THE 17TH INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELLING AND SIMULATION

SEPTEMBER 21-23 2015
BERGEGGI, ITALY

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It gives us great pleasure to welcome you on the 17th edition of the International Conference on Harbor, Maritime & Multimodal Logistics Modeling and Simulation (HMS 2015) part of the 12th International Multidisciplinary Modeling and Simulation Multiconference (I3M).

HMS 2015 upholds a long tradition started in 1999 in the field of simulation and computer technologies applied to logistics, supply chain management, multimodal transportation, maritime environment and industrial logistics. As time goes by, HMS looks at the future of science and practice seeking to capture new and emerging development trends but not only. As challenges are put forward by the fast changing social, technical and economic situation, a great effort has been done to set up an advanced scientific program with lots of talks, seminars, research presentations and discussions.

Valuable research experiences need to be shared for developing new knowledge and generating new groundbreaking ideas. This is, in essence, the inner meaning that HMS nurtures. Therefore HMS gives a not-to-be-missed chance of networking among colleagues to set up new relations and strengthening long-established ties on joint research interests.

It's our firm determination that HMS 2015, as indeed past and future editions, could end with some strong take-home messages rewarding merits and scientific excellence. To this end, HMS provides the Authors of the best papers with the opportunity to extend their works for publication in International Journals Special Issues.

We are proud to host HMS 2015 in the lovely setting of Bergeggi, a delightful town overlooking the sea where, we are sure, all the delegates will have a pleasant as well as enriching experience.

Our sincere thanks are due the invaluable work of the Organizing Committees, International Program Committees, Reviewers and Local Organizers that have hardy worked to make the conference a success and above all to provide many and good journal publication opportunities.

We look forward to opening our doors to everyone who is coming to Bergeggi for HMS 2015!

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A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

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DESIGN OF A LOGISTIC PLATFORM THROUGH DE OPTIMIZATION OF AGRICULTURAL DISTRIBUTION NETWORKS IN PANAMA

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ABSTRACT
One of the main challenges of the agricultural sector in Panama is the weakness that can be found in the links of the agricultural supply chain. The objective of this project, funded by the National Secretariat of Science, Technology and Innovation of Panama, was to model, for the first time, the supply chain of produces and to design and propose the corresponding policies for the logistic platform that would optimize distribution of agricultural products in the country. Specifically lettuce was used as the main product for the analysis, and an optimization model was developed in order to validate the decisions made, not only with respect to volume but also with respect of the type of vehicle used. A cost analysis was performed in order to study the implications for the different elements of the supply chain. Finally, a decision for a new distribution center was made for different scenarios.

Keywords: Agricultural supply chain, transportation, distribution networks, linear programming applications

1. INTRODUCTION

Panama has been considered a logistics center point for the American Continent. Different publications have mentioned Panama from this stand point. Projects such as the Panama Canal expansion, the Colon Free Zone (one of the largest in the world) the Tocumen International Airport and the Copa Airlines Hub of the Americas, the Panama Canal Railroad and the different container ports located in the Pacific and the Caribbean side of the Canal are just examples of logistics initiatives in the country.

On the other hand, according to the Panamanian Comptroller Office (2013), agriculture and other related activities are the main sources of employment in the rural areas represent over 20% of total employment nationwide the Agricultural Gross Domestic Product (AGDP - 2013) represents just 3% of total Gross Domestic Product (GDP). One of the results of this situation has been the lack of attention that has been provided to the analysis, modeling and optimization of the internal agricultural supply chain.

Boudahri, et al (2012) define the term agri-food supply chains (ASC) to describe the activities from production to distribution that bring agricultural or horticultural products from the farm to the table. ASC are formed by the farmers, distribution, processing, and marketing of agricultural products to the final consumers. In Panama, the interface between producers and supermarkets or municipal supply centers (final destination) is completely monopolized by intermediaries (carriers) which seem to increases the final product cost. All of these intermediates make up almost all the distribution networks for agricultural products in the internal food supply. This carriers transport the products of more than 60% of total producers and the remaining 40% is transported by private companies. In addition, there are losses of 40% of transported products. Therefore, these wastes in produce are transferred to the final customer (Secretariat of the Cold Chain, 2012).

The Province of Chiriquí (see map in figure 1) provides almost 80% of the vegetables consumed in Panama. It is located in the western sector of the country and it is the main supplier node in the food distribution network of the country. On the other hand, the Province of Panama at about 500 kilometers east of Chiriquí is the largest market with 1.71 million habitants (little less than 50% of the nation's population), hence an optimal distribution networks system is required throughout the country to serve the rest of the province in an efficiently way. In addition, Veraguas, Herrera, Los Santos and Coclé are the central province of Panama with an overall population of approximate 660,246 according to the National Institute of Census and Statistics. Together with Chiriquí, with a population near 300,000 complete the main market area for agricultural products.

The objective of this paper is to develop a mathematical model that depicts both the behavior of the agricultural supply chain and to analyze the transportation equipment used in the logistic chain in order to obtain an optimal transportation policy of agricultural products from the main production center to the different consumption points in Panama. This optimization model is the main result for a project funded by the National Secretariat of Science, Technology and Innovation of Panama (Orozco and Tuñon 2012, Álvarez and Orozco 2013) that is aimed to study the distribution network of agricultural products and propose a making decision model for optimal locations of modal interchange facilities and logistics platforms "hubs". The rest of the document will present a brief literature review of work done in this area, the methodology used and some of the main results of the project.

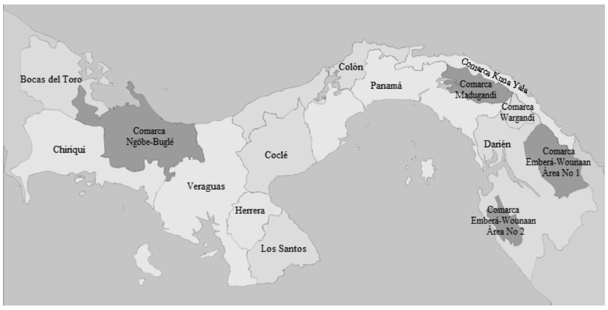

Figure 1: The geography of the Republic of Panama

2. LITERATURE REVIEW

Studying food distribution systems becomes an important point in supply chain management for several reasons. First of all, food scarcity becomes critical nowadays due to climate changes. For example, due to recent draughts in the United States and Russia, or constant floods in Colombia, Mexico, Central America or Central and South Europe yields in crops and cattle are decreasing. Thus, cost of food and produces are increasing. On the other hand, people need food to be accessible and safe, in terms of availability, effects in health and costs, becoming a strategic issue for governments. For example, Pietro and Timpanaro (2012) affirm that the issue of agricultural logistics is the subject of great interest because it is considered strategic for the development of a country especially on the possible transport links between different areas of the country.

Moving agricultural products between different points in the country implies handling issues regarding perishability of products, long and tortuous supply chains marked by the presence of several operators, the need to maintain a cold chain to guarantee the quality of the final product, consumption behavior and habits, and the role that health aspects and organoleptic quality play in purchasing decisions of consumers, among others. According to the same authors, the cost the agricultural logistics varies between 20-30% of the cost of the product. This can be even higher depending on the type of chain involved, *e.g* the distance from origin and the type of transportation considered. Thus, it is important to view the transportation and logistics system as a whole since, as Tan (2012) affirms, "the production, exchange, distribution and consumption of agricultural products constitute the organic chain of agriculture reproduction. Any deficiency of them will affect the development of agriculture (p. 106)".

In addition, it is important the study of distribution networks in order to address the different issues existing between the diverse parties involved in the transportation and distribution systems of products. Daganzo (1992), for example establishes the principle of distribution network application with the goal of uniting one origin with one destination, one origin to many destinations and many to many systems using transshipment centers and providing methods to solve it. On the other hand, Agra (2008) demonstrated that the costs associated with the transport of goods represent a large part of the final cost. Estrada (2007), on the other hand, asserted that there are different types of distribution networks, depending on the product, the transportation mode or the demand points.

Several papers have been found in the literature concerning the modeling of the agri-food supply chain. Boudahri, et al (2012) for example, presented a document concerned with the planning of a real agri-food supply chain for chicken meat for the city of Tlemcen in Algeria. The agri-food supply chain network design is a critical planning problem for reducing the cost of the chain. More precisely the problem is to redesign the existing supply chain and to optimize the distribution planning. The authors applied the Allocation Problem Model in order to define points in the network with the objective of minimizing the total distance between customers and these sites, or to minimize the maximum distance.

Moreover, Jones, et al (2001) consider a production-scheduling problem arising when there are random yields and demands as well as two sequential production periods before demand occurs. The paper presented a two-period model with random yield and random demand in which production can occur in either or both periods. The model is solved optimally as a sequential decision problem and it demonstrated that the two-period production strategy has substantial economic payoff for the seed industry.

Shu-quan and Ling (2010) focused the research in the multi-dimension and uncertainty of logistics performance evaluation for agricultural products distribution centers and the lack of evaluation methods. The authors proposed a hierarchy model of evaluation factors that combines fuzzy analytical hierarchy process (FAHP) with fuzzy comprehensive evaluation to generate quantitative comprehensive evaluation of logistics performance for agricultural products. In addition, it finally proves the rationality and application of this method through a practical case. Jang and Klein [(2011), develop models for supply chain issues facing small enterprises, solve them, and suggest their uses and future considerations, focusing the model based on more stochastic issues of risk and return on investment.

More specifically related with the purpose of this paper, Mejia and Castro (2007) worked in the logistics optimization in a Colombian frozen and refrigerated food company. The authors developed a decision model based on linear programming to determine packing and distribution policies of frozen products. Zhang, et al (2011), on the other hand, focused on the research of a distribution model and vehicle routing optimization of fresh agricultural products. On the basic of detailed researching of agricultural products logistic characters, the paper establishes a vehicle optimization model suitable for transferring kinds of perishable agricultural products, to solve the severe losing of fresh produce logistics with transportation distance. The model is solved by genetic algorithm and the algorithm's effectiveness is verified using different examples.

3. PROBLEM DESCRIPTION AND DATA GATHERING METHODOLOGY

The objective of this paper is to present an optimization model that helps finding not only the minimum cost of satisfying supply and demand of agricultural products, but also to implement the minimum transportation cost of a vehicle assignment policy for the minimum allocation of products. In addition, to analyze different scenarios in order to select the best location of main distribution center in Panama City. No previous study about the distribution network of agricultural products has been previously conducted in Panama.

To find the contextual description for the model, preliminary data from the different distribution points was gathered. Students from the logistic program and Industrial Engineering at the Universidad Tecnológica de Panamá (UTP), and students from the International Logistic and Transportation Master Program at the Universidad Marítima Internacional de Panamá (UMIP) gathered the preliminary information in Panama City. Further, students from different regional campuses of the UTP conducted an exploratory research in several locations around the country in order to know the situation and understand the behavior of the distribution of lettuce, potatoes, tomatoes and onions at these points. The information from these sources was collected through interviews and questionnaires applied to a group of stakeholders that were selected more by convenience than by random selection. Data such as transportation costs, operation costs, vehicles availability, production capacities, market demand, warehouses and distribution capacities were gathered.

In addition, data from the National Secretariat of the Cold Chain and the Agro-Marketing Institute allowed the researchers to have production data since the collection of this information is pending of time availability from the researches to travel to the production areas. Furthermore, the data collected from these organizations helped the researchers to compare this information with the one collected from the suppliers and consumers. At this point, the information is being carefully analyzed since there are significant differences between the information collected. Lettuce was selected as the product to be studied in the model due to recommendations from the National Secretary of the Cold Chain.

With the information provided, a map of the distribution network was developed. This map is shown in figure 2. As seen, two production areas were located, both in the Province of Chiriquí, 500 km west of Panama City. Lettuce is transported from these areas to different distribution points. These points are David, the largest city of Chiriquí, which distributes lettuce to the rest of the province. Also, lettuce is sent to Santiago, in the Province of Veraguas, where lettuce is sent to the province and to other areas in the middle of the country, thus it serves also as distribution centers. Finally, the products are shipped to the main distribution point in Panama City, the Supply Central Market that supplies products to the west, east, north and central areas of the Province of Panama, and also to the Province of Colon, located in the Caribbean area of Panama

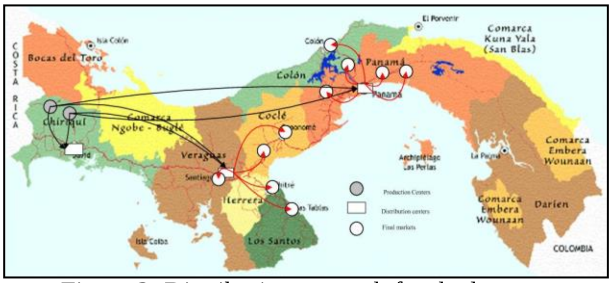

Figure 2: Distribution network for the lettuce

The main suppositions for the model are:

- Only one product is to be studied. In this case the product will be lettuce.
- Supplies and demands at different sources, transshipments and destinations will be considered weekly.
- No inventories are allowed in intermediate points.
- Only three types of vehicles will be considered: pick-ups, trucks and trailers, as seen in figure 3.
- All costs, demands, supplies and availability of vehicles are known.
- No unloading and downloading times are considered.
- The unit load considered is the 40 lbs. (18 kg) crate of lettuce, as seen in figure 4.
- No returning of products.
- The cost is divided in two elements: the transportation cost, that considers production and loading costs, and the vehicle related cost that considers fuel, operation costs and depreciation.
- Production cost is constant and does not depend on the final destination. Thus, it is a fixed cost and has no influence on the model.
- Both production and demand can be assumed constant every week.
- There is no limitation in the availability of vehicles, but a minimum amount is needed in every source.

Figure3: vehicle types

Figure 4: Unit load

4. MODEL DESCRIPTION

To develop the mathematical model, the Minimal Cost Network Flows approach was used, considering the different elements involved in the network. Thus, points as production centers, distribution points and final markets will be introduced, and a transshipment approach will be structured, and the optimal amount of lettuce through the network will be determined. In addition, a minimal flow problem consisting on modeling the optimal amount and types of vehicles used to deliver the lettuce will be included in the general model.

Consider a general network *G = (V, A)* where *V* is a vertex set representing either production centers, distribution centers of final markets, and A a set of directed arcs connecting different points in the set *V*. Every arch A is defined by the pair of indexes *i, j* indicating the origin and destination of such arch.

Let $x_{i,j}$ be the amount of products sent from point *i* to point *j*. In addition, consider $y^{(k)}_{i,j}$ the type of vehicle k used to transport products from point *i* to point *j*. Let $c_{i,j}$, the cost of moving one unit of product and and $b^{(k)}_{i,j}$ the cost of moving vehicle type *k* from point *i* to point *j*. Moreover, consider distribution or transshipment points *l* that will be considered to define the transportation policy of the logistic system. The objective of the problem is to optimize the amount of products sent from the origins to destinations and the optimum amount and type of vehicles used to move the products, at a minimum cost.

Consider the following parameters:

Z	:	Total weekly cost of the transportation policy.
$N^{(k)}_i$	:	Amount of vehicles type *k* available at point *i*.
$A^{(k)}$	:	Capacity of vehicle type *k* in terms of unit loads.
S_i	:	Weekly supply of point i.
D_j	:	Weekly demand at point j.
W_l	:	Weekly capacity of the distribution or transshipment points.
m	:	Number of origins.
n	:	Number of destinations.
L	:	Number of distribution centers.
K	:	Vehicle types, in this case pick-ups, trucks and trailers.

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The model is expressed bellow:

$$\boldsymbol{min\ Z = \sum_i \sum_j C_{i,j} x_{i,j} + \sum_i \sum_j \sum_k b^{(k)}_{i,j}\, y^{(k)}_{i,j}} \qquad (1)$$

Subject to:

- Weekly capacity of the sources:

$$\sum_i x_{i,j} \leq S_i \ \ \forall j \qquad (2)$$

The first constraint requires that the different supply points send no more than the production available at each of them, thus the upper limit of the distribution policy is the maximum supply available at the different production points.

- Weekly demand of the destination points:

$$\sum_j x_{i,j} \geq D_j \ \forall i \qquad (3)$$

For every destination point, the amount sent by the sources must be at least the demand required by each destination point.

- No inventory in the transshipment points:

$$\sum_i x_{i,l} = \sum_j x_{li} \ \forall l \qquad (4)$$

Due to the perishability of the lettuce, no inventory will be allowed at the different origin, transshipment and destination points. Thus, any amount sent from the origins to the transshipment points has to be sent to the destination points.

- Weekly capacity of the distribution points:

$$\sum_l x_{i,l} \leq W_l \quad (5)$$

Each distribution or transshipment point has a specific capacity of storage that must be satisfied with every shipment of products from the production point.

- Weekly availability of vehicles:

$$\sum_k \sum_j y_{i,j}^{(k)} \leq N_i^{(k)} \ \forall k, j \quad (6)$$

The amount of every type of vehicle used to transport lettuce at any supply point (considering also the transshipment points) must be less or equal to the available amount of vehicles at each of these points.

- Weekly transportation capacity of the vehicles at every distribution point:

$$\sum_j A^{(k)} y_{i,j}^{(k)} - \sum_j x_{i,j} \geq 0 \quad (7)$$

At every distribution point, the capacity of all the available vehicles must be at least the amount ready to be sent to every destination point, thus vehicles are to be used only with this product.

- All variables are integer and bounded by their upper limits:

$$x_{ij};\ y_{ij}^{(k)} \in I;\ \forall \begin{cases} i = 1, \dots, n \\ j = 1, \dots, m \\ l = 1, \dots, L \\ k = 1, \dots, K \end{cases} \quad (8)$$

5. MODEL SOLUTION AND DISCUSSION

Tables 1 and 2 show the main data of the problem, and table 3 shows a summary of the optimal solution of the problem.

Table 1: Main data for the case

	Pick up	Truck	Trailer
Capacity of the vehicles	35	75	250
Fuel	$ 70.00	$ 100.00	$ 600.00
Transportation cost	$ 1.25	$ 1.25	$ 1.25
Packing cost	$ 1.75	$ 1.75	$ 1.75
Handling costs	$ 0.05	$ 0.05	$ 0.05
Labor cost	$ 25.00	$ 25.00	$ 25.00
Cost per trip	$ 95.00	$ 125.00	$ 625.00

Table 2: Monthly demand of lettuce, in crates

David	2000
Santiago	1850
Chitré	1300
Las Tablas	500
Aguadulce	550
Penonmé	650
Chorrera	2100
Arraiján	2000
Panamá City	6000
San Miguelito	1800
Colón	2300
Total	21050

Table 3: Optimal Solution

Total cost	$ 19,442.50
For delivering 5, 264 lettuce crates per week	
Cost of moving crates	$ 11.147.50
Cost of vehicles	$ 8,295.00
Using	
23 Pick-ups 36 Trucks 10 Trailers	

**Solved using MPL*

The model was solved using MPL and was developed as part of a undergraduate thesis in Industrial Engineering (Castrellón 2013).

The final results show that the minimum cost for delivering 5,264 crates per week is $19,442.50. The distribution program uses 23 pick-ups, 36 trucks and 10 trailers at a total weekly transportation cost of $8,295

The model provides that the total demand will be satisfied using all the supplies from the different distribution points. This distribution policy takes into account the amount delivered to the intermediate points, Santiago and Central Market that are then delivered to the final consumption points.

In addition, the model provides the optimum amount of vehicles recommended to accomplish the distribution policy. The amount of vehicles used satisfies the availability of the corresponding vehicles: pick-ups, trucks and trailers. Further, the model recommends the use of large transport for longer routes rather than small vehicles, taking advantage of the low unitary cost of transportation in large vehicles.

It is important to recall that the model considers that the vehicles are dedicated to only transport lettuce, and they do not share space with other products, since the model is limited to one produce.

After the model was executed, a cost analysis was performed. The summary is shown in table 4. As seen, the logistic costs are near 31% of the total cost, which confirms the fact of the influence of intermediaries in the final cost of agricultural products in Panamá.

Table 4: Cost analysis for the model

Average price of the crater	$ 12.00
Total crates shipped	5,264
Total weekly cost	$63,168.00
Transportation costs	$19,442.50
Fraction of total cost	30.80%

Finally, several scenarios for different locations for logistic platforms were analyzed. Figure 5 (Orozco 2014) shows them.

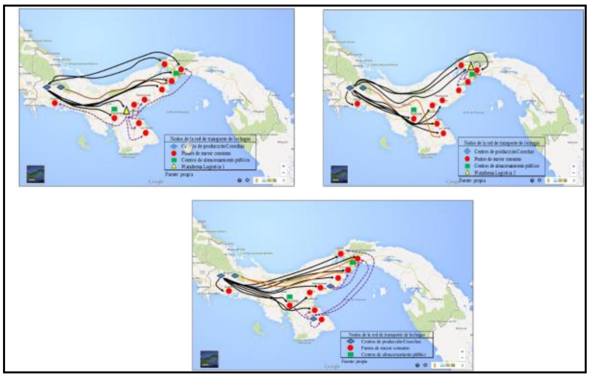

Figure 5: Scenarios for different location of logistic platforms (Orozco 2014)

The model determined that locating the logistic platform close to the central market (or in it) will diminish the logistics costs near 4%. This percentage can be improved if other production areas are implemented and better transportation policies as applied by the producers. With the right policies, costs can diminish up to 12% from the current 31%, so it is important for producers, shippers and government to put together policies that guarantee not only availability of food, but also at a cost accessible for consumers.

6. CONCLUSIONS AND FUTURE WORK

The model provided a solution with a distribution policy consisting on both amounts to be moved from origins to destinations and vehicles, sizes and amounts, to be used. All these variables are tied to costs, such that the result provides, in addition, the minimum cost of the policy.

From the model, it is possible to conclude that any distribution policy must consider not only the supplies and demands but also the facilities for transportation, storage and distribution. Hence, future models should include variables that tie transportation systems with distribution patterns.

Several important aspects have to be mentioned here. First of all, the lack of information on costs, routing, demands and supplies makes really difficult to gather valid information to formulate and evaluate de model. Further, there are no congruence between data from the producers and official institutions. Thus, it was very difficult to validate the results from the model. Finally, it is necessary for the different organizations involved in the agro-food supply chain, to work in a more united manner since it is important to maintain the supply chain in an efficient and effective manner for all, producers, suppliers, and final consumers.

For future work, it is necessary to add more products, thus the problem becomes a multicommodity flows problem (Bazaraa et al 2005) which increases the complexity of the problem adding a number of variables and constraints proportional to the amount of products. In addition, it is necessary to include an additional objective since it is important to maximize the value of the shipment, and to minimize the total cost of the shipment policy. Henceforth, the problem becomes a multicriteria, multicommodity minimum flow problem with equipment assignment.

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DYNAMIC PLANNING OF CARGO TRANSPORTATION FOR UNCERTAIN ENVIRONMENTS

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ABSTRACT
Logistics is one of the mission-critical issues for the oil & gas business. Support logistics, which deals with supplying cargoes from ports to destinations, has a major economic impact on business, and transportation plays an important role in it. One of the important issues in support logistics in the oil & gas area is to mitigate the impact of uncertain factors such as bad weather. In this study, we describe a method of planning transportation for dynamic cargo to mitigate the impact. Our method uses an agent-based trade mechanism and changes the current plan whenever the situation changes. The evaluation results show that our method can make plans faster and more efficiently than weight-based simple planning. Additionally, we clarified that it can be applied to large-scale environments.

Keywords: cargo transportation, agent-based trade, uncertainty, planning method

1. INTRODUCTION

Logistics is one of the mission-critical issues for various businesses including oil & gas. In the oil & gas business, support logistics, which deals with supplying goods for operations, has become the main problem due to the expansion in oil & gas development. For example, recent explorations have found large oil fields located deeper than conventional ones. 'Deepwater' fields have been found in Brazil, West Africa, etc. (Guzman, Carvajal, and Thuriaux-Alemán 2013). Although such fields provide an attractive quantity of crude oil, the expansion makes the support logistics more difficult. Deepwater fields are located hundreds of kilometres from shore, meaning that much more time and money are required for support logistics than with conventional fields. Therefore, logistics performance has to be improved to expand oil & gas development.

Logistics performance can be improved in several ways. For example, Leonard and Voß (2014) proposed a cloud-based IT system to improve port operation efficiency. The key factor of the system is real-time visibility of port operations using Internet of things (IoT) technology. Parreño, Alvarez-Valdés, Oliveira, and Tamarit (2010) created a solving algorithm for container loading problems, one which optimises container location to minimise empty space. They clarified that their algorithm can solve the problem with a large data set. From the view of monetary cost, Tseng, Yue, and Taylor (2005) mentioned transportation plays an important role because around one third to two thirds of enterprises' logistics costs are spent on transportation. As for support logistics in the oil & gas business, transportation is also important because they need frequent supplies to ensure stable operations. Therefore, we focused on transportation optimisation in this study.

Transportation is typically optimised by using operations research techniques. The transportation activities are modelled as mathematical formulations: an objective function and constraint equations. The objective function represents maximising the performance, including cost minimisation, stock-out avoidance, etc. The constraint equations represent conditions such as the number of transportation vehicles and the vehicles' speed. This kind of logistics is typically regarded as a pick-up and delivery problem (PDP) or a pick-up and delivery problem with a time window (PDPTW). Hence, one approach for improving logistics performance is to solve such problems by considering the appropriate cost factors. For example, Romero, Sheremetov, and Soriano (2007) proposed a heuristic approach for the problem, focusing on offshore transportation by helicopters. Korsvik and Fagerholt (2010) proposed a vessle scheduling and routing method for the actual oil & gas support logistics. Their method is based on integration of machine learning and a PDPTW solver. We can use these techniques to make optimised transportation plans. However, transportation is disrupted by uncertain factors like weather changes, and transportation plans should be changed to minimise the effect of these uncertain factors.

Changing plans is crucial for transportation in support logistics because the influence of uncertainty is larger than in other area, like inter-continental transportation. In this study, we designed a dynamic transportation planning method for uncertain environments. The method changes the current plan when the situations are changed to mitigate the impact of the uncertainty. It uses an agent-based trading mechanism. In this paper, we show the preliminary performance evaluation results and discuss the scalability to apply the method to large-scale cases. The remainder of this paper consists of the following. Section 2 defines the problem in detail.

Section 3 explains related work from the viewpoints of operational research and an agent-based trading mechanism. Section 4 describes our approach: transportation planning based on the agent-based trading mechanism. Section 5 shows the evaluation results. Lastly, Section 6 concludes the paper.

2. PROBLEM DESCRIPTION

2.1. Overview

Figure 1 shows an overview of the problem setting used in this paper. As described in Figure 1, we focus on offshore transportation with three elements: offshore platforms, vessels, and ports. Offshore platforms demand supplies required for their operations within a certain period. To satisfy their demands, the supplies stored in cargoes are transported from onshore ports to offshore platforms using vehicles called platform supply vessels (PSVs) (Aas, Halskau, and Wallace 2009). The number of vessels is fixed, and each vessel has the fuel and capacity for storing cargoes. Transportation takes hours depending on the vessels' speed. The problem requires us to make a consistent transportation plan including cargo assignments and vessel routing.

In this paper, we only focus on transportation efficiency, i.e., the number of transported cargoes within a certain period. This means we do not consider cost factors such as fuel fees, purchase costs, and loss of production caused by delays. Additionally, we do not consider time window which is consider by PDPTW. These assumptions make the problem simple and enable us to evaluate the effects of our method easily.

2.2. Supply Cargoes

In this problem, cargoes are composed of supplies for transportation and are prepared at specific ports when they are in demand. Each cargo has a source, destination, and weight. The source is a specific port which prepares the cargo, and the destination is the specific platform which has demand for it. The weight is used for calculating the loading/unloading time and limiting the number of cargoes loaded on vessels.

2.3. Ports and Platforms

In this problem, ports and platforms have the same features. The only difference is whether they are the source or destination of the transportation. They have the number of berths and loading/unloading performance as features. The number of berths limits the number of vessels loading or unloading cargoes at the location simultaneously. The loading/unloading performance defines the time required for loading/unloading cargoes to/from vessels.

2.4. Goal

The goal of this problem is to make an efficient transportation plan, which consists of cargo assignments and vessel routing. Efficiency is typically measured using several criteria. From the viewpoint of monetary cost, the criteria are fuel consumption and the number of vessels used for transportation. In this paper, as noted earlier, we adopted the number of transported cargoes as the evaluation criteria.

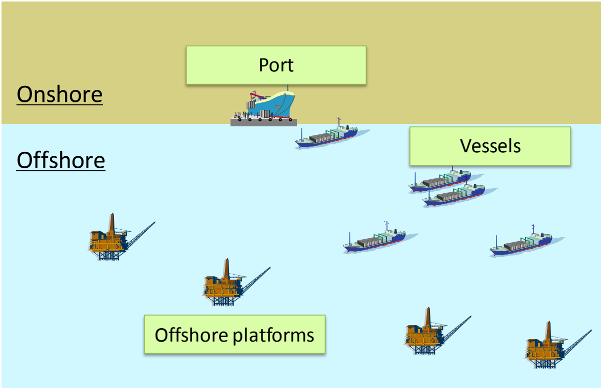

Figure 1 Problem setting overview.

3. RELATED WORK

The most similar problem of transportation planning for uncertain environments is called Dynamic PDPTW. Mitrović-Minić, Krishnamurti, and Laporte (2004) adopted a heuristic approach to make routing and scheduling plans dynamically. They clarified their approach can make near optimal plans in comparison with iterating a static PDPTW solver. Pureza and Laporte (2008) proposed a waiting and buffering strategy for future situation changes. They clarified the strategy can improve the quality of the solution.

However, these approaches typically cannot change constraints. For example, when some routes are closed by bad weather, we have to introduce new constraints representing road closures. To introduce the constraints, we can adopt another technique like constraint programming (Gavanelli and Rossi 2010). Constraint programming can change constraints anytime and output results. Elkhyari, Guéret, and Jussien (2004) applied a constraint programming technique to dynamic train scheduling and clarified it can improve computation time and stability of output schedules. While these approaches can make constraints flexibility, they sometimes require much computation time when solution spaces are large.

Our approach focuses on realising high-speed and flexible semi-optimisation under uncertain environments. We adopted an agent-based trading mechanism for making efficient plans. Using the agent-based approach, Koźlak, Créput, Hilaire, and Koukam (2006) applied a multi-agent mechanism to the PDPTW solver. Their approach is bottom-up, meaning each vehicle makes its plan while considering the estimated future demand. Our approach is another bottom-up approach which uses a trade mechanism to change the assignments of cargoes. Our approach can change plans without estimating future demand.

4. APPROACH

4.1. Overview

Our approach is based on agent-based trading which involves exchanging goods between agents. We regard vessels as trading agents. Each agent is assigned cargoes which should be transported from the source port to the destination platforms, and it has its own plan and cost for cargo transportation. The cost is determined using cargo attributes (e.g., weight and loading location) and transporting routes (e.g., the number of transport locations and the total distance). To make an efficient transportation plan, the agents trade their assigned cargoes with the other agents to minimise their cost. Additionally, our method can manage constraint changes by re-calculating whenever constraints change.

Figure 2 shows the system containing our method. It consists of two modules: a planner and simulator. The planner does its work using the agent-based trade mechanism. The simulator modifies the plans to solve the constraints and to evaluate the plans by several criteria such as fuel consumption, monetary cost, and lead time. Additionally, the simulator has an event controller which generates weather changes—among other things—and new requests of cargo transportation. Once the events occur, the simulator provides the current state to the planner, and it modifies the plan. We can make and modify transportation plans which have no inconsistency under uncertain environments by using the system.

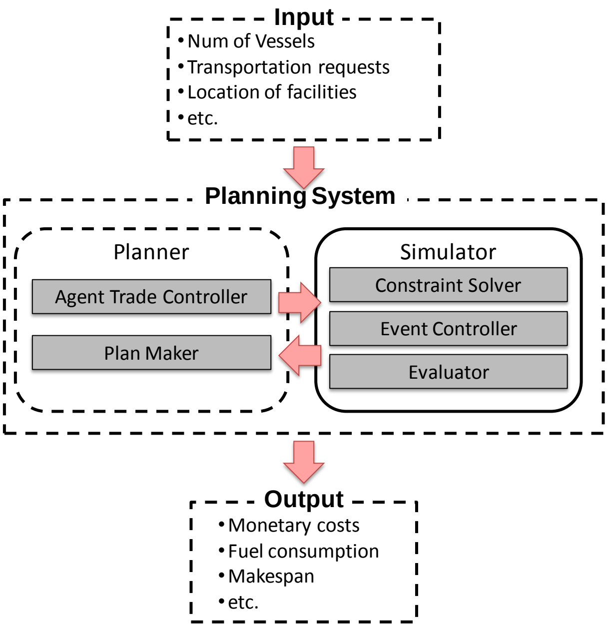

Figure 2 Overview of planning system containing our method.

4.2. Trade Algorithm

Our trade algorithm consists of the following steps.

1. Calculate the current cost.
2. Find cargoes which reduce the cost the most between all the agents.
3. Select the agent which has cargoes found in step 2 as the trade source agent.
4. Find a trade target agent which can reduce the total cost of both agents.
5. Execute the trade.

These steps are iterated until no cargoes are found in step 3, i.e., there are no tradable cargoes.

```
randomAssign()
repeat
    src ← findTradeSourceAgent()
    dest ← null
    max ← 0
    for all the agents except for src do
        profit ← calculateTradeProfit(src, agent)
        if (profit > max) then
            dest ← agent
            max ← profit
        end if
    end for

    if dest ≠ null then
        trade(src, dest)
    end if
until dest = null
```

Figure 3 Pseudo code of our trade algorithm.

Figure 3 shows the pseudo code of our trade algorithm. Function *randomAssign* assigns unassigned cargoes to agents randomly. The sum of the cargo's weight must be less than the max capacity of vessels. Then, the function *findTradeSourceAgent* finds one agent as a trade source using the following steps.

1. Select one agent.
2. Group cargoes assigned to a selected agent by source and destination.
3. Estimate cost reduction when one of the groups is removed from an assignment.
4. Go to step 1 if there are unselected agents.
5. Select one agent which has the max reduction cost.

The trading cargoes are also decided by these steps. The group of cargoes which has the max cost reduction in step 3 are the trading cargoes. Next, the function *calculateTradeProfit* finds the target trade agent by calculating the trading result for each agent. The function calculates cost reductions if two agents exchange a group of cargoes or pass the group from one to the other. Lastly, the function *trade* executes the trade. This process is repeated until it cannot find tradable cargoes, meaning it cannot reduce costs further for any trades.

4.3. Cost Function

The cost function is as essential a factor for our approach as it is for other operational research techniques. As we noted earlier, we use the number of transported cargoes in a certain period as the evaluation criteria. Hence, the higher the number of cargo vessels transporting in one voyage, the lower the costs should be. To represent such relationships, we define our cost function using the following viewpoints:

1. Maximise the weight of cargoes transported in one voyage.
2. Minimise the number of loading/unloading locations.
3. Minimise travel distance.

From these viewpoints, the cost function C of agent v_i is defined by the following equation.

$$C(v_i) = W(v_i) + L(v_i) + D(v_i) \tag{1}$$

$W(v_i)$, $L(v_i)$, *and* $D(v_i)$ are the costs for the weight, location, and distance, respectively.
Weight cost $W(v_i)$ is defined as follows.

$$W(v_i) = 1 + \frac{W_A}{1 + \exp(W_B \times AS(v_i) - W_C \times MC(v_i))} \tag{2}$$

W_A, W_B, and W_C are coefficient values, and function $AS(v_i)$ and $MC(v_i)$ are the available loading space for the current assignment and the max loading capacity of agent v_i, respectively. The weight cost formed as a sigmoid function facilitates loading a certain quantity of cargoes.
The location cost $L(v_i)$ is defined as follows:

$$L(v_i) = ((numPort(v_i)) - 1) \times L_A + 1) \times numPF(v_i) \tag{3}$$

L_A is the penalty coefficient, and $numPort(v_i)$ and $numPF(v_i)$ are the number of ports and platforms stopped in the current voyage. The penalty coefficient limits the number of destination ports because cargoes typically should be transported from one port to a few platforms. However, the number of destination platforms is not limited but increases the cost for aggregating cargoes of the same destination.
Distance cost $D(v_i)$ is defined as follows.

$$D(v_i) = D_A \times TD(v_i) \tag{4}$$

D_A is the coefficient, and $TD(v_i)$ is the total travel distance. This function represents a short voyage as being better than a long one.

4.4. Plan Updates

When a plan should be changed for reasons such as new demand, the current plan is updated. The update does the trading process again by considering the following constraints:

1. Loaded cargoes have to be unloaded only at destination platforms.
2. Assigned cargoes which have not been loaded are tradable.

To re-execute the trading process, all the costs are re-calculated. By calculating cost every time the situation changes, we can consider various events such as new demand and constraint changes.

5. EXPERIMENTS

5.1. Evaluation in Certain Environments

5.1.1. Settings

First, we evaluated our method in certain environments. In these environments, all the constraints and transportation demands were given during the initial planning. For the evaluation, we used the challenge problem proposed at ICKEPS2012 (Igreja, Silva, and Tonidandel 2012), which is the transportation planning problem for offshore oil production. The problem requires satisfying constraints (e.g., fuel, the cargo capacity of transporting vessels, and the number of berths of ports) and efficient plans for given demands.

Table 1 Value settings.

Name	Value
Number of vessels	10
Number of ports	2
Number of platforms	10
Number of cargoes	15
W_A	40
W_B	0.1
W_V	0.55
L_A	500
D_A	0.005

Table 1 shows the major value settings, and the other settings were the same as those in the challenge problem. We evaluated fuel consumption, time required to transport all the given cargoes, and the computation time (hereinafter referred to as the CPU time). As a comparison, we prepared the weight-based simple assigning method which assigns all the cargoes in ascending order of weight. For this experiment, we used a server which has an Intel® Xeon® X5675 with a 3.06-GHz CPU and 24 GBs of memory. All the programs were written in Java and run on OpenJDK 1.7.0u25.

5.1.2. Results

Table 2 shows the results for a static environment. Column 'answer' is one of the optimised results based on the result for the challenge problem (Toropila, Dvořák, Trunda, Hanes, and Barták 2012). The CPU time of 'answer' is the reference value estimated from their paper. The fuel consumption and required time of our method is intermediate between 'simple' and 'answer'. This means that our method makes a plan which is not optimal but nonetheless efficient. Additionally, our method made plans in less than a second while 'answer' required hundreds of seconds. From this result, we can say that our method can quickly make plans which are not optimised but efficient.

Table 2 Results for static environment. Answer is the optimised results. Fuel is the fuel consumption, time is the time required for transportation, and CPU is the computation time. CPU time of 'answer' is the estimated value from the paper.

Method	Fuel [L]	Time [hr]	CPU [s]
Ours	929	218.7	0.93
Simple	1188	222.6	0.11
Answer	887	203.5	600

5.2. Evaluation in Uncertain Environments

5.2.1. Settings

Next, we evaluated our method under uncertain environments which have unknown future demands. Almost all of the settings were the same as those in the previous evaluation. In this experiment, new cargo demands were generated in a certain period. The source and destination were decided randomly upon generation. Hence, we can regard the unpredicted demand as uncertainty.

Table 3 shows the settings of this experiment. The simulation length was 90 days. During the simulation, new demands appeared every generation period. In this experiment, we used the number of transportations for the evaluation. We averaged 50 results for each case.

Table 3 Settings for dynamic planning.

Name	Value
Simulation length	90 days
Generation period	1.5, 3.0, 4.5 days
Number of new demands	3, 5

5.2.2. Results

Figure 4 and Figure 5 show the number of transported cargoes for each generation period when the number of new demands was 3 and 5, respectively. From the results, we clarified that our method can make transportation plans more efficiently than simple plans in every case.

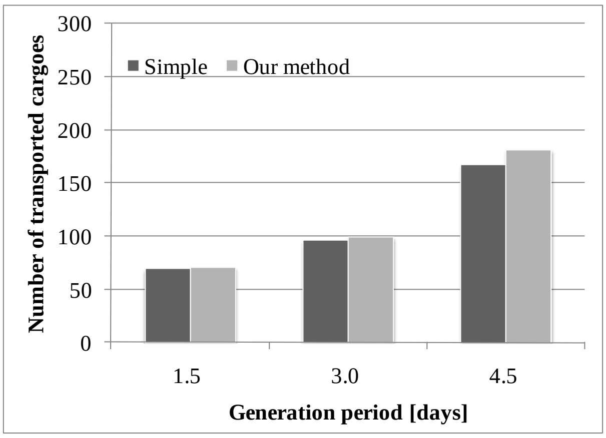

Figure 4 Number of transported cargoes for each generation period (number of new demands is 3).

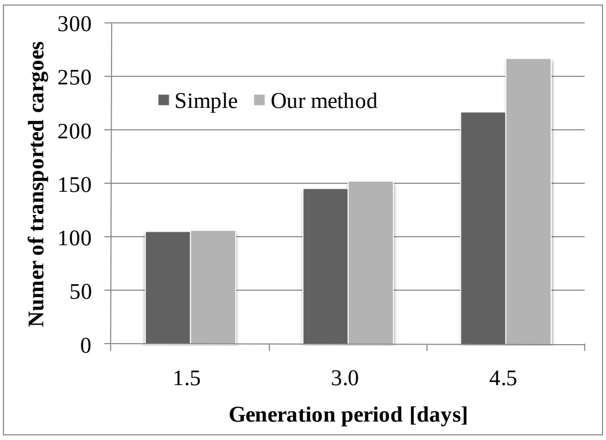

Figure 5 Number of transported cargoes for each generation period (number of new demands is 5).

Additionally, Figure 6 shows the CPU time for each case. From Figure 6, we found that the CPU time was less than 20 seconds in all cases. It is fast enough for periods when emergency response requires rescheduling within minutes.

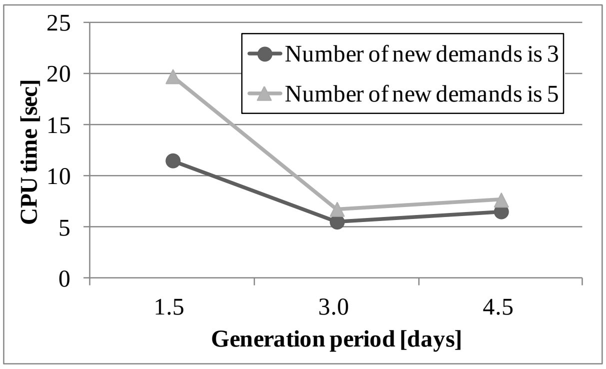

Figure 6 CPU time of our method for each generation period and number of new demands.

5.3. Performance Analysis

5.3.1. Setting

The settings of our previous experiment were for small cases, i.e., only 10 platforms. To apply our method to large cases, we evaluated the CPU time for them. In this evaluation, the generation period was 3, and the number of new demands was half the number of platforms. We averaged 20 results for each case.

5.3.2. Results

Figure 7 shows the CPU time for each case. From Figure 7, we clarified that all the cases were less than 5 minutes. We also found the CPU time increased drastically when the number of vessels was 10. This means there are bottlenecks in specific cases.

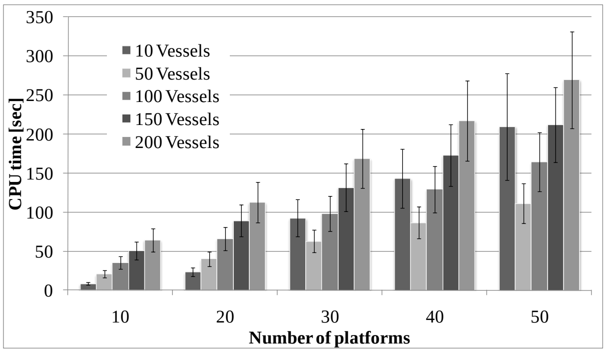

Figure 7 CPU time for large scale.

Figure 8 shows the relationship between the number of new demands and the CPU time when the number of vessels and platforms was 50. We found that the CPU time increased slightly when the number of new demands was less than the number of vessels. When the number of new demands exceeded the number of vessels, the CPU time increased drastically.

One of the causes leading to such drastic increases was calculating the cost function. In this implementation, we calculated the shortest path length when calculating the vessels' routes. The calculation was executed for every cost calculation. However, we could not store the calculation results; storage requires large memory space because the number of combinations is enormous. When we store only the path for 5 destinations under 50 platforms, the number of routes is ${}_{50}P_5 \simeq 2.0\times10^8$. In other words, we need 1.6 GBytes if we store each route with 8 bytes. Therefore, to avoid such a drastic increase, we need either machines with large memory or memory saving implementations such as storing frequently used routes.

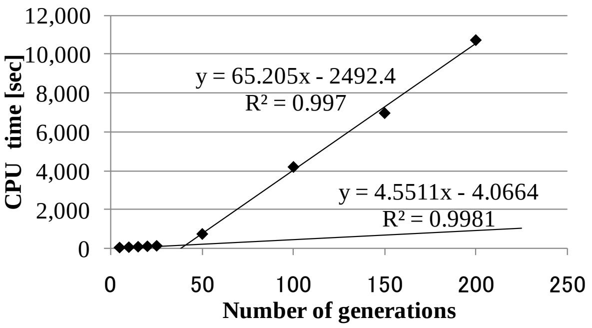

Figure 8 Relationship between number of generations and CPU time when the number of vessels and platforms are 50.

6. CONCLUDING REMARKS

We designed a high-speed transportation planning algorithm to enable dynamic planning of cargo transportation for uncertain environments. Our method is based on an agent-based trading mechanism. Experimental results show that our method can quickly make efficient plans under both certain and uncertain environments. However, our bottleneck analysis shows that we need implementation with efficient memory usage.

Our future work involves two tasks: improving memory usage and verifying constraint changes. The former, as noted, will enable handling large scale problems. The latter will enable handling various emergency situations. In this paper, we tested only the cases of changes in demand. However, many cases involve constraint changes such as platform shutdowns and bad weather conditions. Hence, we need to evaluate our algorithm under such environments.

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SIMULATION-OPTIMISATION BASED DECISION-SUPPORT FOR COORDINATED DISASTER RELIEF LAST-MILE DISTRIBUTION

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ABSTRACT
We present a simulation and optimisation based decision-support system to improve last-mile distribution of goods during disasters. In particular, the impact of road closures on supply and optimal transfer points is analysed by considering road, off-road and air transportation. To deal with panic buying, stockpiling and various consequences of a disaster over a rolling time-horizon, a limited number of transfer points have to be selected. At these points, relief organisations and retailers can transfer shipments to prevent stock-outs at regional stores. Furthermore, shipment requests are scheduled to vehicles, routed and optimised during each simulation run. Results show a significant reduction in average lead times when coordinating last-mile distribution during disasters.

Keywords: humanitarian logistics, agent-based simulation, last-mile distribution, decision support system

1. INTRODUCTION
Transportation highly impacts disaster relief operations (Berariu et al. 2015). Additionally, unexpected increases in demand during disasters are a huge challenge for private companies as well as relief organisations. Naohito et al. (2014) show a significant increase in household spending during the Great East Japan Earthquake of 2011; however, they also report that households were not able to stockpile goods to their desired levels. Holguín-Veras et al. (2014) note that demand also increased in areas not directly damaged by the disasters and that private companies were not able to sufficiently supply goods.
Enabling a robust and efficient supply chain benefits retailers, who are able to sell their goods, and relief organisations as panic is reduced if households are able to purchase the demanded goods. For instance, during Hurricane Katrina in 2005, Horwitz (2009) points out that the private sector was able to supply the affected area long before the public agencies arrived. Additionally, retailers often have a substantial amount of demand data available and the logistic experience to deal with disruptions in supply and demand. Public agencies, in contrast, have the regulatory decision-making and special equipment to ship goods through affected areas.
To support combining these strengths, we introduce a decision-support system (DSS) to coordinate shipments between private and public actors. Therefore, we model road closures as well as road, off-road and air transportation. In particular, we focus on the situation where relief organisations perform shipments between transfer points in the affected areas. This is shown in Figure 1. In contrast to classical last-mile distribution where the relief organisation delivers goods directly to the victims, by coordinating these actions, resources are utilised efficiently and victims are potentially served faster and more consistently. Therefore, retailers perform the first and the last part of the shipment where roads are still intact, while relief organisations ship between two transfer points through the affected area.

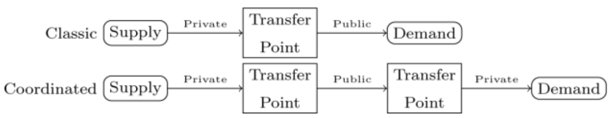


Figure 1: Disaster relief last-mile distribution

The DSS optimises routing and scheduling decisions, selects promising transfer points and allows analysing various disaster scenarios. Furthermore, users can interactively modify the analysed settings to test the impact of different policies. This enables improved decision-making and supports last-mile distribution. Consequently, the contribution of this paper is twofold, namely introducing a simulation-optimisation based DSS for disaster relief last-mile distribution and analysing the potential of coordinating shipments.

2. LITERATURE REVIEW
High computational times and a lack of integrated systems with the right complexity level are the main challenges in humanitarian logistic models (Özdamar and Ertem 2014). The selection of optimal transfer points in our work equals an uncapacitated facility location problem. It aims to find an optimal subset from potential candidate locations derived from an objective

function. For a survey on this topic, refer to Gao and Robinson Jr. (1994) and Verter (2011). Facility location in humanitarian relief is discussed by Balcik and Beamon (2008).

In disaster relief routing, optimisation can lead to major improvements; however, only little work is found (de la Torre et al. 2012). Routing full truckloads between transfer points can be classified as a full truckload pickup and delivery problem (FT-PDP) as introduced by Gronalt et al. (2003). Location-routing problems consider routing decisions when optimising facility locations. For recent surveys on this topic, refer to Prodhon and Prins (2014) and Drexl and Schneider (2015). Only few articles investigate stochastic problems and the impact of network disruptions is rarely analysed.

Longo and Ören (2008) note the importance of modelling and simulation to study supply chain vulnerability and to improve resilience. By combining simulation and optimisation, uncertainties and complex interactions within optimization models can be overcome (Glover et al. 1996). This allows one to investigate the impact of network disruptions as well as disasters on last-mile distribution and to further discuss the potential of coordination.

3. PROBLEM DESCRIPTION

In an area affected by a disaster, roads may be closed for certain durations of time during a day. Potential reasons for this are floods or road blockages as a result of earthquakes or mudslides. Due to panic buying and unexpected demand, stores randomly request additional shipments. Full truck-loads are assumed, i.e. no split-deliveries are performed and shipments have exactly one supply and one demand point. The private actor, e.g., a retailer, can either ship these directly or use the service of a public actor, e.g., a relief organisation. In the latter case, the retailer transports the goods to a transfer point. At this point, the relief organisation takes over the shipment through the affected areas to a second transfer points from where goods are delivered to the store by the retailer. To perform this service, the relief organisation has a number of given heterogeneous helicopters and off-road vehicles available which are dedicated for this purpose. Each is assigned to one of multiple depots where the vehicle starts and ends its operations. If idle, the vehicle always returns to the depot. Private trucks of the retailers are assumed to be always immediately available. While the retailer is only able to drive on open roads, the relief organisation can either fly or utilise closed roads due to special permissions and equipment. Relief organisations only perform shipments between predefined transfer points, where a limited number of facilities have to be selected from a large set of potential candidates. This selection has to be done before the first request occurs and cannot be altered later due to the high organisational effort of moving transshipment equipment. Transfer points can either be large parking areas, open fields or any other suitable area where transshipments can be performed. All vehicles travel respecting speed limits on the individual arcs and are subject to loading and unloading times. The objective is to minimise the average lead time over all shipping requests, i.e. how long it takes on average to deliver shipments to stores from when the request occurred. Therefore, an optimal arrangement of transfer points, an optimal scheduling of requests to vehicles and optimal routes, all considering an uncertain environment and road closures, have to be derived.

Figure 2 gives a simple sample problem with only one request, four potential transfer points, one public vehicle, one depot, one supply point and one demand point. Due to the closure of a bridge, the retailer can perform a detour crossing the next bridge or coordinate the shipment with the relief organisation, which has an off-road vehicle available to cross the closed bridge. As the detour is substantial, the shipment is coordinated. Therefore, two transfer points have to be selected and the shipment has to be scheduled to the public vehicle. As a result, both vehicles travel to the first transfer point where the goods get transhipped. After arrival of the public vehicle at the second transfer point, the retailer delivers the goods to the store. The lead time is denoted by the difference between the arrival time at the store and the time when the request occurred.

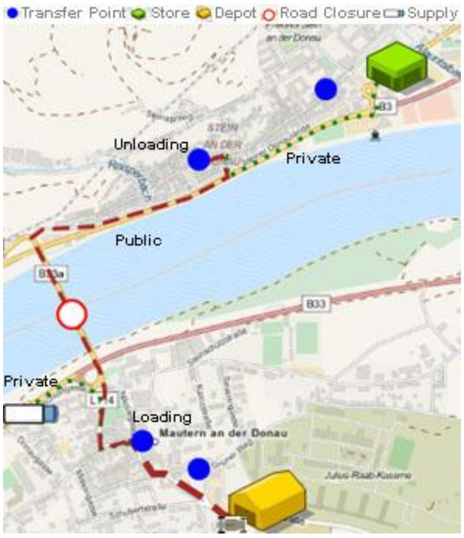


Figure 2: Problem description

4. SIMULATION-OPTIMISATION BASED DSS

An agent-based simulation, a heuristic optimisation procedure to improve vehicle routes and a Tabu Search metaheuristic to select promising transfer points are combined to analyse the introduced problem. Inputs are demand and supply points, vehicle depots, potential transfer points as well as available vehicles, network data and information about road closures. The user specifies a number of requests and a time horizon in which these shipments occur. The simulation stops as soon as the last request is delivered and outputs lead times, vehicle routes and coordination decisions.

