THE 16TH INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELLING AND SIMULATION

SEPTEMBER 10-12 2014
BORDEAUX, FRANCE

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Welcome to the 16th Edition of the International Conference on Harbor, Maritime and Multimodal Logistics Modeling & Simulation, HMS 2014!

At global scale, logistics is continuously reshaping itself under the pressure of different technologies and trends. Indeed, from one side we can easily understand that logistics stakeholders need to decide how and when adopting new technologies such as mobile devices and applications, internet of everything, new sensors and embedded technologies, sustainable transportation solutions etc. From the other side, they are continuously pushed to increase their efficiency to satisfy multiple (and sometime conflicting) requirements: to cite a few, consumerism, sustainability, financial crises, new developing countries, massive urbanization, etc.

In such a context, the goal of the HMS conference is to understand how and to which extent the "logistics change" can be supported by Modeling & Simulation. Over the year, Modeling & Simulation has already proved to be one of the most suitable approaches to support both training and decision support in logistics and supply chain; and nowadays the role of Modeling & Simulation is becoming even more important thanks to the evolution of the concept of "Simulation as a Service".

To this end and thanks to its specific focus on logistics, supply chain and marine ports, the HMS conference is the ideal framework to understand the latest advances in many logistic areas including container terminals, innovative transport system for urban areas and urban freight transport, intermodal and sustainable transportation systems, traffic and transportation.

We would like also to take this opportunity to thank all the authors and reviewers of HMS; over the years they did a great job in selecting and publishing papers with high scientific and scholarly value and today, thanks to their invaluable work, all the HMS proceedings (starting from 2007) are indexed by SCOPUS.

This year the HMS conference, together with all the other I3M conferences and workshops, is held in Bordeaux, France, a perfect and wonderful location for a fruitful work and an enjoyable time in good company of a glass of wine.

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SIMULATION MODEL OF YARD TRUCK DOUBLE CYCLING TO IMPROVE CONTAINER TERMINAL PRODUCTIVITY

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ABSTRACT
In transhipment container terminals, minimizing vessel turnaround time (time to discharge and load vessels) is always the target of the container terminal operators. This time reduction can be achieved by improving one or more of the containers handling equipment's or improving handling strategy. This research aims at maximizing the yard trucks productivity and minimizes the vessel turnaround time by introducing an efficient strategy of handling containers. This strategy based on combining the efforts of two quay cranes to work as a unit to be able to implement yard trucks double cycling. A computer simulation has been used to test the strategy. The Ezstrobe simulation reveals improvements in yard truck productivity when using double cycling comparing to single cycling. Moreover, a sensitivity analysis is implemented and the result indicates more efficiency when using 7 yard truck for storage yard located within a range of 500 - 1500 meters from the berth.

Keyword: Container terminal, Yard Truck, Double Cycling, Simulation

1. INTRODUCTION

In container terminals, reducing vessel turnaround time improves container terminal productivity and increases the capacity for world trade over the oceans. Minimizing vessel turnaround time (the time it takes for a vessel to be unloaded and loaded at its berth) accelerates the shipping time and reduces delays in delivering trade goods. This time reduction can be achieved by improving one or more container terminal resources. Iris F.A. Vis et al (2003) stated that the capacity of vessels will be increased by up to 800 TEUs (twenty-foot equivalent unit containers). Vessels today have been upgraded to carry more than 15000 TEUs to means of minimize container shipment costs. While much research has been done on improving container terminal efficiency, more improvements can still be achieved. Minimizing the empty journeys of yard trucks would improve container terminal efficiency with reasonable time and cost investment. This research aims to maximize container terminal productivity by minimizing vessel turnaround time within reasonable hourly and unit costs. A handling container strategy is introduced by employing double cycling to reduce the empty travel of yard trucks. This double-cycling strategy still requires the use a single-cycle strategy before the trucks can be incorporated into double-cycle scheduling. The strategy is based on uniting the efforts of two quay cranes to unload and load a yard truck during its cycle. The EZstrobe simulation system is used to test the efficiency of the proposed strategy. The research is expected to improve container terminal productivity using existing facilities and resources. Gains will also be realized by reducing vessel turnaround time, which could save shipping costs and accelerate the global trade transported by sea. Simulation results indicate an improvement in the productivity rate combined with the unit cost savings using YT double cycling compared to the standard single cycle operation.

