives possibility to calculate mean and standard deviation of total transportation costs during 6 months, and cost for transportation of one container. From the obtained results we can see that mean and deviation of costs values is small and 10 realizations in enough.

Table 8: Total transportation costs for PTS

No of realization	Quantity of delivered containers	Total costs for transportation, EUR
0	710	980 133
1	710	977 655
2	710	981 873
3	710	980 816
4	710	978 919
5	710	977 450
6	710	976 950
7	710	980 813
8	710	979 350
9	710	983 050
Mean		979 701
Standard deviation		2 004
Costs for transportation of one container		1 380

In Table 9 final optimization results for both transportation schemes are shown. Having these results, it is possible to compare the current scheme ETS and proposed scheme PTS.

The results of comparison ETS and PTS show that proposed scheme is more efficient in terms of transportation costs for one container, which decrease in 1,3 times. But ETS has one day better delivery time then PTS, which is not a big advantage as all containers are taken out of port. Besides, according to the PST more containers are returned back to the port of Riga. Talking about number of trucks, PST requires for 3 trucks more. But in middle and long-term perspectives, in terms of additional investments, this difference is not essential.

Table 9: Criteria of efficiency of existing and proposed schemes

Main criteria	ETS	PTS
Transportation costs per one container	1814 EUR	1380 EUR
Time for delivery of one container	6.5 days	7.5 days
Required number of trucks	28 trucks	14 truck heads in LV 17 truck heads in RU 31 trailers
Number of containers, delivered back to seaport	700	710

CONCLUSIONS

Application of simulation method of freight transportations between two customs unions gives a researcher the convenient tool for an estimation of alternative freight transportation schemes for the various initial data, characterizing technical and economical indices of transportation system.

In present research constructed models allowed comparing two different approaches to transportation, the existing scheme ETS and proposed scheme PTS using 4 main criteria:

1) loading all containers at seaport of Riga;
2) time for delivery of a container from loading till unloading;
3) required number of trucks;
4) transportation costs per one container.

The results of comparison show that proposed scheme is more efficient in terms of transportation costs for one container. At the same time proposed scheme allows to switch from international transportations to national with less dependence on the external factors. Switching to new schemes also brings other advantages like relief of border crossing points from lines and increase of capacity without investing additional big funds into border infrastructure.

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AUTHORS BIOGRAPHY

EUGENE A. KOPYTOV was born in Lignica, Poland and went to the Riga Civil Aviation Engineering Institute, where he studied Computer Maintenance and obtained his engineer diploma in 1971. Candidate of Technical science degree (1984), Kiev Civil Aviation Engineering Institute. Dr.sc.ing. (1992) and Dr.habil.sc.ing. (1997), Riga Aviation University. Professor (1998). Present position: Head of Computer Science Department of Transport and Telecommunication Institute, professor. Member of International Telecommunication Academy. Fields of research: statistical recognition and classification, modelling and simulation, modern database technologies. Publication: 290 scientific papers and teaching books, 1 certificate of inventions.
His e-mail address is: kopitov@tsi.lv

DMITRY ABRAMOV was born in Riga, Latvia and went to the Transport and Telecommunication Institute (TTI), where he studied Business Logistics and obtained his professional diploma in 2005. Master of Management Sciences degree (2007), TTI. Since 2007 PhD student, TTI. Was working at DB Schenker Latvia as Seafreigh Operation Manager and later Multimodal Traffic Manager from 2006 until the end of 2010. Currently occupies a position of Managing Director at Logotek Ltd.
His e-mail address is: dmitry.abramov@inbox.lv

MIHAILS SAVRASOVS was born in Daugavpils, Latvia and entered the Transport and Telecommunication Institute where he studied computer science and obtained the Master's degree of Natural Sciences in Computer Science in 2006. Current position: Head of the Research Department in Transport and Telecommunication Institute, lecturer of Mathematical Methods and Modelling Chair and PhD student (Transport and Logistics programme). Fields of research: modelling and simulation. Publications: 25 scientific papers.
His e-mail address is: savrasovs.m@tsi.lv

OPERATIONAL CONTROL FOR STACKER/RECLAIMERS

T.A. van Vianen[(a)], J.A. Ottjes[(b)] and G. Lodewijks[(c)]

[(a), (b), (c)] Delft University of Technology, Faculty of Mechanical, Maritime and Materials Engineering
Department of Marine and Transport Technology, Section Transport Engineering and Logistics,
Mekelweg 2, 2628 CD Delft, the Netherlands

[(a)]T.A.vanVianen@tudelft.nl, [(b)]J.A.Ottjes@tudelft.nl, [(c)]G.Lodewijks@tudelft.nl

ABSTRACT
At dry bulk terminals, combined machines for stacking and reclaiming (stacker/reclaimers) are generally installed to handle the incoming as well as the outgoing flow of bulk materials. At the seaside of an import dry bulk terminal, large bulk carriers are unloaded while at the landside trains or barges are loaded. During unloading and stacking of the bulk materials a stacker/reclaimer is occupied for a long time. When trains or barges arrive during that time, they may have to wait a long time before getting loaded. The operational control of an import terminal can be improved by interrupting the ship unloading and load trains or barges in between. With the proposed simulation-based approach, the effect of this change in operational control was investigated. Trains or barges can be loaded significantly quicker still guaranteeing the agreed seaside service rate.

Keywords: dry bulk terminal, operational control, discrete-event simulation, service rate

1. INTRODUCTION

Dry bulk terminals are essential nodes in the major transportation links for coal and iron ore. These bulk materials are used for the worldwide production of energy and steel. This paper focuses on import terminals where bulk materials are imported at the seaside and exported at the landside. The operation at export terminals is comparable but the direction of the bulk materials flow is opposite. An import dry bulk terminal consists of (i) a seaside where bulk carriers are moored to be unloaded, (ii) a stockyard equipped with stockyard machines for the temporary storage of the bulk materials and (iii) a landside where trains or barges are loaded. In Figure 1 an example of an import terminal in Rotterdam is shown at the time when one of the largest bulk carriers in the world arrived at the terminal's seaside.

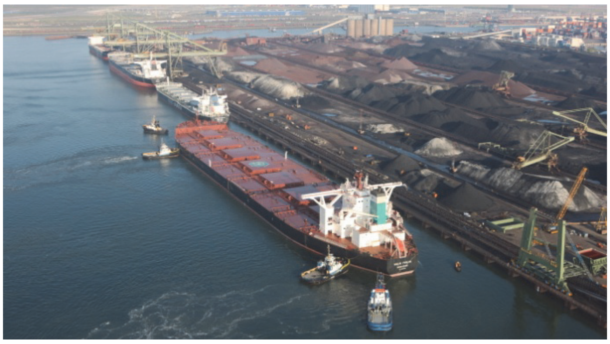

Figure 1: A dry bulk terminal (Courtesy of EMO BV)

Generally, at import terminals stacker/reclaimers are used. These machines combine the two functions of stacking and reclaiming into a single unit. Consequently one of the two functions can be fulfilled at a time. Figure 2 shows a bucket wheel stacker/reclaimer during stacking of coal. For reclaiming, the bucket wheel, at the end of the machine's boom, digs the material from the pile and dumps it onto the boom conveyor. The material is transported through the machine, dumped on a yard conveyor and transported to its new destination.

Figure 2: Bucket wheel stacker/reclaimer (Courtesy of ThyssenKrupp)

The seaside and landside transport modalities vary considerably in sizes. Bulk carriers can contain more than 350,000 tons (like the arriving bulk carrier of Figure 1) but the average train load, in for example Western Europe, is limited to 4,000 tons. During the unloading of one bulk carrier, many trains arrive at the terminal's landside. If the stacker/reclaimer continues unloading a bulk carrier and at the same time trains request material which is stored in the reach of this active stacker/reclaimer, trains have to wait before being loaded. Excessive waiting of trains leads to an unsatisfactory service to the train operators and cargo owners. Interrupting the ship unloading and handling trains in between can be a solution. However, serving the bulk carrier cannot be interrupted infinitely because terminal operators have limited time to unload ships.

The terminal performance can be expressed in the seaside and landside service rates. The seaside service rate is generally agreed between terminal operators and ship-owners and indicates the maximum time that a ship may spend in the port. The seaside service rate is calculated by dividing the ships load by the total time that this ship spends at the terminal. The total time is the sum of the waiting and the unloading time. For the landside service rate, it is less common that this rate is agreed on beforehand but the quicker a train or barge is served the better.

This paper assesses two different operational procedures for stacker/reclaimers.

2. OPERATIONAL PROCEDURES

Stacker/reclaimers handle bulk materials which are stored in piles at the stockyard lanes parallel to the machine's belt conveyor. Figure 3 shows a fictive situation where bulk materials are stored in lanes parallel to the stacker/reclaimer. A bulk carrier filled with grade B is unloaded and these materials are stacked by the stacker/reclaimer. During stacking, a train arrives which must be loaded with grade D. The stacker/reclaimer has now two options. The first one is to continue unloading and let the train wait. The second one is to interrupt the stacking action, and so the ship unloading, travels to pile D and reclaims the bulk materials which can be loaded in the railcars. When the railcars are filled, the stacker/reclaimer can continue stacking the materials out of the bulk carrier.

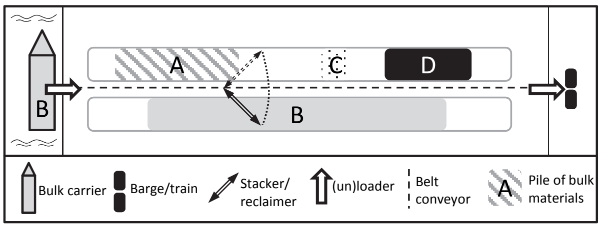

Figure 3: Situation sketch

The first option is called the FIFO (First In, First Out) operational procedure. Based on the order of arriving, the first job is served completely without any interruption, no matter if this is a bulk carrier or train. Figure 4A shows this procedure schematically; the arrival sequence determines which job is served.

The second option is called the FIFO+ operational procedure, which is displayed in Figure 4B. The order of arrivals still determines the order of the served jobs. However, if during ship serving a barge or train arrives and the bulk carrier has enough time left, this landside job is served in between. Figure 4B shows an arbitrary situation that during unloading of a bulk carrier, three arriving barge/trains are loaded. The intended advantage is that the landside service rate will be increased because the barges or trains have to wait shorter.

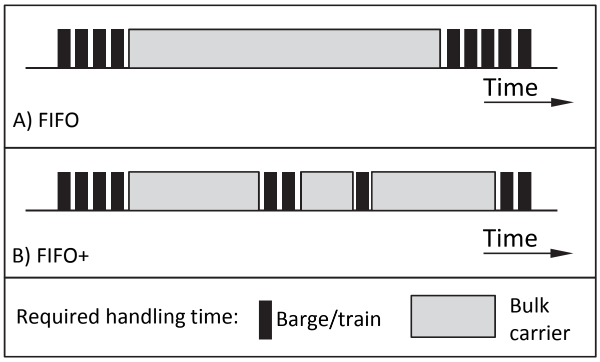

Figure 4: Two different operational procedures

For the comparison of the two operational procedures it was assumed that (i) the (un)loaders and the belt conveyor have the same handling capacity as the stacker/reclaimer, (ii) there is always area available to store the incoming material, (iii) the requested bulk material at the landside is always available and (iv) the needed travelling time of the stacker/reclaimer is not considered.

Besides, the following preconditions for the FIFO+ operational procedure were defined:

1. The handling of landside jobs during bulk carrier unloading is only performed if there are no bulk carriers waiting.
2. There is no time lost for switching between seaside and landside jobs.

3. SIMULATION-BASED APPROACH

Both operational procedures have to be judged by comparing the seaside and landside service rates. For the analytical derivation, queuing theory formulas look promising. However, previous research showed that the machine's service time distribution cannot be represented with a general distribution (Van Vianen, Ottjes and Lodewijks 2012). Furthermore, interrupting a job and continuing with another one cannot be regarded using queuing formulas.

That's why a simulation-based approach is proposed. For modeling the stacker/reclaimer activities the process-interaction method was used. This method was introduced by (Zeigler, Praehofer and Kim 2000; Fishmann 2001; Veeke and Ottjes 1999). In this approach the system is virtually broken down into relevant element classes each with their typical attributes, which results in an object oriented data structure of the system. For all active element classes process descriptions, which describe the functioning of this element as a function of time, have to be defined. The last step is to create all necessary elements according to their classes and start the processes of these elements. In the simulation model all active elements act parallel in time, synchronized by the sequencing mechanism of the simulation software (Ottjes and Lodewijks 2004).

The simulation model is built in Delphi and TOMAS (which is an abbreviation for Tool for Object oriented Modeling And Simulation) is implemented as a toolbox in the application-development environment of Delphi. (TOMAS can be downloaded for free from www.tomasweb.nl). Generally, a seaside job generator was used to create the arriving of bulk carriers and a landside generator generates the landside jobs. Both jobs were handled by the predefined simulation element stacker/reclaimer. Details for the job generators are presented in section 3.1 and a description for the stacker/reclaimer is shown in section 3.2.

3.1. Job Generators

Two job generators were created, one for the seaside and one for the landside jobs. Table 1 shows the attributes, the process and an algorithm (CheckTime) for the landside job generator. The 'CheckTime' algorithm checks if the current unloaded ship has time left to be interrupted for loading a landside job in between. The process for the seaside job generator is not shown in this paper but is comparable to Table 1.

Input files (SeaFile and LandFile) were used as input for the job generators for the jobs arrival times, loads and grades. These input files have to be composed separately and can be based on historical data or, when historical data is unavailable, be derived from stochastic distributions.

A job is created after waiting the interarrival time between two jobs. For the FIFO procedure a new job is directly putted in the JobQ and in the LandsideQ. If the FIFO+ operational procedure is activated and the stacker/reclaimer is idle, this landside job can directly be served and is therefore directly placed in the JobQ as well. For FIFO+, the algorithm CheckTime is activated when the stacker/reclaimer is active at the moment that the landside job is created.

In the function CheckTime is first determined if there is already a waiting ship. If there is a bulk carrier waiting, the result of this function is 'No SR Available' according precondition 1 of section 2. If there is no new ship waiting, the available time of the current served ship will be calculated using the following relation:

$$t = t_m - \left(W_t + W_s + W_{s\_req} + W_i \right) \quad (1)$$

Where t is the job's available time [h], t_m is the maximum time that this ship may spend in the port [h] (which can be calculated by dividing the job's load with the agreed minimum service rate), W_t is the time that this ship already waited before getting unloaded [h], W_s is the total service time till now [h], W_{s_req} is the required service time to finish this job [h] and W_i is the ship's total interrupted time [h].

If the available time (t) exceeds the required time to serve the landside job, the stacker/reclaimer can be used. The stacker/reclaimer is then interrupted, the current ship is defined as the previous job and its remaining load is calculated. The stacker/reclaimer starts serving the landside job. If there is no available time left, the landside job cannot be served directly and has to wait in the JobQ.

Table 1: Landside Job Generator

Attributes MyJob: JobClass, MyFile: TomasFile, Process: Procedure, CheckTime: function, t: double (available time)
Process MyFile = LandFile Read input (T_A, tons, grade) from MyFile Wait Interarrival time between two successive arrivals MyJob=JobClass.Create and add attributes MyTons and MaxTime If FIFO or FIFO+ and SR is idle then MyJob.EnterQueue(JobQ & LandSideQ) else FindSR If 'SR Available' then • stop this SR, define the new job of SR as MyJob and define the SR's previous job (SJob) • calculate the remaining tons of the previous job • restart SR If 'No SR Available' then MyJob.EnterQueue(JobQ & LandSideQ)
CheckTime If there is a SJob in SeaSideQ then result = 'No SR Available' If SeaSideQ is empty and SR handles a SJob then • determine SR.MyJob.t_m, SR.MyJob.W_t, SR.MyJob.W_s, SR.MyJob.W_i, SR.MyJob.W_{s_req} • calculate t based on equation (1) • if t – (MyJob.MyTons / MySR.ReclaimCap) >= 0 then result = 'SR Available' • if t – (MyJob.MyTons / MySR.ReclaimCap) < 0 then result = 'No SR Available'

The seaside job generator differs from the discussed landside job generator because seaside jobs are always directly putted in the JobQ and in the SeaSideQ.

Table 1 shows that the common object oriented dot notation was used for qualifying methods and properties to the main elements of the simulation model. So for example MyJob•MyTons means the amount of tons of this job and MyJob=JobClass•Create causes creation of an instance of the job class.

3.2. Stacker/Reclaimer

For the stacker/reclaimer a specific element class was defined which contains a process and a function SelectJob. Table 2 shows details for this element. The function SelectJob is activated when the stacker/reclaimer has finished a job. When the machine had already worked on an interrupted job and there is a ship waiting, the stacker/reclaimer will continue serving this ship (which was defined by the landside job generator as previous job). When the interrupted job leaves enough time to handle a landside job in between, there are only trains waiting, a train can probably be served. To check if material for a train is stored in the reach of a stacker/reclaimer, this machine has a specific queue, MyGradesQ. In this queue the accessible grades are listed. If the grade of this job corresponds with one of the grades stored in MyGradesQ, this job will be selected to be served.

In the stacker/reclaimer process, the selected job will be moved from the right queues and the job's handling time (t_h) will be calculated based on the job's load and the machine's capacity. After the handling time the job is finished and erased from the system.

Table 2: Stacker/Reclaimer Class

Attributes MyJob : JobClass, PrevJob: JobClass (previous job but interrupted during serving), StackCap, ReclaimCap: double, SelectJob = function, t_s: double (handling time)
Process Repeat While there is no Job to handle: standby (SelectJob: 'No Job') If Result = Seaside Job then MyJob.LeaveQueue(WSQ) else MyJob.LeaveQueue(LSQ) MyJob.LeaveQueue(JobQ) If Result = Seaside Job then t_h=MyJob.Mytons / StackCap else t_h=MyJob.Mytons / ReclaimCap Wait during t_h MyJob.Destroy

SelectJob
If (no assigned MyJob but there is an assigned PrevJob) and (no time available anymore of the PrevJob ór there is a ship waiting) then Result= PrevJob
Else MyJob=JobQ.FirstElement
Begin
If MyJob.MyGrade.IsInQueue(MyGradesQ) then Result = MyJob
If NOT MyJob.MyGrade.IsInQueue(MyGradesQ) and MyJob is not last element of JobQ then MyJob = successor in JobQ
If NOT MyJob.MyGrade.IsInQueue(MyGradesQ) and MyJob is the last element of JobQ then Result = 'No Job'
end

The simulation model uses three general queues, where elements are stored for the control of the model. In the JobQ, the seajobs and landjobs are stored in the order of arriving. The seaside queue and the landside queue are used to store the seajobs and landjobs respectively when these jobs have to wait before getting served. A simplified representation of the simulation model is shown in Figure 5.

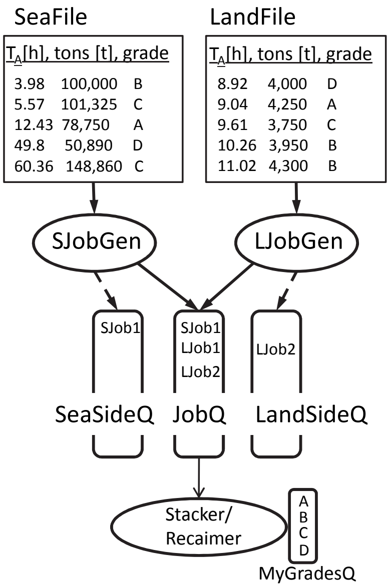

Figure 5: Schematic representation of the simulation model

3.3. Verification and Validation

The simulation model aims to be an accurate representation of a conceptual operational model for using the FIFO or FIFO+ procedures at a dry bulk terminal. According (Kleijnen 1995) verification is required to determine if the simulation model performs as intended. Validation is concerned to determine if the simulation model is an accurate representation of the system under study.

Verification was performed using (i) the tracing function of TOMAS and (ii) comparing the simulation results with analytical results. The average ship's waiting time (W_t) as function of the inverse of the service rate ($1/\mu$) was determined analytically for an M/D/1-queuing system using the Pollaczek–Khinchine mean value formula (which was reformulated by Adan and Resing 2002). The simulation model was also used to determine the average ship's waiting time versus the machine's utilization (ρ) for the same queuing system. Both ships and train arrives according a negative exponential distribution (M), the service times were constant, and one stacker/reclaimer was used with the FIFO operational procedure. Figure 6 shows that the analytical results (M/D/1) correspond with the simulation results, which implies that the model is verified.

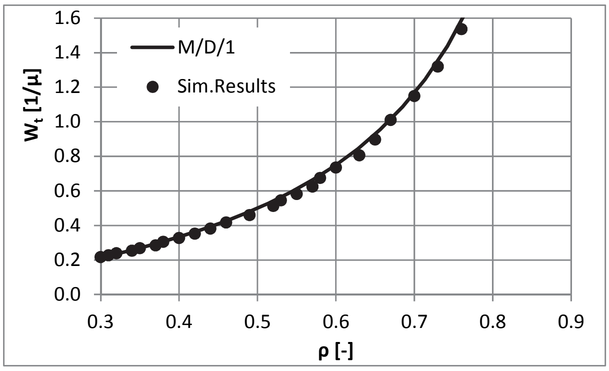

Figure 6: Verification of simulation model

Validation was not possible because there does not exist real data to compare with yet because the system under study is a conceptual model.

4. SIMULATION RESULTS

Both FIFO and FIFO+ operational procedures will be assessed for a specific case by varying the annual throughput per stacker/reclaimer. The annual throughput when the average service rate will fall beneath the minimum required service rate is the maximum annual throughput per machine. It is expected that when the FIFO+ operational procedure will be used, this value can be increased. In section 4.1, the used input parameters will be specified and in section 4.2, the results will be shown.

4.1. Input

To create input files, which comply with daily practice at import terminals, the seaside and the landside processes were investigated for several dry bulk terminals.

4.1.1. Seaside

Previous research showed that the ships interarrival times can be modeled using standardized stochastic distributions (Van Vianen, Ottjes, and Lodewijks 2012).

Depending on the terminal type, a specific distribution type must be selected. For this case, it was assumed that the terminal is a stevedoring import terminal. This terminal has to serve many clients and does hardly have any influence in the arrival times of the ships. The interarrival time distribution can then as best be represented by the negative exponential distribution.

Generally, the carrier tonnage distribution cannot be represented with generalized distribution types. The investigated terminals showed a large variation mainly based on the visiting carrier classes. Historical data of visited ships during three years of operation of a specific terminal was used as input for the ship sizes.

4.1.2. Landside

For this case it was assumed that also the interarrival time distribution of the landside jobs can be represented with a negative exponential distribution. This happens when, for example, trains can be temporarily congested in railway lines or barges can be blocked on the rivers. The arrival process is then not regular anymore. The terminal has to wait for the arrival of trains and barges followed by a close succession of trains and barges.

For the landside it was assumed that the job loads do not vary that much. This assumption corresponds with the historical data of the investigated terminals. A uniform distribution between a minimum (2 [kt]) and a maximum value (4 [kt]) was used to represent the landside size distribution in the LandFile.

In Table 3 the used parameters for the simulation runs are listed.

Table 3: Input Parameters

	Seaside	Landside
Interarrival time distribution	NED	NED
Tonnage distribution	Based on historical data	Uniform
Average tonnage [kt]	101	3
Net machine capacity [kt/h]	2.5	
Minimum required service rate [kt/h]	1.75	

Table 3 lists the minimum required seaside and landside service rate of 1.75 kilotons per hour [kt/h]. This rate corresponds to realistic agreed service rates between import terminal operators and ship-owners. Besides, it was assumed that this rate must also be achieved at the landside to provide acceptable service to train operators and cargo owners. Note that the installed machine capacity has a higher value (2.5 [kt/h]) which allows ship waiting and/or interruption during unloading. The simulation runs were performed using a simulation run time of 25 years to minimize the influence of the stochastic variances of the interarrival time distributions.

4.2. Results

The performance indicators, which will be used for the assessment of both operational procedures are (i) the average seaside and landside service rates (which must at least exceed the predefined service capacity of 1,75 [kt/h]) and (ii) the realized annual throughput.

The average seaside and landside service rates were determined at the end of the simulation run. Figures 7 and 8 show the realized service rates versus the stacker/reclaimer annual throughput for the FIFO procedure (Figure 7) and for the FIFO+ procedure (Figure 8).

For the FIFO operational procedure, the maximum annual throughput for a stacker/reclaimer is 4.6 million tons per year [Mt/y] guaranteeing an average service rates of 1.75 [kt/h].

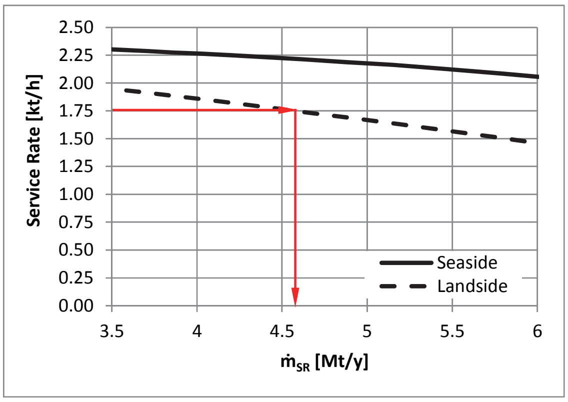

Figure 7: Service rates versus the stacker/reclaimer annual throughput for the FIFO operational procedure

When the FIFO+ operational procedure was used (see for the results in Figure 8), the landside service rate can be increased significantly. Obviously, this leads to a reduction of the seaside service rate. But for an annual throughput until 5.7 [Mt/y], the service rates still exceed the minimum required service rate. From Figure 8 can also be detected that the seaside and landside service rates are in the same range, in contrast to the FIFO procedure.

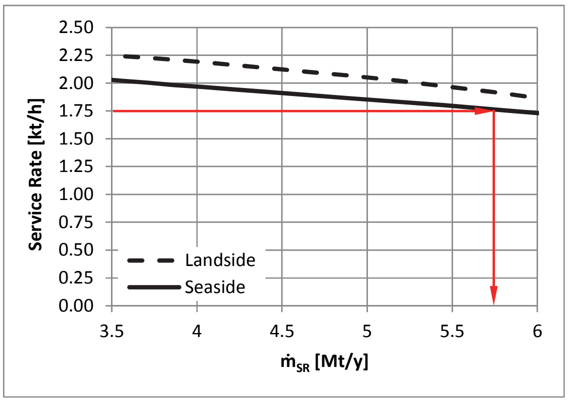

Figure 8: Service rates versus the stacker/reclaimer annual throughput for the FIFO+ operational procedure

Figures 7 and 8 show the realized average service rates for both seaside and landside. To verify if ships are still served when the FIFO+ procedure is used, the service performance was measured. This indicator represents the percentage of ships which do not have to stay longer at the terminal then agreed. Figure 9 shows the performance of served ships for both operational procedures versus the machine's annual throughput. From Figure 9 can be concluded that there is no difference in service performance regarding the used operational procedures. The used algorithm enables the realization of a higher landside service rate without a reduction of the seaside performance. The arrival processes and the installed machine's capacity determine ships waiting and thus the service performance.

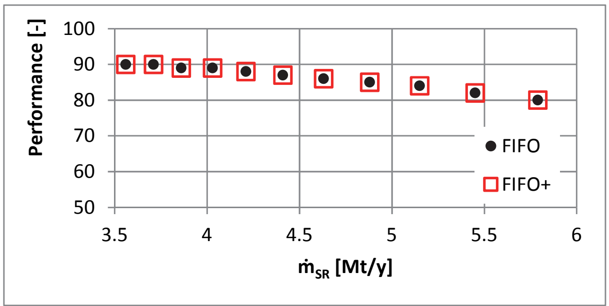

Figure 9: The percentage of ships which were served on time versus the annual throughput

For the FIFO+ operational procedure, the average number of interruptions (N_i) during ship unloading was registered and is shown in Figure 10. As expected, ship unloading will be interrupted more when the annual throughput increased. For the determined annual throughput of 5.7 [Mt/y] (see Figure 8), the unloading process of a bulk carrier is on average 6.5 times interrupted.

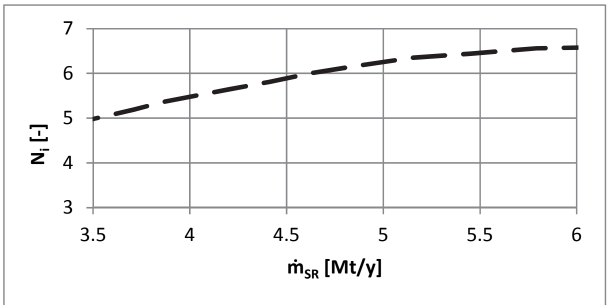

Figure 10: Average number of interruptions during ship unloading for the FIFO+ operational procedure

5. CONCLUSION AND DISCUSSION

The FIFO and the FIFO+ operational procedures for stacker/reclaimers were evaluated. Using the FIFO procedure causes a large variation between the seaside and landside service rates. The maximum annual throughput for the stacker/reclaimer is then limited by the landside service rate while the seaside service rate exceeds the minimum required service rate. The landside service rate can be increased significantly by interrupting ship unloading while still guaranteeing the ship's service rate. This procedure was called FIFO+. Results for a specific case showed that the annual throughput for a stacker/reclaimer can be increased with 24% from 4.6 until 5.7 [Mt/y] while the minimum predefined service rates were still realized. The FIFO+ operational procedure enables terminal operators to serve clients at the landside better which will made these terminals more attractive. However, ship unloading must be interrupted 6.5 times on average per bulk carrier to realize this improvement, which requires more effort of the terminal operator.

It was assumed that switching from a seaside job to a landside job for the stacker/reclaimer does not take time. However, practical data showed that the belt conveyors, which are connected to the stacker/reclaimer, have to run empty for approximate fifteen minutes to prevent contamination between the different bulk materials. During these fifteen minutes the machine needs to be repositioned as well. When this aspect will be considered, the possible improvement for the FIFO+ operational procedure will be decreased slightly.

ACKNOWLEDGMENTS

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DESIGN OF THE SEEWOP SOFTWARE PROTOTYPE

Thomas Kern[(a)], Tanja Peschetz[(b)], Gerald Petz[(c)]

[(a,b)] University of Applied Sciences Upper Austria, School of Informatics/Communications/Media,
Softwarepark 11, A-4232 Hagenberg, AUSTRIA
[(c)] University of Applied Sciences Upper Austria, School of Management,
Wehrgrabengasse 1-3, A-4400 Steyr, AUSTRIA

[(a)] thomas.kern@fh-hagenberg.at, [(b)] tanja.peschetz@students.fh-hagenberg.at, [(c)] gerald.petz@fh-steyr.at

ABSTRACT

E-mobility in the sense of virtual mobility – the performance of tasks via electronic networks by so-called e-workers – reduces the necessity to commute physically to a workplace. It represents a working method, from which both companies and employees expect benefit in terms of flexibility, productivity and cost. Existing micro-job platforms already offer an easy possibility to tender small work assignments via social-web in order to be processed by an e-worker community. However, dealing with complex task settings is difficult. In this paper we describe the prototype of the Semantically Enriched E-Working Platform (SEEWOP) which enhances the capabilities of an existing micro-job-platform by Event-driven Process Chains (EPC) and Semantic Web Technologies for the design of business processes and the automatic division of tasks within the e-worker community.

Keywords: e-mobility, e-work, crowdsourcing, semantic web, Event-driven Process Chains

1. INTRODUCTION

E-working platforms can be used as an efficient method for enterprises to support the management and execution of tasks over the Internet. They can be very useful in order to improve communication and increase working efficiency between companies (requesters) and their employees (as e-workers). The biggest challenge for requesters is to divide complex workflows into separate *Human Intelligence Tasks (HITs)* so that they can be distributed and processed through the crowdsourcing system. Especially workflows, which often have to be performed in a similar, but infrequently in the same way within a company – e.g., the creation of a monthly advertising catalogue for a company by commercial graphic designers – cannot yet be assigned via crowdsourcing, because of the fact that the effort to define, manage and control the HITs and the merging of the individual results would be too big (Kern and Petz 2012). Therefore, the *Semantically Enriched E-Working Platform (SEEWOP)* is in development, combining a classic Web 2.0 micro-job platform with Semantic Web Technologies to provide a novel method of intelligent e-work management.

The actual development step of the SEEWOP prototype presented in this paper provides the ability to model business processes as ontologies to be used as templates for generating HITs within a micro-job platform automatically. It simplifies the distribution and management of tasks as well as the management of e-workers.

2. STATE OF THE ART

2.1. Micro-Job Platforms

Similar to the job-marketplace *Amazon Mechanical Turk* described in (Kern and Petz 2012) the micro-job platform *Klickwork* (http://www.klickwork.com) allows its clients (requesters) to tender small jobs (HITs) and process them via a user-friendly web platform (see Figure 1). Requesters can determine the amount of work, set prices, and check the results to approve them. Additionally, each job is provided with a number of points for payment (corresponding to the effort) and a deadline.

Figure 1: Klickwork Website in German.

E-workers can select from a list of offers and apply for a job according to their interests and talents. After surcharge the job can be processed by the selected e-workers and finally, after completion, the results can be submitted via the platform. After approval by the requester payment is initiated.

Typical areas of application are digitally producible services like online marketing, viral marketing, internet information retrieval, copywriting, market and competitive studies, data analysis and other small jobs (CYBERhouse 2013). As part of our research collaboration with Cyberhouse Ltd. we use this platform as a test front end for SEEWOP.

2.2. Event-driven Process Chains

An *Event-driven Process Chain (EPC)* is a modelling language which can be used to describe business processes and workflows (ARIS 2013). This semi-formal graphical representation is commonly used in modelling frameworks – e.g., Architecture of Integrated Information Systems (ARIS) – or as a component in enterprise resource planning (ERP) systems – e.g., SAP R/3.

2.3. Web Ontology Language (OWL)

The *Web Ontology Language (OWL)* is specified by the *World Wide Web Consortium (W3C)* to create, publish and distribute ontologies based on a formal description language that even software is able to understand and process the meaning of concepts and their relationships among themselves (World Wide Web Consortium 2013d). It extends the *Resource Description Framework (RDF)* which enables the description of (true) statements about resources in the form of a directed graph and *RDF Schema (RDFS)* which provides a basic vocabulary for RDF.

3. REQUIREMENTS

Currently only small tasks can be distributed and processed easily via micro-job platforms. To provide a solution for complex tasks it is intended to enrich these platforms with EPCs.

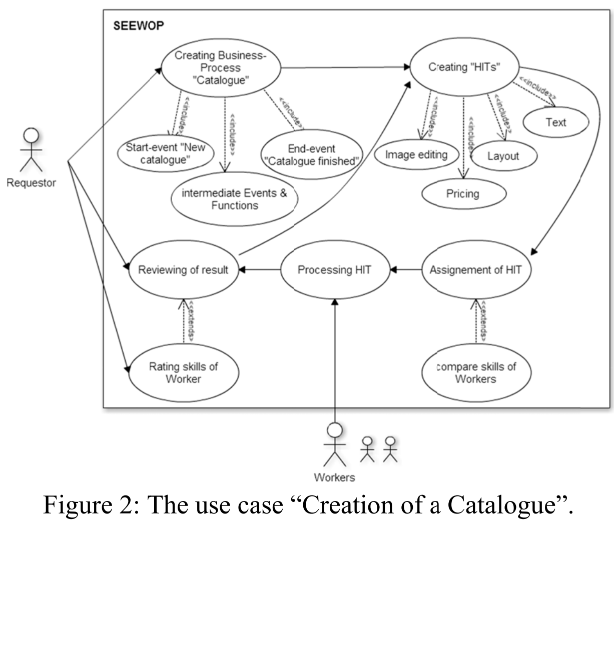

Figure 2: The use case “Creation of a Catalogue”.

The main idea is to generate HITs within an e-working platform no longer by (the requester’s) hand but automatically on demand based on a previously modelled common EPC-workflow description according to the respective actual parameters, process-states, events and results. To show the required functionality of the SEEWOP prototype a very simple use case named “Creation of a Catalogue” is shown in Figure 2.