4.1. Agent-based Simulation

The agent-based simulation consists of four main components: locations, vehicles, requests and closed roads. Each is modelled as an agent in a geographic space based on the respective network data and coordinates. Locations further differ in stores, depots, transfer points and supply nodes. Vehicles indicate public vehicles, while private trucks are represented within the request agent. As dynamic changes in the simulation can lead to a high number of substantial rerouting and rescheduling decision, vehicles are defined with the statechart shown in Figure 3. If a request gets scheduled, the vehicle moves to the pickup location where it waits if it arrives before the private truck. While moving or waiting, the current task may be aborted to reroute the vehicle to serve a different shipment request. After a loading time delay the vehicle travels to the delivery location. During this trip, we assume that no rescheduling is possible as the vehicle is already loaded. As a result, splitting a shipment in multiple stages to be performed by different vehicles is not enabled. Finally, at arrival at the delivery location, the shipment is transferred to the private truck and the public vehicle continues with its next scheduled request. If no further requests are scheduled, the vehicle returns to the depot.

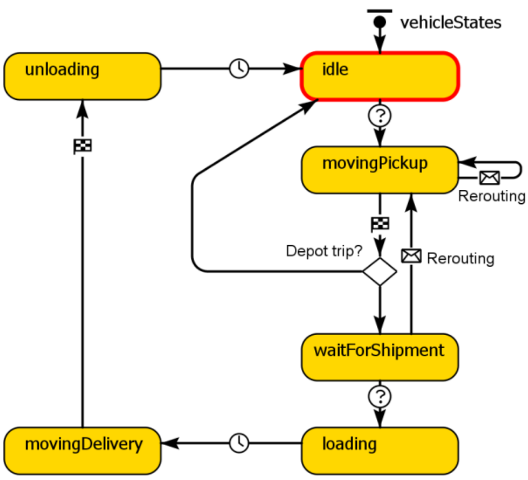
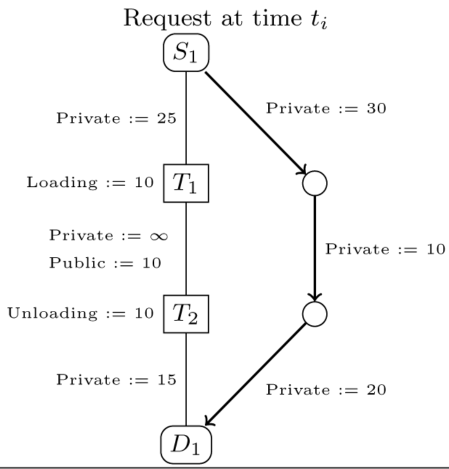


Figure 3: Statechart of public vehicles

The given number of requests are uniformly randomly distributed over time and associated to randomly selected supply points and stores. To calculate the shortest path on the street network between two locations, a bidirectional implementation of the A* algorithm (Hart et al. 1968) is used. Helicopters are assumed to fly in a straight line; however, adding a special routing graph for this purpose is possible. Closed roads are specified as input and associated with a start and end time. The cost of traversing closed roads with private vehicles is set to infinity, forcing the routing algorithm to look for alternative paths.

4.2. Coordination Decision

Each time a new request occurs or roads open or close, the solution procedure has to decide if a transshipment should be performed. If so, it decides at which transfer points and which public vehicle should at what time bridge the affected area. Figure 4 gives a simplified example of a decision if a transshipment should be performed considering loading and unloading times of 10 minutes. Due to a road closure, the direct delivery between supply point S_1 and store D_1 is not possible. As a consequence, the retailer can either select a detour or request a transshipment via transfer point T_1 and T_2 with a relief organisation. Due to loading times, the detour is faster, which results in no transshipment in this case.



Route	Lead Time
Private $S_1 \rightarrow D_1$	60 min
Coordinated $S_1 \rightarrow T_1 \rightarrow T_2 \rightarrow D_1$	70 min

Figure 4: Routing and transshipment decision

If coordinating is potentially beneficial, where to load and unload this request on a public vehicle has to be decided. Therefore, a cheapest insertion heuristic tests all promising transfer combinations on each position within each vehicle's schedule. One option is to select transfer points, which result in the shortest total travel duration, i.e. the shipment travels on the shortest path; however, depending on the current availability of public vehicles this potentially results in substantial wait times. Depending on which vehicle arrives later, either the shipment or the public vehicle waits. As a consequence, wait times are considered by selecting transfer points individually for each vehicle within the routing and scheduling algorithm. Therefore, all combinations of loading and unloading points where the shortest path is less than the best found combination so far for this request are evaluated. Figure 5 gives a simplified example ignoring loading and unloading times. Vehicle V_1 first finishes its current shipment to transfer point T_3 and then continues to T_1. This trip requires 20 minutes. The private truck arrives after 15 minutes, resulting in 5 minutes of wait time for the request. After the loading operations, the request continues to the demand point with transshipment at T_2. The request arrives at the final location after 35 minutes. This value is compared to the best found combination for the request so far and updated if improved. Changes in the route of the public vehicle can, however, lead to delays for other requests scheduled after the inserted change. These costs have to be additionally considered to evaluate transshipments.

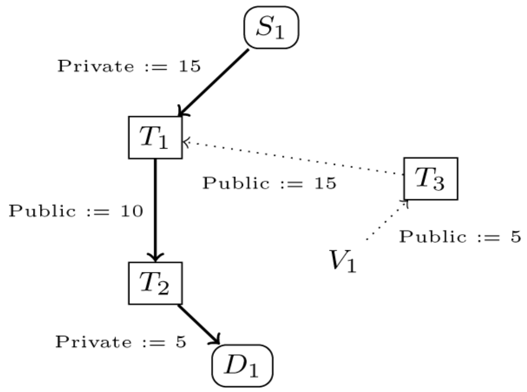


Figure 5: Lead time calculation to select transfer points

The best combination is selected and scheduled. Whenever a road is closed or reopened, all previously made decisions are re-evaluated and improved if possible. To speed up computation, non-promising combinations are aborted if already worse than the best found combination so far. In the next step, the routing of the vehicle is optimised.

4.3. Trip Assignment and Improvement

Each time after a request is scheduled or re-scheduled an intra-route optimisation operator aims to improve the schedule where the request is inserted. Therefore, swapping the order of two requests on this vehicle is tested. Additionally, an inter-route relocate operator checks if moving a request from one vehicle to another improves the objective value. Both operators follow a best improvement strategy, i.e. all potential improvements are tested and the best is applied. This is repeated until no further improvements are found.

The occurrence of new shipments can, however, lead to a situation where it is advantageous to cancel earlier made coordination decisions as it beneficial to utilise public vehicles for other requests instead. To consider this fact, a drop operator is implemented and run after inter-route optimisation. It checks if removing a request from a public vehicle and delivering it directly with a private truck from its current position reduces the average lead time over all requests. Therefore, only public vehicles which were changed during the inter-route optimisation or as a result of an insertion of new requests are evaluated to reduce computational time. In case a request is dropped from a vehicle, the inter-route optimisation procedure is restarted.

4.4. Selection of Transfer Points

As equipment to perform transshipment is limited and further time-consuming to relocate during disasters, the decision-makers may only be able to operate a limited number of transfer points. Selecting a good set of transfer points allows reducing lead times and improving the system's performance. Nevertheless, this decision is not trivial due to network disruption and unknown demand. As a consequence, a Tabu Search (Glover 1989; Glover 1990) was implemented to select a limited number of transfer points out of a set potential candidate locations. Tabu Searches show promising results for multiple related optimisation problems such as the uncapacitated facility location problem (Ghosh 2003), the p-median problem (Rolland et al. 1997) and locating emergency facilities under random network damages (Salman and Yücel 2015). Each candidate location is associated with a binary variable y_i, which equals 1 if open and 0 if closed.

To generate an initial solution, a construction heuristic was developed which selects transfer points based on their attractiveness for transshipments. Therefore, the simulation is run for a pre-specified number of replications runs with all potential candidate transfer points being open and collects statistics about how often a shipment was loaded or unloaded at a certain candidate. In the next step, these candidates are sorted and the most utilised transfer points are added to the initial solution until the maximum number of transfer points is reached.

The initial solution is further improved in the following iterations by a swap operator which opens one transfer point by simultaneously closing a previously open one. Each potential solution in this neighbourhood is evaluated by running the specified number of replication runs of the simulation. The best solution of the iteration is stored and acts as the incumbent solution for following iteration. The selected move is set tabu for τ iterations, i.e. it is not allowed to be undone. Nevertheless, if performing this move improves the overall best found solution so far, the tabu criteria is revoked. Furthermore, moves which lead to a worse objective value compared to the last iteration are penalised based on how often the respective candidate has been added to the solution in prior iterations. This helps to diversify the search procedure and is done by the following evaluation function $g(S)$ with $f(S)$ indicating the objective value of the solution, k_i the times a transfer point has been previously added to a solution and ζ the penalty weight.

$$g(S) = f(S)(1 + \zeta k_i) \quad (1)$$

After either a given time limit or a maximum number of iterations, the Tabu Search terminates and returns the best found objective value as well as the best set of transfer points to operate.

4.5. Dynamic extensions

The simulation further allows including sudden car breakage as well as changes in air weather, which enables or disables air transportation. Furthermore, roads and transfer points may be closed or open dynamically based on pre-specified stochastic distributions or by user interaction. In each of the cases, all affected requests are re-evaluated if transshipment should be adjusted considering the new situation. Allowing the user to dynamically perform such changes during a simulation run enables one to test different scenarios, run risk assessments and to visualise potential impacts.

5. COMPUTATIONAL EXPERIMENTS

The DSS is developed with AnyLogic 7.1 (AnyLogic 2015) using OpenStreetMap (OpenStreetMap 2015) and a custom implementation of GraphHopper 0.3 (GraphHopper 2015) to route vehicles on different networks. The solution procedure is coded in Java. Computational experiments were run on an Intel Core i7-4930K, 64GB RAM, MS-Windows 7 and 6 threads operating in parallel.

5.1. Test Scenario

Test area is Krems an der Donau, Austria, and the surrounding area, a region often affected by floodings of the Danube River Basin. To reach the city center of Krems, shipments either have to cross the Danube River on one of two bridges or circumvent the area to take a major highway bridge in the east of the region. As demand points, the geographic position of supermarkets, pharmacies and other major retailers in the area are selected. These stores are supplied from two supply points in the east, one north of the Danube and one south, both located at highway exits. To indicate potential transfer points, large parking lots as well as football pitches and industrial areas were selected. Therefore, it is assumed that all transfer points are accessible for both air and off-road vehicles. In total, 29 stores, two supply points and 80 potential transfer points are available. Figure 6 plots the studied region.

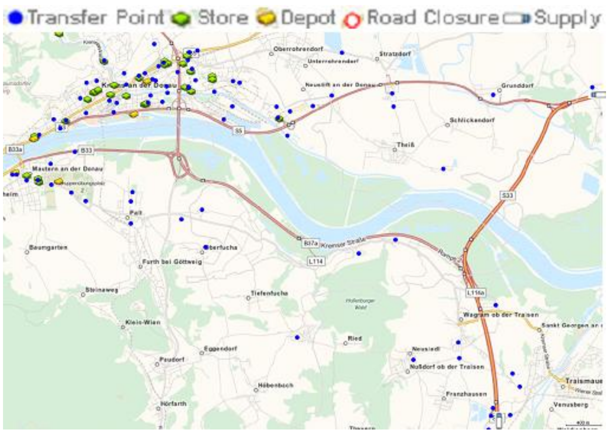


Figure 6: Test scenario area

Two helicopters and three off-road vehicles are stationed at five depots in the region. Vehicle depots were located based on fire-fighter stations in the area, a military barrack and a major hospital. Helicopters travel with an average speed of 135 km/h and require six minutes for loading and unloading operations. Off-road vehicles travel with 45 km/h and take three minutes for loading operations. Private trucks travel respecting individual speed limits of each road with a maximum travel speed of 95 km/h. Road closures are set as reported by the Austrian Press Agency (APA-OTS 2013) for the 7th of June, 2013 when the region was struck by a major river flooding. Roads are closed for the entire period and travel times are considered to be certain, e.g., there is no random component in the time it takes to travel between two points. Based on opening hours of stores in the region, the simulation starts at 8am and shipment request may occur until 4pm. The average number of shipment requests per store in the computational experiments is varied between one and fifty requests over the eight hours simulation horizon. Furthermore, all dynamic extensions reported in Section 4.5 are disabled for the computational experiments to enable clearer comparisons of different policies by reducing stochastic impacts.

5.2. Parameter Setting

To consider stochastics effects in demand, each evaluation is run with 100 replications and average results are reported in this work. The initial solution is constructed based on the attractiveness of transfer points after 6 runs. For the optimisation of facility locations, the tabu tenure τ is uniformly randomly selected after each iteration in $[0,\lceil\sqrt{n}\rceil]$ with n indicating the number of potential candidate facilities. The diversification penalty ζ is randomly set in [0,0.1] after each iteration to vary diversification. The time limit is set to 30 minutes. To speed up optimisation, replications are aborted for a single solution if the current mean is worse than the best found solution in the current iteration based on a confidence level of 95% and after a minimum of 6 replications. Additionally, memory techniques are used to store reoccurring evaluations, solutions are evaluated in parallel on multiple threads of the computer systems and all visual animations are disabled.

5.3. Preliminary Results and Discussion

Figure 7 shows a solution with three transfer points to open and with on average five shipments requests occurring per store during the simulation horizon. Due to the road closures, two main connections within the city of Krems as well as one of the two bridges are not traversable for private vehicles. As a consequence, out of the 80 potential candidate locations, the Tabu Search selects three candidate locations for the coordination with the objective to reduce average lead times.

Figure 7: Sample solution for the 07th June 2013.

Two transfer points are located closely to stores where direct connections are disrupted by road closures. The third one is located closely to the exit of the main bridge entering the area. At this point, the public actor takes over the shipment to bridge the affected area to one of the other two transfer points.

5.3.1. Impact of Coordination

To analyse the impact of coordinating last mile distribution, three settings are compared. Therefore, the three prior selected transfer points are used. "Best case" indicates the situation where no roads are closed. It gives a natural lower bound for the system performance. Note that, due to a higher travelling speed and different routes of helicopters, coordination can potentially lead to a lower average lead time if no roads are closed; however, it can be assumed that no coordination between public and private actors is performed in such a setting. "Worst case", in contrast, indicates the situation where no public vehicles are used and private trucks use the remaining open roads to deliver goods to stores. This setting acts as a natural upper bound. Both can be, assuming a uniform distribution of supply and demand points of requests and no changes in the street network, calculated by determining the average lead time $\mu_{c_{j,m}}$ from all *s* supply points to all *m* stores under the given street network.

$$\mu_{c_{ij}} = \frac{1}{sm} \sum_{i=1}^{s} \sum_{j=1}^{m} c_{ij} \qquad (2)$$

"Coordinated" allows transshipments of goods as studied in this paper and requires one to run the solution produce. Figure 8 plots the benefits of providing public vehicles to transfer goods through the affected areas.

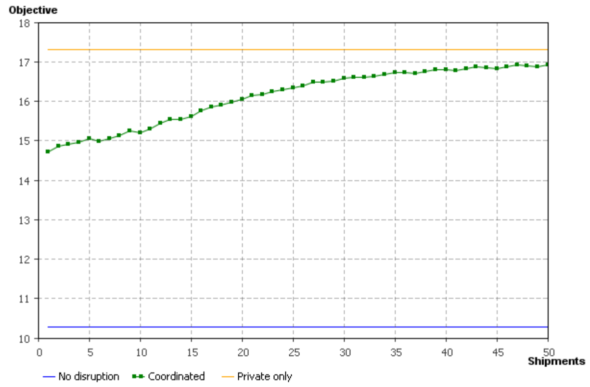


Figure 8: Impact of disaster-relief coordination

Compared to the worst case scenario, average lead times are substantially reduced, especially if only few shipments occur. In this case, public vehicles are only little utilised and can efficiently transfer shipments. Nevertheless, the optimal scenario where no road closures occur is not reached due to detours to transfer points, additional loading times, waiting times for vehicles and varying travelling speeds of different vehicles. In general, the number of available public vehicles and the extend of road closures, as well as travelling speed of public vehicles and loading and unloading times have a major impact on the benefits of last-mile coordination in disaster relief.

If the number of shipments per store increases, utilisation rises as well and, as a consequence, substantial wait times occur. High wait times further lead to more cases where a detour is faster compared to coordinating the shipment. As a result, with a higher number of shipments, average lead times converge to the worst case lead time without coordination as only few gains can be realised. In such a setting, adding more vehicles for the coordination is beneficial.

5.3.2. Impact of Vehicle Optimisation

Optimisation within a dynamic setting is challenging as decisions which are "optimal" considering the current status of the problem might lead to negative effects later when the problem changes due to the occurrence of new requests. To analyse the impact of our optimisation procedure, it is compared to a simple scheduling rule, which adds a new shipment to the end of the vehicle schedule which results in the lowest average lead time. Nevertheless, all potential combinations of transfer points are evaluated in this step. Furthermore, no inter- and intra-route changes are performed. Results of both methods are compared in Figure 9 with the three prior selected transfer points.

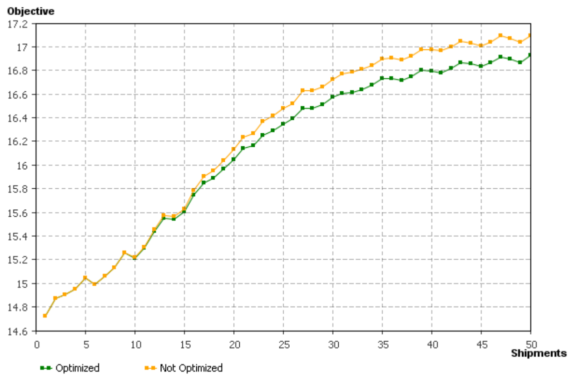


Figure 9: Impact of the optimisation procedure

The analysis shows that given a small number of shipments per store, the optimisation procedure has nearly no impact. The main reason for this is the low number of shipments simultaneously scheduled to a single vehicle. This gives little room for improvement. With an increasing number of shipments, however, the number of simultaneously scheduled requests per vehicle increases, allowing the optimisation procedure to improve average lead times by altering vehicle routes. Based on these results, the user is given the option to deactivate the optimisation procedure prior to a simulation run to save on computational run time.

5.3.3. Impact of Number of Transfer Points

Opening more transfer points increases organisational efforts and potentially costs; however, average lead times are expected to decrease as better coordination can be achieved. To plot the impact of the number of transfer points, the optimisation was run for each potential number of transfer points to open with 5 shipments requests per store. Results of this analysis are shown in Figure 10.

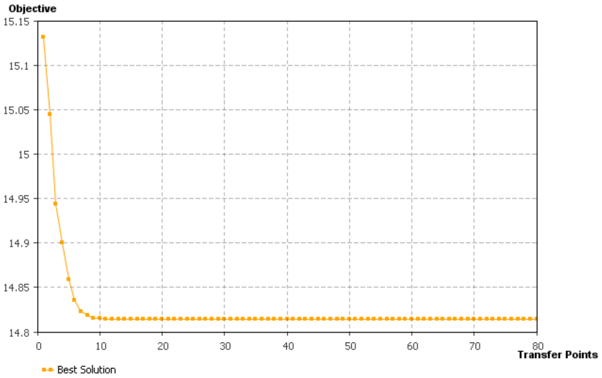


Figure 10: Impact of the number of open transfer points

As expected, average lead times are the highest if only a few transfer points are operated. Adding an additional transfer point decreases the lead time substantially if only few facilities are open, while little to no impact is achieved if many candidates are already selected. Furthermore, after 13 facilities, opening an additional transfer point is no longer beneficial as the additional facility is not utilised for transshipments and, as a consequence, does not improve the system's performance. Analysing the problem in this way, helps to reduce the problem size substantially as non-promising candidates can be removed from the set of potential facilities to improve run times. Additionally, having fewer candidates to consider allows decision-makers to closer investigate the remaining candidates.

6. CONCLUSION

To support coordinated last-mile distribution during disasters, DSSs are crucial to investigate and analyse potential strategies and resulting trade-offs. The introduced DSS offers this by combining simulation and optimisation techniques. The focus on modelling real-world transportation networks and the consideration of road closures enables one to utilise the developed tool in education and training activities. It helps to define promising locations of transfer points, analyse the impact of road closures and further plots the benefits of coordination. As a result, future decision-making in the context of disaster relief logistics can be improved to support victims effectively and to lower the impact of disasters.

Future work includes facilitating the developed DSS to test the impact of certain road closure on the performance of the system. Additionally, embedding the DSS in the development of serious games to train decision-makers is one potential research direction of high interest.

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A SIMULATION MODEL FOR DETERMINING THROUGHPUT CAPACITY OF CONTAINER TERMINALS

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ABSTRACT
Throughput capacity is a vital factor that dominates the suitable time of expansion of container terminals. By analyzing the operation system of container terminals and realizing its complexity, this paper established a simulation model of container terminals to imitate the realistic operation process and determine the throughput capacity of a container berth under various influence factors. The simulation results can be used by decision makers to choose appropriate throughput capacity under required service level and decide the optimal number of berths arranged continuously. The simulation model will be beneficial to guide the construction of container terminals.

Keywords: container terminals, throughput capacity, simulation model, service level

1. INTRODUCTION

As the national economy and external trade continue to expand, seaport container transportation maintains a rapid development in China. Construction of specialized container terminals has been becoming a hot topic in Chinese coastal ports. A good match between throughput capacity and transportation demand is the foremost factor to guarantee the reasonable construction of container terminals, so as to avoid duplication of investment and waste of resources. Thus, throughput capacity is one of the main bases to assess whether the scale of current terminals can fit transportation demand. Besides, the fitness of terminals judged by the throughput capacity is the basis for the government to approve infrastructure projects of terminals and conduct shoreline management. Therefore, it is necessary and urgent to research into throughput capacity of container terminals under the background of accelerated terminal construction and limited excellent shoreline resources, which can not only help to utilize resources efficiently, but also guarantee the investment rationality of terminal constructions.

Currently, the main research methods on throughput capacity are queuing theory and simulation methods. Liu et al. (2008) analyzed the impact of container liner arriving rule, group layout of berths, trend of large vessels and other factors on throughput capacity of container terminals by queuing theory. Shabayek and Yeung (2001) studied the influence of seasonal factors on vessel service time of container terminals. To some extent, due to the complexity of the port operation system, queuing theory models can not accurately reflect the actual operation situations. Therefore, most researchers tended to use simulation methods to study the throughput capacity of terminals. Peng (2004) built a simulation model for a berth of Tianjin Port using object-based computer animation simulation language AUDITION, and the result showed that yard capacity constraints throughput capacity. Yazdani et al. (2005) presented the development of a simulation application called "Port Process Simulator", which can simulate the port operation scenarios to provide recommendations for end-user to make decisions about increasing throughput capacity. Li, Yu, and Yang (2010) built a container terminal simulation model to simulate the influences of annual operating days, handling amount of a single vessel , service levels and other factors on throughput capacity of container terminals, but it ignored the impact of berth tonnage. Ding (2010) studied the throughput capacity under different combinations of arriving vessels by building simulation model, and found that optimizing the combinations of arriving vessels can improve the utilization of berths and throughput capacity. Ng and Wong (2006) built a simulation model by using simulation language PROMODEL to study the impact of vessel traffic flow interference on throughput capacity within the Hong Kong container terminal. Kia, Shayan, and Ghotb (2002) investigated the positive impact of ship-to-rail direct loading on throughput capacity of a container terminal using the real-time statistics by computer simulation. Longo, Huerta, and Nicoletti (2013) developed a simulation model to recreate the complexity of a medium sized Mediterranean seaport and analyzed the performance evolution of such system with particular reference to the ship turnaround time.

However, the abovementioned models focused only on some essential characteristics of the operation of container terminals, there is little research that takes into account all the other important features such as berth tonnage, handling efficiency of quay cranes, daily working hours, and hauling distance of import and export containers to discuss appropriate throughput capacity of a container terminal.

Therefore, this paper proposes a simulation model to study the impact of all important influence factors on throughput capacity of container terminals using the discrete event simulation software Arena 10.0. The remainder of this paper is organized as follows. In the next section, the composition of container terminals, definition of throughput capacity, model assumptions and analysis of influence factors are separately introduced before the establishment of simulation model. And then, a case study is presented and the throughput capacity is discussed in terms of service level. Finally, the conclusion is briefly described.

2. SIMULATION MODEL OF CONTAINER TERMINALS

2.1. Composition of Container Terminals

The operation system of container terminals can be divided into five subsystems which are vessels berthing/unberthing subsystem, loading/unloading subsystem, horizontal transportation subsystem, storage yard subsystem and gate subsystem, respectively. Nevertheless, there is not only physical relationship between each subsystem, but also event relationship generated by the interaction of entities and resources. An organic whole system is thus formed by all subsystems through traffic flows. Therefore, when studying throughput capacity of container terminals, both the design of each subsystem and their inner relationship should be considered.

2.2. Definition of Throughput Capacity

When determining the throughput capacity of container terminals, one needs to find a proper definition of throughput capacity. In general, throughput capacity of a container terminal is defined as the number of TEUs that a terminal can handle in one year under a specific service level in terms of AWT/AST. AWT/AST denotes the ratio of the average waiting time of a vessel to the average service time of a vessel at berth. *Design Code of Container Terminal for Sea Port(JTS165-4-2011)* recommends that large container terminals (more than 50,000 tons) with three continuous berths and above should select 0.1≤AWT/AST≤0.3, while small container terminals with less than two berths should select 0.4≤AWT/AST≤0.5. The change interval of AWT/AST during the analysis of simulation results is limited from 0.1 to 0.5.

2.3. Model Assumptions

The simulation model is based on the following assumptions:

(1) Berthing rule:

Fixed berthing dock mode, and first come first serve.

(2) Loading and unloading operation rule:

Unloading at first and loading at last.

(3) Device configuration and container truck scheduling rules:

The number of quay crane (QC) and yard crane (YC) is determined according to berth tonnage. The number of yard truck (YT) is deployed according to the number of QCs, and YTs follow the "shortest path" scheduling rule.

2.4. Analysis of Influence Factors

Throughput capacity of container terminals is influenced by a series of factors such as arrival interval distribution of vessels, effective berth utilization rate, handling amount of a single vessel, annual operational days of port, number of handling equipment, handling efficiency of QC, conversion coefficient of TEU, influence coefficient of advanced QCs, yard capacity, management level, etc. From the perspective of practicability and for simplicity, this paper focused on arrival interval distribution of vessels, effective berth utilization rate, handling amount of a single vessel, handling efficiency of QC, and operation time per day.

(1) Arrival interval distribution of vessels. According to the analysis of vessels' arrival interval of Yantian International Container Terminals, Ningbo Beilun international Container Terminals and Nansha Stevedoring Co., Ltd of Guangzhou Port, we find that arrival interval distributions of vessels are all negative exponential. Hence, the arrival interval distribution of vessel in the simulation model is set as negative exponential distribution.

(2) Effective berth utilization rate. Effective berth utilization rate is an important indicator which can reflect port operation state. In this model, it is taken as 50%~70% according to Design Code of Container Terminal for Sea Port (JTS165-4-2011).

(3) Handling amount of a single vessel. This is one of the most sensitive factors in determining the throughput capacity of a container terminal. According to the practical research, handling amount of a single vessel is influenced by port scale, shipping line and traffic organization. For ocean-going shipping line, the value can be relatively large. For container terminal which is in the endpoint hub port status with point-to-point transportation form, this value may be larger. Take Nansha container terminal (which is in the status of south point hub port) as an example, the handling amount of a single vessel of internal trading shipping line can be up to 3000 TEU.

(4) Handling efficiency of QC. It's related to mechanical property of QCs, technical level of operators, shipping lines distribution and traffic organization of container terminals, and handling amount of a single vessel as well.

(5) Number of main equipment. The number of QC is connected with port status. In general, mainline port serves larger vessels, and is equipped with more equipment, while feeder port serves smaller vessels, and its equipment is relatively less.

(6) Operation time per day. That is around-the-clock handling operation time and is generally taken as 22~24h. When berth is small and shipping line is less, it can be suitable reduced.

2.5. Establishment of the Simulation Model

Based on the above analysis and assumptions, the simulation model for determining throughput capacity of container terminals can be constructed by respectively establishing vessels berthing/unberthing module, loading/unloading module, horizontal transportation module, storage yard module and gate module, and connecting them with their logistic relationship, as shown in Figure 1. Figure 2 depicts the logistic model for vessel berthing/unberthing module.

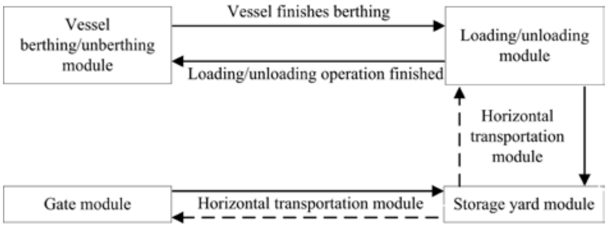

Figure 1: Logistic Relationship between Each Module of Container Terminal Operation System

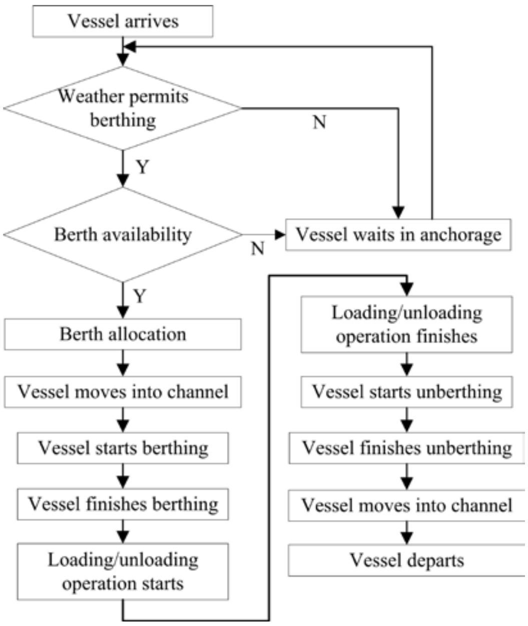

Figure 2: Logistic Model for Vessel Berthing/ Unberthing Module

Vessel berthing/unberthing module includes vessel arrives, vessel waits in anchorage, vessel moves into channel, berthing/unberthing and vessel departs. When handling operation is finished, vessels will leave the port through the channel. During the above processes, vessels are entities, which possess the resources of channel and berth according to the vessels' scale, tonnage and handling amount of a single vessel.

Loading/unloading module consists of vessels loading and unloading process. Vessel loading process means YTs carry containers to wharf apron, and then QCs transfer containers from YTs to vessels. Vessel unloading process refers to QCs transferring containers from vessels to YTs. In these processes, vessels are entities, and the type and scale of the containers need to be determined.

Horizontal transportation module contains receiving and dilivery of containers. Receiving of containers refers to containers transported from gate by external trucks or from berth by YTs to storage yard, while delivery of containers is exactly the opposite. In these processes, containers are entities, and trucks are resources. It is necessary to know where and when to pick up and deliver containers.

Storage yard module includes containers transfered from YTs to the storage yard by YCs, in which containers are entities, and slots and YCs in storage yard are resources.

Gate module is the boundry of simulation model for external trucks. In this process, containers are entities, and lanes are resources.

3. CASE STUDY AND DISCUSSION

3.1. Case Study

The values of the model's input parameters are chosen on the basis of empirical data and *Design Code of Container Terminal for Sea Port (JTS165-4-2011)*. Vessel auxiliary operation time and berthing and departing time is set as a uniform distribution in 3h~5h. The passage time of empty entering port truck, loaded entering port truck, empty leaving port truck and loaded leaving port truck are triangularly distributed random variables with parameters (20,25,30) sec, (30,40,50) sec, (5,10,15) sec, and (30,40,50) sec, respectively. The proportions of import and export containers are all 50%. The ratio of operation machines between QC, YC and YT is 1:3:7. The parameter values of benchmark scenario of simulation experimental program are shown in Table 1. The remaining scenarios are simulated by automatically changing the values of parameters such as vessels' arrival interval (determined by number of arriving vessels), handling amount of a single vessel, handling efficiency of QC, and operation time per day around the values of benchmark scenario using the embedded VBA in Arena. Finally, the effect of different influence factors on terminal service level and throughput capacity under different tonnage and berths is achieved.

3.2. Result Discussion

Taking berths that can berth 100000 DWT container vessels (100,000-tons container berths) as an example, the influence of service level on throughput capacity of a berth is obtained by changing intervals of vessel arrival time. The repeat times of simulation for each change are 10, and the simulation result is shown in Figure 3. Similarly, the effect of handling amount of a single vessel on throughput capacity of a berth is shown in Figure 4.

Table 1: Parameter Values of Benchmark Scenario

Vessels tonnage [10,000 tons]	Reference value				
	Handling efficiency of QC [TEU/h]	Vessel arrival number per year [vessels/berth]	Quayside cranes number [unit/berth]	Handling amount of a single vessel [TEU]	Operation time per day [h]
1	40	470	2	TRIA(200, 600, 1000)	24
2	40	410	2	TRIA(300, 7500, 1200)	
3	48	510	3	TRIA(600, 1050, 1500)	
5	48	430	4	TRIA(800, 1650, 2500)	
7	48	330	4	TRIA(2000, 2500, 3000)	
10	60	410	5	TRIA(2000, 2500, 3000)	
12	80	360	5	TRIA(3000, 3500, 4000)	
15	80	400	5	TRIA(3000, 3500, 4000)	

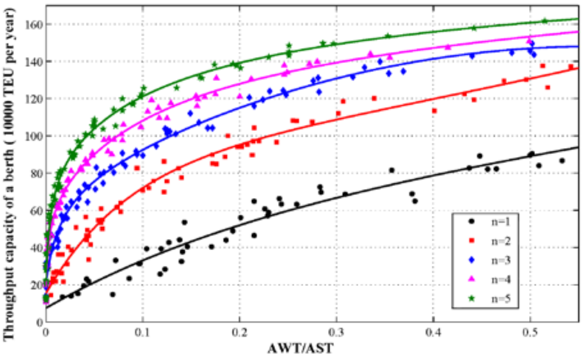

Figure 3: The relationship between AWT/AST and throughput capacity of a berth under n continuous 100,000-tons berth combination

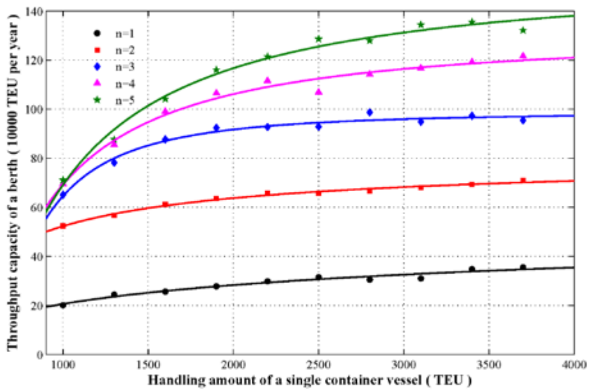

Figure 4: The relationship between handling amount of a single vessel and throughput capacity of a berth under n continuous 100,000-tons berth combination and AWT/AST=0.1

It can be seen from Figure 3 and Figure 4 that:

(1) Throughput capacity of container terminals increases with AWT/AST under the same number of berths. When container terminal is arranged in 4 continuous berths, the throughput capacity of a berth is 1,270,000 TEU under AWT/AST=0.2, and increases by 190,000 TEU than that under AWT/AST=0.1, a gain of about 17.6%. However, the increment of throughput capacity is obtained at the expense of lower service level.

(2) Throughput capacity of container terminals is greatly influenced by the number of continuous berths under the same service level. When AWT/AST equals 0.1, the throughput capacity under 4 continuous berths increases 160,000 TEU than that under 3 continuous berths, which is an increase of about 17.4%. The result shows systematic influence of multiple continuous berths, which is conductive to the reasonable berth allocation and equipment scheduling.

(3) Throughput capacity of container terminals increases with handling amount of a single container vessel under the same number of berths. When container terminal is arranged in 4 continuous berths and AWT/AST equals 0.1, the increase of handling amount of a single container vessel from 1,500TEU to 2,000TEU will result in the increase of throughput capacity of a berth from 940,000 TEU to 1,060,000 TEU.

(4) Multi-berth arrangement can improve the sensitivity of throughput capacity of a berth to handling amount of a single container vessel. Generally speaking, when the handling amount of a single container vessel increases with the same amount from a certain value, the throughput capacity of a berth under the situation with more continuous berths increases significantly more than that with less continuous berths.

4. CONCLUSION

The simulation modeling using computer software is a practical approach to research over the complex large system and to tackle problems that can hardly be solved by mathematical method. Therefore, this paper proposes a simulation model of container terminals to determine the throughput capacity of a container berth under various influence factors. By running the simulation model and analyzing the data obtained, the impact extent of each influence factor on throughput capacity can be found, and the result can be used to determine the optimal number of berths that are arranged continuously under certain conditions. Since the construction of container berths involves hugely investment, the simulation result can play an important role in the reasonable planning of newly planned or expanded container terminals.

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EVALUATION OF SUPPLY CHAINS EFFECTIVENESS AND RELIABILITY BASED ON MODELLING LOGISTICS OPERATIONS

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ABSTRACT
Apart from the total logistics costs (TLC) nowadays to evaluate the integrated supply chains (SC) effective functioning some new criteria are used more often. These criteria characterise the quality and reliability of accomplishing logistics operations and functions. It is obvious that these metrics are connected and their separate representation is a consequence of not enough developed supply chains theoretic model. The paper presents the critical analysis of existing approaches to the TLC evaluation and SC reliability, the methodical approach which allows to evaluate the total costs indexes and supply chains reliability. Taking into consideration that most indicators which describe the chain functioning are the random values, to obtain the required evaluations there is a developed algorithm based on simulation.

Keywords: supply chains, reliability, total logistics costs, simulation

INTRODUCTION

Modern period of logistics and SCM development is characterized by a heightened interest not only for the total logistic costs, but for the row of new concepts such as «sustainability», «flexibility», «adaptability», «response time» and, of course, «reliability».

As for the total logistic costs, there two main directions of research have been set: at a micro and macro levels. Thus, at the macro level collection and analysis of statistical data of TLC let us state that in different countries these costs make up from 8-10 % (the USA, for example) till 20 % GDP (Singapur, Russia) (Ballou 1999; Bowersox and Closs 1996; Jonsson 2008).

These rates are average; they characterize the flow of global economic processes and can subsequently be used for long-term forecasts at the macro level and for the development of strategies, etc.

Another field of research is connected to the collection, systematization and analysis of costs in SC at the micro level (Christopher 2011; Stock and Lambert 2001; Waters 2003). An empirical approach of estimating logistics business operations costs in SC has undoubted advantages, but it also has some significant shortcomings.

It is important to point out that traditionally, the analysis of logistics and transportation (L&T) scenarios within a supply chain considers the overall costs as the most important performance measure (Cohen and Lee 1988). Wherein it is essential to take into consideration different stochastic variables and uncertainties: late deliveries, machine breakdowns, order cancellations, increased inventories, additional capacities or unnecessary slack time, etc. (Van der Vorst et al. 2000). Thus, according to (Bruzzone and Longo 2014), analytical models rarely succeed in indentifying proper and optimal solutions for L&T problems.

As for the supply chains reliability, we have to point out that most experts, for example (Klimov and Merkuryev 2008), think that the reliability is defined as a probability that a system will not fail before predicted time moment. From a known probability distribution (exponential distribution is the most commonly used life distribution for technical system reliability analysis (Ventsel and Ovcharov 1983; Andrew and Moss 2002; Rausand and Hoyland 2004) it is possible to define a mean time to failure.

For our purpose the studies, that contain the quantitative methods of assessing the reliability of supply chains, can be divided into two groups.

In the first group of studies the assessment of the reliability of supply chains is carried out on the basis of the so-called circuit reliability (serial, parallel and mixed compound of elements with different types of redundancy - «active/hot», «standby/cold») (Blanchard 2004). All estimates are based on the probability of faultless operation of the elements of chain.

The second group of studies contains failure models, which, by analogy with technical systems (Gertsbakh and Kordonsky 1966), can be presented by the following types:

- the model of the «perfect» or «ideal» order (Ballou 1999; Christopher 2011);
- the model of «supply and demand» (Kersten and Blecker 2006);
- the «just-in-time» model (Lukinskiy et al. 2014b).

The search for real supply chain efficiency and reliability formulas is difficult and it increases with the development of the theory. Therefore, quantitative methods and supply chains modelling are actively developing on modern information systems and information technologies (Bruzzone et al. 2004; Ivanov et al. 2011; Langevin and Riopel 2005).

Exactly modelling and simulation is one of the most important available methodologies to investigate systems behavior where traditional approaches are unable to deal with their complexity and the high number of interacting phenomena or interoperable components (Longo 2011).

Thorough analysis and synthesis of scientific publications, monographs, textbooks on logistics and supply chain management enabled us to arrive at the following conclusions:

1. There has been a stable tendency of the development of analytic tools, which can be used to manage and improve SC business processes efficiency.
2. The process of the TLC model forming which appeared one hundred years ago in a first variant (Harris 1913) nowadays is a multileveled model and is continuing to develop.
3. To evaluate the supply chains reliability according to (Ballou 1999; Blanchard 2004; Christopher 2011), there is a most often used model which is a product of the probability of no-failure of Pi for each i-th logistics operation or function.
4. Models for the total logistics costs and evaluation of reliability are examined separately which contradicts the actual functioning supply chains.
5. Fundamentally new approach (from accessible sources to the authors) is presented in works (Lukinskiy et al. 2014a; Lukinskiy V.S. and Lukinskiy V.V. 2015) where the supply chain is considered as a recoverable system mainly due to the insurance stocks on the different levels of the logistic system.

1. METHODOLOGICAL APPROACH

The executed analysis of works of logistics and SCM (Bowersox and Closs 1996; Christopher 2011; Stock and Lambert 2001) lets us state that logictic approach is, in fact, is a system approach towards the research of social-economic and human-machinery systems.

For the calculation costs and the reliability indicators of logistics system let's use the idea of a simple supply chain (SSC). By «simple supply chain» we shall mean the following:

- a part of the logistics chain (channel), which include at least two major links of logistics system such as «supplier» and «consumer» that are connected to each other by logistics operations: purchase, order processing, transportation and storage, etc.
- SSC extension is possible due to main intermediaries («the third party» in logistics): carriers, freight forwarders, warehouses, etc.
- any supply chain can be represented as a set of individual SSC.

A supply chain is characterised by self-organization. Essentially supply chains are considered restorable, which is why when assessing reliability one should take into account this most important quality.

In accordance with described approach the supply chain can be presented as a discrete-continuous model and described as a graph, which is based on the Gantt chart.

In this case we have the supply chain in which the delivery of finished goods is made from the plant of manufacturer to warehouse or distribution center The chain includes 6 basic operations that must be made to fulfill the order: agreement of supply; order picking at warehouse; processing of documents for cargo dispatch; transportation (vehicle loading, cargo transportation, unloading); processing of documents when receiving cargo; placing of cargo at warehouse.

2. MODELS DEVELOPMENT FOR THE COSTS EVALUATIONS AND THE SC RELIABILITY INDEXES

The considered methodical approach allows pronouncing a hypothesis that the specification of the educed features of supply chains can be realized if there are three constituents presented: firstly, the dependences for the supply chains TLC; secondly, the equation for the supply chain reliability indexes evaluation; thirdly, a models complex which allows to figure out logistics operations reliability indexes using the parameters included in the TLC. Thus, the interconnection between the total costs and the supply chains reliability shows itself out in that way that the reliability indexes are calculated taking into account the TLC parameters and the expenses (fines) of the supply chains reliability support and renewal are taken into consideration at the TLC calculating process.

We consider it advisable to describe the models complex in three stages.

The first stage. Analysis of numerous researches has allowed us to create a TLC model as follows (for the normal distribution laws of random variables):

$$C_{\Sigma} = C_{ps} \cdot A + \frac{A \cdot C_0}{Q} + \frac{A \cdot C_t}{Q} + \frac{Q}{2} \cdot C_{ps} \cdot f + \\ + C_{ps} \cdot f^* \cdot \sigma_s \cdot x_p + \frac{A}{Q} \cdot \sum_{j=1}^{n} C_{pl\_j} \cdot \sigma_s \cdot I(x_p)_j \quad , \qquad (1)$$

where, C_{ps} is the price from the supplier per unit in conventional units (c.u.), A represents the consumption (products) in units, C_o is ordering costs (where the expenses of order process and goods picking at the warehouse are included) in c.u., Q is order stock in units, C_t is transportation costs in c.u., f is storage costs of the current stock, in total price of products (share), f* is storage costs of an insurance stock, in total price of products (share), σ_s is general root-mean-square deviation of stock in units, x_p is the ratio of the normal law of distribution (Math), j – the type of violation (e.g. delay, lack of documents, wrong order picking and so on.), n – the violations types amount, $I(x_p)_i$ is the integral of losses which characterises the mean size of the violation; C_{pl_j} is the penalty in c.u. (fine size for the j-th violation kind).

The registration of the j-th expenses (fines) kind connected with the failures in supply chains or shortage, or delay at the order picking at the warehouse or transportation is done using the so-called integral of losses (Axsäter 2006) and that is the peculiarity of the equation (1)

$$I(x)=\int_x^{\infty}(t-x)\varphi(t)dt=\varphi(x)-x(1-\Phi(x)), \qquad (2)$$

where $\varphi(x),\Phi(x)$ are accordingly the density and function of random variables distribution of x.

The second stage. To evaluate the reliability indexes let us assume that SSC includes six logistics operations (Figure 1) and every one of them is characterised by the reliable work probability of P_i. In the picture 1 the following indications are used:

1. Purchase, ordering is P_1;
2. Order picking at the warehouse (transportation) is P_2;
3. Supply control at the supplier warehouse is P_3 (the quantity evaluation is P_{31}, the quality evaluation is P_{32} and the documents authenticity is P_{33});
4. Transportation (from the supplier to the consumer) is P_4;
5. Order reception and control at the consumer's warehouse is P_5;
6. Placement at the warehouse is P_6.

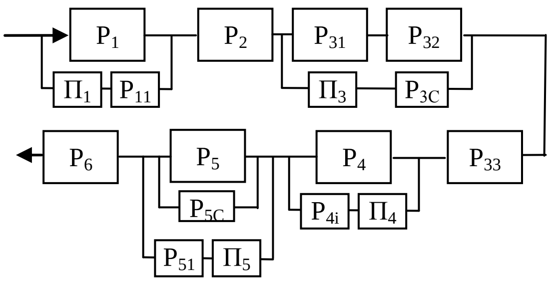

Figure 1: Calculation Chart For The Simple Supply Chain Reliability Evaluation

Along with the main modules in the chart there are logical switches Π_i for some logistic operations which allow us to choose different management solutions.

While calculating or modelling a logical switch allows us to consider various renewal variants if there is a failure at carrying out the i-th operation. If we speak about the circuit reliability calculation, then the i-th switch plays its main role and is taken into account at calculating as a component with a reliable work probability of $P_{\text{пi}}$. If we consider an alternative renewal variant, then the switch allows us to make a decision to use the insurance stocks (in the chart they are components P_{3C} and P_{5C}) or some other variants to restore the reliability of this operation implementation (e.g. using the goods substitute is P_{51}, changing the driving itinerary is P_{4i} and so on) that is $P_{\text{пi}}=1$. If the reservation is not used, the switch reliable work probability is equal to 0.

The general equation for the reliable work probability of the SSC as a system with a serial components uniting is written as following:

$$P_\Sigma=\prod_{i=1}^{n}P_i^* \qquad (3)$$

where P_i^* is the reliable work probability of the i-th operation with the renewal taken into account.

It is obvious that the corresponding dependences considering the serial and parallel connection of components are formed for P_i^*. For example, for the third operation (the supply formation at the consumer's warehouse) the equation to calculate P_3^* is written like that:

$$P_3^*=P_{33}\cdot\left[1-(1-P_{31}\cdot P_{32})(1-P_{\Pi 3}\cdot P_{3C})\right], \qquad (4)$$

where P_{33} is the reliable (correct) documents fulfilment probability; P_{31}, P_{32} respectively is reliable order processing probability according to the quantity and quality; $P_{\Pi 3}$ is a logical switch, $P_{\Pi 3}=1$; P_{3C} is supply reliability probability (the presence of the insurance stocks) at the supplier's warehouse.

The third stage. In Table 1 there are the failure models to evaluate the reliable work probability of the SSC components and there are short characteristics how to use them, as well that have been taken from the work (Lukinskiy V.S. and Lukinskiy V.V. 2015). The presented models are based on the general theory of reliability of complex systems and the disciplines that are included in the operations research (probability theory, the theory of stochastic processes, queuing theory, the theory of recovery, etc.), in particular, on the theorem on numerical characteristics, repeated experiments, the compositions of distributions, the transformation of random variables, etc.

In Table 1 there are main components for every logistic operation. With the help of these components the supply chains reservation is carried out.

Thus, not only does the calculations implementation with the use of the worked out models (see table 1) allow us to evaluate the reliability indexes of some certain operations and the whole SSC, but it also allows us to evaluate changing of the total logistic costs by taking the expenses (fines) into account and possible parameters variations of some certain logistic operations, as well.

Table 1: The Models For Calculation Of The Logistic Operations Reliable Implementation Probability In A Simple Supply Chain

Logistic operation	The model to evaluate P_i of the logistic operation	The model characteristic	Reservation components in SC
1.Purchase, order	«Demand X – Supply Y»	The random variables difference of Z=Y-X is considered	1. Choosing several suppliers. 2. Changing the parameters of demand and supply
2.Order picking at the supplier's warehouse	'Just in time' model	The sum (composition) of random variables $T = \sum \tau_i$, where τ_i is the implementation time of the i-th operation during the order picking	Combinatorial methods to minimise the picking time T
3.Formed order control	Probability model based on the total event probability formula	The use of the general theorem about repeated experiments; special cases: binomial distribution and Poisson's distribution	Insurance stocks at the warehouse; the use of goods substitute; delivery time postponement and others
4.Transport ation (supplier-consumer)	'Just in time' model considering restrictions and delays while moving along the route.	See point 2	Choosing alternative variants (changing the route and kind of transportation, toll road sections, changing the crew and so on)
5.Supply control at the consumer's warehouse	See point 3 and inventory management strategy models, as well.	See point 3 in the view of the theorem about the numerical characteristics of sum of random number of random variables	See point 3
6.Place-ment at warehouse	Linear programming, heuristic methods	Nomenclature analysis of ABC, XYZ and others	The application of 'chaotic cells', RFID sensors and others

3. EVALUATION OF EFFICIENCY INDEXES AND SUPPLY CHAINS RELIABILITY

Having analyzed the first table models lets us conclude that most parameters included in them are random variables that are subjected to various distribution laws. So, the quantitative evaluation must be done with the use of probabilistic descriptions. It is known that analytical and numeral methods can be applied to figure out the sought-for parameters in a general case.

Since analytical methods application for the models from the table 1 is limited, there is a necessity to use other tools, for example, the Monte Carlo method (Ventsel and Ovcharov 1983; Taha 2011; Longo 2011).
In this work we are intending to create the modelling of every logistic operation as corresponding 'realisation' and 'experiment' in two variants. The first variant implies the use of basic values of random parameters. The second one is carried out in the view of external and internal reservation.
Subsequent statistical treatment will allow us to define the distribution parameters and laws which are necessary to calculate the reliability and costs (expenses) indexes included in TLC. Figure 2 shows us the principle block diagram for modelling the logistic operations for the simple supply chain.