This paper is organized as follows. A brief presentation of the background and a literature review is followed by a description of the proposed YT double cycling strategy, compared to the traditional single cycle container handling. The simulation steps and the models for YT single and double cycling are then proposed. A case study is presented to test and validate the strategies and thus the simulation models. A sensitivity analysis implemented on the YTs factor. The conclusions of this work are elaborated in the last section.

2. LITERATURE REVIEW

Vessels today have been upgraded to carry more than 15000 TEUs as one way of minimizing container shipping costs. These large vessels are usually used to transfer containers through large container terminals to be transshipped by smaller vessels between medium or small terminals in a system called transshipment. Large transshipment container terminals now operate 24 hours a day all year long to meet the demand of the worldwide container trade. Not less than 100,000 containers are transferred weekly between berth side and temporary storage yards (SYs) (Matthew &Katta 2009). Quay cranes (QCs), which are huge and costly machines, are used to unload and load containers from and onto sea-going vessels. Vessel can be serviced by more than one QC at a time to minimize vessel turnaround time (Daganzo 1989). When using multiple QCs to service one vessel, the turnaround time is equal to the maximum time one of the QCs must spend to unload and load its assigned hold. The number of QCs also depends on a container terminal's handling equipment availability and its internal road capacity. Horizontal transporters or Yard trucks (YTs) are used to transport containers between the berth and a storage yard (SY). The more trucks that are moving at the same time, the more likely that there could be traffic congestion, which would cause delays in the truck cycle time. Gantry cranes are yard cranes (YCs) that unload and load containers from and onto vehicles at a SY. The rubber-tired gantry crane (RTGC) is one type of Gantry crane. The RTGC has a width of 7 lanes, which are each equivalent to the forty-foot container width; 6 lanes are used to store the containers and the 7^{th} lane is customisable for the yard trucks (Linn et al 2003). It has been concluded that, while YCs can stack containers in stacks of up to seven, the optimal stacking height is five containers (Mark B, Dunikerken et al 2001). It is not only YT congestion that needs to be addressed; YC clashing can occur when more than one crane works in the same lane. Katta (2007) studied both YT and YC problems. Katta improved the layout design with buffering to eliminate YT congestion and YC clashing. Any delay in the availability of these resources directly leads to a proportional delay for the other resources, and ultimately lowers the container terminal productivity in general. Conversely, improving any of these resources will improve container terminal productivity.

Traditionally, vessels are unloaded and then loaded (single cycle) at transhipment container terminals. Goodchild (2005) proposed Quay Crane double cycling to improve effiency. This technique has been developed by Goodchild and Daganzo (2006); Goodchild and Daganzo (2007); and Zhang and Kim (2009) to optimize QC productivity and minimize vessel quay time by minimizing the empty travel of QCs. Single cycling means that the imported containers from a vessel must be unloaded first, and then the exported containers can be loaded, while double cycling means the loading and unloading of containers is carried out at the same time, in the unloading conditions. QC double cycling is "a technique that can be used to improve the efficiency of quay cranes by eliminating some empty crane moves" (Goodchild 2005). A scheduling problem is presumed by Goodchild and Deganzo (2005), one that can be solved by double cycling. Zhang and Kim (2009) extended Goodchild and Deganzo's (2005) research so that it would no longer be limited to just the stacks under a hatch, but would also work for above-hatch stacks. In order to reduce YT empty trips, Nguyen Vu Duc and Kim Kap Hwan (2010) introduced a heuristic algorithm and test it by simulating various scenarios of QC types (single cycling, double cycling and a combination of two QCs, one loading and the other unloading) in different locations. One of their conclusions is that the YT efficiency is affected by the QC operation type. Pap et al (2011) supports the advantages of the double cycling technique as a service method for improving container terminal productivity. They enhanced the conception that doubly cycling is a cost reduction method which does not require any improvement to the existing infrastructure or introduce any new technology.