1. *Business process creation:* The requestor once models a new business process which defines the common way of creating a catalogue according to the rules of the EPCs. This model is stored in the SEEWOP system and serves as template for future process instances.
2. *Business process instantiation:* To start a new catalogue project, the requestor selects a suitable process template and instantiates the process. After parameterizing, the process can be started.
3. *Business process consistency check:* According to entailment rules defined in RDF/OWL and ontology constraints SEEWOP checks the business process model for validity.
4. *Task generation:* SEEWOP begins to work off the business process by creating the first HITs based on the defined business process. For navigation through the control flow user-defined rules are evaluated by a reasoner.
5. *Task distribution:* The generated HITs are distributed to a selected micro-job platform automatically.
6. *Task processing:* The e-workers select and work up the HITs as usual within the micro-job platform and return the results. According to these results and the actual state within the business process new HITs are generated iteratively (step 3) until the end of the process.
7. *Enhanced functionality:* The use case also shows some possibilities of functional enhancements like the assignment of tasks to suitable skilled workers or rating the quality of working results.

3.1. The EPC Ontology

The fact that EPCs commonly just provide a semi-formal graphical representation of business processes results in a lack of processability by machines. Therefore as a first step a machine-interpretable representation – an ontology – for EPCs has to be developed.

The EPC Ontology explicitly specifies the concepts, their properties, and the necessary constraints to enable the modelling of valid EPCs in OWL. This formal semantic description and additional rules enable the SEEWOP-prototype to reason new facts by an inference mechanism at query time.

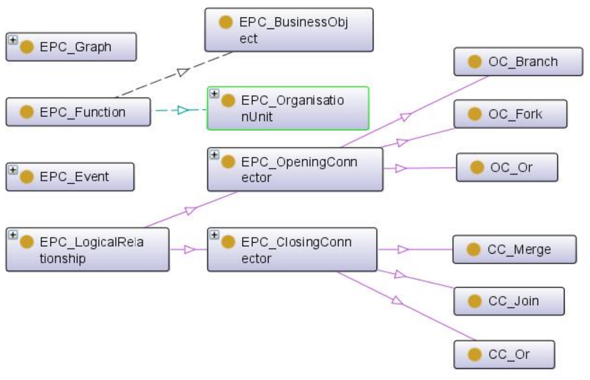

Figure 3: EPC Ontology Key Concepts.

The semantics of the key concepts shown in the simplified diagram in Figure 3 are:

- *EPC_Graph:* An EPC graph consists of finite sets of EPC elements. It starts and ends with an event.
- *EPC_Element:* Elements within an EPC graph are functions, events and logical connectors.
- *EPC_Event:* Events are passive elements in EPC. An event is a state occurring before or after a function.
- *EPC_Function:* Functions are active elements in EPC. A function is an action or task that follows an event.
- *EPC_OpeningConnector:* Opening connectors are used for logical relationships like "Branch", "Fork" and "OR". They may have one incoming and two or more outgoing control flows. A "Branch" is symbolized by an opening XOR connector. Depending on a condition exactly one of the outgoing control flows is activated. It is closed by a "Merge". A "Fork" is represented by an opening AND activating all outgoing control flows concurrently if the condition is fulfilled. It is closed by a "Join". An "OR" relation activates one or more outgoing control flows depending on the condition.
- *EPC_ClosingConnector:* Closing connectors are the corresponding counterparts of the logical relations described above and are also represented by the symbols XOR (for "Merge"), AND (for "JOIN") and OR. They may have two or more incoming and one outgoing control flow.
- *EPC_BusinessObject:* Business objects hold input or output data of functions.
- *EPC_OrganisationUnit:* Organisation units determine responsible persons or departments for a specific function.

4. SEEWOP SYSTEM DESIGN

The SEEWOP system design shown in Figure 4 consists of three layers based on the Semantic Web framework *Jena*.

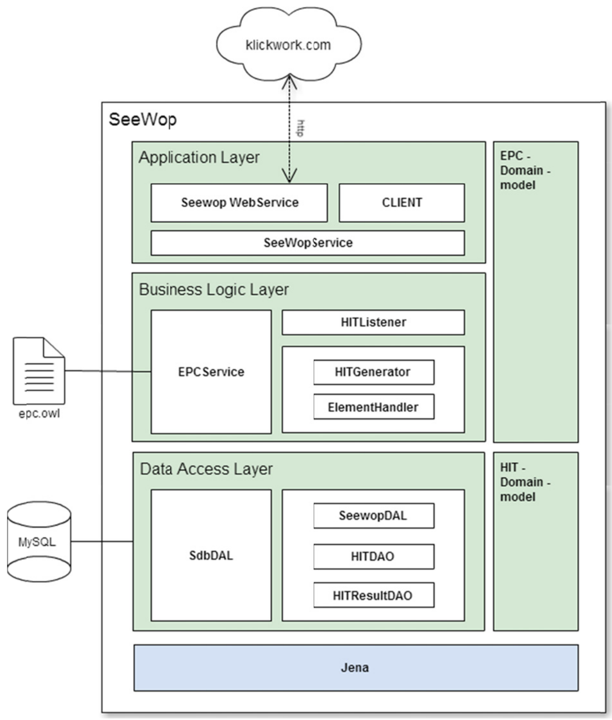

Figure 4: SEEWOP System Design.

4.1. Jena

Jena is a Java-based framework for the development with Semantic Web Technologies (Apache 2013a). It includes an API for reading, processing and writing RDF data, an API for handling OWL and RDF(S) ontologies (World Wide Web Consortium 2013d, 2013a), an inference engine for reasoning with RDF, OWL sources and Semantic Web Rule Language (SWRL) rules (World Wide Web Consortium 2013c), a data store for storing RDFS/OWL graphs, and a SPARQL query engine (World Wide Web Consortium 2013b).

4.2. Data Access Layer

The *Data Access Layer* enables the persistent storage of business processes and HITs and holds the underlying domain models.

- *EPC-Domain model:* This domain model describes all elements of the Event-driven Process Chains as domain objects.

- *HIT-Domain model:* The domain objects *HIT* and *HITResult* are representations of a Human Intelligence Task and their results with their corresponding properties. HITState currently defines the valid states of a HIT as "UNFINISHED" or "FINISHED".

The *SEEWOP Data Access Layer (SeewopDAL)* is responsible for storing and updating the domain objects HITs and HITResult (HITDAO and HITResultDAO). For realising the SeewopDAL the Java Persistence API (JPA) has been used. The JPA is a framework to bind relational databases in Java-based applications.

The generated business processes of the SEEWOP platform are represented as RDF graphs. For storing these graphs in the SQL Database the *Data Access Layer (SdbDAL)* uses the Triple Store *SQL Database (SDB)*. This Triple Store maps all triples of an RDF graph to a relational database and is provided by Jena for enabling the construction of persistent Jena models. An SDB store can be accessed and managed via command line scripts or the Jena API (Apache 2013b).

4.3. Business Logic Layer

The *Business Logic Layer* provides services for modelling and processing business processes. It is responsible for the generation of HITs at runtime.

The *Event-driven Process Chain Service (EPCService)* is responsible for all services which are dedicated to the modeling of business processes. These functions are:

- modeling of business processes based on the ontology Event-driven Process Chains,
- instantiation of business processes with concrete values (so called Individuals),
- adding SWRL Rules to concrete business processes,
- consistency check of produced business process ontologies, and
- storage of business processes.

The *HIT-Generator* creates HITs at runtime based on a given instantiated business process. Whenever an element of the type "Function" occurs in the process a HIT will be generated out of the information of the function. Visited elements of the type "Event" are added to the progress list of the workflow. For special logical connectors like a branch, a join, or a merge the *HIT-Generator* delegates to the *Element-Handler*. Figure 5 shows the generation of tasks out of an instantiated order process at runtime.

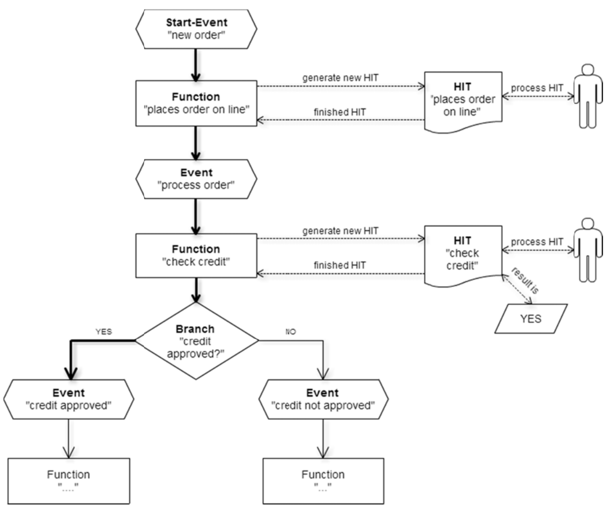

Figure 5: Functionality of the HIT-Generator.

All logical connectors are processed by the *Element-Handler*. If a SWRL-Rule is added to a connector, it will be evaluated and the inferred result will be stored in the knowledge base as new fact. According to these new facts the *Element-Handler* can return the next element to be processed by the *HIT-Generator*. As described in section 3.1 the connectors are categorised in opening and closing connectors for various logical relationships (shown in Figures 6a and 6b).

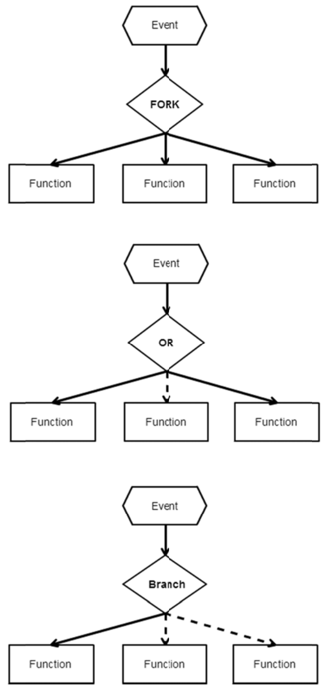

Figure 6a: Opening Connector types.

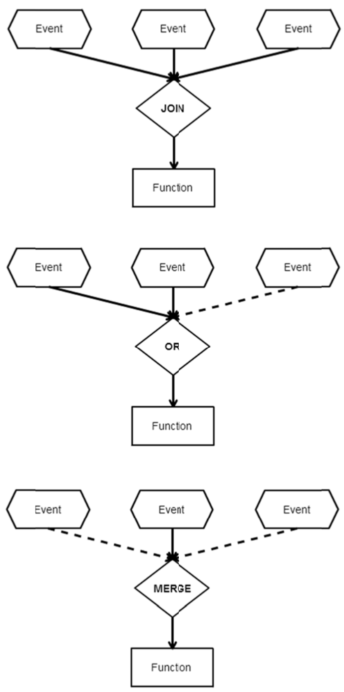

Figure 6b: Closing Connector types.

The *HIT-Listener* reacts to changes of HITs (see Figure 7). Depending on the modifications of the HIT the *HIT-Listener* delegates to other components which process the HITs. Currently the *HIT-Listener* only communicates with the *HIT-Generator* . If the state of a HIT changes to FINISHED, the Listener informs the *HIT-Generator* for processing the next elements of the business process chain and creates new HITs.

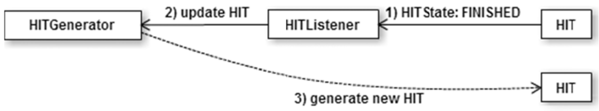

Figure 7: Functionality of the HIT-Listener.

4.4. Application Layer

The *Application Layer* includes all necessary functions for clients. The *Seewop Service* is the interface between the Business and Application Layer. It combines all necessary functionality for clients and web services out of the features from the *EPC-Controller* and *HIT-Listener*. These include above all the modelling, storing, instantiating, and consistency checking of business processes. Figure 8 shows a first implementation of the web-based SEEWOP user interface.

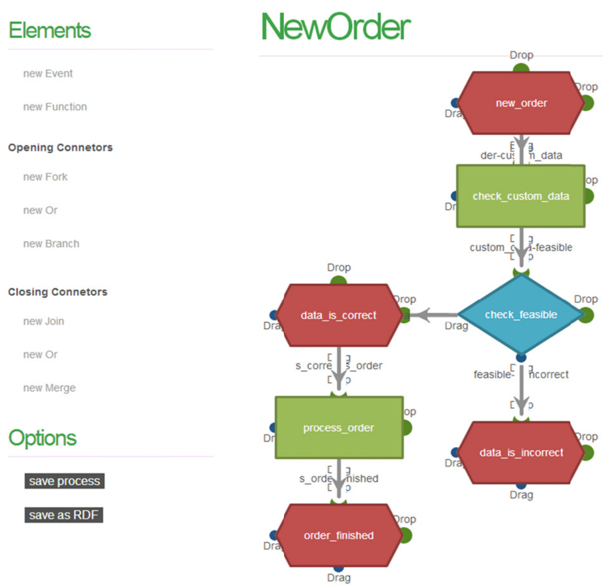

Figure 8: SEEWOP GUI for business processes.

The *SEEWOP-Web-Service* makes the SEEWOP features available for web-based clients such as the Micro-Job platform klickwork.com. It can get new HITs and stores the retrieved information. Afterwards, it is possible to process the HITs and inform the prototype SEEWOP about updates.

5. SUMMARY

The paper describes the design and architecture of the SEEWOP platform. It states the use of ontologies for describing business processes and individuals. By the integration of SWRL rules and inference it is possible to generate new facts. The prototype can use this knowledge to generate HITs at runtime and distribute it to workers. The aim of SEEWOP is to provide an intelligent task manager based on the knowledge of business processes. The prototype e-working platform simplifies the distribution and management of tasks, as well as the management of e-workers.

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AUTHORS BIOGRAPHY

Thomas Kern is head of the Research Center Hagenberg, School of Informatics, Communications and Media, University of Applied Sciences Upper Austria. In this research facility approximately 40 R&D projects per year are carried out in the following three research areas Software Technologies and Applications, Information and Communication Systems, and Media and Knowledge Technologies. He finished his studies in Software Engineering in 1998. After industrial work experience he started as research associate and lecturer for the University of Applied Sciences Upper Austria in autumn 2000. Since 2003 he conducted several application oriented R&D projects in the fields of Bioinformatics and Software Engineering focused on design and implementation of knowledge-based systems. Since 2010 he is member of the 4EMOBILITY research project.

Tanja Peschetz is currently a student in the master degree programme “Software Engineering” at the University of Applied Sciences Upper Austria in Hagenberg. She finished her Bachelor degree in “Software Engineering” at the same University in 2011. Tanja Peschetz works for the R&D project SEEWOP and has implemented the first prototype.

Gerald Petz is director of the degree course “Marketing and Electronic Business” at the University of Applied Sciences in Upper Austria, School of Management in Steyr. His main research areas are Web 2.0, electronic business, electronic marketing and opinion mining; he has also conducted several R&D projects in these research fields. Before starting his academic career he was project manager and CEO of an internet company.

A SIMULATION TOOL FOR MAINTENANCE PROCESSES OF OFFSHORE WIND FARMS

Philip Joschko[(a)], Andi H. Widok[(a, b)], Bernd Page[(a)]

[(a)] University of Hamburg, Dept. of Informatics, Modeling and Simulation, Vogt-KöllnStr. 30, D-22527 Hamburg
[(b)] HTW Berlin, Wilhelminenhof Str. 75A, D-12549 Berlin, Germany

[(a)]joschko@informatik.uni-hamburg.de, page@informatik.uni-hamburg.de[(b)]a.widok@htw-berlin.de,

ABSTRACT
This paper provides an overview over the technical development of a software suite, designed to visualize, connect and simulate relevant processes of the operation and maintenance of offshore wind farms and combine them with other relevant factors, such as for example stochastic weather generators and other wind farm proprietary aspects important to the smooth running of offshore wind farms.

The complexity of relevant factors for the assessment of the quality of offshore wind farms operation only allows for an overview on how to model and assess that quality as a whole. In that regard, this paper will mainly focus on the technical development and the different stages of depicting and analyzing, from the understanding of relevant players, to the interaction between those, the modeling of complex interactions to the visualization in a software and simulation of business processes. In addition, the choices made for different methodologies, such as the business process notation BPMN 2.0, or simulation relevant techniques will be presented, including the given reasons for the choices made.

Keywords: Business Process Simulation, BPMN 2.0, Offshore Wind farms, Meta Modeling

1. INTRODUCTION

After the successful realization of initial offshore wind farms such as Alpha Ventus (Germany), Horns Rev (Denmark), and Thanet (UK), numerous offshore wind projects worldwide are either in the planning phase or already at the construction stage (Klinke, Klarmann & Kodali 2012).

While the onshore wind energy technology has seen a ten-fold reduction in cost over the last two decades and is now competitive with fossil and nuclear energy in many areas worldwide (Musial, Butterfield & Ram 2006), the offshore wind energy branch is still in its early stages, especially as long term projections considering the higher costs for maintenance and servicing are only achieving scientific significance. Nonetheless, there is a broad consensus about their key role in achieving the climate policy targets and the associated energy turnaround (especially for Germany). The absence of suitable locations for large onshore wind farms and the possible higher output offshore is contributing to this fact. The goal of the German Government is to produce approx. 25.000 MW output through offshore wind farms by 2030, which is more than all German nuclear power plants are currently producing. Considering the whole European Union a similar rise in power production can be expected - from approx. 1.400 produced MW in 2009 (see Figure 1) to approx. 37.000 MW produced by the end of 2015 (Figure 2).

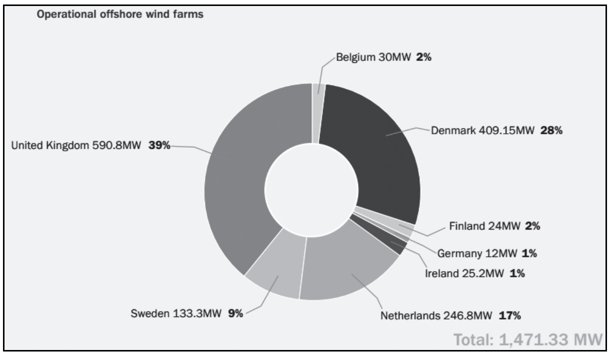

Figure 1: Operational wind farms 2009 (EWEA 2009)

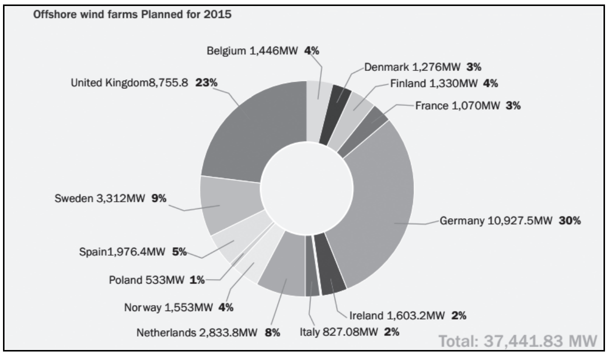

Figure 2: Planed wind farms for 2015 (EWEA 2009)

Most of those newly planned offshore wind farms, at least for Germany, will be located much further out compared to the "near shore" farms from Denmark. This poses new challenges regarding accessibility and the planning of maintenance. Financiers of new wind farms are typically interested in the expected aggregated mean wind energy yield for a future operating period (usually 10–20 years) (Albers 2004; Bakker & van den Hurk 2011), due to the experience from existing installations however, the costs and the amount of uncertainties related to the maintenance processes gain more and more relevance. The decisive factor for the success of these and future offshore wind farms is hence to effectively address the technical challenges and ensure economic feasibility (Klinke, Klarmann & Kodali 2012).

The following sections address the outlined challenges in presenting the project SystOp Offshore wind, which main aim is to analyze relevant process and players, as well as build a software suite for the modeling and simulation of the smooth operation of offshore wind farms.

2. PROJECT SYSTOP OFFSHORE WIND

2.1. Objectives and Partners

The project SystOp Offshore Wind is a three-year joint project financed by the German federal ministry of the environment (support code: 0325283), nature conservation and nuclear safety. It is conducted by the University of Applied Science in Bremen, the University of Hamburg, as well as the BTC AG, and the IZP Dresden. The first objective of the project is to map the relevant players and research their interaction, including the capturing of all resulting business processes that have an influence on the continuous smooth running of all needed maintenance activities of offshore wind farms (Joschko et Al. 2013).

2.2. Data Acquisition and Process Mapping

The capturing of the business processes in question was done on different levels (Figure 3) and subsequently in different detail. Level 1 includes the different (project-) phases of an entire offshore wind park, whereas SystOp Offshore Wind considers the particular case of the operation phase more precisely the execution process of the maintenance.

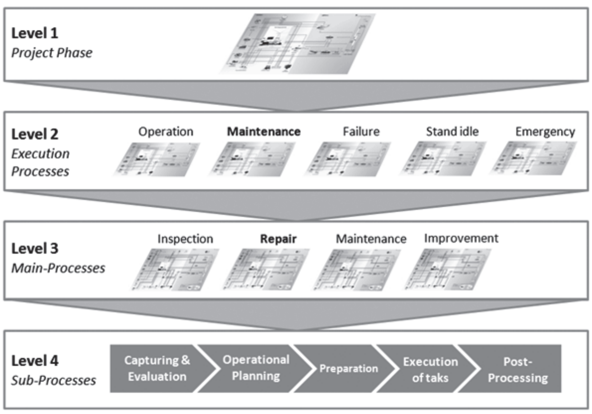

Figure 3: Process levels of SystOp Offshore Wind (Joschko et Al. 2013)

All execution processes corresponding to the operation phase are specified in level 2. They are interconnected and interdependent within the accordant phase. The next hierarchy of processes is shown in level 3 these are the main processes, which do not proceed in a chronological-logical sequence. The sub-processes in level 4 however do occur in a chronological and consequential progression; in case of a maintenance operation these are capturing & evaluation, planning and others. Different subdivisions in further levels below enable a more detailed description of the main and the sub-processes.

In order to gain access to the process in question several market players out of the wind park sector were contacted, such as operators, service companies, owners, transport companies, harbors, airports and employment companies. Some of them contractually agreed to give insight into their perspective of business processes, their resources and their data. A questionnaire was designed including general questions about tasks, resources and typical problems, which provided a substantiated code of practice to describe the project demand for all participants. In successive on-site visits the understanding of the individual business processes, with a focus on interfaces to other stakeholders, was intensified. This included reviews of the already depicted processes with stakeholders over different meetings, regularly workshops and meetings with all industry partners to discuss intermediate results.

Following the description of the processes, they were analyzed in order to deduce critical elements, such as resources or influences on other processes including feedback loops. The main purpose of the processes depiction was to establish an objective basis for communication between the partners that further enabled and evaluated the importance of different stages as well as critical aspects that should be taken under special observation. The different levels of communication and layers of cooperation were thus made more transparent, enabling a higher security considering long term planning and projections.

2.3. Approach for the Modeling and Simulation

The modeling and simulation of the operation of offshore wind farms in this project can be understood bipolar, as the software is, on the one hand able to run already established business process simulation, and on the other hand, in combination with different additional software packages, go beyond their limitations. In order to have a broader approach and pay tribute to the different uncertainties different editors were designed (as section 3 will elaborate), such as wind turbine and component builders that would, placed in a wind farm model and enriched with the appropriate probabilities then start events, which only then start different business processes and, again in dependence on other models have different possible outcomes. In that regard a multitude of different software tools have been connected to allow for the simulation of a continuous operation of different wind farms.

3. BUILDING A SOFTWARE SUITE FOR THE MODELING AND SIMULATION OF THE OPERATION OF OFFSHORE WINDFARMS

3.1. Overview
The design of the software in question was made following a domain specific approach including a multitude of different software packages (see Figure 4).

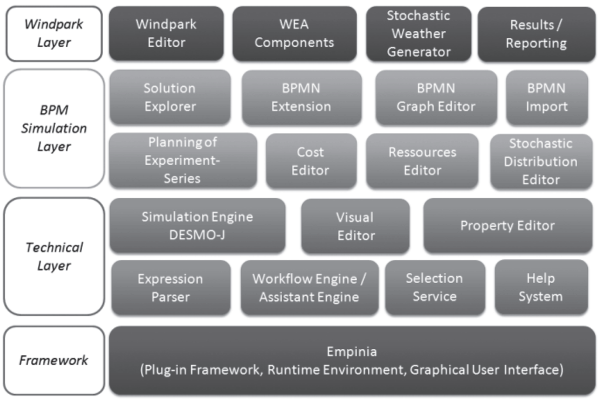

Figure 4: Domains and Services of the main Application

There are four main conceptual layers of the software; the first and the second building the technical backbone(s) as the first layer is the framework enabling the different parts to interact via a plugin mechanism (see section 3.3.1), while the second layer encompassed the simulation engine and other helping systems allowing for the different parts to work efficiently together. The third layer is the process simulation layer, which enables the actual description of the business processes, as well as their interaction and aspects like import/export functionalities of existing business processes. The fourth layer is the wind farm layer, which allows the modeling of different wind farms, including the actual components and their probabilities of failure within the different turbines, as well as additional information considering location and accessibility. The different parts will be further explained in the following sections.

3.2. Scope of Services

3.2.1. Business Process Modeling and Simulation
To document the sequential activities and interactions, the Business Process Model and Notation (BPMN) 2.0 was chosen, which represents a sufficiently formalized graphical notation for business processes. BPMN 2.0 brings out the differentiation of sequence flows, which describe the order of activities within the processes of an organizational unit, and message flows, which describe the interaction between processes of distinct organization units. This aspect contributes to the main focus of the project in order to discover interactions between the stakeholders. The message flows can represent material, data, communication, waste or cash flows. Additionally, there is a huge set of elements, which cover diverse modeling constructs, e.g. there are different kinds of events, particularly attached events, which are able to abort the execution of an activity.

Figure 5 shows an example of a process modeled in BPMN 2.0, which describes the execution of maintenance jobs. The three pools represent the different stakeholder operation office, service units and the carrying businesses shipping respectively helicopter companies. The edges between the pools represent message flows, e.g. the service unit updates the operation office about each single step of the operation as they are starting maintenance, identifying errors, estimated duration, abortive or successful maintenance. While rectangles represent single activities or sub-processes, circles represent events such as a start respectively end occasion, incoming direct messages, broadcast messages, cancelation or compensation.

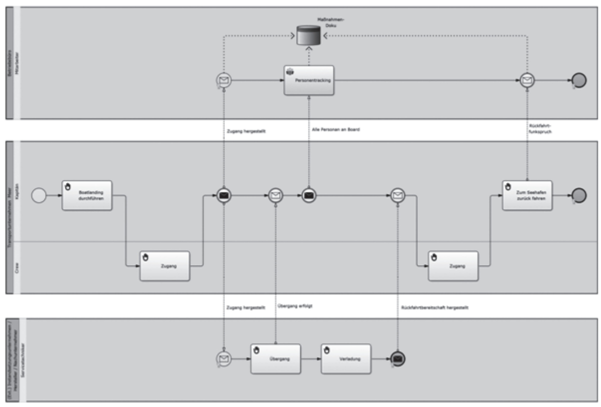

Figure 5: Return after a maintenance job in BPMN 2.0

Additionally to the BPMN process description there are different other tools within the BPMN Simulation layer, such as an editor enabling the setup of resources, which can be used in the simulation to analyze degree of capacity utilization, and attributed necessary probabilities, as well as be responsible for possible bottleneck scenarios. Furthermore there is an editor for choice and usage of different stochastic distribution needed, which includes the possibility of describing relations such as 1 to n connections or probabilities that different flows are chosen according to the distributions in question. Moreover other tools may be used to design and make BPMN 2.0 models which can be imported via XML import/export interfaces (while in accordance with the notifications).

In order to combine the different model types (BPMN just being one of them) a solution explorer was developed. It enables the user of adding different models in one solution, such as a number of BPMN models, wind farm models, generators and any other component each of those models are using without them being integrated within them.

Lastly a component was designed to facilitate a series of experiments integrated in a single simulation

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run, in order to speed up the achievement of well-established results.

3.2.2. Wind Farm Modeling

The modeling of wind farms in done on three different levels, namely the farm itself, its turbines and their respective components. These levels are manifested in the software by three different editors all accessible from each other. The main purpose is to allow for both, a simplistic approach for fast definition of a wind farm and, in case extensive data is accessible, to allow a detailed definition of the components and turbines in question, including their probabilities of failure.

The definition of wind turbines also allows the modeling of their respective energy output and hence allowing the depicting of the energy output of whole farms.

According to Karki and Patel (Karki &Patel 2009) the mathematical relationship between the wind speed V and the generated power P can be given as:

$$P = \begin{cases} 0, & \text{if } 0 \leq V < V_{ci} \\ P_r(a + b \cdot V + c \cdot V^2) & \text{if } V_{ci} \leq V < V_r \\ P_r, & \text{if } V_r \leq V < V_{co} \\ 0, & \text{if } V_{co} \leq V \end{cases}$$

where Pr is the rated power output of the wind turbine (Byon et Al. 2011). Following the elaborations from Byon et Al. the wind turbine editor was designed and is able to depict the actual power output in real time, once the necessary input data is given (Figure 6).

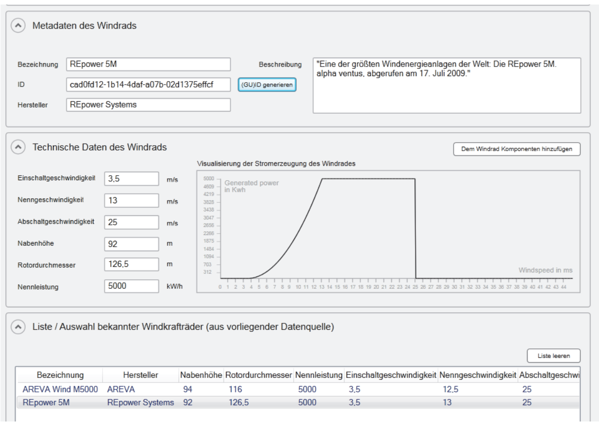

Figure 6: Wind turbine editor

The calculation of the power output is of course of great relevance for the calculation and prediction of the viability of maintenance processes at different times and different seasons, as the profitableness is logically in dependence of the wind speed, which again is within a measure of probability in accordance to different times of the year and different weather phenomena (see 3.2.2).

The wind turbine editor is hence used to connect the wind farm and the multi-model with data considering the power output, while the wind turbine component editor is used to describe the different components of a wind turbine, as for example rotor blades, brakes, generators or pitching systems. This includes meta-information, such as the manufacturer or the costs, as well as the probabilities in which occurrence the component is likely to fail and hence either reduce the power output of the wind turbine or render it completely inoperative. The precise technical and physical properties of each component (for example persistence of a component opposing the erosion due to weather and wave conditions) are not being modeled and are, at this point, not part of the simulation. The probability of failure can however be understood as the representation of the sum of conditions leading the component to failure, and hence include most or in the best case all of the relevant factors. The analysis if maintenance processes are required or if it would be more profitable to group, wait and reschedule them, wait for another event to occur, etc. can then follow such a failure event.

Lastly the wind farm editor is mainly an editor used to assemble different wind turbines and describe their position and Meta information, such as for example the longitude and latitude of the park, or even turbines. The positioning of the turbines has not yet been developed but is thought of to be implemented if demand is there. One can consider different scenarios where maintenance crews are going to stay out on sea for more time consuming work, the time needed to travel from one turbine to the next may become relevant in that regard.

3.2.3. Stochastic Weather Generator

As another main component in the wind farm layer, but autonomous domain implementation the stochastic weather generator is able to analyze data from historic sources (depending on the notation) and extract distributions from there, including, with the help of various different scientific sources, generated new sets of data in order to supply the simulation with realistic weather data.

In the past decade, much attention in the climate change researches has been focused on the potential impacts on temperature and precipitation. Recently, a growing number of studies have looked at potential impacts on renewable energy resources, and on wind power (Sailor et al., 2008). For example, it was found that wind power potential throughout Finland might increase by 2–10% under conditions of climate change Pryor (Pryor et al., 2005) has found that annual wind power potential over Northern Europe under the IPCC A2 and B2 scenarios was highly dependent on the boundary conditions used in Rossby Centre coupled Regional Climate Model (Yao et Al. 2012). Acknowledging these insecurities and different scenarios and realizing the necessity for adaptations in the future and a flexible model for possible weather scenarios different existing editors were sighted for their integration in the existing software suite.

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In the end the decision was made for different components of the CLIMA composite component. CLIMA is a software, made of basic components containing routines to produce synthetic values of the most relevant climate variables (precipitation, air temperature, solar radiation, vapor pressure deficit, wind speed, reference evaporation/-transpiration) from existing daily weather data, largely based on approaches already implemented in weather generators (e.g. ClimGen) and other data analysis tools (e.g. RadEst). Daily values of precipitation, air temperature, and wind speed are generated from stochastic processes. For other variables, such as solar radiation, vapor pressure deficit, and reference evaporation/-transpiration, synthetic values are produced by physically-based relationships. The routines for weather generation/estimation are implemented into sub-components: Rain (precipitation) AirT (air temperature), GSRad (global solar radiation and related variables), Wind (wind speed), ET (reference evaporation/-transpiration and related variables).The component implements the test of pre-conditions and post-conditions for each of the models provided, allowing an input on screen, TXT or XML file; custom output drivers can also be developed. Moreover, data sets used to perform unit tests on each of the models made available is also provided as part of this documentation (CRA 2005).

Even though there are newer approaches on how to access the wind speed and relevant information for long term projections of different weather scenarios (see Bakker & van den Hurk 2011 for example) the components were mainly used due to the easy integration in the existing software (same programming language, component orientated development approach), as well as the flexibility the software package enables. It already incorporates different calculating strategies and different approaches on how to calculate future weather scenarios and datasets, the extension of the software packages by new strategies and other distribution is hence given and made easy.

3.3. Connection of the different Model Types

The connection of the different sub-models was a great challenge due to the different nature of the BPMN, Wind farm proprietary and weather proprietary aspects. A general approach to combine the heterogenic models with BPMN process models was found. The BPMN notation offers a field (Extension Elements) where different kinds of information can be attributed to the element in question. Through this inherit property specific activities or events can be defined which can be attributed, replaced or connected to different model types. For example it is possible to create different kind of signal events, which can receive signals from wind farms (the models) and if the criteria are met, launch different processes, much as reality would be for a real supervising instance. In order to unlock the full potential of that combination slight adaptation to the BPMN 2.0 notation were made. Furthermore adaptations for the editor able to combine, and hence display and change BPMN 2.0 models with the wind farm proprietary elements, were done. Figure 7 displays a wind farm signal event that would be used to send a malfunctioning signal, as well as a wind farm state manipulation activity with which could rewind the process of a wind farm component. In addition, a weather signal can be used to announce changes of weather conditions and there is the possibility to receive weather proprietary information on a gateway and let those influence the actual way the process would take. For example a change of weather conditions can influence the decision if a ship or a helicopter would be taken, or if the maintenance process can happen at all.

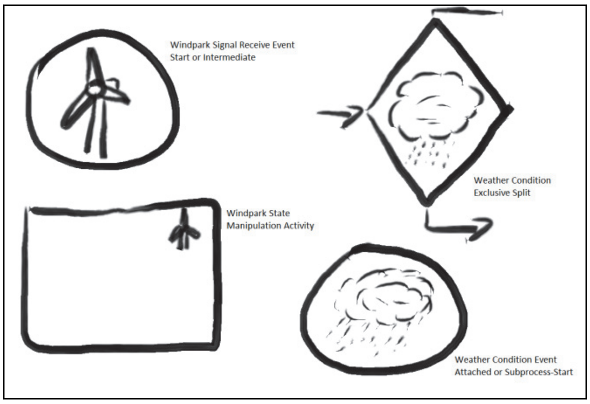

Figure 7: Domain specific BPMN extensions

The newly developed BPMN editor allows for the integration of such domain specific elements through especially designed extension points. Apart from the visual representation of the entities, the code requires a class that is contributing an instance of the domain specific sub model and creates the necessary references between the sub model instance and the BPMN processes.

3.4. Technical Basis of the Software

3.4.1. Framework EMPINIA

As software-framework the software EMPINIA was used, which is an open-source plugin-framework specially designed for rapid component-orientated domain-specific application development. It is based on .NET Technology and notably C# as programming language. EMPINIA is freely available under http://www.empinia.org. EMPINIA supports rapid application development with a highly extensible RCP, like Eclipse (http://www.eclipse.org), based on the Microsoft .NET technology.