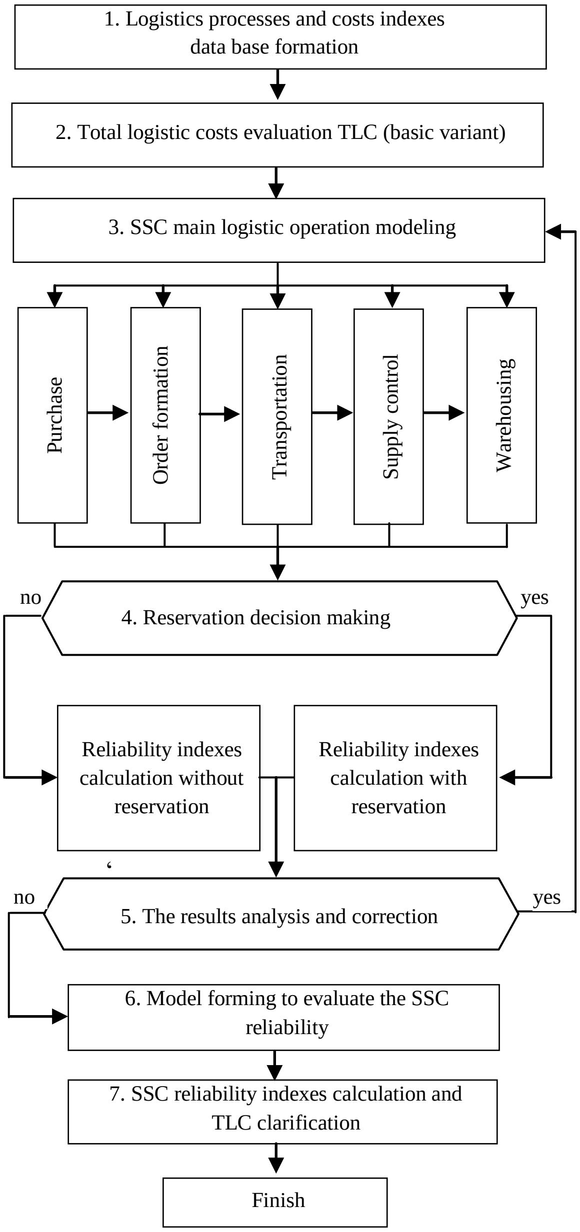

Figure 2: The Principle Block Diagram For Modelling The Logistic Operations For The Simple Supply Chain

The reliability indexes calculations results for the whole chain can be shown as a set of combinations with two extreme variants: either the reservation lack in all the operations, or in the view of maximum quantity of the reserve components in every logistic operation. It is obvious that when the analysis and correction have been carried out, we can choose the optimal variant with the minimal TLC and maximum reliability.

4. APPROBATION

The experimental verification of the developed methodics approach has been carried out using the published in different sources data and also gathered information about the reliability indexes of various logistic operations and functions at the warehouses (terminals) of transport companies and others.
Let us examine some logistic operations to illustrate the calculations implementation sequence based on the developed methodics approach.
We have taken the following parameters as initial figures (see formula 1): A= 1000 units, C_o=100 c.u., C_{ps}=50 c. u., f=0,2 (that is, the costs for the products unit storage a year are 10 c. u.).
If we use the well-known formulas (Stock and Lambert 2001), we will find the optimal order size Q_o = 141 units, the supply quantity a year N=7, costs minimum $C_{\sum min}$=1410 c. u.
Let us examine the logistic operation 'purchase' without reservation. Let us assume that the demand mean value $\overline{A}$ = 1000 units and the root-mean-square deviation σ_A=200 units; respectively, supplier abilities $\overline{A}_n = 1200$ units, σ_n=50 units.
According to the 'demand-supply' failure model the probability shortage absence (for the normal distribution laws) is calculated with the formula:

$$P = 1 - F\left(x_p = -\frac{\overline{A}_n - \overline{A}}{\sqrt{\sigma_n^2 + \sigma^2}}\right), \qquad (5)$$

where x_p is the ratio of the normal law of distribution. On the basis of x_p (according to the table from the Appendix A (Ballou 1999) we find

$$P = 1 - F\left(x_p = -\frac{1200 - 1000}{\sqrt{200^2 + 50^2}}\right) = 1 - F(-0,97) = 0,834$$

Let us use the integral of losses (according to the table from the Appendix B (Ballou 1999) to figure out the average deficit

$$\overline{A}_{sos} = \sqrt{\sigma_n^2 + \sigma^2} \cdot I(x_p = -0,97) =$$
$$= 206 \cdot 0,0882 = 18\, units$$

Let us assume that the fine for the products unit deficit C_{pl}=50 c. u. Then, the products short supply expenses are

$$C_{pl}^* = C_{pl} \cdot \overline{A}_{sos} = 900 \text{ c.u.}$$

These expenses must be considered in the formula (1) at the TLC calculation. It should be emphasized that in this example the purchase is carried out once a year.
Let us examine the variant with reservation when the second supplier takes part in the purchase tender and the faultless supply implementation probability is the same as the first supplier's one, that is, $P_{11}=P_1$ (see figure 1). For the parallel components connection we find

$$P_1^* = 1 - (1 - 1 \cdot 0,834)^2 = 0,972$$

So, we have managed to increase the purchase reliability on $\Delta = \frac{0,972 - 0,834}{0,972} \cdot 100 = 14\%$ at the expense of external reservation.
Let us examine the logistic operation 'the formed order control' which, substantially, implies the 'perfect order' evaluation. According the table 1 the calculation must be carried out by the total probability formula, but in this case we can only use formulas (3) and (4) for the faultless work probability for the serial and reserve components connection.
Let us assume that the faultless order picking probabilities according to the quantity P_{31} and quality P_{32} are even and equal to 0,9 and the reliable document processing probability is P_{33}=0,95. Then, if there is no reservation, the perfect order picking probability P_3 is calculated by the formula (3)

$$P_3 = 0,9 \cdot 0,9 \cdot 0,95 = 0,77$$

To figure the reservation by using insurance stocks at supplier warehouse we will use formula (4). If we take the initial data, and also P_{3C}=0,9 and $P_{\Pi 3}$=1, we will get

$$P_з^* = [1 - (1 - 0,9 \cdot 0,9)(1 - 1 \cdot 0,9)] \cdot 0,95 = 0,93,$$

where P^*_3 is probability of the perfect order forming with reservation.
Let us calculate the faultless implementation probability of all SSC operations, accordingly, without reservation

$$P_{\Sigma_{WR}} = 0,834 \cdot 0,894 \cdot 0,77 \cdot 0,773 \cdot 0,988 = 0,432$$

taking into account the external and internal reservation

$$P_{\Sigma_R} = 0,972 \cdot 0,894 \cdot 0,981 \cdot 0,84 \cdot 0,999 = 0,678$$

The calculations results for all logistic operations included SSC are given in Table 2.

Table 2: The Calculations Results Of The Implementation Probability Of The SSC Logistic Operations

Logistic operation	The P_i evaluation model	Calculation variants	
		Without reservation	With reservation
1. Purchase	'Demand-supply'	0,834	0,972
2. Picking (supplier's warehouse, transportation)	'Just in time'	0,894	0,894
3. Formed order control	'Perfect order'	0,810	0,981
	The same but in the view of documents accuracy	0,770	0,930
4. Transportation (supplier-consumer)	'Just in time'	0,773	0,840
5. The control at the consumer's warehouse	'Perfect order' in the view of inventory management strategy	0,977	0,998
	The same but in the view of alternative (goods substitute)	0,988	0,999
For all the SSC operations		0,432	0,678

In Table 3 the expenses (fines) calculation results are brought for the two variants of supply chain. The analysis of table 3 shows that the reservation (as a result of competent management and process organisation) gives a substantial effect. Certainly, the first variant can serve as a base for the search of logistic operation parameters optimal combination to minimize the SSC costs and expenses.

It is obvious that the second variant reflects only one of possible solutions, as costs and expenses are calculated in the view of corresponding logistic operations faultless implementation.

If the random variables used in the examined models of logistic operations failures submit to the normal law, then calculations can be executed by means of the worked out formulas. However, for some SSC the row of parameters submits mainly to the asymmetrical distribution laws (Rayleigh, Veibulla, gamma distribution and others.). In this case the receiving of the adequate and transparent results is possible with the use of simulation modelling.

Table 3: Expenses (Fines) For The Logistic Operations Implementation In SSC

Logistic operation	Variants of expense calculation (c. u.)		Reliability recovery factors
	Without a reservation	With a reservation	
Purchase	900	250	Engaging the second supplier
Order picking (amount and quantity account)	1050	492	Supplier's insurance stocks forming
Transportation	115	70	Route changing (toll road sector)
Supply control	975	317	Consumer's insurance stocks forming
Total costs (taking into account $C_{\sum min}$)	4450	2539	

Calculations on the basis of block diagram (see figure 2) allows us to do the following conclusions:

- for most logistic operations models the amount of the modelled random variables hesitates from 2 to 6, and logical ones switch to 2;
- for some operations (for example, "purchase" or "placement at the warehouse") a modelling and calculation based on analytical dependences give close results;
- for the project calculations it is possible to be limited by the worked out failures models due to the lack of necessary statistical data for a modelling;
- maximal calculation results deviations obtained by a modelling and on the basis of failures models for logistic operations are 15-20%.

Thus, the SC examining as a renewable system due to the internal and external reservation allows to increase the indexes of faultlessness. So, for example, the registration of supplier and consumer's insurance stocks, engaging the second supplier possibility, the transportation route changing, for example (Kabashkin and Lučina 2015; Kopytov and Abramov 2013), and the use of goods substitute caused the increase of the SC reliable functioning probability for 36%.

5. CONCLUSION

1. An offered hypothesis legitimacy about intercommunication of total logistic costs and SC reliability indexes is confirmed, wherein the failure models of logistic operations and functions are the basic connective components.

2. The worked out approach originality lies in the fact that the first time formed complex for the SC efficiency and reliability evaluation which include the equation of total costs, model of renewable SC by reservation and failures models of basic logistic functions and operations complex.
3. The worked out methodical approach allows to calculate not only the reliability indexes but also to increase accuracy of total logistic costs evaluation by taking into account the expenses (fines), possible varying of separate logistic operations parameters, and also the latent connections.
4. It is necessary to emphasise that the row of questions requires the further researches related to the multi-nomenclature supply, necessity of various limitations registration, structuring and development of greater failure models amount for the SC, the calculations implementation possibility for the multilevel distributive systems.

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SUPPORTING REAL-TIME DECISION-MAKING IN LOGISTICS AND TRANSPORTATION BY COMBINING SIMULATION WITH HEURISTICS

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ABSTRACT

Supporting decision making in logistics and transportation is one of the most fruitful application areas of simulation and optimization techniques. In a global world, many enterprises need to perform complex procurement and delivery activities. Usually, these problems have an intricate nature, being NP-hard in most cases, which means that heuristic-based optimization approaches are necessary to deal with real-life and large-scale instances whenever a high-quality solution is needed in a short amount of time. Examples of these problems include many variants of the well-known vehicle routing problem, the facility location problem, and the arc routing problem. We will discuss here the role played by Monte Carlo simulation in a suitable mixture with skewed probability distributions to enrich the performance developed by heuristic-based constructive methods. Some examples will highlight the efficiency of this simple yet powerful approach.

Keywords: Logistics and Transportation, Simulation, Heuristics, Biased Randomization.

1 INTRODUCTION

Decision-making process in real-life logistics and transportation are usually complex and, at the same time, they need to be completed in reasonably short times. A considerable number of them can be modeled as combinatorial optimization problems. Typical examples are: the vehicle routing problem (Toth and Vigo, 2014), the arc routing problem (Corberan and Laporte, 2015), or the facility location problem (Chan, 2011). All these problems are NP-hard in nature, meaning that the space of potential solutions grows very fast (exponential replication of the number of feasible solutions) as the size of the instance is increased. For that reason, using exact methods is not always the most efficient strategy in order to solve these problems, especially when considering large-size instances for which high-quality solutions are needed in relatively short computing times. Under these circumstances, heuristic-based approaches constitute an excellent alternative to exact methods. Hence, a large number of heuristic and metaheuristic algorithms have been developed during the last decades to solve NP-hard problems in a myriad of practical scenarios, ranging from transportation and logistics to supply chain management and services optimization (Faulin et al., 2012; Longo, 2012; Merkuryeva et al. 2011).

Monte Carlo simulation (MCS) can be combined with the use of skewed or asymmetric probability distributions in order to easily improve the performance of the heuristic algorithms along with the quality of the solutions generated by them. Having the purpose of generating a suitable good solution, most of these procedures make use of a greedy behavior which consist of choosing the 'best next step' from a list of potential constructive movements. Typically, this selection is based on a certain logic that tries to take advantage of the specific characteristics, which usually are subject to uncertainty, corresponding to the optimization problem being considered. In this context, the main idea behind our approach is to introduce a slight modification in the greedy constructive behavior, in such a way that the constructive process is still based on the heuristic logic but, at the same time, some degree of randomness is introduced. This random effect tries to take benefit to the internal structures (usually unknown and subject to uncertainty) of the problem to solve by means of the biased selection of solutions generated by a skewed statistical distribution (Figure 1).

Some initial steps in the process of combining MCS with heuristic approaches were done by Faulin and Juan (2008), who designed a MCS with entropy control to solve the Capacitated Vehicle Routing Problem. Using this simulation-based approach it is possible to easily enhance the quality of the solutions generated by the original heuristic. Also, it is important to notice that using a uniform probability distribution instead of a skewed one, this improvement would very rarely occur since the logic behind the constructive heuristic would be destroyed and, accordingly, the process would be random but not correctly oriented (Figure 1).

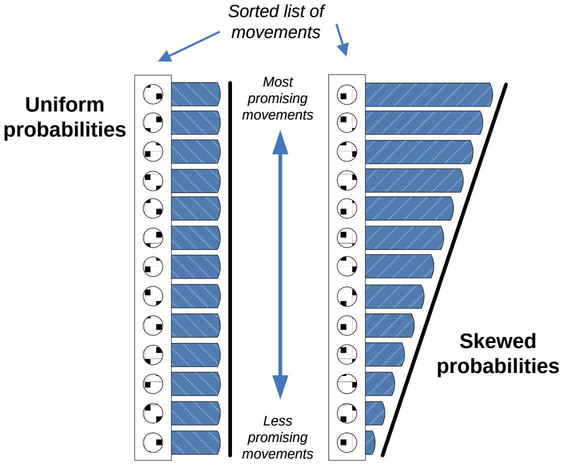

Figure 1: Ways to introduce randomness into heuristics.

2 SOME CLASSICAL ROUTING PROBLEMS AND HEURISTICS

In the vehicle routing problem, a set of customers' demands must be satisfied by a fleet of capacitated vehicles that typically begin from a central depot. Moving vehicles between any two nodes (customers or depots) in the map has a distance-based cost. The goal is to find the set of vehicle routes that minimizes the delivery cost while serving all demands and taking into consideration the vehicle capacity constraints. One popular procedure for solving this problem is the savings heuristic (Clarke and Wright, 1964), whose acronym is CWS. In that procedure, an initial dummy solution is built by sending a virtual vehicle from the depot to each customer. Then, the list of edges connecting each pair of nodes is considered. This list is sorted according to the savings criterion that would be obtained by using the corresponding edge to merge two routes in the dummy solution. Thus, merging edges associated with higher savings are located at the top of the list, while edges with lower savings are located at its bottom. At this point, the sorted list of edges is traversed from the top to the bottom, and new route merges are carried out whenever the corresponding edge can be used to merge the two routes it connects without violating any constraint. A similar savings-based heuristic, called SHARP, was developed by Gonzalez et al. (2012) for solving the arc routing problem. The arc routing problem is similar to the previously described vehicle routing problem, but it differs in several details: to start with, the demands are not located on the nodes, but on the edges connecting these nodes; also, only some nodes are directly connected among them (i.e., the associated graph related to this problem is not complete). Again, the SHARP heuristic makes use of a dummy initial solution and a sorted list of connecting edges to merge those routes that provide the highest possible savings at each step without violating any problem constraint.

3 A SIMULATION-BASED APPROACH FOR ENHANCING HEURISTICS

Most constructive heuristics make use of a list of potential movements, then sort that list according to some problem-specific criterion, and finally traverse the sorted list selecting, at each step, the element at the top of the list. By following this greedy behavior, which tries to select the next 'most promising' movement according to the sorting criterion, these heuristics are expected to generate a high-quality solution once the entire list is traversed. Notice, however, that this is a somewhat 'myopic' behavior, since the heuristic selects the next movement without being able to consider how this selection would affect subsequent selections as the list is processed downwards. What is even worse, this behavior is also deterministic: once the heuristic has been run, further runs of this deterministic process make no sense since they all will provide the same output. Knowing that running a heuristic might take only a few seconds –or even less in a modern computer if the heuristic is correctly implemented and the problem size is not very large (for instance, less than 100 customers for a routing problem)–, one might consider to introduce some type of randomness in the heuristic's behavior, in such a way that it can be run several times –either in sequential mode or in synchronous mode by using different computers–, and then select the best of the stochastic outputs. However, this is not always true: if uniform randomization is introduced inside the heuristic without any further modification of the original list of candidates, the logic behind the sorting criterion is lost and, therefore, the probabilities that any stochastic solution improves the original one provided by the heuristic are almost non-existent. To avoid that, GRASP algorithms (Feo and Resende, 1995) introduce uniform randomization on a restricted candidate list, which is composed of the first *n* elements (*n* being an algorithm parameter) in the original list. Instead of following the GRASP approach, our methodology proposes to use the entire sorted list of potential movements, but then use a skewed probability distribution (e.g., a geometric or a descending triangular one) in order to assign different probabilities of being selected to each of the elements in the list. Then, direct Monte Carlo simulation can be used at each stage of the solution constructive process to select the next element from the list according to the desired probabilities. In the particular case of the vehicle routing problem, some computational results obtained with this strategy can be found in Juan et al. (2009). This approach can easily generate solutions that improve the original ones provided by the heuristic in short computing times, which represents an interesting alternative to the use of more complex metaheuristics.

4 EXPERIMENTAL RESULTS

We implemented in Java the previously described heuristics and their corresponding skewed-randomized versions. A series of classical benchmarks were then run on a desktop computer (Intel Core i3 CPU M 370 @2.40GHz on Windows 7). Each instance was run once for a maximum of 30 seconds, and then a comparison was made between the heuristic value (*h*) and the best value obtained with the skewed-randomized version (*rh*). This comparison was given by the perceptual gap between both solutions, computed as: gap = (*rh* – *h*) / *h*. We have calculated these gaps for a set of classical instances (Kelly instances) for the vehicle routing problem, which are publicly available at http://neo.lcc.uma.es/vrp/vrp-instances/capacitated-vrp-instances/. The results are that in 16 out of 20 cases the solution provided by the skewed-randomized version of the heuristic (RandCWS) outperformed the solution provided by the original version of the heuristic (CWS-Clarke and Wright's savings procedure), with an average improvement gap of -2.45% and a maximum improvement gap of about -13.17% for the Kelly08 instance (Table 1). In this case, a Geometric distribution with parameter 0.2 was used to randomize the selection of potential movements from the sorted list of edges.

Table 1: Results for the vehicle routing problem.

	CWS Heuristic	**RandCWS**		
Instance	**Cost**	**Cost**	**Time (s)**	**Gap**
Kelly01	5,956.50	5,776.93	22.0	-3.01%
Kelly02	9,880.40	9,696.08	10.3	-1.87%
Kelly03	13,494.43	12,941.51	19.0	-4.10%
Kelly04	68,694.43	68,141.51	23.6	-0.80%
Kelly05	12,000.00	12,000.00	0.0	0.00%
Kelly06	16,800.00	16,800.00	0.0	0.00%
Kelly07	21,600.00	21,600.00	0.0	0.00%
Kelly08	16,927.66	14,698.87	19.8	-13.17%
Kelly09	663.57	630.54	2.7	-4.98%
Kelly10	838.92	802.97	16.8	-4.28%
Kelly11	1,052.13	1,014.97	24.8	-3.53%
Kelly12	1,270.99	1,231.46	29.7	-3.11%
Kelly13	952.74	932.14	5.6	-2.16%
Kelly14	1,221.69	1,194.80	22.6	-2.20%
Kelly15	1,512.66	1,488.47	17.0	-1.60%
Kelly16	1,774.68	1,774.68	0.0	0.00%
Kelly17	771.71	756.10	14.2	-2.02%
Kelly18	1,069.29	1,059.34	20.4	-0.93%
Kelly19	1,466.00	1,459.61	22.8	-0.44%
Kelly20	1,963.47	1,948.69	8.5	-0.75%
Average			*14.0*	*-2.45%*

Likewise, the results of a similar experiment for the arc routing problem are summarized. The set of classical instances used for this experiment (the so called GDB instances) are publicly available at: http://www.uv.es/belengue/carp.html. The solution provided by the heuristic (SHARP) is improved in 14 out of the 15 tested instances, with a maximum improvement gap of -13.82% (gdb12) and an average improvement gap of -6.26%. Again, a Geometric distribution with parameter 0.2 was used here to randomize the selection from the sorted list of edges.

5 CONCLUSIONS AND FUTURE WORK

This work discusses how simulation can be used to easily improve the performance of already existing or new heuristics aimed at solving combinatorial optimization problems in the fields of transportation, logistics, and production systems. By combining skewed probability distributions with direct Monte Carlo simulation, the logic behind the heuristic can be slightly randomized without losing its good properties. This allows transforming the deterministic heuristic procedure into a probabilistic algorithm that can be run several times to obtain several alternative solutions to the original problem, some of them better than the original one provided by the heuristic itself. Several examples of different heuristics and optimization problems contribute to illustrate the potential of the proposed approach. Finally, we would like to highlight that this paper contribution is mainly devoted to explain the good qualities that have the heuristics randomization to provide a suitable set of potential good solutions to the problem to solve, even if it is difficult.

ACKNOWLEDGMENTS

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MODELLING AND ASSESSMENT OF RISKS IN LOGISTICS USING MULTIDIMENSIONAL STATISTICAL METHODS

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ABSTRACT
Logistics process of cargo delivery from point A in point B, as a chain of consecutive risks, is considered in the article. All risks are shared into three main groups. Authors investigate each risk influence on insurance premium volume, and, therefore, insurance component influence on cargo delivery cost. Ranking of risk factors according to their influence on the cargo insurance premium is carried out by authors. The resulting research model estimates cargo delivery costs, takes into account the ordered risks, and makes it easier to model the logistical task considering the most significant risks of delivery. For modelling of delivery costs risk component is applied Monte-Carlo multidimensional statistical modelling method, similar to modelling process which was presented in the article by Jansons, V., Jurenoks, V., Didenko, K., 2013. Use of modelling for assessment of Latvian road safety and logistics costs minimization.

Keywords:
Logistics, ranking of risks, insurance modelling, cost optimization.

1. CREATION OF MATHEMATICAL MODEL FOR ANALYSIS OF CARGO DELIVERY COSTS

Cargo transportation and logistics services are very important industries in the national economy of Latvia. This is due to geographic location of Latvia and the development of logistics infrastructure. Importance of cargo transportation and logistics services is indicates of their share in the total value added of all economic sectors in Latvia (see table 1).

Table 1: Cargo Transportation And Logistics Services Share In The Total Value Added In Latvia

	2011	2012	2013
Total value added, ths EUR	17 793 585	19 236 456	20 214 557
Cargo transportation and logistics services value added, ths EUR	1 820 167	1 983 771	1 968 685
Cargo transportation and logistics services value added, %	10,2	10,3	9,7

The process of transportation of goods from one point to another is subject to many risks. Many accidents may happen during transportation process, there is no guarantee of delivery safety, and cargo may be damaged or lost. To ensure cargo safety methods of risk management are applied, and the most popular of them in logistics is insurance. In cargo insurance should be interested cargo owners; as the policyholder may be a shipper or a consignee - depending on the conditions of delivery contract and responsibility for the goods and property rights to it, written in the contract. Policyholder may be also freight forwarding companies, in this case the insurance contract is signed in favor of the cargo owners. Insurance costs are an important part of the total delivery costs, so the authors propose to distinguish them of total logistics costs as separate component:

$$C_{delivery} = C_{logistics} + P_{insurance}, \qquad (1)$$

where $C_{delivery}$ – delivery costs,

- $C_{logistics}$ - logistic service costs,
- $P_{insurance}$ – cargo insurance premium.

In a general case, the value of $C_{logistics}$ can be presented as a function of a range of variables (factors characterizing the particular cargo and its terms of delivery), namely:

$$C_{logistics} = \Phi\ (KF,\ V,\ WT,\ KT,\ FR,\ KR,\ T,\ F_{t_1},\ F_{t_2},\ M,\ W,Y). \qquad (2)$$

The parameters of the model are follows:

- KF – type of cargo transported (table 2);
- V - total volume of cargo carried in containers;
- WT - transportable cargo weight;
- KT – type of cargo transportation (table 3);
- FR - types of financial risks (table 5);
- KR – the type of roads;
- 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;
- W – warehouse costs;

- Y - other factors characterising the particular cargo to be transported and its terms of delivery (for example, expedition service costs, labour costs, etc.).

Table 2: Types Of Cargo Transported (KF)

	KF_i	Risk detailed description
1	Dangerous Goods	high fire and explosion hazard
2	Perishable goods	- sensitivity to temperature changing, - State health authorities' requirements that allow these products to be sold.
3	Live transportation	- special treatment and food supply requirements; - sensitivity to climatic influences; - Veterinary certificates are necessary.
4	Car transportation	- small paint damage the car body; - theft of small components and parts of car.
5	Bulk and liquid cargoes	- the difference in weight when sending and receiving; - pollution; - hygroscopicity; - sensitivity to climatic influences.
6	Non-standard and heavy cargo	-external impact on the goods (damage during loading / unloading or transporting); - theft of small components and parts
7	Consolidated cargo	theft of small components and parts
8	General goods	depending on the type of goods
9	Others types of cargo	depending on the type of goods

Types of cargo transportation are presented in table 3.

Table 3: Types Of Cargo Transportation (KT)

i	KT_i	Risk detailed description
1	Road transportation	- risk of theft or robbery; - risk of theft of the vehicle; - risk of accidents; - risk of vehicle breakdown, - risk of damage to the goods during transportation.
2	Railroad transportation	- risk during loading/ reloading of goods; - risk of injury from fire or accident; - risk of theft or robbery.
3	Sea transportation	- risk during loading/ reloading of goods (damage or theft); - water damage; - risk of total loss of the goods.
4	River transportation	- risk during loading/ reloading of goods (damage or theft); - water damage; - risk of total loss of the goods.
5	Air transportation	- risk of total loss of the goods; - risk of catastrophe.

Cargo transportation in Latvia is divided by types of vehicles rather evenly (see table 4).
River and air transportation share is very small, less than one percent, and are not included in table 4.

Table 4: Cargo Transportation Structure In Latvia

Railroad transportation, mln t	
Total	55,8
domestic	1,2
international	54,6
Sea transportation, mln t	
sent from the latvian port cargo	62,4
delivered to the Latvian ports cargo	8,1
Road transportation, mln t	
Total	60,6
domestic	50,5
international	10,1

Types of financial risks (FR) are shown in the table 5.

Table 5: Types Of Financial Risks (FR)

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

Types of roads (KR_i) have been analyzed by authors in the previous articles (see references), and classified depending on owners (state roads, local government, private) and types of road paving (paved roads, gravel roads, not covered roads).
The scheme of the $M_{AWi}{}^{th}$ route of traffic with the relevant road traffic parameters of every section of the route from point A to point B is presented in figure 1.

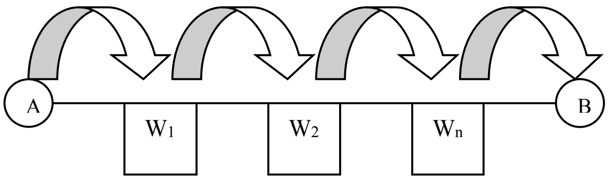

Figure 1: Scheme Of The $M_{AWi}{}^{th}$ Route Of Road Traffic Between Points A And B

Cargo transportation can be multimodal, i.e. using multiple modes of transportation and reloading, during which the goods for a certain period of time stored in warehouses W_1, W_n (see figure 1). Therefore, the authors add to the mathematical model for calculating logistics costs $C_{logistics}$ the component W - the costs of storage, handling and processing of goods in warehouses and terminals.

2. MODELLING OF CARGO INSURANCE PREMIUM

One of the essential components of the logistic service is cargo insurance $P_{insurance}$.
Therefore, it is important to build an economic and mathematical model for calculating the premium $P_{insurance}$ (3) at different parameters of the transportation process.

$$P_{insurance} = F\ (S\ , DP,\ H, T\ , KT,\ KF,\ KR,\ FR\ , M\ , IC, DC, W, Y\ ), \quad (3)$$

where DP – declared value of the goods carried;

- S – amount of insurance sum for cargo calculated by formula (4):

$$S = k \cdot DP, \qquad 0 < k \le 1, \tag{4}$$

where k – correction coefficient of sum for cargo insurance;

- H_i - hazard risk of cargo, according to the IMO (International Maritime Organization) classification;
- T - time of delivery from the consignor to the consignee;
- KT – type of cargo transportation (table 3);
- KF – type of cargo transported (table 2);
- FR - types of financial risks (table 5);
- M_i - route which is used for transporting cargo. The scheme of the M_{AWi}^{th} route of traffic with the relevant road traffic parameters of every section of the route from point A to point B is presented in figure 1.
- W – type of warehouse;
- IC – insurance conditions;
- DC – delivery contract rules.

According to international insurance practice, for cargo insurance as insurance conditions (IC) mainly are used London Institute cargo clauses ICC. Depending on the breadth of coverage insurance companies change the value of the insurance premium, so that the conditions of insurance are also one of the factors affecting the size of the insurance premium $P_{insurance.}$

Institute cargo clauses are attached to a type of marine insurance that covers cargo in transit. These clauses are to specify what items in the cargo are covered should there be damage or loss to the shipment. Institute cargo clauses can cover everything from the cargo itself to the container that holds it to the mode of transportation used to ship it.

There are three basic sets of institute cargo clauses; A, B, C.

These clauses were developed by the International Chamber of Commerce (ICC) as a means of insurance for cargo while it is being shipped from the original location to its final destination.

As the more risks are covered as the higher premium has to pay policy holder. The three clauses are briefly described the same way:

- Institute Cargo Clause A is considered the widest all risks insurance coverage including theft, pilferage and non-delivery, rough handling, piracy and perils covered under ICC (B) & ICC (C);
- Institute Cargo Clause B is considered a more restrictive coverage including washing overboard, entry of sea, lake of river water into vessel, craft, hold, conveyance, container, lift van or place of storage, earthquake, volcanic eruption or lightning, total loss of package lost overboard or dropped whilst loading on to or unloading from vessel or craft , perils covered under ICC (C);
- Institute Cargo Clause C is considered the most restrictive coverage and is limited to those risks as fire or explosion, vessel/craft being stranded, grounded, sunk or capsized, overturning or derailment of land conveyance, collision or contact of vessel, craft or conveyance with external object other than water.

The Incoterms rules are widely used in International trading and delivering processes as international delivery contract rules (DC). The Incoterms rules or International Commercial Terms are a series of pre-defined commercial terms published by the International Chamber of Commerce. The Incoterms rules are intended primarily to clearly communicate the tasks, costs, and risks associated with the transportation and delivery of goods.

The Incoterms rules are accepted by governments, legal authorities, and practitioners worldwide for the interpretation of most commonly used terms in international trade. They are intended to reduce or remove altogether uncertainties arising from different interpretation of the rules in different countries. As such they are regularly incorporated into sales contracts worldwide.

The value of insurance premium depends on the delivery contract rules, because they define the duties of contract parties during cargo transportation, including the responsibility for risk of cargo loss and cargo insurance.

For the calculation of the insurance premium $P_{insurance}$, the empirical data and methods of statistical Monte Carlo simulation are used.

The scheme of financial modelling of insurance process is presented in figure 2.

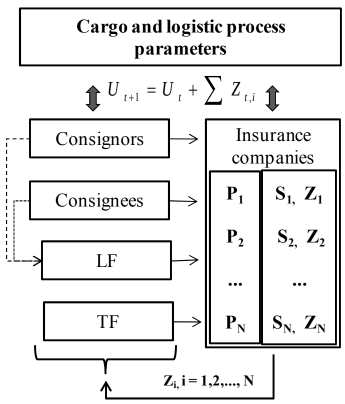

Figure 2: Scheme Of Financial Modelling Of Insurance Process

In figure 2 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.

$$U_{t+1} - \sum_{i=1}^{N} Z_{t,i} > 0. \tag{5}$$

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 (5) during all time T ($0 < t \leq T$) of functioning of the insurance process with probability 1-α. To solve the inequality (5), the premium P is calculated based on the parameters of the insurance process (figure 2). Based on the above, the formula for calculating value $P_{insurance}$ (the insurance premium for cargo) can be presented as:

$$P_{insurance} = P_0 + P_R, \qquad (6)$$

where P_0 - risk-free component of the premium, which also includes the burden of insurance;

- PR – risk component of the premium, which is depending on risk factors ri.

$$P_R = DP(r_T + r_{KT} + r_{KF} + r_{KR} + r_M + r_{FR} + r_W), \qquad (7)$$

where 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_{KF} – 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;
- r_W – warehousing risks.

Authors offer to apply the analytic hierarchy process for priority of cargo insurance premium risk factors determination and influence on the cargo insurance premium assessment.

3. RANKING OF RISK FACTORS ACCORDING TO THEIR INFLUENCE ON THE CARGO INSURANCE PREMIUM

As is mentioned above, the risk component of the insurance premium P_R depends on many risk factors r_i, which are different for each type of cargo and each carriage. So, delivery risk is function of many variables r_i:

$$R_{delivery} = f(r_T, r_{KT}, r_{KF}, r_{KR}, r_M, r_{FR}, r_W) \qquad (8)$$

Authors review an example of practical applying of analytic hierarchy process for priority of three risk factors determination:

- r_{KF} – risk due to the type of cargo transported, which is named in this research as A factor group;
- r_{KT} – risk due to the type of cargo transportation, which is named as B factor group;
- r_{FR} – financial risks, which is named as C factor group.

In each group A, B and C were identified factors:

A group – 9 factors (A1-A9) (table 6);
B group – 5 factors (B1-B5) (table 7);
C group – 4 factors (C1-C4) (table 8).

The group of experts made comparative estimates of factors by the principle everyone with everyone. It is supposed that these groups of factors are poorly connected among themselves that allows to consider them as independent groups at the initial stage of research. In this case to order the factors on extent of their influence on cargo delivery risks it is possible to use analytic hierarchy process method. Realization of this method consists of three stages: Formation of hierarchies; Paired comparison of factors; Calculation of priorities (ranking).

The following hierarchical structure of risk factors is supposed by the authors (see figure 3).

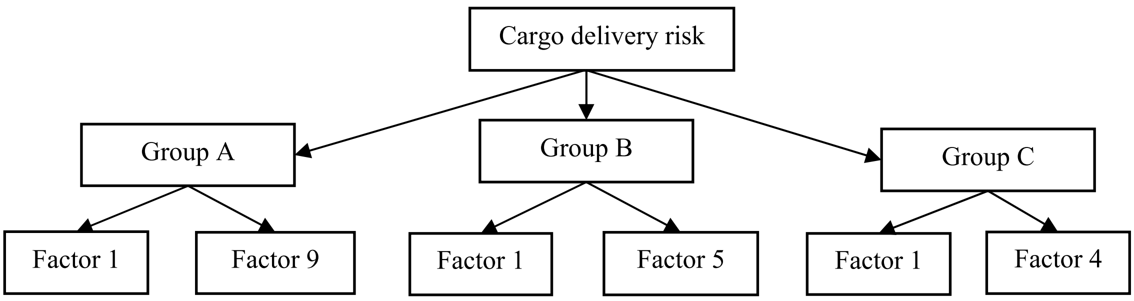

Figure 3: Hierarchical structure of the factors influencing cargo delivery risk

Table 6: Cargo delivery risk factors – A group

	A group (Types of Cargo Transported)
A1	Dangerous Goods
A2	Perishable goods
A3	Live transportation
A4	Car transportation
A5	Bulk and liquid cargoes
A6	Non-standard and heavy cargo
A7	Consolidated cargo
A8	General goods
A9	Others types of cargo

Table 7: Cargo Delivery Risk Factors – B Group

	B group (Types of Cargo Transportation)
B1	Road transportation
B2	Railroad transportation
B3	Sea transportation
B4	River transportation
B5	Air transportation

Table 8: Cargo Delivery Risk Factors – C Group

	C group (Types of Financial Risks)
C1	Operational risk
C2	Credit risk
C3	Market risk
C4	Liquidity risk

Paired comparison of factors groups A, B, C is carried out (see table 9).

Table 9. Paired Comparison Of Factors Groups Of A, B, C

	A	B	C	Σ	PV=Σ/Σ(Σ)
A	1	2	3	6	0,493
B	0,50	1	3	4,50	0,370
C	0,33	0,33	1	1,667	0,137
			Σ(Σ) =	12,167	1,000

The highest priority PV=0,493 (highest influence on insurance premium) has type of cargo transported, the second priority PV = 0,370 has type of cargo transportation, and the lowest priority PV=0,137 has type of financial risks.
As a result of paired comparison for factors in each group we will receive matrixes of paired comparisons were received.
Tables 10, 11, 12 summarize the results (see column PV in the tables) of calculation of factors priorities using the simplest method.

Table 10. A Group Factors Priorities

	A1	A2	…	A9	Σ	PV=Σ/Σ(Σ)
A1	1	2	…	7	39	0,206
A2	0,5	1	…	8	37,5	0,198
A3	0,33	0,5	…	6	26,83	0,141
A4	0,33	0,25	…	7	27,08	0,143
A5	0,2	0,25	…	7	21,03	0,111
A6	0,2	0,2	…	6	16,15	0,085
A7	0,17	0,17	…	6	12,54	0,066
A8	0,14	0,14	…	5	7,27	0,038
A9	0,14	0,13	…	1	2,26	0,012
				Σ(Σ) =	189,66	

Table 11. B Group Factors Priorities

	B1	B2	...	B5	Σ	PV=Σ/Σ(Σ)
B1	1	2	...	6	15	0,324
B2	0,5	1	...	7	13,5	0,292
B3	0,5	0,5	...	5	9	0,194
B4	0,25	0,33	...	5	7,08	0,153
B5	0,17	0,14	...	1	1,71	0,037
				Σ(Σ) =	46,29	

Table 12. C group factors priorities

	C1	C2	C3	C4	Σ	PV= Σ/Σ(Σ)
C1	1	3	5	6	15	0,476
C2	0,33	1	4	5	10,33	0,328
C3	0,2	0,25	1	3	4,45	0,141
C4	0,17	0,2	0,33	1	1,7	0,054
				Σ(Σ) =	31,483	

Using the indicator of coherence of factors assessment CI (see formula 9), it is possible to specify expert estimates of paired comparisons of factors. Than the coherence indicator is closer to zero, especially expert estimates are carried adequately out (usually, CI< 15%-20%).

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (9)$$

Where size of a matrix (number of investigated factors), λ_{max} – maximal value of a matrix. After carrying out all these calculations, it is possible to define final arrangement of priorities for all factors. It gives the chance to choose such factors which with sufficient degree of reliability will estimate risks factors influence on insurance premium.
Using special software, the authors calculated λmax for each of A, B and C groups. As a result, the indicator CI can be calculated:

A group: n=9, λmax = 10,319, CI_A = 0,1649= 16,49%;

B group: n=5, λmax = 5,179, CI_B = 0,0448= 4,48%;

C group: n=4, λmax = 4,209, CI_C = 0,0697= 6,97%.

CONCLUSION

The attention in the article is paid to the assessment of the logistics risks, as well as the analysis and estimation of the cargo insurance premium and modelling of logistics service costs $C_{logistics.}$
The methods used in the study (statistical simulation method for assessing risks of the logistics process, method for modelling the financial risks, hierarchical

method for risks significances evaluation, expert method for risks comparing) allow us in a more complete and accurate way assess the borders of the changes of the logistic service cost, using more significant risks.

The application of statistical modelling using Monte Carlo method together with risks assessment allows:

- to investigate the safety of Latvian roads;
- to analyse the dynamics of changes of road accidents taking into consideration the time factor);
- to define economic losses caused by logistics risks;
-to model the value of the cargo insurance premium P and logistics service costs $C_{logistics}$.
- 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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PEDESTRIAN MODELLING: AUTONOMY AND COMMUNICATION NEEDS

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ABSTRACT
A better understanding of pedestrian movement can lead to an improved design of public spaces, to the appropriate dimensioning of urban infrastructure (such as airports, stations and commercial centers), and, most importantly, to a design that is more responsive to people and to that very fundamental human activity: walking.
Walking is a highly communicative and social activity: we walk with other people and meet strangers, friends and neighbors. The potential for such communication is in itself a measure of the quality of the space. However social integrations among pedestrians have been largely neglected in the analysis and in the planning process.
The research aims at modeling pedestrian needs, taking into account a more inclusive spatial behavior which includes both autonomy needs of pedestrian walking alone towards a target and communication needs of people walking in groups towards a target.

Keywords: pedestrians, groups of pedestrians, pedestrian communication needs, pedestrian autonomy needs, pedestrian modeling and simulation, heterogeneity in pedestrian needs.

1. INTRODUCTION
The literature about pedestrian locomotion could be roughly divided in two parts: engineering, physics and mathematicians focus on pedestrian obstacle avoidance behavior whilst sociologies and psychologies study human spatial behavior taking into account communication needs.
Human interactions between independent pedestrians have been extensively described in terms of collision avoidance behavior. As reported by Karamouzas et al. (2014), in terms of its large-scale behaviors, a crowd of pedestrians can look strikingly similar to many other collections of repulsively interacting particles (Helbing et al., 2001). These similarities have inspired a variety of pedestrian crowd models, including cellular automata and continuum based approaches (Hoogendoorn and Bovy, 2000), as well as simple particle or agent based models (Hoogendoorn and Bovy, 2003; Fajen and Warren, 2003; Reynolds, 1987). Many of these models conform to a long-standing hypothesis that humans in a crowd interact with their neighbors through some form of "social potential" (Helbing and Molnar, 1995), analogous to the repulsive potential energies between physical particles. Many simulation models are based on the Social Force model as presented in Helbing and Molnar (1995). The principle of the Social Force model aims at representing individual walking behavior as a sum of different accelerations: the acceleration of an individual towards a certain goal: it is defined by the desired direction of movement with a desired speed. The movement of a pedestrian, influenced by other pedestrians, is modeled as a repulsive acceleration. A similar repulsive behavior for static obstacles (e.g. walls) is represented again by accelerations. There exist several different formulations of the Social Force model in the literature: the first model from Helbing and Molnar (1995) is based on a circular specification of the repulsive force; the second model uses the elliptical specification of the repulsive force; in the third model the repulsive force is split into one force directed in the opposite of the walking direction, i.e. the deceleration force, and another one perpendicular to it, i.e. the evasive force.
In all these models human communication needs are neglected and pedestrians are represented as independent individuals that walk towards a goal. In doing that, autonomous individuals may be disturbed by other individuals and in this case they interact in order to avoid each other.
In social science instead, interpersonal distances have been analyzed not only as a consequence of repulsive accelerations due to other individuals, but in a wider context in terms of:

- Communication needs: interpersonal distance is viewed both as communicating information and as determining the quantity and quality of information exchanged
- Stress and overload: an individual maintains a preferred interaction distance from others in order to avoid excessive stimulation
- Constraints: personal space serves to provide an optimal level of behavioral freedom
- Ethology: interpersonal distance is adopted to protect against threats of physical attack.

The proposed research is a first step in the direction of developing a microscopic simulator able to reproduce pedestrian interactions in a given physical environment and the related discomfort. The simulation model we are developing is microscopic in the sense that every pedestrian is treated as an individual entity. The explicit and detailed modeling of individuals allows introducing subjective aspects characterizing specific motion, sensitive abilities and specific comfort needs. These are decisive elements for introducing individual heterogeneity in the model, in order to make it sensible to the behavioral variation related to the difference of gender, age and physical ability.

The paper aims at modeling pedestrian needs in terms of space, taking into account a more inclusive spatial behavior which includes both autonomy needs of pedestrian walking alone towards a target, and communication needs of people walking in groups towards a target. We'd like to underline the importance of modeling groups since a small amount of pedestrians walks alone (only one third of the pedestrians observed by Moussaïd et al. 2010) and pedestrian groups have an important impact on the overall traffic efficiency.

In the following, the term "group" is used here in its sociological sense, that is for indicating individuals who have social ties and intentionally walk together, such as friends. The term "stranger pedestrian" is used to indicate a pedestrian who walks alone and has not social ties with the other pedestrians.

When pedestrians are not able to keep their desired personal space, due to the interactions with stranger pedestrians, personal space drops and/or speed changes and/or changes in the trajectories occur. Depending on these reactions a discomfort results. In the case of personal space drops, the discomfort is related to the extension of the personal space that drops.

When pedestrians walking in a group are not able to keep conversation due to the absence of their friends in the communication area, discomfort results.

The paper has been structured in the following way: section 2 describes pedestrian needs in terms of space and proposes a model for personal space and communication space. Section 3 concerns the impact of personal space and communication space on the pedestrian's comfort. Section 4 outlines the simulator structure. Conclusions follow.

2. PEDESTRIAN SPACE MODELLING

Edward T. Hall in his study of human behaviors in public spaces (Hall, 1959, 1966) found that every person holds unconsciously a mobile territory surrounding him like a bubble. The violation of this space by a tierce person results in an effective reaction depending on the nature of relationship between two persons.

The space around a person could be divided into four areas: the intimate, personal, social, and public spaces as shown in Figure 1.

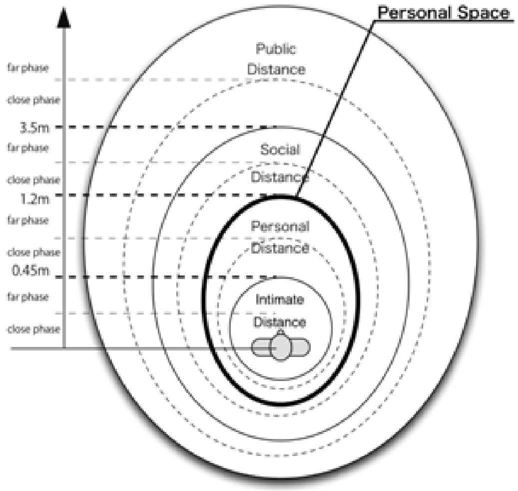

Figure 1: Structure of the space around a person (asaikarate.com).

The shape of the space around a person is affected by several parameters: intrinsic and extrinsic factors. Intrinsic factors include gender and age. Extrinsic factors are related to the social relationships that people maintain including: friendly relationship and stranger relationship. The effect of the main parameters have been analyzed in http://martintolley.com/environment/PersSpaceEnvPsy7.html and summarized in the following.

Gender: males interacting with other males require the largest interpersonal distance, followed by females interacting with other females, and finally males interacting with females. However it probably depends on the situation, or the relationship, or the age group and so on as well.

Age: some evidence suggests that the space around a person gets bigger as we grow older. Children tend to be quite happy to be physically close to each other, something which changes as awareness of adult sexuality develops. In addition the gender difference does tend to also appear at this time.

Culture: Hall (1959) identified the importance of cultural variation. He suggested that while all cultures use space around a person to communicate, and tend to conform to the different categories, the size of the space within the categories varies across cultures. Hall also identified the essential issue in inter-cultural difference as the tendency to interpret invasions of personal space as an indication of aggression.

Personality: there is some evidence of personality difference but effects here need to be treated with caution given the situational dependence of traits. Extraverted and gregarious persons tend to require smaller space, while cold and quarrelsome people require a larger interpersonal distance.

Situational effects on personal space: it is generally found that where attraction between individuals is strong, where friendships exist and where the general tone of the interaction is friendly, we are more willing to decrease our personal space requirement.

Alternatively where people dislike each other, and where the tone of the interaction is unfriendly, people move further apart.
Status: the general finding for status focuses on differences in status and it appears that the greater the difference in status between individuals, the larger the interpersonal distance used. There doesn't seem to be any evidence regarding personal space between same status individuals at different levels.

2.1. Autonomy Needs and Personal Space

The normal pedestrian behavior, according to Canetti (1984), is based upon what can be called the fear to be touched principle: “There is nothing man fears more than the touch of the unknown. He wants to see what is reaching towards him, and to be able to recognize or at least classify it.” “All the distance which men place around themselves are dictated by this fear.”
Personal Space (PS) has been defined as “an area with an invisible boundary surrounding the person’s body into which intruders may not come” (Sommer, 1969).
Humans have large multi-joined bodies, and because the clearance should be provided for all body parts to avoid contacting elements during locomotion in a confined and cluttered environment, avoiding collisions becomes more complex than just adjusting heading directions (Graziano et al., 2006).
It has recently been suggested that personal space is used by the locomotor control system to navigate safely around obstructions (Ge´rin-Lajoie et al., 2006). The same work showed that, for the rightward circumvention of a human-like obstacle at a natural walking speed, the left hemi PS had an elliptical shape with longitudinal and lateral radii representing on average approximately 2 and 0.5 m, respectively. People enlarged their PS when their attention was divided between the avoidance task and auditory stimuli. This effect was shown to be even greater in older adults.
Personal space has been measured in shape and size in ten adults as they circumvented a cylindrical obstacle that was stationary within their path (Figure 2).

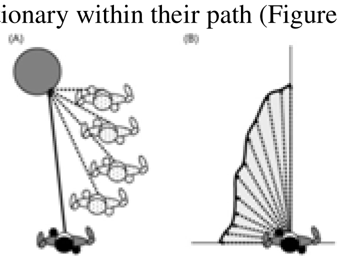

Figure 2: Personal Space experiments (Ge´rin-Lajoie et al., 2006)

The amplitude of personal space was not found to be a function of the walking speed since it resulted always equal to about 1 square meter. There was a main effect for the size of the PS with respect to the avoidance side, with the right side being smaller than the left side.
Many previous studies suggested that the shape of the PS varies with the face orientation. For example, the PS is twice wider in the front area of a person than in the back and side areas.
According with these empirical results, neglecting the asymmetric nature of personal space, assuming that the characteristics of personal space do not change during fixed and mobile obstacle circumvention, we assumed that each individual has the personal space shown in Figure 3.

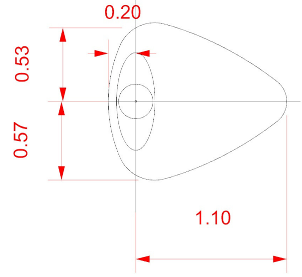

Figure 3: Model of Personal Space

2.2. Communication Needs and Communication Space

In the data collected by M. Moussaïd et al. (2010) at low density, group members tend to walk side-by-side, forming a line perpendicular to the walking direction, thereby occupying a large area in the street. Hence, when the local density level increases, the group needs to adapt to the reduced availability of space. This is done by the formation of 'V'-like or 'U'-like walking patterns in groups with three or four members, respectively. These configurations are emergent patterns resulting from the tendency of each pedestrian to find a comfortable walking position supporting communication with the other group members (Moussaïd et al. 2010)

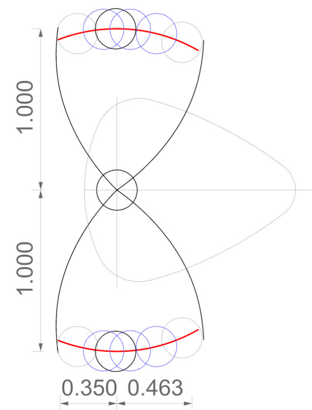

Figure 4: Model of Communication Space

Figure 4 shows the models we propose for the communication space and the personal space of a pedestrian. The communication space (with a shape like butterfly wings with the subject in the middle) include the possible positions of other group members when they communicate with the subject while walking. The proposed communication space model is based on empirical observation about average angle and distance values between group members, for different group size and density level, provided in Moussaïd et al. (2010).

3. IMPACT OF PERSONAL AND COMMUNICATION SPACES ON THE SUBJECT'S COMFORT

3.1. Interactions with stranger pedestrians

Since different regions in the PS, with the same extension have different impact on the pedestrian's discomfort, we divided the personal space in cells. A weight w_K is assigned to each cell k. The weight is proportional to the importance of the cell space for the comfort of the subject.

Figure 5 refers to the case a pedestrian walks alone and shows the subject's comfort (on the y axis) as a function of the distance of the PS's cells from the subject (which is represented on the x axis). So, if a cell very close to the subject drops, the comfort is zero; if a cell on the border of the PS drops, the comfort is high even if not at the maximum level. The comfort is maximum only if there is not any drop in PS.

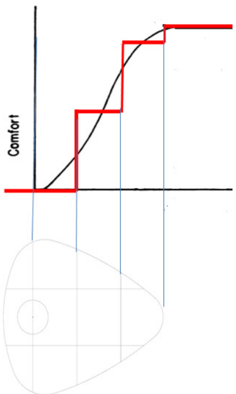

Figure 5: Impact on comfort of the PS's cells

Weights have been assigned to each cell. First, we assigned a weight (from 1 to 3) to each main direction around the subject (forward: 3, lateral 2, backwards 1); secondly we assumed that the weight decreases increasing the distance from the subject (with a rate of 1 point on each cell). Finally, we normalized the resulting values. The resulting weights are shown in Figure 6.

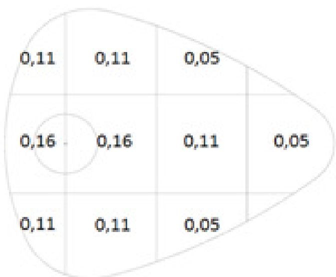

Figure 6: Weights of the PS cells

If a drop in PS occurs due to interaction with stranger pedestrians, a subject perceives a discomfort which increases as the dropped PS area increases.

In this case, the subject's comfort is assessed according to equation (1) :

$$COMFORT^A = 1 - \frac{\sum_{\forall k \epsilon PS^A} w_k * PSarea_k^{dropped}}{\sum_{\forall k \epsilon PS^A} w_k * PSarea_k^{desired}} \quad (1)$$

Where:

$COMFORT^A \epsilon [0,1]$ is the comfort in a given time instant perceived by subject A.

w_k is the weight of cell k. k is a generic cell of the subject's personal space (PS^A).