Improving the productivity of existing container terminals without introducing new equipment, and thereby expanding and/or developing the infrastructure of a facility is the primary objective of this research. This research is focussed on implementing the double cycling of YTs based on this QC double cycling technique, thereby minimizing empty YT journeys. A new container handling strategy is proposed, one that is able to combine the effort of two QCs to work as a unit. Because of its complexity, container terminal productivity is commonly tested by using simulation. The effectiveness of this proposed strategy is verified via a simulation model.

3. OBJECTIVES

The overall objective of this research is to minimize vessel turnaround time and optimize container fleet size and hourly costs by implementing the yard truck double cycling technique to minimize empty truck journeys. Developing a simulation model is a part of this research and makes it possible to test the technique. An optimization of the simulation outcome's group solutions will be used as an input to a sensitivity analysis to optimize fleet size and the associated hourly costs.

4. METHODOLOGY

The research methodology consists of three sections. Each section is divided into its sub-phases according to the priority order. The first section addresses the understanding of container terminals, and starts with a comprehensive literature review. This section also includes a state of the art review of yard crane scheduling, container transporting between storage yard and berth, temporary container storage yards, quay crane and allocation problems, quay crane double cycling and Yard truck double cycling. The second section introduces a container handling strategy and shows how this method will affect the vessel turnaround time. The simulation is developed in the third section. It starts with the simulation modeling of both single and double cycling, followed by a case study and the collection of the data required for the simulation, the simulation implementation and model validation. The methodology ends with a conclusion and recommendation based on the results. This study introduces a strategy of container handling, called the YT double cycling technique. The new strategy depends on being able to combine the efforts of two QCs to work as a unit, with one crane discharging a vessel while the other loads it. Both QCs will serve the same truck, unloading a container from the truck to be loaded into the vessel and loading it with a container discharged from the vessel. Each truck will transport containers from the storage yard to the vessel and from the vessel to the storage yard in the same cycle. Just as with the QCs, two YCs will load and discharge the trucks at the SY. QCs must be located more than two rows of forty feet container apart. In the interest of safety and to prevent conflicts, the QCs in this system will be three rows of forty feet apart. YT single cycle unloading is still needed to create space on a vessel to be able start loading and thus switching to double cycling. At least two YCs will be allocated at the SY to load and discharge the trucks. These could be in the same lane, in two neighbouring lanes or even further apart, depending on the SY layout. Certainly, shorter distances produce better results. To be able to fully understand the proposed strategy, it is important to know the traditional strategy (YT single cycling).