The main function of the EMPINIA framework is to offer a plugin mechanism where developers can add any kind of extension. An extension is always added to an existing extension point. Extensions themselves can be further extended if they define their own extension points. EMPINIA provides modules for designing an application with graphical user interface (GUI) and other standard software components (such as the graph editor and the property editor) (Jahr, Schiemann, Wohlgemuth 2010).

The usage of this framework enabled the concentration on the specific problem domain instead of doing repetitive software developing tasks, such as persistence, logging, application and user settings, message notification and user interface design. Many components as different visual editors or selection services were already integrated and ready to use.

3.4.2. Simulation Engine DESMO-J

As simulation engine DESMO-J was used. DESMO-J (see http://desmoj.sourceforge.net/) is an object-oriented framework, targeted at programmers developing simulation models. The choice was made as DESMO-J supports both, the process-oriented and the event-oriented modeling style, also known as process-interaction approach or event-scheduling approach, respectively, which contributed to the development of different model/domain types.

By integrating the mentioned DESMO-J engine, and adjusting it to work with the modeled business processes, critical system sections could already be tested and information on running times were delivered, as well as waiting periods, identification of non-valid modeling, i.e. errors in the modeling process itself considering the depicted business processes.

4. EXPERIMENTATION AND RESULTS

4.1. Beginning of the Experimentation Phase

As with most simulation projects the data basis is an ongoing challenge, even though, due to the well established connection with partners in the wind farm industry and consulting industry related to offshore projects, the data considering the runtime of activities is looking promising, the data basis for the costs is currently still posing problems.

The experimentation phase is, due to the early stage of the project, only at the beginning, but first simulation runs were made and are expected to continuously take a greater part of the ongoing research. The current verification process is still reduced to the BPMN models, as the connections to the different sub models is not yet fully operational, or rather, its data cannot yet be verified.

4.2. Provisional Results

Without the connection of the sub models, different modeling errors in the existing processes could already be identified. This includes, among syntactic errors, also hard to find deadlocks (at which for example a process would wait for a message from another process without chance of ever getting it, as the process in question already terminated).

At this moment in the project, apart from the continuous development, the work is being shifted to control all known processes that have a stable data basis considering the runtime of activities and enrich their gateways with the concrete requirements for the decision making process.

4.3. Expected Results

Through the connection with the sub models a well defined load can be put on the O&M processes. In that regard results can be (and are particularly already) created considering the frequency of the processes as well as the runtime and resource usage of the processes. In light of these results the plausibility of the processes can be verified.

For an effective maintenance strategy a sound aggregation of work assignments is mandatory, for example needed repair work can be timed in accordance with close, already scheduled, regularly maintenance assignments. Such an aggregation happens currently in many cases in accordance with the logic of the deciding personal, but is, in most cases, not the result of a wind farm spanning simulation output. This aggregation of possible work assignments is an important, yet to be accomplished task in the underlying project. It is expected that, once this feature has been developed, different maintenance strategies (corrective, preventive, state/condition based) can be compared and proactive recommendations can be deduced. The planning for this feature is to have first presentable approaches by the middle of 2014, including the tested implementation.

5. CONCLUSION

One year before the project SystOp Offshore Wind is ending first results become presentable; it was managed to gather large amounts of process models of O&M-practices from actual existing performances. These models were depicted with aid of the BPMN 2.0 notation and in order to simulate them, a software suite was developed that is not only able to represent and simulate the BPMN models but also combine them with domain specific sub models in order to represent the reality of an operating offshore wind farm and needed (or existing) maintenance processes. The notation was therefore expanded with a few new components.

The simulation can already indentify syntactic modeling errors as well as critical deadlock situations. The data basis however is still lacking, due to the fact that data for the costs of different activities is rarely made public and even the involved industry partners do not always want to share this kind of sensible data. Yet, the basis is sufficient for first plausibility tests considering the runtime and frequency of tasks. The results from such tests are continuously being discussed with experts from the offshore industry or consulting partners. Once that this phase of testing and adjusting will finish, a strategy comparison by means of aggregation of different maintenance tasks is scheduled as next phase.

The simulation software was designed in a way to allow for high flexibility and an easy integration of different domains. In that regard work is intensified considering the creation of new extensions of BPMN-models (and notation expansions), especially for the logistic sector, which will be usable for coming operational scenarios not only in the offshore wind farm sector. The persistence level was meant to pay tribute to the high flexibility and is hence completely based on XML, allowing for different strategies and adaptations in the future.

Additionally the usage of the software is discussed as support for the decision making in the operational phase of existing wind farms. While the software is currently primarily envisioned to be a safeguard and verification tool of existing process models, it is possible and likely that the focus will shift to a tool which can support maintenance strategy decision-making in the future.

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AUTHORS BIOGRAPHY

ANDI H. WIDOK studied Industrial Environmental Computer Science at the HTW Berlin, University of Applied Sciences. He holds a (M.Sc.) degree in Industrial Environmental Computer Science and works as a research assistant at the HTW Berlin. In 2011 he became a PhD student of the University of Hamburg and started working on the project SystOp at the University of Hamburg in 2012. His research interests are mainly sustainability theory and its applications in computer simulations, cooperative model building, and sustainable software development for organizations. His email is <a.widok@htw-berlin.de>.

PHILIP JOSCHKO studied Computer Science at the University of Hamburg. He holds a diploma (M.Sc.) degree in Computer Science and works as a research assistant and PhD student at the department of informatics at the University of Hamburg. His research interests are business process modeling, business process simulation and discrete event simulation. His email is <joschko@informatik.uni-hamburg.de>.

BERND PAGE holds degrees in Applied Computer Science from the Technical University of Berlin, Germany, and from Stanford University, USA. As professor for Applied Computer Science at the University of Hamburg he researches and teaches in the field of Computer Simulation as well as in Environmental Informatics. His email is <page@informatik.uni-hamburg.de>.

SHIP DAMAGE CONTROL ACTION SIMULATION USING HLA

Paulo T. Martins [a], Rosaldo J. F. Rossetti [b], António Carvalho Brito [c],

[a] [b] [c] Faculty of Engineering of the University of Porto
[a]Centro de Investigação Naval, Portuguese Navy

[a]deg11010@fe.up.pt, [b] rossetti@fe.up.pt, [c]acbrito@fe.up.pt

ABSTRACT

This work discusses on the simulation of a ship crew reaction in controlling damage in a single watertight compartment, taking into account ship's hydrostatics and equipment limitation. Three different simulators were built which exchange data using High Level Architecture concepts, implemented with an open source RTI called CERTI and a MatlabHLA Tollbox.

Keywords: Ship Simulation, High Level Architecture, Discrete Event-Oriented Model, Damaged Ship, Ship Human Factors

1. INTRODUCTION

Large ships are complex "hard systems" that rely on their crew and their interactions with machinery and equipment, to navigate independently through water, while performing the roles for which they were built, such as: fishing, freight transport, entertaining passengers, scientific research, and force projection.

In any case, Human Factors (meaning all issues related to personnel) have large impact on the fulfillment of any vessel operational roles. In particular, personnel movement on board has a major influence on operability, time reaction and efficiency, which in turn is strongly related to the ship's architecture and the knowledge one has (Andrews, Galea, et al. 2008). Nonetheless, crew performance is also affected by the ship's hydrostatic behavior and the way the ship responds to wave excitations (seaworthiness) (Rawson and Tupper 2001, O'Halon and McCauley 1974). In case of an accident, there are other variables that may affect crew's performance, namely smoke spread, ship inclination and many others (Gwyne, Galea, et al. 2003, Gwyne, Galea, et al. 2001, Ginnis, Kostas, et al. 2010).

Ship's operation and survivability in case of damage are also affected by her equipment layout, equipment redundancy, and the paths of the auxiliary systems (electrical cabling, ventilation conduits, water refrigeration pipes, etc). Yet, some of these equipment are vital to the ship's operation and/ or survivability, such as radars, propulsion plants, communication systems, and if broken they must be fixed, whatever the situation, normal operation or damage (Simões-Marques and Pires 2003).

The aim of this work is to present a first approach to crew's performance simulation in case a single watertight compartment is damaged, and analyzing how the ship's architecture may affect it. We are interested in simulating the damage, checking the ship's hydrostatic response in case of flood (inclination), and crew's movement on getting to the damaged area. In fact, these are two very different models and therefore we used High Level Architecture (HLA) concept (Defense Modelling and Simulation Office 1998, IEEE Standard 1516 2010) in building a federation formed up of three different federates: i) damage generation; ii) ship hydrostatic response; iii) damage control teams movement and equipment analysis. To implement it we used an open source Run Time Infrastructure (RTI) called CERTI (Siron, Noulard and Rousselot, 2009) to serve as middleware. To build up federates, we used the MatlabHLA toolbox developed at the Wismar University (Stenzel and Pawletta 2008).

Throughout this paper, we first present the state of the art on the subject of study, and then we describe how the simulation was built following the phases of a simulation project, as much as possible. Finally, some conclusions are drawn and lines for future work are proposed.

2. STATE OF THE ART

Simulation is widely used in ship design to check whether all owner requirements, operational capabilities and international standards have been fulfilled or not.

In opposition, crew and passenger behavior simulations are not that common. Human factors considerations are introduced in new concept designs by applying construction standards, rules derived from experience, designers' common sense, and very specific ergonomic studies of man-machine interface. An exception is made to the study of evacuation routes, since there are standards that oblige passenger ships to verify evacuation behavior (International Maritime Organization MSC Circ 1/ Circ 1238), and several studies were published about the subject in the past (Gwyne, Galea, et al. 2003, Gwyne, Galea, et al. 2001, Ginnis, Kostas, et al. 2010).

To the best of our knowledge, the first study on developing a tool to explore the interaction of personnel movement with the ship design at an early stage was carried out by the University College London and the Greenwich College (Andrews, Galea, et al. 2008). In this study, ship's compartments, equipment and auxiliary systems (connectivity items) were represented using the design building block approach (Andrews and Dicks 1997, Andrews 2003, Andrews, Burger and Zhang 2005) implemented under the Paramarine-Surfcon software suite (produced by QinetiQ Graphics Research Corporation) and for people movement the Maritime Exodus was used (Gwyne, Galea, et al. 2003). To enable both software to work together an interface toolset built in C++, with several spreadsheets and macros was used.

However, in this work there is no explicit mention to two different problems that we believe affect crew's performance: i) how hull geometry affects ship's seaworthiness and crew's wellbeing (O'Halon and McCauley 1974); ii) how equipment layout and auxiliary systems affect routes, as not only compartment layout may increase crew's workload (Simões-Marques and Pires 2003).

On the subject of the software interface, previous works such as (Stenzel and Pawletta 2006) have used distributed simulation in ship design, applying the High Level Architecture (HLA) concept. HLA evolved from the Aggregate-Level Simulation Protocol (ALSP) and Distributed Interactive Simulations (DIS). The earlier versions of the HLA standard were developed for military applications by the United Sates Department of Defence (Defense Modelling and Simulation Office 1998). Nevertheless, today, HLA is a wide-spread open IEEE standard (IEEE Standard 1516 2010).

In the next sections, both our own approach to analyze crew's performance and the means to implement an HLA instance to simulate and evaluate it are explained and discussed.

3. PROBLEM FORMULATION AND STUDY OBJECTIVES

The main objective of this study is to evaluate a ship's crew performance when a single watertight compartment is damaged, and how it is affected by the ship's architecture and equipment layout. In case of damage the crew carries out several actions in order to limit damage effects and to solve any equipment malfunction, aiming to increase operational capability of the vessel.

Explaining, generically, the problem in hand, when a ship is damaged by flood or fire, she and her crew are affected in several ways, both in her structural integrity, seaworthiness and operational capability. Simplifying the subject, we may consider that in case damage occurs:

- The structural integrity may be affected due to impact, flooding (Vassalos and Jasionowski 2011), or by the effects of fire and high temperature on structure (International Maritime Organization 2010);
- Flood will incline the vessel, affect her ability to float, and her capacity to come back to the upright position when any disturbing moment is applied by wind seas or any other reason (Biran 2003);
- Both previous effects will change her seaworthiness (Gaillard 2011);
- Fire and smoke will spread in case of fire onboard (Gwyne, Galea, et al. 2003, Gwyne, Galea, et al. 2001);
- There will be equipment and auxiliary systems that will be damaged (Simões-Marques and Pires, 2003).
- All above will affect passengers' evacuation and crew performance while trying to reduce the damage effects (Gwyne, Galea, et al. 2003, International Maritime Organization MSC Circ1/ CIRC 1238 2007, International Maritime Organization SOLAS 2009);
- For all of these reasons the ship's capacities to navigate and to proceed with different operations are going to be affected.

All these different issues are very difficult to simulate, and therefore in our first approach to the problem, we are simplifying them even further. At this stage, we are interested in simulating damage of a single compartment and, for each one, finding:

- what is the ship hydrostatic response, i.e. how much she inclines;
- what are the equipment affected by proximity or by means of damage of its electrical power cables;
- how long does a "damage control team" spend to reach the damaged compartment from their normal waiting position.

As for the latter point, we consider that the team selected to reach the incident is the closest one and that it will use the shortest path to reach it. The travelling speed is different while is travelling through a corridor or through stairs (International Maritime Organization MSC Circ1/ CIRC 1238 2007) and it is reduced when the ship inclines due to flooding (Gwyne, Galea, et al. 2003, Ginnis, Kostas, et al. 2010).

All in all, in order to evaluate crew's performance and how the ship's internal layout affects it, which is the ultimate goal of the study, we intend to use three different types of metrics related to the previous points, being the two last ones (2 and 3) used as performance measures of the architecture:

1. ship's draught, hell and trim angle;
2. list of equipment affected;
3. time interval to reach the damaged compartment by a team.

4. MODEL CONCEPTUALIZATION

The nature of the problem in hand suggests the use of a discrete event-oriented model for its simulation, allowing for each time the starting event occurs to verify the evolution over time (dynamic simulation) of the overall system (ship-compartments-crew-equipments-auxiliary systems).

To build the conceptual model, we already know the simulation's objectives and performance measures, and it is easy to identify the starting event (compartment damage). The next step is to identify the components of the system, namely, the other events, activities and entities along with their states and attributes.

We can identify several entities: i) Ship; ii) Compartments; iii) Equipment; iv) Auxiliary systems; v) Damage control teams. All of them, except for the damage control teams, have two states "fully operational" and "damaged", meaning the first does not require repair, and in the second it requires repair. As far as the team is concerned, it can be "waiting" in its initial position, "in action" when moving, combating damage or repairing equipment, and "nonoperational" if the damage occurs in the compartment coincident with their initial position.

The behavior of each entity in the model is understandable, though uncommon in this case is that it is necessary to identify from all entities the ones that change their state in case of a "compartment damage" event or not. While the ship operation capability is always affected, the influence upon the other entities depends upon their relative position in space to the damaged compartment. Other compartments (problem formulation states a single compartment is damaged), as well as equipments that are not in the compartment and whose vital auxiliary systems do not cross the compartment will not be affected. Further, only the damage control team closer to the incident is going to intervene, except in the case its state is "nonoperational".

Undamaged compartments and equipment, as well as the team that is not "in action", do not change their state during the model run and do not contribute for the final evaluation. Therefore, Figure 1 shows the Activity Cycle Diagram that takes only into account the entities that will affect the performance measures.

We can see that after a "compartment damage" event, flood or fire starts to spread, the compartment becomes useless ("damaged" state), the equipment inside is lost and the equipment whose electrical cables go across it also are considered malfunctioning ("damaged" state). The selected damage control team goes towards the incident ("in action" state) and after a while the ship inclines if there is a flood (damaged compartment under the waterline) affecting the team's moving speed. When the team arrives to the damaged compartment, first the fire must be extinguished or the reason for the flood must be repaired. After that, equipment and auxiliary systems may be repaired. Only when all repairs are finished the ship may be considered fully operational once again, and the team can go back to its initial position.

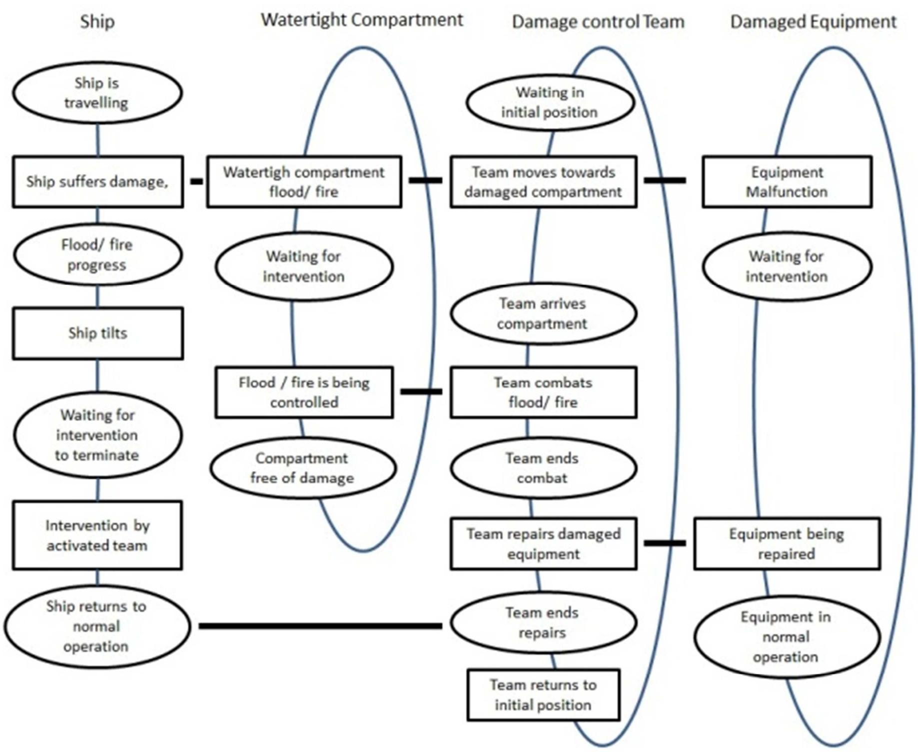

Figure 1: Activity Cycle Diagram

5. MODEL TRANSLATION

First, in order to translate the conceptual model into a computer form, we have to decide which is the best available option. In other words, what the most adequate implementation language to use is, if we may use commercial simulators, and what the most proper software architecture is.

Because the performance measures are quite different from each other, we believe it is best to build different simulators, allowing exchanging data between them, using software architecture such as the "High Level Architecture" (HLA). HLA is based on the concept of federation (collection of federates) and federates (interacting models) that require a middleware, the "Run Time Infrastructure" (RTI), through which data is exchanged and time may be controlled. These concepts are developed further on.

The initial decision on using HLA limited our next selections. Though there are commercial packages that implement HLA, our intention is also to be able to understand and be able to control all software we use. Hence, we use an open-source RTI called CERTI, which was developed by the French Aerospace Lab ONERA (Siron, Noulard and Rousselot 2009), and to build up federates we used Matlab R2010a, making use of the MatlabHLA toolbox (Stenzel and Pawletta 2008, Grades 2001), since previous work has already been done using it. Both run under the Ubuntu operating system (open source operating system built around the Linux kernel) (Ubuntu open source).

In the next paragraphs, we first present the program design options and how entities and their attributes are defined; next each one of the federates is analyzed; and finally we verify how everything comes together checking out the federation and how the HLA works making use of CERTI and the MatlabHLA toolbox.

5.1. Program design

The option of using procedural programming instead of using object-oriented programing is justified due to the fact that defining classes and objects in Matlab is not straightforward and that existing MatlabHLA toolbox work uses this approach, though the toolbox itself requires object definition, since HLA is object-oriented.

Nevertheless, the entities mentioned before have their own attributes and relations, though they do not have their own class operations. The entities are implemented using a structure (struct) that contains other structs. Figure 2, presents the rationale followed to define entities' attributes using a Class Diagram that we entitled Relations Diagram. Though, as mentioned before, for the sake of simplicity this was not exactly the implementation used, serving us just as a conceptual model.

5.1.1. Ship attributes

Attributes incorporate all characteristics that are unique of the ship, such as dimensions, hydrostatic tables and cross curves (variables calculated from the hull geometry) and light ship weight distribution (initial). Also, there are others that may change in case of damage (flood), such as the specific cargo condition, heel, trim and draught.

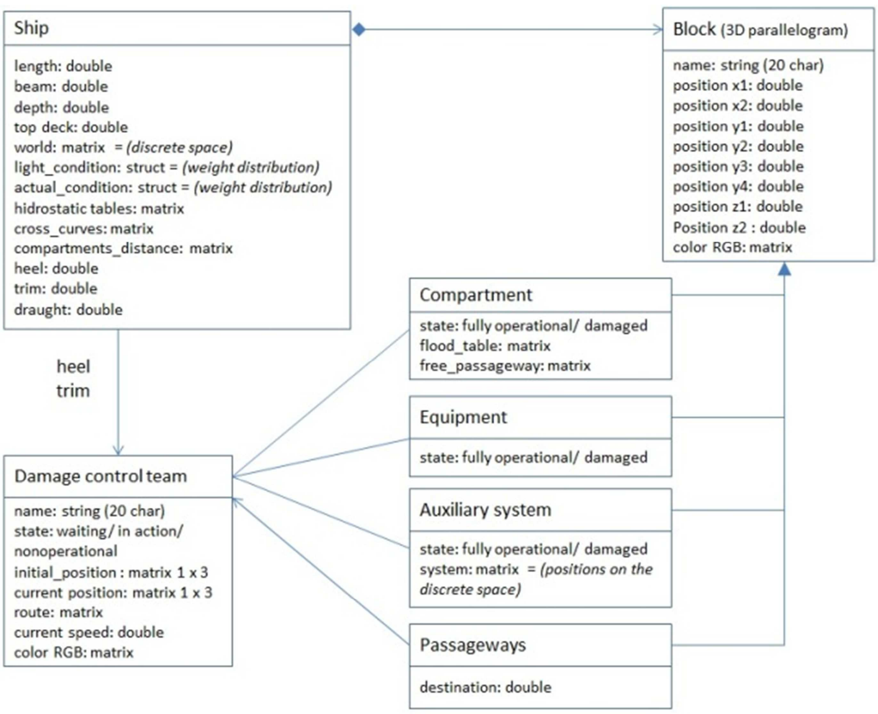

Figure 2: Relation Diagram

There are still another two attributes that are related to how space is defined: a) a large matrix (world) of 0.5 x 0.5 x 0.5 m cells that describes the hole ship using a simple code of cells occupied by numbers indicating equipment, auxiliary system and other entities position, or 0 otherwise; b) a compartments distance matrix that allows for knowing whether there is a passageway between them and that is used to determine the shortest path from one compartment to another using Dijkstra's algorithm (Dijkstra 1959).

5.1.2. Block attributes

This is similar to a superclass, which would be implemented if object-oriented programming were used. This is equivalent to the Block concept in ship design (Andrews and Dicks 1997), which conceives the ship as an arrangement of blocks that can be either compartments or equipment, or any other significant item. All blocks are regular 3D parallelograms defined by their vertices coordinates, and they have their own color which is related to their function (such as technical, rest and service areas).

5.1.3. Compartment attributes

Compartment is derived from Block. It is defined by a state, a matrix that specifies the variables required for flood calculations, and another matrix that specifies internal free corridors for crew movement limiting their occupation (this is going to be used to determine the 0 filled cells in the ship's attribute: *world*).

5.1.4. Equipment attributes

It is also derived from Block that differs from the compartment because it is only defined by its state attribute besides the parent attributes.

5.1.5. Auxiliary systems attributes

It as well derives from Block and is further defined by its state, and by a matrix which provides positioning information. This information is necessary because this is not truly a 3D parallelogram but an addition of 3D parallelograms that form a route between two or more equipment with change on directions in all axes.

5.1.6. Passageways attributes

This derived structure is a 3D parallelogram with dimensions corresponding to only one cell. This is specified within each compartment to represent a door a hatchway or a stair that leads to another compartment, and therefore requires an attribute to identify the compartment it leads to.

5.1.7. Damage Control team attributes

The Team is defined by its name, state and color, as well as its speed and three other attributes related to its positioning: the initial position and position (current position) which are self-explained; and the routing matrix. As far as the route is considered, it stores the coordinates of each step to go from its initial position to its destination (damaged compartment). The speed changes depending it is moving in the horizontal plane or it is going up or down, following IMO's guidance (International Maritime Organization MSC Circ1/ CIRC 1238 2007) and as a function of the ships inclination (Gwyne, Galea, et al. 2003, Ginnis, Kostas, et al. 2010) estimated from ship attributes: heel and trim. This classifier relates to Compartment, Equipment, and Auxiliary System since it may change their state and to Passageway, because it needs its attributes to define its route.

5.2. Ship and Block models

To help defining some of the classifiers default attribute values, it was necessary to build up an application software using Matlab called *DamageHLA*.

The aim of such an application is to, knowing the positioning attributes of the Compartments, Equipments, Passageways and most the ships attributes (dimensions, light condition, tables, and compartment distance), find out the default values for the auxiliary system attribute: system, and the ship attribute: *world*.

DamageHLA allows both to visualize the ship and the blocks, and also to insert all entities into the matrix *world*, which defines the discrete space (0.5 x 0.5 x 0.5 m) that then is used for the damaged teams' movement. The *world* definition and insertion is done following a pre-defined sequence internal to the software:

1. The *world* matrix is all filled with one only obstacle (no clear space);
2. Compartment attributes are read. Within the limits of their positions the cells of the *world* matrix are clear (clear values, i.e. changed to 0);
3. The corridors and free-space within the Compartment are then added, whose data is stored in the *free_passageway* matrix, marking all cells with a different number (e.g. -6000);
4. Passageways are included changing the values of the *world* matrix cells with the value of the destination attribute;
5. Equipment are included, by changing the values of the *world* matrix cells within the 3D parallelogram to each equipment identification number;
6. Auxiliary systems path are defined (*system*) finding out the optimized route between two equipment avoiding obstacles (equipment and free passageways), using Lee maze solving algorithm (Lee 1961).

5.2.1. Auxiliary systems routing

This is made by a standalone routine which implements a modified 3D Lee maze solving algorithm (Lee 1961). This algorithm consist on flooding the discrete space cells with sequential numbers if they are not already filled with an obstacle, in all directions (north, south, east, west, up, down). This is repeated until the goal is reached, beginning than to backtrack to the origin while storing the optimum path positions. The implementation consists in connecting two pieces of equipment. First, it is necessary to shorten the search space limiting it to the limits of the compartments where the equipments are. Next we define one piece of the equipment as the origin and another as the goal. The path is then defined avoiding other equipment, free passageways and other previously defined auxiliary system. The world matrix cells are marked with the identification number of the destination equipment making possible to identify which equipment is affected when its required auxiliary system is affected.

Figure 3 presents the interface window and Figure 4 two images of the ship representation with and without auxiliary systems representation.

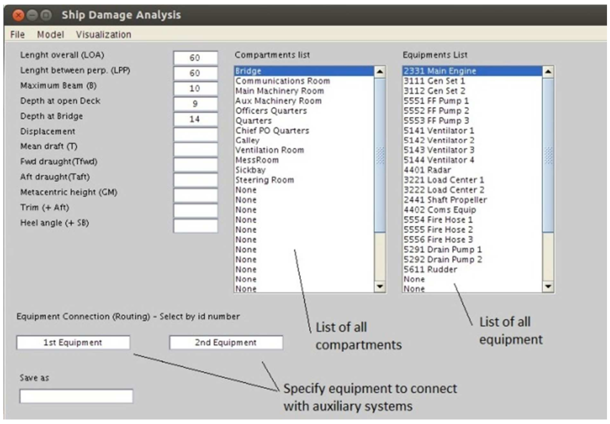

Figure 3: User interface window of *DamageHLA.m*

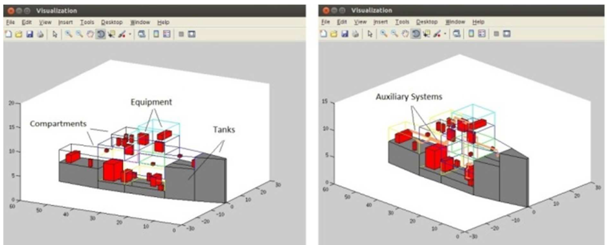

Figure 4: Ship visualization (left) without auxiliary systems; (right) with auxiliary system

5.3. Accident federate

The "*Damage_rt*" federate has the task of originating the starting event (compartment damage), and to control time synchronization with the Run Time infrastructure. The federate communicates with all other federates, that previously declared to receive its attributes every time an event occurs, which may be "hit" and "solved".

Explaining the process, the first event to occur is "solved", which means there is no damage. We identify that after 5 seconds a new event will occur, this time it will be a "hit", meaning that one of the compartments is going to be damaged.

The damaged compartment can either be selected by the user or pseudo-randomly selected by the software, allowing for a continuous cycle of "hit" - "solved" events without user's intervention. After 60 seconds of the initial time of the "hit" event, a "solved" event occurs allowing the user to check the time interval that the damaged control team spent to reach the damaged compartment (performance measure).

Figure 5 shows the interface window of this federate.

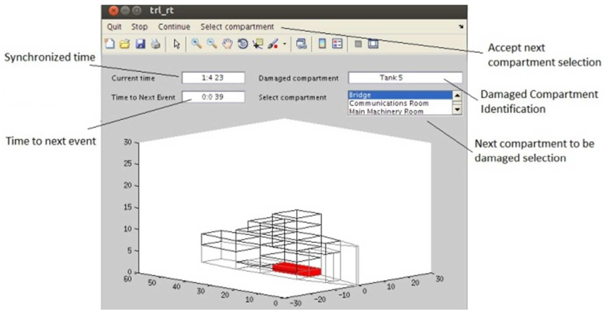

Figure 5: User interface window of the accident federate (*Damage_rt.m*).

5.4. Hydrostatics federate

When the ship is damaged under the waterline, it is most probable that there is a flood (water ingress), and therefore the ship will increase its draught and most probably incline. In case the ship is damaged above the waterline, there will be no flood, though for reasons out of the scope of this work hydrostatics could also change.

What happens can be explained by the added weight approach to damaged stability (Rawson and Tupper 2001, Biran 2003). As water enters the damaged compartment the ships total weight increases, and so her draught also increases. Consequently, even more water enters on board, and the level of fluid will increase, and so on until the level of fluid equalizes with the new draught caused by water ingress.

Additionally, only if the compartment is in the ship transverse and longitudinal center, the flood will not cause a disturbing moment due to the added weight of water. Au contraire, if the compartment is away from the center longitudinally it will produce a trim angle, and if the compartment is away from the transverse axes to port or starboard the ship will heel towards the side of the flood.

The federate uses an external routine to calculate the hydrostatic behavior of the ship after damage which has already been used and validated against commercial software in previous works done by the author (Martins and Lobo 2011). In this case, after the damaged compartment information has been received, the data stored in the values of the compartment attribute: *flood_table* and ship attributes: *light_condition*; *cross_curves*; *hydrostatic_tables* are used to determine the new load condition (ship attribute: *actual_condition*) and the angles of trim and heel. These two last ship attributes are going to be declared and published to all other federates that previously declared to receive them, every time they change. Figure 6 presents the output window of the hydrostatic behavior of the ship when damaged in compartment “Tank 2” heels the ship.

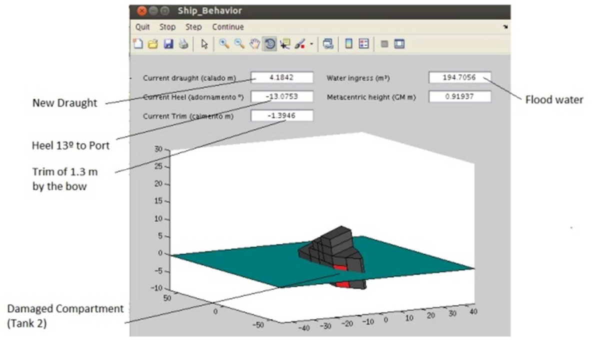

Figure 6: Output window of the Hydrostatics federate (*Actual_ts.m*)

5.5. Damage Control federate

This federate enables the user to gather the performance measures when any of the ship’s compartments are damaged; verifying the list of equipment in a “damaged” state and the time the closest Damage Control Team spends to arrive the damaged compartment from its initial position. The identification of the damaged compartment is received from the accident federate, and the values of the trim and heel after damage are received from the hydrostatics federate.

5.5.1. List of damaged equipment

The damaged equipments are gathered and presented in a list, by making a partial sweep of the world matrix, checking all equipment or their auxiliary systems identifications in the cells. The reduction of the search space is done for the particular damaged compartment whose identification has been obtained from the damage federate, in a similar form as in the *DamageHLA* case and the sweep has no specificity.

5.5.2. Damage Control team movement

The movement of the team raises two distinct questions: the first is what the team’s route is; and the second at what speed is the team moving. While the teams are in motion, the teams change their state from “waiting” to “in action”.

As far as the first issue is considered, all teams’ routes across compartments are estimated using the Dijkstra’s algorithm (Dijkstra 1959) applied to the ship attribute: *compartment_distances*. In this case, the starting point for each team is its *initial_position* and its goal is the damaged compartment. The team with the lowest “cost” is the selected one. However this does not specify the path within the compartments. In order to do this, we used the Lee algorithm (Lee 1961) to cross from passageway to passageway avoiding any obstacle. The implemented procedure is:

1. The route across compartments is estimated for all teams using Dijkstra algorithm applied to the *compartment_distances* matrix;
2. The team with the lowest “cost” is selected;
3. To find the path within each compartment, the search space matrix used is a reduction of the world matrix, limited to the compartment boundaries;
4. Within each one of these reduced matrices the passageways from the previous compartment and the next compartment in the route matrix are identified;
5. The shortest path within the compartment is found using Lee’s algorithm taking the passageways as the start and goal points, avoiding any obstacle.

The movement speed is another relevant issue. IMO distinguishes velocity values for passenger evacuation while walking in the same deck, going down stairs and going up (International Maritime Organization MSC Circ1/ CIRC 1238 2007). Further we assumed a 5% reduction value for each heel angle, taking into consideration there are measures that specify a reduction of 35% in speed with a 7% deck inclination (Ginnis, Kostas, et al. 2010), nevertheless it is our believe that not only the inclination should be considered but also the roll period of the ship from port to starboard due to the seasickness state it can cause (O’Halon and McCauley 1974).

Some implementation particularities are:

- we consider no equipment or auxiliary systems inside tanks;
- we assume that if any tank is damaged then the team will go to the nearest compartment;
- if the damaged compartment is the team’s initial position, then its state becomes “nonoperational” and therefore another team must come to rescue.

Figure 7 shows the output window where the list of damaged equipment can be seen and the motion of the damage control team can be followed.

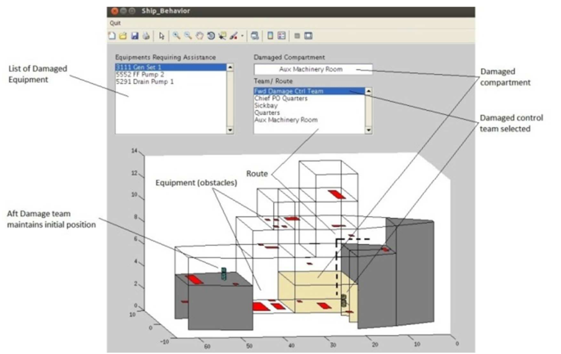

Figure 7: Output window of the Damage Control Action federate (*Observ.m*)

5.6. HLA Implementation

The previous paragraphs discuss on two quite different models (hydrostatics and damage control action) and a third one whose aim is to generate events.