$PSarea_k^{dropped}$ is the extension (m^2) of the cell k that drops due to interactions with stranger individuals.

$PSarea_k^{desired}$ is the extension (m^2) of the cell k in the subject A's personal space.

The methodology for assessing: the extension of the PS area that drops due to too small interpersonal distances is described in Cepolina et al (2015).

3.2. Low quality of communication

In the case pedestrians walk in groups, if they are not able to keep the conversation they feel a comfort reduction.

Since different regions in the Communication Space (CS), with the same extension have different impact on the pedestrian's communication quality, we divided the personal space in cells. A weight w_K is assigned to each cell k. The weight is proportional to the importance of the cell space for the communication quality.

The impact of each cell of the Communication Space on the subject's quality of conversation is shown in the Figure 7. The figure refers to a subject walking in the direction of the y axis

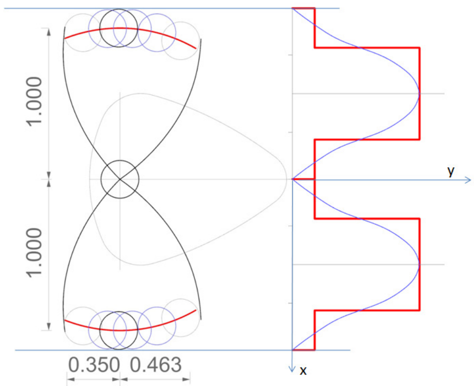

Figure 7: Communication Space and the related impact on the quality of conversation

The red line, on the left side of the figure, represents the comfort related to the quality of communication (on the y axis) against the distance from the subject.

From the subject's position, increasing the distance in the direction orthogonal to the motion direction, the impact of the cells within the communication space on the subject's comfort first, decreases as the distance of the cells from the subject increases; secondly, increases as the distance of the cells from the subject increases; and then, again decreases as the distance of the cells from the subject increases. Figure 8 shows the CS and the weights that have been assigned to space inside the CS. A given PS's area with a give weight could be composed by several cells: to each cell the same weight will be assigned.

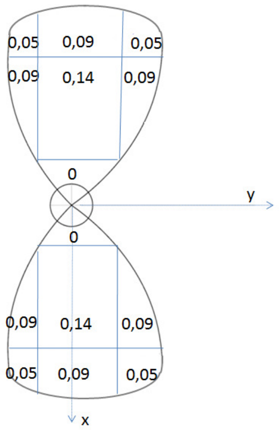

Figure 8: Weights of the CS's areas

If during the motion in a physical environment, a pedestrian is able to keep the other group members in the CS cells characterized by the maximum weight, the comfort is maximum (equal to 1). If not, according to the positions of the group members' centers of mass with respect to the subject's CS, the subject feels a reduced comfort (<1) given by:

$$COMFORT^A = \frac{\sum_{\forall k \epsilon CS^A} w_k * CellStatus_k}{N * \max_{\forall k \epsilon CS^A} w_k} \quad (2)$$

Where:

$COMFORT^A \epsilon [0,1]$ is the comfort in a given time instant perceived by subject A.

$CellStatus_k$ assumes a Boolean values: it is 1 if the cell is occupied by the center of mass of a member of the subject's group; it is 0 otherwise.

N is the number of members in the subject's group

4. SIMULATION MODEL

We now discuss a microscopic simulation model (Cepolina and Tyler, 2004) that shows promise of being able to incorporate the conceptual principles discussed so far in this paper; however the target of the following sections is not to be exhaustive on the simulation model since it is under implementation.

The main aim of the research is to simulate pedestrian behaviour in pedestrian physical environments (like museums, commercial centers, public transport stations) taking into account both pedestrians walking alone and pedestrians walking in groups. The phenomena being analyzed refer to the interactions between pedestrians. Each pedestrian has unique space needs: in this way the model is able to include individual pedestrians. Owing to these aspects, this simulation model is different from other microscopic simulation models of pedestrian behavior.

The simulator, which main input and output data are shown in figure 9, is object oriented, specifically suitable for the simulation of parallel processes, flexible and applicable to new scenarios. The simulation model is discrete in time and space. The physical environment is represented in terms of a discrete grid of square cells.

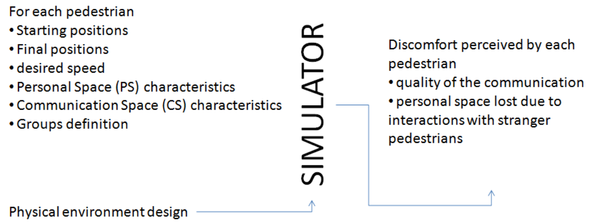

Figure 9: Simulator input and output data

The simulator environment is written in MODSIM III language. The research presented in the paper contributes to the characterization of some attributes (PS and CS) of the pedestrian object. The main methods of the pedestrian object are underlined in Figure 10.

Current (t) positions of pedestrians in the area
For each pedestrian (subject):
1. Detection of potential obstacles within the subject perceptual area, given the current position of the subject
2. Foreseen of the positions of the detected potential obstacles in the next time step
3. For each possible position of the subject in the next time step:
   a. assessment of the PS of the subject in the next time step
   b. assessment of the CS of the subject in the next time step, if the subject belongs to a group
   c. assessment of the subject foreseen discomfort in terms of
      a. the drops in PS due to interactions with stranger pedestrians, given their foreseen positions
      b. quality of the communication with the other elements in the group, given their foreseen positions
      c. delay due to a possible change in trajectory or in speed
   END for 3
4. Assessment of the best position of the subject in the next time step, given the assessed discomfort values for each of the possible position (evaluated at point 3)
5. Subject position updating
END (For each pedestrian (subject))
t:=t+Δt

Figure 10: Main methods of the pedestrian object

5. CONCLUSIONS

Pedestrian flows have been studied through analogies with gases, fluids and granular media. Nevertheless these analogies, the equations are difficult and not flexible. As a consequence, current research focuses on the pedestrian as a set of individuals paradigm. This means microscopic models, where collective phenomena emerge from complex interactions between many individuals (self organizing effects). The motion of individuals is described by mathematical equations that do not reproduce explicitly human behavior but are able to give rise to realistic emerging phenomena of pedestrian flows: in terms of lane formations of uniform walking direction; oscillatory change in the flow direction at bottlenecks in case of bidirectional flows and moderate density; stripe formation in intersecting flows. These mathematical equations allow the computer simulation of large number of homogeneous pedestrians (social force model, cellular automata of pedestrian dynamics and AI based models). Realistic simulation of a crowd of people is a challenging area also of computer graphics. Many of the problems with creating lifelike 3D animated models have been solved, but the difficulty lies in creating behavior that is believable.

The proposed pedestrian simulation model is based instead on a behavioral approach and tries to include socio-physiological aspects that characterize human behaviors.

The paper presents a model of personal space and a model of the communication space, which are input data for the proposed simulator. The paper analyses the state of art and provides average characteristics of these spaces. In the next future empirical research will allow to introduce individual heterogeneity in the proposed models of personal space and communication space in order to make it sensible with respect to age, gender, physical ability.

The overall presented research constitutes a preliminary activity for the simulator development.

ACKNOWLEDGMENTS

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PEDESTRIAN MODELLING: DISCOMFORT ASSESSEMENT

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ABSTRACT
A bad design of a pedestrian infrastructure hardly achieves congestion in the pedestrian flow, it is easier than it causes only bother among the pedestrians. Nevertheless infrastructures bad planned might result not accessible to particular classes of consumers in normal situations or might provide low levels of service linked to low comfort in using them.
The authors are developing a microscopic simulator that aims at analyzing virtual indoor and outdoor pedestrian environments in order to assess the quality of their design. The quality of the design is based on the comfort of people moving around the environment and is a function of the level of satisfaction of every pedestrian.
The paper proposes a methodology for assessing the discomfort resulting from interactions between pedestrians, in a given physical environment, in terms of personal space lost and low quality of communication. The proposed methodology has been applied to a real case of study. Pedestrian positions have been obtained by a photogrammetric survey.

Keywords: pedestrian discomfort assessment, personal space, communication space, quality of communication, interpersonal distances, object-oriented simulation.

1. INTRODUCTION
The research aims at developing a simulator for the analysis of virtual indoor and outdoor pedestrian environments (like museums, commercial centers, public transport stations) in order to assess the quality of their design. The quality of the design is based on the comfort of people moving around the environment and should be a function of the level of satisfaction of every pedestrian and not of the level of service related to the mean characteristics of the pedestrian traffic flow (Cepolina and Tyler, 2004). The comfort is also linked to the possibility to maintain a free space, during the motion, that every pedestrian requires around itself, and to the possibility of continuity of the communication with other pedestrians, if the pedestrian is part of a group.

Owing to these aspects, the simulation model we are developping is different from other microscopic simulation models of pedestrian behaviour: Pedflow (Kerridge and McNair, 1999), the agent based models developed by the Centre for Advanced Spatial Analysis at University College London: SimPed (Leal et al., 2005), the 'social force' model (Helbing and Molnár, 1995)), the 'self-organization' model (Helbing and Molnár, 1997) and the Gwenola model (Gwenola, 1999).
The simulator is object oriented, specifically suitable for the simulation of parallel processes, flexible and applicable to new scenarios. The simulation model is discrete in time and space. The simulator environment is written in MODSIM III language. The main input and output data have been reported in Figure 1.

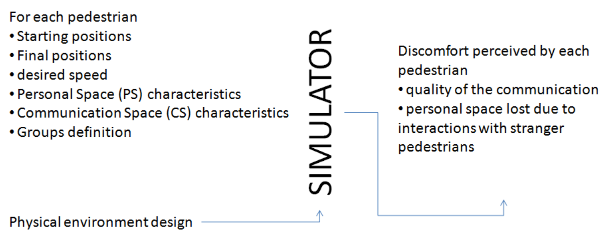


Figure 1 - Simulator input and output data

Current (t) positions of pedestrians in the area
For each pedestrian (subject):
1. Detection of potential obstacles within the subject perceptual area, given the current position of the subject
2. Foreseen of the positions of the detected potential obstacles in the next time step
3. For each possible position of the subject in the next time step:
   a. assessment of the PS of the subject in the next time step
   b. assessment of the CS of the subject in the next time step, if the subject belongs to a group
   c. assessment of the subject foreseen discomfort in terms of
      a. the drops in PS due to interactions with stranger pedestrians, given their foreseen positions
      b. quality of the communication with the other elements in the group, given their foreseen positions
      c. delay due to a possible change in trajectory or in speed
   END for 3
4. Assessment of the best position of the subject in the next time step, given the assessed discomfort values for each of the possible position (evaluated at point 3)
5. Subject position updating
END (For each pedestrian (subject))
t:=t+Δt

Figure 2: Main methods of the pedestrian object definition

The paper concerns a methodology for assessing, given the pedestrian positions:

- the drops in personal space that lead to discomfort (point 3. c. a. in Figure 2) and
- the quality of conversation that depends on the relative positions of group members (point 3. c. b. in Figure 2).

In the following, the term "group" is used here in its sociological sense, that is for indicating individuals who have social ties and intentionally walk together, such as friends. The term "stranger pedestrian" is used to indicate a pedestrian who walks alone and has not social ties with the other pedestrians.

2. INTERACTIONS BETWEEN STRANGER PEDESTRIANS

Each pedestrian has a personal space (PS), as described in Cepolina, Cervia and Gonzales (2015). If during the motion in a physical environment, the pedestrian is able to keep the whole personal space, the comfort is maximum (=1). If some cells of the PS drop due to the interaction with stranger pedestrians, the pedestrian feels a reduced comfort given by equation (1).

The proposed methodology aims to assess the extension (m^2) of the cell k that drops due to interactions with stranger individuals.

The methodology is based on the Voronoi cells. In mathematics, a Voronoi diagram is a partitioning of a plane into regions based on distance to points in a specific subset of the plane. That set of points is specified beforehand, and for each seed there is a corresponding region consisting of all points closer to that seed than to any other. These regions are called Voronoi cells (Wikipedia).

$$COMFORT^A = 1 - \frac{\sum_{\forall k \epsilon PS^A} w_k * PSarea_k^{dropped}}{\sum_{\forall k \epsilon PS^A} w_k * PSarea_k^{desired}} \quad (1)$$

Where:

$COMFORT^A \epsilon [0,1]$ is the comfort in a given time instant perceived by subject A.

w_k is the weight of cell k. k is a generic cell of the subject's personal space (PS^A).

$PSarea_k^{dropped}$ is the extension (m^2) of the cell k that drops due to interactions with stranger individuals.

$PSarea_k^{desired}$ is the extension (m^2) of the cell k in the subject A's personal space.

Given the current positions of the centers of mass of pedestrians, we assess a Voronoi cell for each pedestrian walking alone and for each group of pedestrians. To do it, we used Grasshopper which is a graphical algorithm editor tightly integrated with Rhino's 3-D modeling tools.

The following figure refers to 2 stranger pedestrians that interact due to the small interpersonal distance. The center of mass positions and pedestrians' personal spaces are shown on the left side as well as the segment that links the 2 centers of mass and the orthogonal line that define the 2 Voronoi cells. The line that defines the Voronoi cells cuts the 2 personal spaces and thus, defines the personal space areas that drop due to the interaction ($PSarea^{dropped}$). The personal space area that does not drop due to the interaction is shown on the right side of the Figure 3.

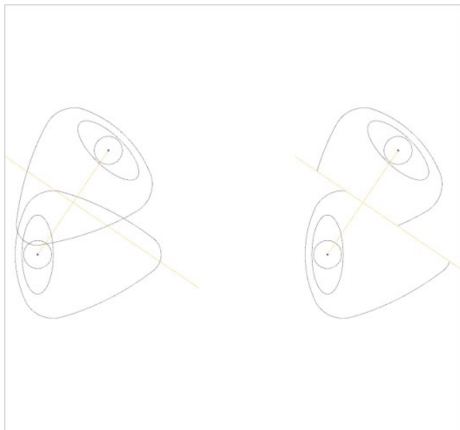
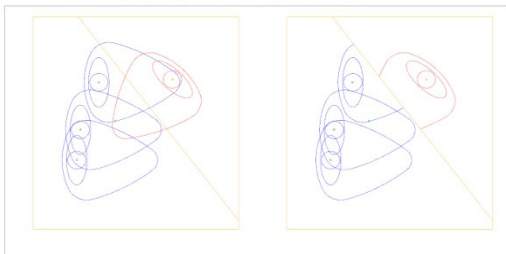


Figure 3: Assessment of PS drops due to the interaction with a stranger pedestrian



Figue 4: Assessment of PS drops due to the interaction between a stranger pedestrian and a group

Figure 4 refers to a stranger pedestrian that interacts with a group of pedestrians. The personal spaces of all the pedestrians are shown: in red the one of the stranger pedestrian, in blue the ones of the group members. The center of mass position of the stranger pedestrian is shown; the group's center of mass position has been assessed. Given the positions of the two centers of mass, it is possible to build the segment that links the two centers of mass and thus the orthogonal line that defines the two Voronoi cells, as shown in figure 4. The line that defines the Voronoi cells cuts the stranger's personal spaces and the personal space of one of the group members. The personal space area that does not drop due to the interaction is shown on the right side of the figure.

3. INTERACTIONS BETWEEN GROUP MEMBERS

Pedestrians belonging to groups have a communication space (CS), as described in Cepolina, Cervia and Gonzales (2015). According to the relative positions of the group members, the individual discomfort due to a low quality communication is assessed.

If during the motion in a physical environment, a pedestrian is able to keep the other group members in the CS's cells characterized by the maximum weight, the comfort is maximum (equal to 1). If not, according to the positions of the group members' centers of mass, the pedestrian feels a reduced comfort (<1) given by equation (2):

$$COMFORT^A = \frac{\sum_{\forall k \epsilon CS^A} w_k * CellStatus_k}{N * \max_{\forall k \epsilon CS^A} w_k} \quad (2)$$

Where:

$COMFORT^A \, \epsilon[0,1]$ is the comfort in a given time instant perceived by subject A.

$\mathrm{CellStatus_k}$ assumes a Boolean values: it is 1 if the cell is occupied by the center of mass of a member of the subject's group; it is 0 otherwise.

N is the number of members in the subject's group

4. EMPIRICAL DATA

Experiments have been organized at the University of Pisa. 40 students participated to the experiments. Some participants have been divided in groups of different dimensions and have been asked to cross a pedestrian street inside the university campus and to talk with the other group members while walking. Some other participants have been asked to walk alone along the street as "stranger" pedestrians and to interact with the groups.

Data relating to the pedestrians positions against time have been collected.

The target was to apply the methodology proposed in sections 2 and 3, in order to assess the discomfort resulting from interactions between pedestrians in terms of personal space lost and low quality of communication.

Pedestrians have been assumed homogeneous with respect to personal space and communication spaces. The dimensions of these areas have been assumed according to average values provided in Cepolina, Cervia and Gonzales (2015).

4.1. Photogrammetry for pedestrian route surveying

In order to obtain the coordinates of the canters of mass of each pedestrian in each time step, a photogrammetric survey has been performed. In detail, since for the research purposes the road surface on which pedestrians move can be assumed as planar, a monoscopic photogrammetry survey has been performed, with subsequent homography data processing.

4.1.1. Homography

A photographic image is a center perspective view of an object, where different elements have variable scales, and therefore image objects may not be directly measured.

Photogrammetry techniques allow to solve this problem by means of stereoscopy, i.e. by surveying the same scene at the same time from two different viewpoints it is possible, by way of collinearity equations (3), to compute internal and external orientation parameters of the camera (X0, Y0, Z0, rij, ξ0 , η0 and c).

$$X = X_0 + (Z - Z_0)\frac{r_{11}(\xi-\xi_0) + r_{13}(\eta-\eta_0) - r_{13}c}{r_{31}(\xi-\xi_0) + r_{32}(\eta-\eta_0) - r_{33}c}$$

(3)

$$Y = Y_0 + (Z - Z_0)\frac{r_{21}(\xi-\xi_0) + r_{22}(\eta-\eta_0) - r_{23}c}{r_{31}(\xi-\xi_0) + r_{32}(\eta-\eta_0) - r_{33}c}$$

These parameters define the internal reference system of the camera and set the six degrees of freedom in space, framing the camera in the real world reference system of the survey object. Subsequently, by way of the same equations it is possible to obtain the 3D coordinates (X, Y and Z) of each point of the scene from its pixel coordinates (ξ, η) digitized on a pair of images.

If the survey object lies entirely on a plane, the collinearity equations are simplified in homography equations (4). These allow, once the 8 parameters (ai, bi e ci) have been computed, to define planar X and Y coordinates on the basis of ξ and η digitized on a single image.

$$X = \frac{a_1\xi + a_2\eta + a_3}{c_1\xi + c_2\eta + 1}$$

$$Y = \frac{b_1\xi + b_2\eta + b_3}{c_1\xi + c_2\eta + 1} \quad (4)$$

In order to assess the 8 parameters, the coordinates of at least 4 points of a plane object should be known.

4.1.2. Photogrammetric survey

In order to collect images from which pedestrian canter of mass coordinates could be obtained, a SLR Nikon D700 still camera, fit with a fixed 20mm lens has been placed about 10m above the road plane, with the focal axis roughly orthogonal to this.

At this height, ground coverage on the wide side of the image was roughly 20m, with a Ground Sampling Distance (GSD), i.e. the ground-level size for each pixel, of about 5mm.

The camera position did not vary during the survey; shots were triggered in time lapse every second, with a total duration of 10 minutes.

Besides, in order to solve the homography equations, coordinates of 10 Ground Control Points (GCP) lying on the road plane have been surveyed and framed in a local reference system, allowing to compute the 8 unknown parameters (Figure 6).

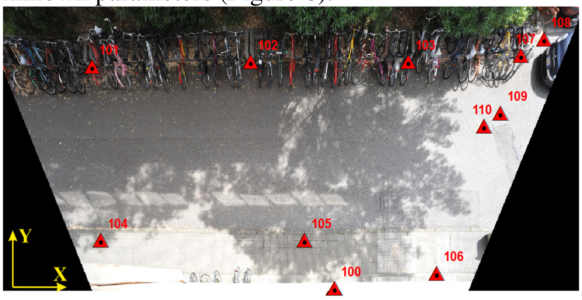


Figure 6: GCP on rectified image

4.2. Interface for data digitization

As already stated in paragraph 2.2.1, once the 8 unknown homography parameters have been computed it is possible to obtain the actual X and Y coordinates of any point on the object plane from image coordinates.
In order to build the required data base, a dedicated software has been implemented in the Matlab environment.
A GUI enables operators to sequentially view images and to digitize pixel coordinates of pedestrians' feet, also associating any information required for the subsequent modelling step (Figure 7).

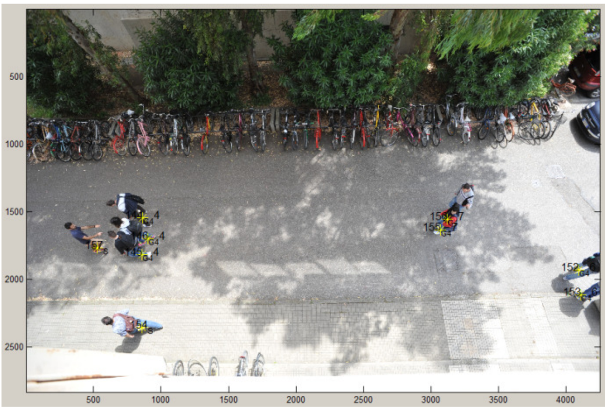


Figure 7: Pedestrian foot digitalization interface

In detail, the GUI assigns a univocal ID to each pedestrian, indicates its gender, labels it as a single pedestrian or a group member: in this case, it links the pedestrian's ID with the ID of the other group members. This information is then entered in a worksheet, in which homography equations compute the actual coordinates; these, in turn, yield the data required for modelling, including the trajectories of each pedestrian (Figure 8).

Figure 8: Pedestrian trajectories

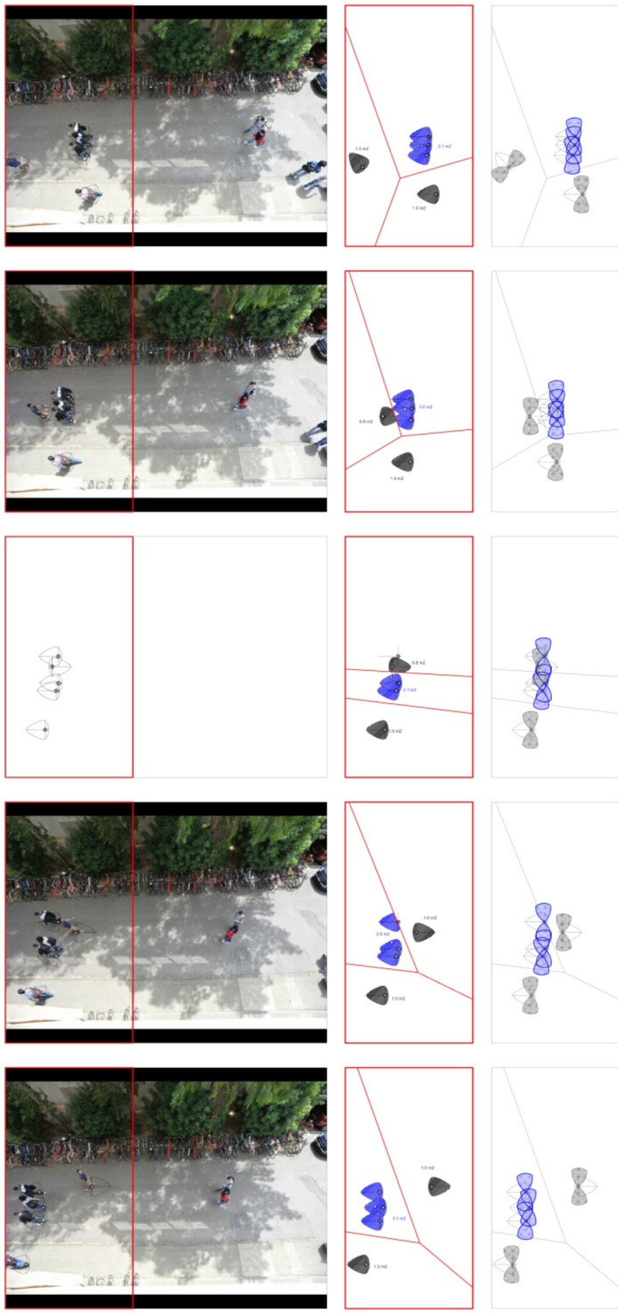


Figure 9: Comfort assessment in scenario 1

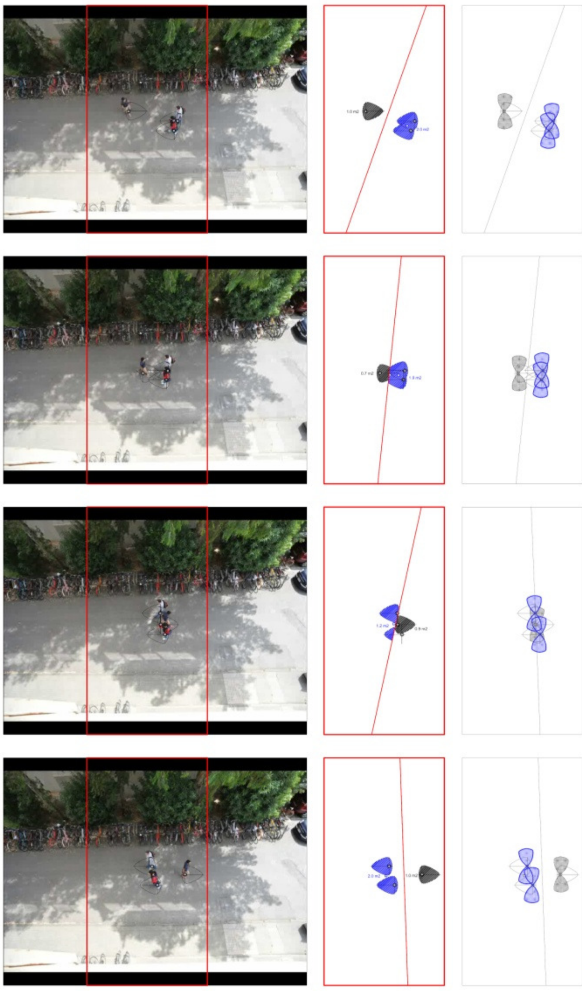


Figure 10: Comfort assessment in scenario 2

4.3. Results

Given the data base built with the methodology described in the previous section, we applied the proposed methodology for assessing the personal space lost due to interactions with stranger pedestrians and the comfort in communication for group members.

Two scenarios are here reported: the first one refers to a stranger pedestrian that crosses the street and interacts with a group of 3 individuals walking in the opposite direction. The second scenario refers to a stranger pedestrian that crosses the street and interacts with a group of 2 individuals walking in the opposite direction.

As it concerns the personal space drops, the Voronoi cells construction and the resulting personal space drops are shown in the middle part of the Figure 9, for scenario 1 and Figure 10 for scenario2.

As it concerns the assessment of comfort in communication for group members, the CS of each group member has been built given the subject position. For each cell k of subject's CS, the $\mathrm{CellStatus}_k$ value has been assessed given the positions of the centers of mass of the other group members. The assessment of the comfort related to the quality of communication is shown in the right side of the Figure 9, for scenario 1 and Figure 10 for scenario2.

5. CONCLUSIONS

The paper proposes a methodology for assessing individual comfort for pedestrians walking in a given physical environment. The characteristics of the individuals in terms of PS and CS have been assumed to be the same for all the pedestrians since we did not have data for assessing potential differences. Experiments have been organized in the university campus in Pisa in order to have a database for testing the proposed methodology. In order to obtain the pedestrians' coordinates, a photogrammetric survey has been performed and data have been analyzed. The resulting individual comfort is realistic and the methodology resuted able to cope with all the typologies of pedestrian interactions that occurred in the field.

In the next future we are interested in implementing in a simulator the proposed methodology in order to simulate the pedestrian positions against time and the related individual comfort. This will allow to analyze different designs for a given physical environment with different pedestrian loads (in terms of flows).

ACKNOWLEDGMENTS

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INTELLIGENT TRANSPORT MEASURES AS A COMPONENT OF CYBER-PHYSICAL SYSTEMS: CASE STUDY FOR ADAZI CITY

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ABSTRACT
Nowadays, the systems developed to integrate real physical processes and virtual computational processes – the cyber-physical systems, are used in multiple areas such as medicine, traffic management and security, automotive engineering, industrial and process control, energy saving, ecological monitoring and management, avionics and space equipment, industrial robots, technical infrastructure management, distributed robotic systems, protection target systems, nanotechnology and biological systems technology. Current paper provides an overview of CPS, their application in different fields of modern business, with main accent to intelligent transport system. Various ITS strategies and its evaluation measures are considered for transport intelligent transport system effective management. Example of transport management solutions realization process (problem definition, data collection, initial model development, verification, validation, ITS strategies developments, testing and evaluation) based on transport modelling is presented. Example is illustrated for one of the Latvian cities – Adazi, where was necessary to improve accessibility level for local drivers to get to and from city center.

Keywords: cyber-physical systems, intelligent transport system, modelling, transport management solutions

1. INTRODUCTION

New competitive approach to the physical and virtual world integration with cyber-physical systems is one of the European Union research priorities. Cyber-physical systems will change the way people interface with systems, the same way as the Internet has transformed the way people interface with information.

Concept of cyber-physical systems, their history and main components and characteristics are considered in this work. Cyber-physical systems can be and is used in different business areas such as commerce, industry, and public health, military and so on. In this paper application of cyber-physical systems in Internet of things, Industry 4.0, healthcare and transport intelligent systems are presented. Main accent is directed to transport intelligent system where physical systems working together with ITS technologies allow developing more sustainable and effective solutions for transport systems management.

To evaluate ITS solution effectiveness, complex mathematical models are used based on transport simulation models. Simulation models allow evaluating complex solutions before realization and selecting the better alternative from existing. Example of transport management solutions realization process and simulation model development and evaluation process are presented in chapter 3.3. One of Latvian cities – Adazi was selected for case study to illustrate transport management solutions realization and simulation model development process for ITS measure evaluations. Case study of Adazi city includes all steps of transport management solutions realization process: definition of case study aims and ITS measure requirements, data collection and initial model development, model verification and validation, development of strategies and evaluation of results for new ITS strategies.

2. CONCEPT OF CYBER-PHYSICAL SYSTEMS

Cyber-physical systems are developed to integrate real physical processes and virtual computational processes. Many objects used in modern daily life are cyber-physical systems. Concept of CPS is complicated (Skorobogatjko 2014), it can be illustrated with a concept map (see Fig. 1), developed in Berkley University (http://cyberphysicalsystems.org/).

The definition of Cyber-physical system from Cyber-Physical Systems Week (www.cpsweek.org): "Cyber-physical systems (CPS) are complex engineering systems that rely on the integration of physical, computation, and communication processes to function."

Cyber-physical systems have not appeared from nowhere, they have a long history of development, which continues. This chapter is an introduction to cyber-physical systems, their history and overview of the main components and characteristics.

Always growing need for different purpose information management systems leads to optimization of computing tools design techniques. Most of the world's currently used information management systems are embedded systems and networks. They are closely related to the control or management objects.

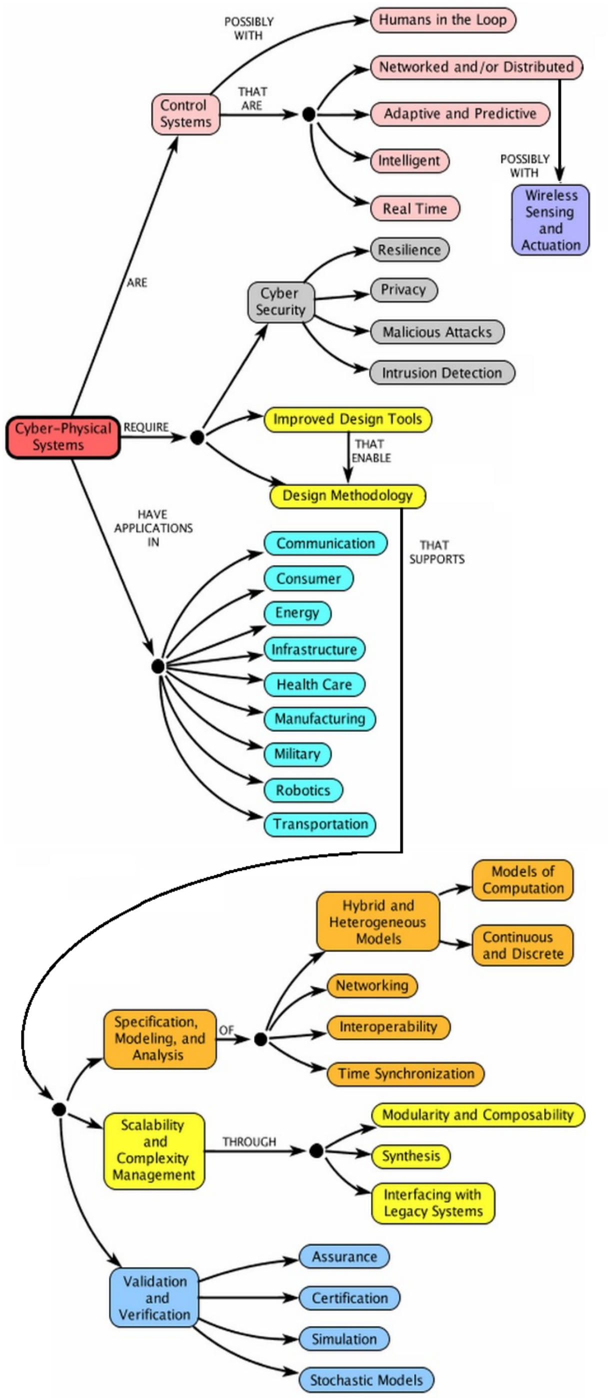

Figure 1: A concept map of Cyber-physical systems

From certain common computing systems' classifications best suited to the modern situation is classification proposed by David Patterson and John Hennesy (Patterson 2013). Their classification was guided by the use of the system. They divided computing system into 3 categories: desktop computers, servers and embedded systems. Embedded systems by the area of use are separated into:

- Automatic control systems;
- Measuring systems and systems that read information from sensors;
- Real-time "question – answer" type information systems;
- Digital data transmission systems;
- Complex real-time systems;
- Moving objects management systems;
- A general purpose computer system subsystems;
- multimedia systems.

The concept of embedded systems appeared in the early 50's and it is in rapid development even today. It is interesting to view the evolution of embedded systems:

- Information management systems, 60's;
- Embedded computing systems, 70's;
- Embedded distributed systems, 90's;
- Cyber-physical systems, from 2006.

Information management system is a computing system designed for management purposes, but it is the most alienated from the control object. Integrated micro-scheme and microprocessors development led to information management system bringing directly to the management object. World had entered the era of embedded systems. System elements are gradually becoming cheaper and their integration increases, as well as the security level and the opportunity to combine them in controlled networks.

Downturn in embedded systems' elements prices and increasing connection with physical management objects led to appearance of cyber-physical systems.

Cyber-physical systems are specialized computing systems that interact with control or management objects. Cyber-physical systems integrate computing, communication, data storage with real world's objects and physical processes. All above said processes must occur in real-time, in safe, secure and efficient manner. Cyber-physical systems must be scalable, cost-effective and adaptive. Cyber-physical systems are in use in various areas such as smart medical technologies, environmental monitoring and traffic management.

Wireless sensor networks can become an important part of cyber-physical systems, because of high sensitivity capability it is one of the main driving factors of cyber-physical systems application distribution. The rapid development of WSN, medical sensors and cloud computing systems makes cyber-physical systems impressive candidates for use in inpatient and outpatient health care improvement (Milenkovic 2006). Cloud computing maturity is a direct result of few technologies such as distributed computing, internet technology, system management and hardware development (Buyya 2011).

Cyber-physical systems integrate computing and physical processes. Compared with embedded systems much more physical components are involved in CPS. In embedded systems, the key focus is on the computing element, but in cyber-physical systems, it is on the link between computational and physical elements. Cyber-physical system parts exchange information with each other that is why the third component - communication is added there. For this reason, cyber-physical system is denoted by the symbol

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C3 (Computation, Communication and Control). Links improvement between computational and physical elements, extends cyber-physical systems usage possibilities.

3. CYBER-PHYSICAL SYSTEMS APPLICATION

Cyber-physical systems are used in multiple areas such as medicine, traffic management and security, automotive engineering, industrial and process control, energy saving, ecological monitoring and management, avionics and space equipment, industrial robots, technical infrastructure management, distributed robotic systems, protection target systems, nanotechnology and biological systems technology.

3.1. Internet of Things and Industry 4.0

In several sources (Buyya 2011; AENEAS 2014; Koubaa 2009) it is predicted that within ten years almost half of the electronic devices will be connected to the World Wide Web. This network is termed as Internet of Things. It connects not only household appliances such as refrigerators, thermostats, but also sophisticated production equipment.
Industry 4.0 concept aims a comprehensive cyber-physical systems use in manufacturing, customer relationship management and supply chain management processes, combining it all into one system. Smart manufacturing lines communicate with each other in order to optimize the production process.
Modern construction technology enables the creation of intelligent building designed with minimum energy consumption or even without it. However, they need constant monitoring. Engineers must attach smart buildings to smart grids, and add control mechanism – cyber-physical systems (CyPhERS, 2014).
Comprehensive use of cyber-physical systems for commerce, industry and public health, military and civilian purposes, makes the protection of these systems a matter of national significance. That is why embedded systems security systems, mainly anomaly detection system that enables resist spoofing and service failure type attacks, are currently actively developed (Amin 2013).

3.2. Healthcare Cyber-Physical Systems

There are hospitals, where robots already bring dishes to patients, sort mail, change bed linen and collect waste. Robotic beds transport patients to the surgery room. However, fully automated healthcare system has not been implemented yet. Currently, a number of hospitals in the world remote operations are carried out by the help of a robotic hand and high-resolution cameras (NITRDP 2009), however, there is still a long way to autonomous surgery when cyber-physical system itself, without human management, performs the operation.
Human-in-the-Loop Cyber-Physical Systems can greatly improve lives of people with special needs. Human-in-the-Loop Cyber-Physical Systems formulate opinions about the user’s intentions based on his cognitive performance by analysing data from sensors attached to the body or head. Embedded system convert these findings to robot control signals, which, thanks to robotic management mechanisms, allow users to interact with the surrounding natural environment. Example of Human-in-the-Loop CPS is robotic assistance systems and intelligent prosthesis (Schirner 2013).
Existing healthcare cyber-physical systems were mapped to this taxonomy and number of healthcare CPS groups (with several examples) were allocated: notable CPS applications (Electronic Medical Records, Medical CPS and Big Data Platform, Smart Checklist), daily living applications (LiveNet, Fall-Detecting System, HipGuard), medical status monitoring applications (MobiHealth, CodeBlue, AlarmNet), medication intake applications (iCabiNET, iPackage.).

3.3. Intelligent transport system

Intelligent transport system (ITS) provides realization of complex functions that can process of high dimension information and development of optimal and efficient decisions. ITS various strategies, guides, technologies are directed to existing transport system improvements without major reconstructions and investments with aim to provide more information, safety for all transport system operators, better coordinated transport network, congestion reduction, sustainable transport development and increase accessibility.
ITS technologies (wireless, radio, optics etc.) together with physical systems (traffic cameras, sensors, processors, variable message signs, ramp metering, data collectors etc.) help to manage transport systems and provide control of these systems. As result of such cooperation various ITS technologies are developed for more sustainable economic and social growth (Ezell 2010):

- Highway, freeway, road management system. Examples of application: ramp metering, traffic control, parking management, traffic signal control system, demand management, variable message signs.
- Transit management system. Examples of application: fleet management, lane preemption, signal priority, demand management.
- Freight transport management. Examples of application: system that can execute control of vehicle height and load limits.
- Accident and emergency management system. Examples of application: automatic accident detection, re-routing of traffic in case of accidents, detections of dangerous transport situations at roads, identifying driver’s level of alcohol, drugs.
- Multimodal management system
- Traveler information system. Examples of application: pre-trip, route information.

- Traffic control systems. Examples of application: traffic signals, traffic monitoring, vehicle and pedestrians detectors.
- Automatic fare payment systems. Examples of application: electronic tolls, transit fare payment, parking fare payment.

Smart transport systems equipped with various computerized and integrated management systems at different levels provide data collection from different sources and assign it between vehicles group or separate vehicles, for example Vehicle-to-Vehicle and Vehicle-to-Infrastructure interaction technologies that provide communication between vehicles; and vehicle and surrounding infrastructure. Such technologies allow improve road network capacity, transport operator safety, drivers' interaction on roads, decrease traffic delays, and number of car accidents. (Hashimoto 2009). An example of cyber-physical systems known to the general public is Google car, which does not require a driver.

Example of transport management solutions realization process in order to propose the most effective solution from developed is presented in Fig 2.

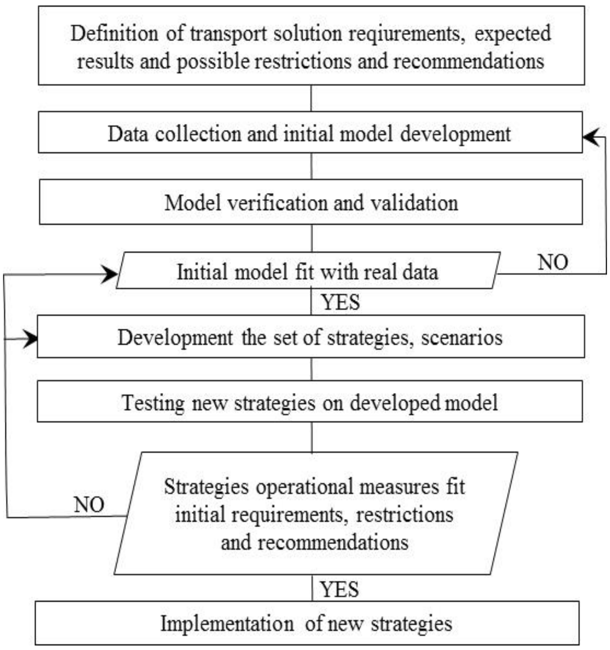

Figure 2: Example of transport management solutions realization process with transport modelling

Effective use of ITS can reduce delays, congestion time, accident counts, fuel consumption and improve traveler travel time, traffic flow, traveler mobility. Various types of measures can be used to evaluate ITS benefits (Koonce 2005):

- Capacity. To evaluate the capacity and/or level of service maximum number of vehicles or persons in peak hour can be used.
- Mobility. Mobility can be expressed as delay time and travel time per time unit.
- Safety. Safety usually is measured as number of accidents at roads, number of injury, fatalities.
- Productivity. Productivity is measured as cost saving, level of service analyzed unit (roads, lanes, pedestrians, public transport).
- Energy and environmental. Energy and environmental changes is measured by emission level, fuel use.

To evaluate ITS measures the good understanding of the dynamics of traffic at micro and macro levels, bottlenecks effects on the network, driver's behaviors, elements that influence on congestion initiation are essential. Simplified mathematical models are not enough for such complex dynamical problems and the better way how to evaluate and control various complex transport management systems strategies and solutions are to use traffic simulation models (Papageorgiou 2012). Example of simulation model development and evaluation process is presented in Fig. 3.

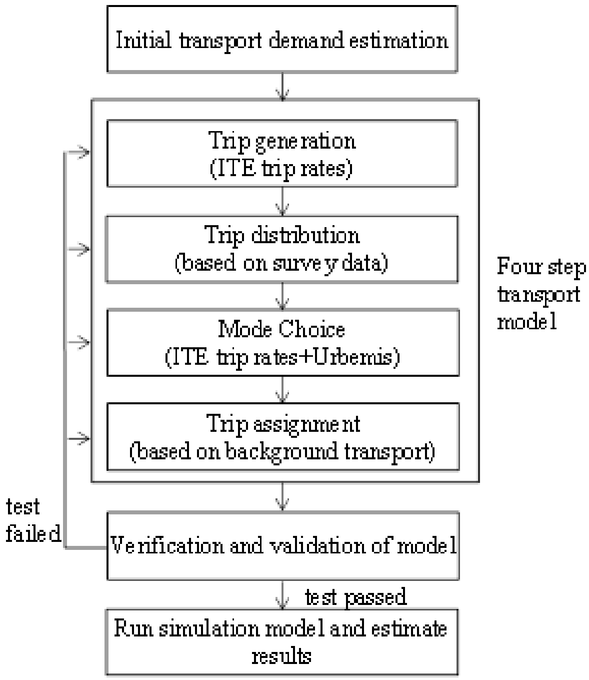

Fig. 3. Simulation model development and evaluation process

When simulation model is developed, verified and validated then different transport management scenarios, strategies, solutions can be developed and tested on simulation model in order to propose the most effective solution from developed.

4. CASE STUDY

The case study has been divided into group as it is showed in Fig. 2 in order to illustrate transport management solutions realization process and transport model development process with modelling for Adazi city.

4.1. Definition of case study aims and ITS measure requirements

The primary objective of the case study is to manage the bypass vehicles at Adazi city Local Street (Fig. 4 – yellow line) in the moments when Main road (Fig. 4 – blue line) is overloaded with heavy transports and drivers choose Local Street to overpass the congested road section. In such situation Local Street becomes over congested too and local drivers cannot with accessible level of service get to home (Adazi city center) or from home.

Figure 4: Research area. Yellow line - main road; blue one – bypass road

The aim of the study to improve transport accessibility for local drivers, to provide the efficient way for them to get to / from city center in case of Main Street peak hours by developing ITS measures. It was decided that for this study the following measures will be considered and analyzed based on local capacity and available land space:

- Improvements of transport infrastructure (changes in specific intersection geometry),
- Improvements in traffic lights signalization,
- Implementation of Variable message signs (VMS). VMS is devices that display messages of special events, time, road congestion and so on.
- Implementation of incident management system at Main road that allows detecting traffic accident and quick clear road from accident event participants to reduce the traffic blocking time.

Research area with Main and bypass (Local) streets is showed in Fig 4. In peak hour's Main road is loaded preliminary with the heavy transport that by transit is going to Estonia and non-truck drivers try to bypass Main road section by using Local Street despite the fact that travel time is approximately the same at Main and Local Street. Analyzed Local street section contains two roundabouts and 4 additions minor accesses to Adazi city.

4.2. Data collection and initial model development

To develop initial simulation model two modelling software Aimsun 8.0 developed by Trafficware Corporation and Synhro/Simtraffic 6.0 developed by Traffic Simulation Systems were selected based on literature comparison. Aimsun 8.0 is integrated transport analysis tool that can be used for transport planning, microscopic modelling, and demand and transport data analysis. Aimsun simulation tool provides integrated platform for statistical and dynamical modelling. Synchro simulation tool provides transport flow capacity analysis and signal timing optimization. Trafficware simulation tool provides Synhro 2d animation.

In the case study Aimsun simulation tool is used to create four step transport demand model: trip generation, trip distribution, mode choice and trip assignment. And Synhro tool is used for specific access traffic signal timing optimization. For analyzed alternatives with signal timing, signals optimization was done with Synhro to select best alternative and then this signal timing is used in transport demand model developed in Aimsun.

Initial model for existing situation was developed based on the following steps:

- Road geometry creation (lines, signs, pedestrian crossings, road types, free-flow speed etc.).
- Initial matrix and matrix adjustment creation with traffic data for different vehicles types: cars, trucks, buses, pedestrians.
- Public transport lanes with stops, transit schedules and set time spent for passenger departing and arriving.
- Signal timing definition for each intersection.
- Matrices, public transport, signal timing addition to travel transport demand model.
- Model initiated parameters configuration (warmup time, lane changing, modelling periods, number of runs etc.)

At this step initial model is developed and are ready for running the simulation. After model is finished simulation, verification and validation of model should be done to receive reliable model.

4.3. Model verification and validation

To verify and validate initial simulation model the following technics were used: Root mean square error (1), correlation coefficient (R), Theil's Inequality Coefficient (2).

$$RMS_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(w_{ij} - v_{ij})^2} \qquad (1)$$

$$U = \frac{\sqrt{\frac{1}{n}\sum_{j=1}^{n}(w_{ij} - v_{ij})^2}}{\sqrt{\frac{1}{n}\sum_{j=1}^{n}w_{ij}}^2 + \sqrt{\frac{1}{n}\sum_{j=1}^{n}v_{ij}}^2} \quad (2)$$

The root mean square error between estimated and observed results was 11%, correlation coefficient was 0.92 and and Theil's Inequality Coefficient was 0.11. The results of initial model verification and validation were showed appropriate results and simulation model can be used to test new strategies.

4.4. Development of strategies

To fit projects objectives six different scenario were considered to improve accessibility for local Adazi city drivers:

1) Scenario without changes. Local Street has two roundabouts (Fig. 5). This scenario will be used to compare results with other scenario.
2) Scenario 1. Local Street geometry is not changed. At Local Street entrance Variable message sign (VMS) is placed that in real-time shows travel time necessary to cross Main and Local Streets sections for transit drivers.

Figure 5: Scenario 1. Local Street has two roundabouts

3) Scenario 2. One of roundabouts at Local Street is changed to signalized intersection (Fig. 6) and without VMS.

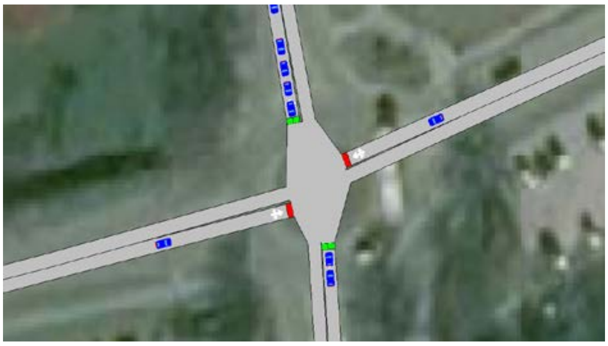

Figure 6: Scenario 2. One of roundabouts is changed to signalized intersection

4) Scenario 3. One of roundabouts at Local Street is changed to signalized intersection with protected left turns (Fig. 7) and with VMS.

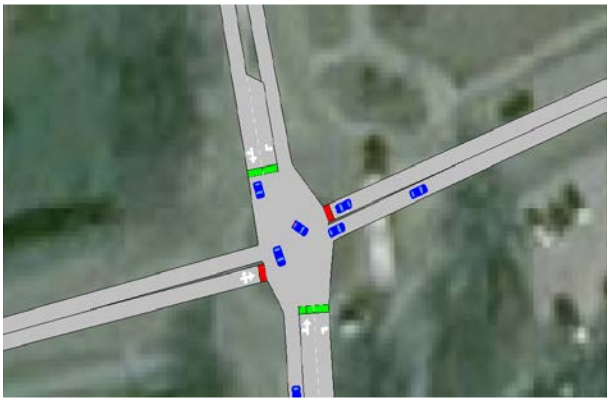

Figure 7: Scenario 3. One of roundabouts is changed to signalized intersection with protected left turns

5) Scenario 4. Both roundabouts geometry at Local Street is changed to signalized intersections with protected left turns (Fig. 8) and with VMS.

Figure 8: Scenario 4. Both roundabouts geometry is changed to signalized intersections with protected left turns

6) Scenario 5. Both roundabouts geometry at Local Street is changed to signalized

intersections with protected left turns (Fig. 8), Variable message sign is placed at Local Street entrance and accident management system will be implemented at Main road section.

4.5. Evaluation of results for new ITS strategies

For each considered scenario transport simulation model was build based on initial transport model. Each scenario was modelled during one hour. To evaluate results of each scenario the evaluation measures (Table 1) were divided in two groups: measures for Local drivers and for transit drivers that used Local Street.
Measures for local drivers consist:

- Travel time for local driver to get to city center.
- Level of service for intersections.
- Delay time for signalized intersections (for scenarios 2 - 5).
- Capacity for roundabout (base scenario without changes and scenarios 1, 2).
- Emission level calculated according to simulation software Aimsun.

Measures for transit driver consist:

- Travel time for transit driver to pass Local Street.
- Travel time at Main road.
- Number of trucks at Main road.
- Emission level calculated according to simulation software Aimsun.

Table 1: Evaluation results of scenarios

Measures for local drivers:						
	Base	Sc 1	Sc 2	Sc3	Sc4	Sc5
Travel time for local driver to get to city center, sec	214.6	208.1	205	208.3	206	207.4
Level of service	-	-	C	B/C	B/C	B
Delay time, sec	-	-				
Capacity for roundabout	0.75	0.76	-	-	-	-
Measures for transit driver:						
Travel time for transit drivers to pass Local Street, sec	253.9	253.1	260.9	259	258.9	254.9
Travel time at main road, sec	267.1	269.9	268.8	270	267.3	271.4

Level of service and delay time were calculated according to Highway capacity manual 2010 (HCM 2010). Level of service and delay time estimation methodology according to HCM2010 is presented in Fig. 9.
The evaluation results of new ITS strategies (scenarios) showed then better strategy from level of service, travel time and capacity point of view is the fifth scenario in which both roundabouts geometry at Local Street were changed to signalized intersections with protected left turns (Fig. 8), Variable message sign was placed at Local Street entrance and showed time necessary to pass Local street and Main street; and with implemented accident management system at Main road section.