4.1. YT Double Cycling

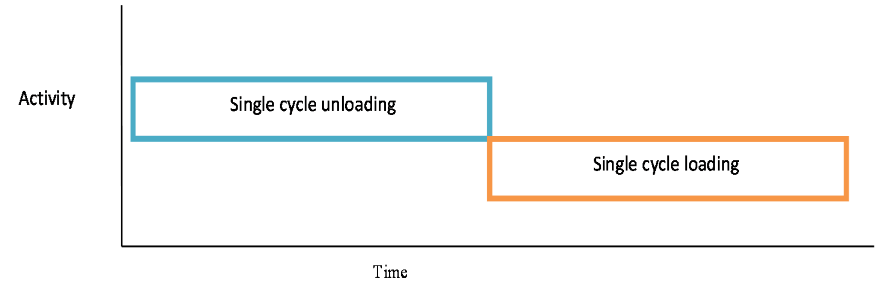
In general, vessel turnaround time starts with the unloading the imported containers and continues until the last exported container has been loaded. With the single cycling technique, loading the vessel should not start until the vessel has been fully discharged. The total unloading and loading time is then counted as the vessel turnaround time. Figure 1(a) describes the operation. In YT double cycling, as with single cycling, vessel turnaround time starts with the unloading of the first imported container and ends with the loading of the last exported container. However, in double cycling, loading exported containers can be started at a certain time, in parallel to the unloading process. When it is time to convert to double cycling, two QCs will work together as a unit to serve YTs with different activities (loading and unloading). The overlapping of some of the QCs' cycle time reduces the vessel turnaround time, which the main justification for applying the double-cycling technique. A vessel still needs to be loaded with the last exported container before departure. Turnaround time is counted as the sum of the series of single cycle unloading, double cycling and single cycling loading of the imported and exported containers. The operation timeline of double cycling begins with the unloading activity and continues with simultaneous unloading and loading activity. The total time T_D is the summation of the single cycling unloading, the double cycling and single cycling loading times see Figure 1(b)

5. SIMULATION OF CONTAINER TERMINAL OPERATION

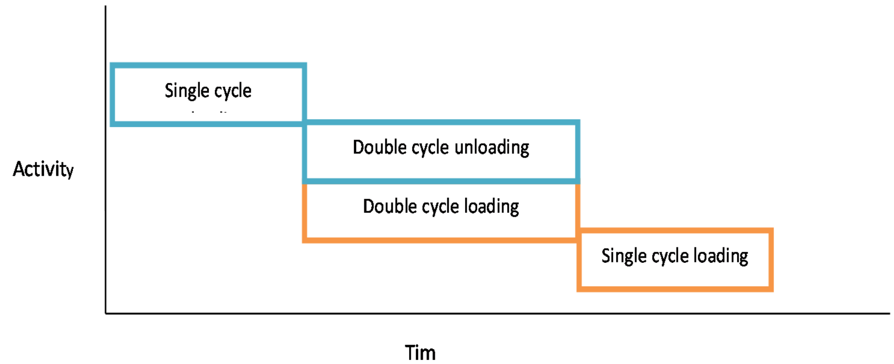
Single and double-cycling simulation models are designed in accordance with pre-defined steps. The EZstrobe simulation system has been used to model the container terminal operation due to its simplicity and power. To apply the EZstrobe simulation system, some steps must be followed, as mentioned above. The data collection stage will be clarified in depth in the next section, followed by a case study to test and validate the simulation models. The single- and double-cycling steps are presented in more detail, as part of the simulation model development.

5.1. Double-cycle simulation model

The double-cycle simulation model is designed as a form of integration between single and double cycling. This process begins with the single-cycle unloading of three or more rows before starting double cycling-, in order to minimize the fleet size and maximize the crane use. Next, the unloading QC_1 will change from unloading to loading the containers on the vessel. Another QC, (QC_2), is introduced to the fleet to continue unloading the containers from the fourth row to the end while QC_1 starts loading the containers from the first to the last row. The trucks, loaded by YC_1 at the export storage yard, arrive at the berth side to be discharged by QC_1. After being discharged, each truck will precede empty to QC_2,to be loaded with a container unloaded from the vessel. QC_1 simultaneously starts its cycle to load its container on the vessel. The loaded truck will move back to the (import) storage yard to bedischarged by YC_2, which should be ready for this discharge.



a) YT Single cycle operation



b) YT double cycle operation

Figure 1: Different scenarios of vessel turnaround time lines

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After being discharged by YC_2, the truck will proceed to the export SY to be loaded by YC_1 and start a new cycle. YC_2 starts its cycle as soon as it lifts a container from a truck. The YTs, QCs and YCs continue repeating their cycles until the last container has been fully unloaded. The fleet will then be reduced to one QC and one YC and fewer trucks to complete loading the vessel as a single cycle, as described earlier in the single-cycle simulation.