HLA is a software architecture that enables distributed simulation. The basic principle of the HLA, is that several applications, called federates, are brought together to form up a federation, being able to exchange information in accordance to a specification called federation object model (FOM), through a run time infrastructure (RTI) which serves as a middleware and provides common services to the simulation system. The communication between federates and RTI is done trough a RTI ambassador, while communication in the opposite direction is made through a federate ambassador. HLA interface specification to the HLA 1.3 standard includes six management areas (Defense Modelling and Simulation Office 1998, Grades 2001):

1. **Federation Management**: this includes creating/ destroying federations; joining/ resigning federates to/ from federations; federation-wide synchronization; etc.
2. **Declaration Management**: specifies the data that each federate will send and receive by means of publication, subscription and supporting control functions;
3. **Object Management**: provides the means to register and distribute objects, including registration and updates (sender), and discovery and reflection (receiver).
4. **Ownership Management**: since the RTI allows two or more federates to shear the responsibility of updating objects, these procedures manage this information.
5. **Time Management**: time advance policies selection (real time, step-by-step, etc).
6. **Data distribution Management**: provides mechanisms to filter the transmission and reception of undesired data.

Figure 8 presents our HLA implementation using the open-source RTI called CERTI, and the MatlabHLA Toolbox, both compliant with the HLA 1.3 standard (Defense Modelling and Simulation Office 1998). This was done using Ubuntu operating system.

CERTI, is a local distributed system, made of three components: i) the RTI Ambassador; ii) the RTI Gateway; and iii) the library libRTI. The RTIA interacts locally with the federate, and RTIG manages the creation and destruction of federations, as well as, the publication/ subscription of data.

The MatlabHLA Toolbox is used to connect federates to the RTIA in one direction and the Federate Ambassador to federates in the other. As described in reference (Stentzel and Pawletta 2008) the Matlab external interface (MEX) allows access between set of m-functions that provide RTI and federation services and the C++ wrapper function (*rti.cpp*) that provides all necessary conversions.

The three existing m-file federates include the necessary routines for communicating via the RTI. All of them hold federation and declaration management capabilities. As far as the object management capabilities, federates have built in routines that allow for exchange data making use of two different procedures: Send/ Receive Interaction and Update/ Reflect Attribute values. The first is used by the Accident federate (sender) to inform the other two of the event (damaged compartment). The second is used by the Hydrostatic federate that sends regular updates of the attribute values, which are received by the Damage Control Action federate (object management capabilities).

Finally, for the architecture to work, it is only missing the federation declaration and specification. This is done making use of a FED file (FOM) where all management capabilities available to federates and all shared information must be declared.

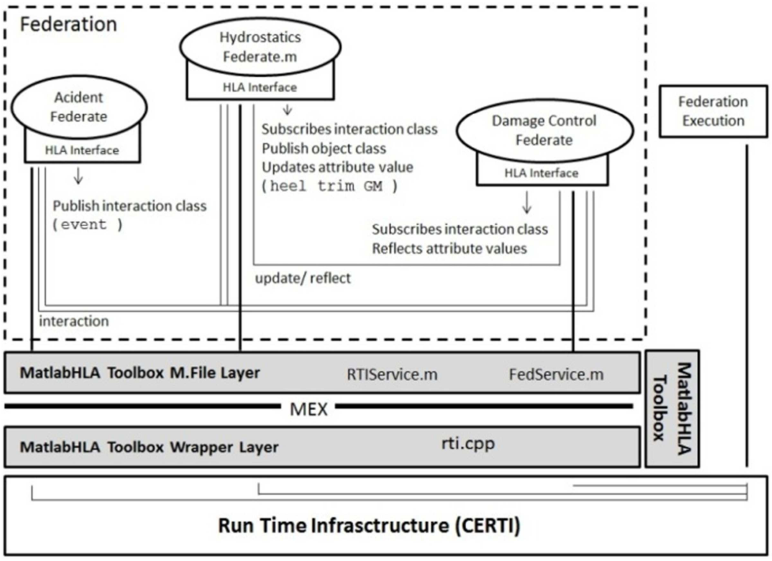

Figure 8: Functional view of simulation under HLA using CERTI and the MatlabHLA toolbox

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6. VERIFICATION

The verification of the work has been done running all possible damage compartments one by one, and checking the reasonability of the results.

As far as the hydrostatic response of the ship is concerned, we used routines previously verified and validated against commercial software (Martins and Lobo 2011), and also partially validated against real inclining tests. Similarly, Lee algorithm has also been tested in the past and verified against several limited problems (Martins and Lobo 2009).

The performance measures were verified, checking the list of equipment against the ship and block models (paragraph 5.2), as well as verifying the teams' routes across compartments and if the movement speed would correspond to the direction of movement and to the ship's heel.

7. CALIBRATION

The speed of movement is an issue that would require calibration. As mentioned before, there is no confidence in the data used to reduce speed due to inclination and we could find no reference to the speed reduction due to roll period, though we know, from seakeeping studies that this will be a major factor of seasickness (O'Halon and McCauley 1974) and therefore most probably of speed reduction.

8. CONCLUSION

Through this work we present step-by-step the creation of a simulator that aims to analyze crews' performance and ship interoperability when she suffers a single water-tight compartment damage.

The conceptual model was built assuming that any damage would affect the ship's operational capacity. The crew would act to return the ship to her initial status, both restraining the damage impact and solving equipment malfunctions. Yet, the actions of the crew are affected by the inclination the ship caused by flood, if that is the case.

To implement this concept, first we had to create the ship's model building dedicated software to define her in a discrete space, locating compartments, passageways, equipment, and auxiliary systems. In the auxiliary systems case we used Lee's maze solving algorithm to find the optimum route connecting different equipment (Lee 1961).

Next we built three different simulators using Matlab. The first generates events (damages), the second calculates the hydrostatic behavior of the ship, and the third simulates a damage control team moving towards the damaged compartment. The team's route selection was done using Dijkstra's algorithm (Dijkstra 1959) and the motion through each compartment cell-by-cell we used the same Lee's algorithm.

In order to allow communication between the simulators we used the High Level Architecture standard (HLA 1.3 standard) (Defense Modelling and Simulation Office 1998), allowing data exchange with each other through CERTI (open source RTI) (Siron, Noulard and Rousselot, 2009), using the MatlabHLA toolbox as an interface (Stentzel and Pawletta 2008).

9. FUTURE WORK

We expect this work to be part of a larger study about optimum ship design concept over the Pareto frontier, taking into account several concurrent requirements.
HLA is supposed to have a crucial role in this work to allow the designs' evaluation using multiple simulators, different scenarios, while including crew related issues.

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AUTHORS BIOGRAPHY

Paulo Martins began his carrier in 1996 as a Portuguese Navy crew officer on board several ships. After time at sea he enrolled in the MSc in Naval Architecture at University College London finishing by 2002. Returning to Portuguese Navy he spent time in the Directorate of ships where he worked in refits of different kinds of ships. From 2004 he has been working in new vessels' constructions programs and been engaged in navy's research. Currently he is attending the PhD Program in Industrial engineering and management at the Faculty of Engineering of the University of Porto.

Rosaldo Rossetti joined University of Porto in 2006, where he is an Assistant Professor with the Department of Informatics Engineering, and a Research Fellow with the Artificial Intelligence and Computer Science Lab. Dr. Rossetti received the B.Eng.(Hons) degree in Civil Engineering from UFC, in 2005, and both the M.Sc. and the Ph.D. degrees in Computer Science from UFRGS, Brazil, in 1998 and in 2002, respectively. He carried out most of his doctoral research as a full-time Ph.D. research student at Leeds University's Institute for Transport Studies, Leeds, U.K. His areas of interest generally include complex systems analysis, systems optimization, computer simulation, Artificial Intelligence, and multi-agent systems. Dr. Rossetti is an active member of IEEE, ACM, APPIA, and AISTI.

António Carvalho Brito studied mechanical engineering at Universidade do Porto and obtained his degree in 1981, staying in the same institution as Lecturer where he did his M.S. in 1985. He obtained his Ph.D. in Simulation from the School of Management at the University of Cranfield (U.K.) in 1993. Currently he is an Assistant Professor at Universidade do Porto, where he leads research in the field of Simulation and Information systems.

IMPROVING CAR PORT TERMINALS EFFICIENCY THROUGH MODELLING AND SIMULATION

James Brucato[(a)]

[(a)] Palermo Euro Terminal s.r.l.

[(a)]jamesbrucato@gmail.com

ABSTRACT

Palermo Euro Terminal (PET) s.r.l. is an Extended Enterprise of the Italian shipping company "Grimaldi Group" and specialises in multimodal port logistics of cars, and vehicles in general, carried to the port of Palermo through the Grimaldi Group car carrier ships and Sicilian road transporters trucks. On behalf of the Grimaldi company, PET performs physical operations (receiving, unloading, stocking, delivering and loading, cars onto ships or trucks) and the related informatics tasks (cars data collecting, updating, warehousing), including mandatory reports about order and conditions of managed cars. This paper aims to show how the Object-Process Methodology (OPM) modeling and simulation approach supported the analysis and overall improvement of PET efficiency highlighting a lack of effectiveness of the informative system, and of a number of internal processes, mainly leading the implementation of a new, significantly more effective and less expensive infrastructure for the management of cars data.

Keywords: port terminal efficiency improvement, multimodal port logistics of cars, modeling and simulations, object-process methodology

1. INTRODUCTION

Palermo Euro Terminal (PET) has been established in 1997 by the Italian shipping owner Grimaldi (http://www.grimaldi.napoli.it/it/index.html) and a private local partner with the purpose of provisioning an effective port logistics to the car manufacturers and the road transporters operating in the European Automotive market area and specifically in Sicily.

The well known Global Market Crisis, began in the end of 2008, led the companies of all the world to a huge loss of turnover, including the world wide Automotive market which estimated loss in sells of cars has been estimated approximately around 40%, compared to the previous year. This in turn led all cars manufacturers and related supply chain companies, like road, railway, airway and maritime transporters directly or indirectly involved, to the same, but not always equal, dramatic and unexpected situation. In those circumstances, the PET management decided to implement a strong costs reduction policy in order to avoid dangerous waste of resources.

With respect to the Informative System used at that time, the management of PET company asked its Data Centre system engineers for a wide and well detailed analysis of the infrastructure and the related enabled operations.

This paper aims to describe methodologies and techniques used by PET Data Centre managers to identify a set of more affordable and more usable options available on the market through those used at that time by the other port terminals of the Grimaldi Group, including hardware devices and software interfaces, with the specific purpose of improving the overall efficiency of the PET company through a reduction in costs and, simultaneously, an elevation of the quality of services provided.

2. MISSION

In 2008 PET performed 100.000 car transits. From the beginning of 2009 to the end of 2010, the global automotive market lost about 40% of sales. In the same period, PET lost about 30% of its turnover. This, coupled with the increasing amount of information about location and conditions of cars required by the clients, led the PET management to perform a detailed spending review. A mandatory reduction in personnel, about 20% less, was highlighted and operated. This, coupled with an increasing request of information by the clients, led the company management to ask its Data Centre for testing the performances and investigating the effectiveness of the Informative System, and evaluating affordable alternatives in order to maintain the same level of quality of services provided and reduce the high costs required by the system management and maintenance.

3. METHODOLOGY

In order to perform an efficient and effective logistics, it is mandatory that all the involved operators (Car Port Terminals, Shipping Companies and Road Transporters) are able to perform simultaneously the highest number of activities in order to complete the highest number of both Physical and Informatics operations in the smallest amount of time. This in turn requires effective and updated facilities (i.e. Informative Systems), and well trained personnel.

With respect to the Port Terminals Logistics, incoming cars must be first checked on board the carrier means of transport by the stocking yard "Surveyors" who are responsible for filling the specific reports about the order and condition of received cars before the "Drivers" unload them.

After stoking the arrived cars inside the port terminal compound, the "Tallymen" scan the barcodes of the cars with specific mobile scanners and provide the "Office Personnel" for collected cars data in order to update the PET database and integrate the data uploaded with last informations.

Next, office personnel generates many different kinds of files, depending on the specific transporter or manufacturer database to update.

Cars data must be uploaded onto clients databases in time, usually within 24 hours from the physical arrival, and with the maximum level of accuracy in order to keep clients well informed about locations of cars and their conditions.

After this, the transporters send a list of required cars that must be arranged in charging lines in order to be quickly loaded onto the specific means of transport when the transporter arrives at the port terminal.

Finally, outgoing cars are checked again by the PET Surveyors together with the transporter drivers and loaded onto trucks or ships.

3.1. Models and Simulations

According to the Object-Process Methodology, OPM, (Dori 2002) and the Divide and Conquer Strategy (Knuth 1998), a Decompositional Approach has been adopted by the PET system engineers in order to perform an early analysis of the structure and the behavior of the company and build an OPM System Model providing a consistent overview of the whole set of involved facilities (represented as object together with their related states) and processes, with respect to both the related Physical and Informatics tasks. A list of building blocks has been created and validated together with both PET personnel and Grimaldi Group supply chain to check the correspondence between the model and the real company. Next, using the OPCAT modeling tool (free academic version available at http://www.opcat.com), the behavior of system model of the PET company has been simulated, as shown in Figure 1-4, above.

The structural view of the PET supported, and it's still doing that, the management of the company with an effective tool to keep under control the whole set of costs centers and their related effectiveness and efficacy level.

The behavioral view highlighted the fundamental role here played by the Informative System with respect to the time required to complete all the tasks belonging to the management of the cars data, which is closely dependent on their complexity.

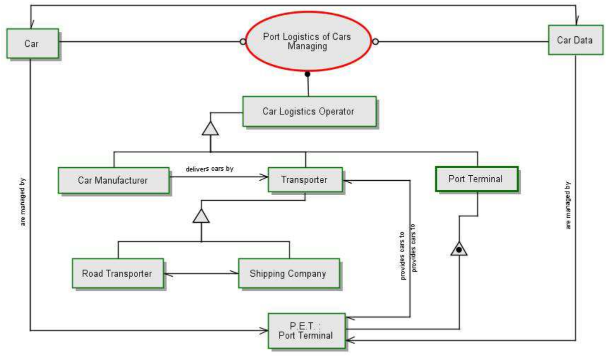

Figure 1: PET OPM System Diagram representing the main process of Port Logistics of Cars Managing

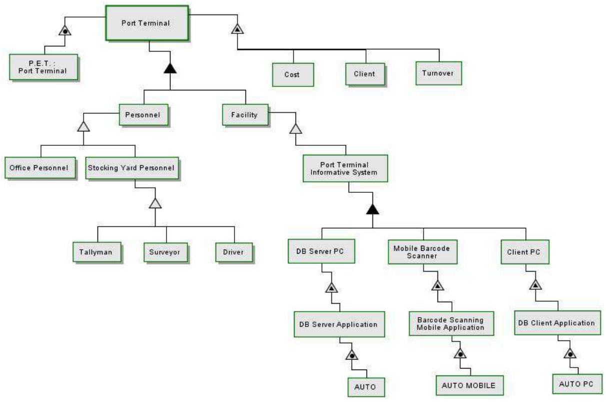

Figure 2: PET OPM System Diagram representing the Port Terminal Unfolding

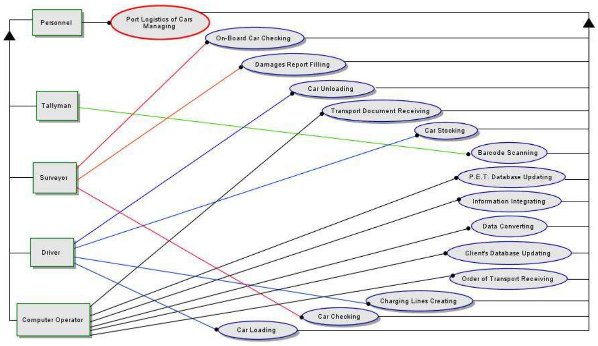

Figure 3: PET OPM System Diagram representing the Port Logistics of Car Managing Unfolding

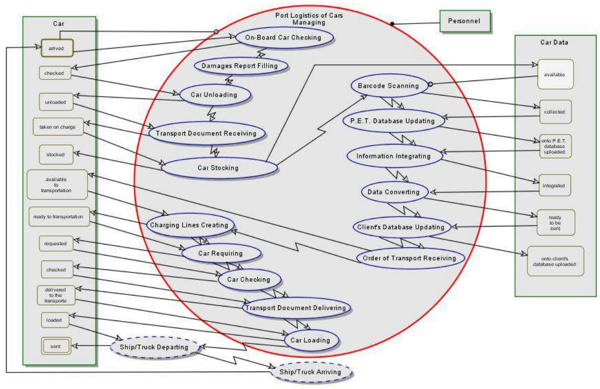

Figure 4: PET OPM System Diagram representing the Port Logistics of Cars Managing Inzooming

Next, system engineers performed a wide range analysis of the informative systems used by the most representative European Grimaldi Group port terminals in order to collect information about the widest set of available options and related costs and performances.

Finally, the informative system to be implemented has been identified and the expected company efficiency improvement has been obtained, leading in addition some unexpected but positive result with respect to the personnel way of working which in turn led an overall improvement of the quality of services provided by the PET company to its clients.

In the Conclusions are presented the results and the main outcomes of the activities mentioned above.

3.2. Initial Findings

Simulations highlighted a lack of effectiveness related to those processes enabled by the informative system.

Figure 4 shows how the simultaneity of physical and informatics processes ends very early and is not recovered until all the informatics processes are executed and related tasks are performed. Because this is widely considered the main efficiency and effectiveness factor bearing down on the time a car requires before it is physically available on the market (Time to Market).

In other terms, given a fixed amount of time, the more a port terminal is able to manage simultaneous processes, the more cars are delivered to clients or, given a fixed amount of cars, more processes a port terminal is able to perform simultaneously bigger is the saving of Time to Market.

This early finding led the PET system engineers to further analysis into the internal processes and alternative informative systems available on the market.

3.3. Port Terminals Informative Systems Analysis

Supported by Supply Chain and Data Centres' managers of the Grimaldi Group, PET system engineers have visited some of the most representative European port terminals of the Grimaldi Group and a couple of Italian Grimaldi partner logistics company stocking yards. Very huge number of data about architectures, performances and costs of many different informative systems were collected paying attention to the number and complexity of tasks performed by every single port terminal.

The survey that was carried out confirmed the necessity of PET company to implement more effective informative systems in collaboration with the various logistics operators PET met during these visits.

The list below contains Grimaldi Group port terminals and partners involved

- AET (Antwerp Euro Terminal), Antwerp, Belgium
- VTE (Valencia Terminal Europa), Valencia, Spain
- Setram Port Terminal, Barcellona, Spain
- Terminal San Giorgio, Genova, Italy
- LTM (Livorno Terminal Marittimo), Livorno, Italy
- CTE (Civitavecchia Terminal Europa), Civitavecchia, Ialy
- SAT (Salerno Auto Terminal), Salerno, Italy
- Agenzia Marittima Marangolo, Catania, IT

All of those analysed informative systems required the use of barcode scanners and custom software interfaces that allow the conversion and upload of cars data onto the clients databases. Those architectures provided for automated data upload software modules shown the best performances in terms of user cognitive workload, error or delay avoiding and overall time saving.

Some port terminal was testing the effectiveness of RFID into the domain of the port logistics of cars. At that time some trouble due to the Tag positioning onto the cars affected the experiments and the solution was rejected, even those it was very interesting with respect to the time saving during the Cars Data collecting activity.

Some of the informative systems that have been evaluated shown very high costs, with respect to the devices implementation, management and maintenance costs whilst others required very expensive servers and/or a very time consuming personnel training, to name just a few key issues, but all the systems analysed shown a remarkable level of effectiveness and notable performances.

The right balance between system complexity, usability, performance, cost efficiency and training duration has been found in the informative system AUTO, developed by the Italian software house SOFTNET which is a trusted supplier of the Grimaldi Group after the remarkable performances shown in many circumstances by the AUTO system.

Because the AUTO informative systems is actually used by a huge number of Italian Grimaldi Group port terminals (Palermo, Genoa, Livorno, Catania, Savona, Ravenna) and the files they need to share are fully interchangeable and compatible, the improvement of efficiency of the entire Grimaldi port logistics is rapidly increasing and widely appreciated by its managers and Data Centre's operators.

3.4. PET Efficiency Improvement Evaluation

The final stage after implementation has been focused on the evaluation of usability and of both mobile Barcode Scanners (Pirhonen, Brewster and Holguin 2002) and databases User Interface (UI) to assess the real final PET efficiency improvement obtained through the implementation of the AUTO informative system. For this purpose specific Tasks Analysis (Benyon, Turner and Turner 2005) have been performed on both the old one and the new one informative systems.

Evaluations have been performed in collaboration with the PET personnel according to the principles of the Participatory Heuristic Evaluation (Hix and Hartson

1993; Shneiderman 1998; Nielsen 1993; Nielsen and Mack 1994; Muller, Matheson,Page and Gallup 1998).

Collected data confirmed initial findings about the level of effectiveness of the old informative PET system due to the following outcomes.

3.4.1. Barcode Scanner Effectiveness Assessment

The outdated barcode scanner mobile application mainly did not fulfil the PET needs with respect to the clients requests of informations and did not allow the decode of the most part of informations contained in the barcodes of the cars, with the exception of the chassis number, as shown in Figure 5, below. In other terms, PET operators was required to input manually all the basic cars informations during the scanning activity or, after that , the office personnel had to often recover missing data, like the origin, the destination, the brand and the model of the cars, the carrier name and type (ship or truck), through the Grimaldi shipping company database or asking for informations directly to the related manufacturer Data Centre.

This unnecessary waste of time coupled with the high risk of wrong data collection were due basically to a lack of compliance to the basic principles of the User Centred design of software interfaces, this in turn led the most common problem the related literature has investigated within last thirty years.

A different set of problems, strongly contributing to the mentioned lack of effectiveness of the early informative system, were caused by a low functional file transfer software interface responsible for a not unusual total loss of the data collected during the upload process onto the PET database. This in turn often led unpleasant delays in delivering cars to and share data with the clients together with a huge and unnecessary waste of time.

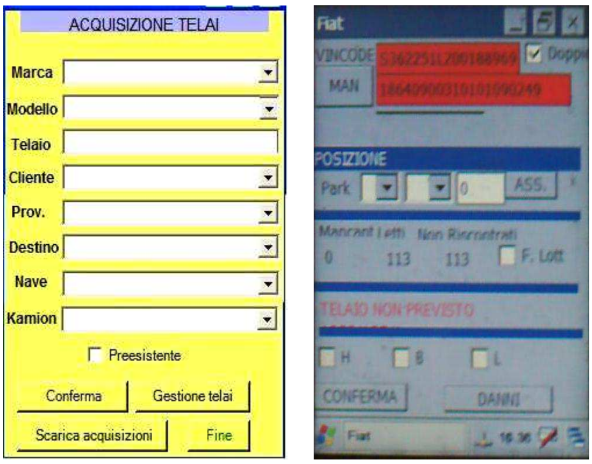

Figure 5: The Old and the AUTO Barcode Scanner Mobile Application Graphic User Interface (GUI)

Conversely, the AUTO barcode scanner together with the mobile application provided, as shown in Figure 7 above, requires the operator simply scan the barcode to retrieve and display the informations contained inside the scanned barcode. The manual mode is always available in order to enable the operator to insert the cars data even those the barcode is not readable. In addition, a strong reduction in time with respect to the scanning activity (the time saving has been estimated about 50% less) has been obtained thanks to the implementation by the SOFTNET of the Sequential Barcode Scanning option very useful in case of a temporary unavailability of all operators required or if a group of cars for some reason must be quickly scanned and delivered to the road transporters or loaded on a ship close to its departure. In addition, since the early implementation of the AUTO informative system, it never happened that some information has gone lost because the new scanner, provided for an external SD card, saves the data of the scanned barcodes one by one after each single scanning operation. Then, to execute the file transfer onto the PET database, the office personnel must simply open the folder where the mobile application stored the barcode data and copy and paste onto the PC desktop folder the files generated during the last scanning session. This in turn definitely avoided the loss of data, because of the duplication of the file made by the office personnel before uploading it onto the PET database server, and strongly reduced the uploading time required to update the PET database.

In addition, SOFTNET offers a cheap widely appreciated service consisting of the remote maintenance and update of the entire AUTO infrastructure, including hardware components, software modules and interface depending on the company needs and on the shipping company Data Centre requests. In case of unavailability of connections, the PET logistics operations can be performed because both the barcode mobile application and the file transfer interface installers have been released to the Data Centre system engineers in order to restore them in case of failure or communications breakdowns avoiding costly and time consuming interruptions of informatics and related physical operations.

3.4.2. Database User Interface Effectiveness Assessment

As shown in the Figure 6 and Figure 7, below, the old P.E.T. informative system was provided for a Textual User Interface (UI) which made very difficult the execution of tasks in parallel like recalling informations related to a specific chassis number and integrating the data related to a new group of cars at the same time. In other words, also the simultaneity of informative operations was not allowed by the old informative system UI. This in turn unnecessary increased the Office Personnel workload together with the risk of data loss and/or data errors.

In addition, while the AUTO system automatically moves the cars delivered to the transporters from the available car stock onto the sent car group, the old system did not do that requiring the Office Personnel every end of the day a very hard work to calculate, the exact amount of cars sent and physically available inside the compound. This, because of both the manufacturer databases and the transporters databases must match in every moment. Also this activity was often affected by some error leading the company management to unpleasant consequences.

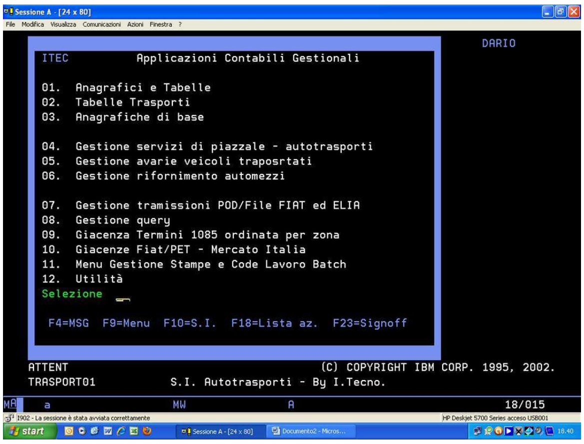

Figure 8: Old Client Server Application Interface

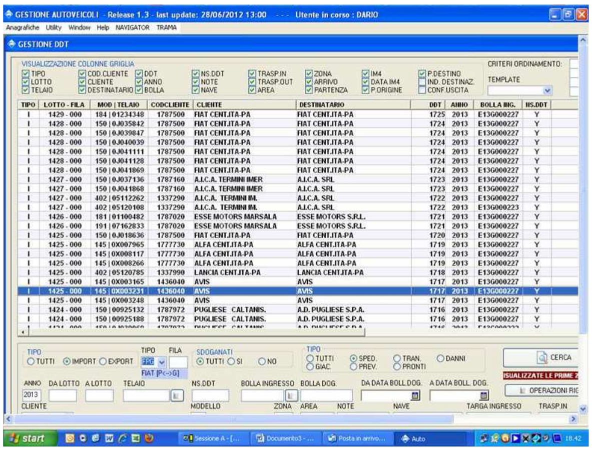
Figure 9: AUTO Client Server Application Interface

4. CONCLUSIONS AND FUTURE WORKS

Usability tests results confirmed the initial findings came out from the OPM Modeling and Simulation early stage that underlined the Palermo Euro Terminal (PET) company was affected by an excess of resources consuming mainly due to a lack of both the simultaneity in executing internal Physical and Informatics processes and the effectiveness of the Informative System in use at that time.

Latest measurements confirmed that the system AUTO drastically reduced the time (up to 50% compared to the PET old informative system) to complete most of the tasks related to the cars data collection, warehousing and sharing through the implementation of more usable hardware and software interfaces that pushed down their overall complexity.

Simultaneously, the implementation of the AUTO Informative System helped the management of the company to enable the mandatory costs reduction policy because of the lower number of personnel units required by the management of the cars data together with very low management and maintenance costs.

In addition, all the mentioned improvements contributed to elevate the overall Quality of Service provided to the clients because of the very low amount of errors in cars data shared with them now completely compatible.

Further positive effects have been obtained with respect to the lower workload requested to the employees and their higher awareness of the extended logistics chain they are part of.

All the mentioned results strongly contributed to the requested improvement of the PET company overall efficiency and led the management to ask the Data Centre for further analysis focused on assessing the availability of some additional software module to integrate in the AUTO system in order to manage the port logistics of Lorries, since it is becoming the new company core business because of the strategic position of the Port of Palermo inside the Mediterranean Market Area with respect to the countries of the North Africa.

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AUTHORS BIOGRAPHY

James Brucato is a System Engineer. He graduated in Philosophy of Science from the University of Urbino (Italy) in 2001, after a one year stage at the Institute of Sciences and Technology of Cognition (ISTC) of the Council for National Researches (CNR) in Rome tutored by the Prof. Alessandro Laudanna. During the mentioned stage he took part in many experiments and learned how to manage methodologies and tools for the development of tests and the data analysis. His thesis "*Logics of the Compositionality and Computability of the Meaning"* tutored by the Prof. Alessandro Di Caro from the University of Urbino (Italy) was focused on investigating the contribution of Neural and Semantics Networks to the comprehension of the Natural Language structures. Between 2001 and 2002 he worked at the Institute of Sciences and Technologies of the Cognition of the University of Salerno (Italy) and was involved in the development of the "*IWB*" e-learning platform. After this, in 2003 he attained a one year Master in Interaction Design from the University of Rome Tor Vergata winning the second prize for the best Project Work of the year that led him to the Interaction Design Institute (IDC) of Limerick, Ireland, where he spent three weeks as Visiting Resercher in order to present his work to PhD students. He also attended last three editions of the "*Systems Engineering, Architecture and Lifecycle Design: Principles, Models, Tools, and Applications*" MIT summer course held by prof. Edward Crawley from Massachusetts Institute of Technology and prof. Dov Dori from Technion - Israel Institute of Technology. Actually he works for the Palermo Euro Terminal srl, Palermo (Italy) as Head of the Data Centre. He is member of Italian UNINFO and the International Standard Organization (ISO). As Italian Delegate expert in "*Automation systems and integration*", he participates actively to the works of the TC/ 184SC5/WG1 and WG5.

ANALYSIS OF THE APPLICABILITY OF THE PUBLIC UPPER AUSTRIAN TRANSPORT GRAPH FOR SOLVING A LOCATION-ALLOCATION PROBLEM

Andreas Pell[(a)], Andreas Meingast[(b)], Stefan Rotter[(c)], Markus Pajones[(d)]

[(a) (b) (c) (d)] University of Applied Sciences Upper Austria

[(a)]andreas.pell@fh-steyr.at, [(b)]andreas.meingast@fh-steyr.at, [(c)]stefan.rotter@fh-steyr.at, [(d)]markus.pajones@fh-steyr.at

ABSTRACT
In this study, the applicability of the Austrian national transport graph "GIP.at", which is provided and constantly updated by Austrian public authorities, for a location-allocation problem-solving approach is examined. For this purpose ESRI's ArcGIS Network Analyst™ was applied on the part of the graph which represents the roads of the Province of Upper Austria. Therefore, the geometric network and its attributes are compared with other provider's geographical data. In a second step the street network graphs are used to solve a location-allocation problem in a case study about an Upper Austrian food retailer. The comparison of the results shows, that using diverse geographic data leads to the same facility locations and allocations. Subsequently, the applied geographic data are investigated in more detail. Missing data attributes which are highly relevant for heavy goods vehicles (HGV) routing like vehicle specific restrictions (height, width, weight) or HGV driving bans are depicted.

Keywords: GIS, national transport graph, energy-efficient logistics, location-allocation problem

1. INTRODUCTION

A Geographic Information System (GIS) like ESRI's ArcGIS™ as a computer-based system is able to collect, manage, edit, analyse and visualise spatially referenced information that can be used for different fields of application (Bill 2003). The increasing use of GIS for transportation (GIS-T) in combination with intelligent transportation systems (ITS) raises the demand for specialised and standardized digital maps for the purpose of routing and as a geo-referencing system. Focusing on commercial vehicle operations (CVO), GIS can be used within commercial vehicle preclearance, administrative processes and fleet management to increase the fleet safety and efficiency through routing and location-allocation procedures (Chen and Miles 1999). When it comes to these concrete applications of GIS the users are looking for maps with additional network parameters that are attuned to the commercial vehicle specifications. Heavy goods vehicles (HGV) cannot use all roads because of restrictions in vehicle total weight (e.g. bridges), height (e.g. tunnels, underpasses), width (e.g. narrow roads), severe inclines, narrow bends or sector-related HGV driving bans. To provide sufficiently valid results, it is also necessary to use frequently updated accurate maps.

There are many data suppliers which are anxious to provide their users with up-to-date accurate spatial data either commercially or free of charge. Vendors like NAVTEQ®, TomTom® MultiNet® and ESRI® provide frequent updates for their commercial datasets. Open Street Map (OSM)'s road network data is updated by the OSM-community and is free of charge.

In Austria together local and national authorities and administrations provide and constantly update the Austrian national transport graph (GIP.at) and Basemap.at. The public can use it without a licence fee because it is treated as Open Government Data. The GIP.at's national transport graph is the outcome of a several years lasting process of digitising administrative processes relating to transport infrastructure (Heimbuchner 2013a). "*The GIP.at offers the public administration and authorities an overview of the entire transport infrastructure by furnishing all the essential information in a nutshell. […] The GIP is also necessary to implement the Intelligent Transport Systems Act (IVS), the INSPIRE Directive and the PSI Directive with the local and regional authorities*" (Heimbuchner 2013b). It is the link between historically developed parallel systems. It covers all modes of transport (passenger car traffic, public transport, cycling and walking) on the road. With the help of e-government-processes the platform is continuously updated (Heimbuchner 2013a). The GIP.at graph is used as the basis of traffic modelling in the on-going projects "ITS Austria West" (ITSAW) and "ITS Vienna Region" (ITSVR) to can estimate real-time traffic conditions and short-term traffic predictions. In the project "Traffic Information Austria (VAO)" the GIP.at graph is used to geo-reference traffic information (Heimbuchner 2013c).

The aim of this study is to compare the Upper Austrian's GIP.at transport graph with different maps regarding their included parameters and their routing results. To provide comparable results of applications used these graphs a systematic approach is required. Therefore, a case is solved with each map. The different geographical datasets are integrated in ESRI's ArcGIS® software to analyse the effects of the integrated attributes on route suggestions. The case deals with an actual location-allocation problem of an Upper Austrian food retailer.

Strategic location planning is a quite complex task for companies – especially because decisions cause long-term effects. Retail businesses with lots of supermarkets are regularly faced with this problem. To solve this task, the location planning process needs quantitative as well as qualitative analysis. A location-allocation problem is part of the quantitative analysis and tries to calculate optimal locations while considering weighted customer locations. An analysis with ArcGIS Network Analyst™ provides solutions by using company data and geographical data. Due to the fact, that the same company data is used within each run, the quality do not influence the results and geographic data can be compared in terms of quality and applicability.

Additionally the attributes of the three graphs are analysed regarding their usability for commercial vehicle traffic and road restrictions regarding heavy goods vehicles (HGV), e.g. vehicle weight, height, width or sectoral prohibition on road transport.

2. CASE STUDY

The underlying case study deals with the supply network of a food retailer in Upper Austria. The company plans to strategically select some of the exiting supermarkets as cross-docking stations for unloading incoming merchandise from the central distribution centre and loading outgoing merchandise from regional food producer. This situation correspond to a location-allocation problem, that is, where to locate such cross-docking stations and which regional supermarket should be allocated to which station through minimizing costs within the supply network. The impedance within a network can be indicated differently, e.g. time, money CO_2 equivalents, or distance. The latter holds true for this case study. Furthermore, the food retailer decided to set up 10 cross-docking stations in order to ensure local products (grown locally, produced within the area).

3. METHODOLOGY

An important as well as critical component in the field of logistics represents facility location and allocation problems (Melo 2009). Whilst in early years only geographers had been interested in these problems, facility location and allocation models expanded their acceptance into other research areas, e.g. operations research. The problem is defined as locating *"…a set of new facilities such that the transport costs from facilities to customers is minimized and an optimal number of facilities have to be placed in an area of interest in order to satisfy the customer demand"* (Azarmand and Jami 2009, 93).

Several types of location-allocation problems have evolved over time, for instance, p-Median problem (Weber problem), the p-Center problem, uncapacitated facility location problem, capacitated facility location problem, or quadratic assignment problem (Eiselt and Sandblom 2004). According to Klose and Drexl (2005), respective models differ in space (continuous, discrete), objective (Minsum, Minmax), capacity (capacitated, uncapacitated, echelons (single-stage, multi-stage), product (single-product, multi-product), time (static, dynamic) and data reliability (deterministic, stochastic).