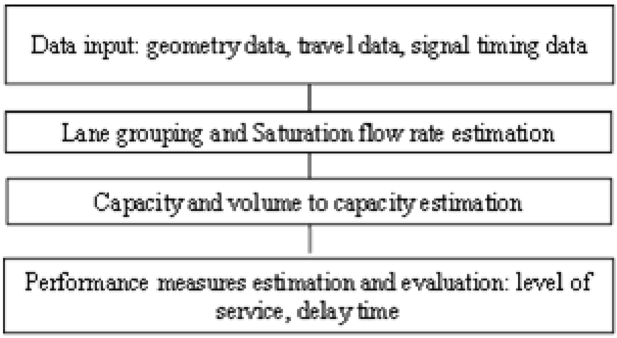

Fig. 9: Level of service and delay time estimation methodology

The second result showed scenario 1 in which Local Street geometry was not changed, but at Local Street entrance Variable message sign (VMS) was placed that in real-time showed travel time necessary to cross Main and Local Streets section for transit drivers.

5. CONCLUSIONS

An overview of CPS, their application in Internet of Things and Industry 4.0, healthcare and intelligent transport system is presented. The main aspect of research was devoted to intelligent transport system. Various ITS technologies that combine intelligent transport solutions and physical systems are listed. Example of transport management solutions realization process (definition of requirements, data collection and initial simulation model development, model verification and validation, development of scenarios, testing new scenarios and implementation) for Adazi city is considered. Six different development strategies were analyzed for Adazi city to improve accessibility for local drivers to get to city center: 1) strategy without changes in transport network geometry at Local street; 2) strategy without changes in transport network geometry at Local street and with implemented Variable message sign that will redirect transit transport from Local Street to main Street; 3) strategy with changes at one of road intersection at Local Street and without VMS; 4) strategy with changes at one of road intersection at Local Street and with VMS; 5) strategy with geometry changes at two road intersections at Local Street and with VMS; 6) strategy with changes at two road intersections at Local Street, with VMS and with implemented accident management system at Main road section. Performance measures (travel time, delay time, level of service, capacity) were used to evaluate each development strategy for Adazi city. Strategy evaluation results have shown that from all considered strategies, the sixth strategy showed the smallest travel time for local drivers to get to city center and travel time for transit drivers at Main road increased only for 2%.

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AGENT-BASED SIMULATION FOR PLANNING AND EVALUATION OF INTERMODAL FREIGHT TRANSPORTATION NETWORKS

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ABSTRACT

This work presents an agent-based simulation model for the planning and evaluation of intermodal freight transportation networks with a system-wide scope. This approach covers actors, transportation infrastructure, terminal operation strategies and train services. The relevant actors in continental intermodal freight transport, their contributions and tasks are identified and their specific planning rules are as well as the dedicated coordination structures and the code of conducts between the agents are modelled in order to analyse the overall behaviour of the system. Each agent acts according to its own goals and rules and has to consider its domain specific restrictions. They have the ability to make autonomous decisions. These may be set actively or according to system's restrictions or requests. Typical agents considered are terminal agents, link agents, train operator, route planner and container owner respectively. The developed class model structure is also shown. The developed agent-based simulation model enables the dynamic performance evaluation of the whole intermodal freight transport system, as well as on the level of individual elements.

We define an arbitrary freight network with 15 terminals to supply 23 demand regions. Source-sink relations are generated from databases of joint research centres of the EU commission. Also we consider empty container depots in the network. Model trains and corresponding schedules for each terminal and load units are defined in order to generate a basic network load. The modelling approach is applied to standard processes like execution of regular transportation orders, balancing of empty container stocks and introduction or close down of transportation services. A deviation management is applied for booked load units which are too late, late arrivals of trains, insufficient terminal capacity (loading tracks, container storage) and availability of load units.

We apply a scenario approach to observe system's behaviour if we are changing transportation demand, modify terminal network or adopt train schedules.

We can conclude that the agent-based simulation is an appropriate approach for evaluation the intermodal freight network.

Keywords: agent-based simulation, intermodal freight transportation, network evaluation

1. INTRODUCTION

Future prospects in the development of intermodal transport clearly show that Eastern Europe actually faces challenges in terminal network evolution. Figure 1 displays an overview of the expected network in Eastern Europe (UIC, 2010). It can be used to derive transhipment and line capacities in the region and for setting up an intermodal freight network in the area.

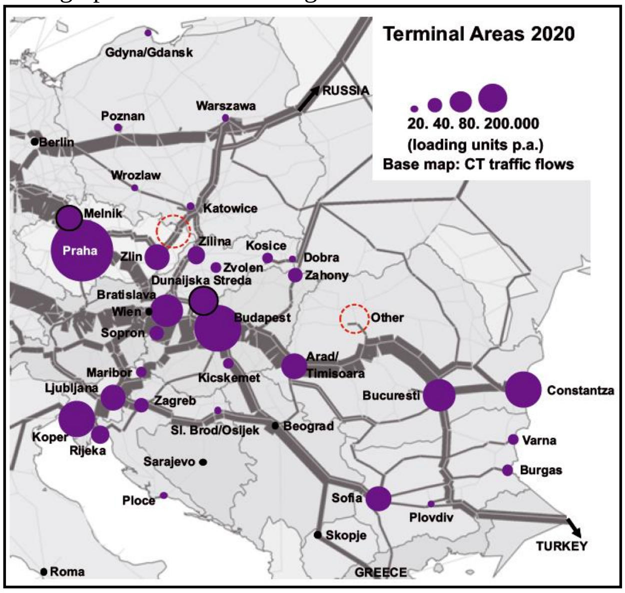

Figure 1: Estimated terminal areas and transportation volumes for 2020 (Source: UIC 2010)

The challenges are now in the timely planning of the development of transport infrastructure and the introduction of more efficient operational concepts, both for terminals as well as for services in intermodal freight transport. In order to strengthen these activities sea ports in the area must be adopted and their hinterland connectivity improved (EC, 2005).

Usually, in intermodal freight transport a number of different actors are involved to organize and transport an ITU. Figure 2 shows the different actors the information flow and the flow of the load units.

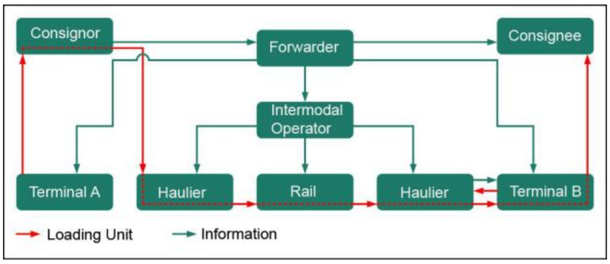

Figure 2: Information and load unit flow in intermodal freight transport (source: Posset et al. 2014)

2. MODELLING INTERMODAL FREIGHT NETWORKS

The first step in planning of transportation networks is to define its topology. Alumur and Kara (2008) give an overview of location planning problems, so-called Hub Location problems. In Yamada et al. (2009) a combined optimisation approach for the design of multimodal transport networks is applied. The proposed method on the one hand decides on infrastructural level on improving or re-introduction of roads, railways, waterways and terminals, and is combined with an allocation method for the transport flows, which takes into account the earlier decisions on infrastructural changes. Etlinger et al. (2013) show an approach to determine the basic topology and allocation of transport flows for intermodal networks. A Mixed Integer Linear Program for site planning of terminals is applied. Based on the total cost of container transportation and handling for a specific transport demand from a set of possible terminals it aims at determining optimal locations. A selected terminal corresponds to a certain terminal type which differ according to capacity and cost structures.

At the strategic planning level in order to forecast multi-mode freight traffic so called macro traffic models are used. For instance, the model STAN (Guélat et al, 1990; Crainic et al, 1990) was applied in Scandinavia to support national transport planning. In DSSITP - Decision Support System for Intermodal Transport Policy (Macharis et al, 2011) three models were compiled to enable an overall approach. The model NODUS combines (see Jourquin and Beuthe, 1996 and Geerts and Jourquin, 2001) transport mode and route selection decisions. Forecasting freight transport at a national level for Germany and determination of the modal split and the terminal selection is used by the SimuGV model (Schneider et al., 2003). SimuGV is also part of system MOSES - integrated Strategic Simulation and Modelling Tool for Rail Freight Transportation. It is applied by the German Railroad, Inc. (Schneider, 2003). Going one step further we will now present models that are specifically designed towards the optimization and simulation of intermodal freight transport.

Rail network simulation models allow for detailed description of general-train movements and specific analysis of rail network capacities, where model output parameters are then given as the summation of delays, the number of delayed trains or average delays. Models with this functionality include SIMONE, RailSys, SiSYFE, SIMU, IS SENA (CAPMAN, 2004) or Open Track (Nash and Hürlimann, 2004; Open Track, 2010).

On a tactical level Wieberneit (2008) provides an overview of the treatment of problems in the design of transportation services by means of mathematical optimization approaches. The tasks there include decisions about the frequency, mode, the schedule and the route of a transport service, as well as the routing in a cargo service network.

In a further literature review on multimodal freight transport planning SteadieSeifi et al. (2014) confirm these findings. Their analysis which focused on tactical planning problems shows that simultaneous planning for various different resources, dynamic and stochastic aspects in the data should be considered.

Using an optimization model for tactical planning level objectives Andersen et al. (2009) aims to identify potentials for improving the interoperability of cross border transports. The aim of the model used is an improved integration of fleet management and the design of the service network. The main objective is to minimize the processing time for a certain amount of demand for a given timetable of services. The approach takes into account also waiting and processing times at network nodes. Another approach is presented by Anghinolfi et al. (2011) for planning of container transports in rail networks where terminals are equipped with special technology for quick container handling. The route through the network and hence selected trains are to be determined so that the arrival time of the different shipments can be met.

Many works address the objective of minimizing costs of the overall transport systems. For example, Lindstrom Bandeira et al. (2009) present a decision support system for full and empty container transportation in order to minimize the overall cost of transportation, handling and storage. The method suggests the splitting of the problem in a static model for cost-effective allocation of containers, including transport, handling and storage, to the demand points without taking into account the transport times. This solution is used as a starting point for detailed planning.

Ballis and Golias (2002, 2004) and Abacoumkin and Ballis (2004) perform a comparative cost and pricing analysis for different bimodal terminal designs. Taking into account both various parameters in terms of infrastructure and technology and organizational flow parameters such as arrival time distributions of trucks and different train products. The question of how intermodal transport can be competitive to monomodal road transport is raised by Bierwirth et al. (2012). The authors develop a planning model for consolidation of freight flows at the tactical level, taking into account cost factors on transport mode, transport services and terminals.

Other works focus on the conditions for transport systems and coordinating processes between system participants. Miller-Hooks et al. (2007) develop a framework for simulation and dynamic allocation of transport orders to different variants of a multimodal transport network along the Baltic Adriatic transport network link. First, a set of paths and combined transportation modes are determined by means of a costly and time-based routing algorithm, which is then used by a mapping component for the generation of the network flows. Finally a simulation model is applied to analyse the time requirements for transport orders in the overall network (Mahmassani et al., 2007).

Puettmann and Stadtler (2010) propose a cooperative approach for managing inter-modal transport chains and multiple service providers. They present a system for minimizing the overall shipping costs for three parties, a carrier, a rail operator for the main run and shipper for the follow-up where each actor optimizes its own decisions first. The solution is generated by iterative negotiations and solution updates between the actors. An interesting and important issue of that contribution is that confidential data need not be disclosed during the negotiation process. Other works (Zhang et al., 2010 Nossack and Pesch, 2013) focus on the planning and control of container transports by truck between shippers, receivers, terminals and depots. Solution were generated by using either exact or heuristic methods. Zehendner und Feillet (2014) build a MIP model in order to improve the quality of services for road transport. They also consider terminal operations and restrictions of other transport modes to facilitate the due date setting for truck transports. The results of this model serve as input for a discrete event simulation model for allocation of cargo handling equipment.

In recent years simulation has evolved into a reasonable method for analysing freight transport and its decision processes. Boschian et al. (2011) apply meta modelling to describe a generic reference model for intermodal transport. Holmgren et al. (2013) apply a multi-agent simulation system to model a regional transport network with a certain number of supplier and customer. The approach fosters to find an appropriate shipment for given constraints on resources and infrastructure. A detailed and comprehensive description for an agent based simulation model for analysing intermodal freight transport network is provided by Schindlbacher (2014). This paper is based on this work and on findings of the research project SimNet (2013).

3. AGENT BASED SIMULATION APPROACH

Usually, agent based simulation is used for complex systems where the behavior of agents influences the overall system. Each agent may independently choose its decisions and applies its own control strategies. Also agents communicate with others and somehow are also interfering the decisions of others. Each agent has its own goals or some given targets to fulfill. The collection of decisions of all agents results in the overall network behavior.

We develop an agent based simulation model for analyzing the behavior of an intermodal freight network. In a first step a generic transport process is defined to identify relevant activities and entities. These are: transport order, network routing, train booking, empty container supply, pre haulage, terminal handling, main haulage, terminal handling, onward carriage and empty container repositioning. We present now the constitutional elements of our simulation system which support the transport processes.

The elements are structured in organizational units (actors), information flow, transportation, transportation units, services and framework conditions, and network infrastructure. The corresponding class model is shown in Figure 4, where the network infrastructure contains the classes:

- *Terminal Agent*
- *Terminal Module*
    - *Equipment*
    - *Tracks*
- *Rail Link*
- *Road Link*
- *Catchment Area and*
- *Residual Area*.

Transportation and transportation unit use the *train*, *truck* and *load unit* classes. Organizational units were modelled with the classes: *Entity Generator*, *Route Planner, Container Owner* and *Link Agent*. Figure 3 displays the statechart for a terminal agent. It handles (loading) track and equipment assignment for processing incoming and outgoing trucks and trains.

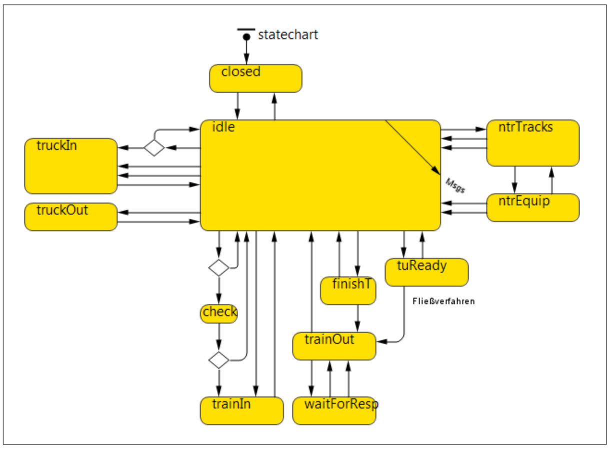

Figure 3: Statechart Terminal Agent

This system's architecture allows for analyzing both standard transportation processes and deviation management. The standard processes include the handling of regular transports, the balancing of empty container stocks and the introduction of new transport connections or the stop of transport relations with low utilization.

The deviation management is activated if

- the booked load unit has not arrived the terminal when the corresponding train is just leaving,
- incoming or outgoing trains are delayed,
- no handling capacity is available and

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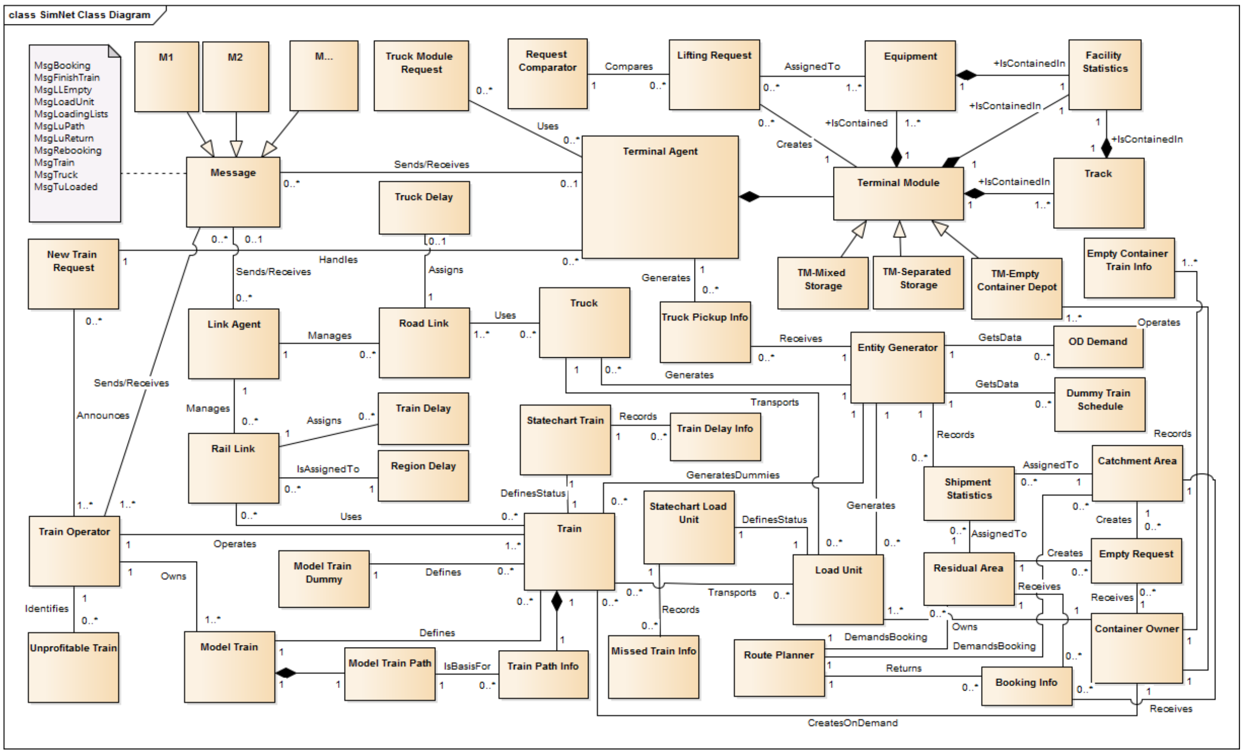

Figure 4: Class diagram of the intermodal network

- no container is available in the catchment area.

The overall system is implemented with AnyLogic®.

3.1. Performance measurement

The performance of the intermodal network is evaluated on different levels and of different actors. On system's level this is provided by 1. General Data, 2. Rebooking, 3. Transportation Order and 4. Train delays. For each category a set of output parameters have been defined. Next for each terminal (*Terminal Agent* and *Terminal Module*) the terminal operation and the storage of load units are collected for analyzing the performance at this level. At the next level indicators for the *Container Owner* are defined. There, for example empty container trains in the system are captured. For measuring the *Train Operator* indicators like cycle time for each train relation are recorded in order to support decisions on their actual and future operation. The overall set of indicators can be found in Schindlbacher (2014).

3.2. Model terminals and model trains

For validation a base scenario is defined which contains a set of model trains and a small number of model rail road terminals in the network. The terminals are categorized in small, medium, large and x-large depending on their transshipment capacity and empty container handling. The functionality of a terminal includes storage capacity, loading and marshalling tracks, handling equipment, operating hours and time windows for trucks. All terminal types may also operate an empty container handling. All terminals are operated according to the train floating procedure.

Starting point for the definition of model trains is data which contains more than 220 real life trains. Trains differ with respect to their length, the portion of different types of intermodal loading units and the function of the train in the network. This could be block trains, shuttle or liner trains. Out of these, 13 model trains were used to generate a train schedule which constitutes a basis traffic load for the terminals in the system. This schedule is also based on real life data. For each model terminal a basic train schedule is defined and the simulation evaluates the system for a six months runtime.

4. USE CASE FRAMEWORK

We apply our agent based approach on a network with 15 terminals out of a set of 35. A single train operator is active. According to the selected nodes we set up a network for connecting the terminals. Also we have to consider traffic flows that leaves this network and vice versa which have their origins outside. To cope with this residual areas were defined. Altogether to connect all areas and terminals 552 oriented network links were established. Each link has a set of attributes like distance, velocity, capacity. For some areas we also introduce a standard delay pattern for the trains. In addition to connect the catchment areas with the terminals and empty container depots 104 non oriented links for road transports are generated.

The schedule of the train operator in the basis scenario contains 549 relations which were covered by various model trains. Out of these, 197 relations are connections within the network and the remainder are either export or import trains. 534 trains are block trains, 14 shuttle trains and a single line train. 2.4% of the trains have a maximum transportation capacity of 50 TEU, 14.8 % of 70 TEU, 22.8 % of 80 TEU and the remaining 59.9 % of 90 TEU. The main portion of the relations are used once a week.

The background for the use case framework constitutes the intermodal freight network in south-eastern Europe. For generating transportation demand on a NUTS 2 level the data of a Joint Research Centres of the European Commission is used (TRANS TOOLS, 2012) and raw data are converted to intermodal units i.e. TEU.

5. SCENARIO ANALYSIS

We apply a scenario analysis to systematically change parameter values and observe system's behaviour. By doing this we distinguish between structural and organisational parameters (see Table 1 and Table 2). Structural ones are: runtime, transportation volume, container volume, empty container depots, depot equipment, basic utilization at terminals and system's traffic. Organizational parameters include: train schedule, maximum booking duration per relation, minimum utilization per relation and number of empty container trains.

Parameter		Value	Description
Runtime	LZ1	8	Simulation Runtime in weeks
	LZ2	12	
transportation volume	TM 1	491.280 TEU	annual transportation demand
	TM 2	982.560 TEU	
	TM 3	1.965.120 TEU	
Container Volume	CM1	100.000 20' 30.000 40'	
	CM2	75.000 20' 22.500 40'	
	CM3	50.000 20' 15.000 40'	
	CM4	30.000 20' 9.000 40'	

Table 1: structural parameters for scenario analysis

train schedule	F1	Basic schedule	train schedule used by train operator
	F2	Adaption of F1	
	F3	Adaption of F2	
maximum booking time offset	MB1	10	Maximum average time between a booking request and the actual availability of a realtion measured in days, required for a new train relation
	MB2	14	
minimum utilization	MA1	0,90	minimum average utilization of a relation
	MA2	0,97	
empty container trains	ALCZ-D1-1	6	maximmum number of of empty container trains
	ALCZ-D1-2	8	
	ALCZ-D1-3	10	
	ALCZ-D2-1	1	
	ALCZ-D2-2	2	
	ALCZ-RA1	6	
	ALCZ-RA2	4	

Table 2: organisational parameters for scenario analysis

We establish a scenario tree (Figure 5) in order to figure out consistently the coherence between changing some parameter values and the performance indicators of the intermodal freight network. This procedures allows not to test all possible parameter combinations but instead iteratively checks the results of a particular branch and then defines new promising or missing parameter settings.

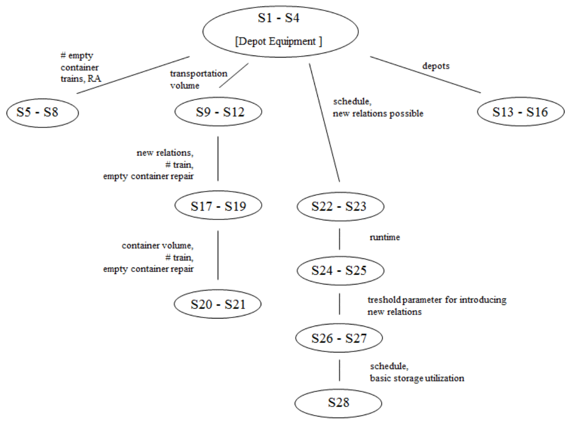

Figure 5: Scenario tree

Scenario S1-S4 start with (LZ1, TM1, see Table 1) and consider different Depot Equipment. In S5-S8 the number of trains in residual areas are changed. The path S9 – S12, S17-19 and S 20-S21 investigates an increase in transportation volume, introduction of new relations and a rise in container volume. In the other path (S22 – S28) we are changing the train schedule and thereby forcing new relations. In Figure 6 we compare the average utilization of a relation to the overall number of operated relations. Transportation volume TM2 is used for S9 and S11 and TM3 for S10 and S 12 rsp. We can observe that due to an increase in transportation volume the average utilization of relations is decreasing, because we need more relations to cope with the transportation volume. Obviously this is an important management parameter to figure out the appropriate supply of transport relations.

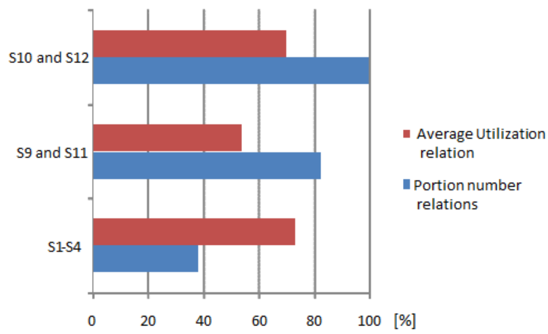

Figure 6: Relation utilization and operated relations

CONCLUSION

We can state that the developed approach is very well suited to cope with the complexity of modeling and simulation an intermodal freight network. The results generated are very robust and show the potential of agent based simulation in this domain. During further developments will work on a better aligned basic train schedule and we will elaborate the network attributes.

Also the class diagram can be adapted in order to facilitate the introduction of wagons for train formation.

ACKNOWLEDGMENTS

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HIERARCHICAL MESOSCOPIC SIMULATION MODELS OF PARCEL SERVICE PROVIDER NETWORKS

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ABSTRACT

The market for parcel service providers has been growing dynamically over the past 15 years. Especially the increasing e-commerce is one major factor for this development. According to forecasts, this development will continue in the future, which leads the parcel service providers towards several challenges. They have to adapt their existing networks to the increasing quantity of parcels. For this reason, tools for analyzing the impact of increasing quantity of parcels are necessary. This paper will present hierarchical mesoscopic simulation models of a parcel service provider's network to support analyzing and planning tasks.

Keywords: networks of parcel service providers, hierarchical mesoscopic simulation modeling

1. INTRODUCTION

Networks of parcel service providers are complex and highly dynamic systems with a high quantity of flow objects. There are different impacts (e.g. customer behavior, incidents on transfer points etc.) on those networks, which are mostly stochastic in nature. Methods like OR-algorithms or static models are not adequate to analyze those complex networks and experiments on the real system are hardly possible.

Simulation models allow gaining knowledge of the system behavior of those complex networks. Relatively common is the use of discrete-event simulation models in the field of logistics. Discrete-event simulation models are object-based and allow for microscopic simulation models. But there are some noticeable disadvantages of this method, using it for modeling and simulation of large systems with high quantity of flow objects. These disadvantages are a long simulation runtime as well as a time consuming creation and implementation phase. The mesoscopic modeling and simulation method developed by (Reggelin, Tolujew, 2011) enables quick model creation and calculation in order to perform extensive analysis of large logistic networks. The basis of this method is the use of piecewise constant flow rates to simulate the movement of flow objects. This paper presents an application of a mesoscopic modeling and simulation method on a network of a parcel service provider.

One important aspect of modeling is the selection of an appropriate level of detail for the model. There are often conflicts between a high level of detail and fast simulation runtime as well as creation time. To meet these conflicts this paper will present a concept and an application of hierarchical mesoscopic simulation modeling.

2. SIMULATION MODELS OF NETWORKS OF PARCEL SERVICE PROVIDERS

Networks of parcel service providers are a special type of logistic networks. They are in particular open transport systems and differ in several characteristics from other logistic networks such as industrial distribution and supply chain networks. Characteristics of networks of parcel service providers are (Bretzke 2008, p.312):

- *Multi-directionality:* parcels flow in both incoming and outgoing directions of a network node
- *Many-to-Many structure:* parcels can flow from any node to any other node
- *Paired transport:* loaded trucks in both directions to minimize empty journeys
- *Interrupted Transport chain:* parcel transport consists of several transport stages
- *Multi-user-system:* anyone can use parcel service providers
- *No safety stock:* since every delivery is unique it is not possible to hold a safety stock

The network of each parcel service provider has its own individual structure, depending on its business model. For example, some parcel service provider focus more on the B2B others more on the C2C or B2C segment. But all networks are based on the hub-and-spoke and direct-transport system and represent hybrid types of those. The network of a parcel service provider consists of two basic elements: Network nodes and the transport relations in between. Network nodes can represent hubs, depots, sub-depots and parcel-shops. The parcel delivery process is partitioned in three parts:

Pre-carriage, main carriage and on-carriage.

The offered services of parcel service providers such as wide geographic coverage, reliability, short delivery time and track and trace differ hardly noticeable, and don't represent a unique selling point anymore (Bretzke 2008, p. 308). To keep and gain new customers it is important for parcel service providers to offer flexible delivery at an acceptable price (Niehaus 2005). This forces the parcel service providers to run their networks as efficient as possible in order to stay profitable. Increasing quantity of parcels can overburden the existing networks of parcel service providers and lead rapidly to inefficiency.

3. LITERATURE REVIEW

The following research can be found on modeling and simulation of parcel and postal networks:

(Larsen 2003) describes a discrete event simulation model for the postal industry to improve the performance of postal networks. He presents an extensive Postal Network Planner for analysis of the postal logistic chain. How the postal processes are exactly modelled with the discrete event paradigm is not clearly described.

The following papers describe isolated simulation models that focus on a single transfer point of a parcel or postal network.

(Cornett and Miller 1996) present the development of a flexible data driven model of the aircraft operations at the United Parcel Service Louisville Air Park.

(White et al. 2002) present an object-oriented paradigm for simulating postal distribution centers. They describe how discrete-event simulation is an established tool for the design and management of large-scale mail sortation and distribution systems.

(Swip and Lee 1991) present the application of an integrated modeling tool on a United Parcel Service reload operation.

(Tuan and Nee 1969) present a simulation program with the purpose to provide the U.S. Post Office Department with a computer model for evaluating the relative merits of alternative nonpriority mail processing, handling, and transportation plans.

(Fedorko, Weiszer and Borzecky 2012) present a simulation model of the process of package sorting at a courier service.

This paper presents the modeling of a network of a parcel service provider using a mesoscopic simulation modeling approach.

4. MESOSCOPIC SIMULATION MODEL OF A PARCEL SERVICE PROVIDER'S NETWORK

(Reggelin 2011; Reggelin, Tolujew, 2011) described a mesoscopic modeling and simulation method to support a quick and effective execution of analysis and planning tasks in the field of logistics networks. The basis for mesoscopic simulation is to model the movement of objects as piecewise constant flow rates. The beginning, ending or changing of a flow rate is controlled by events that occur in a model. This concept is employed in the discrete rate simulation paradigm, which is implemented in the simulation software ExtendSim (Krahl 2009; Damiron and Nastasi 2008). The resulting linearity of piecewise constant flow rates enables event scheduling which leads to high computational performance. To increase the level of detail a mesoscopic model also uses impulse-like flows as known from object based simulation. This is necessary to enable the modeling of bundled movements of logistic objects such as the transport of goods in a truck. Thus, mesoscopic models have hybrid characteristics (Reggelin, Tolujew, 2011).

This paper presents a mesoscopic simulation model of a parcel network. Figure 1 illustrates the conceptual model of the network structure.

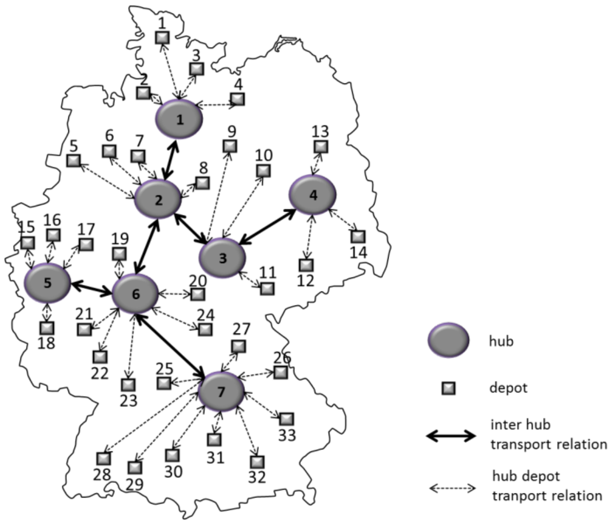

Figure 1: Network of a parcel service provider

The main components are hubs and depots. Each depot has a transport relation to a regional hub. There are also several inter-hub transport relations due to the fact that the parcel service provider operates at a high level of consolidation. The focus of this model is on the main carriages and transfer points in between. Thus, the system boundaries are the depots. All operations that take place on the per- and on-carriage are not represented in the model. Instead, a source and sink is directly connected to each depot to send and receive parcels. Figure 1 illustrates a number above each depts. The numbers represent mailing addresses which clearly identify each depot.

The flow objects are trucks and parcels. The movements of trucks are modeled as impulse-like flows. The movement of parcels within the transfer points (hub and depots) are modeled on an aggregated level as piecewise constant flow rates.

The model control works similar to a real parcel network. Each parcel that is send into the model has an attribute which represents the mailing address. The parcels are sent through the network and delivered to the correct depot by means of the mailing address.

Large depots represent complex production systems. Since the modeling takes place on a mesoscopic level the model doesn´t represent all processes. Figure 2 illustrates the conceptual model of a depot. The colored arrows show which simulation paradigm is used to model the movements of flow objects between the process stations. The depots represent the system boundary, therefore it´s not necessary to model a complete sorting process, because all delivered parcels go directly to the connected sink. Parcels entering the simulation model from the source are scanned whether it´s regional or supra-regional delivery. The regional deliveries go directly to the connected sink. The supra-regional deliveries are loaded into truck and transported to the connected hub.

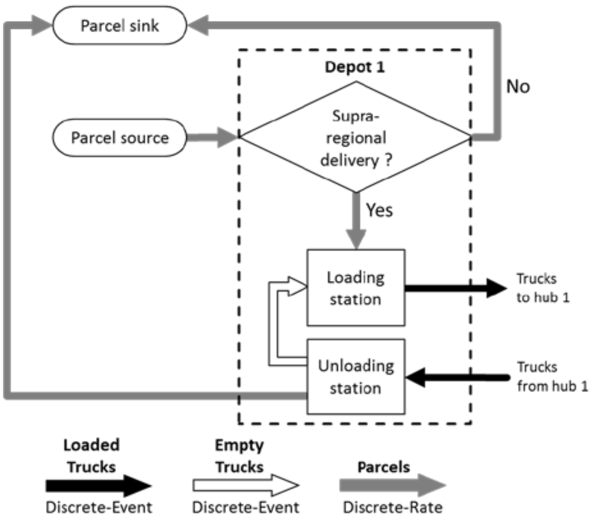

Figure 2: Conceptual model of a depot

Figure 3 illustrates the conceptual model of a hub. A hub represents a complex production system. Since the modeling takes place on a mesoscopic level the model doesn´t represent all processes but is reduced to the unloading, loading and sorting processes. In Figure 2 the colored arrows show which simulation paradigm is used to model the movements of flow objects between the process stations.

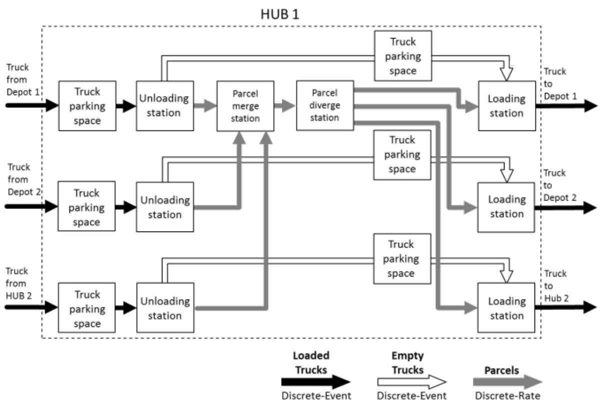

Figure 3: Conceptual model of a hub

The model is designed to allow flexible adjustments of the system parameters in external data files. The main parameters to adjust the model are:

- *Handling rates of hubs*
- *Handling rates of depots*
- *Capacity of the trucks*
- *Quantity of trucks on transport relations*
- *Speed of trucks*
- *Length of the transport relations*

The quantities and distributions of parcels entering the model are also adjusted in external data files. Figure 4 illustrates a principle data file for adjustments of parcels. Arrival depot and Departure depot are the attributes attached to every parcel that enters the model.

Quantity of parcels	Arrival depot	Departure depot
124	7	1
244	3	1
365	6	1
144	12	1

Figure 4: Parcel quantity and distribution adjustment

During simulation, various performance data are collected and reported in multiple output reports. The model collects detailed performance data regarding the throughput of all hubs and depots as well as the running time of all parcels.

5. HIERARCHICAL MESOSCOPIC SIMULATION MODEL OF A PARCEL SERVICE PROVIDER´S NETWORK

A central question in modeling and simulation is the choice of level of detail of the model (Balci 1989). Finding the right level of detail is even for experienced simulation engineers not a trivial task. A high level of detail leads to a time consuming creating phase and a long simulation run time. A low level of detail involves the risk of modeling system components inaccurately, which can lead to invalid simulation results or reduce the adjustability of system parameters (Wenzel et al. 2008, p.128). This paper presents an approach for hierarchical mesoscopic modeling and simulation in order to meet the problem described above (Lulay 1998).

The main idea of a hierarchical mesoscopic simulation is that at first a system is modeled on a mesoscopic level of detail. Afterwards specific components of the system that have to be analyzed in more detail are modeled another time with a higher level of detail, which is still within the mesoscopic level. These sub-models are connected through switches with the main model. Thus, it is possible to manually switch the hierarchy and therefore the level of detail. Modelling a system component several times on different levels of detail leads to a time consuming creation and implementation phase. But for extensive simulation experiments hierarchical modelling and simulation can be beneficial. For less detailed experiments the hierarchical system components operate on the hierarchy with lower level of detail. That leads to a relatively fast run time of the simulation model. Only for detailed experiments the system components operate on the hierarchy with higher level of detail. For the expansion of the analysis capabilities of the simulation model presented in section 4 the mesoscopic hierarchical modelling and simulation approach was applied. Therefore, the hubs were modeled a second time on a higher level of detail. Figure 5 illustrates the conceptual model of a hub on a higher level of detail. Compared to the hub illustrated by Figure 3 it represents more processes. Since the movements of parcels between the process stations are modeled as piecewise constant flow rates the level of detail is still on the mesoscopic level.

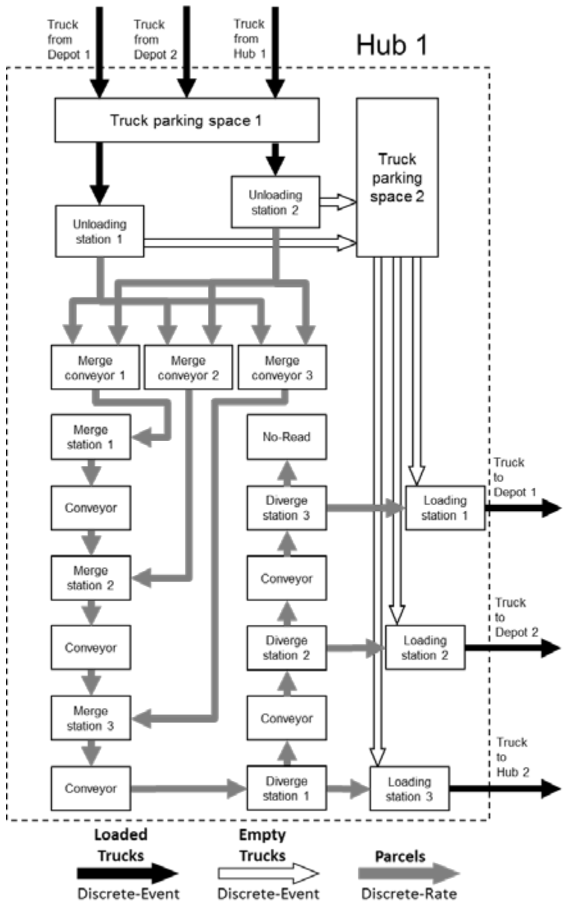

Figure 5: Conceptual model of a hub

This level of detail allows analyzing specific components of the hub. For example, the impact of a damaged or slow running conveyor is analyzable. The main parameters to adjust the hub are:

- *Loading rate*
- *Unloading rate*
- *Speed of parcel sorter*
- *Length of parcel sorter*
- *Capacity and speed of feeding lines*

Figure 6 illustrates the principle concept of a hub with different levels of detail. Manually can be set whether a hub operates on a hierarchy with a lower or hierarchy with a higher level of detail. The hierarchy that doesn´t maintain a transport relation can´t receive any loaded trucks. Thus, no operations will take place on this hierarchy that burden the system.

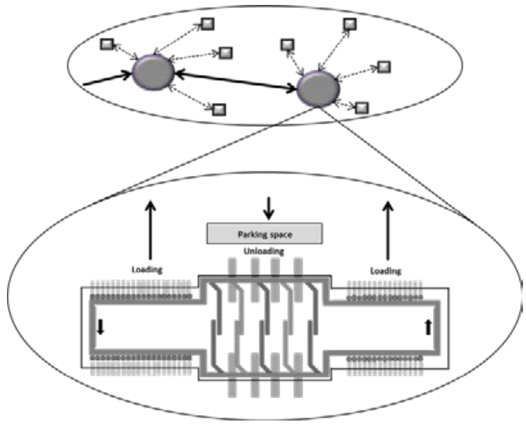

Figure 6: Hub hierarchies

6. EXPERIMENTAL RESULTS

The extensive measurements that are taken during the simulation runs allow specific analysis of the system behavior. In this section a few examples of explorative and user configurable graphs will be given to show the merits of the simulation model as a tool for analyzing the behavior of a parcel network under various conditions. In a sensitivity analysis the reaction of a parcel network to changing parameters are investigated. Therefore, the simulation results of a basis model setting are compared to results of individual parameter variations.

Figure 7 illustrates the percentage of parcels which need less than 48 hours for delivering.

Figure 7: Analysis of performance data – delivery time

The quantity of parcels was increased by 10 and 20 percent and the simulation results compared to the basis model setting. In conclusion, it is obvious that the parcel network is not able to process the increasing quantity within an acceptable period of time. The network performance clearly decreased.

Figure 8 illustrates the mean delivery time on specific delivery routes. The simulation results of the basis setting are compared to the results of the settings with a quantity of parcels increased by 10 and 20 percent. The results show that all delivery routes have an increased mean delivery time for the increasing quantity of parcels. This analysis approach is useful to discover critical delivery routes that may emerge as the quantity of parcels increase.

The hubs of the simulation model operated on a lower level of detail to gain the simulation results presented above. The following example shows the use of a higher level of detail. Therefore, hub 1 operated on the hierarchy with the higher level of detail during the simulation runs.

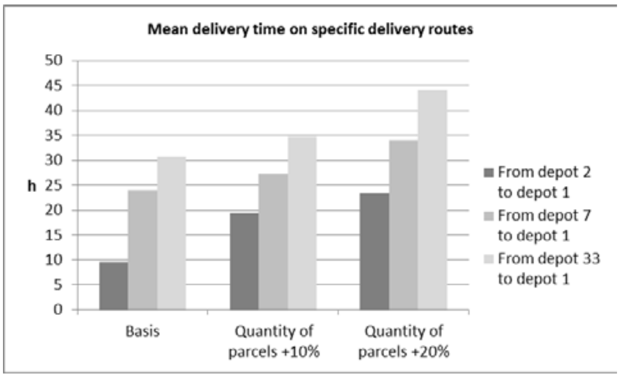

Figure 8: Analysis of performance data – parcel routes

Figure 9 illustrates the throughput of hub 1. The graph shows how the daily throughput of hub 1 changes as the speed of the parcel sorter is reduced. Therefore, the parameter speed of parcel sorter is reduced by 10 and 20 percent. The simulation results are compared to the basis setting of the model. During a simulation run every day parcels departure from the depots expect for Sundays. In Figure 9 Sunday is presented by Day 7, the parcel network doesn´t operate on that day and parcels don´t departure from the depots. It is obvious that the reduction of speed of the parcel sorter decreases the daily throughput of hub 1.

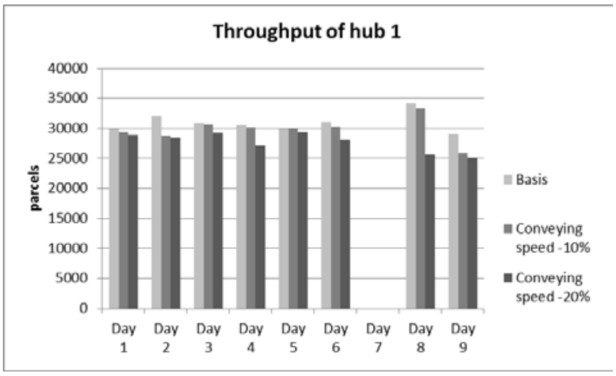

Figure 9: Analysis of performance data – throughput

This analysis approach is useful for daily operations. For example, it allows analyzing the impact of incidents on parcel sorters that may occur during the hub operations. Thus, short-term measures can be taken more accurately.

7. SUMMARY

This paper presented a simulation model of a parcel service provider´s network. A mesoscopic modeling and simulation approach is applied to create a model on a sufficient level of detail that allows quick simulation runs and analyses to support planning tasks. Furthermore, a hierarchical modeling and simulation approach is applied to allow analyses of specific system components in order to support daily operations. The model is flexibly configurable and collects various performance data during simulation runs. Several examples of simulation results were presented to give an insight about the analytical capability of the simulation model. Finding bottlenecks and weak points in the parcel network leads to the next step of taking appropriate measurements. For this task, the simulation model can be used to create operating curves finding the ideal setting for the various model parameters.

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A DEMAND SHIFTING ALGORITHM TO SMOOTH THE PEAKS AT AIRPORT SECURITY SCREENING CHECKPOINT (SSC) FACILITIES

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ABSTRACT
Airports are considered complex systems since they must coordinate the right availability of resources with an unknown demand in a context with poor predictability and fierce competition. This paper illustrates a solution to improve the passenger flow experience through the Security Screening Checkpoint (SSC) by minimizing the queuing time and, in some cases, transforming the queuing time into waiting time, without requiring investments in additional airport screening infrastructure. The main idea is to minimize the passenger queuing time at the SSC by means of a right balance between screening airport capacity and passenger demand under a time stamp constraint, applied in the form of passenger slot assignment. Demand Shifting Algorithms (DSA) is one of the key approaches that could minimize queues in the screening area while also avoiding idleness capacities, thus providing a cost-saving screening service to the airport and a good quality service to passengers.

Keywords: workstation design, work measurement, ergonomics, decision support system

1. INTRODUCTION

Despite recent developments in screening technology and the increased ability to detect threats, the average amount of time required to screen a passenger still remains a concern.

It is well accepted that an increment in the amount of passengers at the SSC entails drastically-longer queuing times, increased screening device operational costs, and a larger task-force of security personnel. Moreover, these effects are magnified as the number of travelers increase each year, along with their impatience and dissatisfaction with the ever-changing airport security procedures.

Due to the impact on the quality service to passengers, the managing and maintenance costs and the impact on the scheduled departure time, airports have analyzed different alternatives to improve:

- The ability of new screening devices to detect threats
- The flow of passengers through the airport security screening checkpoint

The objective of the simulation model implemented is to improve the passenger flow experience through the SSC by minimizing the queuing time and, in some cases, transforming the queuing time into waiting time, without the need for investing in extra airport screening infrastructure.

Several papers have been published which could be considered to be related with the slot-screening assignment process. However, no work has yet been reported with the scope of the present proposal as regards the slot screening assignment, aimed at avoiding idleness and capacity deficit of screening resources on the airport side, and providing a service to change queuing into waiting on the passenger side.

Our previous work (Nosedal 2014) included a description of tree functional prototypes based on innovative approaches in some ways similar to the new slot-assignment approach proposed. These solutions have been implemented in some airports and represent the current state of the art.

Intelligent Transport Systems (ITS) try to avoid extra investments in infrastructures while satisfying extra demands through the enhanced management of the current resources and information technologies (Piera 2014).

The decision-support tool implemented fits ITS philosophy: it reduces passenger queuing time by means of a proper balance between screening airport capacity and passenger demand under a time stamp constraint. So, instead of acquiring more screening infrastructure, the approach will consist of better management of the current screening facilities by smoothing the peak demands through a reward mechanism that allows idle capacities to be avoided.

A new paradigm of balancing screening capacity with passenger queuing time will be described, aimed at a range of different operational contexts, and taking into account:

- A stochastic model for passenger preferences: different arrival probability distributions will be considered according to different passenger profiles

- Scaling the airport capacity taking into account the demand

The intended result is to provide an optimal strategy to smooth the peak congestion of passenger queuing at the screening checkpoint while also minimizing idle capacity (and in consequence, operational costs).

The key contribution of screening slot assignment is the efficient and effective use of available screening resources and a significant time reduction for passengers at the airport.

The proposed new paradigm for the screening slot assignment does not take the following areas into account:

- There is a consensus that using multiple levels of screening can result in a significantly more efficient security system. Thus there are some works on the assignation of passengers to different screening lanes that include a classification of passengers into different security classes. In (McLay 2009, Lee 2009, Nikolaev 2007) different discrete optimization models are described in which passenger classification is performed when perceived risk levels of passengers are known only upon check-in.

- Methods for structuring the optimal use of detection device technologies in security checkpoint screening, given specified cost and capacity constraints. In (Feng 2009, McLay 2007) several methods have been proposed: New Rx or ADM technologies.

2. PROBLEM DESCRIPTION

The demand for screening capacity fluctuates according to the programmed amount of flights departing in the immediate future, the passenger arrival pattern, and behavior during the screening process (Figure 1 and Figure 2).

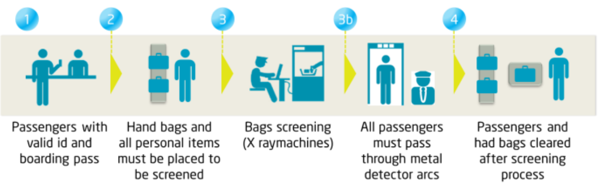

Figure 1. Passenger screening process

As well, after arriving at the airport but before the screening process, passengers experience queuing, particularly during peaks of demand.

During this phase passengers are “trapped” in the system without a chance to employ their time. This situation is concerning and has direct impact on passenger quality perception (Figure 2).

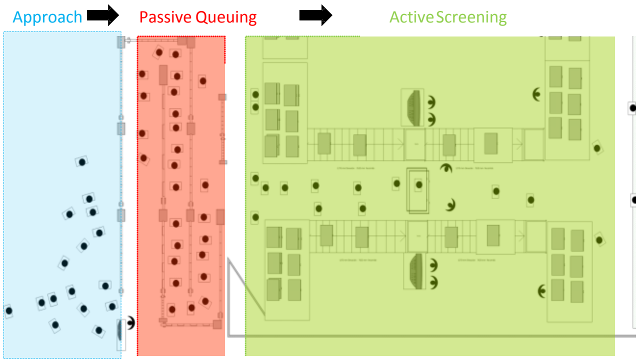

Figure 2: Queuing before security screening

Assuming the performance of security staff is quite constant (fatigue is not considered), the demand fluctuation can be modeled by a deterministic aspect which corresponds to the programmed flights, and a stochastic aspect concerning the passenger arrival pattern, which is sometimes correlated with flight characteristics.

In Figure 3, the random aspects of passenger arrival preferences are illustrated by means of empirical Cumulative Arrival Curves.

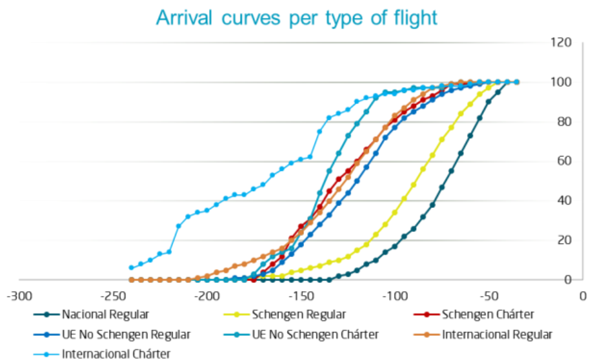

Figure 3: Empirical cumulative passenger arrival curves per type of flight

From this figure, it is possible to estimate the expected amount of passengers that will arrive, for a specific value or interval of arrival earliness.

Once passengers are in the terminal, there is also a random dwell time until they move to the SSC which depends on the type of check-in (Figure 4).

The stochastic model implemented considers different rates for each option correlated with certain relevant flight information such as the destination, departure time and flight occupancy.

Thus, an early flight with a business capital as destination (i.e. Brussels) will tend to show a higher rate of online check-in passengers than a flight to a tourist destination.

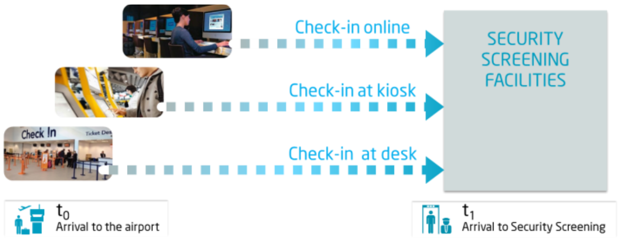

Figure 4. Passenger characterization

The combination of the different arrival pattern behaviors and type of check-in, produces a fluctuating demand that leads to idle capacity (Figure 5) during certain time period peaks and to the generation of queues during the peak periods (Figure 6), since sometimes the arrival of passengers exceeds the screening capacity.