6. DATA COLLECTION AND CASE STUDY

6.1. Data collection

Since it is not yet possible to collect the data directly in this research, a technique to estimate the data needed to run the simulation is utilized. To employ this technique, the QC, YTs and the YC cycle times must first be calculated. It is assumed that the timeswill vary according to the speed variance. Any delay or acceleration of the cycle times will relate to the variations in speed. For instance, a crane operator's skills should have an impact on the vertical and horizontal speeds of the trolley, i.e. a skilled operator's machine would work faster than that of an inexperienced operator. The same variability occurs if the weather changes, affecting the machine's efficiency and/or the road conditions. The YT cycle time is calculated according to the expected distances from the vessel to the SY.

Finally, To mimic reality, the durations are assumed to vary from one cycle to another. This has been represented by changing the speeds and motions of the equipment. Decreases in the speeds were set to descend from 90% of the maximum speed to 60%, decreasing 5% each time, and were assumed to result in related increases in the cycle times. The derivation function of each equipment cycle time was used to calculate each equipment's cycle time. The resulting data was collected and analysed using an EasyFit distribution to draw the histogram and to calculate the mean and the standard deviation. Lifting and loading containers into or from a vessel and a YT was estimated using a deterministic of 0.166 minutes. Because it is a very small time compared to the other durations, moving the QC between rows is neglected.