In this case study, a simple p-Median problem is set up which access real world street network data. Given a set of nodes N within a network, consisting of a set of potential facilities $J \in N$ and a set of customer $I \in N$ the following linear optimization model can be formulated:

$$\text{(1.1)} \qquad \min z = \sum_{i \in I} \sum_{j \in J} w_i d_{ij} x_{ij}$$

where

$w_i \rightarrow$ *weight on edge (transport volume)*
$d_{ij} \rightarrow$ *distance between customer i and facility j*
$x_{ij} \rightarrow$ *binary decision variable equals to* 1 *if a customer i is allocated to facility j and* 0 *otherwise*
$y_j \rightarrow$ *binary decision variable equals to* 1 *if a facility j is opened and* 0 *otherwise*

subject to

$$\text{(1.2)} \qquad \sum_{j \in J} x_{ij} = 1 \qquad \forall\ i \in J$$

$$\text{(1.3)} \qquad x_{ij} - y_j \leq 0 \qquad \forall\ i \in I, j \in J$$

$$\text{(1.4)} \qquad \sum_{j \in J} y_j = p \qquad \forall\ i \in I$$

$$\text{(1.5)} \qquad x_{ij} y_j \in \{0, 1\} \qquad \forall\ i \in I, j \in J$$

The objective function aims at minimizing the total weighted distance within the network (1.1). Constraints (1.2) guarantee that every customer is served by one facility, whereas Constraints (1.3) couple the location and allocation decision. The last Constraints (1.4) fix the number of selected facilities to p . Constraints (1.5) indicate binary variables for x_{ij} and y_j.

After setting up the mathematical model, data are integrated in ESRI® ArcGIS™ 10.0 software. To start with, all supermarkets' addresses are geocoded by the Address Locator 9.3.1 ESRI Europe Geocode Service (ArcGIS Online). Thereafter, three individual network datasets are created for the location-allocation analysis conducted by the ArcGIS Network Analyst 10.0: (i) national transport graph (GIP), (ii) OpenStreetMap (OSM) and (iii) TomTom MultiNet® 3.6.1 (TomTom).

Besides conducting a location-allocation analysis for the case study, the above-mentioned network datasets are analysed in more detail. Three categories were built to analyse different attributes. Especially data attributes which are required for commercial heavy goods vehicle (HGV) traffic, e.g. restrictions on weight, height, width or sectoral driving bans are investigated. Furthermore, the applicability of the defined network datasets for truck routing is tested.

4. FINDINGS

In the selected case study, the retailer plans to distribute regional products through cross-docking stations at least costs. In the forefront of the analysis, the retailer claimed 10 cross-docking stations for its supply network in Upper Austria. Conducting three different location-allocation analyses yield the following results.

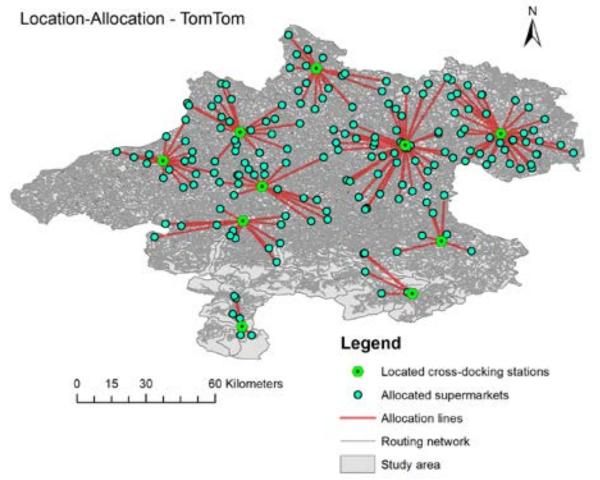

Figure 1: Location-Allocation – TomTom MultiNet®

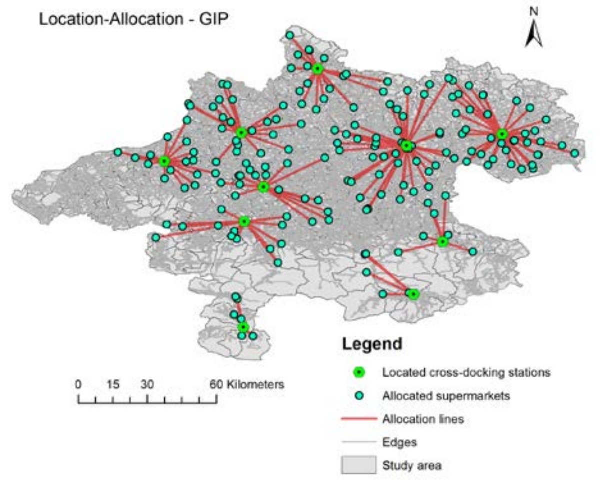

Figure 2: Location-Allocation – GIP

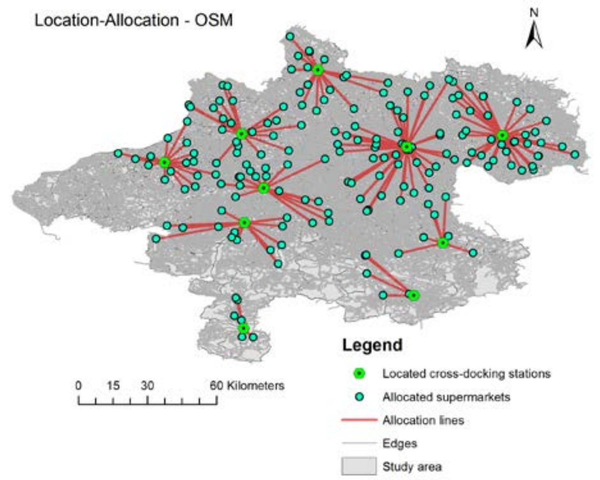

Figure 3: Location-Allocation - OSM

As can be seen in the figures 1-3 the analyses depict the same supply network structure for all three network datasets. It can be concluded that all of the selected spatial data – fee required or free of charge – exhibit sufficient data quality for strategic logistics problems. The following analysis focuses on tactical logistics problems dealing with truck routings and shows the applicability of the selected network datasets for this purpose.

To supply a detailed analysis of the three graphs, network attributes were regarded. Therefore, three categories,

- connections,
- general attributes, and
- HGV specific attributes

were defined and user guides of GIP, OSM (converted by Ramm Frederik) and TomTom were analysed regarding these categories.

- PRISMA Solutions (2012)
- Ramm (2011)
- TomTom (2013a)
- TomTom (2013b)

The findings are summarized below in Table 1 and discussed in the following section.

Table 1: General and HGV-specific attribute analysis

X yes O no	GIP	OSM	TomTom
connections			
road	X	X	X
ferry	O	O	X
congestion charge/ extra tolls	O	O	O
general element attributes			
street name	X	X	X
road category	X	X	X
one way	X	X	X
bridge	X	X	X
tunnel	X	X	X
altitude & grades	O	O	O
road element length	X	O	X
number of lanes	X	O	X
maximum speed limit	X	X	O
travel times	O	O	X
elevation of road elements	X	O	X
HGV-specific attributes			
vehicle height restriction	O	O	X
vehicle width restriction	O	O	X
vehicle weight restriction	O	O	X
low emission zone	O	O	X
HGV load restrictions	O	O	X
restricted manoeuvres	O	O	X
hazardous goods restrictions	O	O	X
time dependent HGV bans	O	O	O
parking space for HGVs	O	O	O
truck diversions	O	O	O
preferred truck routes	O	O	O

Table 1 shows the supported attributes of the compared graphs GIP, OSM and TomTom. Analysing the general attributes of the three network graphs it appears, that all graphs include street names, road categories, one way restrictions, bridges and tunnels. While GIP and TomTom use different attributes to define the road type (e.g. functional road class, form of way), OSM provides only one attribute which gives information about the street category and its use. Due to the fact, that Upper Austria has plain and mountainous regions a categorization of tunnels and bridges is desirable. Within the OSM and TomTom databases bridges and tunnels are entered as Boolean attributes. GIP takes bridges and tunnels into account in the road category using “bridge” and ”tunnel” as string extensions at the end. However, the altitude of road segments and their grade is implemented by none of the graphs.

Analyses of single network elements show that the support of some attributes vary. The element lengths are given as attributes in GIP and TomTom. However, also OSM provides this information indirectly via the elements geographic location. The number of lanes is given in the graphs of GIP and TomTom. Focusing on the availability of the number of lanes, it seems that this information is only available for motorway junctions and a few junctions on primary roads in the TomTom graph. OSM graph doesn’t support this information. The GIP graph seems to provide complete and accurate information about the number of lanes of each road.

All three graphs include the attribute speed. While GIP and OSM take the official speed limit into account, TomTom uses calculated average speeds that seem to be higher than the official maximum speed limit. Nevertheless, TomTom provides estimated travel times for each road element. GIP and OSM can also provide this information by calculating it as far as they provide information on length and maximum speed for the regarded element.

The elevation of roads, which describes the level of an element in relation to another element at junctions without cross traffic or bridges, is implemented by GIP and TomTom.

Taking into account logistic activities it appears, that only TomTom provides specific attributes in an additional package. Examples for included restrictions are:

- vehicle height,
- vehicle width,
- vehicle weight,
- entry in low emission zones,
- HGV load,
- manoeuvres at junctions, and
- hazardous goods.

Specific characteristics like the Austrian time dependent HGV ban at weekends and information about available parking space for HGVs are not integrated in any of the graphs. Also preferred truck routes and diversions are not emphasised in the graphs.

The following section discusses the completeness and accurateness of the three transport graphs in a map extract of the city centre and a highly frequented road junction of the City of Steyr.

Figure 4: City of Steyr with representations of OSM (blue), GIP (green) and TomTom (red)

Figure 4 shows the three graphs for the Upper Austrian City of Steyr lying upon another. The blue network refers to the OSM graph, which looks to be very detailed. A reason for that is the integration of walking and cycling paths and private roads at company sites. However, the red GIP graph and green TomTom graph, which integrate only roads, show that also OSM does not cover all road elements in this area.

Additionally, there are also differences how the nodes and links of streets are located and so the roads and lanes are geometrically recorded in the three graphs. This fact is shown in figure 5, which illustrates a main junction in the City of Steyr and their divergent graphical representations. As shown in Figure 5 access walking paths are implemented in OSM (blue) only.

Figure 5: Imprecise and divergent graphical schematic views of a crossroads in Steyr by OSM (blue), GIP (green) and TomTom (red)

A comparison of web-routing-services based on TomTom, VAO and OSM transport graphs shows, that street restrictions in these spatial datasets may differ. While planning a route through Steyr, it is shown that the TomTom Route Planner (TomTom 2013c) ignores a road closures due to road constructions (figure 6: section S1), which was set up several months ago. The VAO routing planner (VAO 2013), which uses the GIP transport graph, ignores a pedestrian zone (figure 7: section S2) as well as the Open Source Routing Machine (OSRM 2013) does, which uses the OSM transport graph (figure 8: section S3). Summarising the above, it has to be noted that none of the routing services achieved a reasonable result.

Figure 6: TomTom Online Route Planner

Figure 7: VAO Routing Planner (GIP graph)

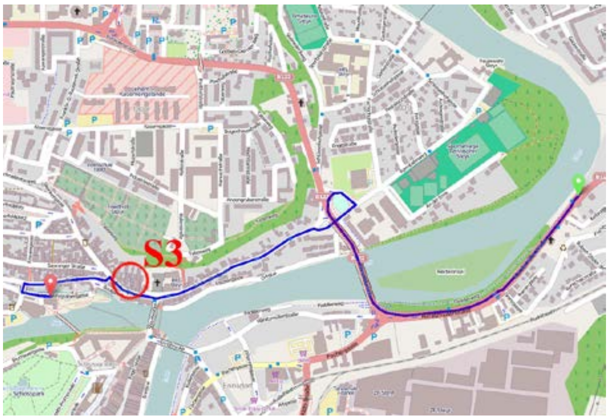

Figure 8: Open Source Routing Machine (OSM graph)

5. DISCUSSION

Research shows, that all three maps are practicable for the location-allocation problem. Further the analyses depict the same supply network structure for all three network datasets. Therefore it can be concluded that all of the selected spatial data – fee required or free of charge – exhibit sufficient data quality for strategic logistics problems in the Upper Austrian territory.

The following analyses focused on tactical logistics problems and on network parameter details revealed, that the considered datasets may differ in how nodes and links are geometrically recorded and attributes like road restrictions are supported or their values are entered.

While all maps seem to be relatively up-to-date, the GIP.at for Upper Austria provides persistently updated maps by the competent administration itself. Furthermore it's free of charge. However, there are missing HGV-specific attributes to use them for a commercial logistics purpose. To become the reference for all commercial or open-source transport graphs the following HGV-specific network parameters should be implemented:

- vehicle height restrictions
- vehicle width restrictions
- vehicle weight restrictions
- entry in low emission zones
- HGV load restrictions
- manoeuvres at junctions
- hazardous goods
- altitude & grades
- curve radius
- time dependent HGV bans
- parking space for HGVs
- congestion charge/ extra tolls
- multimodal/intermodal hubs
- truck diversions and bypasses
- preferred truck routes

The latter is of particular importance to be able to intervene in the road freight transport system and to redirect heavy goods vehicles away from residential areas. The integration of multimodal/intermodal hub data could strengthen the position, attractiveness and ease of use of intermodal transport systems.

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COMPLEX OBJECTS REMOTE SENSING MONITORING AND MODELING FOR PORT MARITIME MANAGEMENT

Boris V. Sokolov, Vjasheslav A. Zelentsov, Victor F. Mochalov, Semyon A. Potryasaev, Olga V. Brovkina

Russian Academy of Science,
Saint Petersburg Institute of Informatics and Automation (SPIIRAS)
39, 14 Linia, VO, St.Petersburg, 199178, Russia

Email: sokol@iias.spb.su, semp@mail.ru

ABSTRACT
In this paper the concept of integrated modeling and simulation the processes of the Complex Technical – Organizational System (CTOS) is presented. The main goal of the investigations consists of the practice of the predetermined modeling. The practice direction as the remote sensing ecological monitoring and inventory of the port maritime objects is proposed by the authors.
Here the methodical foundations of the integrated modeling and simulation, the process of CTOS operation, the technology of the remote sensing ecological monitoring are considered. Principal concern is attended to the continuity of the model and object solving practical issues. More over results of CTOS remote sensing monitoring make it possible to adapt models of this system to changing environment conformably to maritime port management.

Keywords: complex technical–organizational system, control process, simulation model, processing of the space, airborne and ground measurements.

1. INTRODUCTION

In practice the processes of CTOS operation are non-stationary and nonlinear. The perturbation impacts initiate the CTOS structure-dynamics and predetermine a sequence of control inputs compensating the perturbation. In other words we always come across the CTOS structure dynamics in practice. For example, monitoring of the port maritime ecological situation or actualization the port object infrastructure is considered. There are many possible variants of CTOS structure dynamics control (Ohtilev et al., 2006).

In this paper we propose the practice of the predetermined modeling where CTOS is a Remote Sensing ecological monitoring. Earlier various combinations of the analytical and simulation models were considered at the conferences with the similar theme (EUCASS 2005, Vena 2012, Aalesund 2013).

We can present the modified multiple-model multi-criteria description of CTOS problems:

$$J_\theta(\vec{x}(t),\vec{u}(t),\vec{\beta},\vec{\xi}(t),t) \rightarrow \underset{\vec{u}(t)\in\Delta_\theta}{extr}, \tag{1}$$

$$\Delta_\Theta = \left\{\vec{u}(t) \mid \vec{x}(t) = \vec{\varphi}_\Theta(T_0,\vec{x}(T_0),\vec{x}(t),\vec{u}(t),\vec{\xi}(t),\vec{\beta}_\Theta,t)\right\}, \tag{2}$$

$$\vec{y}(t) = \vec{\psi}_\Theta(\vec{x}(t),\vec{u}(t),\vec{\xi}(t),\vec{\beta}_\Theta,t), \tag{3}$$

$$\vec{x}(T_0)\in X_0(\vec{\beta}_\theta), \vec{x}(T_f)\in X_f(\vec{\beta}_\theta),, \tag{4}$$

$$\vec{u}(t) = \| \vec{u}^T_{pl}(t), \vec{v}^T(\vec{x}(t),t) \|;$$

$$\vec{u}_{pl}(t) \in Q_\theta(\vec{x}(t),t);$$

$$\vec{v}(\vec{x}(t),t) \in V_\Theta(\vec{x}(t),t);$$

$$\vec{\xi}(t)\in \Xi_\Theta(x(t),t); \vec{\beta}_\Theta \in B; \vec{x}(t)\in X(\vec{\xi}(t),t);$$

$$\vec{\beta}_\Theta = \| \vec{\beta}^T_0 \vec{w}^T \|^T; \vec{w} = \| \vec{w}^{(1)T}, \vec{w}^{(2)T}, \vec{w}^{(3),T} \|^T \tag{5}$$

The formulas define a dynamic system describing CTOS structure-dynamics control processes. Here $\vec{x}(t)$ is a general state vector of the system, $\vec{y}(t)$ is a general vector of output characteristics. Then, $\vec{u}(t)$ and $\vec{v}(\vec{x}(t),t)$ are control vectors. Here $\vec{u}(t)$ represents CTOS control programs (plans of CTOS functioning), $\vec{v}(\vec{x}(t),t)$ is a vector of control inputs compensating perturbation impacts

$\vec{\xi}(t)$). The vector $\vec{\beta}_{\Theta}$ is a general vector of CTOS parameters. According to [3], these parameters can be divided into the following groups (Skurihin V.I., Zabrodsky V.A., Kopeychenko Yu.V., 1989):

– $\vec{w}^{(1)}$ is a vector of parameters being adjusted through the internal adapter. This vector consists of two subvectors. The first one $\vec{w}^{(1,n)}$ belongs to the scheduling model, and the second one $\vec{w}^{(1,p)}$ belongs to the model of control at the phase of plan execution;

– $\vec{w}^{(2)}$ is a vector of parameters being adjusted through the external adapter. This vector consists of the subvector $\vec{w}^{(2,n)}$ belonging to the scheduling model and the subvector $\vec{w}^{(u)}$ including parameters of simulation model for CTS functioning under perturbation impacts. In its turn, $\vec{w}^{(u)} = \| \vec{w}^{(2,o)\mathrm{T}}, \vec{w}^{(2,b)\mathrm{T}}, \vec{w}^{(2,p)\mathrm{T}} \|^{\mathrm{T}}$, where $\vec{w}^{(2,o)}$ is a vector of parameters characterizing objects in service; $\vec{w}^{(2,b)}$ is a vector of parameters, characterizing the environment; $\vec{w}^{(2,p)}$ belongs to the model of control at the phase of plan execution;

– $\vec{w}^{(3)}$ is a vector of parameters being adjusted within structural adaptation of CTS SDC models.

The vector of CTOS effectiveness measures is described as (6).

$$\vec{J}_{\Theta}(\vec{x}(t),\vec{u}(t),\vec{\beta},\vec{\xi}(t),t) = \| \vec{J}^{(g)T}, \vec{J}^{(0)T}, \vec{J}^{(k)T}, \vec{J}^{(p)T}, \vec{J}^{(n)T}, \vec{J}^{(e)T}, \vec{J}^{(c)T}, \vec{J}^{(v)T} \| \quad (6)$$

Its components state control effectiveness for motion, interaction operations, channels, resources, flows, operation parameters, structures, and auxiliary operations (Okhtilev et al., 2010, Ivanov et al., 2010, 2012). The indices «*g*», «*o*», «*k*», «*p*», «*n*», «*e*», «*c*», «*n*» correspond to the following models: models of order progress control ($M_{<g,Q>}$); models of operations control ($M_{<o,Q>}$); models of technological chains control ($M_{<k,Q>}$); models of resources control ($M_{<p,Q>}$); models of flows control ($M_{<n,Q>}$); models of operations parameters control ($M_{<e,Q>}$); models of structures control ($M_{<c,Q>}$); models of auxiliary operations control ($M_{<n,Q>}$). In (5) the transition function

$$\vec{\phi}_{\Theta}(T_0,\vec{x}(T_0),\vec{x}(t),\vec{u}(t),\vec{\xi}(t),\vec{\beta}_{\Theta},t)$$

and the output function $\vec{\psi}_{\Theta}(\vec{x}(t),\vec{u}(t),\vec{\xi}(t),\vec{\beta}_{\Theta},t)$ can be defined in analytical or algorithmic form within the proposed simulation system; $Q_{\Theta}(\vec{x}(t),t), V_{\Theta}(\vec{x}(t),t), \Xi_{\Theta}(\vec{x}(t),t)$ are correspondingly allowable areas for program control, real-time regulation control inputs, perturbation inputs; B is a area of allowable parameters; $X(\vec{\xi}(t),t)$ is an area of allowable states of CTOS structure-dynamics. Expression (4) determines end conditions for the CTOS state vector $\vec{x}(t)$ at time $t = T_0$ and $t = T_f$ (T_0 is the initial time of a time interval the CTOS is being investigated at, and T_f is the final time of the interval). In our paper the proposed multiple-model multi-criteria description of CTOS will be used for port maritime management.

2. PROBLEM STATEMENT

Nowadays the theory, methods and techniques concerning the application of mathematical models are wide used. Nevertheless such problems as a quality estimation of multi-criteria models, an analysis and classification of applied models, as well as justified selection of task-oriented models are still not well investigated. The importance of the problem increases when a research object is described not via a single model, but with a set or a complex of multiple-models including models from different classes or combined models such as combined analytical–simulation models, logical-algebraic ones, etc.

In the solution of problems of modeling of complex objects $Ob^{op}_{<>}$ (in our case we investigate complex objects remote sensing processes and systems), the problems of providing a required adequacy of the results and controlling the quality of models and the modeling processes is of special importance. It is obvious that, using the model (or multiple-models) $Ob^{m}_{<>}$ in practical investigations, we should evaluate its adequacy each time relative to $Ob^{op}_{<>}$. The reasons for inadequacy may be inexact source prerequisites in determining the type and structure of the models, measurement errors in testing, computational errors in processing sensor data, etc. (Ohtilev et al., 2006). The use of inadequate models may result in considerable economic loss, emergency situations, and failure to execute tasks posed for a real system.

For definiteness, following (Ohtilev et al., 2006), we consider two classes of modeled systems. By the *first class*, we refer to those systems with which it is possible to conduct experiments and to obtain the values of some characteristics by measuring. We refer to the *second class* of modeled systems, for which it is impossible to conduct experiments (according to the technique presented in Figure 1) and to receive the required characteristics. Large-scale economic and social systems and complex technical systems that function under essential uncertainty of the effect of the external environment are examples of these systems. The human factor plays an important role in these systems (organization structures).

Figure 1 presents the generalized technique for estimating and controlling the quality of models of objects of the first class.

In this figure, we take the following notation: 1, for forming the goals of functioning of $Ob^{op}_{<>}$; 2, for determination of input actions; 3, for setting goals of modeling; 4, for the modeled system (objects $Ob^{op}_{<>}$) of the first class; 5, for the model ($Ob^{m}_{<\theta>}$) of the investigated system $Ob^{op}_{<>}$; 6, for the estimation of the quality of a model (poly-model system); 7, for controlling the quality of models; 8, for controlling the parameters of models; 9, for controlling the structures of models; and 10, for changing the concept of model description.

All complex technical – organizational systems (including complex objects remote sensing processes and systems) working in an autonomous mode are examples of systems of the first class.

Let us show possible implementation proposed technique of estimation and control of models quality for applied area which is connected with Earth Remote Sensing Monitoring.

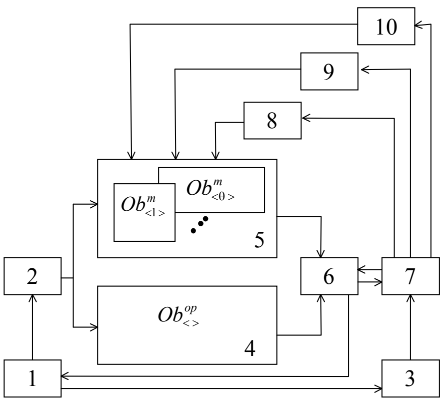

Figure 1: The generalized technique of estimation and control of the quality of models of the first class

The ecological monitoring of the environmental conditions is one of the primary ranges of the space imagery application. The monitoring of the pollutions at the three main nature environments (Water, Land surface and Atmosphere) is provided on the local, regional and global levels. The quality of the adaptations of the management decisions is increased as a result of the Remote Sensing monitoring. These adaptations are directed to the maintenance of the ecological safety of the research site and optimization of the events of the elimination of the disturbances consequence. The executor of the project aims to obtain required information with high quality and minimum cost. The effectiveness of the project depends of the source data quality (Remote Sensing data), methodical approach, software and the presentation of the project results. The integrated modeling of the basic technological processes of the Remote Sensing monitoring is realized for making the synthesis of the technical requirements for the hardware-software.

The framework of the main technological processes of the Remote Sensing monitoring is presented (fig. 1). With regard to technical characteristics of the space monitoring and facts influencing to these characteristics it demands to choose in the capacity of the source data one or some space vehicles and/or the airborne equipment complex, to choose an optimal conditions for the survey conducting base on the seasonal and daily variability of the reflectance and radiative characteristics of the landscapes and mode of operation of equipment, to organize the thematic treatment of the Remote Sensing data and the ground measurements using hardware-software, to present the results of the project in the user-friendly form permitting to make a management decisions promptly and reasonably.

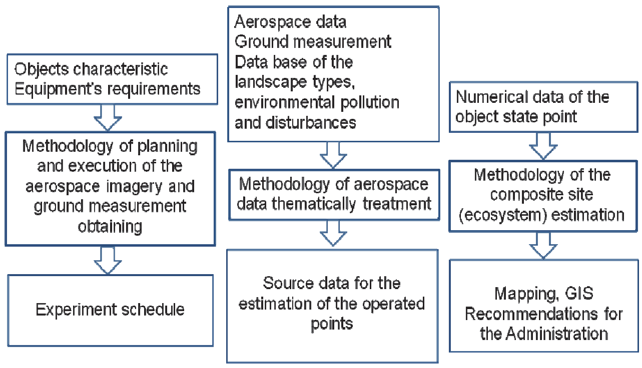

Figure 2. Framework of the methodology of the space monitoring data applying

Nowadays scientific and practical issue of the synthesis of the space monitoring components requirements is solved on the base of the modeling and simulation, the system parameters determining and expert analysis of the prospect of application solutions (see formula (2)).

The modeling and simulation of the technological processes has some uncertainty and limitations that influence to the quality of the optimization task (the vector $\vec{\beta}_\theta, \vec{u}_{pl}(t)$).

The CTOS has the following sources of information as space imagery in the visible, infrared and super high frequency spectral bands, airborne imagery, pilotless vehicle imagery and test ground measurements for the verification of the results of the imageries thematic treatment.

The execution of the space ecological monitoring and an actualization of the port object infrastructure consists of the some stages. Firstly, it is the planning and preparation of the works (the vector $\vec{w}^{(1,n)}$ and $\vec{u}_{pl}(t)$). This stage includes the choice of the objects, the list of controllable parameters determining and scheduling of the survey.

Secondly, it is the data acquisition. The stage includes the process of survey and ground-based measurement (the vector $\vec{w}^{(1,p)}$).

The name of the third stage is the processing of the data and presentation of the results. The treatment of the Remote Sensing data and ground measurement, creation of the thematic layer of the digital map, forming the forecast models, calculation of assessments and recommendations are executed (the vector $\vec{w}^{(u)}$).

The most convenient form of the project results presentation is the thematic layers of the digital map with the attributive information and database and photo scheme as raster image.

Moreover, it is possible to estimate the system functioning quality and the choice of the optimal monitoring conditions for the demand imagery quality obtaining. The prediction is accomplished on basis of the optical system taking into account the monitoring conditions and provides for a qualitative result. The spatial resolution of the image forms the main predictive parameter and determines as an object-background contrast value.

The movement of equipment, the Sun height, irradiance of the object, albedo of the site, physical specifications of the atmosphere is taken into account.

Accordingly, the modeling and simulation of the private elements of the space monitoring system and expert evaluations of the system functioning determine the values of the parameters of the space monitoring system functioning.

3. THEMATIC PROCESSING OF THE SPACE IMAGERY

Thematic treatment of the Remote Sensing data is the key link in the system of the space monitoring and inventory of the port objects. Generally the primary and secondary treatments are applied. The operations are done based on the modeling and simulation in automatic mode supported by the expert's knowledge.

The experience of the thematic treatment of the many and hyperspectral data with the high spatial resolution defined some important factors. One of them is the data presentation with the automatic identification of the test sites for algorithm training and adaptation. The next one is the complex treatment of the source many(hyper)spectral and temporal Remote Sensing data and ground measurements. Third factor is the data results calibration and validation and optimal application of the spectral features data base of the landscape elements with reference to seasonal and daily variability. Lastly, the organization of the distributed access to the data is exchanged on the base of the special portals, geographic informational system capability and crowd sourcing.

The informational flow rises and the necessity of the integrated modeling is determined. At that the qualitative and quantitative requirements are increased.

Commonly the main steps of the thematic treatment of the Remote Sensing data are designated for the qualitative solution of the integrated modeling task:

Phase 1. Input data array (block 3, fig.1)

- Step 1.Optimal survey parameters;
- Step 2. Change reflective and radiative settings of the landscape elements in seasonal and daily variability;

Phase 2. Data acquisition and treatment

- Step 1. Imager radiometric correction and calibration;
- Step 2. Imagery geometric correction;
- Step 3. Maintain of the system of initial data relative to the reflective and radiative characteristics of the landscape elements;
- Step 4. Combination of methods and algorithms of the thematic treatment (cluster analysis, Fourier analysis, method of principal components, classification algorithms and others) (blocks 8 and 9, fig. 1);
- Step 5. CTOS modeling and simulation on the base of the expert's knowledge (blocks 1 and 3, fig. 1);
- Step 6. Analysis of the situation dynamic based on the multi-temporal Remote Sensing data treatment (block 6, fig. 1);
- Step 7. Predictive modeling of the step 5 results influence to ecological situation (block 5, fig. 1);
- Step 8. Crowdsoursing through the geo-informational portal application (blocks 1,3 and 4, fig. 1);
- Step 9. Automatic environmental assessment in the space ecological monitoring network (blocks 6 and 7, fig. 1);

Phase 3. Creation of the thematic layers and attributive information of the monitoring.

Analysis of the main trends for modern systems of the space monitoring indicates their peculiarities such as: multiple aspects and uncertainty of their behavior, hierarchy, structure similarity in the detection and recognition of the landscape elements, redundancy from the source data and variety of implementations for control functions. One of the main features of modern systems of the space monitoring is the variability of their parameters and structures due to objective and subjective causes at different phases of the system life cycle. In other words we always come across the system structure dynamics in practice.

4. EXAMPLE

Example demonstrates the integrated modeling and simulation of the CTOS described as the system of the space monitoring and inventory of the port maritime objects.

The integrated modeling and simulation application to the data collection, treatment and results presentation of the space monitoring and inventory of the port maritime objects determines the source of the data requirements, the monitoring frequency and efficiency.

A waters and territory of the maritime port are the complex objects. The state of these objects is described by simulation model based on the space imagery infrastructure.

An actual practice issues are resolved based on the space monitoring: the inventory and zoning of the waters, territory and port objects; a map and scheme actualization; the turnover of goods control; the ecological monitoring of the waters and territory of the port maritime; detection of the sources of the negative impact to environment.

The maritime, airborne, space and ground measures are used during the infrastructure monitoring.

On the base of the thematic treatment of the Remote Sensing data the tasks for the port maritime management are tested. CTOS is presented as original software for oil water pollutions, the dumps and garbage contamination, the vegetation stress identification and the actualization of the port objects inventory information. CTOS consists of the input RS data (block 3, fig.1), automatic RS data processing (blocks 1,3,4,5-9, fig.1) and results. The perturbation influences are presented by the control model parameters, that can be evaluated on the real data available in CTOS and parameters that can be evaluated via simulation models for different scenarios of future events.

Evaluated model parameters from block 3 include:

− type of the satellite system, above all spectral and spatial resolutions;

− square of the analyzable part of the maritime port waters and territory;

− square of the processing area of the space image.

Evaluated model parameters from blocks 1,3,4,5-9 include:

− threshold of some vegetation indexes;

− method of the classification, furthermore number of classes, distance function;

− method of the reclassification;

− threshold of the entropy;

− minimum inventory object dimension;

− minimum water and ground pollution dimensions;

− spectral radiance values from database.

Results include oil pollution, ship bilge water (fig. 3), dumps, stress vegetation outlines and actual data base of the characteristics of the port objects (fig. 4, 5) in geographic informational system.

Consequently, the method of the estimation and control of the models organization is determined.

Examples of the Remote Sensing monitoring and inventory of the port maritime objects are being illustrated on the website of the ESTLATRUS projects 1.2./ELRI-121/2011/13.

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Figure 3. Remote sensing identification of the ship bilge water

Figure 4. Inventory of the maritime port depositories based on the remote sensing data treatment

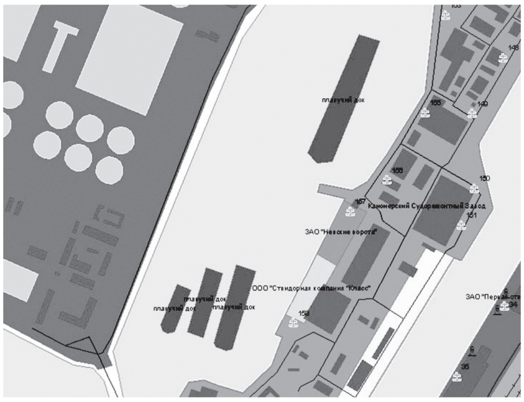

Figure 5. Inventory of the maritime port wet/dry docks based on the remote sensing data treatment and geoinformational system

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AUTHORS BIOGRAPHY

BORIS V. SOKOLOV obtained his main degrees in Mozhaisky Space Engineering Academy, Leningrad. MS in Automation Control Systems of Space Vehicles in 1974. Candidate of Technical Sciences subject the area of planning automation and decision making in 1982. Doctor of Technical Sciences subject the area of military cybernetics, mathematical modeling and methods in military research. Professional Interests: Basic and applied research in mathematical modeling 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 multi- criteria. At present he is a deputy director of SPIIRAS. His e-mail address is: sokol@iias.spb.su and his Web-page can be found at `http://litsam.ru`

VIACHESLAV A. ZELENTSOV obtained his main degrees in Mozhaisky Space Engineering Academy, Leningrad (1977). Ph.D Eng, Dr. Sc. Eng. and Prof., Leading researcher, Laboratory for Information

Technologies in Systems Analysis and Modeling, Head of Research Consulting Center for Space Information Technologies and Systems at SPIIRAS, professor and Director of Research and Education Center “AeroSpaceInfo” in St Petersburg State University of Aerospace Instrumentation. **Author of** more than 180 scientific paper, more over 50 research and engineering projects, 5 teaching books.

VICTOR F. MOCHALOV obtained his main education in Mozhaisky Space Engineering Academy, Leningrad (1986). Professional interests: treatment of the RS data, ecological monitoring and state value of the ecosystem, project management, mathematical models and methods of support and decision making.

SEMYON A. POTRYASAEV is PhD research fellow at the Russian Academy of Science, Saint Petersburg Institute of Informatics and Automation. He graduated from the Baltic State Technical University “VOENMEH” with a degree of control systems engineer and Moscow Institute of International Economic Relations as an economist in finance and credit. Research interests: applied research in mathematical modeling, optimal control theory, mathematical models and methods of support and decision making in complex organization-technical systems under uncertainties and multicriteria.

OLGA V. BROVKINA is PhD at the Herzen State Pedagogical University of Russia, St. Petersburg. She graduated from the St.Petersburg State University of Aerospace Instrumentation with a degree of control systems engineer and Institution of Russian Academy of Sciences Saint-Petersburg Scientific-Research Centre for Ecological Safety RAS (SRCES RAS) in the specialty of Aerospace research of the Earth and Photogrammetry. Professional interests: treatment of the RS data, ecological monitoring and state value of the ecosystem, applying the results of the RS data processing to the Forestry.