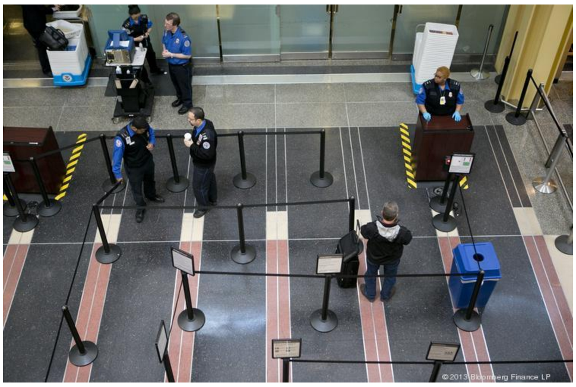

Figure 5: SSC Idle capacity periods between peaks of demand

Figure 6: Passenger queuing during peaks of demand at SSC

The problem of assigning passengers to a specific time window (*i.e.* Slot) to cross the SSC without queuing requires the proper modeling of the slot availability (Figure 7) which is dependent on prior passenger behaviors.

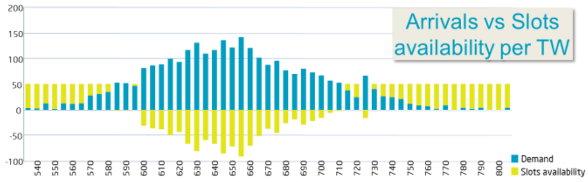

Figure 7. Demand vs capacity at SSC

The availability of slots is computed by means of the capacity (i.e. maximum workload possible in a time frame) and the total demand expected for each time window. The dark-colored bars represent the expected demand (always positive), while the light-colored bars show the availability. Thus, the light bars in the negative area represent the capacity shortages to be avoided by allocating passenger to the idle periods (i.e. light-colored bars in the positive area).

3. INPUT DATA AND THE ALGORITHM

The data inputs required for the causal simulation model implemented are summarized in Figure 8.

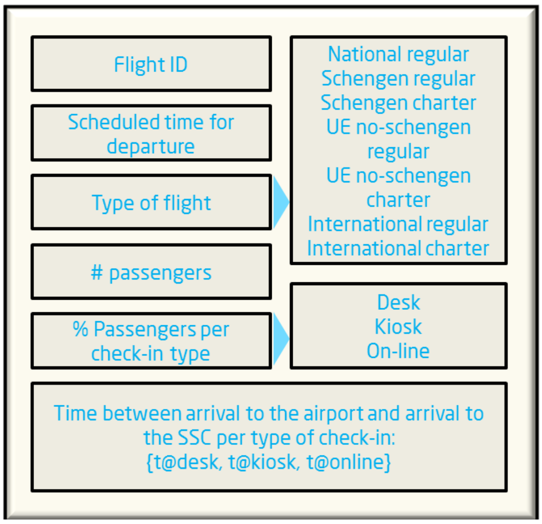

Figure 8: Data inputs to the algorithm

The input data are pre-processed according to the steps indicated in Figure 9.

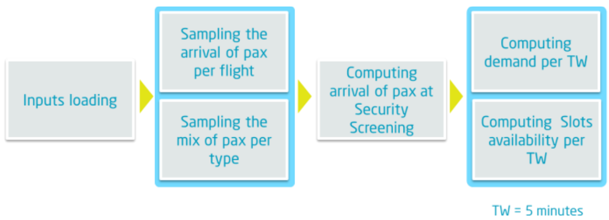

Figure 9: Data pre-processing steps

The outputs of the pre-processing allow the identification of demand peaks and compute the availability of Time Windows in the whole timeframe of the study (i.e. 3 hours or a complete day).

Based on these results the redistribution of the demand can be addressed. Thus, the outputs obtained after the pre-processing of the data allow the parameterization of the model. These outputs are summarized and illustrated in Figure 10.

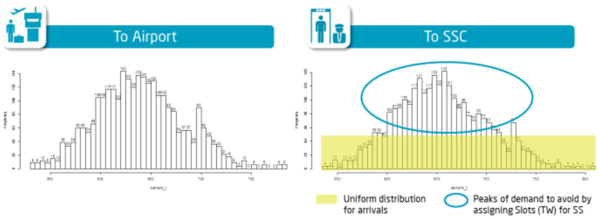

Figure 10: Outputs after the pre processing

On the left is the expected distribution of arrivals at the airport, and on the right, the corresponding demand at the SSC, with the peak to be redistributed being indicated by the ring, and the rectangular shaded area representing the desired demand distribution (i.e. uniform during the time frame and defined by the maximum workload allowed).

In order to measure the quality of the solution being developed, two indicators have been defined, both seeking to evaluate the impact of the solution on the quality service factor to the passenger.

By defining the passenger preference and adjusted earliness as:

Pax preference = time stamp for arrival at the SSC (pax arrives in a preferred slot)

Adjusted Earliness (AE) = (Scheduled Time for Departure – Slot proposed), that must be always bigger than 30 min

Two different KPIs have been designed:

Earliness = Scheduled Time for Departure – Slot preferred, that must be always bigger than 30 min

Pax preference deviation (PPD) = Slot proposed – Slot preferred

The passenger slot assignation has the form of a generic scheduled problem, and thus it can be formalized as a Constraint Satisfaction Problem, the structure relating the feasible Time Windows (i.e. slots) to the restrictions to balance the demand is illustrated as a matrix in the Figure 11.

Pax	TW1	TW2	TW3	...	TWn	Restrictions
P1	F(PPD, STD) @ P1					Sum =1
P2		F(PPD, STD) @ P2				Sum =1
P3						Sum =1
. . .						Sum =1
Pm	F(PPD, STD) @ Pm					Sum =1
Restrictions	Sum < = L	Sum < = L	Sum < = L		Sum < = L	

Where
L = maximum Load or demand allowed per TW
PPD = Pax preference deviation
STD = Flight scheduled time for departure

Figure 11: DSA in the Constraint Satisfaction Problem structure

The set of capacity constraints (*i.e.* work load defined as L) must be satisfied for all the time windows (columns 1 to n in the matrix) and the set of allocations must be restricted to one per passenger (*i.e.* the restrictions in the last column of the matrix).

Note also that the allocation is computed in the interval restricted by the Scheduled Time of Departure (STD) and the passenger preferences (PPD).

4. CASE STUDY AND RESULTS

Reward mechanisms to engage passengers in the use of slots to cross the SSC are highly dependent on the airport layout. Thus, centralized SSC layouts are usually placed before the commercial area of the airport, while in de-centralized layouts the commercial area is placed before the SSC.

The algorithm developed can be applied to centralized SSC layouts (Figure 12) or de-centralized SSC layouts (Figure 13).

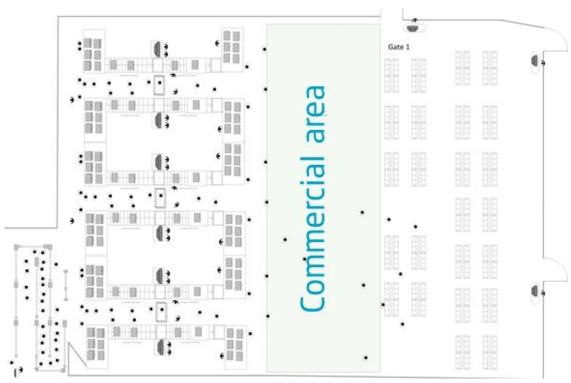

Figure 12: Centralized SSC facilities layout

Figure 13: Decentralized SSC facilities layout

To avoid idle capacity or capacity deficit, as illustrated in Figure 5 and Figure 6, the slot assignment service should consider new efficient mechanisms and layout redesign to allow the use of screening resources by normal passengers when there are no-show passengers in the slot assignment services, and also to allow the use of screening resources assigned to the general queue by slot-assigned passengers to preserve zero queuing time in the slot service.

In Figure 14 a different approach has been represented based on a layout redesign (Buil 2011) in which passengers with a slot assigned can access any screening facility.

This approach provides a natural capacity/demand mechanism in which the quality of service for slot passengers can be supported.

The implementation of the slot assignment service will require an analysis work to determine both the technologies and the layout re-design that will allow a flexible and efficient assignation of screening resources.

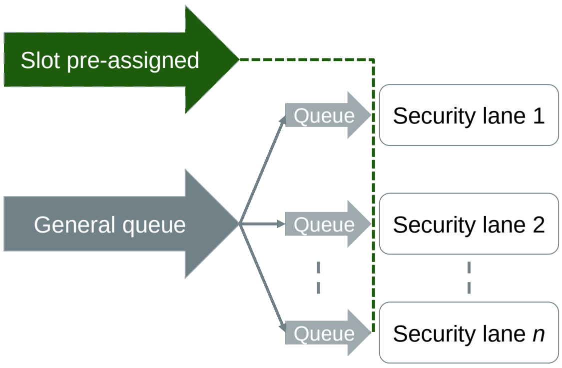

Figure 14: Layout redesign

In order to test the quality of the DSA results, it has been used a realistic scenario provided by AEGEAN airlines.

The scenario was tested assuming in the first case a Centralized layout. The scenario and results are summarized in Figure 15, in which it can be observed that the peak of 330 pax/TW has been reduced to 228 pax/TW.

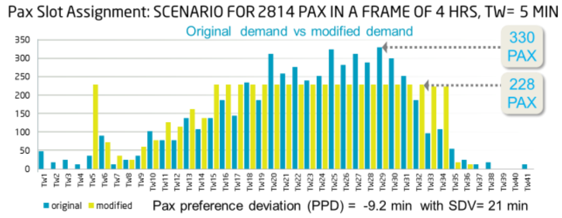

Figure 15: Original demand vs modified demand after passenger slot assignment (centralized)

The second analysis was performed assuming a decentralized layout. Figure 16 presents the expected arrival pattern at SSC.

As can be observed, the scenario can be separated into 4 time frames, as indicated in the figure.

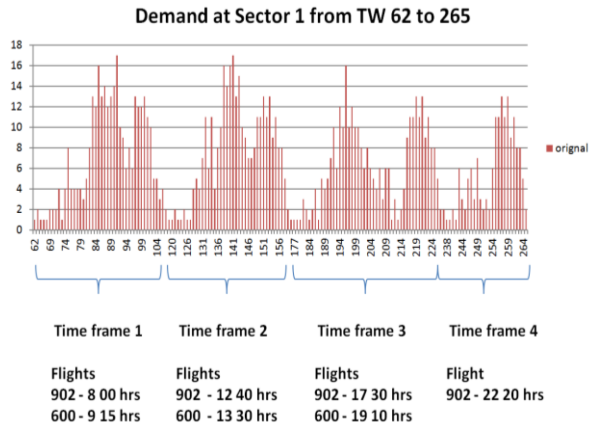

Figure 16: Original demand before slot assignment (decentralized)

For time frame 1, the original demand vs. the modified demand is illustrated in Figure 17.

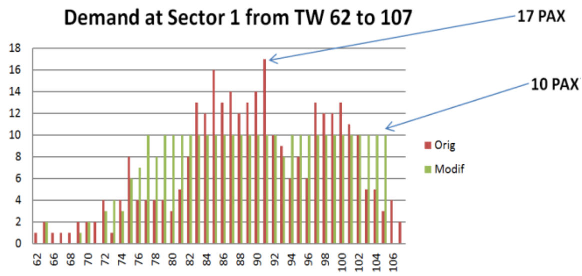

Figure 17: Solution obtained for time frame 1

After the slot assignment, the maximum workload is reduced by 41 %, (from 17 to 10 pax in the busiest TW) meaning that the workload is better balanced, uniformly distributed across almost the entire time frame 1 (light color bars).

In terms of KPIs, the solution obtained for time frame 1 addresses the demand peak redistribution with an average PPD of -0.25 min and standard deviation of 24.4 minutes, with the minimal earliness being granted in all cases.

For the full scenario (Figure 16), the proposed allocation of TW (i.e. Slots) provides a solution to decrease the idle periods by redistributing the passenger arrival. The peaks of demand are reduced between 30 and 40 %.

The overall comparison of original vs. modified demand is presented in Figure 18.

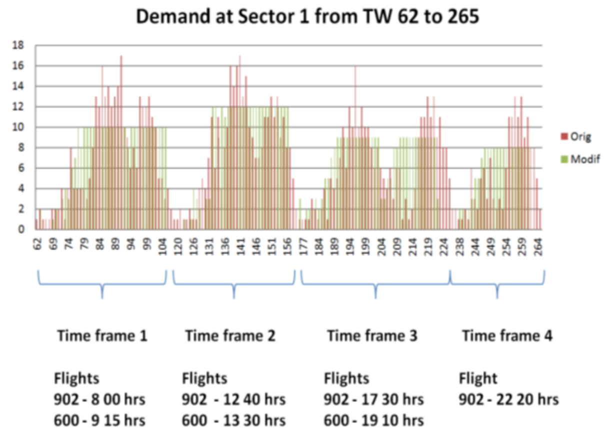

Figure 18: Original and modified demand pattern for the complete time frame (decentralized)

5. CONCLUSIONS

The solution proposed will help to better manage not only the queues at security screening but also the resources being used as one of the aims of the algorithm is to distribute the demand across the overall capacity (as much as possible).

The algorithm developed relies on a socio-technological modeling approach (Nosedal 2014) to influence human behavior under a win-to-win approach in which:

- Passengers can have more control over the process as they will be able to better manage their time, which positively impacts the passenger buy-in
- The airport will avoid non-added-value operations such as idle resources at the security screening check-point
- The airline will be able to have better control of the location of their passengers in different time-lines

Passenger preferences may depend on different aspects such as cultural characteristics, type of travel, and ground access to the airport, among others.

The model developed must be properly parameterized to the boundary conditions of each airport. Thus field work is required in order to have a realistic prediction of the demand, together with a sample of passenger profiles.

The present socio-technical modeling approach, relying mainly on influence variables, can be extended with a system engineering approach in which control variables would allow fine-tuning of the times passengers wait at the kiosk or check-in counter.

It is expected that the right combination of control variables and influence variables could provide a new gap to integrate passengers in the expected time-stamp flow of activities considering available resource capacity.

Reward mechanisms are essential to engage passengers with the slot assignment:

- Priority boarding
- Free wi-fi
- Airlines' reward cards (extra miles)...

These reward mechanisms are independent of the layout of the airport (*i.e.* centralized or decentralized SSC). However, particular reward mechanisms should be properly designed by taking into account the facilities in the terminal.

5.1. Potential impacts and benefits

The proposed solution impacts mainly the passenger, airport, airline and the third party responsible for the airport security screening process.

The assignment of slots at security screening control will help better manage the security control resources as the peak congestions will be smoothed and the idle capacity decreased. This will increase the availability of security control resources and the management of passengers flow at the security control which will reduce the delays due to security control.

A reduction of the delays due to security control will increase turnaround punctuality (*i.e.* avoiding delays because of late passengers at gates). As well, the assignment of slots to pass through security screening will let airports (or the third party responsible for the security process) better manage the security resources, by smoothing the congestion peaks and reducing idle capacity. This improved management of resources will imply a reduction of the number of resources needed (including personnel), and thus could allow a reduction of personnel at the security point, meaning a reduction in the operating costs.

However, the current state of definition of the solution does not permit a solid cost benefit analysis. The areas directly impacted by the solution are Airport Terminal Operation and the particular stakeholder being mainly benefited from the implementation of this solution will depend mainly on the implementation itself. Different stakeholders may be able to implement the solution and accept the responsibility for it.

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MULTIVARIATE FREIGHT DATA GENERATION FOR ASSESSING CUSTOMS' RISK EVALUATION TOOLS

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ABSTRACT

Nowadays, enormous volumes of goods are transported all over the world in containers, mostly in container ships. It is a formidable task to ensure that no illegal activities such as smuggling of prohibited goods that violate customs rules and regulations occur. Many indications on potential smuggling can be found just by scrutinizing all documentation that follows these containers, and the goods within them. In the EU's container security project (CONTAIN), one among many important tasks has been to present a prototype document analysis system for customs, called CustAware, to find these indications. The standardized way to submit necessary information to customs today is via Entry Summary Declarations (ENS) messages, normally in electronic form. We have developed a simulator (the ENS-Simulator) that generates a high flow of realistic customs-oriented data contained in such ENS messages. By adding a much smaller amount of ENS messages that could indicate peculiar shipments the data is used to train CustAware to find the needles (indications on strange activities) in the haystack (all normal ENS messages). In this paper, we describe the process of generating a high rate of normal messages in a realistic way, to represent a typical message inflow at a large customs risk assessment and management centre.

Keywords: container traffic, multivariate data generation

1. INTRODUCTION

In today's global world, enormous amounts of goods are transported along supply chains between producers and consumers. Of particular importance is the shipping container traffic on the oceans and between sea and inland ports, accounting for about 70% of all cargo transport. Inland ports often work as shunting and reloading sites between different means of transport such as trucks, barges and trains. To ensure that all steps from sender ("consignor") to receiver ("consignee") function smoothly; supply chain security therefore is a subject that continuously attracts more attention. The challenge is to use the available data and information in order to detect and prevent threats to the supply chain.

There is a lot of data available in logistics that could potentially be used for security purposes. Different stakeholders have different needs of control of the container and goods flow. Business partners must exchange commercial and logistic information, also known as Business to Business (B2B) information, in order to guarantee reliable, economically profitable and efficient goods transfer as well as secure transfer of payment. What is basically important is to satisfy the needs of the consignors and consignees of the goods. There are freight forwarders, port operators, shipping lines, truck, barge and train companies and different kinds of brokers involved in the process with the common goal to satisfy those needs.

Customs' needs are largely different from business partners' needs. Customs' task is to facilitate trade and collect customs duties, as well as to control the flow of goods so no illegal or hazardous goods enter national borders. The information customs needs is partly requested from the business side, known as Business to Authority (B2A) information, and has some overlap with B2B information. They also need other types of information, such that can be provided by intelligence services like customs' own confidential sources, nationally and internationally, police, military and coast guard.

Threats to the supply chain of relevance for Europe can be divided into different categories:

- Threats towards Europe through the supply chain. This encompasses smuggling of illegal and counterfeit goods, pirate copies, and smuggling of dangerous substances and weapons in order to perform a terrorist attack inside Europe.
- Threats towards the supply chain itself. This could be theft and intrusions into ports and terminals or terrorist attacks against supply chain infrastructure.

- Natural disasters and accidents. This category is characterized by the lack of an antagonistic opponent.

In order to meet the challenges posed to Europe's supply chain, the European Commission (EC) included a large portfolio of supply chain security projects in the EU's Seventh Framework Programme for Research (FP7 2014) agenda. In this paper, we describe parts of the CONTAIN project, which started in October 2011 and had its final demonstrations in the first quarter of 2015. CONTAIN deals with several aspects of container security, from advanced sensors for positioning and localization to shared infrastructure and message formats for information sharing to decision support systems (DSS). Addressing the first of the threats above, CONTAIN has developed the CustAware system (Brynielsson, Westman, and Svenson 2015), which aims to provide customs inspectors with a DSS that enables them to determine, which containers to inspect manually and/or using sensors (*scanning*) based on all available information. There is a strong need for systems like this, since resource constraints put a limit on the number of containers that are inspected, especially in large ports where it is only possible to inspect a few percent of all containers that pass through. Choosing *which* containers to inspect (*targeting*) is one of the most important tasks for customs.

CustAware will enable customs inspectors to work more dynamically with the risk profiles that they are currently using, and shows how they could update the models continuously based on feedback from inspections and police investigations. In order to test this decision support tool, there is a need for realistic data. However, it is normally difficult to get real B2B (Business to Business) or B2A (Business to Authorities) data for evaluation purposes. B2B data is often commercially proprietary and only available for collaborating companies. B2A data can most often not be shared by customs to other authorities or companies for confidentiality reasons. Businesses must be able to rely on customs keeping their data secure in order to be willing to share their data with them. Customs themselves must be guaranteed that the data and methodology they use for finding indicators for illegal trade are not revealed.

Hence, in order to test CustAware and other tools developed in the CONTAIN project, we need a simulator that can be used to provide data that is similar to real B2A data. In this paper, we describe the simulator developed for this purpose.

An important part of the CONTAIN project is the evaluation of results. The technological advances developed in CONTAIN presented in the final demonstrations are used as the basis for an assessment and evaluation procedure, following the procedure developed by (Asp, Carling, Hunstad, Johansson, Johansson, Nilsson, and Waern 2008).

The present paper contributes both to the development of CustAware and its evaluation. In order to develop the methods and procedures for updating the risk profiles, it is necessary to have realistic data to work with. The outputs of the simulator can also be used to evaluate the effectiveness of the procedures for dynamic risk profile adaptation that are developed in CONTAIN.

2. RELATED WORK

Modelling and simulation (M&S) based methods have been used in marine environments such as harbours in order to support decision makers in operational procedures. Tremori, Massei, Madeo, and Reverberi (2013) provide an overview on a combined approach using M&S and data fusion techniques to analyse complex maritime scenarios involving asymmetric threats. Longo (2010) uses simulation and design of experiments techniques to develop analytical models that express the operational efficiency as function of critical parameters of the inspection process.

As mentioned in the introduction, EU is currently funding a large number of projects addressing supply chain security. In this section, we briefly describe some of these projects and how the work presented here complements them.

SAFEPOST, EUROSKY and CASSANDRA address the first risk mentioned above (threats towards Europe using the supply chain). SAFEPOST deals with postal security and is developing an information-sharing platform and advanced sensors that will enable faster and more accurate detection of dangerous substances in parcels. The EUROSKY project deals with similar matters as CONTAIN, but for air cargo transport instead of shipping containers, while CASSANDRA also focuses on shipping containers. In CASSANDRA, the main emphasis is on the data pipeline concepts, which will enable customs to use business information in a better way.

The second risk (threats towards the supply chain itself) is also the subject of a number of projects, amongst others SUPPORT, ARENA, PROTECTRAIL, and TASS. The subject of SUPPORT is port security and in particular perimeter security for ports using advanced sensors and information fusion systems. PROTECTRAIL and TASS are devoted to railroad and airport security, respectively, while ARENA deals with securing transports in motion, studying both ship and truck security.

Finally, the EC is also looking into ways of handling natural disasters and accidents, for example in the Demonstration Programme Driver. The Demonstration Programme CORE also aims to collect the results from all previous supply chain security projects and show how everything fits together.

In some of these projects, simulators have been used to construct synthetic data to be used to test the developed tools. However, none of them has developed a simulator for generating freight data. To our knowledge, the present work is the first that deals with generating multivariate freight data to enable realistic evaluation of supply chain security systems.

3. CONTAINER SECURITY DATA AND INFORMATION

Different types of information are generated before and during container transport. For keeping track of physical status of the container and the goods therein, electronic door seals, as well as, e.g., light, temperature, humidity and CO2 sensors can be placed on or within containers to detect when the container door is opened, or to detect anomalous changes of the physical parameters measured. Alarms or logs from such detectors can be used to indicate abnormal events from the container, e.g., cooling failure for a container with such functionality, or attempts to break into and smuggle items, animals or people. Furthermore, positioning devices can be used to keep track of a container's location. One of the motivations for this is to log the positions and times during land transport for logistics as well as security purposes. Unjustified stops or deviations from planned truck routes can indicate suspicious activities. Information messages are also routinely generated at certain events; from first load to final unload, during fully normal logistic handling of a container along its route. This is done to log its transport status, and to transfer necessary documentation on its contents and planned final route. Adherence to national and European level work laws can also be verified by checking such log information.

3.1. Information for Customs

Since the CONTAIN project is oriented towards customs' needs, we have focused on how to simulate the requested B2A information exchange in the container handling process, more specifically that requested by customs. Today, this B2A information is most often submitted as so-called Entry Summary Declaration (ENS) messages (European Customs Information Portal 2013); a pre-arrival information sent to the customs authority for all goods entering the EU, according to EU legislation (Taxation and Customs Union - European Commission 2006).

Within the EU, an ENS should be lodged at the first port of entry into the EU by the carrier or by an agent acting for the carrier. Normally, the ENS for containerized goods should be formally lodged at least 24 hours before the goods is loaded at the first port of departure, which is often many days or several weeks before it is expected to reach its final port of destination. The ship might be visiting several transit ports in between, which in many cases are not known whilst creating the ENS-document. In such case the ENS declarant is responsible for sending updated ENS information to customs. In any case, the time span between lodging of the ENS and the call of the container ship at the first port of entry in Europe can be used by customs to reason about what goods will probably arrive with the ship, and what actions to take. In some situations, this can even lead to a so-called "Do Not Load" response before the ship leaves the port, in which case the container cannot be loaded on board at all. Thus, customs needs an effective DSS for finding containers, which have a higher than average probability of carrying unmanifested or prohibited material. Especially, having in mind the enormous volumes of goods that can be transported on a single large-size container ship (a single ship can carry up to 18 270 TEU (ten-foot equivalent units), i.e., 18 270 half-size or 9 136 full-size containers).

3.2. Implementation of the Entry Summary Declaration

Each member state within the EU has to implement an Import Control System (ICS) according to a specific architecture (European Customs Information Portal 2013). However, front-end systems for data entry differ between nations. Large shippers of course interface directly to the customs information system and submit bulk data.

In some cases some of the data attributes are allowed to be placed at different levels; at the declaration item of goods level, at the declaration header level, and at the conveyance report level. Moreover, different member states have different sanction possibilities regarding the quality of the submitted ENS document, meaning that some countries simply reject the transport if not certain quality level of submitted data is achieved, while other countries have no legal support for doing so. Altogether, these conditions have led to different ICS-systems, with different ENS document structures having different levels of quality.

4. GENERATING CRS

Within several earlier freight-oriented EU projects, the so-called Common Framework (CF) information model was developed (e-Freight 2013a), see Figure 1.

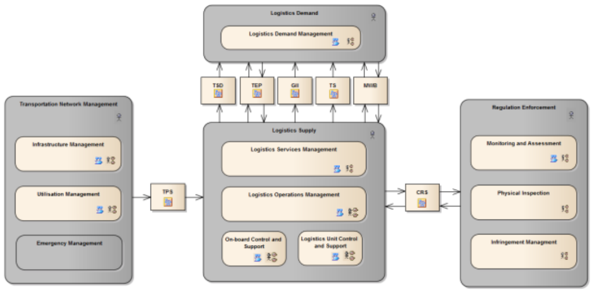

Figure 1: A high-level picture of the Common Framework. CRS forms the connection between "Regulation Enforcement" and "Logistics Supply". Picture from the e-Freight project.

CF extends the OASIS Universal Business Language (UBL) model intended for standardized B2B information transactions in XML (OASIS). The extensions are mainly to provide more interoperability between logistics stakeholders and to enable the expression of B2A data. The latter (B2A) subset of CF, called the Common Reporting Schema (CRS), is "a single, standardized, electronic reporting document which includes all the information fields which are necessary and sufficient for reporting to authorities in all member states and across all modes" (e-Freight

2013b). Parts of CF have been tested (e.g., in Gothenburg port), but the overall framework is still not in operation. However, being intended as a pure electronic way to exchange information, it will probably be recommended within the EU countries. The CRS format is implemented as an XML Schema, containing all necessary fields for mapping ENS data requirements. Table 1 demonstrates a suggested mapping between the ENS data requirements to corresponding fields within the CRS. The ENS simulator to be described in the following produces a Comma Separated Values (CSV)

Table 1: Mapping from ENS to CRS fields.

ENS	CRS tag
Transport document number	<cbc:ID>
Declaration date and signature	<crs:SubmissionDate>
Person lodging the summary declaration	<crs:ReportingParty>
Carrier	<cac:CarrierParty>
Notify party	<cac:NotifyParty>
	<crs:Consignment>
Commercial reference number	<cbc:ID>
Number of items	<cbc:TotalGoodsItemQuantity>
Gross mass	<cbc:GrossWeightMeasure>
Place of loading	<cac:PlannedPickupTransportEvent>
Place of unloading code	<cac:PlannedDeliveryTransportEvent>
Consignee	<cac:ConsigneeParty>
Country(ies) of routing codes	<cac:TransitCountry>
First place of arrival code	<cac:FirstArrivalPortLocation>
Transport charges method of payment code	<cac:PaymentTerms>
	<cac:TransportHandlingUnit>
Container number	<cbc:ID>
	<cac:TransportEquipment>
Seals information and seals identity	<cac:TransportEquipmentSeal>
	<cac:GoodsItem>
Goods description	<cbc:Description>
Type of packages (code), number of packages, shipping marks	<cac:Item>
Goods item number	<cbc:ID>
UN Dangerous Goods code	<cac:HazardousItem>
	<crs:MainCarriageShipmentStage>
Mode of transport code	<cbc:TransportModeCode>
Date and time of arrival at first place of arrival in the EU	<crs:EstimatedArrivalTransportEvent>
	<crs:TransportMeans>
Identity of active means of transport crossing the border	<crs:MaritimeTransport>
Nationality of active means of transport crossing the border	<cbc:RegistrationNationalityID>
Conveyance reference number	<cac:DocumentReference>

The CRS tags above are defined with the following XML namespaces:
cac=”urn:oasis:names:specification:ubl:schema:xsd:CommonAggregateComponents-2”
cbc=”urn:oasis:names:specification:ubl:schema:xsd:CommonBasicComponents-2”
crs=”urn:eu:specification:efreight:schema:xsd:CommonReportingSchemaExtensions-1.0”

list of simulated text entries, such as consignor name, address, goods commodity code, etc., that must fill the corresponding fields in a valid ENS, or as in our case, CRS message. CRS messages are required to be serializable and exchanged in some kind of self-describing format, such as JSON or XML reflecting its semantic (tagged) content. In the CRS generator, written in Java, we have chosen to parse the simulated CSV-formatted ENS message and from this build up a Java CRS object with fields that reflect the message, followed by serialization of this object to XML using the Java XML Binding (JAXB) framework. This automatically structures the ENS fields of the CRS message in the proper hierarchical format of such messages. The message is then regarded as complete to submit to a hypothetical customs office, in our case an instance of CustAware that parses the messages and analyses their content on the fly for indicators on malicious goods or activities. The submission uses the same web service REST communication paradigm (Fielding and Taylor 2000) that is used by CustAware, and that is also used by the common platform in CONTAIN.

5. SIMULATING CONTAINER SECURITY DATA

Since our focus is on information to customs, we simulate ENS data by synthesizing a large ”bulk” stream of realistic messages, which are continuously received by customs in a real situation. In practice, this stream can be voluminous; perhaps several thousands of messages per second to a single national customs centre. This enormous inflow must to a major extent be analysed on-the-fly, which requires the analysis to be at least partly automatized. Another task in the CONTAIN project is to develop tools for customs to implement their already existing knowledge into software on how to find suspicious indicators and patterns in the ENS data they receive, such as that recently implemented in CustAware. Verifying and validating such a tool will be very important, from message parsing to the ability of the analysis of message content on different levels of complexity.

5.1. Introduction to Problem Setting

When simulating information on goods transported in containers, as well as on the containers, we must in some consistent way be able to put together information such as typical data on shipping line, port of first departure, transit ports, final destination port, consignor, consignee, goods type, points in time for lodging ENS and for call at first port of entry in the EU so it mimics some real goods status message, e.g. B2B status messages sent between business partners, or B2A messages as ENS to customs.

One natural way to generate ENS data is to model the entire system as a many-to-many interlinked logistics process with actors as agents. Goods are requested by consignees in destination countries, in which ports act like sinks for shipped goods. Sources are departing ports in countries where consignors export the goods. In between, we have the entire logistic process. Shipping lines follow specific routes and containers are filled with requested goods at the exit ports. This combined trade and logistics simulation would then produce ENS messages when a ship leaves its first port of departure with all containers and goods within them. At transit ports, one could simulate container off-loading and loading onto another ship as well as the movement of goods between offloaded containers. Since this method generates the data according to the definition of the process, it ensures that the variates are correctly correlated.

Although it is theoretically possible to develop such a simulation system, the modelling required for this would be too time-consuming and too difficult to validate for our needs: simulation of ENS messages. A more pragmatic approach is to use real data to generate simulated input data. A naive method would be to create a table where columns are different ENS data types containing valid ENS data values extracted from real data (e.g. consignor, consignee, shipping line, container ID, goods type) and randomly sample from table columns and combine the results to form a message. However, this process ignores the correlations among data and could produce combinations that are unrealistic. One needs some kind of restrictions or conditions that guides the process, for instance who tends to ship what goods to whom. Incorporation of this knowledge is necessary to avoid generation of unrealistic combinations of, e.g., consignors and goods such as fruit dealers that ship petrol or electronics. The key requirement in the generation of multivariate samples is the need to ensure an appropriate correlation structure among the components of the multivariate vector (Cheng 1988).

The simulated ENS bulk stream should have a profile very much like real messages of this type. This should of course include errors that might appear due to simple carelessness and misunderstandings of how to correctly fill in the information in an ENS message. This can be accomplished by using real messages as a ground for the simulation, which will be described in Section 6. This simulated data will then mimic the stream of standard messages that constitutes the "normal picture" of incoming goods and containers. The process is sketched in Figure 2.

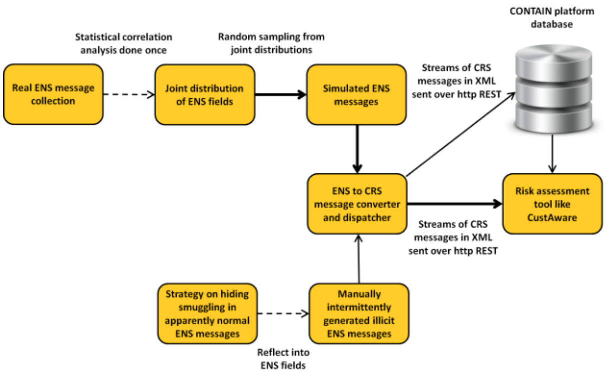

Figure 2: The entire ENS generation to analysis chain in one picture. Full line thickness: Message flow volume. Dashed lines: Strategies for message simulation.

6. REAL DATA AS BASE FOR SIMULATIONS

Several types of real data exist that could be used as "templates" for generating a ground for simulated goods data messages. This is typically B2B transactional data generated along the goods logistic chain or B2A data, such as ENS messages sent to customs. What we ideally need for the simulation of such messages is the statistical joint distribution between all different data contents in a large set of real messages. This means that the number of messages in the sample data must be large enough, and the frequencies of unique occurrences of its entries, must not be too small in order to get high enough statistical confidence for different combinations of entries in the messages. In practice, it is not so easy to find this data. Annually compiled data from national statistical institutions on trade patterns tend to be rather heavily aggregated and therefore not suitable for generating statistical distributions on a fine-grained level. Non-aggregated raw-data is often more or less classified since it might reveal business-sensitive information. Therefore, it is of great value to acquire raw-data with a fine level of granularity. We have achieved this by obtaining some real data from a customs agency. In total, we have received around 130,000 ENS messages that were anonymized in order to not reveal classified contents and replaced potentially sensitive fields in the messages like names and addresses by hash codes or unique aliases.

6.1. Generating Univariate Random Variables from Empirical Data

There are several advantages associated with generating random variates from empirical distributions, perhaps chief among them the fact that an empirical distribution by definition is valid and there is no need for validation. However, there also may be problems which should be considered when sampling from empirical distributions. One problem is that if the data is not sufficiently large, it may not be representative of the complete probability distribution. Outliers and rare data may also cause problems. The procedure for variate generation from a discrete empirical distribution is the following:

1. Arrange the data X in some arbitrarily order $X = \{(x_1, m_1), \dots, (x_n, m_n)\}$, where m_i is the number of occurrence of item x_i.
2. Determine $\{(x_1, F(x_1)), \dots, (x_n, F(x_n))\}$, where $F(x_i) = \sum_{j=1}^{i} \frac{m_j}{m}$ and $m = \sum_{i=1}^{n} m_i$.
3. Generate u from $U(0,1)$.
4. Find the interval $(F(x_i) \le u \le F(x_{i+1}))$.
5. Return x_i.

6.2. Generating a Multivariate Distribution from Empirical Data

It is generally more difficult to model dependent data using empirical data, since it requires a larger amount of data to capture the structure of the mutual dependence. Below we discuss four approaches to this problem.

6.2.1. Independent variables

If the components of a random vector $X = (x_1, x_2, \dots, x_n)$ are independent, that is $F(x_1, x_2, \dots, x_n) = F(x_1)F(x_2)\dots F(x_n)$, one can generate X_i from the marginal distributions $F_i(\cdot)$ independently and combine them to produce X. However, this method cannot be used to generate dependent variates. In general, the marginal distributions contain far less information about the structure of the data than required to generate dependent variates. It is worth to recall that even knowledge about the correlation matrix, which is a measure of linear coupling between variables, does not provide sufficient information about the underlying distribution of data (in the same sense that expected value and variance in general do not capture all information about a random variable). This can be illustrated, considering samples generated from three completely different bivariate distributions, having the same correlation matrix (see Figure 3).

Figure 3: Three different bivariate distributions, having the same correlation matrix (Wikipedia 2014).

6.2.2. Using the complete joint distribution

The joint probability density function of a set of stochastic variables gives the probability that a particular outcome of one variable is combined with certain outcomes of other variables. Assuming that the number of variables is small and the joint distribution is known, that is, for each item $(x_1, x_2, \ldots, x_n)_j$ in the random vector $X = (X_1, X_2, \ldots, X_n)$, the number of occurrences of that item, m_j is known, one can use the procedure described in Section 6.1 to generate samples from $(X_1, X_2, \ldots, X_n)$. Since the generated variates have the same frequency as the empirical data, the dependence between variables is preserved. One obvious drawback of this method is the exponential growth of the size of the probability table by increasing the number of variables. If each discrete variable X_i can take on d_i different values, then the size of the probability table is $\prod_{i=1}^{n} d_i$. However, if the variables are strongly dependent, that is if the values of some of the variables to some extent determines the values of the others, then the probability of many of entries in the table will be 0, which results in a sparser probability table.

6.2.3. Conditional sampling

Another equivalent approach is conditional sampling, which uses the Bayes chain rule. This approach exploits causal dependence between the variables to express a joint distribution as a product of conditional probabilities, for example see (Russell and Norvig 2010).

While the full joint distribution gives random samples of all variables concurrently, conditional sampling provides a more step-wise process based on a causality reasoning, where conditional probabilities are built from assessments of the dependence of variables. This assessment can sometimes be derived from the available data. The conditional sampling procedure is straight-forward; the joint distribution function $F(x_1, x_2, \ldots x_n)$ is used to determine all marginal distributions $F_i(\cdot)$ of X_i for $i = 1,2,\ldots,n$ and conditional distributions $F_k(\cdot \mid X_1, X_2, \ldots, X_{k-1})$ of X_k given $X_1, X_2, \ldots, X_{k-1}$ for $k = 2,3,\ldots n$. By a tedious but straightforward manipulation of definitions of marginal and conditional distributions, one can show that the following procedure generates multivariate samples with given joint distribution $F(x_1, x_2, \ldots, x_n)$:

- Generate X_1 from the marginal distribution $F_1(\cdot)$
- Generate X_2 from $F_2(\cdot \mid X_1)$
- Generate X_3 from $F_3(\cdot \mid X_1, X_2)$
- $\ldots$
- Generate X_n from $F_n(\cdot \mid X_1, X_2, \ldots, X_{n-1})$
- Return $X = (X_1, X_2, \ldots, X_n)$

If it is possible to partition X into two sets of independent variables Y and Z such that

$$F_X(X) = F_Y(y)F_Z(z), \quad (1)$$

for all $x \in X$, $y \in Y$ and $z \in Z$, $x = y \cup z$, one can use the above procedure to independently generate these two set of variates and combine them to produce the vector X.

Moreover, if there exist Y, Z and W, such that

$$F_{Y,Z}(y,z \mid W) = F_Y(y \mid W)F_Z(z \mid W), \quad (2)$$

that is Y and Z are conditionally independent given W, the above algorithm can be used to generate W. Then given W, both Y and Z are generated from $F_Y(y \mid W)$ and $F_Z(z \mid W)$, respectively and vector X is produced as the union of Y, Z and W.

Since one can transform between using joint probability distributions on one hand and conditional sampling and using the Bayes chain rule on the other hand, it might be a matter of taste how it is implemented in practice; joint, conditional, or a mixture of those like so-called Bayesian Networks (Russell and Norvig 2010).

6.2.4. Copulas

Consider a continuous random vector $(X_1, X_2, \ldots, X_n)$, where marginal distributions are denoted by $F_i(x)$.

Then,

$$(U_1, U_2, \ldots, U_n) = (F_1(X_1), F_2(X_2), \ldots, F_n(X_n))$$

is a random vector with uniform margins. The joint cumulative distribution function (CDF) of $(U_1, U_2, \ldots, U_n)$, that is

$$C(u_1,u_2,\ldots,u_n) = P[U_1 \le u_1, U_2 \le u_2, \ldots, U_n \le u_n]$$

is said to be the copula for $(X_1, X_2, \ldots, X_n)$ (Embrechts, McNeil, and Straumann 1999).

A nice property of the copula is that it separates the dependence structure between the components of the random vector and the marginal distribution functions. In order to generate a random vector $(X_1, X_2, \ldots, X_n)$, one can generate a sample $(U_1, U_2, \ldots, U_n)$ from the copula distribution and then construct $(X_1, X_2, \ldots, X_n) = (F_1^{-1}(U_1), F_2^{-1}(U_2), \ldots, F_n^{-1}(n))$, where $F_i^{-1}(U_i)$ is the inverse of the cumulative distribution function for margins.

However, the problem to generate variates is not completely resolved, since the copula $C(u_1,u_2,\ldots,u_n)$ depends on the joint distribution, which is usually unknown. In that case, the copula is approximated by some known distribution. One used approximation is the Gaussian copulas with the correlation matrix Σ:

$$C_\Sigma^{Gauss}(u) = \Phi_\Sigma(\Phi^{-1}(u_1), \Phi^{-1}(u_2), \ldots, \Phi^{-1}(u_n)),$$

where Φ_Σ and Φ^{-1} are the CDF of a multi-Gaussian distribution with mean zero and covariance Σ and the inverse CDF of a standard Gaussian, respectively. The use of Gaussian copula can be justified by the fact that the distribution is the sum of a large number of i.i.d. random variables with finite variance so the central limit theorem applies. The correlation matrix Σ can be estimated from statistical data.

Another approach is to learn the correct copula from sample data. This could be done using Genetic Programming or a similar technique that gradually refines a function based on comparison with real data.

6.3. Generating ENS Records Using Empirical Data

We have developed an application in Java that generates sample ENS data that is converted on-the-fly to CRS messages as was described in Section 4. Here, the main concern has been that the generated data is convincing and does not contain impossible or improbable items, as a consequence of systematic errors or shortcomings in the input data modelling process. A clear example of an impossible data item is existence of two different ENS records that indicate that a specific container is simultaneously in two different vessels. An example of improbable data item is a record indicating that Sweden exports bananas to Ecuador. Without a careful examination of the input data and a clear strategy for generating variates it is difficult to avoid these kinds of deficiencies in the synthetic data. However, it should be clarified that, it is accepted or even desired that the generated data contains the same types of abnormality as those found in the empirical data, for instance spelling errors or incomplete data.

Each ENS record consists of 141 fields (columns in Excel file), most of which are discrete-valued (e.g. name, address, country of consignee and consignor, type and code of goods, vessel and container ID). However, the records also contain some continuous-valued fields such as the weight of goods and arrival time. This means, theoretically that we require generating a highly-correlated random vector with 141 components. In order to reduce the number of components, several data pre-processing measures (i.e. cleaning, integration and reduction) have been taken:

- all fields that are empty or very rarely used are removed from the table,
- fields containing irrelevant information for the input modelling, such as internal ID values for Swedish Customs are ignored,
- redundant fields like country name where the information is already given by country code are removed,
- some fields containing relevant information that seem not to affect the result of the risk calculation algorithms are removed,
- by making assumptions like the uniqueness of the name of companies in each country, some fields such as the address of companies are determined by other fields (name and country) and are removed.

These steps reduce the number of fields to 55, which is considerably less than the original 141 fields, however, still too large to calculate the frequency of unique records. Therefore, a core of 26 highly correlated fields is distinguished and their frequency is used as the joint distribution to generate the corresponding features as described in Section 6.2.2.

Although the remaining 29 fields are in different ways correlated to these 26 fields, they are either dependent on one or a small number of fields in this subset, or can be treated as independent without compromising the trustworthiness of the generated data. For instance, it is less critical if the amount of import of some goods by different consignors does not follow the real distribution. Hence, it is possible to generate the remaining fields conditioned on one or a small number of fields. As described in Section 6.2.3, when it is possible to partition random variables into independent subsets, or conditionally independent subsets, equation (1) respectively (2) can be used to randomly generate these subsets of variables and combining them afterwards.

Most of the goods that enter European ports are transported in containers. The ID number of the carrying container (BIC), which is an ISO standard, is one of the entries in ENS messages, and an important one for associating a container with which goods is transported in it. Container IDs are sampled uniformly from the list of container IDs existing in the data set (nearly 18,000 unique IDs) and are assigned to the vessels sorted by the arrival date. In order to avoid assigning a container simultaneously to different vessels, they are marked as occupied once they are drawn and are not added back to the pool of containers until a fixed time period has elapsed.

6.4. Injecting "Dangerous Containers"

Above, we described a process to simulate an in some sense "normal" inflow of ENS messages. This requires that real messages, which are the ground of the synthetic data, contain few enough anomalous messages that are even in reality indicators of illicit activities. However, how customs exactly finds those messages is often secret, so we have not been able to remove them. But pretending that all messages in the common ground are fully normal, we also want to intermittently "inject" a much smaller amount of information that could indicate malicious activities; mainly smuggling of illegal goods. In the end of the message flow chain, it is then up to the analysing functionality (customs officers, Artificial Intelligence tools, or a combination thereof) to find the needles (messages indicating malicious activities) in the haystack (normal messages) (Brynielsson, Westman, and Svenson 2015). Thus, it is important to make sure that injection of "dangerous containers" is separate from risk-assessment or decision support system that has the task to find them.
The details of the CustAware tool is out of the scope of this paper. However, initial tests conducted in non-operational environments for demonstration purposes has been promising. The CustAware is be able to use different models to produce risk indicators (risk values) and support the user to decide which containers or consignments to inspect. The models can be either rule based (blacklists, whitelist, etc.) or learn from data. Both unsupervised learning (anomaly detection) and supervised learning (outcomes from previous inspections) can be used to create the risk models.

7. DISCUSSION

We have described a methodology for simulating ENS-like messages for customs. It is preliminary used within the CONTAIN project to test systems developed to handle ENS data in the CRS format. One important aspect is to evaluate the working process of updating and refining the risk profiles in the CustAware tool for efficient identification of potential illegal activities such as smuggling. It can also be used to test customs' systems for receiving such messages, as well as the ability of those systems to detect indications on ongoing attempts for smuggling or other illicit behaviour.

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MAS SIMULATION FOR DECISION MAKING IN URBAN POLICY DESIGN: BICYCLE INFRASTRUCTURE

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ABSTRACT
Urban policies requires a deep knowledge about the dynamics that can affect the acceptability of the investments by the population, considering not only the present context but also the different future scenarios that can emerge. In this paper, an agent based simulation model to evaluate the impact of different urban bicycle infrastructure investments is described as an excellent tool to mitigate the risk in the decision making process. It is well accepted that a critical factor to extend the use of bicycle in a city for mobility purposes is to achieve a minimum amount of citizens satisfied with the bicycle infrastructures, which will act as a seed to extend the use of bicycles by influencing their communities. Thus, the main idea is to prioritize those investments that can contribute to achieve the critical mass of urban cyclists.

Keywords: Simulation, modeling, policy design, CPN, MAS, Bicycle, Infrastructure, decision support system

1. INTRODUCTION

Simulation techniques offer the right experimental framework for a new way of thinking about individual and population feedback dynamics, based on ideas about the emergence of complex behaviour from relatively simple activities (Simon 1996).

While some simulation modellers emphasize the desire for understanding and others emphasize the need for making predictions, urban policy design should aim at least to satisfy the following two goals:

- Explanatory model: To help citizens understand their neighbourhood area in order to control and change it.
- Predictive model: the urban policy decision makers need tools to predict the impact of their decisions on the future use of the infrastructures and services under design, within real social context scenarios.

Thus, a better understanding of some features of the social world should pave the way to develop simulation models that could reproduce the dynamics of some behaviour in order to 'look into the future'. Despite the modelling difficulties, both goals are not incompatible: a successful explanatory model can be used to generate acceptable predictions, while a good predictive model can contribute to a better understanding. Moreover, a trade-off between accuracy and simplicity should always be kept in mind during the modelling phase (Axelrod 1997).

The role of citizens in e-government should be seen as a rich source of knowledge about the phenomenon being modelled, thus their involvement in the understanding of the context scenario and the experimentation of different policy alternatives through simulation models could raise their interest in the policy design process and could improve their level of knowledge about the issues at hand, transforming opinions into valuable implications. To deal with such citizen engagement in e-participation, the research efforts in new simulation developments should not be placed in better representation of simulation results, but it should instead focus on fostering model transparency for explanatory and predictive urban policy purposes.

Among the different modelling formalisms (Gilbert N. 2005, Li An 2012), agent-based simulation is well suited to e-participation, since end-users not properly familiarized with modelling usually catch easily the idea of autonomous agents carrying out activities and communicating with each other in a way similar to citizens interactions (Ramanath and Gilbert 2004). By means of a Multi Agent System (MAS) simulation platform, a library of causal models to allow citizens to test the benefits and shortcomings of different proposed urban policies and check new policies according to their own beliefs has been developed in the FP7 project FUPOL (Piera et al., 2013; Buil and Piera, 2013; Piera et al., 2014).

This paper presents the use case in Bicycle infrastructure developed for the city of Skopje, Macedonia. The objective of the model is to help city planners to schedule the infrastructure investments to increase the number of bicycle users in the city. They expect to double the number of users in few years, going from the current number of bikers, which is around 2.5% of the population, up to 5% of the

population, a percentage typical of northern European cities, where bicycle transport is a consolidated option.
In this paper it is introduced in section II a description of the Skopje facilities to support bicycle mobility, while in section III it is proposed a MAS model approach to improve the decision making process. Section IV provides a short background on the use of coloured petri net modeling formalism which is used to open the state space of the system to better understand the model causality and evaluate the reacheability of some system states. Finally, section V illustrates the results obtained.

2. PROBLEM DESCRIPTION

Intermodal passenger transport, also called mixed-mode commuting, involves using two or more modes of transportation in a journey. The goal of mixed-mode commuting is often to combine the strengths (and offset the weaknesses) of various transportation options. A major goal of modern intermodal passenger transport is to reduce dependence on the automobile as the major mode of ground transportation and increase use of public transport.
The benefits of the use of bicycles for flexible mobility, emission reductions, physical activity benefits, reduced congestion and fuel use, individual financial savings and support for multimodal transport connections are well known and accepted by the transport community. However, there are some barriers that should be properly addressed to successfully promote the use of bicycle as an alternative to well consolidated transport means.
Among the barriers, safety is a major concern including a perceived lack of suitable bicycle infrastructure, as well as regular a negative attitude of some car drivers. Considering the former concern, it has been reported that the right location of bicycle docking stations to be better integrated with public transport, as well as suburban locations, beyond the inner areas bordering the municipalities is a critical factor to be analysed.
All main access roads to Skopje lead straight to the city centre. Mainly used transport means in Skopje include:

- public busses,
- taxis,
- individual cars,
- individual bicycles,
- individual motorbikes,
- pedestrians

The city infrastructure mostly provides space where people can park their cars in an outdoor parking place or parking garage. The problem with which Skopje is facing is the lack of bicycle parking lots. Furthermore, bicycle rental services are also scarce or even non-existent.

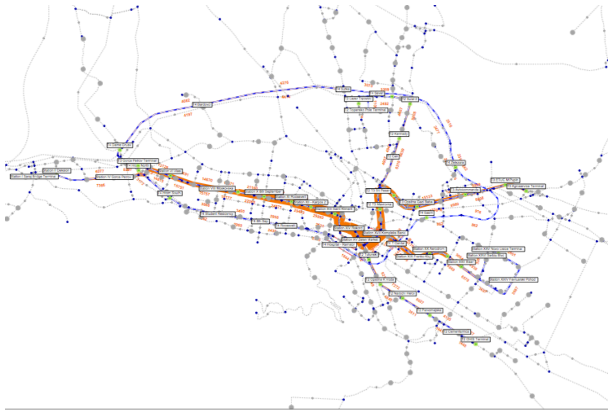

Figure 1: Bus Station in Skopje City

Usually, city centre is already well serviced by public transport (see figure 1) but linking suburbs and major destinations lacks of enough bicycle infrastructures. Furthermore, bicycle lanes use to fail to provide a continuous route to their destination and that leads to longer route in order to avoid ''problem spots''.
The use of a bicycle can, for example, make an (inexpensive compared to a car), a typical 10km bus journey attractive even if the endpoints of the journey each sit 1km out from the stations: the 20 minutes walking time becomes 8 minutes bicycling time. As in the example above, location plays a large role in mixed mode commuting. Rapid transit such as express bus may cover most of the distance, but sit too far out from commute endpoints. At approximately 5 km/h walking, 3 km represents about 40 minutes of commute time; whereas a bicycle may pace 15 km/h leisurely, cutting this time to 10 minutes. When the commuter finds the distance between the originating endpoint (e.g. the home) and the destination (e.g. the place of employment) too far to be enjoyable or practical, commute by car or motorcycle to the station may remain practical, as long as the commute from the far end station to the destination is practical by walking, a carry-on cycle, or another rapid transit such as a local or shuttle bus.
In general, locations close to major transit such as rail stations carry higher land value and thus higher costs to rent or purchase. A commuter may select a location further out than practical walking distance but not more than practical cycling distance to reduce housing costs. Similarly, a commuter can close an even further distance quickly with a bike, motorcycle, or car, allowing for the selection of a more preferred living area somewhat further from the station than would be viable by walking or simple bicycle.
For a proper planning of their infrastructures, the Skopje municipality required a decision support tool to:

- Predict the increment of bicycle users depending on the bicycle facility investments (renting stations, parkings, and signalised paths in good shape).
- Study the locations and capacities of renting stations and parkings.