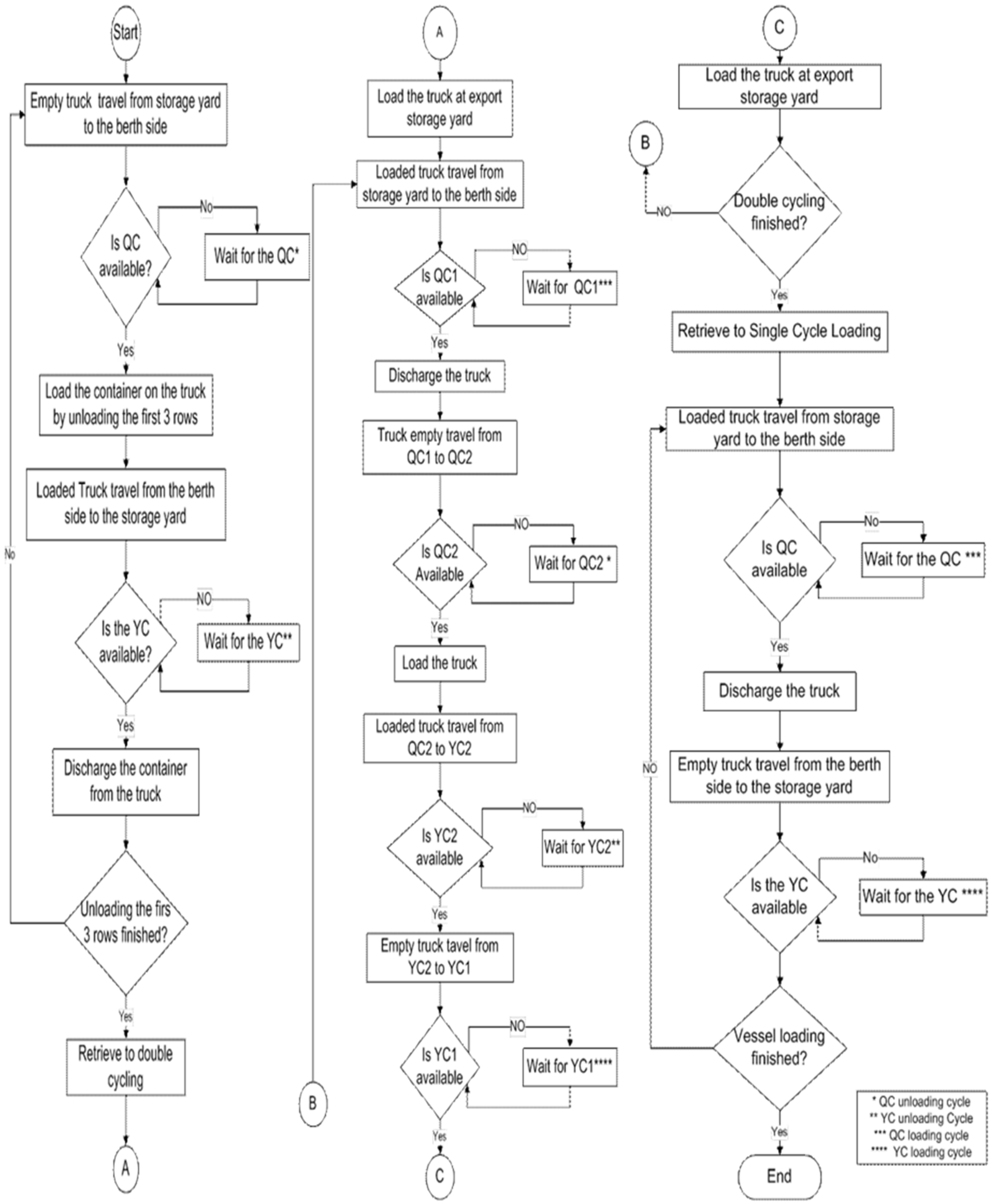
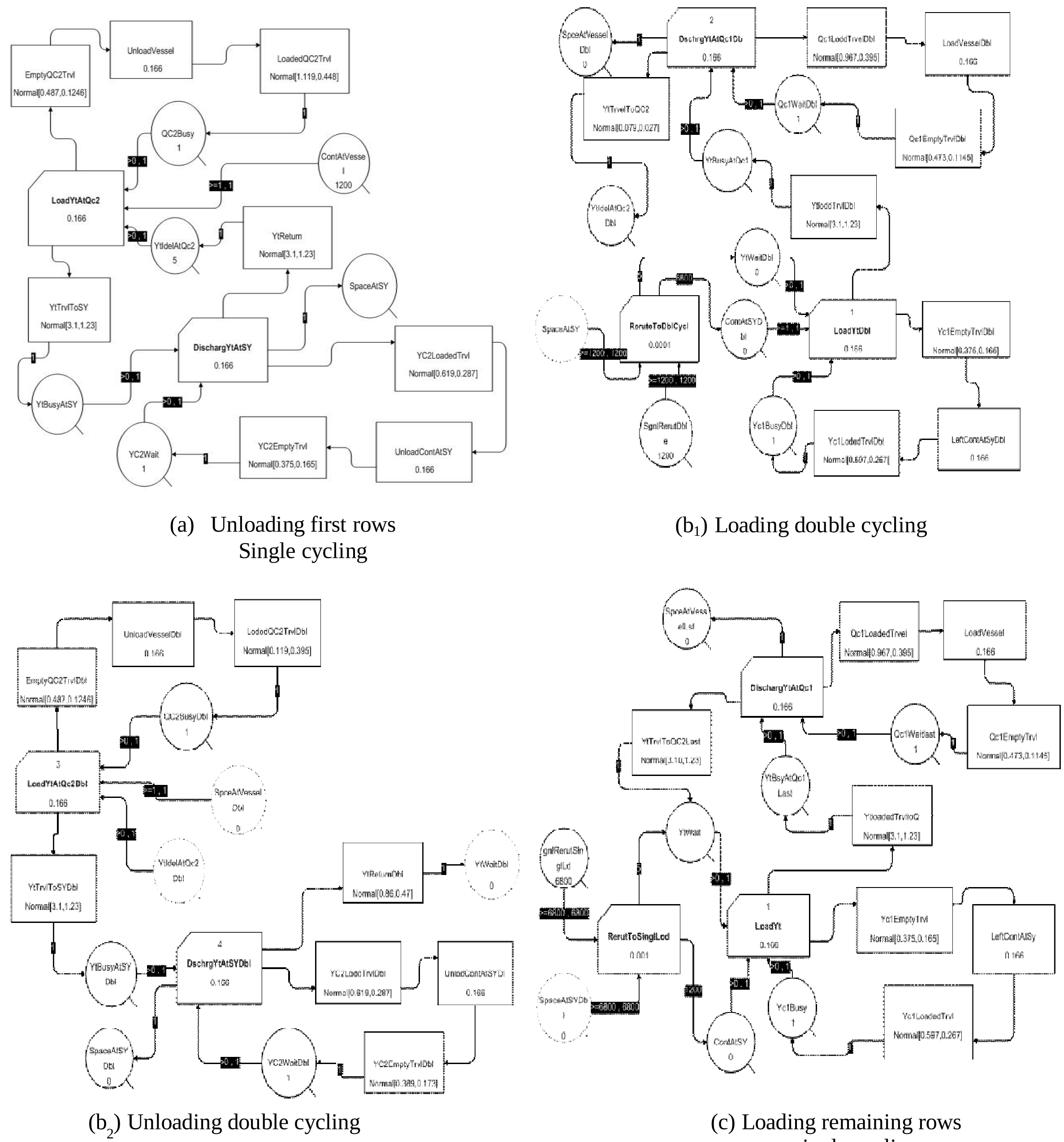