CONSIDERATION OF SOME PERFORMANCE OF CONTAINERS' FLOW AT YARD

Maja Škurić[(a)], Branislav Dragović[(b)], Nenad Dj. Zrnić[(c)], Romeo Meštrović[(d)]

[(a), (b), (d)] Maritime Faculty Kotor, University of Montenegro
[(c)] Faculty of Mechanical Engineering, University of Belgrade

[(a)] mskuric@ac.me, [(b)] branod@ac.me, [(c)] nzrnic@mas.bg.ac.rs, [(d)] romeo@ac.me

ABSTRACT
Performance of containers' flow at yard represents very important point of container terminals. The organization of container transport and stacking policies leads to less congestion and lower costs. Otherwise, containers wait in queue before they are serviced. This study presents an analytical approach for obtaining the average number of containers in queue. We proposed two models (constant and geometric) of bulk arrival multi-server queuing system. Traffic intensity and utilization factor are very important parameters that consist of data for arrival and service rate and number of servers (yard cranes). In this paper, we assume that there are three yard cranes that operate at container yard. A given numerical example for two models will improve the best values for performance of containers' flow at container yard.

Keywords: container yard, average number of containers in queue, bulk arrival, numerical example

1. INTRODUCTION

For determining the optimal capacity of a container yard, a maximum attention should be paid to the stacking policies defined by yard cranes. This is due to the accommodative capacity of the yard, expressed by the number of yard cranes, determining the required capacity of container yard as a whole. Applying queuing models, container yard can be treated as: a system with the infinite waiting capacity and determined number of yard cranes, a single or multi-server system (depending on the number of yard cranes), a system in which servicing is most often carried out according to the FCFS rule (first come, first served), but it is possible that there are certain containers which have priority in servicing and a system where containers must be serviced at once (Škurić, Dragović, and Meštrović 2011).

In this paper we calculate the average number of containers in queue at container yard. We assume that the containers are arriving in group at yard and follows constant or/and geometric distributions. Their service time follows the exponential distribution. In accordance to the extended Kendall's queuing notation, these two models may be denoted as $(M^{X=const}/M/c(\infty))$ for constant and $(M^{X=(1-a)^{k-1}a}/M/c(\infty))$ geometric distributions of container group arrivals. The number of assumed yard cranes is three. The level of traffic intensity and values of some other parameters are also stated. The objective is to describe these models for defining the strategies at yard and calculate the average number of containers in queue.

This paper is organized as follows. Literature review is given in Section 2, while in Section 3 the analytical formulations are provided. Related numerical results' analysis for obtaining the average number of containers in queue with corresponding graphical results is shown in Section 4. Final conclusions are given in Section 5.

2. LITERATURE REVIEW

Generally speaking, authors used queuing models (single or multiple) to describe the arrival and service processes of customers (ships) in ports. They are used to analyze complex dynamic and stochastic situations (see e.g. Dragović, Park, Zrnić, and Meštrović 2012). The models contain analytic formulations and numerical solutions for the performance evaluation of port systems. Various models from simple queues to complex queuing network models have been suggested to analyze: movement of ships in port, ship traffic modelling, mechanism of congestion occurrence, composition and congestion costs, evaluation method for optimal number of berths, optimum allocation and size of ports, optimal berth and crane combination in ports, average cost per ships served, the ship turn-around time at the port and so on. Regarding multiple queuing system, the authors presented in Table 1 have investigated bulk arrivals of the customers.

Their considered problems are based on the following statements: a comparison of analytical and simulation planning models, the analysis of a queue with bulk arrivals and bulk-dedicated servers, an analytical methodology of bulk queuing system that determines the capacity of berths within seaports and river ports, port storage locations as queuing systems with bulk arrivals and a single service, the optimal number of servers with bulk arrivals by minimizing the total costs of system, the anchorage-ship-berth link at the port utilizing queuing theory with bulk arrivals, a multi-server queue with bulk arrivals and finite-buffer space and queuing approaches at container yard with

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detailed analytical expressions and real case study (see e.g. Škurić, Dragović, and Meštrović 2011).

The importance of bulk queuing models for container terminal problem is explained in Kozan (1997). The analysis of a queue with bulk arrivals and bulk-dedicated servers is specified in Gullu (2004). In this paper, it is considered the $M/G/\infty$ queuing system with bulk arrivals whose jobs belong to a batch have to be processed by the same server. Similarly to this study, bulk arrivals are presented by pushed and pulled convoys of barges in Radmilović (1992). The queuing system describes that barges in convoy have a constant or geometric probability distribution. On the other hand, in Radmilović, Čolić, and Hrle (1996), the authors deal with the port storage locations with bulk arrivals and a single service. Finally, in Radmilović, Dragović, and Meštrović (2005) the aim was to minimize the total cost of system by determining the optimal number of servers. The processes of anchorage-ship-berth link at the port described by the non-stationary multi-server queuing system are presented in Dragović, Zrnić, and Radmilović (2006) and in Zrnić, Dragović, and Radmilović (1999). Likewise, partial and total bulk rejections and the distributions of the numbers of customers in the system for multi-server queue are explained in Laxmi and Gupta (2000). Again, the related literature overview is given in Table 1.

Table 1: Related Literature Overview

References	Considered problem	Results
(Radmilović 1992)	Analytical methodology of bulk queuing system.	Determined the optimum number and capacity of berths within seaports and river ports.
(Radmilović, Čolić, and Hrle 1996)	Bulk arrivals and a single service.	Port storage locations as queuing systems are solved.
(Kozan 1997)	A comparison of analytical and simulation planning models of container terminals.	The advantages of simulation are shown because it is able to capture all details and the complexity of a real system.
(Zrnić, Dragović, and Radmilović 1999; Dragović, Zrnić, and Radmilović 2006)	Analyzed the anchorage-ship-berth link utilizing queuing theory with bulk arrivals.	Determined cost ratio and total system cost.
(Laxmi and Gupta 2000)	A multi-server queue with bulk arrivals and finite-buffer space.	Partial and total bulk rejections and the distributions of the numbers of customers in the system are obtained.
(Gullu 2004)	The analysis of a queue with bulk arrivals and bulk-dedicated servers.	Considered the $M/G/\infty$ queuing system with bulk arrivals whose jobs belong to a batch have to be processed by the same server.
(Radmilović, Dragović, and Meštrović 2005)	Optimal number of servers in with bulk arrivals.	Minimized the total costs of system.
(Škurić, Dragović, and Meštrović 2011)	A multi-server queue with bulk arrivals.	Obtained average number of containers in queue and related cost ratio.
(Dragović, Park, Zrnić, and Meštrović 2012)	Discuss dynamic system performance evaluation in the river port utilizing queuing models with batch arrivals.	The results have revealed that analytical modelling is a very effective method to examine the impact of introducing priority, for certain class of ships, on the anchorage-ship-berth link performance.

3. ANALYTICAL FORMULATIONS

In this Section, we present the methodology that contains analytical formulations of parameters for calculating the average number of containers in queue. First, we start with obtaining the explicit formulae for steady-state probability that n containers are at the yard. After providing the probabilities of constant and geometric distribution of X in case when there is specified number of yard cranes, we give formulae for related numbers of containers in queue that corresponds to the mentioned probabilities. Finally, numerical example is used for sensitivity analysis of average number of containers in queue in relation to three parameters (number of containers in group, number of yard cranes and traffic intensity).

Traffic intensity of containers at yard is in dependence of their arrival and service rate, denoted as $\theta = \lambda / \mu$ where λ is the average arrival rate of containers in group and μ represents the average service rate of containers. These are serviced by yard cranes (c) which represent the number of servers. The average number of containers in group is given as $\overline{a}$ while the utilization factor for bulk queuing system is defined as $\rho = (\lambda \overline{a})/(c\mu)$. Notice that $\rho = (\theta \cdot \overline{a})/c$.

We consider a bulk arrival multi-server queue $M^X/M/c$ where the bulk size X is a constant or geometrically distributed random variable. The yard cranes have independent, exponentially distributed service times. The containers that arrive for service in groups X and the mean of X is equal to $E(X) = \overline{a} = 1/a$ and the variance of X is equal to $\operatorname{var} X = \sigma_a^2 = 1/a^2$. The case when X is a constant that

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is $P(X=b)=1$ for some fixed $b \in \{1,2,3,...\}$, then $E(X)=\bar{a}=b$ and $\sigma^2(X)=0$. The inter-arrival times, the bulk sizes and service times are mutually independent. It is known that a probability that containers are present in queuing system is (Chaudhry and Templeton 1983)

$$-\sum_{n=0}^{c-1} nP_n = c(Q_0 - \rho) \qquad (1)$$

where Q_0 is a probability that average number of containers that are present in a queuing system, L_c, are busy. The above formula immediately yields

$$\sum_{n=0}^{c-1}(c-n)P_n = c\left(\left(Q_0 + \sum_{n=0}^{c-1} P_n\right) - \rho\right) \qquad (2)$$

which in view of the fact that $Q_0 = \sum_{n=c}^{\infty} P_n$ becomes

$$\sum_{n=0}^{c-1}(c-n)P_n = c(1-\rho) \qquad (3)$$

where $\rho = \lambda\bar{a}/(c\mu)$ is the utilization factor. Following Chaudhry and Tampleton (1983),

$$L_c = L_q - c - \sum_{n=0}^{c}(n-c)P_n \qquad (4)$$

where P_n is steady-state probability that n containers are at the yard, i.e., that n containers are just being serviced or are waiting in a queue to be serviced. On the other hand, it is suitable to determine the probabilities P_0 and P_n using Kabak's recurrence formulae (Dragović, Zrnić, and Radmilović 2006; Kabak 1970; Škurić, Dragović, and Meštrović 2011). These probabilities follow recurrence relations:

$$P_n = y(n)\sum_{k=0}^{n-1} P_k A_{n-k}, \qquad n = 1, 2, ...$$

(5)

with

$$y(n) = \lambda / \mu(n), \; \mu(n) = \mu \min\{n, c\} \qquad (6)$$

and

$$A_{n-k} = 1 - \sum_{i=0}^{n-k-1} a_i \quad (A_1 = 1) \qquad (7)$$

where a_i is a probability that a group of i containers arrives in the bulk queuing system, $P(X=i)=a_i$, $i \ge 1$. Substituting (6) and (7) into (5), the probability P_0 is obtained as

$$P_0 = 1 - \rho - \frac{\sum_{n=1}^{c}(c-n)P_n}{c}. \qquad (8)$$

Furthermore, the average number of containers present in queuing system with c yard cranes is

$$L_c = \sum_{n=0}^{\infty} nP_n \qquad (9)$$

and it also holds for the bulk arrivals queuing system. Following Chaudhry and Templeton (1983),

$$L_c = \frac{\theta}{2}\cdot\frac{\sigma_a^2 + \bar{a}^2 + \bar{a}}{c - \theta\cdot\bar{a}} + \frac{\sum_{n=0}^{c-1} n(c-n)P_n}{c - \theta\cdot\bar{a}}. \qquad (10)$$

In the case when there are three yard cranes i.e. $c=3$, it is necessary to substitute $\bar{a} = 1/a$, $\sigma_a^2 = 1/a^2$ into (10) and (6), respectively. Also, for taking the values for geometric distribution of X with $P(X=k) = a_k = (1-a)^{k-1}a$, $k = 1, 2, 3 ...$, where $0 < a < 1$, and putting $A_k = 1 - \sum_{i=1}^{k-1} a_i = 1 - a\sum_{i=1}^{k-1}(1-a)^{i-1} = (1-a)^{k-1}$, $k = 1, 2, ...$ in (7), we obtain the formulae for P_k related to geometric distribution of X. The corresponding formulae for average number of containers in queue, P_k^{const} and P_k^{g} related to the constant and geometric distribution of batch size X, respectively, are as follows (Škurić, Dragović, and Meštrović 2011):

- The probabilities of constant distribution of X in case when $c=3$ yield

$$P_0^{const} = \begin{cases} \dfrac{2(1-\rho)}{2+4\rho+3\rho^2} & if\ b=1 \\ \dfrac{2b^2(1-\rho)}{2b^2+5b\rho+3\rho^2} & if\ b>1 \end{cases},$$

$$P_1^{const} = \begin{cases} \dfrac{6\rho(1-\rho)}{b(2+4\rho+3\rho^2)} & if\ b=1 \\ \dfrac{6\rho b(1-\rho)}{2b^2+5b\rho+3\rho^2} & if\ b>1 \end{cases},$$

$$P_2^{const} = \begin{cases} \dfrac{9\rho^2(1-\rho)}{b^2(2+4\rho+3\rho^2)} & if\ b=1 \\ \dfrac{9\rho^2(1-\rho)}{2b^2+5b\rho+3\rho^2} & if\ b>1 \end{cases} \quad \text{and}$$

$$P_3^{const} = \begin{cases} \dfrac{9\rho^3(1-\rho)}{b^3(2+4\rho+3\rho^2)} & if\ b=1 \\ \dfrac{9\rho^3(1-\rho)}{2b^3+5b^2\rho+3b\rho^2} & if\ b>1 \end{cases}. \qquad (11)$$

- The probabilities of geometric distribution of X in case when $c=3$ are

$$P_0^{g} = \frac{2(1-\rho)}{2+a(5-a)\rho+3a^2\rho^2},$$

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$$P_1^g = \frac{6a\rho(1-\rho)}{2+a(5-a)\rho+3a^2\rho^2},$$

$$P_2^g = \frac{3a\rho(1-\rho)(1-a+3a\rho)}{2+a(5-a)\rho+3a^2\rho^2} \text{ and}$$

$$P_3^g = \rho a\left(\left(1-a^2\right)+\frac{9\rho a(1-a)}{2}+\frac{9\rho^2a^2}{2}\right)P_0 . \qquad (12)$$

- Related numbers of containers in queue that corresponds to the probabilities given by (11) and (12) are

$$L_3^{const} = \frac{14\rho+10\rho^2-15\rho^3}{(2+4\rho+3\rho^2)(1-\rho)} \text{ if } b=1,$$

$$L_3^{const} = \frac{18\rho(b+\rho)}{2b^2+5b\rho+3\rho^2}+\frac{\rho(b+1)}{2(1-\rho)} \text{ if } b>1 \qquad (13)$$

and

$$L_3^g = \frac{6a\rho(3+3a\rho-a)}{2+a(5-a)\rho+3a^2\rho^2}+\frac{\rho(2+a)}{2a(1-\rho)} . \qquad (14)$$

4. NUMERICAL RESULTS' ANALYSIS

The numerical example is in relation to container terminal in port of Bar, Montenegro. The container terminal throughput from 2008 to 2012 is given in Figure 1 (PBR 2012). The biggest throughput of 43708 TEU is reached in 2008. We observe that the container yard is consisted of three yard cranes that serve for container stacking. Tractor trailer system and fork lifters are used for terminal transport of containers from berth to yard and vice versa.

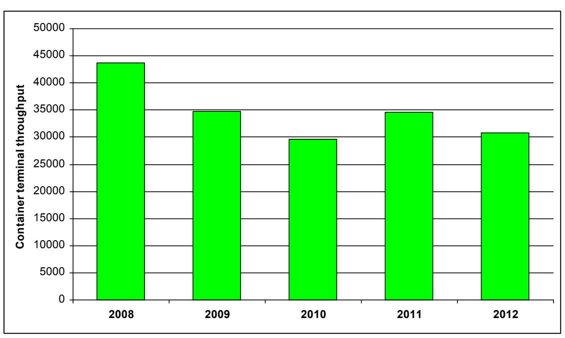

Figure 1: Container terminal throughput in port of Bar

At time, container terminal in port of Bar is consisted of one berth and one quay crane for servicing the container ships. The maximum carrying capacity of container ships is 4000 TEU. There are also the rail and road vehicles for inland connection (Škurić, Dragović, and Meštrović 2011). The input data for the analytical models are based on the actual containers' arrivals at the terminal of port of Bar where we assumed that the containers' arrivals fit constant or geometric distribution.

Using formulae (13) and (14), in Figures 2 and 3 we compare the values for the average number of containers in queue which are in function of traffic intensity for $\overline{a}=b=2$ and $\overline{a}=b=4$ with constant and geometric distribution. The graphs are obtained in *Mathematica* 8. Considering Figure 2, the input data such as average number of containers in group $\overline{a}=b=2$ is specified as well as the different values of traffic intensity are from $\theta=0.1$ to $\theta=1.3$ while the number of yard cranes is 3.

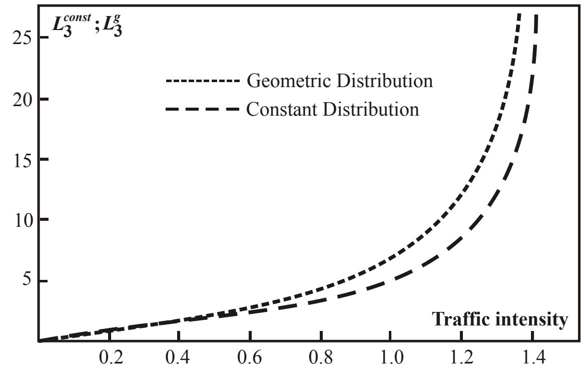

Figure 2: Average Number of Containers in Queue for Constant and Geometric Distributions of X with $\overline{a}=b=2$, $c=3$ and $\theta\in(0,1.3)$

From Figure 2, we can notice that the results for average number of containers in queue are in function of three different parameters (average number of containers in group, traffic intensity and number of yard cranes) and may serve to see related parameters for comparing results for constant and geometric distributions. The increase of average number of containers in queue causes higher traffic intensity of containers at yard. Therefore, for the same traffic intensity, the average number of containers in queue for geometric arrivals of containers implies higher values then those for constant distribution.

The results for average number of containers in queue in the case of $\overline{a}=b=4$ are given in Figure 3 with the same number of yard cranes as in the first case and traffic intensity values are from $\theta=0.1$ to $\theta=1.3$. Obviously in Figure 3, the values for geometric distributions are more dynamic and are increasing faster then those for constant distributions. It means that in case that the group arrivals of containers have its behaviour by constant distribution; it implies that the average number of containers in queue is lower in comparison to the geometric distributed containers' arrivals with the same value of traffic intensity.

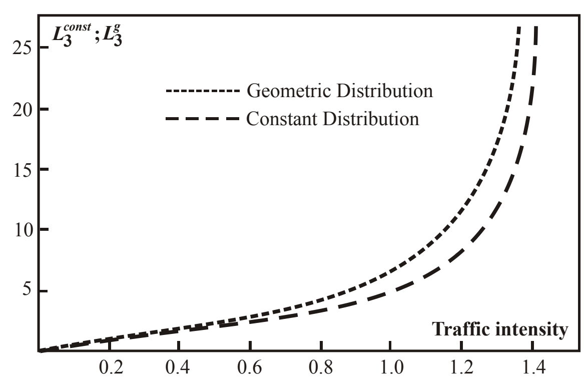

Figure 3: Average Number of Containers in Queue for Constant and Geometric Distributions of X with $\overline{a}=b=4$, $c=3$ and $\theta\in(0,1.3)$

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5. CONCLUSION

The numerical results' analysis for different values of parameters for presenting the performances of containers' flow at container yard in port of Bar leads to the following conclusions:

- The dynamical arrivals of containers in accordance to constant distribution showed better results in the view of average number of containers in queue which may lead to less congestion in comparison to the geometric distributed containers' arrivals.
- As a matter of fact that Figure 1 implies that there would not be huge fluctuations in container terminal throughput in coming years, this suggests that the level of traffic intensity will not be drastically changed and that assumed values in numerical example represent the real situation in port.
- The values of average number of containers in queue directly impact on specific cost ratio of total annual cost for queuing system to the annual container cost and total system costs.
- The obtained results suggest that the operational strategy at container yard can be improved by reducing the average number of containers in queue. This can be evaluated through the employment of another yard crane or to observe other group arrivals of containers.

On the other hand, this analysis also has some limitations. There are a lot of parameters that did not taken into account, but no matter to that, we suppose that it represents a convenient approach for implementing some other modelling techniques and in some further investigations simulation model employment would be able to capture the complexity of a real system such as container yard.

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AUTHORS BIOGRAPHY

Maja Škuric is a PhD student at Maritime Faculty, University of Montenegro. After graduations, she started to work as a Teaching Assistant at the same faculty. She received her Master of Science degree at Faculty of Transport and Traffic Engineering, University of Belgrade. Up to now she published more then 30 conference papers and few journal papers. Her main research interests are related to modelling and optimizing processes at container terminals and lastly she included the cruise ship traffic modelling in her interests. These topics are mainly concerned with the investigations of queuing systems, planning transportation systems and operations research in transport.

Branislav Dragović is a Professor at the Maritime Faculty, University of Montenegro. He received his BSc and MSc at Maritime Transport and Traffic. Further, he received his PhD from Faculty of Mechanical Engineering, University of Belgrade with specialization on planning and design of transport systems. He was a Visiting Professor of the Korea Maritime University from 2006 to 2007. He was invited as a Lecturer in the country and abroad many times. He has published over 130 scientific papers including ones in journals such as Journal of Waterway, Port, Coastal and Ocean

Engineering; Maritime Economics and Logistics; Maritime Policy and Management; Mathematical Problems in Engineering among others. He has written four books, three national and two international monographs. He was quoted many times. He is a member of IAME and WCTRS.

Nenad Zrnić is Associate Professor at the Faculty of Mechanical Engineering of the University of Belgrade. He received engineering degree Dipl.-Ing. (equivalent to MSc) from the UB, FME in 1992, MagTechSc (equivalent to CSc) in 1996 at the same institution. He received his DrSc from the Faculty of Mechanical Engineering, University of Belgrade in 2005 with in material handling equipment in ports and terminals. He is a reviewer in the journals Mechanics Research Communications (SCI), Mechatronics (SCI), Natural Hazards and Earth System Sciences (SCI), among others. He has published over 120 scientific papers in the country and abroad, among them 15 in world's leading journal (SCI). He presented 7 invited plenary lectures at international conferences. He wrote 1 national monograph, 1 international monograph and 1 book. He was quoted several times.

Romeo Meštrović is a Professor of Mathematics at University of Montenegro. He received his BSc from the University of Zagreb and his MSc and PhD from the University of Montenegro, in the area of mathematics. His topics are complex analysis, combinatorial number theory, operation researches and queuing theory in transport systems. He has published more than 20 papers in academic journals such as Journal of Mathematical Analysis and Applications, Journal of Inequalities and Applications, Ars Combinatoria, American Mathematical Monthly etc.

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THE NETWORK DESIGN OF CHINA'S NORTHEAST COLD CHAIN

Nam Kyu Park[(a)], Woo Young Choi[(b)], Jian Hui[(c)]

(a) Professor, Department of International Logistics, Tongmyong University, Korea
(b) Doctoral student, Department of Port Logistics System, Tongmyong University, Korea
(c) Researcher, Department of Port Logistics System, Tongmyong University, Korea

[(a)]nkpark@tu.ac.kr, [(b)]cwy1228@tu.ac.kr , [(c)]buyka@tu.ac.kr

ABSTRACT

Yet logistics base in China has a refrigerated storage facilities installed areas, the number of those is very limited and is generally insufficient. According to these especial points, a new construction cold chain logistics network design strategy is required from how to use the existing refrigerated warehouses to new issue.

For example, however refrigerated storage facility is supplied, can it satisfy all demand of this area? Then does it have optimized location of this area? If future demand expansion, adding that already other refrigerated storage facilities matter? Or, add another refrigerated facilities, optimum cold chain established a network matter? So on. Above problems can be occurred. In order to solve facing many of these issues of distribution network, northeast area in China has been selected as a subject, and we designed a new cold chain distribution network.

Keywords: Cold chain, Integer programming, Logistics network design, Logistics cost

1. INTRODUCTION

In 2012, China recorded gross domestic product of CNY 353,480 (by September) and a growth rate of 7.7% from the same period last year. Although the speed of China's economic growth has slightly slowed down from the past, the country's economic growth continues to display a trend of increase based on the domestic demand (especially consumption). In line with the expansion of domestic market, China's international trade is also increasing.

According to an announcement of Chinese Meat Association, 2011 in China recorded 894,000 tons of meat export and a growth rate of 1.1% from the same period in the previous year. However, the country's import increased by 23.1% from the previous year to 1.905 million tons. As a result of an increase in the domestic meat demand, China's domestic price continuously increased, leading to a trend of increase in the country's meat import as a preparatory measure. Logistics business to import, store and transport frozen food is an attractive business. However, foreign logistics companies are facing difficulties as they endeavor to enter China's frozen logistics market due to lack of facilities and inferior road conditions in China. In other words, although the frozen food consumption increases in line with an expansion of China's domestic frozen freight market, According to report of China Warehousing Association, China is recording a loss of CNY 100 billion or more a year due to a lack of cold chain infrastructures in the country. At present, China uses discarded refrigerated containers that have previously been used in ships. These containers do not produce proper refrigeration function. In addition, there are no vehicles especially designed for container transportation. All of these factors add to difficulties in successful cold chain operation. In other words, refrigeration technology for transport using general vehicles is inferior and this leads to problems in keeping standard freshness of products, and thus in logistics and distribution of frozen food items.

As a result of such problems, refrigerated freight transport in China accounts for only around 10 - 20% of total transport freight, which is significantly lower than 80 - 90% in the advanced countries in Europe as well as the U.S. and Japan. As of 2011, the area of refrigerated and frozen storage facilities in China measures 70 million square meters. This is far insufficient to satisfy the refrigerated transport market demand. The annual average increase rate of refrigerated and frozen facilities construction in 2009~2011 is 7.94% and most constructions are to build large-scale storage facilities. The performance of refrigerated and frozen facilities construction for wholesale and retail business is unsatisfactory as a whole.

This study targets the northeastern part of China and aims at solving the problems of logistics network design to distribute imported frozen meat products that enter the country through Dalian Port at the minimum cost. The problems in logistics network design are as follows.

1) To select distribution center locations?
2) To decide the number of distribution centers?
3) To decide the size of distribution centers?
4) To decide which of the central and regional distribution centers are to distribute which products at which level?
5) To decide which products are to be distributed at which level from regional distribution centers to consumers?

For designing of a cold chain logistics network for a foreign invested logistics company that enters the refrigerated distribution market in China, the purpose of this study is to propose the optimal solution for a cold chain logistics network that minimizes the total cost.

2. LITERATURE REVIEW

Studies on logistics network design using a deterministic model have been developing since a study by Geoffrion et al. (1974) On a design of a logistics network for multiple products. This model has since expanded to studies on more realistic issues, such as growth, storage and distribution. On the subject of a logistics network design, a number of studies have been conducted in relation to single/multiple-step network, multi-stage network, ability restraining network and single/ multi-product network.

Studies on the single-step facility locations without limitations in facility capacity were conducted by Melkote and Deskin (2001)

In addition, studies on multi-stage facility locations with capacity limitations were conducted by Chardaire et al. (1999) and studies on facility locations for multiple products were conducted. Brown et al. (1987) suggested a mixed integer programming model for production and distribution system of multiple products and implemented it in a similar decomposition method as of the algorithm of Geoffrion et al. (1974)

In addition, Cohen et al. (1988) studied a mixed integer programming method for a network flow model of multiple products in order to find an optimal product flow in the integrated logistics.

Studies conducted over a number of periods of times were conducted by Beamon et al. (2004) and Melachrinodis et al. (2000) conducted a study to design a multi-period and multi-purpose mixed integer programming model to suggest the optimal relocation bases.

This study was differentiated from the existing studies as it took into consideration the multi-layer network design and dynamic aspects.

There are other studies on implementation of a logistics network design in the form of hub and spoke. These studies are divided into the cases of

Amiri (2006) conducted a study focusing on the issues of distribution network design in logistics system. This study also used the mixed integer programming model and suggested a heuristic solution.

Fleischmann et al. (2006) studied the issues concerning supply of materials and distribution of finished products in the global market over a long period of time by suggesting a strategic programming model for optimized allocation of BMW's diverse products.

Hugo and Pistikopoulos (2005) conducted a study focusing on the issues of production capacity expansion and transportation-linked allocation to satisfy market demands, and thus suggested materials flow and production profile that are optimized to various layers within the logistics network.

Ko and Evans (2007) mentioned that 3PL companies must determine orders of the related decision-making processes for customers who want improvement in the forward and recovery logistics systems and suggested the mixed integer nonlinear programming for an integrated dynamic logistics network design to achieve forward and recovery logistics integration and optimization.

Melachrinoudis and Min (2000) conducted a study to assess implementation possibility of the multi-period and multi-purpose mixed integer nonlinear programming within dynamic changes in regions that have been proposed from a viewpoint of supply network. In the 2000s, a number of studies considering issues of both the location selection and inventory were conducted by Teo et al. (2004) suggested a set-covering model to design a network between distribution centers and retailers under a determinate demand of retailers, while Daskin et al. (2002) suggested a set-covering model to create the optimal logistics with inventory cost and that their studies could be carried out more efficiently when demand of each distribution center was determinate or in Poisson distribution.

Dogan and Goetschalckx (1999) suggested a mixed integer linear model targeting multiple products for integrated logistics design and used Bender's decomposition algorithm to solve large-scale problems.

Erlebacher and Meller (2000) studied a model to minimize transportation cost between retailers and distribution centers and between manufacturers and distribution centers and inventory cost, fixed cost and operating cost in distribution centers.

Eskigun et al. (2005) studied a logistics network design considering the selection of transportation means, selection of distribution center locations and the required time and suggested a solution more efficient than the rationally calculated time as a Lagrangian heuristic model.

The previous studies on logistics network design focused on the initial-phase design of the existing logistics networks and a majority of them aimed at minimizing transportation cost as well as costs associated with facility capacity and vehicle routes considering several characteristics. However, there is still a lack of optimized model design that preferentially takes into consideration the overall cost within the range of study in addition to individual costs incurring in logistics network design. Accordingly, this study attempted at designing optimal networks under two scenarios where the existing refrigerated facilities are used while customers' demand fluctuations based on constrain conditions, the variable costs and the fixed costs are compositely taken into consideration and where the existing facilities are used without considering these factors.

3. LOGISTICS NETWORK MODEL DESIGN

3.1. Logistics Network Model Design

The main purpose of this study is to minimize logistics cost between nodes and links in solving the problems of cold chain logistics network design in the northeastern part of China. For freights gathered from producing districts through CDCs, the issue is limited to the problem of selecting RDCs from the candidates, which is solved using an object function on logistics cost minimization. In this study, the cold chain logistics network analysis in the northeastern part of China was modeled as shown in [Fig.1]

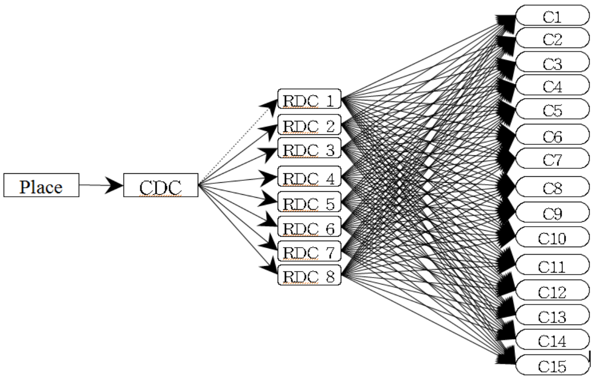

Figure 1: Logistics Network Flow

3.2. Minimum Cost Calculating Formula

The scope of this study consists with various nodes from producing districts to CDCs and from places of import through RDCs to demand areas. In this study, customers are selected as places of demand and logistics cost is comprised of transportation cost between each node and the fixed cost of RDCs.

The purpose of this study is to find RDCs and logistics network that minimize the total logistics cost. The optimal RDC selection lead to implementation of a logistics network and the formula to calculate the minimum logistics network cost is expressed as of the following.

$$\textbf{minimize} \sum_{ijkl} C_{ijkl} X_{ijkl} + \sum_{k} [F_k \; Z_k + V_k \sum_{l} \left(\sum_{i} D_{il} \right) Y_{kl}$$

This is a model formulation for a problem of multi-variety warehouse location using mixed integer linear programming method.

Constraining Factors:

The usable production capacity cannot be exceeded.

$$\sum_{kl} X_{ijkl} \; \leq \; S_{ij} \text{ for all } ij$$

All demands must be satisfied.

$$\sum_{j} X_{ijkl} \; = \; D_{il} Y_{kl} \text{ for all ikl}$$

Each consumer must be supplied with products from a single warehouse.

$$\sum_{k} Y_{kl} = 1 \text{ for all } l$$

Warehouse processing amount must be kept between $\underline{V}_k$ and $\overline{V}_k$

$$\underline{V_k} \leq \sum_{l} (\sum_{i} D_{il}) Y_{kl} \; \leq \; \overline{Y_k}$$

And, For all $X_{s,}$ $X \geq 0$

For all $Y_{s,}$ $Y = 0 \; or \; 1$

For all $Z_{s,}$ $Z = 0 \; or \; 1$

Where,

i = Number of item

j = Number of CDC

k = Number of RDC

l = Number of demand area

$\underline{V_k}, \overline{V_k}$ = RDC point *k* for the min. and max. allowed annual retention and operating cost

F_k = Fixed cost at RDC point k (fixed cost of the annual retention and operating cost)

V_k =Variable cost at RDC point *k* (variable cost of the annual retention and operating cost)

C_{ijkl} =Average unit cost in production, landing and transportation process from CDC *j* through RDC *k* to customer area *l*

X_{ijkl} =Transport amount of item *i* from CDC *j* through RDC *k* to customer area *l*

Y_{kl} =1 if warehouse *k* handles supply for customer area *l*, 0 if not

Z_k =1 if warehouse *k* is open 0 if not

3.3. Logistics Cost Calculating Method

In this study, the total logistics cost is comprised of fixed and variable costs. Fixed cost is divided into depreciation cost of warehouses, capital cost, insurance premium, sales and administrative cost and labor cost. Variable cost consists of handling and transportation cost, which fluctuates according to land transportation cost by distance and the amount of demand. A hierarchical structure of total logistics cost [Fig. 2].

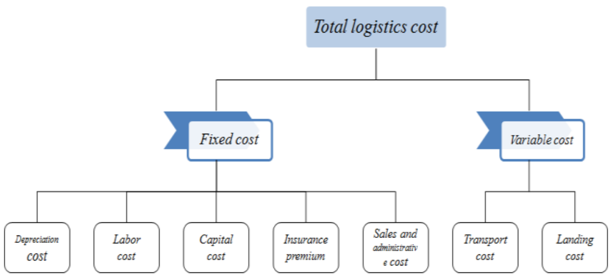

Figure 2: Structure of total logistics cost

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4. BASIC DATA COLLECTION

4.1. Demand in Each Demand Area

To find demand in each demand area, data outlining the amounts of frozen food consumption in each city were obtained. To calculate the amount of demand for imported frozen meat foods, the national daily average consumptions per person and total number of customers in each demand area were found. In addition, the ratio of meat food export to import in China was assumed as 5:5. As for the import of meat, it was assumed that the products are imported frozen, and thus the percentage of frozen meat to total amount of imported meat is 100%. Accordingly, the total annual demands in each demand area were estimated as the total amounts of import and annual average meat consumption per person is calculated as the total of annual average consumption of beef, pork and poultry that are mainly consumed in China.

Table 1: Annual Consumption by City

Unit: Ton

Consumption	Population (10,000 persons)	Annual Average Mean Consumption per Person	Imported/ Exported Meat Ratio	Frozen Meat to All Imported Meat	Demand
Dalian	303.4	0.03517	50%	100%	53,307
Yingkou	89.85	0.03517	50%	100%	15,800
Anshan	147.05	0.03517	50%	100%	25,858
Liaoyang	73.91	0.03517	50%	100%	12,997
Benxi	95.33	0.03517	50%	100%	16,763
Shenyang	513.83	0.03517	50%	100%	90,357
Fushun	138.70	0.03517	50%	100%	24,390.
Tieling	44.64	0.03517	50%	100%	7,849
Dandong	78.88	0.03517	50%	100%	13,871
Panjin	60.82	0.03517	50%	100%	10,695
Fuxin	77.79	0.03517	50%	100%	13,679
Jinzhou	93.36	0.03517	50%	100%	16,417
Chaoyang	58.68	0.03517	50%	100%	10,318
Huludao	99.56	0.03517	50%	100%	17,507
Qinhuang dao	84.50	0.03517	50%	100%	14,859
Total Demand	-	-	-	-	344,673

Source: 1) China City Statistical Yearbook, National Statistics of china, 2011.
2) Meat industry, second five development plan, China Meat Association, 2012.