- Determine which paths will be more used by citizens and thus should be maintained properly.

A simulation model has been developed to support two types of experiments with two different objectives:

- **Simulation 1 Best Configuration for a given Budget**: To select the renting stations and parkings configuration which can impact with better increment of bicycles users in Skopje.
- **Simulation 2 Analysing the use of Bicycles in Skopje**: To allow citizens get a better understanding of the usability of bicycle facilities considering different scenarios, in order to support the municipality investment proposal and/or to provide evidence of the benefits o a different investment proposal. Thus, end-users will be able to modify the location of renting stations, parking capacities, pavement improvements, etc.

For both simulations it is considered the amount of funds expected to be available in order to deploy any of the bicycle facilities.

3. MODEL DESCRIPTION

The model consists in a set of stations that can be origins and/or destinations (bus stations, train stations and points of interest), a set of tracks between these stations (not all stations are connected), and the users. Stations are fixed and they can be renting bike stations or/and bikes parking (for private bikes). It is considered that, at each station, a renting station can already exist, can be planned, can be possible or cannot be possible. Similar alternatives are considered also for bicycle parkings.

Tracks are fixed. There is one track for each possible connection between stations. These tracks can already be an existing bike path, can be a planned bike path, can be a possible bike path or they can never be a bike path.

Tracks and stations planned can be treated as existing, thus it can be tested what would happen if they would be available. Possible tracks and stations can be set as existing to also test what would happen if they would be available.

User agents can use the bike or not. Ones using bikes have defined trips that are performed depending on weather conditions and tracks and stations condition. A user that can make a trip by bike or by another transport system will use one or the other depending on its satisfaction with the tracks and the stations included in its trips. If it usually uses the bike but the city of Skopje invest during several years in other stations and tracks, even though the tracks it uses are crowded and without a built bike path or a bike path in bad conditions, its satisfaction will decrease and it can imply that the user skip the use of the bike to start using the alternative transport system. On the other hand, the satisfaction (about bike infrastructures) of one user that usually takes some other transport system will increase if it exist a good combination of well conditioned tracks, and parking station at its destination, with an appropriate capacity to easily find a spot to park the bike.

The satisfaction of the users can be also modified by occupancy conflicts at renting stations or at parkings, and finally also by the satisfaction of the neighbours: If the majority is satisfied, its satisfaction will increase, if not, it will decrease. There are several opinion formation models that can be applied in order to use the neighbours' satisfaction to modify the satisfaction of one agent. Two of these opinion formation models have been already tested obtaining good results.

The first one counts the satisfied and unsatisfied neighbours around the agent and its satisfaction is modified following these rules:

1. If more than 50% of the neighbours consulted are satisfied, the satisfaction of the agent increases.
2. If more than 50% of the neighbours consulted are unsatisfied, the satisfaction of the agent decreases.
3.

The second opinion formation model also counts the satisfied and unsatisfied neighbours, and is formalized by means of the (Weidlich, 2000) model:

$$\mu\uparrow = \sigma \exp(U)$$

$$\mu\downarrow = \sigma \exp(-U)$$

$$U = \pi + k\,\frac{n\uparrow - n\downarrow}{n\uparrow + n\downarrow}$$

In which

$\mu\uparrow$: is the probability of the individual transition from no to yes while $\mu\downarrow$ is the probability of individual transition from yes to no.

σ is a flexibility parameter. High values increase the probability of an opinion transition leading with more opinion changes.

Π is a preference parameter, in which a high value increases the probability of changing to yes, while a low value will decrease the probability of changing to no. A 0 value means neither yes neither no is preferred.

k is a coupling parameter used to represent the influence of a yes majority on an individual change to yes (the same is true for the influence of a no majority on an individual change to no). A high value of k means a high influence while a zero value means that individual transition probabilities do not depends on the population opinion distribution.

$n\uparrow$ and $n\downarrow$ represents the amount of individuals with a yes option and a no option respectively.

4. CPN DESCRIPTION

The description of the causality of the different events that can affect the acceptability of the proposed investment distribution in the Bicycle Inter-Modality model, has been defined using the CPN modelling formalism.

In order to simulate the policy acceptability according to a certain time horizon, some citizen attribute information can change on a time based mechanism according to the boundary conditions. Thus, a prediction of an increment of population in a municipality, or a new set of stations can be considered to evaluate the impact on the proposed investments.

Table 1: Events formilized in CPN

Transition	Meaning
T0	Initialization of the CPN model using the Boundary Conditions that specify the simulation scenario: Initializes the activities, resources, user group and weather attributes defined in the previous section.
T1	Initialization of a trip: For a user group, it is generated a bike trip considering the user group profile and the simulation clock.
T2	Renting a bike: For a particular user group, it is generated randomly considering the time preferences the renting of a bike in a station.
T3	Parking a bike at the destiny: Transition T1 generates a time event T2 which updates the variables regarding the docking information and the use of tracks.
T4	Returning a rented bike at the destiny: Transition T1 and T2 provide the information to generate a time event that represents the return of a renting bike.
T5	Return trip: Each time a transition T3 is fired, it generates a transition T5 which is delayed according to the profile information. This transition updates the docking information.
T6	End of a trip: Transition T5 generates a time event T6 which updates the variables regarding the use of tracks.
T7	Opinion formation: This transition evaluates the acceptability of the bike investments policy by a member of a user group chosen randomly
T8	Opinion formation: This transition evaluates the rejection of the bike investments by a member of a user group chosen randomly
T9	Satisfaction: This transition evaluates for each user group its affinity to the proposed investments.
T10	Distributing investments in renting facilities, docking and tracks: This transition is not part of the Bicycle Inter-Modality dynamics, instead it will be implemented in the observer agent, and will try to deal with a better trade-off between the investments by evaluating its impact on the amount of kike users.

Figure 2 illustrates the CPN model of transition T9 : satisfaction evaluation for each user group about the proposed investments

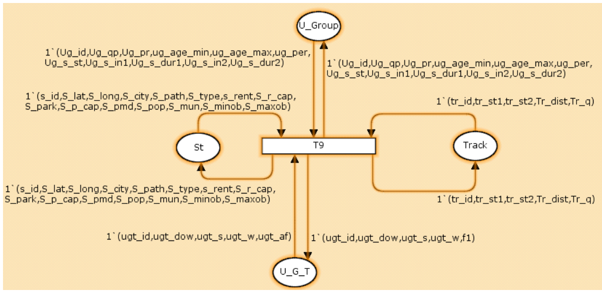

Figure 2: CPN model of T9

Bike users have been formalized in CPN considering the following attributes:

- id: it is the agent id, automatically generated.
- groupID: it is the group Id taken from the input tables.
- profile: indicates the type of user.
- description: Indicates an area or neighbourhood, or indicates that it has an exact location for the house.
- age: it indicates the age of the agent.
- destination: it indicates the Municipality destination (code).
- destinationID: it indicates the exact ID of the destination station.
- originID: it indicates the exact ID of the origin station.
- tripStations: set of ordered stations from origin to destination.
- duration: duration of the trip between stations
- startTime: time to start the first trip (going to destination).

- backTime: time to start the second trip (going back to origin).
- durationTotal: duration of the trip.
- distance: length of the trip.
- personality: Level of personality of the agent.
- satisfaction: Level of satisfaction about the bicycle infrastructure.
- tripStatus: variable in which the status of the tracks are added in order to generate a global status.
- trackID: id of the performed trip.
- stationID: The station where the user is parking or taking a bike.
- pDay: Day parameter to determine if the bike is used.
- WEcomp: Parameter to determine if the pDay value for weekend is complementary or not, which means that bike must be used one of the two days.
- weVisit: indicates if a complementary weekend, the bike has been already used.
- pMonth: Month parameter to determine if the bike is used.
- pWeather: Weather parameter to determine it user uses the bike.
- park: Indicates if the user bike is parked in a bike parking slot.

5. MAS DESCRIPTION

The MAS model consists in a set of stations that can be origins and/or destinations (bus stations, train stations and points of interest), a set of tracks between these stations (not all stations are connected), and the users. Stations are fixed and they can already exist, can be planned, can be possible or cannot be possible.

Tracks are also fixed and they connect two stations. Minimum distance tracks are just considered and the distance with other tracks, not directly connected, is calculated using some graph search algorithm, as for example, the Dijkstra's Algorithm. It finds the shortest path from a point in a graph (origin station) to a destination. These tracks can also be an existing bike path, can be a planned bike path, can be a possible bike path or they can never be a bike path.

User agents can use bike or not. Ones using bikes have defined trips that are performed depending on weather conditions and tracks and stations condition. A user that can make a trip by bike or by another transport system will use one or the other depending on its satisfaction with the transport system it selects.

This satisfaction can increase or decrease depending on the profile of the user (citizen) and/or the quality of the infrastructure of the transport system it is using. For example, for bikers, it will depend on the condition of the tracks, its occupancy, also on the capacity of the station at the destination, and its occupancy. Satisfaction of users is also affected by others opinions. There are several opinion formation models that can be applied in order to use the neighbours' satisfaction to modify the satisfaction of one agent. During the development of other models two of these opinion formation models have been already tested obtaining good results; therefore, they are also used for this model. The satisfaction is the factor that will make a citizen start using the bike or stop using the bike.

The simulator works in two different modes:

1. Municipality Mode: Used to compare different actions (defined by officials) taking in to account the available budget. Once all options are evaluated, it determines which set of measures are the most adequate according to their impact. It is a mode specially created for city officials.
2. Citizens Mode: Used to test different options introducing few small modifications into the default configuration defined by the city officials. It allows the users "to play" with the simulator and send suggestions, based on the results, to the city officials.

In Figure 3 it is illustrated the flow of information and actions implemented in the bike user Agent when deciding its mobility to a preferred destination. As reported in (Piera 2014), the CPN model formalization is used to validate the model events by means of the reachability tree, while the MAS implementation is used for experimentation purposes of specific parameterized scenarios. Thus, Agent behaviour is always codified as a DES considering the CPN events.

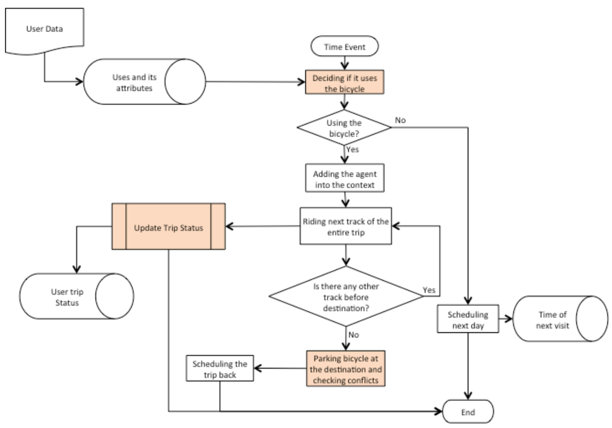

Figure 3: User Agents behaviour. Trip to Destination. Time event dependant process

In figure 4 it is illustrated the opinion formation method to update user satisfaction by track status while in figure 5 illustrates the opinion formation method to update user satisfaction by neighbour opinión influence.

Different model validation techniques has been used to properly parametrize the Agents opinions dynamics in order to obtain realistic increments of bike users.

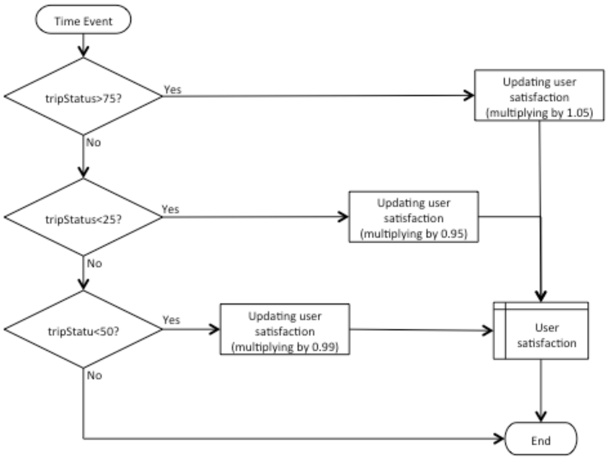

Figure 4: Opinion formation method to update user satisfaction by track status

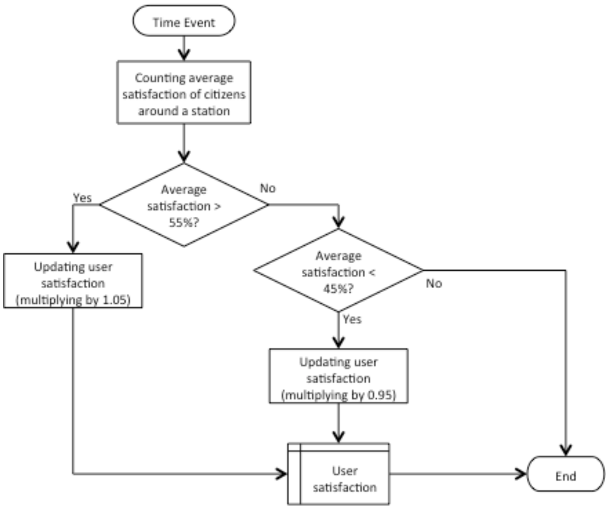

Figure 5: Opinion Formation method to update user satisfaction by neighbours

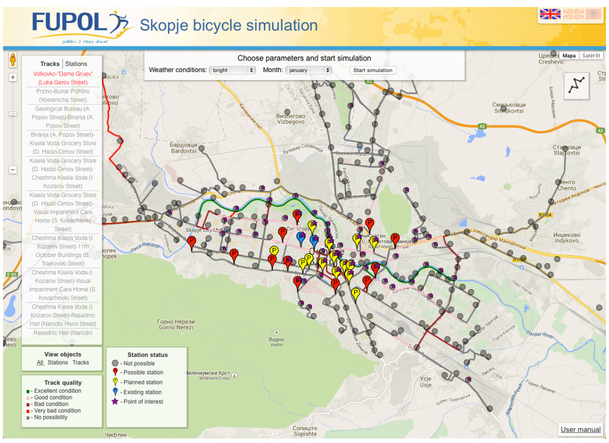

Figure 6: Bicycle Infrastructure in Skopje (Stations and tracks

6. MAS VALIDATION

Figure 6 presents the web simulator with the map showing the stations and the tracks. Stations can be Impossible, Possible, Planned or Existing, depending on the possibility or not to have parking station in that spot. Tracks can be also Impossible, Possible, Planned or Existing.

The implemented ABM validation was based on the structure and parameterization analysis by field experts, and the comparison of the observed model behaviour with the monitorized real system behaviour. This type of validation is called plausability. Bicycle infrastructure experts participated on the model development. Several conceptual models were developed to check field expert opinions till a consensus on the causal relationships was agreed between experts in conformity with historical data used. Thus, experts through different experiments confirmed that both, the conceptual model implemented in CPN and the MAS model implemented in Repast "looks logical"; satisfying the first part of the plausability validation. The second part of the validation is to test the simulation model by comparing results generated with the simulator with data collected from the real system. For that reason, a fieldwork was organized in the city of Skopje, and several persons got data from some of the sources in the system during 6 different days: Saturday, October 11th 2014; Sunday, October 12th 2014; Tuesday, October 14th 2014; and Wednesday, October 15th 2014; from 7:00 to 19:00; and Saturday, November 8th 2014; and Wednesday, November 12th 2014; from 9:00 to 14:00.

Two different plausibility validation test have been performed.

6.1. Users by Hour

Differences between simulation results and real data regarding the number of bikers per hour are very high for all the measured points due to two main reasons:

a) The random generation of the origins for a given destination

b) The distribution of the departure hours

Origin is directly related to the entire trip duration; therefore, it also affects the departure hours. The distribution of the departure hours should be different for the users with same origin and destination. Some times it could be equal, but not for all users, and not always.

In figure 7 it is represented the bike users for L70 track during Sunday, October 12th 2014. Since the total amount of users is the same for real data and simulation, extra parameterization effort is required to find out how many origins and times must be correctly generated in order to get similar number of bikers by hours for both simulation and real system. It would be necessary to determine the distribution of bikers by hour using all the data collected, instead of using the arrival time minus the time of the trip.

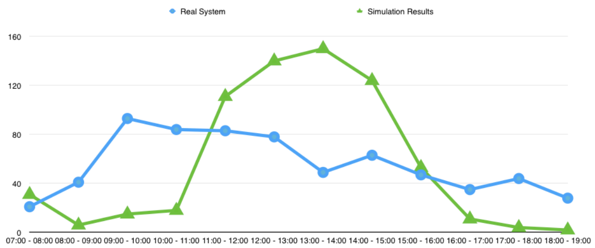

Figure 7: Hourly Bikers evolution on Sunday, October 12th 2014

6.2. Users by Day

Table 2 and Figure 8 show the total bikers going through station L70 during the collecting data days. First row of the table and the line in blue of the figure represent the number of bikers observed in the real system. Second row of the table and line in green of the figure represent the mean value of a set of 20 simulation's runs. Last two rows of the table and yellow and orange lines of the figure, respectively, represent the minimum and maximum number of bikers obtained during the 20 simulation's runs.

Table 2: Total Bicycle Users in L70

Data Source	Saturday 11/10/14	Sunday 12/10/14	Tuesday 14/10/14	Wednesday 15/10/14
Real System	733	666	1129	1174
Simulation Mean Value	672.7	625.3	1268.5	1145.2
Simulation Min	599	573	1127	1065
Simulation Max	745	690	1412	1279

As it can be seen, the model has been properly arranged to get simulation results closer to the reality. Due to the number of variables influencing the final results, it is not possible to adjust all the parameters of the model and get results more similar to reality. A micro modelling approach would require collecting some extra data about origins, destinations and departure times and it would allow to deep in some details out of the scope of FUPOL simulation model.

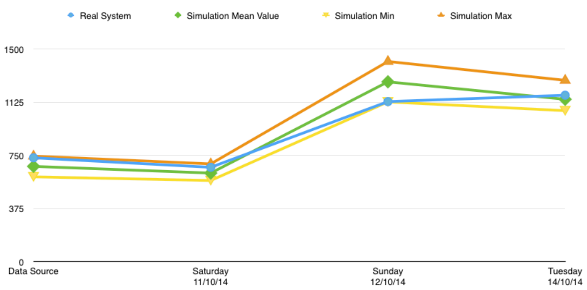

Figure 8: Total Bicycle Users in L70

7. CONCLUSIONS

The use of MAS model as decision support tool for infrastructure investment purposes has been presented as a successful approach to design urban policies in which citizens can be involved in the priorization of the investments by transforming its opinions in valuable knowledge.

The macro model implemented provides a well accepted solution for planning purposes, however it lacks of a proper micro level representation to allow citizens to obtain a better understanding of simulation results

The suggestions to improve model transparency for a better engagement of citizens as potential end-users of the simulation model are:

a) Origins and destinations should be provided in some other more realistic manner. Just this modification would modify simulation results since currently origins are randomly generated from 1 km to 3 km away of the destination
b) Routes of the bikers should be analysed and determine if using the Dikjstra algorithm is appropriate or they need to analyse the routes bikers use. Dikjstra algorithm considers the distances but not the quality of the tracks.
c) The distribution of the departure times must be modified also because not all users start the bicycle trip with the exact time they need to rich their destination. Most of them use some more time. It would be needed to collect extra data about the time bicycle users leave the house when going to some destination by bicycle. It depends on the weather? it depends on the month? All this information would be necessary to really generate the correct parameters for the simulation model.

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A TOOL TO SUPPORT HARBOR TERMINALS DESIGN

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ABSTRACT

Flows management is a crucial aspect in harbor terminals and entails several issues such as high flows of containers to be handled during loading, unloading and housekeeping operations. It requires implementing proper allocation strategies in terms of resources so as well as to maximize productivity and ensure good performances. To this end, the proposed research work is meant to assess the potentials of Modeling & Simulation to support container terminal design and to come up with an easy to use tool able to support terminal managers in decision-making at various levels. Based on design requirements for a new container terminal scenario, the paper shows how the proposed simulation tool can be used to explore design possibilities including low and high operational levels and to detect terminal behavior during and after its start-up period.

Keywords: container terminal design, decision support system, scenarios analysis, simulation

1. INTRODUCTION

A container terminal is part of a complex transportation network. Usually it is a cross-platform hub linking multi-modal transportation systems up and in most cases it is required to coordinate and synchronize heterogeneous equipment and means such as containerships, feeders, trains, trucks, etc. ensuring high operational efficiency. Because of the many variables involved and the high flows containers, terminal design is quite a difficult task especially when management strategies pursue different and conflicting objectives such as cost efficiency, productivity, etc. Examples of problems in container terminals include scheduling of loading/unloading operations, berth position assignment, cranes and container handling equipment assignment, etc. For instance, relevant efforts have been made to come up with even more automated systems (Kemme, 2012) such as automated rail-mounted-gantry-cranes. To this end, simulation-based optimization approaches have been widely used for problem solving such as berth planning and crane scheduling (Hartmann, 2004; Jimenez and De La Parte, 2003). This is the case, for example, of Beskovink and Twrdy (2010) where simulation is used for operations optimization in a maritime container terminal as well as of Bruzzone et al. (2011) and Bruzzone and Longo (2013) where advanced 3D interoperable simulators are used to support operators training and to improve terminal efficiency. Simulation models are also used to investigate the performances of already existing container terminals Yun and Choi (1999) or to understand to what extent a simulation model could predict the actual container terminal operations with a high order of accuracy (Shabayek and Yeung 2002; Kia et al. 2002). Simulation based optimization is then used to investigate resources allocation and scheduling problems (Gambardella, 2001; Lau and Zhao 2008; Lee et al. 2007; Bruzzone et al. 2012). Additional references in this area can be found in Moorthy and Teo (2006), Bielli et al. (2006), Alattar et al. (2006). Additional simulation approaches to investigate security issues in container terminals (Longo 2010; and Longo 2013).

The great deal of research works in this area allows ascertaining the advantages that simulation based design can bring but not only. Indeed, recreating a terminal container in a simulation model entails a huge amount of modeling and coding work due to the need of setting up a clear and comprehensive picture of processes, entities and relations involved in here and turn such a representation in an executable as well as parametric computerized model (Banks, 1998). This is the reason why simulation development is usually underpinned by strong methodological approaches that are meant to drive the research activities and pave the way for reliable and fully deployable outcomes.

Needless to say that capturing the inherent complexity of a container terminal in a simulation project raises significant research challenges both in terms of modeling capabilities and in terms of ability to find out practical solutions to implement. In other words simulation practices involve many different aspects featured by multisided and multidisciplinary facets.

In particular, container terminal simulation models can be very different from one another depending on their scope, applicability, functionalities, level of detail and underlying paradigms. With this in mind, the proposed research work, seeks to bring about a comprehensive as well as flexible tool that can be used for design testing, dynamic analysis, decision support but also for performances monitoring and control. To this end the simulation model capabilities include the ability to simulate operational processes such as arrivals (vessels, feeder-ships, trains and trucks) and loading/unloading operations occurring quayside and landside in a typical container terminal (expressly conceived for being as general as possible in such a way that it can enclose all the typical features of a container terminal). Moreover, the simulation model input parameters have been accurately selected to allow evaluating different design possibilities based on real and potential resources availability and structural changes to investigate a wide variety of scenarios. It goes with a careful evaluation of constraints on loading and unloading critical times, yard capacity, equipment capacity, etc. given that waiting times and delays are cost to be avoided.

The paper is organized as follows: section 2 describes the requirements for the design of a new container terminal, section 3 deals with data collection while section 4 briefly presents the simulation model. Section 5 and 6 reports simulation results and summarizes the conclusions.

2. REQUIREMENTS FOR THE DESIGN OF A NEW CONTAINER TERMINAL

As already mentioned in the Introduction section, Container terminal design is quite a complicated issue because of the different entities and flows interacting each other. This section summarizes the requirements for the design of a new container terminal.

It is assumed that the container terminal must work h24, d365. The terminal lay-out is characterized by:

- a 1200 meters quay;
- a 900 meters wide yard with up to 30000 available containers slots;
- a rail terminal with 8 tracks;
- an entrance gate with up to 30 lanes.

At this stage of the design, it is supposed that the container terminal life cycle will be subdivided in three phases:

- low operational efficiency (start-up period), up to 12 months (Lo-O);
- regular operational efficiency, at least 12 months (R-O) after the Lo-O period;
- high operational efficiency, during the remaining part of the terminal life cycle (Hi-O).

Table 1 reports the duration of each single operational efficiency level, the total number of TEUs expected as well as the expected division between 20” and 40” containers. Additionally, table 2 reports information about the Import/Export flows during the three operational efficiency levels and expected percentage of TEUs moved by feeder ships, trucks and trains.

The import flow will come from international shipping companies through containerships (mother vessels) with capacity up to 12500 TEUs. Such containers will be then redirected within the region through feeder ships, trucks and trains. The export flow (arriving through feeder ships, trucks and trains) may leave the port through international shipping companies (mother vessels). Imported and exported containers are stored in the yard before leaving the terminal with very limited transshipment operations. In addition, it is required that the average waiting time of containers in the yard area is 10 days with a 48 hours variance.

Berth unloading and loading operations will be executed by using quay cranes while yard connections will be assured by Straddle Carriers; the rail terminal will make use of Rail Mounted Transtainer (RMT). In particular cases it will be also required the use of Reach Stackers to move containers to and from the yard as well as for housekeeping operations (e.g. in case of Straddle Carriers maintenance operations, containers flow peaks, etc.).

Table 1 – Duration of the different operational efficiency levels and containers flow division

Operational Efficiency Level		Duration [Months]	Containers Flow [TEUs/year]	Total Flow Division	
				40”	20”
Lo-O	Low Operational Efficiency	12	250000	87500	75000
R-O	Regular Operational Efficiency	12	700000	245000	210000
Hi-O	High Operational Efficiency	TBD	1000000	350000	300000

Table 2 – Average containers import/export flow division

Operational Efficiency Level		Average Import/Export Flow	Average Import/Export Flow Division		
			to/from Train	to/from Truck	to/from Feeder Ship
Lo-O	Low Operational Efficiency	50%	70%	20%	10%
R-O	Regular Operational Efficiency	50%	70%	20%	10%
Hi-O	High Operational Efficiency	50%	70%	20%	10%

According to the information reported above and in tables 1 and 2, the design requires to check if the yard capability is enough to handle the TEUs flow hypothesized in the three operational efficiency levels. It is also hypothesized that the weight of containers handled in the terminal does not exceed 45 tons.

To this end, it is required a risk lower than 10% to saturate more than 75% of the available yard capability. It is also required to design the three operational efficiency levels scenarios by evaluating the total number of Straddle Carriers, Quay cranes, Reach Stacked and Rail Mounted Transtainers.

The following are additional requirements (starting from the beginning of the Regular Operational Efficiency phase):

- mother vessels unloading and loading operations must be completed within 48 hours (even in case of equipment failure and maintenance operations);
- up to 4 trains (with capacity up to 60 containers) must be unloaded and loaded within 6 hours from their arrival.

3. DATA COLLECTION

One of the most important steps in a simulation study is to accurately collect all the data needed to appropriately feed the simulation model. Without containers handling equipment technical data it would be impossible to design the terminal design and meet all the requirements reported in section 2. Table 3 reports an example of technical data collected for container handling equipment including the equipment name, capacity, speed and productivity. The speed is intended as the equipment overall speed while the operational productivity is the number of containers that the equipment can handle per hour. Note that the portainers (quay cranes) outreach is always greater than 44 meters (for each type of container).

Table 3 – Example of technical data for container handling equipment

Equipment		Capacity	Piled Containers	speed	Operational Productivity
		[kg]	-	[m/s]	[TEU/h]
PT-1	Portainer	80000	5	0.75	30
PT-2	Portainer	50000	5	0.75	25
PT-3	Portainer	46000	5	0.50	25
RT-1	Rail Transtainer	50000	5	1.00	25
RT-2	Rail Transtainer	50000	5	1.00	20
RS-1	Reach Stacker	46000	5	7.00	20
CS-1	Straddle carrier	50000	4	10.00	25
CS-2	Straddle carrier	50000	5	10.00	25
CS-3	Straddle carrier	50000	5	10.00	25

Table 4 reports an example of information about purchase costs, operative costs and maintenance costs for the container handling equipment. The operative costs include personnel costs and all other direct costs (e.g. fuel, energy, etc.) while the maintenance costs are evaluated on a yearly base. Additional information have been collected regarding the inter-arrival times for mother vessels, feeders, trucks and trains.

Table 4 – Information about Purchase Costs, Operative Costs and Delivery Time for each container handling equipment

Equipment		Purchase cost	Operative Cost	Maintenance Cost
		[kEuro]	[Euro/h]	[kEuro/year]
PT-1	Portainer	8471.11	210.21	20.74
PT-2	Portainer	6763.47	167.19	18.67
PT-3	Portainer	2387.70	73.58	36.60
RT-1	Rail Transtainer	2346.15	44.91	8.80
RT-2	Rail Transtainer	1740.28	48.42	23.98
RS-1	Reach Stacker	348.74	8.26	3.73
CS-1	Straddle carrier	580.40	8.92	3.43
CS-2	Straddle carrier	950.40	9.42	4.50
CS-3	Straddle carrier	780.44	9.64	5.80

In addition, according to Longo (2010) and Bruzzone et al. (2007), breakdowns and maintenance operations for quay cranes and yard resources have been taken into account. For container handling equipment, the following parameters have been taken into consideration: the failure rate (Fr-1) during the Infant Mortality Period (IMP), the failure rate (Fr-2) during the Useful Life (UL), the failure rate (Fr-3) in the last part of the equipment lifecycle, Wear Out Period (WOP) and the Life Extension Date (LED). The approach used by author for modelling the equipment failure rate is a graphical representation known as bathtub curve. The approach based on the bathtub curve is reported in many books on reliability theory (Birolini, 2003; Rausand and Hoyland, 2004).

The failure rate during the IMP and during the WOP is calculated using a two-parameter Weibull distribution. The failure rate during the UL makes use of a negative exponential distribution. Equations (1) and (2) are used within the simulation model for evaluating the reliability and the failure probability density function of each container handling equipment.

$$R(t) = e^{-\int_0^t Fr(t)dt} \tag{1}$$

$$f(t) = Fr(t) * e^{-\int_0^t Fr(t)dt} \tag{2}$$

- R(t) reliability function
- Fr(t) failure rate, defined as number of failures per unit of time
- f(t) failure probability density function

Table 5 reports information about non operative service time for each container handling equipment. Non operative service time must be intended as up-times in which the equipment is available but cannot be used due to ongoing operations such as re-fueling, operators shift, etc.

Finally, Table 6 reports information about other costs, including annual operating costs, control room operating costs, gates annual costs, yard annual costs, rail annual cost and quay annual costs.

Table 5 – Information about Non Operative Service Time for each container handling equipment

Equipment		Non Operative Service Time [hours/year]
PT-1	Portainer	286.93
PT-2	Portainer	287.75
PT-3	Portainer	603.28
RT-1	Rail Transtainer	431.98
RT-2	Rail Transtainer	400.59
RS-1	Reach Stacker	899.04
CS-1	Straddle carrier	867.79
CS-2	Straddle carrier	728.50
CS-3	Straddle carrier	984.00

Table 6 – Information about other terminal annual costs

Cost Type	Value [k€/year]
Container Terminal Preparation Costs	120000,00
Annual Operating Costs	9000,00
Control Room Annual Costs	2200,00
Gates Annual Costs	900,00
Yard Annual Costs	500,00
Rail Annual Costs	800,00
Quay Annual Costs	320,00

4. DESIGNING THE CONTAINER TERMINAL THROUGH A SIMULATION MODEL

The simulation model consists of four different parts:

- a flow chart
- an animation
- an input section
- an output section

Within the flow chart part the user can visually assess how the simulation model works in terms of entities, resources, flows and relations. The animation shows the evolution of the container terminal operations over the time (Yazdani et al., 2005); the input section allows the user setting up a number of different input parameters such as number of straddle carriers, number of reach stackers, inter-arrival times for mother vessels, feeders, trains and trucks, etc. Finally, the output section reports the main simulation results, including the total number of containers currently stored in the yard, the risk of yard saturation, the total number of vessels, trucks and trains served from the beginning of the simulation, the vessels turn-around times, the trains turn-around times, the container handling equipment utilization levels.

Figure 1 shows the simulation model animation that includes vessels unloading/loading operations, movements from/to the yard performed by straddle carriers, trains unloading/loading operations executed by rail transtainers and trucks entering to and exiting from the yard area through dedicated gates. It is worth noticing that the user can switch among the three operational levels just by clicking the buttons in the right part of the animation (Low-O, R-O and Hi-O respectively).

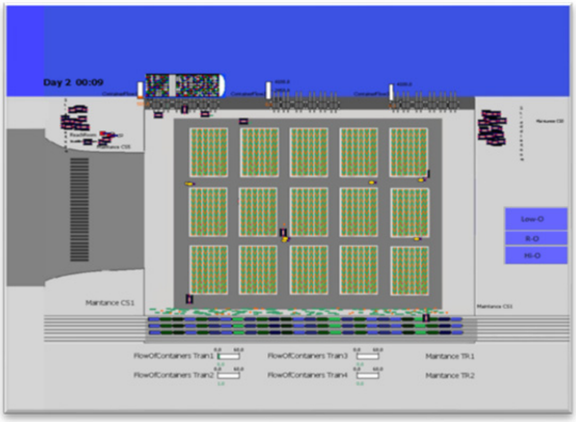

Figure 1 – Simulation Model Animation

The figure 2 shows a view of the Input Section and some of the parameters that can be changed at run-time by the user (additional parameters can be changed by the user before the beginning of the simulation).

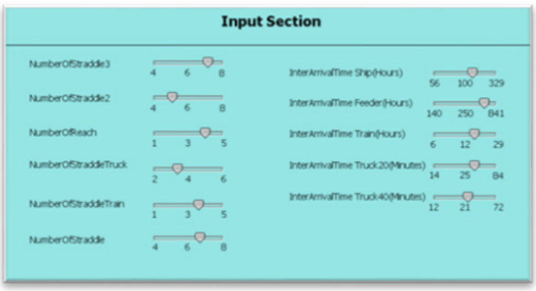

Figure 2 – Simulation model input section

The figure 3 shows the output section reporting the most important simulation results.

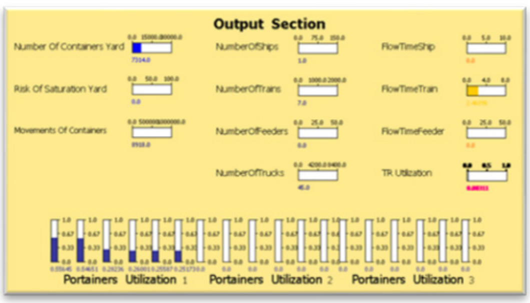

Figure 3 – Simulation model output section

Simulation results are also saved in databases and can be accessed both at run-time and at the end of the simulation as well as they can be exported on .txt or .xls files for additional analysis.

5. SIMULATION BASED DESIGN ANALYSIS AND RESULTS

In this section an application example is proposed that shows how the simulation model can be used to support the design of the container terminal. The simulation model briefly presented in section 4 has been used to support the container terminal design and to meet the requirements described in section 2. To this end multiple simulation runs have been executed and the results are summarized below.

As first step the simulation model has been used to check possible combinations of mother vessels, feeders, trucks and trains to respect the yearly flow of import/export containers reported in tables 1 and 2. Table 5 reports the results of the simulation with average number of mother vessels, feeders, trucks and trains in the three different operational efficiency level phases.

Table 5 – Number of mother vessels, feeders, trucks, trains and flow of containers over 1 year in the three operational levels scenarios

	Mother Vessels	Feeders	Trucks	Trains	TOTAL TEUs FLOW
Low-O	32	14	25000	1458	250000
R-O	88	36	70000	4083	700000
Hi-O	126	50	100000	5833	1000000

As far as the risk to saturate more than 75% of the available yard capacity is concerned, according to the data reported in table 5 it never happens that the risk is greater than 10%. Basically, this means that the current yard design (with capacity up to 30000 TEUs) can be accepted and it is able to handle the import/export flow of containers.

The simulation model has been also used to set-up correctly the number of quay cranes, straddle carriers, reach stackers and rail transtainers. To this end, note that from the 12th month (starting of the R-O phase), there is a requirement about the mother vessel unloading and loading operations; such operations must be completed within 48 hours from the vessel arrival (even in case of equipment failure and maintenance operations). In order to meet this requirement, simulation results show that 18 quay cranes are required (PT1-type portainers).

A similar analysis has been carried out regarding the number of straddle carrier needed to meet the requirement in each operational efficiency scenario. It has been found out that in the Hi-O scenario, 4 straddle carriers for each quay crane are needed to move container to/from the yard. As far as the requirement for train unloading and loading operations is concerned (4 trains to be handled within 6 hours from their arrival), the simulation results show that 2 rail transtainer (RT1) are needed each one served by 3 straddle carriers for yard connections.

As far as the number of reach stackers is concerned, the simulation model shows that 10 reach stackers are enough (in the Hi-O scenario) to support yard operations in case of straddle carriers failure and maintenance and in case of flow peaks.

Finally, the simulation model is also able to calculate the main costs both for container handling equipment purchase and for running the terminal container. An example of costs evaluation is reported in tables 7 and 8. Table 7 reports the purchase costs, the operating costs and maintenance costs for the portainers, while table 8 reports the same costs for the rail transtainers.

Table 7 – Purchase, Operating and Maintenance costs for the Portainers

Portainers	**Cost [k€]**
Purchase Costs	152479.98
Operating Costs	22097.28
Maintenance Costs	373.32

Table 8 – Purchase, Operating and Maintenance costs for the Rail Transtainers

Rail Transtainers	**Cost [k€]**
Purchase Costs	4692.30
Operating Costs	786.83
Maintenance Costs	17.600

6. CONCLUSIONS

The main goal of this study was to assess the potential of Modeling & Simulation to support the design of container terminals. To this end, a specific container terminal design scenario has been proposed; the scenario is characterized by three operational efficiency levels (according to the terminal evolution over the time) and, for each level, the expected import/export flows of containers have been hypothesized. Additional information (needed for the design) are also reported: technical data for each container handling equipment and costs (purchase, operative, maintenance and annual general costs).

Based on these data and information, the authors have developed a simulation model that is able to recreate with high-accuracy all the container terminal operations, including vessels arrival and departure, vessels unloading and loading operations, movement to/from the yard by straddle carriers, trains and trucks arrivals and departures and related loading and unloading operations. The simulation model is equipped with a nice animation to show the ongoing operations during the simulation, with an easy to use input section (for parameters variation) and with an output section to show the simulation results.

In the last section of the paper, an application example is provided that shows how the simulation model can be used to support the container terminal design. In order to fulfill the design requirements, the simulation model has been used to evaluate sustainable flows of vessels, feeders, trains and trucks and to calculate the number of portainers, straddle carriers, reach stackers and rail transtainers needed and related costs.

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DISCRETE EVENT SIMULATION FOR VIRTUAL EXPERIMENTATION ON MARINE DECISION SUPPORT SYSTEM

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ABSTRACT

This paper proposes the use of constructive simulation as test bed to virtually experiment the validity of a decision support system devoted to plan the patrolling paths of a set of assets in naval operations. The test case proposed is based on anti-piracy scenarios and integrates a discrete event simulator with an Asset Allocator Decision Support System (AADSS) through web services in order to keep them aligned among themselves as well as with the existing situation. The authors included description of the proposed architecture that guarantees flexibility in terms of interoperability with other systems.

INTRODUCTION

Today the availability of big data, new models and high performance distributed computational power is enabling innovative solutions for decision making in a wide spectrum of applications. From industry to defense as well as in very specific areas the planners are evolving culturally in terms of capability to use evolved ICT solutions integrated within their decision processes. Often these resources are enablers for finalizing more quickly more reliable plans; so it is evident these elements are pushing forward the development and adopting of new generations of DSS (Decision Support Systems) able to integrate simulation and other planning methodologies and optimization tools. These conditions are also present in defense and homeland security generating a growing importance of these methodologies for major entities in the sector (Bruzzone et al. 2011b). In general these integrated solutions could be applied over a wide spectrum of scenarios involving actors playing their role over different domains (Bruzzone et al. 2011c, An et al., 2012; Sujit, Sousa, & Pereira, 2015). The evaluation of optimal solution for such complex non-conventional scenarios requires the ability to evaluate several alternative plans against courses of action (Richards, Bellingham, Tillerson, & How, 2002; Bruzzone et al. 2011a).

As anticipated Decision Support Systems fulfill their potential by being integrated with modeling and simulation and there are consolidated experiences in this sector (Bruzzone & Signorile, 1998; Tulpule et al., 2011; Tulpule et al. 2010; Longo F., 2012; Bruzzone 2013; Grasso et al. 2014a). Indeed interoperable simulation supports the evaluation of performances and hypothesis inconsistencies between DSS and the real world.

Modeling & Simulation is thus used to evaluate in details the effects of decisions and planning proposals suggested by the smart planner and to measure their resilience to stochastic external factors (Medeiros & Silva, 2010; Cavallaro & Melouk, 2007; Bruzzone & Mosca, 2002; Massei et a. 2011), as well as for VV&A purposes (Bruzzone, 2002; Balci, 1998). In the present paper the authors propose this approach for supporting patrol planning over an oceanic area for anti-piracy missions.

In this paper, it is proposed the integration a route optimizer based on genetic algorithms to increase the probability to prevent pirate actions with a stochastic discrete event simulator focused on evaluating the fitness and supporting the decision maker in finalizing the plan.

The present paper addresses these issues within an anti-piracy mission in order to provide the decision makers with an improved capability in finalizing their patrol routes with respect to many boundaries conditions including attack probability, weather forecasts, available asset characteristics, deployment, etc.

1 THE SIMULATOR AND THE PATROLLING PATH OPTIMIZER

In the present paper the authors propose a solution for supporting patrol planning over an oceanic area in anti-piracy operations. The proposal is integrating a route optimizer based on genetic algorithm (AADSS) which reduces the probability of pirate actions with a

stochastic discrete event simulator (JAMS2) focused on evaluating the fitness and supporting the decision maker in finalizing the plan (Grasso et al.2013). Indeed JAMS2 (Advanced Marine Security Simulator) is a simplified version derived from PANOPEA simulator created to reproduce the whole traffic over large areas by Simulation Team (Bruzzone et al. 2011c, Bruzzone et al. 2011d). JAMS2 has been adapted to respond dynamically and quickly to the need of quantitative evaluation of the performance for a DSS (Decision Support System) in anti-piracy scenarios. The simulator executes the path proposed by the Optimal Asset Allocator embedded into the AADSS reacting dynamically to the contingencies and requests received by the vessels to investigate and inspect suspect boats. The vessels in the simulator are directed by IA-CGF (Intelligent Agents Computer Generated Forces) developed by Simulation Team for a wide spectrum of applications and operate autonomously based on the situation awareness resulting from their C2 status (Bruzzone, Tremori, Massei, 2011e).
The simulation allows to check the path robustness and efficacy within the proposed piracy scenario. In the case studied for this case-study the mission environment is the Indian Ocean. JAMS2 adopts stochastic discrete event agent driven paradigm in order to test the effectiveness and efficiency of the AADSS (Asset Allocator Decision Support System); this is achieved, as anticipated, by simulating the mission over a time frame based on the patrol plan assigned to each vessel of the coalition.
JAMS2 simulates threats and asset behavior based on external conditions and operating states; appropriate target functions are implemented in the simulator for evaluating sensor performance and platform capabilities with respect of the dynamic evolution of the boundary conditions (e.g. radar efficiency versus weather conditions). In JAMS2 the real threats as well as the false alarms are generated based on probability matrices based on historical data; these data could be made consistent with the ones used by the AADSS for the planning or could differ in order to evaluate planning robustness (Grasso et al. 2014b); the IA-CGF directs the reaction of the assets based on existing ROEs (Rules of Engagement); in general these assets correspond to Frigates or Destroyers that could proceed by themselves or, more often, by activating their available resources; each asset has its own configuration which could include UAVs (Unmanned Aerial Vehicles), Helicopters, and RHIBs (Rigid Hull Inflatable Boats); therefore the JAMS2 assets and resources structure are able to model also other type of assets such as Patrolling Aircraft, AUV & gliders, Long Range UAV, Gliders etc. for more extended scenario. In order to carry out detection, classification and, when applicable, engagement of the suspect boats the assets should apply specific procedures that could affect the assigned plan including deviations, delays, changes, etc.
The false alarms are included in the simulation to evaluate the patrolling robustness to external phenomena. Obviously the simulator provides detailed metrics for quantitative evaluation of the solution proposed by the Asset Allocator; in addition JAMS could be used also to support training and capability assessment over these scenarios. The main goal is to evaluate potential inconsistencies between hypothesis used in the Assets Allocator and the real world simulated by JAMS. The simulator, in addition, to playing the role of the "real world" to test and validate the proposal, it could also be used to conduct what-if analysis directly by the decision maker. As anticipated the mission environment corresponds to the West Indian Ocean covering a wide geographic area of around 1500 by 1500 Nautical Miles with four patrolling surface vessels able to deploy other resources (i.e. helicopters, UAV, RHIB) for investigation, inspection and engagements of potential threats. As anticipated the current implementation of JAMS2, in Java, is derived from PANOPEA and IA-CGF; so it is designed for being interoperable through High Level Architecture Standard (HLA); therefore this characteristic is not yet activated due to the nature of the structure of the AADSS working through web services and due to the priorities in tailoring it with respect to the available resources for this initiative.
The simulator has been tested through virtual experimentation by applying Analysis of Variance techniques (ANOVA) on the proposed scenario (Kleijnen, 2007; Montgomery, 2000; Longo, 2010; Telford, 2012). The results of the experimentation campaign are used in the process of Verification, Validation and Accreditation (VV&A) of the Asset Allocator (Bruzzone 2002).
Currently the vessels and boats are modeled as surface elements (friends, foe, neutral) characterized by dynamic behavior. As anticipated the simulator includes the assets' reaction to detected threats and action to be undertaken for suspect threats. In terms of use mode JAMS2 is currently available for different applications; it could be used to support AADSS for the Asset Patrol Optimization as well as for educating and training planners in operational planning and related improvement and dynamic reorganization by using innovative tools like the ones proposed here. The evaluation of the proposed plan respect of risks and stochastic factors is achieved by replicating JAMS2 simulation runs just by changing random seeds to finalize the ANOVA. JAMS2 results measure the AADSS plan, in terms of:

- Robustness
- Responsiveness
- Feasibility
- Actual Duration
- Actual Cost
- Scenario Awareness
- Area Coverage
- Detections
- Capability to inspect and/or Engage Targets
- False Alarms
- Overall Success of Patrol Mission

JAMS2 efficiency in terms of computational time has been tested to evaluate the possible dynamic interaction

with the genetic algorithm embedded within the AADSS (Figure 1) (Bruzzone et al. 2013b; Grasso et al. 2014b).
The JAMS2 implementation is based on Java NetBeans to be able to operate over multiple Operating Systems.
The integration with AADSS is obtained sharing configuration and solution Dbase through a web service.

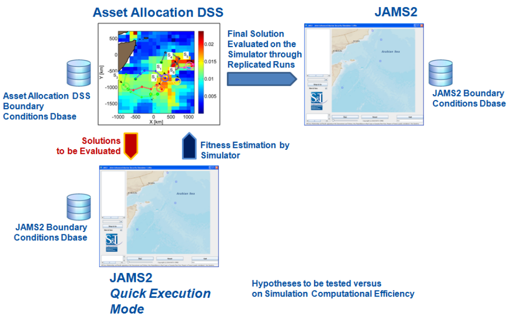

Figure 1: JAMS2 Dynamically Used With the Asset Allocator

Therefore in future by enabling JAMS capability to be connected to an HLA federation could allow to operate both as stand-alone and federated with other simulators.
The Graphical User Interface (Figure 2) is designed to tune simulation parameters, such as replication runs, random seeds and additional boundary conditions, and to execute the simulator. Furthermore the GUI is useful in validating the simulation by observing simulation run in terms of dynamic behavior of assets, resources, false alarms and threats. JAMS2 is enabled to run in real time and fast time. Statistical distributions, such as risk map for threats, and weather databases are used during simulations by applying Montecarlo techniques to generate discrete events and corresponding actions/behaviors. Threats and false alarms adopt stochastic behavior reacting dynamically to assets evolution; indeed Intelligent Agents (IA) are used to reproduce sophisticated behaviors for small/medium size boats in order to react to the patrol actions and policies within the area suggested by the AADSS.

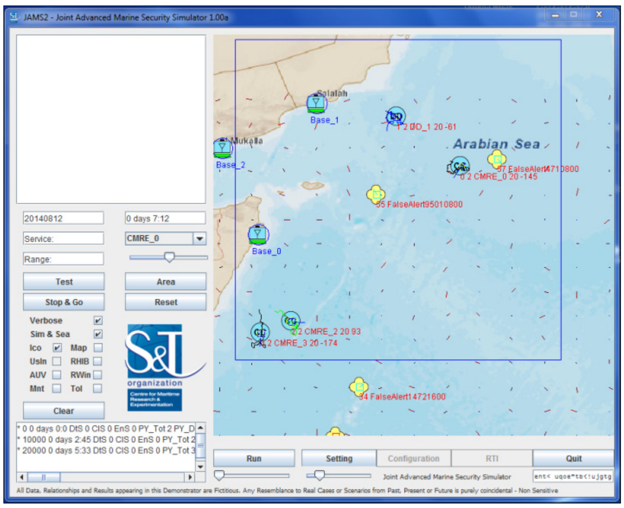

Figure 2: JAMS2 GUI

In a similar way the agents controlling the patrolling vessels adopt their different behaviors based on their situation awareness and their specific characteristics; in general the IA controlling the patrol units could decide among different alternatives such as:

- EXE: execution of the planned path
- CLA: use of their resources for target identification, classification and/or engagement, deviating from the planned path
- RQS: request external support for target identification, classification and/or engagement
- RES: restoring the assigned planned path after contingencies

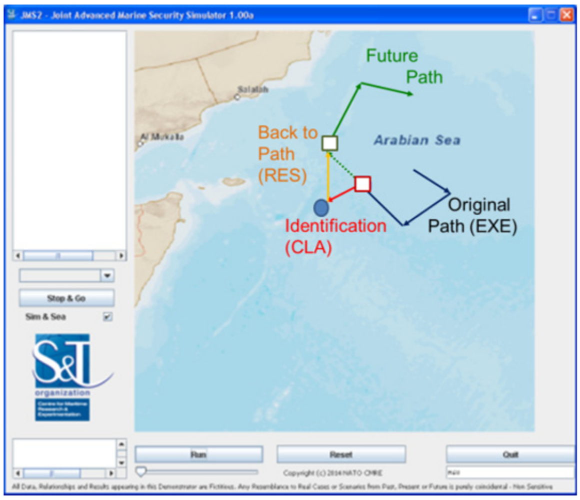

Figure 3: Asset Undertaken Actions and Operating Modes

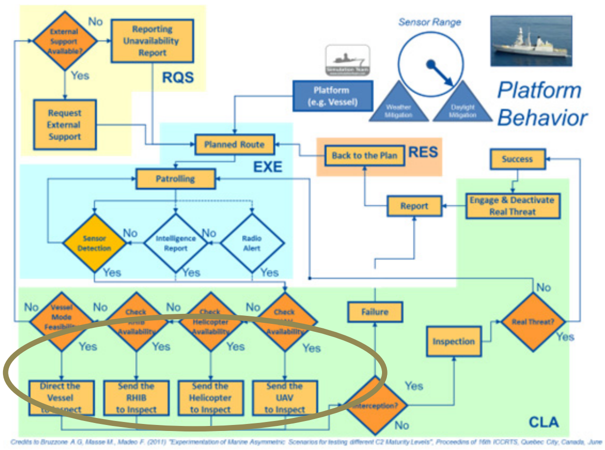

Figure 4: JAMS2 Platform Behavior

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Figure 3 shows the visual representation in the GUI of the policies adopted by the IA interacting with targets.
The current release of JAMS2 does not simulate intelligence reports and radio communications contrary to PANOPEA (Bruzzone et al. 2011d); basic rules are implemented in terms of priorities in using the different resources; so when it is necessary to assign some resources to inspecting a boat based on the available resources and target distance, the agent selectd the proper choice (Figure 4).
The capability to simulate different shared resources in the scenario is necessary to create complex autonomous

behavior; this is critical in developing a tool whether for training of operators and officers, for testing Rules of Engagement (ROE), and/or to support analysis

2 TARGET

Targets represent a possible risk source. Indeed the behavior, as for assets, is based on external conditions and operating states. Targets are characterized by importance factors, hiding capabilities, status and class of boat; both real threats (pirates) and false alarms (small/medium sized boats) are generated based on risk maps defined by historical data and simulated using Montecarlo techniques. In the simulator, only asymmetric assets are implemented, nonetheless JAMS2 structure allows the implementation of other types of targets for different scenarios. The following target operation modes are implemented in the simulator:

- REG: Regular behavior
- NRE: Non-reactive behavior
- COP: Cooperative behavior
- NCP: Non-cooperative behavior
- FOE: Aggressive behavior

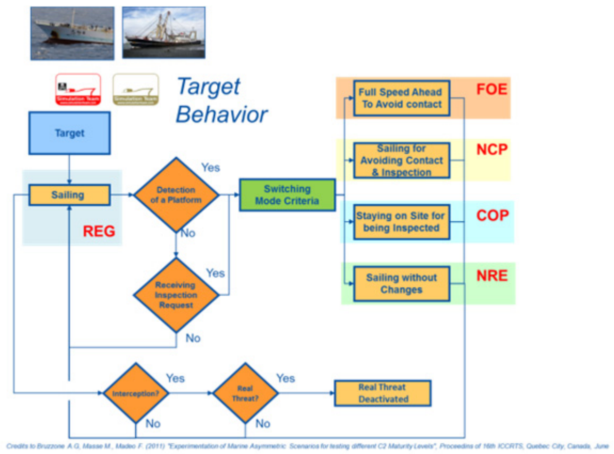

Figure 5: JAMS2 Targets Behavior

Switching Mode Criteria is applied in the simulator to assign operation modes to threats perceiving an asset when detected or when receiving an inspection request (Figure 5).
In JAMS2 the "*mode probability*" of the boats depends on their nature (if pirates are on board), Current Status (e.g. REG, NRE, etc.), and Platform distance (in three levels) as shown in the explicative Table 1.

3 INPUT FILES

JAMS2 receives data and information about current situation from the AADSS; these data are used as simulation boundary conditions and represent the real data collected over the area (e.g. sea, wind, temperature, currents etc.) as well as information corresponding to historical data (i.e. probability of attack in a zone). The data are extracted from the maritime scenario database and transferred as files through a web service application to the JAMS2 operative directory; these elements include, among the others, the following information:

- Planned path exploited in waypoints (CSV format)
- General Configuration (ASCII format)
- Asset basic characteristics (ASCII format)
- Candidate solution identifier (ASCII format)
- Probability of attack (Piracy Activity Group maps, PAG maps) over 20x16 cells (TIFF format)
- Weather Conditions over 20x16 cells (TIFF format)

Table 1: Target Mode Probability

Switching Mode Input			Mode Probability				
Target Nature	Current Status	Platform Distance	RE G	NR E	CO P	NC P	FO E
Real Threat	NCP	≤1 NM	0%	4%	1%	25 %	70 %
Real Threat	NCP	(1 NM, 4 NM]	5%	4%	1%	60 %	30 %
Real Threat	NCP	>4 NM	5%	4%	1%	70 %	20 %
Real Threat	NRE	≤1 NM	0%	14 %	1%	25 %	60 %
Real Threat	NRE	(1 NM, 4 NM]	5%	24 %	1%	50 %	20 %
Real Threat	NRE	>4 NM	10 %	49 %	1%	30 %	10 %
False Alarm	REG	≤1 NM	10 %	10 %	70 %	5%	0%
False Alarm	REG	(1 NM, 4 NM]	20 %	15 %	50 %	10 %	5%
False Alarm	REG	>4 NM	20 %	30 %	20 %	25 %	5%

As JAMS2 goal is the evaluation of planned path robustness and flexibility, input database and data for processing threats and assets behavior are kept separated.

4 EXPERIMENTATION

Experimental campaign within the JAMS2 project addresses VV&A of the simulator. Due to the strong non linearities of the simulated system a careful experimental design is necessary for proper verification of the stochastic influence on the results and to quantify corresponding experimental error (Kleijnen, 2007). The methodology used is the analysis of the Mean Square Pure Error (MSpE). The corresponding results allow the identification of the optimal duration of the simulation run for properly estimating the pure experimental error introduced by the stochastic factors. In this paper it is proposed a part of the preliminary analysis conducted on a subset of target functions:

- Total Covered Area
- Mean Time Elapsed Deviating from the Planned Path
- Max Time Elapsed Deviating from the Planned Path
- Patrolling Time Percentage

Patrolling Time Percentage is the percentage of time spent on the planned path with respect to the mission time; Mean and Max Time Elapsed Deviating from the Original Path are respectively mean and maximum time spent by the ship deviating from the planned path, intervening and going back on the planned path.

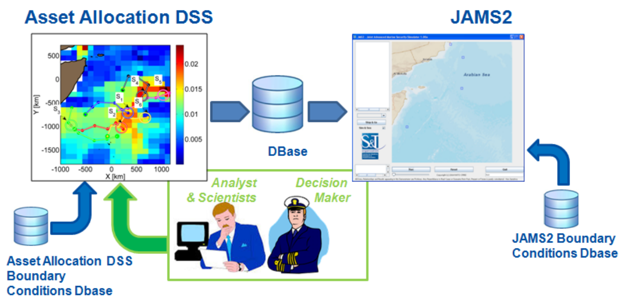

Figure 6: JAMS2 Original Configuration with Optimal Asset Allocator

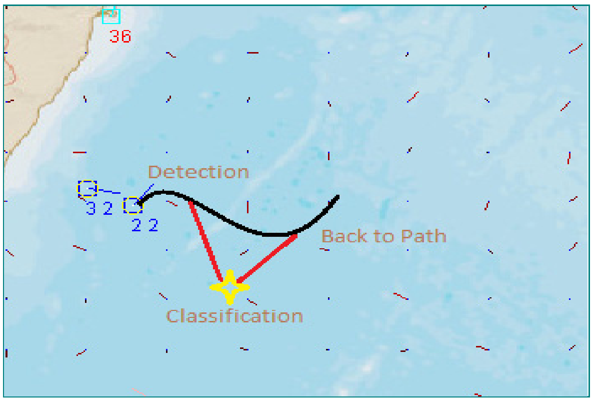

Figure 7: Asset Deviating from the Planned Path

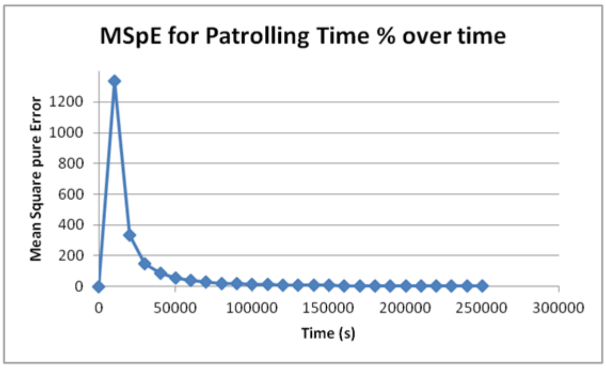

Figure 8: MSpE for Patrolling Time Percentage over time for Detection Range R1

In Figure 7 it proposed the graphical representation of the ship deviating from the planned path (black line) after detecting a target.

The experimentation was conducted choosing three values of Intervention Range as input parameter: R1, R2, R3 (where R1<R2<R3).

For each of the three cases the experimentation was conducted with the same number of replication using the same boundary conditions. The simulation duration is set to three days for each run; JAMS results over the experimental campaign represent an important element for VV&A of the models and for evaluating robustness of AADSS algorithms.

The results obtained summarize the evolution of MSpE for each target function with respect to the simulation time and replications; for instance Figure 8 shows Patrolling Time Percentage variance for Intervention Range R1 stabilizing within one simulation day; similar graphs are proposing the other target functions.

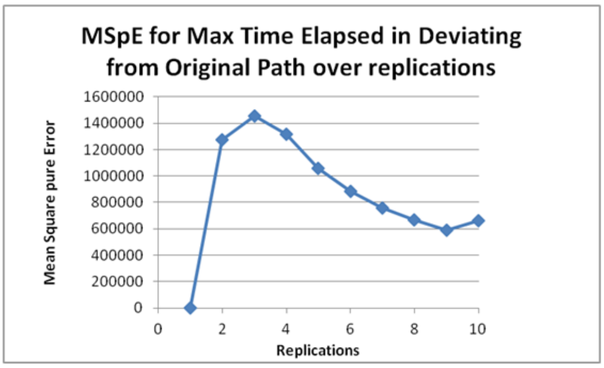

Figure 9: MSpE for Max Time Elapsed in Deviating from Original Path over replications for detection range R1

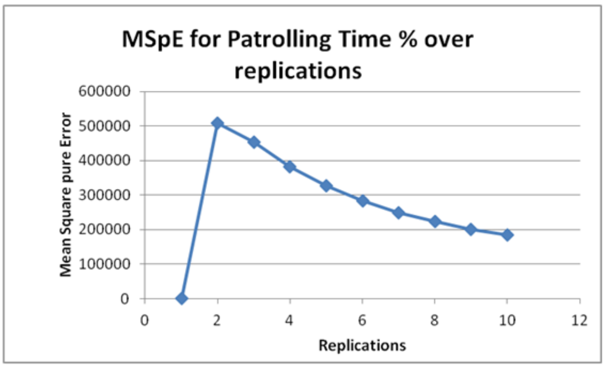

Figure 10: MSpE for Patrolling Time Percentage over replications for Detection Range R1

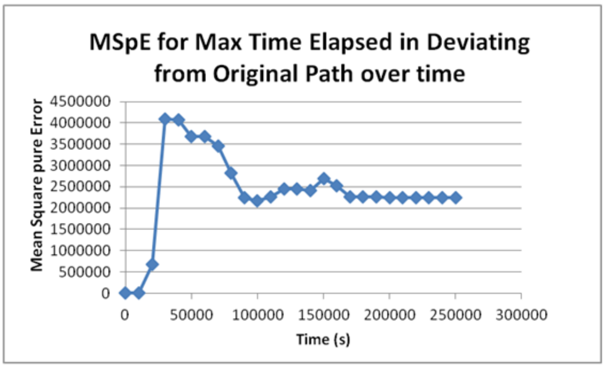

Figure 11: MSpE for Max Time Elapsed in Deviating from Original Path over time for detection range R2

Figure 11 shows the MSpE for Max Time Elapsed Deviating from the Original Path stabilizing within three days. Comparing the graphs is possible to outline a common trend for target functions changing the Intervention Range. Figure 15 shows the Max Time Elapsed in Deviating from Original Path is increasing with the *Intervention Range*. This means that assets spend more time investigating targets with high intervention range than with small ones. The same is observable in Figure 17. Today the current release of the JAMS2 simulator does not include detailed models for sensors, weapon systems and communication due to resource constraints. Meta-models already implemented in JAMS2 guarantee the generalization capacity leaving space for future further developments related to evaluating the influence of innovative solutions or procedures in anti-piracy as already done in other cases (Bruzzone et al. 2011c).

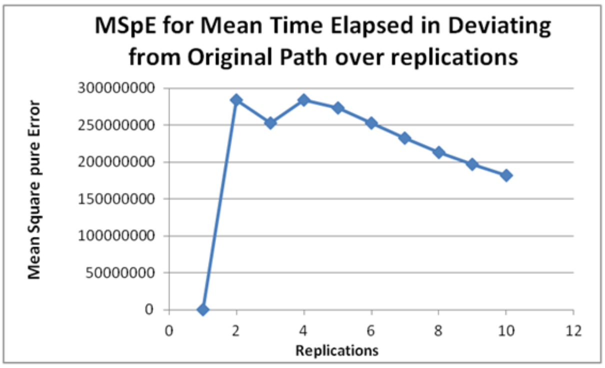

Figure 12: MSpE for Mean Time Elapsed in Deviating from Original Path over replications for detection range R3

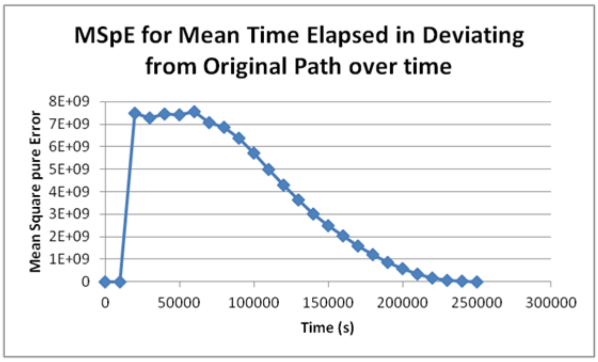

Figure 13: MSpE for Mean Time Elapsed in Deviating from Original Path over time for detection range R1

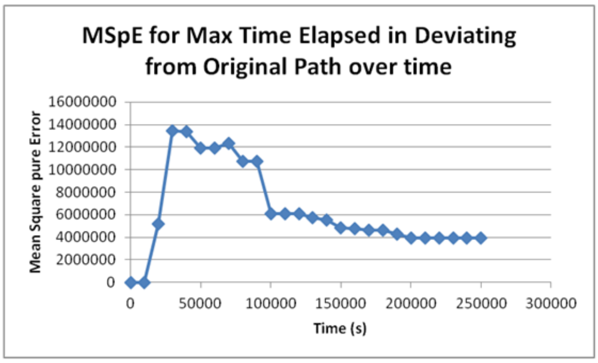

Figure 14: MSpE for Max Time Elapsed in Deviating from Original Path over time for detection range R3

For the same reason, currently a detailed Recognized Maritime Picture (RPM) and a traffic simulator reproducing all the targets in the area are not included; indeed in JAMS2 targets are generated based on a specific risk map for the simulation derived from the ones used in the AADSS. The solution is good for current purposes, but it does not allow for the evaluation of the resilience of alerts generated by analyzing the RPM such as the deviating course of a boat toward a cargo ship (corresponding to generating suspects on its behavior); these kind of behavioral data fusion are currently somewhat limited in this case contrary to simulators such as PANOPEA and it could be possible to consider the extension of the current model.

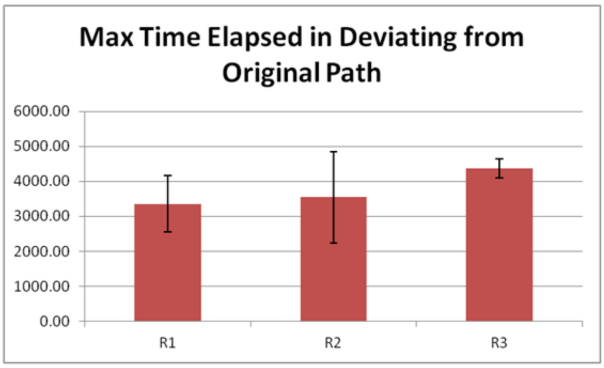

Figure 15: Average Max Time Elapsed in Deviating from Original Path over Intervention Range

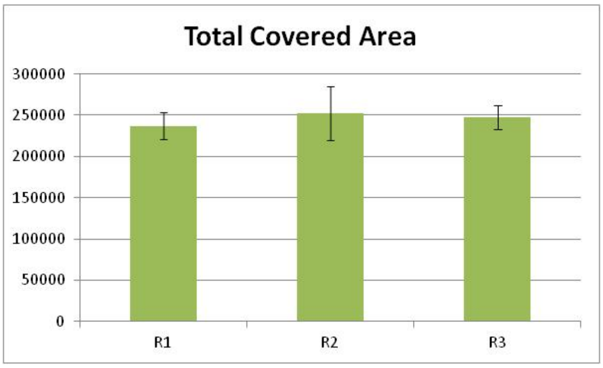

Figure 16: Average Total Covered Area over Intervention Range

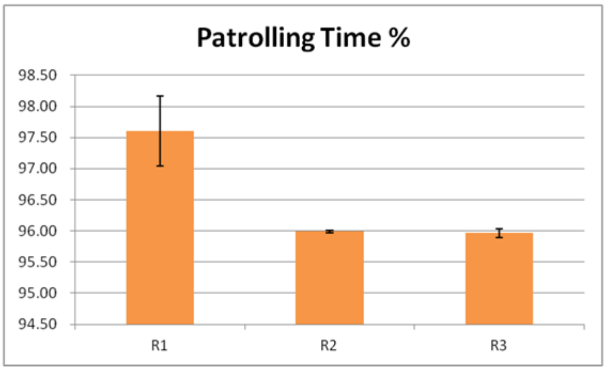

Figure 17: Average Patrolling Time Percentage over Intervention Range

In addition, thanks to the versatility of the JAMS2 architecture new type of assets could be implemented to address different scenarios for asymmetric warfare; the same implementation could be carried out for deployable resources to simulate more complex scenarios.
The Switching Mode capability model guarantees an easy way to redefine the tables; therefore the authors are evaluating the possibility to investigate the adoption of Fuzzy Allocation Matrices to determine threats operation mode. Another important potential of the current simulator is the possibility to develop a federation involving other existing simulators for supporting training and education. An example of such kind of

federation is shown in Figure 18

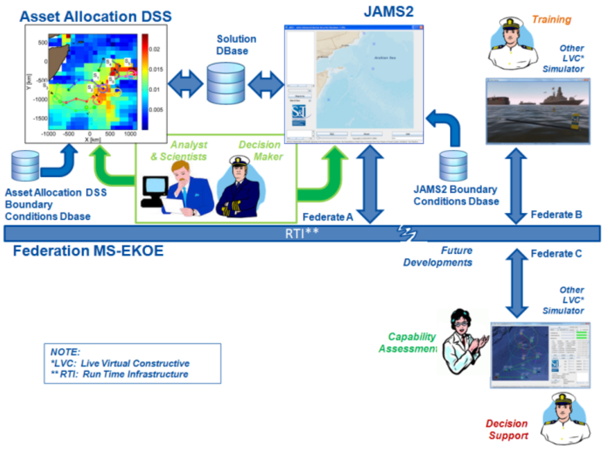

Figure 18: Example of a Federation with JAMS2

CONCLUSIONS

This paper presents an example of the study for the development of a simulation framework integrated with planning aids as support for patrolling routing optimization in anti-piracy operations; the flexible architecture used allows to achieve interesting conclusions even with limited resources within short time; in addition there is a big potential in further developing these models to create interoperable federation open for integrating other elements including real C2. In this case it could be interesting to create decision support systems integrating artificial intelligence methodologies and simulation within dynamic and reliable decision support systems.
Last, but not least the use of simulation in this context provides a strategic advantage in creating educational and training aids to promote the use of such innovative DSS among the user community and in improving the planning capability to face complex asymmetric scenarios.
Indeed the authors suggest using JAMS2 and the Optimal Asset Allocator for training and education purposes for decision makers; this is an important added value for this system in addition to its capability to be used as virtual test bed for Decision Support Systems

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INTEROPERABILITY AND PEROFRMANCE ANALYSIS OF A COMPLEX MARINE MULTIDOMAIN SIMULATION BASED ON HIGH LEVEL ARCHITECTURE

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ABSTRACT

In Modelling and Simulation the main standard for interoperability is HLA (High Level Architecture): this paper is focused on interoperability combining different simulators to create a modular and scalable approach for complex scenarios characterized by heavy computational workload. The case study addressed a within an extended maritime framework (EMF) including underwater operations, cyber warfare, autonomous systems and traditional vessels. The paper presents the architecture of the federation and also provides a performance analysis of the implementation when using different RTIs as well as a methodological approach to identify the most reliable and performing solution for the interoperability within this context.

Keywords: *HLA, Interoperability, Modelling and Simulation, Maritime Scenario.*

INTRODUCTION

Interoperability in Modelling and Simulation (M&S) addresses the goals of building large distributed simulations and facilitating model reuse. It is a key concept for organizations such as NATO where transformation efforts across multiple countries and research centers need to be integrated. For M&S applications the main standard for interoperability is HLA (High Level Architecture) (IEEE, 2010a), although other standards exist such as Distributed Interactive Simulation (DIS) (IEEE, 2015, 2012), CTIA, TENA, etc. Indeed HLA has been adopted as a international standard after being a solution promoted by US DoD; this architecture is evolving along last years and it has been subject of intense research for improving its potential and evaluating its capabilities .
This paper describes the work carried out in reference to a complex naval scenario involving multiple aspects requiring specific simulators. In the proposed case the authors address naval operations that involve multiple domains of the EMF including sea surface, underwater, air, cyberspace and space.
The paper presents an overview on interoperable simulation by addressing HLA and M&S related efficiency issues; these elements are used to address a specific simulation developed as HLA MCWS-MSTPA Federation by combining antisubmarine operations with cyberspace activities in a LVC (Live, Virtual Constructive) environment. The experiments conducted over this federation during integration tests are reported and used to address the performance analysis. In the tests, different analysis are conducted respect the influence of RTI (Run Time Infrastructure) respect federation involving multiple MCWS federates and execution federating MCWS simulators and MSTPA engine.

1. INTEROPERABILITY FOR MODELING THE CONTEXT

Indeed due to the complexity of this application area it is evident that it is an ideal context where interoperability represents an added value being able to integrate and substitute different models of the components (e.g. acoustic communications, electromagnetic communications, operational activities.. Indeed in the proposed case the use of a simulator developed by Cooperative Anti-Submarine Warfare based on multistatic sonar and autonomous systems is combined with the cyber warfare and its impact over the heterogeneous networks; the research is currently addressing aspects investigated by PARC and CASW programs within CMRE and carried out in collaboration with Simulation Team. Indeed the main focus of this paper is on interoperability of models operating within different domains and coupled by the operational environment: for instance in this case it is created an HLA federation where an acoustic physical model, a constructive tactical simulator and cyber warfare simulation interoperate dynamically real time and/or fast time. It is important to outline that this scenario is characterized by complex elements including physical components (e.g. environment, oceanic engineering, underwater acoustics), actor behaviors (e.g. ASW doctrine, submarine tactics, cyber defense) as well as influence of stochastic factors (e.g. sensor performance, system reliability, operational times and environmental conditions). Many boundary conditions strongly affect the overall performance of the ASW scenario and the entities are interacting dynamically within a context affected by uncertainty.

The introduction of AUVs (Autonomous Underwater Vehicles) and multistatic acoustic further emphasize the impact of cyber warfare being more sensitive to these aspects; the proposed case is based on not-classified releases of the models and by using variable that are not sensible (Bruzzone et al.2013b).

Traditionally Modeling & Simulation (M&S) has to be regarded as one of the most powerful methodologies for performance analysis of complex systems (Banks et al., 2010; Longo, 2011); indeed M&S has been largely used in this area (as suggested by the many research works already published, e.g. Longo et al., 2013; Longo et al. 2012) and, therefore, due to the reasons reported above, it represents the ideal a research tool to leverage on interoperability for producing scenarios within the interdependencies and constraints outlined above.

The authors developed these models and their interactions and studied how to federate together different systems, in particular the authors developed a Federation by integrating two federates adapted from previous models (Bruzzone et al. 2013c); one federate is the MCWS (Marine Cyber Warfare Simulator) tactical simulator (Bruzzone et al., 2013a). The other one is the acoustic engine MSTPA (MultiStatic Tactical Planning Aid) that has been adapted to operate as an HLA federate (Been et al., 2010, 2007; Wathelet et al., 2008).

MCWS is a simulator developed to explore operational scenarios involving the extended maritime framework over several different domains: underwater, surface, air, space and cyber with special attention to model the interoperability among actions carried out on the real world and that ones on the cyberspace. Indeed MCWS simulates a small scenario involving sonobuoys, multiple AUVs (Autonomous Underwater Vehicles) and surface vessels equipped by helicopters. In this case the geographic area is focused on a 400 square nautical miles where the role of the blue forces is to patrol the area and avoiding hostile submarine to cross it; indeed, concurrently, the simulator includes the model of an opposite submarine characterized by the goal to be able to move east to west under this area. It is possible to define different rules of engagement (ROE) to regulate the reactions of the submarine as well of the Surface ship. For instance with "*operational scenario mode*" whenever the submarine is detected the vessel proceed in engaging it and the submarine could react, while in "*not operational scenario mode*" the simulation goal is just to move the helicopter over the submarine without finalizing any engagement; in reality the model includes possibility to activate different ROEs (e.g. submarine could enabled/disabled to attack or just to react to an attack as well as the ship). This simulator allows estimating the probability of success of different players as well as detailed report on events, actions and Measure of Merits (MoM). In the model the heterogeneous network simulation is a critical component dealing with acoustic underwater modems, radio frequency, satellite communications (SATCOM) and LAN/WAN; indeed it is possible to consider the satellite constellation coverage as well as the influence of the weather conditions and general military traffic on their performance; as element of the networks it is also included a central HQs in charge of some decision along the operational processes.

The other model is an acoustic engine defined MSTPA that implements a set of advanced and reliable mathematical models and algorithms developed by CMRE for assessing the performance of a static and multistatic active sonar over a configurable mission environment (Strode et al., 2012). This model had to be adapted to be integrated within a federation with special attention to time management; indeed it was requested a set of architectural improvements to let it to become part of a dynamic interoperable simulation; indeed the federation developed requires to interact dynamically with events evolving based on stochastic simulation and with the humans in the loop in similar way to real system (e.g. sonar operator console in operations room) as in the reality; indeed this model has been subjected to refurbishments to become part of the proposed HLA Federation while further enhancements are planned.

2. HLA AND INTEROPERABILITY

The High Level Architecture (HLA) was originally developed by the US Department of Defence (DoD) and it has become a remarkable standard for distributed simulations for the whole M&S community. HLA uses range from military applications to civilian ones and have dealt with both simulation based learning (Massei and Tremori, 2010; Massei et al., 2013) and analytic purposes. Indeed HLA has been more successful in defense respect other sectors of application such as industry even if there are several case of successful use in logistics and aerospace manufacturing, (Boer et al., 2008; Bruzzone et al. 2008; Longo et al. 2013; Longo et al. 2014); currently HLA constitutes a key reference in the development of large distributed simulations and there are remarkable cases of application in different industrial sectors (Anagnostou et al., 2013; Bruzzone, 2002).

HLA is an architecture including a set of specific rules to be used for managing interoperability among simulators; in addition to these concepts the HLA provides a standard API to be used between a federate and the Run Time Infrastructure (RTI), which is the middleware that manages the federation execution and supports communications among federates. However, HLA does not specify the wire mechanism employed for communications among the different federates.

Originally the DMSO (former name of actual MSCO, Modeling and Simulation Coordination Office, US DOD) was distributing freely (through a controlled authorization process) the first releases of the RTI and the related libraries; the process was centrally controlled and supported updates and maintenance of the DMSO RTI promoting the HLA diffusion (McGlynn 1996); indeed since the beginning also private companies created a commercial releases of RTI and soon also open source software become available; therefore after first years US DoD stopped to support the DMSO RTI maintenance considering that commercial developments were mature in the sector. Currently there are different RTI implementations from different developers and vendors that use different wire mechanisms and algorithms and thus are not compatible among themselves in general (Ross, 2014, 2012). This issue may cause some problems when a federate designed for operating with one RTI is adapted to work with another RTI, but it also has the advantage that different implementations can be optimized for different purposes.

One important aspect studied in the literature about HLA is performance. Latency or throughput issues are a major concern when dealing with large federations that run in scaled time or in real time, in particular with hardware in the loop (De Grande et al., 2011; Knight et al., 2015; Malinga and Le Roux, 2009). Time management mechanisms in HLA ensure that the federation time is consistent among all federates. However, this requires that the advance of the federation for each federate is blocked until the time is granted by the RTI. If the delays due to latency and computational times are too long, the simulation time will not follow up the desired ratio to real time.

Some key factors that determine the efficiency of a federation are:

- The time management algorithms. HLA ensures time consistency among federates by a request/grant mechanism that blocks each federate until the RTI ensure that the whole federation has reached the next time step requested by the federate. HLA supports event driven, time stepped and parallel discrete event simulation paradigms (Fujimoto, 1998). In the case of parallel discrete simulation it allows for either conservative or optimistic synchronization.
- The wire protocol employed by the RTI to send and manage messages (Ross, 2014, 2012). Both TCP and UDP unicast and multicast protocols have been adopted by different RTIs as well as different size limits for the messages. Both reliability requirements and latency of the messages differ among RTIs and their differences might be significant depending on the case of use.
- The workload distribution among federates. Some federations may not allow to distribute the computational workload among federates because they perform tasks of different nature. Scheduling algorithms, whenever feasible, may help to balance the workload and thus avoid one federate to become the bottleneck that delays the whole federation. The works by De Grande are a good example of strategies that reduce this problem (De Grande and Boukerche, 2011; De Grande et al., 2012, 2011; Grande and Boukerche, 2010).

In this paper, three different RTI implementations have been tested to evaluate their influence on the efficiency of this specific simulation framework. Thus, this work contributes to the HLA literature by analyzing performance issues with a real complex federation as well as by demonstrating the synergies that can be achieved through the HLA integration of existing simulators from different fields. The interoperation of specialized simulators from different fields allows increasing the fidelity of a model in complex scenarios.

3. THE MCWS-MSTPA FEDERATION

3.1. Federation Design

The main goal set for the design of the MCWS-MSTPA federation was to test the technological capability to create an interoperable simulation to address EMF; in addition it was interesting to investigate the efforts to integrate MCWS with a legacy mathematical model such as MSTPA within an interoperable simulation. These results have been achieved by adopting the HLA interoperability standard and by defining modes, architecture, updates, and tests devoted to integrate, validate, and verify the federation. Obviously, in order to achieve these results it was necessary to address technological interoperability as well as conceptual model consistency.

Such a concept allows for separated models to be combined in an overall simulation architecture with each contributing its particular strengths. In this particular case, MSTPA is used primarily to conduct acoustic calculations with which to determine whether a given combination of sources and receivers existing within the MCWS framework are able to track a submarine target while MCWS handles platform motion and tactics.

In line with recommended practices in M&S, the steps followed in the development of the federation were:

1. M&S Requirement & Objective Definition
2. Scenario Definition
3. Revision of Conceptual Models and Architecture
4. Federation Design
5. Implementation and MSTPA Modification
6. Tests and Analysis of Results

After the definition objectives and the definition of the scenario to be simulated (Bruzzone et al., 2013a) the design of the federation begun and the main templates and object models were set up for the federation between MSTPA and MCWS.Figure 1 shows the scenario simulated by MCWS. MCWS is a stochastic discrete event simulator able to run in stand-alone and federated mode, enabling both real time and fast time simulation; its implementation allows it to run on multiple OS (Operating Systems) and it was tested in Windows, Mac OS and Linux; therefore in this experimentation MCWS is operating on Windows workstations. MCWS models include a destroyer that carries 2 helicopters, submarines, AUV, etc. The communication links are also simulated along with the headquarters and cyber networks. The destroyer may also use active sonar and/or work in passive sonar mode, on which it would be simply listening, while AUVs are controlled by Intelligent Agents sailing around to serve as receiver into a multistatic sonar architecture. AUV communication are simulated as they evolve along their dynamic network that is self reorganizing by connecting themselves in a chain, if possible, till the RF gateway (a buoy); these communications are operating while the autonomous systems are underwater by using acoustic communication while a mores simple approach based on RF (radio frequency) is used when they surface.

In the same area, an enemy submarine operates in the scenario and it is the target to be tracked by the blue force. The MCWS federate contains all the elements that correspond to a complex sonar architecture such as the vessels, sonobuoys and AUVs (from zero up to 4, concurrently, operating). MCWS includes meta-models of active mono-static sonar, active multi static sonar and passive sonar; these meta-models are simplified therefore consider all major parameters (target strength and target characteristics, relative direction, course, speed, mutual interference, etc); in general these have been developed based on public domain information to guarantee the not sensitive nature of MCWS allowing to move it around without heavy constraints introduced by any kind of security issue.

These metamodels could be substituted by MSTPA acoustic algorithms when requested; in the proposed federation for instance multistatic sonar are simulated by MSTPA engine; potentially this federate could address all the sonar issues, however, as of nowadays, only the active sonar operation is fully supported.

In the test simulation is directed by IA-CGF (Intelligent Agent Computer Generated Forces) by Simulation Team integrated within MCWS (Bruzzone, Tremori, Massei 2011).

MCWS includes tactical operations as well as cyber attacks and cyber defense actions (Bruzzone et al.2013b). these could be concurrently activated addressing each node and each link of the heterogeneous network; the attacks are addressing three different major cyber proprieties: availability, confidentiality and integrity; the element could be compromised and/or restored also partially and their status affects the operations: for instance, if the integrity of the buoy is depleted and this entity is serving as gateway between acoustic comms arriving from AUVs to Radiofrequency comms to the Destroyer, the sonar contacts of all the autonomous systems can't be more used for detection and tracking.

In addition to cyber defense issues, all the elements consider communication saturation due to simulated traffic plus other background data flow reproduced by statistical distributions; indeed all the nodes of the networks are also subjected to regular failures modeled as stochastic breakdowns regulated by MTBF (Mean Time between Failures) and MTTR (Mean Time to Repair). For simplicity in the current scenario all cyber attacks are carried out by red forces and all defensive actions are up to the blue forces even if the model allows to create more sophisticated issues.

In sense of tactical operations, the red submarine moves towards west reacting to its perception about foe activities and positions; when submarine detects suspects elements it deviates in order to reduce detection probability, concurrently time by time he tries to reach his destination crossing the area. So the submarine control course, speed and deep in order to avoid detection and cross the area by applying simple rules; even in this case it was decided to don't implement sophisticated cloaking tactics to avoid any classification issue, even if the simulator could easily implement most of them.

Indeed the agents could sail the submarine even outside of the area in case he feels in danger, but it should then come back; depending on submarine ROE it could react or attack the surface vessel. In addition to IA (intelligent Agent) driven simulation, MCWS allows also to control the submarine by an operator through da simple user interface; in this case it is possible to define course, speed, deep; the user could even to operate the weapon systems and activate attack procedures through its interface; in such case if the submarine by moving towards the ship detects it and the target is within weapon range, it launches a torpedo. Although MCWS could be used to simulate a broad range operating conditions, this scenario was selected as a significant one on which to perform the tests. The active sonar is simulated by MSTPA simulator; indeed the multi-static sonar system is composed by a source (the sonobuoy) plus different listeners; in our case the simulation was run including two AUVs as well as the destroyer, corresponding in MSTPA to three listeners controlled dynamically by MCWS. Water acoustics are simulated by MSTPS considering water conditions such as salinity, temperature, etc.

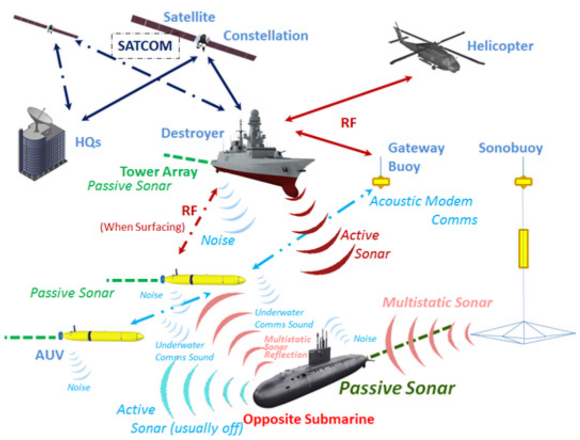

Figure 1. Simulated scenario

A general Federation structure is proposed on Figure 2 by using Pitch RTI; indeed the federation is enabled to to operate automatically with different RTI based on initial settings; currently the federation supports Pitch, Mäk and Portico RTIs. It shows the MSTPA and the MCWS federates. Actually, as the figure shows, the MSTPA is internally connected with other models that perform part of the calculations.

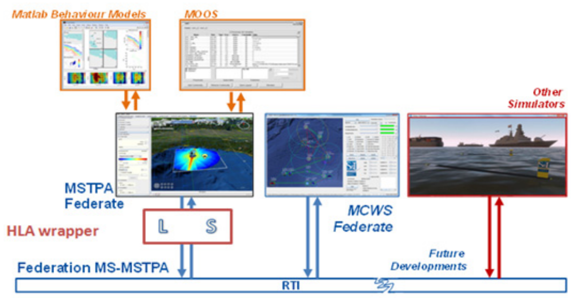

Figure 2. Federation structure.

This study has addressed the validation issues by applying logic structure analysis through flow charts and dynamic V&V as proposed in Figure 3. In terms of dynamic testing, the integration test has included: federation join test, publishing and subscribing attribute test (DoD, 2009). Further VV&A effort are planned for the future to improve realism of the simulation, but it was not conducted in this phase of the research as the main goal was the technological testing and demonstration.

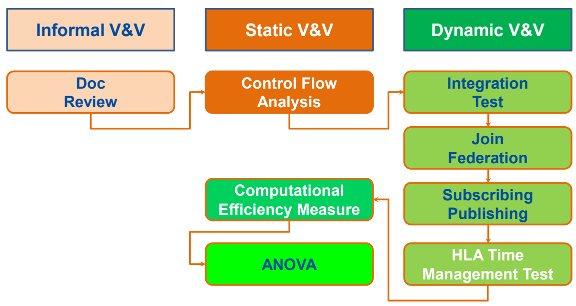

Figure 3. V&V flow diagram.

3.2. Federation Object Model (FOM)

The FOM (Federation Object Model) is a specification defining the information exchanged at runtime accordingly to the federation objectives. A first step to achieve interoperability is to set a common understanding of the semantics of data. The FOM lexicon provides the Federation with an available definition of all object classes, interaction classes, object class attributes, and interaction parameters (IEEE, 2010b).

We have chosen, at this stage, to have one Object class that represents each vehicle or system present in a defined scenario as well as each track by the acoustic analysis of each Fusion Set; a fusion set corresponds to a Command and Control (C2) solution able to combine single or multiple data to detect and classify potential targets. Thus, target detection and preliminary classification is carried out by MSTPA and decision making given the targets detected is performed by MCWS.

Table 1. Object class definition table

Class	Definition
Platform	Every asset on which sensors or weapons are mounted in the scenario (e.g. vessel, AUV, submarine, buoy)

The attributes defined for the platform class contain information about the name, type and characteristics of the platform, the geographical position, the speed, course and acceleration, the angles, the operational status the condition and the sensors. The condition attribute states whether the platform represents a real asset or a dummy track generated by MSTPA.

An interaction is an explicit action taken by a federate that may have some effect or impact on another federate within a federation execution. The federation considers pings generated by sonar and echoes generated from various objects in the scenario. During the simulation MCWS sends PING interactions and MSTPA subscribes to them (
Table 2).
The parameters of the PING interaction contain information about the emitter, its location and the physical characteristics of the sonar pulse.

Table 2. Interaction class definition table.

Interaction	Definition
PING	Ping Acoustic Sonar: pulse emitted by sonar

3.3. Federation Rules

Apart from the FOM, the federation rules are a necessary agreement among federates to ensure interoperability. They state the behavior of each federate and what information they expect to send and receive from the rest of the federates.

3.3.1. MCWS rules.

1. MCWS will run in its own simulation mode w/o any time synchronization with MSTPA.
2. MCWS will run in time constrained and time regulating mode. The look ahead time will be updated according to the time to next event.
3. MCWS will publish PING interactions and send them when the sonar is requested.
4. MCWS will publish and subscribe the PLATFORM class.
5. MCWS will register PLATFORM objects corresponding to the real assets in the scenario.
6. MCWS will start simulation execution upon pressing the Run button.
7. MCWS will update PLATFORM objects position attributes as they move through the map.
8. MCWS will discover the PLATFORM instances registered by MSTPA that correspond to the tracks.
9. MCWS will reflect the position attributes updated by MSTPA and display the tracks on the map.

3.3.2. MSTPA rules.

1. MSTPA will run in “simulation mode”, where events in its internal event queue are processed as soon as possible.
2. MSTPA will subscribe to PING interactions but will not use such information.
3. MSTPA will publish and subscribe to the PLATFORM class.
4. MSTPA will discover the PLATFORM objects registered by MCWS.
5. MSTPA will read from its xml configuration file the platforms configuration
6. MSTPA will link platforms specified in the configuration file to HLA platforms registered by MCWS thought the platform Name attribute
7. MSTPA will start simulation execution as soon as all the expected PLATFORM objects are discovered and their position attributes are updated.
8. MSTPA will reflect the position attributes for the PLATFORM objects.
9. MSTPA will ping accordingly to an internally scheduled time base using the last PLATFORM objects positions for ping calculation.
10. At the starting time of the simulation MSTPA will publish the PLATFORM class.
11. When MSTPA generates a track it will register it as a PLATFORM instance related to new targets tracks resulting from contacts detected with the sonar.
12. MSTPA will update the attributes of PLATFORM instance position and condition. The condition attribute will be set to 1 meanwhile the track is alive.
13. When a track dies in MSTPA, it will first change the Conditions attribute to 2 and then it will remove it from the RTI.

4. MCWS HLA EXPERIMENTATION

4.1. MCWS HLA Integration test

The goal of this integration test was to verify that the MCWS was fully interoperable through HLA and able to join the MCWS-MSTPA federation and running with time managed by the RTI; multiple instance of MCWS could be federated together to carry out more complex scenarios based on a scalable patrol solution. The proposed tests were conducted with three MCWS running on two different machines connected through a LAN.

Indeed the three MCWS federates were tested running together and synchronized being each one time constrained and time regulating. They publish and subscribe all submarines and frigates belonging to the different MCWS federates. They are also all able to see the different platforms in their sonar and select them as targets. They are able to launch torpedoes towards the objects owned by other federates, and it should be created a specific interaction to inform other federates by a message about the fact that the target has been terminated.

In this test, the submarines were published as if they were potential suspect tracks proposed by other federates in order to test also tracks visualization. Hence, the federates visualize each other's submarines as tracks and not as already confirmed enemy submarines. Figure 4 shows a screenshot of the integration test.

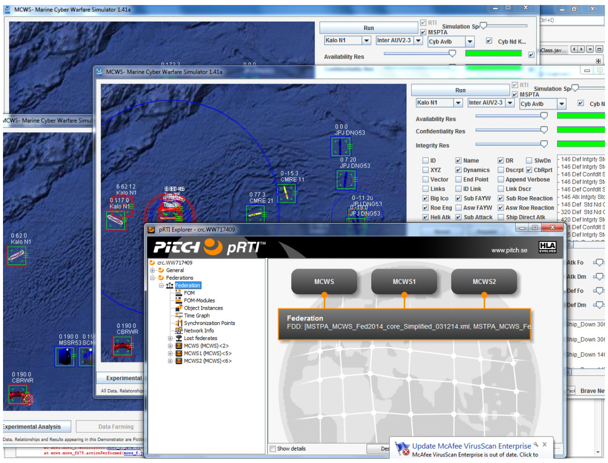

Figure 4. Screenshot displaying the Pitch CRC with three MCWS federates connected as well as the three windows that correspond to the three instances of MCWS running.

4.2. Analysis on the Federation Performance

The maximum time scale (simulation time / real time) that the federation is capable of achieving during a simulation run is used as a measure or performance.

As anticipated MCWS is able to run real time and paged and unpaged fast time depending on the settings; usually it could go at least 300 time faster than real time in stand alone paged mode also with the full scenario based on 4 AUV dynamically interacting with all other assets and elements.

The performance indicator carried is useful for analytic purposes since it is a measure of the computation time that is required to complete a simulation experiment in federated mode.

The maximum time scale (MTS) was measured under different conditions of experimentation. Two factors were considered:

- The RTI implementation. Three RTIs were used:
  - RTI 1: Mak 4.4.1.
  - RTI 2: Pitch 5.0.1.
  - RTI 3: Portico 2.0.1.
- The number of MCWS federates running in parallel

The RTI implementation may affect the maximum time scale since different RTIs may differ in the wire protocol used, the time management algorithms and the efficiency of the RTI implementation. In the experiment conducted Pitch and Mak use the TCP/IP protocol for communications. Portico uses the UDP multicast functions implemented in the library JGroups.

Table 3. Maximum time scale achieved by each federate (seconds of simulation time / seconds of real time).

RTI	Number of Federates	
	1	2
Pitch	3112.6 ± 77.19	1056.2 ± 59.02
Mak	3073.02 ± 77.19	978.93 ± 59.02
Portico	3242.92 ± 54.58	702.3 ± 41.73

* Error values correspond to the 95% confidence interval with 8 runs of each scenario.

Table 4. Rate of object updates received per second.

RTI	Number of Federates
	2
Pitch	125.88 ± 7.19
Mak	117.58 ± 7.19
Portico	82.74 ± 5.08

* Error values correspond to the 95% confidence interval with 8 runs of each scenario.

Table 3 and Table 4 show the results achieved when running the simulation using the different RTIs with 1 and 2 federates. The results show non-significant differences among the RTI implementations when running with only one federate, as it might be expected considering that no communications are necessary under this circumstances. Figure 5 displays the same results in a graph. The error bars correspond to the 95% confidence intervals.

When two federates join the federation, communications through the local area network are required. In this case, time synchronization mechanisms and latencies reduce the maximum time scale achieved by a factor of 3. In this case, Portico RTI showed a significantly lower performance. Pitch was achieved a 50% increase in time scale compared to Portico and Mak a 39.4% higher time scale. The difference between Pitch and Mak was significant at the 95% level of confidence The relative difference was a 7.3% in the proposed scenario. The number of object updates achieved per second is also an indicator of how fast the federation run with different RTIs and the conclusions are analogous to the previous ones. Figure 6 and Figure 7 graphs show the same results.

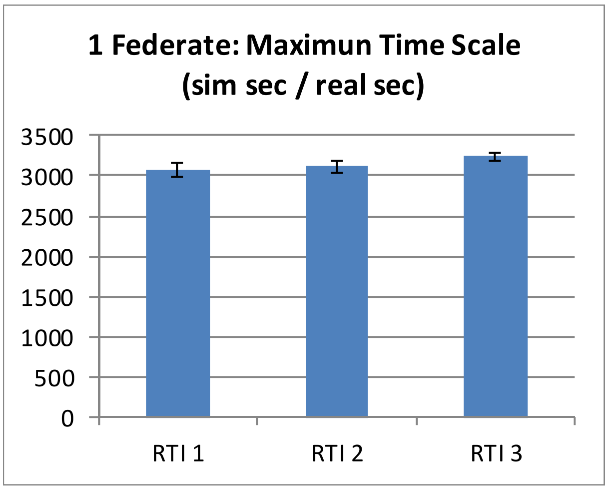

Figure 5. Maximum time scale for the federation running with 1 federate.

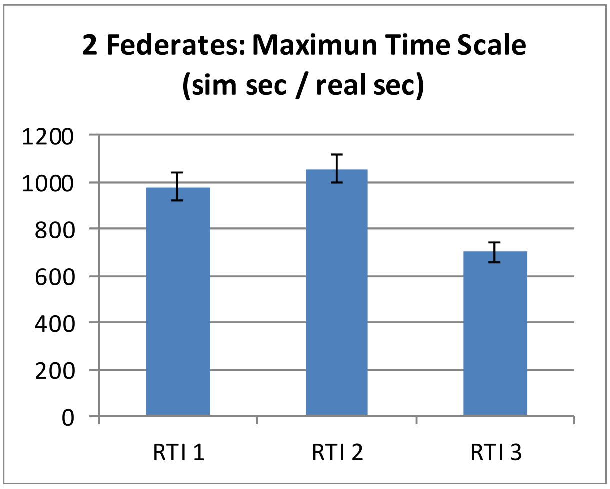

Figure 6. Maximum time scale for the federation running with 2 federates.

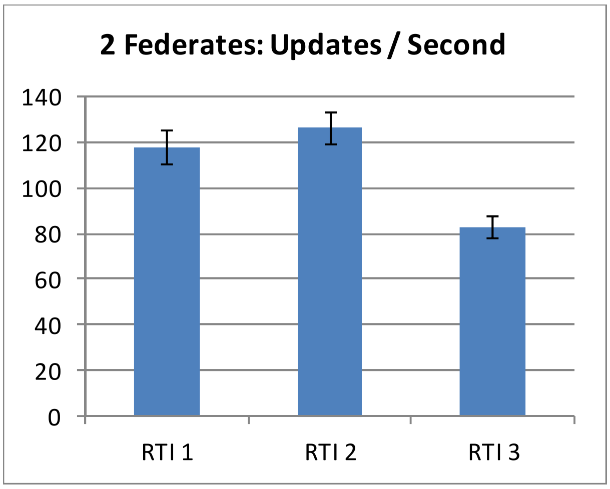

Figure 7. Object updates received per second running with 2 federates.

5. MCWS-MSTPA FEDERATION TEST

5.1. Integration tests

Once the MCWS- MSTPA federation was developed, three integration tests were conducted based on the simulation scenario implemented in MCWS. The goals of the integration tests were:

1. Check that both federates join the federation and publish and subscribe objects classes and interactions.
2. Check that both federates register and discovers object instances, that they add the discovered objects to their internal models and that they update and reflect object attributes.
3. Check that PING interactions are sent and received and that tracks are generated accordingly.

Figure 8 shows a screenshot of the 2nd integration test where the platforms in the MCWS federate is synchronized with the platforms in MSTPA after they have been discovered.

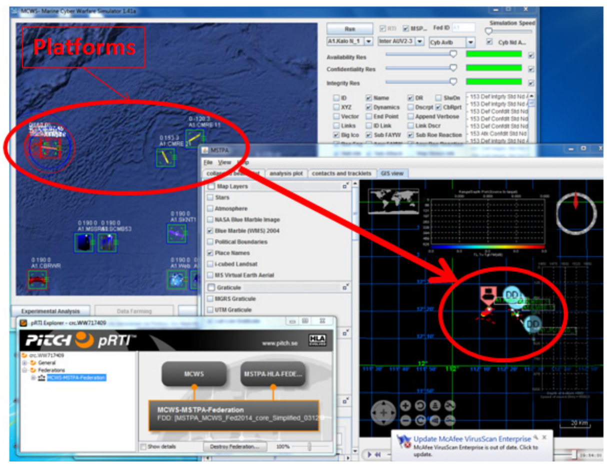

Figure 8. Integration Test 2: MCWS platforms synchronization in MSTPA's GIS.

Figure 9 displays a screenshot of the 3rd integration test where the track for the submarine generated by MSTPA is visualized in MCWS. MCWS is actually managing the movement and decisions of the submarine, but only the track generated by MSTPA through the acoustic calculations is displayed on MCWS as a red rhombus.
Figure 10 shows the platforms in MCWS along with the tracklets calculated by MSTPA based on the acoustic calculations.

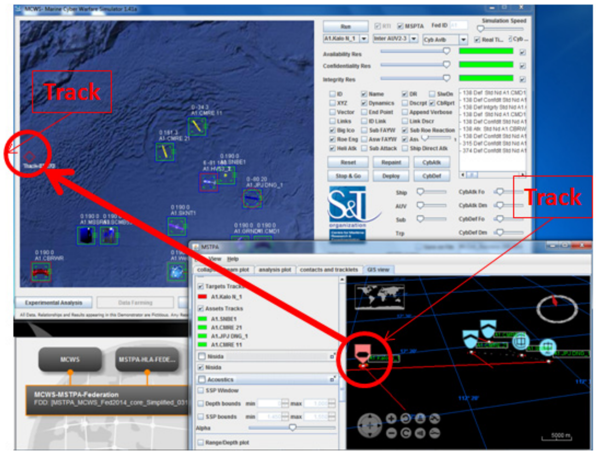

Figure 9. Integration Test 3: submarine's track calculated by MSTPA visualized in MCWS whilst the submarine is hidden.

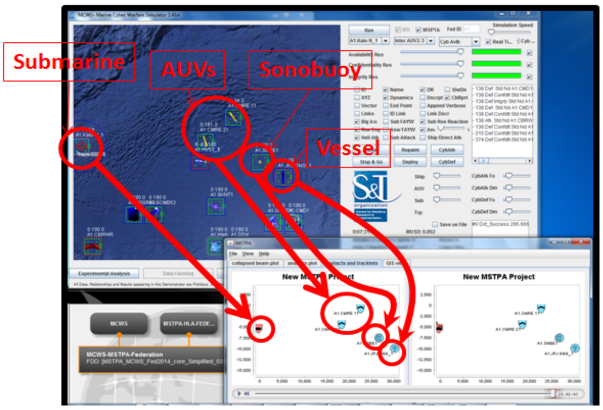

Figure 10. Integration Test 3: Contacts and Tracklets tab of MSTPA.

6. CONCLUSION

This paper describes an HLA federation that has been developed by combining different simulators used for marine operations. It demonstrates the potential of HLA for integrating models specialized in the evaluation of different elements in a complex scenario. In this case, the operations in this scenario are simulated by the MCWS federate and the sonar simulation is carried out by the MSTPA federate.
However, obviously federating a simulator through HLA comes at a cost in computing time and communications delays. In this specific federation it was observed a 66.6% reduction in the maximum time

scale achieved when using a federation with two federates connected through a local area network. Three RTI implementations were compared as well. The difference among them was not significant when using only one federate. When using more federates, it was possible to identify difference among different RTI performance; for instance in this specific scenario Pitch and Mak showed an higher performance respect Portico, the open source RTI solution. The difference observed between Pitch and Mak on the specific scenario used for the test was significant, although small; this suggest that even if the relative results it cannot be generalized to other federations or other setting it could make sense to conduct these tests to identify the most performing solution for the specific implementations in case extensive experimentation is expected for using an HLA simulator.

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