4.2. Land Distance to Each Demand Area

The inland transportation cost is calculated with freight charges per ton - kilometer and distances. The results of measuring land distances to each demand area are listed in <Table 3>. For simple expression, names of the cities have been expressed with codes (see <Table 2>) Use the style labeled with "List 1" to create an enumerated list. Insert one blank line before starting the list.

Table 2: Input Code per City

Input Code per City					
DL	Dalian	SY	Shenyang	FN	Fuxin
YK	Yingkou	FS	Fushun	JZ	Jinzhou
AS	Anshan	TL	Tieling	CY	Chaoyang
LY	Liaoyang	DD	Dandong	HL	Huludao
BX	Benxi	PJ	Panjin	CH	Qinhuangdao

Names of 14 cities, the demand areas, were converted into codes. Then, land distances to and between each cities were measured as shown in <Table 3>

Table 3: Expressway and urban road network

Unit: km

	DL	YK	AS	LY	BX	SY	FS	TL	DD	PJ	FN	JZ	CY	HL	CH
DL	0														
YK	220	0													
AS	292	84	0												
LY	319	110	30	0											
BX	388	177	97	73	0										
SY	386	179	95	69	78	0									
FS	431	214	134	108	84	46	0								
TL	458	249	165	139	143	73	59	0							
DD	330	280	232	237	205	282	289	348	0						
PJ	260	61	97	122	192	155	201	228	324	0					
FN	435	205	186	194	262	205	251	244	419	143	0				
JZ	363	144	184	216	279	234	284	312	482	93	112	0			
CY	480	250	291	297	365	308	354	373	517	200	141	106	0		
HL	418	187	229	262	324	283	329	356	454	137	164	52	127	0	
CH	585	371	396	422	529	453	457	523	621	314	331	219	294	167	0

Source: China Expressway and urban road network, Shandong Province Map Publishing, 2011

4.3. Freight Charge per Ton-Kilometer

The freight charges for road transportation in China are calculated by dividing freights into grade 1, 2 and 3 general freights and hazard goods. Freight charges vary according to the item grade (See <Table 4>).

Table 4: Road Freight Grades

Road Freight Grades			
Grade 1	Grade 2	Grade 3	Hazard Goods
Coal, sand, stones and rocks,	Sand, water, grasses, cement	Oils, marble, rubber	Oils, explosive, fuses

Source: http://wenku.baidu.com/view

Freight charges for road transportation are as shown in <Table 5>. In this study, freight charges for each demand area are calculated based on long-distance transportation of 30km or more.

Table 5: Freight Charges according to Freight Grade

Unit: CNY(ton/km)

Grade & distance	Grade 1	Grade 2	Grade 3	Hazard Goods
1Km	1.75	2.013	2.275	2.625
5Km	0.88	1.012	1.144	1.32
10Km	0.76	0.874	0.988	1.14
15Km	0.66	0.759	0.858	0.99
20Km	0.56	0.644	0.728	0.84
25Km	0.46	0.529	0.598	0.69
30Km or more	0.35	0.400	0.460	0.53

4.4. Handling Cost

Handling cost is paid by ton of loading and unloading works. The standard landing tariffs in China are as shown in <Table 6>. Han cost varies according to the item type. In this study, which focuses on frozen foods, the landing cost for grade 2 freights (4.4/ ton) is applied.

Table 6: Landing Tariff

Unit: CNY/Ton

	Loading Cost	Unloading Cost	Total Landing Cost
Grade 1	1.8	1.2	3.0
Grade 2	2.2	2.2	4.4
Grade 3	4.0	3.8	7.8
Hazard Goods	4.0	3.8	7.8

5. OPTIMAL CALCULATION

5.1. Using Existing Refrigerated Logistics Warehouses in Dalian

When selecting three RDS, the selection would be carried out considering two already decided RDCs. For a solution with which the total logistics cost is minimized, RDCs in Dalian, Shenyang and Yingkou were selected. The total logistics cost in this case is CNY 91,268,719, which is lower than the cases where one RDC (Dalian) and two RDCs (Dalian and Shenyang) are selected. The logistics network composition is as shown in [Fig 3]

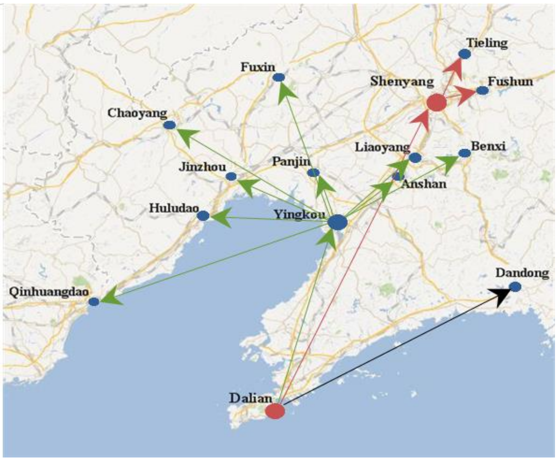

Figure 3: Logistics Network Composition when 3 RDCs are selected

Constraint conditions in this case are as follows. First, sizes of warehouses in Dalian, Shenyang and Yingkou (W1, W2 and W3) must satisfy total demand in each consumption area.

Second, ① Constraint condition is applied with actual volume of the existing refrigerated warehouses in Dalian (70,000 tons/ year), ② Constraint condition is applied with actual volume of the existing refrigerated warehouses in Shenyang (172,400 tons/ year).

Third, three out of eight RDCs are selected and the formula is as follows.

$$zW1+zW2+zW3+zW4+zW5+zW6+zW7+zW8 = 3$$

When selecting three RDCs, if RDCs in Dalian and Shenyang are the existing refrigerated warehouses of fixed capacities, the selection is limited to actual capacity of each warehouse. Aa for Yingkou, a condition that a single RDC can satisfy demand of the entire area was set. In this case, freights are sent to Dalian and Shenyang for as much as the available capacity of the proposed warehouses. On the other hand, all freights can be sent to Yingkou RDC. The results estimated using an optimization model also indicate a fixed capacity (Dalian and Shenyang) and a maximum capacity (Yingkou) rather than an appropriate capacity of the three RDCs. Therefore, the capacity of warehouses in Dalian, Shenyang and Yingkou are adjusted and the fixed costs are calculated again. The results of calculating fixed/ variable costs and total logistics cost are as shown in <Table 7>

Table 7: Transportation Amounts in 3 RDCs and Logistics Cost Calculation Results

Unit: CNY/Ton

3 RDC	Transportation Amount	Fixed Cost	Variable Cost	Logistics Cost
Dalian→ Dalian	53,307	21,225,420	895,558	
Dalian→ Dandong	13,871		2,002,972	
Shenyang→ Shenyang	90,357	14,753,412	14,348,690	
Shenyang→ Fushun	24,390		4,321,908	
Shenyang→Tieling	7,850		1,475,800	
Yingkou→ Yingkou	15,800	8,430,024	1,459,920	
Yingkou→Anshan	25,859		3,258,234	
Yingkou→ Liaoyang	12,997		1,772,791	
Yingkou→ Benxi	16,764		2,735,885	
Yingkou→ Panjin	10,695		1,249,176	
Yingkou→ Jinzhou	16,417		2,462,550	
Yingkou→ Fuxin	13,679		2,385,618	
Yingkou→ Chaoyang	10,319		1,985,376	
Yingkou→ Huludao	17,508		2,927,337	
Yingkou→ Qinhuangdao	14,859		3,578,048	
Total	344,672	44,408,856	46,859,863	91,268,719

5.2. Selecting Optimal Warehouse Position without Taking into Consideration the Existing Refrigerated Warehouses

If the existing refrigerated warehouses are not taken into consideration, Yingkou is selected as the optimal solution. In designing an optimal logistics network, the total logistics cost is estimated as CNY 69,199,910. This is lower than a case where Dalian is selected as the solution. The logistics network composition is shown in [Fig. 4].

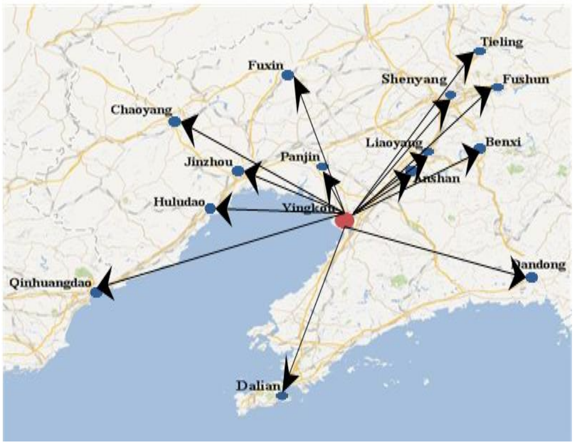

Figure 4: Logistics Network Composition when 1 RDC is Selected (2)

In case of a one RDC, the total logistics cost was estimated as CNY 69,199,910 based on calculations of transportation amounts, variable costs and fixed costs in each consumption area. The results of total logistics cost calculation are as shown in <Table 8>.

Constraint conditions in this case are as follows. First, sizes of warehouses in Yingkou (W3) must satisfy total demand in each consumption area.

Second, the following formula must be satisfied by selecting one distribution center in Yingkou out of eight RDCs

$$zW1+zW2+zW3+zW4+zW5+zW6+zW7+zW8 = 1$$

Table 8 Transportation Amounts in 1 RDC and Logistics Cost Calculation Results

Unit: CNY/Ton

1 RDC	Transportation Amount	Fixed Cost	Variable Cost	Logistics Cost
Yingkou-Dalian	53,307	12,052,764	9,829,811	
Yingkou-Shenyang	90,357		14,818,550	
Yingkou- Yingkou	15,800		1,459,920	
Yingkou- Anshan	25,859		3,258,234	
Yingkou-Liaoyang	12,997		1,772,791	
Yingkou- Benxi	16,764		2,735,885	
Yingkou-Panjin	10,695		1,249,176	
Yingkou-Jinzhou	16,417		2,462,550	
Yingkou-Fushun	24,390		4,341,420	
Yingkou-Teiling	7,850		1,507,200	
Yingkou-Dandong	13,871		2,835,232	
Yingkou-Fuxin	13,679		2,385,618	
Yingkou-Chaoyang	10,319		1,985,376	
Yingkou-Huludao	17,508		2,927,337	
Yingkou-Qinhuangdao	14,859		3,578,048	
Total	344,673	12,052,764	57,147,148	69,199,912

6. OPTIMAL TREND OF TOTAL LOGISTICS COST ACCORDING TO CHANGES IN RDC COUNT

6.1. Using Existing Refrigerated Warehouses in Dalian and Shenyang

When the existing refrigerated warehouses in Dalian and Shenyang are taken into consideration, the fixed costs display a trend of a decrease and then an increase according to changes in the number of RDCs. When one and two RDCs are selected, the total logistics cost is higher than when three RDCs are selected. This is because, first, a large amount of demand exists in Dalian and Shenyang and, second, the fixed costs in Dalian and Shenyang are high. Therefore, fixed costs increase when one and two RDCs are selected and then decrease when three RDCs are selected.

It picks up an upward trend and continues the increase when four or more RDCs are selected. As for variable costs, they decrease significantly when one, two and three RDCs are selected. Then, the value gradually drops when four or more RDCs are selected. This pattern corresponds to the phenomenon detected in this study. The trend of total logistics cost according to changes in RDC count is shown in [Fig. 5]

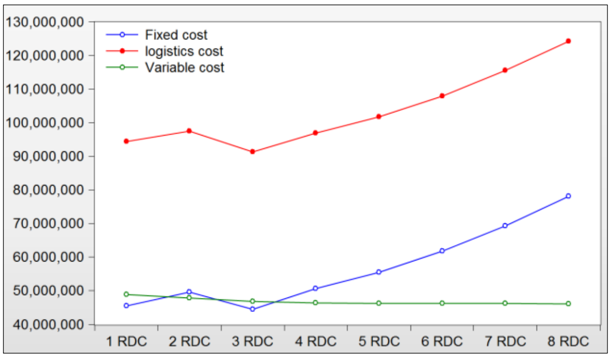

Figure 5: Total Logistics Cost Fluctuation according to Changes in RDC Count (1)

6.2. Using Existing Refrigerated Warehouses in Dalian and Shenyang

When the existing refrigerated warehouses in Dalian and Shenyang aren't taken into consideration, fixed costs display a trend of continuous increase according to changes in the RDC count. Variable costs significantly decrease when one and two RDCs are selected. Variable costs decrease slightly when two-seven RDCs are selected and then again start to decrease significantly when eight RDCs are selected. Total logistics cost increases continuously as the number of RDCs increases. Therefore, the case of one RDC selection is estimated as an optimal solution. The trend of total logistics cost according to changes in RDC count is as shown in [Fig. 6]

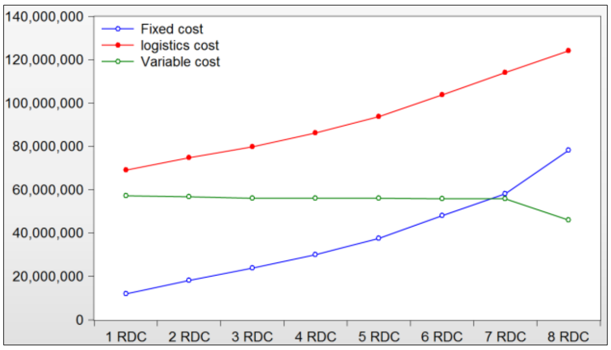

Figure 6: Total Logistics Cost Fluctuation according to Changes in RDC Count (2)

7. CONCLUAION

This study aimed at demonstrating the significant contributions of cold chain network design to logistics base network optimization. In China, frozen food imports increase rapidly in line with an expansion of the domestic market for cold chain products. Accordingly, the country faces a necessity of a cold chain logistics network design. Some logistics bases in China have refrigerated and frozen warehouse facilities installed. However, the number is extremely limited and the facilities are insufficient as a whole. Accordingly, China is in need of various strategies for cold chain logistics network design that cover from a method using the existing refrigerated warehouses to a method of building new facilities. For example, it is necessary to address such problems as which refrigerated warehouse facilities can satisfy total demands of the respective areas, whether the facilities are built on optimal locations in the respective areas and, in case of expansion in future demand, if it is necessary to establish an optimal cold chain network by adding to the existing refrigerated facilities or building other facilities. In this study, a cold chain logistics network was designed targeting the northeastern part of China in order to solve such issues in the logistics network. The effects of the optimized cold chain network solution derived from this study are summarized as of the following. First, if the existing refrigerated warehouses in Dalian and Shenyang are taken into consideration, fixed costs display a trend of a decrease and then an increase according to changes in the RDC count. In addition, the total logistics cost is higher when one and two RDCs are selected than when three RDCs are selected. This is because, first, a large amount of demand exists in Dalian and Shenyang and, second, the fixed costs in Dalian and Shenyang are high. Therefore, fixed costs increase when one and two RDCs are selected and then decrease when three RDCs are selected. It picks up an upward trend and continues the increase when four or more RDCs are selected. As for variable costs, they decrease significantly when one, two and three RDCs are selected. Then, the value gradually drops when four or more RDCs are selected. This pattern corresponds to the phenomenon detected in this study.

Second, when the existing refrigerated warehouses in Dalian and Shenyang are not taken into consideration, fixed costs display a trend of continuous increase according to changes in the RDC count. Variable costs significantly decrease when one and two RDCs are selected. They decrease slightly when two - seven RDCs are selected and then again start to decrease significantly when eight RDCs are selected. Total logistics cost increases continuously as the number of RDCs increases. Therefore, the case of one RDC selection is estimated as an optimal solution.

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AUTHORS BIOGRAPHY

Nam Kyu Park received his Ph.D. from department of Shipping Management, Korean Maritime University. He is currently teaching at department of Port Logistics, in Tongmyong University and Port Logistics Industrial Research director. His research focuses on Port Modeling, Port-MIS, SCM and distribution management. E-mail: nkpark@tu.ac.kr

Woo Young Choi is researcher at institute of Port Logistics, Tongmyong University nowadays. His research focuses on distribution network optimization.
E-mail: cwy1228@tu.ac.kr

Jian Hui is at Institute of Port Logistics, Tongmyong University nowadays. His research focuses on distribution network optimization.
E-mail: buyka@tu.ac.kr

MODEL DEVELOPMENT FOR THE ASSESSMENT OF AN INTERNATIONAL RAILWAY CORRIDOR – METHODOLOGICAL OVERVIEW

Rosa Rios Prado[a], Diego Crespo Pereira[b], David del Rio Vilas[c], Nadia Rego Monteil[d], Oscar de Gregorio Vicente [e]

[a)(b)(c)(d] Integrated Group for Engineering Research – University of A Coruna (Spain)
[e] Consultrans S.A. (Spain)

[a]rrios@udc.es, [b]diego.crespo@udc.es, [c]daviddelrio@udc.es, [d]nadia.rego@udc.es, [e]oscar.degregorio@consultrans.es

ABSTRACT
Transport modelling is a critical step in the design and economic assessment of transport infrastructures. Decisions on large investments must be based on the results of a model that has to cope with the complexities involved in transportation activities under long planning horizons. This paper discusses the methodological issues faced in the development of a model for the economic assessment of the Bolivian Central Bi-oceanic Railway Corridor (CFBC). This large infrastructure will connect the ports in Peru with the ones in Brazil by railway through the Andes. The project faces technical challenges from the harsh geographical and climatic conditions along with the uncertainty on whether the economic benefits will offset the large construction costs. Our goal is to develop a combined freight and passenger transport model that provides traffic absorption forecasts for a long time span of 50 years. The model has to cope with different levels of resolution for regional and international flows and its development is constrained by limited information sources.

Keywords: Modelling and simulation, transportation model, mode choice, multimodality, Railway Corridor

1. INTRODUCTION

The CFBC (Central Bi-Oceanic Railway Corridor) is a railway corridor infrastructure project promoted by the Bolivian Government and funded by the Inter-American Development Bank. It will link the Atlantic and Pacific coasts of the central part of South America. Its construction is expected to save both costs and time of transporting cargo and passengers through the great natural barrier which are the Andes. As of nowadays the only way to cross them is by narrow mountain roads that impede large trucks flow.

The study presented in this paper is part of a wider project for the analysis of prospective trade, market and logistic alternatives. It seeks to determine the levels of passenger and freight demand and the CFBC's flows absorption among Bolivia, its neighbouring countries and the rest of the world. The goal is to analyse its competitiveness compared to that of other existing alternatives such as the Paraguay-Parana Waterway or the Panama Channel. Import and export trades are regarded as one of the most promising sources of demand and thus accurate international transport modelling is considered a major challenge in the project development.

This study has three main goals. The first one is a prospective analysis of freight and passenger transportation, in different geographic (worldwide, national, regional) and temporal frameworks (long and short term). The second goal is a market study, establishing demand levels, transport service characteristics, competition, commercial strategic etc. The last objective is the study of logistic alternatives in order to obtain multimodal options (where the CFBC is one of the stretches) that generates synergies and increases the competitiveness of the Bolivian Integrated Transport System.

The paper discusses the methodological issues and challenges faced in the development of the project. As this project is still at an early stage of development at the time of this publication, the paper focuses on the discussion of methodological aspects rather than in the analysis of results.

The different approaches used in each step of the model are also explained, remarking the differences with other models employed for transport planning, like the resolution of the model at different levels and the use of optimal order quantity for transforming tonnes of cargo into number of trips.

2. METHODOLOGY OVERVIEW

The models employed for transport planning applications can be divided in those concerning either passengers or freight. The case of Passenger Transport Modelling has been widely studied, generally using the Classical Model of the Four Stages (Ortúzar and Willumsen 2011). In this method, the geographical area under consideration is divided into Traffic Analysis Zones (TAZ), which are the smallest regions in which passenger flows are aggregated. This methodology adopts a successive approach that consists of four main steps:

1. Trip Generation. The trips generated in each TAZ are estimated.

2. Trip Distribution. This step connects each of the trips generated in the previous stage with its destination TAZ. The result is a matrix travel between each pair of origin and destination TAZs (commonly called Origin-Destination, OD Matrix).
3. Modal Split. It gives the transport mode that a trip uses (obviously, in the case that more than one transport mode is available for this trip).
4. Traffic Assignment. This step gives the links of the network used for a trip.

This model can and has been adapted to the case of goods carry. However, several challenges are faced for a successful adaptation, mostly related to the difficulty of modelling policy makers' preferences. Thus, despite of the research effort carried out in the last decades, the freight transport modelling methods are less developed than those applied in passengers modelling (Ortúzar and Willumsen 2011). Freight transport decisions are business management decisions made upon complex criteria. They can be affected by several factors such as those spanning the cost of the transported goods, the transport reliability, the frequency of shipments and the transport time.

In this project the goal is to jointly estimate freight and passenger flows. Thus a multilayer model has been designed in which passengers will be treated as one of the freight classes with specific characteristics to account for passengers' behaviour. Passengers flow is not expected to be a high fraction of the total demand so estimation inaccuracies are less critical than in freight estimation.

The main decision problem that will determine the competitiveness of the CFBC in relation to other transportation alternatives is a modal choice problem. The key feature of the model must be the ability to determine the allocation of freight flows between CFBC and all transportation alternatives considered.

This modal choice is determined by the interaction between the two main actors who make decisions: cargo shippers and carriers (Samuelson 1977, Holguín-Veras 2002). The shippers determine what freight is transported, to which destinations, in what quantities and how often. The carriers determine the characteristics of the transport system, the level of services and set freight rates. In a competitive market, the interaction between them will determine the service conditions and the transported flows. Shippers have influence on carriers' decisions about transport settings, because they define the characteristics of shipped goods, and in turn carriers have influence on the shipment sizes and modal choices made by the shippers through their pricing policies or established service levels. This interaction can be modelled as a cooperative game in which previous research results (Jose Holguín-Veras et al. 2009) show that it can be assumed with a high degree of confidence that the decision finally adopted corresponds to the one that minimizes the total shipping costs, including those of both carriers and shippers.

The application of the general four steps analysis framework to this project requires an adaptation to the specific objectives of the study. The extended methodology employed is based on the work of Holguín-Veras (2002), and it is outlined in the Table 1.

OD matrices can be obtained directly from a single initial step in which either by surveying or historical data analysis representative origin-destination matrices can be obtained. In the case where the source destination pairs are clearly defined (as befits a significant percentage of the goods of this study) based on surveying methods, they provide specific information on the types of units transported and thus avoiding more aggregated and less accurate approaches.

Table 1: Methodological Schema

Steps of the model	Methodology
Freight Generation	Market Survey
Freight Distribution → OD Matrices	
Trip Generation and Mode Choice	Model based on Economic Order Quantity and Logit model for modal choice
Network Assignment	All or Nothing assignment

2.1. M&S approach as analysis methodology

One of the main sources of uncertainty in any transportation planning model, and given the long planning horizons required in practice, is given by the temporal projection of the variables that feed the model. Growth forecasts of economic activity and commodity flows are subject to great uncertainty that can seriously compromise the reliability of the model results (Flyvbjerg et al. 2006).

The design of logistics and transport services requires collaboration between multiple disciplines such as data mining, statistical analysis, forecasting methods, modelling and simulation and optimization techniques (M. Bielli et al. 2011). These technologies are widely used in various fields of logistics and terminal design (Longo 2010) or transport networks.

The methodology chosen to conduct the evaluation adopts a modelling and simulation approach in order to achieve flexibility and adaptation in model building and experimentation scenarios in terms of regional units, and infrastructural decisional considered.

Main advantages of this kind of methodology are that it is not necessary to build a system to evaluate it and its results are accurate, in general, compared to analytical models. Also it is important to notice that it allows "What if" analysis to be performed so predicting the behaviour of the system under different conditions. This last reason is the most important one, because it is one of the requirements of the Bolivian Government as a result of the project. Simulation is also a tool widely used in the design state (Robinson 2004), as it is a new infrastructure.

Sokolowski and Banks (2010) list a group of advantages, most of them supporting the choice of M&S methodology for this case. As they say, simulation can help explore new policies, operating procedures, etc. in a case like this, in which a new infrastructure is in the planning phase and no real system is yet available for experimentation. Another of these advantages is that new transportation systems can be tested before performing the large investments involved, as can be the use of different train types in Bolivian new infrastructure. This methodology also helps identify the important variables of the system which have more impact on its performance as well as their interactions. Still, the most important advantage is the possibility of assess different scenarios under a "What if" analysis.

Accordingly, two key features of the tool are:

- The scenario generation, which will not only get the desired results of the project to the defined scenarios from market survey but also future updates of the model in the light of developments CFBC demand or its alternatives. This will provide greater flexibility in managing the infrastructure to facilitate decision when there are changes in environmental conditions.
- The sensitivity analysis gives on one hand an element to assess the robustness of the model against the uncertainty in the input data and on the other hand to assess the economic risks associated with the investment. The analysis techniques of the uncertainty in the input data are methodologies developed in recent years and provide a convenient way to validate models in conditions where it is difficult or totally unfeasible have data to conduct an experimental validation of the model (Ankenman and Nelson 2012).

2.2. Market Survey

The nature of this study is essentially a market survey which aims to assess the competitiveness of the CFBC to attract freight traffic. Its development by surveying techniques is a fundamental tool for getting information about current commodity flows and criteria affecting transport decisions. Information collected will be used in the calibration of analytical models and the validity of the results depends on this data.

In such studies, usually little information and heterogeneous data sources are available. Getting a set of data of the highest quality possible ensure that the model is valid and has adequate accuracy for the purposes of the study. The difficulties that arise in practice when collecting data sets suggest the adoption of robust models with a level of complexity corresponding to the information availability.

On the other hand, a remarkable set of goods which are potential users of CFBC are iron, soybeans and forest products. This particular set of goods will require a detailed analysis of their origins and destinations, operating restrictions and costs. In this sense, the market survey will provide detailed information about them on which to base the analysis.

The proposed methodology, which is based on principles of the field of logistics, will further evaluate the impact of these particular market segments in the CFBC. Other planning methods with a higher aggregation level would be undesirable for these goods as they would reduce the estimation accuracy of the main sources of demand CFBC.

3. MODEL ELEMENTS

3.1. Origin Destination Matrices

The origin-destination matrices are the input model. They collect various goods flows between origins and destination for each group

These source and destination areas, is what are called transportation planning TAZ (Traffic Analysis Zones). These zones are geographic areas able to attract and generate goods or passenger trips. When the goods are clearly identified an element, such as iron ore, these points of origin and destination are easily identifiable. In cases where the production and consumption centres present lower geographic concentration has to pay special attention to the choice of these TAZ, especially with regard to geographical coverage. Excessively large sizes can reduce the accuracy in the calculation of distances, being in close proximity (e.g. two countries), and sizes too small make the characteristics of the area become very heterogeneous, and that increase the complexity of the model and computational cost. Data should be available at the aggregation level sought; therefore choosing the TAZ is also related to the availability of data for the real case.

The accuracy of the model depends on the quality of data of the matrices. It is often necessary to use approximations that transform data into operational data available, i.e. if we aggregated to higher levels of TAZ, these approaches should allow us to disaggregate at the desired level.

3.2. Network

The transportation network contains all information of the infrastructure to be used to perform various transports. It is defined by a set of routes between sources and destinations. In practical applications it is necessary to use some kind of mapping on which to work, such as geographic information systems (GIS) containing all the information and not just geographically but other data such as the characterization of the TAZ population or some economic data from them. It is important to have the tools to add elements to these information systems, because when it comes to evaluating a new infrastructure, they are not usually available

3.3. Mode Choice

The model indicates the choice for a particular user that selects a particular freight under certain conditions. This is an essential step because this is where the competitiveness of each of the options available is assessed.

This choice model is divided into two distinct but interrelated turns. The first is to obtain the economic order quantities (EOQ) and secondly the model of choice of the individual. This is necessary because the relationship between demand and traffic is not direct (José Holguín-Veras et al. 2011). The need for the definition of an optimal amount of cargo, to minimize the total costs, is either in that an agent may prefer multiple small shipments for short times needs instead of others for which time do not affect, or in accounting for the reduction in costs obtained by taking advantage of economies of scale.

The total cost of logistic operations is obtained from the transport costs of the option chosen and inventory costs associated with consolidating all cargo that will form a shipment. The optimal order quantity depends on the total transport cost and therefore depends on the mode of transport. Thus the modal selection is necessarily affected by the amount of ships and vice versa, requiring the joint consideration of both aspects (Jose Holguín-Veras et al. 2009).

There are multiple mathematical developments that can approximate the shippers mode choice (Ortúzar and Willumsen 2011). Logit models (in any of its various forms) are the most widely used in applied problems in the field of logistics. Logit models are the most widely used Multinomial Logit Models (MNL) and Nested Logit Models (NLM).

- They all start from the same theoretical framework (Ortúzar and Willumsen 2011):
- Decision makers have perfect information to make choices and act rationally.
- There are a set of alternatives (transportation) and there is a set of attributes that quantify the utility of each alternative for the decision maker.
- Each alternative has a net profit for each decision maker, which is how attractive is that option for him.
- The decision maker behaves rationally looking to maximize the utility of your choice.

The variables that are commonly used in utility functions are cost and time; the findings of most studies in this regard (Kreutzberger 2008) indicate that these are the variables on which most decision makers focus their choice.

The time must take into account the total duration of the transport, thus not only the time when the vehicle (for each transport) is moving but respect those rules derivatives (such as resting time) of the waiting times at stations and times intermodal operations of loading and unloading of cargo.

In terms of cost it is important to fully define the costs the options incur because it determines the establishment of pricing policies and the evaluation of the profitability of the infrastructure. There is an important relationship between flows absorbed by a line (Behrens and Picard 2011) and rates as high flows may allow the exploitation of economies of scale.

3.4. Assignment

In the step of assigning traffic the total flow through each section of the network is obtained. There are different methods of allocation depending on the needs of the model. So when the effect of network congestion can be skipped or no material can be used one of the simplest methods is assigning all or nothing (All or Nothing Assignment, AON). In this case, it is assumed that the travel time through each link is not dependent on its charge. Then all traffic flows between pairs of origin and destination can be assigned by the method of shortest path in terms of time, duration, cost or generalized cost function.

With regard to road transport, it is assumed that the congestion effects are fundamentally influenced by its interaction with the transport of passengers. However, for the estimated travel time to analyse the large-scale flow (national or international) the impact of congestion is relatively lower than at smaller scales as is the urban one. Then, simple estimation based on distances and travel times means provides sufficient accuracy.

4. CONCEPTUAL MODEL

4.1. Levels of resolution

The level of detail required in modelling freight worldwide is below than for the regional traffic; besides their choice alternatives are different. We propose the adoption of a method of analysis in two stages. First step is modelling the distribution between ports (entries and exits) of the freight flows. These freight flows are the ones between the countries inside the hinterland of the CFBC and the rest of the world.

On the second step we will model the freight traffic from the zones inside the hinterland of the CFBC and the entry/exits ports.

4.1.1. Zoning international TAZ

We propose the grouping of the different model TAZ in a total of 9 groups that allows pre-filtering of the decision alternatives affecting each source-destination pair to be done.

The *TAZ of the hinterland of CFBC* define the hinterland of CFBC as the set of regions whose intraregional traffic may be susceptible to recruitment by the CFBC. These TAZ are:

- Western Area: North of Chile, Peru and Bolivia high Andean plateau.
- Central Area: Eastern Bolivian Andes and central regions of Bolivia.
- Eastern Area: western Bolivia, Brazilian states bordering Paraguay and northern Argentina.

The *TAZ outside hinterland of the CFBC* considered are:

- Asian countries.
- Western strip of North America, Central America and northern South American countries.
- Eastern strip of North America, Central America and northern South American countries.
- Eastern strip of America.
- European and African countries.
- Central and southern Chile.
- Central and southern Argentina and Uruguay.

In Figure 1 a diagram with the above geographical areas is shown. This zoning permits the initial filtering of decision alternatives that will be present between each source-destination pair. For example for the traffic between the hinterland and Western Europe it would not make sense to consider Pacific ports as an alternative outlet.

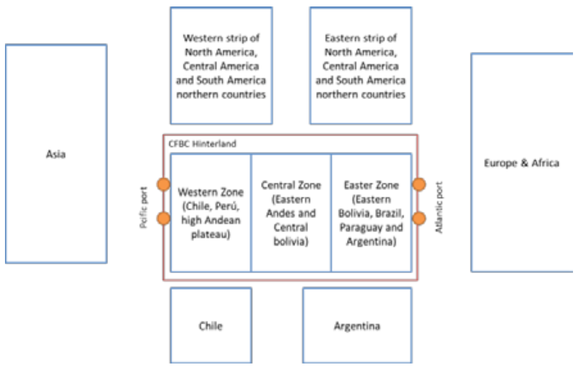

Figure 1:TAZs Groups.

Figure 2 helps explain the performance of the model. It has two main parts; the first one is related to the international flows and the second one to regional flows. The following notation is employed:

- ***t***: Time period (year or trimester).
- m: Type freight Index according to Standard Classification of Transported Goods (SCTG).
- i: TAZ Origin.
- j: TAZ Destination.
- k: Each transportation mode.
- l: Each type of vehicle, for all transportation modes.

4.1.2. International Traffic

In this step the Origin and Destination pairs of the matrices are all the countries that have an important commercial relationship with the hinterland of the CFBC and the TAZ of the hinterland. Inland traffics are not considered in both areas.

In this case there are two *transportation alternatives*, one that uses Atlantic ports as entry/exit ports, and the one that uses the Pacific ports.

The *elements of the model* are:

- $FI_{t,m,i,j}$: Flow OD matrix in physical units between TAZ of the hinterland of the CFBC.
- $d_{i,j,k}$: Distance Matrix for each OD pair and each transportation modes.
- $t_{i,j,k}$: Time Matrix for each OD pair and each transportation modes.
- $q^{Int}_{t,m,i,j,k}$: Economic Order Quantity (EOQ) Matrices for each OD pair and each transportation modes.
- $CTI_{t,m,i,j,k}$: Total Cost Matrix for each OD pair.

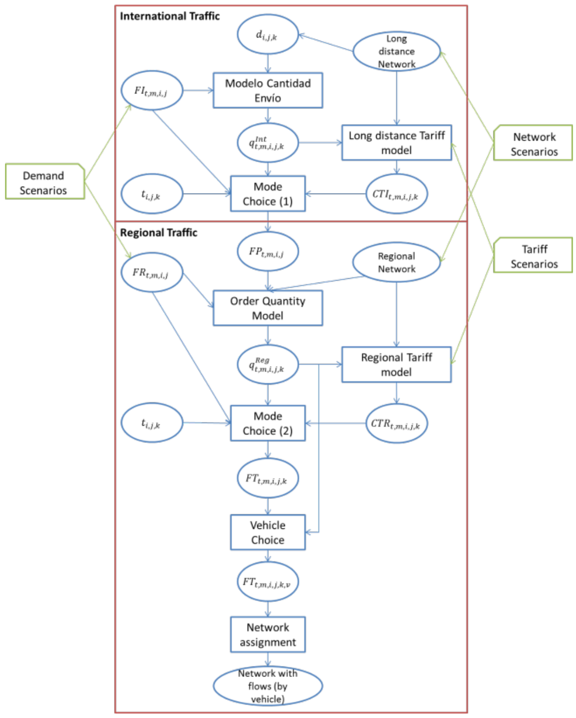

Figure 2: Conceptual Model Diagram

Modelling the entire system requires modelling every sub-model that is part of it. In this first approximation we have to define the following *used models*:

- Economic Order Quantity models (for which regression analysis will most likely adopted).
- Long distance tariff model. Represents the shipper cost for all alternatives, in the case of international traffic. It takes into account the haulage costs to CFBC terminals or alternatives passages, Fare of the CFBC or alternatives passages, Port fares, tariffs and customs fees
- Mode Choice Model (1): the entry and exit ports are here chosen

4.1.3. Regional Traffic (CFBC hinterland)

In this step the Origin and Destination pairs of the matrices are between TAZs in the hinterland and the entry/exits ports.

The *transportation alternatives* are:

- Road
- CFBC + Road
- Alternatives Passages + Road

The *elements of the model* are:

- $FR_{t,m,i,j}$: Flow OD matrix in physical units between TAZ of the hinterland of the CFBC.
- $FP_{t,m,i,j}$: OD matrices between the TAZ in the hinterland and entry/exit ports
- $q^{Reg}_{t,m,i,j,k}$: EOQ Matrices for OD pair and regional traffic.
- $t_{i,j,k}$: Time Matrix for each OD pair and each transportation modes.
- $CTR_{t,m,i,j,k}$: Total Cost Matrix for each OD of the hinterland and the ports.
- $FT_{t,m,i,j,k}$: Freight flow matrix for each OD pair and transportation alternative.
- $FT_{t,m,i,j,k,v}$: Freight flow matrix for each OD pair, each transportation alternative and each vehicle type.
- Network with total freight flows in trips and physical units for each type of vehicle.

The *models used* in this step are:

- Regional Tariff Model, similar as the international traffic one but in the regional level.
- Mode Choice Model (2): for choosing one of the transportation modes considered.
- Vehicle Choice Model, for each transportation mode, allows the type of vehicle for a shipment to be chosen
- Assignment, this step assigns the freight and passengers flows to the links of the network.

5. MODEL IMPPLEMENTATION

Once the conceptual model is defined, a test model is implemented in TransCAD. To do so, a set of macros in GISDK language was developed.

Origin-destination (OD) matrices are the input for the model and the analysis methodology chosen is the modelling and simulation approach, so it is necessary to obtain future forecasts of their values. The first macro implemented uses a gravity model in order to obtain the total flows distribution based on the forecasted production and consumption values of each TAZ. An OD matrix for each commodity and year of the analysis is estimated. After that, a new macro allows the user to choose the set of OD matrices to be employed for the analysis and also the geographical layer that contains the alternative to assess.

Once the scenario has been established in terms of flows and geographic alternative, it is necessary to select the level of resolution. Another macro makes it possible to restrict the analysis to International or Regional chosen flows. Depending on the resolution level, the following macro builds the network. It gives the outline of all the transport modes considered in the analysis, taking into account all the TAZs of the OD matrices. With this last macro the complete scenario of analysis is set, so the main steps of the model - the mode choice and the network assignment- can proceed.

Mode Choice depends on the utility function of each transport mode considered, so there is a macro that introduces these utility functions of the transportation modes considered. As it has been mentioned, the main variables of the utility functions are time and cost, so there are a set of macros that build the matrices of time and cost that feed the mode choice model. These macros take into account the waiting time in the intermodal change nodes and also the cost of these changes. The utility functions and time and cost matrices feed the Mode Choice model, which gives the probability of each transportation mode for each origin-destination pair.

Using these probabilities and the OD matrices, the OD matrices for each transportation mode are built. Once the OD matrices for all the transportation modes are built the next macro provides the assignment to the network. In this case an *All or Nothing* method is used, where the travel time is the variable to minimize.

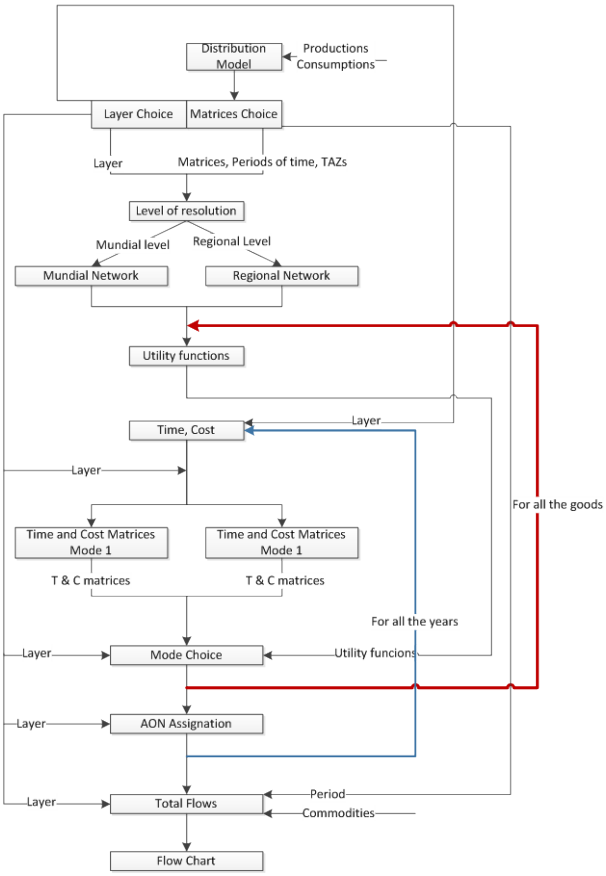

Figure 3: Test Model Implementation.

All these macros are part of a main macro for conducting the analysis for all the commodities (and passengers) considered and for all of the periods of time within the planning horizon. It gives a net assignment for every period of time and each freight type or passengers flow. So a new macro calculates the total amount of flows for every period considering all the different freight or passenger flows that are occurring. A last macro represents in the graphical layer the flows of the period chosen. Figure 3 represents and summarizes in a general way the operation of these macros.

6. CONCLUSIONS

The development of an entire and ready to use transport model for the assessment of different transport alternatives within actual constraints is a complex work. This is not only because a minimum set of good quality data is very difficult to obtain, but also due to the intrinsic methodological difficulties to solve.

A simulation based model is adopted since the "what if" analysis naturally fits and expands the options for the assessment of infrastructures and transportation services. It helps reduce uncertainty about what might happen under some economic and services conditions, and their variations, and then make decisions based on it. These decisions could be about the design of a new infrastructure or about the transportation services (fees, frequencies, etc.).

The methodology presented is an adaptation of some different existing models for analysis in two levels. One of them, more aggregated, at international level, where the main entry/exit ports of the country are established. The other level, more disaggregated, is a regional level where the internal traffic flows and the traffic flows to the main ports are obtained. This innovative approach will provide the means for the economic and service assessment of different multimodal alternatives.

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AUTHORS BIOGRAPHY

Rosa Rios Prado, MSc Industrial Engineer. Rosa is a research engineer in the Integrated Group for Engineering Research (GII) of the University of A Coruna (UDC) in Spain. Rosa is mainly devoted to the development of transportation and logistic models for the assessment of multimodal networks and infrastructures.

Diego Crespo Pereira, PhD, MSc Industrial Engineer. Diego is Assistant Professor of the Department of Economic Analysis and Company Management of the UDC. He also works in the GII of the UDC as a research engineer. He is mainly involved in the development and coordination of R&D projects related to industrial and logistic processes optimization.

David del Rio Vilas, MSc Industrial Engineer. He is Adjunct Professor of the Department of Economic Analysis and Company Management. He is mainly involved in R&D projects related to industrial and logistic processes optimization.

Nadia Rego Monteil, MSc Industrial Engineer. Nadia works as a research engineer at the GII of the UDC. Her areas of major interest are in the fields of Ergonomics, Process Optimization and Production Planning.

Oscar de Gregorio Vicente, MSc Telecommunications Engineer and Master in Transportation and Logistics. Oscar is currently Project Manager in the Transport Department of the Spanish company Consultrans S.A.

A SIMULATION FRAMEWORK FOR SHIPS PILOTS TRAINING

Francesco Longo[(a)], Roberto Musmanno[(b)], Letizia Nicoletti[(c)], Alessandro Chiurco[(d)]
[(a)(b)(c)(d)]DIMEG, University of Calabria, Rende (CS), Italy

f.longo@unical.it[(a)], musmanno@unical.it[(b)], letizia.nicoletti@unical.it[(c)], a.chiurco@unical.it[(d)]

ABSTRACT
The paper proposes an advanced simulator of a commercial containership within a virtual environment reproducing the port of Salerno. The motion of the ship at sea is based on a 6 Degree Of Freedom (DOF) model that includes the MMG model for surge, sway and yaw and closed form expression for pitch, roll and heave. The simulator is part of an on-going research project (HABITAT, Harbour Traffic Optimization System) and is intended for ship pilots training for manoeuvring inside the port area (i.e. while entering and/or exiting from the port, mooring operations, etc.) therefore it seeks to recreate the experience of a real ship manoeuvring with accuracy.
To this end, the analytical model for the ship motion has been validated through a dedicated software tool that has been developed writing a C++ programming code. This tool allows testing the behaviour of the simulator according to the desired configuration of the ship.

Keywords: Ships Pilots Training, Modelling& Simulation, marine ports

1. INTRODUCTION

Steering a large ship inside a commercial port can be a complex and dangerous process for several reasons. Indeed, in standard traffic conditions it is possible to have a great number of vessels of different sizes (i.e. small motorboats, huge container carriers, cruise ships etc.). In addition, manoeuvring times (and reaction times) of vessels are very slow compared to other vehicles especially for large vessels. Due to their prominent size and mass, in case of mistake and accident, large vessels may cause enormous damages (consider the recent accident on May 7th, 2013 of the Italian container ship Jolly Nero in the port of Genoa).

In the Logistics area, Modeling & Simulation (M&S) has widely proved to be a powerful and profitable tool (Merkuryev and Bikovska, 2012; Narciso et al. 2010); as far as the ship manoeuvrings in the port area are concerned, M&S can be profitably used for ship pilots, training purposes, for procedures definition, evaluation and testing, for understanding vessels interactions within the port area, for evaluating the effects on ships maneuvering in the port area of adverse weather conditions (including wind, sea waves and marine currents). As a matter of facts M&S allows a greater standardization and effectiveness of training processes. The trainee can steer the virtual ship in any critical or dangerous condition; he can perform both standard and non-standard manoeuvres and therefore he is trained to handle those situations that cannot be recreated during traditional training sessions in a real ship.

There is a relevant reduction of direct costs. These costs reduction is related to the increase of productivity when workers (in this case ship pilots) are well trained to perform their job. There is also a reduction of the indirect costs caused by accidents during training and normal activities as well as the possibility of collecting a large amount of data about trainees' performance in a controlled simulated environment.

Moreover, simulation-based training is fruitful not only for beginners but also for expert pilots. For instance, it can be useful to have a first approach with a never used type of ship or to learn how to put in practice the procedures currently adopted in a specific port. Moreover the simulator can be used to understand how manoeuvring a ship in critical conditions (i.e. strong wind and/or marine currents), how to carry out complex manoeuvres with the help of tugboats, how performing mooring operations and control the ship when close to the assigned berth area, etc.

Indeed, the literature review confirms that there is quite a large amount of research works that show how simulation has already been successfully applied for training operators working within the port area, i.e. cranes, trucks, straddle carriers operators, etc. (Kim, 2005). Many simulators are intended to quay cranes operators' training (Wilson et al., 1998; Huang, 2003; Daqaq, 2003; Rouvinen et al., 2005) and specific research works have also investigated the training for supporting security procedures integration in the marine port operations (Longo et al., 2006, Longo, 2010 and Longo 2012). To this end, it is worth mentioning that a comprehensive survey of research projects dealing with advanced simulation systems for operators training in marine ports is the main deliverable of the OPTIMUS project (Operational Port Training Models Using Simulators, financed by the European Community). The OPTIMUS project provides a detailed description of many commercial simulators for marine port operators training. Such simulators include crane simulators mainly.

In addition, innovative approaches based on interoperable simulation have been proposed. Specific examples regards the training of marine ports operators, i.e. Bruzzone et al. (2011-a), Bruzzone et al. (2011-b) developed interoperable simulators based on the High Level Architecture (HLA) integration standard for different container handling equipment (gantry cranes, transtainers, reach stackers, trucks, etc.) offering advanced solutions in terms of external hardware i.e. motion platform, different types of external controllers from joystick to wheels and pedals, etc.) and even containerized solutions.

As for ship simulators, interesting applications can be found in Ueng et al. 2008, Sandaruwan et al. (2009), Sandaruwan et al. (2010) and Yeo et al. (2012). Although in such works an immersive visualization system and the dynamic behaviour of the ship have been implemented, there is still substantial room for improvement above all in terms of ship motions predictions and validation. Moreover, in these works no attention has been paid on the last/second last mile of navigation (including manoeuvring and mooring operations in the port area) that, as explained before, it is as important as offshore navigation. A review of the state of the art related to traffic controllers and ships pilots training in marine ports can be found in Bruzzone et al. (2012).

Indeed, the main goal of this paper is to present a six degree of freedom ship simulator intended for the pilots involved in the last mile of navigation. The proposed tool can be used for training of both inexperienced pilots and experienced pilots steering a new kind of ship. Besides the proposed simulator can be also used to train ship pilots on specific port procedures regulating entering/exiting manoeuvres; as a matter of facts such procedures are established by port authorities based on port characteristics and therefore may be different from port to port.

The simulator has been developed within the framework of an on-going research project: HABITAT. This project is co-founded by the Italian Ministry of Education, University and Research as part of the PON Research Program.

Before going into details, the paper is organized as follows: section 2 summarizes the main features of the simulated scenario (that recreates the port of Salerno, Italy). Then, the commercial containership, which the simulator refers to, is introduced. Section 3 illustrates the mathematical model that has been adopted to recreate the ship motion at sea; section 4 describes the software tool that has been implemented for Verification, Validation and Accreditation (VV&A) of the ship motion models. Section 5provides an overview about the development phases and the requirements of proposed ship simulator providing also an overview of the 3D virtual environment. Lastly, section 6 summarizes the scientific contribution of the paper and future developments.

2. THE TRAINING SCENARIO

The training scenario considered in this research work is the Port of Salerno (see Figure 1) while the ship being simulated is a commercial container carrier.

The port of Salerno, thanks to its central position in the Mediterranean Sea, has a crucial role in the national and international maritime trade. The port area includes the following quays:

- Quay of Ponente , length 563m, dockings n. 22-24;
- Rosso quay, length 226m, dockings n. 20-21;
- Trapezio quay, length 890m, dockings n. 13-19;
- Ligea quay, length 250m, dockings n. 11-12;
- 3 Gennaio quay, length 446m, dockings n. 7-10;

Outside the commercial area, on the east side of the port is located the Manfredi quay (length 380m, dockings n. 1-3) where a Marine Station devoted to cruise ships is being built. An entrance channel (280m large and 13m deep) with a 550 m diameter and 12 m deep evolution area characterizes the port. Moreover the port is served by 4 tugboats (working 24/24 h), 5 expert pilots with 2 equipped pilot-boats and 10 mooring operators with 2 equipped motorboats.

Vessels can pass across the entrance channel only one-by-one; according to this restriction if a boat is entering the port and another one is exiting, the incoming boat has to wait until the other has safely completed its manoeuvres. In addition, owing to Port Authority restrictions on side thrusters' use and to strong winds (that can reach 40kn) most of the large ships are supported by at least one tugboat during their manoeuvres.

Figure 1- Panoramic view of Salerno port

As mentioned before, the ship that has been modelled by the simulator is a commercial containership based on the Kriso containership model, whose main particulars are summarized in the following:

- Hull
  - Length between perpendiculars 230.0 m
  - Length water line 232.5 m
  - Breath 32.2 m
  - Depth 19.0 m
  - Displacement 52030 m^3
  - Coefficient block 0.651
- Rudder
  - Type semi-balanced horn rudder
  - Surface of rudder 115 m^2
  - Lateral area 54.45 m^2

- Turn rate 2.32 deg/s
- Propeller
  - Number of blades 5
  - Diameter 7.9 m
  - Pitch ratio, P/D (0.7R) 0.997
  - Rotation Right hand

3. THE SHIP MOTION EQUATIONS

A 6DOF mathematical model is used to reproduce the ship motion at sea. In particular, for surge, sway and heading the Manoeuvring Mathematical Modelling Group model (MMG) has been followed. Such model takes the name from the Japanese research group that implemented it for the first time between 1976 and 1980). Hence, the MMG group (1985) defined for the first time a prediction method for ship manoeuvrability.

Afterwards, Kijima (1999) taking into account the effects of the stern, proposed the approximate formulas for evaluating the hydrodynamic forces acting during manoeuvring motions. As for the hydrodynamic coefficients within the ship manoeuvring, empirical formulas are given in Rhee and Kim (1999) and Lee et al. (2003). Moreover, Yoshimura (1986) and Perez et al. (2006) describe how some parameters and dimensions influence manoeuvrability characteristics while Hasegawa et al. (2006) have discussed the course-keeping in windy condition. These findings have been integrated within the MMG model that includes three equations of motion (1, 2, 3) for surge, sway and yaw respectively based on the Newton's second law.

$$(m+m_x)\dot{u} - mvr = X \tag{1}$$

$$(m+m_y)\dot{v} + mur = Y \tag{2}$$

$$(I_{zz}+i_{zz})\dot{r} = N - x_G Y \tag{3}$$

In equations 1, 2 and 3:

- *m* is the mass of the ship;
- m_x and m_y are the added mass in x and y direction respectively;
- I_{zz} is the moment of inertia;
- i_{zz} is the added moment of inertia around z;
- *u* is the surge speed;
- *v* is the sway speed;
- *r* is the rate of turn;
- x_G is the distance from amidship to the centre of gravity of the ship
- *X* and *Y* are respectively the total external surge and sway forces;
- *N* is the yaw moment;

Added masses and added moment of inertia can be found using the equations proposed by Hooft and Pieffer (1988). In some equations non-dimensional variables are used, they are marked with the prime symbol. The external forces are those produced by the hull, the propeller and the rudder; they are marked with the subscripts H, P and R respectively, therefore surge sway and yaw can be also expressed as shown in equations 4, 5 and 6.

$$X = X_H + X_P + X_R \tag{4}$$

$$Y = Y_H + Y_R \tag{5}$$

$$N = N_H + N_R \tag{6}$$

Since the hull of the ship has a complex shape it is quite difficult to calculate hull forces. To this end, the equations 7, 8 and 9 (proposed in the Proceedings of the 23rd ITTC 2002) have been used.

$$X'_H = -(X'_0 + (X'_{vr} - m'_y)v'r') \tag{7}$$

$$Y'_H = Y'_v v' + (Y'_r + m'_x)r' + Y'_{vvv}v'^3 + Y'_{vvr}v'^2 r' + Y'_{vrr}v'r'^2 + Y'_{rrr}r'^3 \tag{8}$$

$$N'_H = N'_v v' + (N'_r + m'_x)r' + N'_{vvv}v'^3 + N'_{vvr}v'^2 r' + N'_{vrr}v'r'^2 + N'_{rrr}r'^3 \tag{9}$$

It is worth noticing that the higher order terms have been omitted in the surge force equation because their influence is negligible and an appropriate formula to calculate the coefficients is not available yet.

The equations 7, 8 and 9 define a relation between velocities and hull forces with hydrodynamic non-dimensional coefficients. Such coefficients are normally obtained through tests but a set of semi-empirical equation can be found in Lee et al. (2003). Therefore, the total non-dimensional resistance, X'_0, has been calculated as shown in equation 10 where C_T is the total resistance coefficient (obtained from model resistance tests), *S* is the wetted surface, *L* is the length between the perpendiculars, and *d* is the draft.

$$X'_0 = \frac{C_T S}{Ld} \tag{10}$$

On the other hand, the equations for non-dimensional variables are given in 11, 12, 13, 14, 15 according to Kijima (1993).

$$m', m'_x, m'_y = m, m_x, m_y / 0.5\rho L^2 d \tag{11}$$

$$X', Y' = X, Y / 0.5\rho L d U^2 \tag{12}$$

$$N' = N / 0.5\rho L^2 d U^2 \tag{13}$$

$$r' = \frac{rL}{U} \tag{14}$$

$$v' = \frac{v}{U} \tag{15}$$

In equations 11, 12, 13, 14 and 15, ρ is water density and U is the ship speed that can be calculated according to 16.

$$U = \sqrt{u^2 + v^2} \tag{16}$$

The force generated by the propeller is obtained using the equation 17 from Kijima(1993) where n is the propeller rate expressed in RPM, t is the suction coefficient, D_p is the propeller diameter and K_T is the propeller thrust coefficient.

$$X_P = (1 - t)\rho n^2 {D_p}^4 K_T \tag{17}$$

It is possible to express K_T as a function of the propeller advance coefficient J, as shown in equations 18 and 19.

$$J = (1 - w_P)u/(nD_P) \tag{18}$$

$$K_T = C1 + C2 + C3J^2 \tag{19}$$

In equation 18, w_p is the wake fraction while to identify $C1$,$C2$ and $C3$in equation 19 it is necessary to use the least squares method on Wageningen B systematic series for the appropriate propeller.

Lastly, the equations used to calculate rudder forces are 20, 21 and 22 taken from Kijima (1993). In these equations:

- t_R is the rudder drag coefficient;
- F'_N is the normal force applied on the rudder;
- a_h is a coefficient that expresses the interaction between rudder and hull forces;
- x'_R is the non-dimensional coordinate of the centre of lateral force along the x-axes;
- x'_H is the non-dimensional coordinate of the centre of additional lateral force along the x-axis (such values can be evaluated by using the equations given in Kijima et al., 1993);
- δ is the rudder angle.

$$X'_R = -(1 - t_R)F'_N sin\delta \tag{20}$$

$$Y'_R = -(1 - a_H)F'_N cos\delta \tag{21}$$

$$N'_R = -(x'_R - a_H x'_H)F'_N cos\delta \tag{22}$$

On the other hand, heave pitch and roll have been modelled according to Jensen, (2001) and Jensen et al (2004). The proposed model is based on simplified equations, one for each DOF, devoted to work out ship motions in regular waves. Basically, in these equations, the coupling terms are neglected and the sectional added mass is equal to the displaced water.

$$2\frac{kT}{\omega^2}\ddot{\omega} + \frac{A^2}{kB\alpha^3\omega}\dot{\omega} + \omega = aF\cos(\overline{\omega}t) \tag{23}$$

$$2\frac{kT}{\omega^2}\ddot{\theta} + \frac{A^2}{kB\alpha^3\omega}\dot{\theta} + \theta = aG\sin(\overline{\omega}t) \tag{24}$$

$$\left(\frac{T_N}{2\pi}\right)^2 C_{44}\ddot{\varphi} + B_{44}\dot{\varphi} + C_{44}\varphi = Ma\cos(\overline{\omega}t) \tag{25}$$

The equations 23 and 24 are related to heave and pitch respectively while equation 24 refers to roll motions. Here, derivation with respect to time is denoted by a dot, k is the wave number, ω is the wave frequency, B is the ship breadth, T is the ship draught, $\overline{\omega}$ is the frequency of encounter, a is the wave amplitude and A is the sectional hydrodynamic damping that can be evaluated according to Yamamoto et al. (1986). F and G are the forcing functions whose values can be worked out according to Jensen et al. (2004).

As for roll, φ is the roll angle, T_N is the natural period for roll, B_{44} is the ship hydrodynamic damping, C_{44} is the restoring moment coefficient and M is the roll excitation moment.

The hydrodynamic damping coefficient B_{44} can be found by applying the method described in Jensen et al. (2004). The roll excitation moment M can be derived from the Haskind relation, while the restoring moment coefficient C_{44} can be expressed as a linear function of the displacement Δ, the transverse metacentric height GM_T and the acceleration of gravity g (see equation 26).

$$C_{44} = gGM_T\Delta \tag{26}$$

It is worth noticing that this research work proposes a new application of the Jensen's et al. (2004) model. As a matter of facts, ship responses are calculated in in the time domain instead of in the frequency domain as it was in the original formulation. Thus, this model has been used to provide the simulation and visualization system with real-time data about heave, pitch and roll motions.

4. THE SHIP MOTION TEST

The above-discussed mathematical models have been extensively validated before being implemented within the simulator. To this end, a dedicated tool has been developed by Visual Studio 2008 with the C++ programming language.

This tool allows setting the most important parameters such as the number of iterations to be executed, the time between two iterations, the propeller rate, the initial speed and the rudder angle. In this way, it is possible to execute circle tests, zigzag tests and stop tests according to different configurations as shown in figure 2, 3, 4 and 5.

During the execution of such tests, a plot of the ship motion evolution is drawn on the screen and sensible data as speed, drift angle, yaw rate, acceleration, heading, position are recorded on text files. This tool has proved itself very useful. Since the preliminary tests carried out at the earlier validation stages were not in agreement with the empirical data that have been used as test-bed, the mathematical model has been carefully reviewed and some parameters, such as the dimensionless derivatives, where suitably calibrated. Even during calibration, the C++ tool has been used to assess whether the applied adjustments had improved the output results to achieve closer empirical evidence. Thus after tuning, the results are better suited to the existing data collected on tests for container carrier. Figure 2 and 3 show the trajectory for two Circle tests executed by the tool, moreover they provide a comparison with empirical data given by two circle tests executed at the same conditions of speed and rudder angle. Empirical data are taken from The Specialist Committee on Esso Osaka, Final Report and Recommendations to the 23rd ITTC.

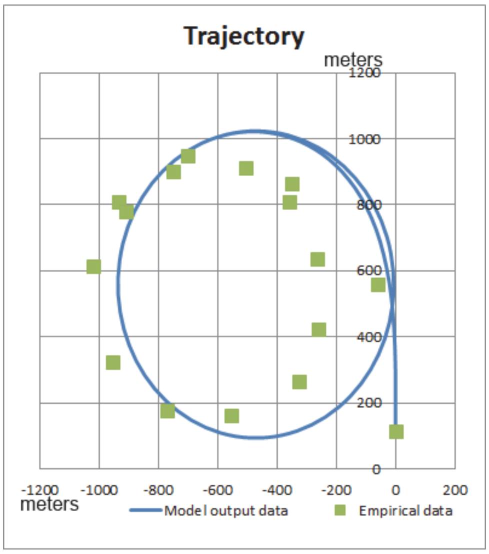

Figure 2: Turning trajectory in port side circle test, speed 8kn, rudder angle 35°.

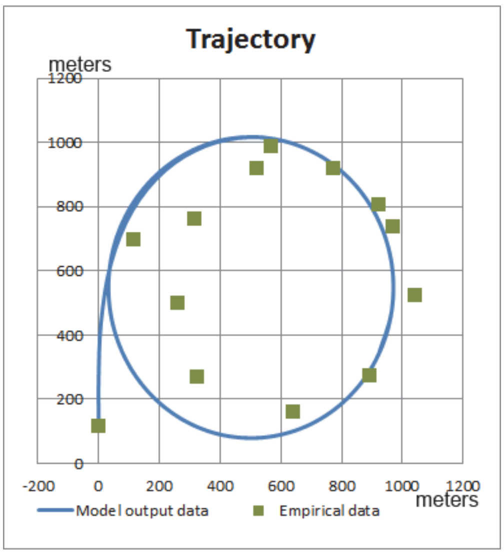

Figure 3: Turning trajectory in starboard side circle test, speed 10kn, rudder angle 35°

Figure 4 and 5 show two zigzag tests. They reflect the empirical data that can be seen on The Specialist Committee on Esso Osaka, Final Report and Recommendations to the 23rd ITTC.

As for heave, pitch and roll validation activities have been based on the comparison of the ship empirical Response Amplitude Operators (RAOs) to the model-based RAOs. Such comparison led to deem the model outputs enough accurate and therefore suitable to achieve the research goals behind the simulator development.

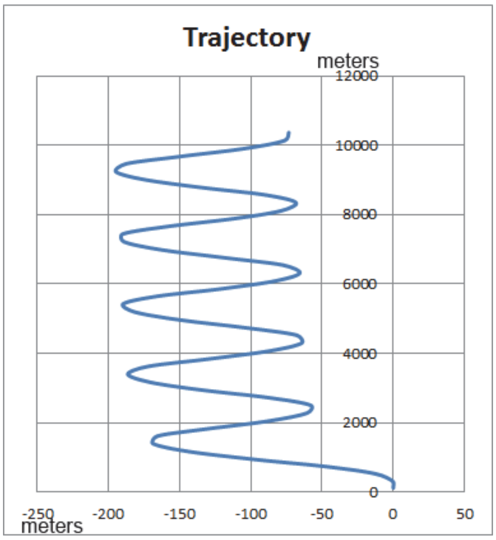

Figure 4: Turning trajectory in port side 20/20 zigzag test, speed 5kn

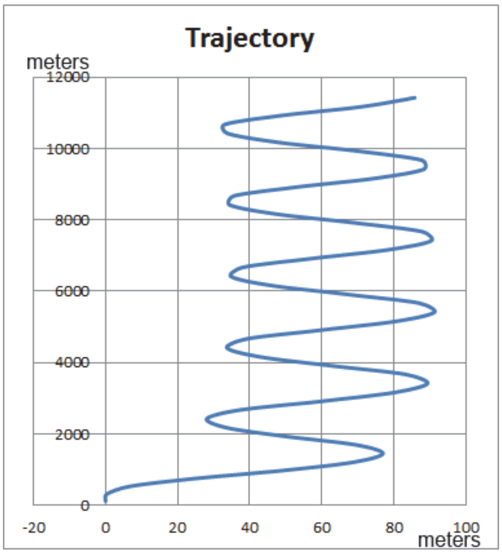

Figure 5: Turning trajectory in starboard side 10/10 zigzag test, speed 5kn

5. THE TRAINING SIMULATOR

Control and support of ship navigation in the second last/ last mile of navigation are very complex activities. The high number of ships and vessels that usually enter to and exit from a marine port, the adverse visibility and weather conditions that may occur, the type of ship (i.e. container carriers, passengers ships, etc.), the docking times, the loading/unloading times, are examples of factors that slow down the traffic. These factors also increase the risk of collisions during the navigation in the harbour area. In this scenario, the proposed simulator aims at providing a concrete support by leveraging the role of pilots training. As a matter of facts, manoeuvring a ship while it is exiting from or entering into a port area is quite difficult and may cause terrible losses. To this end, it is crucial that ship pilots are well trained and fully aware of the consequences of their actions. Since simulation provides a safe training environment where trainees can gain experience and explore possibilities, simulation-based training has great potentials in this application domain. However, it is worth saying that the effectiveness of simulation based training increases as the trainee's feeling of realism increases. Hence, greater attention has been paid on the virtual environment that recreates with accuracy the port of Salerno and on modelling the dynamic behaviour of the ship that has been extensively validated by the comparison with empirical data. This way the simulator conceptual and operational model has been developed. Afterwards such models have been encoded into a computerized model written in the C++ programming language within the Visual Studio 2008 Integrated Development Environment. Moreover, the Vega Prime by Presagis and the Creator by Presagis have been used forcreating highly optimized 3D geometric models and high-fidelity 3D real-time simulations respectively. As a result the simulator gives the possibility to steer a container carrier in the last mile of navigation, as well as offshore, setting the rudder angle and the propeller rate dynamically.

Furthermore, different viewpoints are available: inside the bridge, outside the ship (therefore it is possible to see the whole ship from different points of view) and the control tower. Figures 6, 7 and 8 show three different points of view of the ship.

In addition, the simulator has been conceived in order to provide the users with a large spectrum of operative scenarios; in fact, the trainer can set weather and marine conditions before the training session starts or even during the execution. Data such us main engine RPM, side thrusters utilization levels, rudder positions, wind intensity and directions, compass, 2D map of the port areas including the other ships (Automatic Identification System – AIS) are always available during the simulation. Performance measures such as mission time (average and standard deviation values over multiple training sessions), collisions, and wrong manoeuvres are recorded and are available at the end of the simulation. Besides, the accuracy and quality of the simulator has been guaranteed by Verification, Validation and Accreditation (VV&A) processes that have been carried out during the entire development period (Bruzzone et al. 2010). As mentioned before, the ship dynamic has been verified and an ad-hoc tool has been developed to this purpose. As for the computer simulation model a preliminary verification has been carried out by using the debugging technique to ensure high levels of accuracy and quality.


Figure 6: Inside the commercial containership bridge

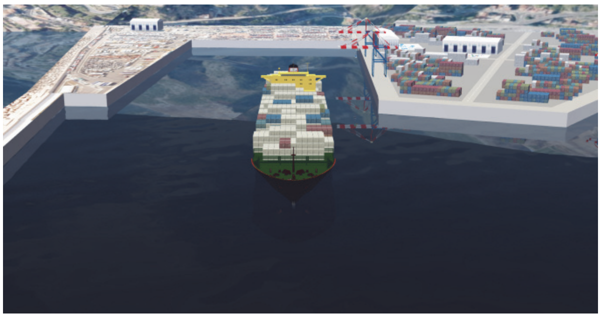
Figure 7: Front view of the commercial containership


Figure 8: the commercial containership back view

6. CONCLUSIONS

This paper proposes the implementation within a simulator of a 6 DOF model for the motion of a containership at sea. Throughout the paper, the equations that allow recreating the motion of the ship are proposed and commented. Before their implementation within the ship simulator, the equations have been tested by using an ad-hoc tool developed by authors to give the possibility to tune the equations and obtain a realistic behaviour of the ship at sea. The 6 DOF models has been then implemented within the ship simulator with the aim of developing a simulation based training tool for ship pilots involved in the last/second last mile of navigation. To this end, the simulator has been conceived in order to provide the trainees with an experience as much realistic as possible. In this way, the simulation-based approach seeks to maximize training effectiveness, lesson learned and at the same time reduces the need for training on the real system with real equipment. As a matter of facts, the trainee can safely exercise on ship manoeuvring in any desired condition and at any time so that he/she canimprove his/her skills and develop the capability of predicting the possible outcomes related to the course of actions he/she undertakes. In addition, the simulator can be used by inexperienced pilots but also by expert's pilots who wish to be acquainted with a never steered kind of ship or simply learn the entry/ exit procedures that are adopted in a specific port.

In fact, it is possible to replace the current scenario and or the kind of vessel with a moderate effort. To this end, it is worth saying that the current ship can be changed but it would require the calibration of the dynamic model and as a consequence, a new validation process.

The simulator dynamic behaviour has been recreated by implementing the MMG model for surge, sway and yaw, while simplified differential equations have been solved numerically for evaluating ship response in terms of roll, pitch and heave. The simulator conceptual and operational model has been implemented in Visual Studio 2008 IDE using Vega Prime graphic engine while the virtual environment (Salerno port) and all the geometric models (included the container carrier model) have been made with Creator by Presagis.

Furthermore for VV&A purposes an ad-hoc tool has been developed. This tool allows carrying out manoeuvrability tests such as circle, zigzag and stop tests in any desired ship configuration.

Currently, further research activities are still on-going in order to include as part of the simulator additional ships, including a tanker and a ro-ro ship.

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AUTHOR BIOGRAPHIES

Francesco Longo received his Ph.D. in Mechanical Engineering from University of Calabria in January 2006. He is currently Assistant Professor at DIMEG University of Calabria and Director of the Modelling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES). He has published more than 80 papers on international journals and conferences. His research interests include Modeling & Simulation tools for training procedures in complex environment, supply chain management and security. He is Associate Editor of the "Simulation: Transaction of the society for Modeling & Simulation International". For the same journal he is Guest Editor of the special issue on Advances of Modeling & Simulation in Supply Chain and Industry. He is Guest Editor of the "International Journal of Simulation and Process Modelling", special issue on Industry and Supply Chain: Technical, Economic and Environmental Sustainability.

Roberto Musmanno is full Professor at DIMEG University of Calabria. He currently follows as Principle Investigator and Scientific Responsible different national and international research project in the Operations Research area in the field of Logistics and Supply Chain Design and Management. He is scientific Responsible of the TESEO lab at University of Calabria and President of the ITACA company a spin-off of the University of Calabria. He has published more than 60 international journals articles and many conferences papers.

Alessandro Chiurco is Researcher at MSC-LES, Department of Mechanical, Energy and Management Engineering, University of Calabria. His research activities concern the development of 3D immersive and interoperable simulators for training based on the HLA standard. He is also used simulation for investigating problems related to supply chain and marine ports security.

Letizia Nicoletti is PhD student at MSC-LES, Department of Mechanical, Energy and Management Engineering, University of Calabria. Her research interests include Modelling & Simulation for training in complex system with particular attention to marine ports and container terminals. She is also using Modelling & Simulation based approaches for inventory management problems in industrial plants and supply chains. From 2010, she actively supports the organization of the I3M Multi-conference where she is co-chairing the Inventory Management Simulation track.

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