Figure 2: Double cycling simulation process



(a) Unloading first rows
Single cycling

(b_1) Loading double cycling

(b_2) Unloading double cycling

(c) Loading remaining rows
single cycling

Figure 3: YT double cycle simulation model

6.2. Cost estimation

As previously described, the hourly costs were estimated. These estimates are not exactly 'real' and are not confidential. To make this data useful and easier to manipulate, the savings in each category of productivity rate, hourly cost and unit cost are given as percentages.

Table 1: YT single and double cycling simulation inputs

Strategy	Numbers of resources					Hourly costs $/hr			
	Loaded containers TEUs	Unloaded containers TEUs	QCs	YCs	YTs	QC	YCs	YTs	Overhead cost
Single cycling	16,000	16,000	1	1	5	150/QC	100/YC	50/YT	110
Double cycling	16,000	16,000	2	2	5	150/QC	100/YC	50/YT	110

Table 2: YT single and double cycling simulation outputs

simulation output	Single cycle	Double cycle	Difference	Improvement
Productivity rate (TEU/Hour)	63.73	107.6	43.87	68.83% (increases)
Unit cost ($/TEU)	9.57	7.99	1.58	16.50% (saving)
Total cost ($)	30,625	25,574	5,051	16.49% (saving)
Total hours	502	297.3	205	40.77% (saving)

6.3. Case study description:

The proposed case study considers a hatched vessel with a 16000 TEU (8000 40 -t containers) capacity. The vessel will totally unload and be loaded with the same number of containers. The containers are estimated to be distributed uniformly on the vessel in 20 rows and 20 stacks. The number of stacks above the hatch is equal to the number of stacks below the hatch, with 10 levels of containers each. The total number of containers per row is 400. For single cycling, only one QC and one YC will do the job of unloading and loading. However, for double cycling, two QCs and two YCs are needed to do the job. Each activity (loading and unloading) requires one QC and one YC. The same trucks will work as duel loading/unloading YTs to serve the QCs and the YCs. The small movement of QCs between the rows is neglected due its minor time value compared to the total time of unloading each row. The YCs are RTG-type. The trolley speeds of the QCs and the YCs have been quoted from the cranes' manufacturer publications .The hourly costs are estimated, asreal data from container terminals is not yet available. Other inputs are also needed to run the simulation model. The simulation parameters and hourly costs are presented in Table 1.The simulation results reveal an improvement in terms of productivity, time and cost. This improvement can be seen in Table 2. In summary, it is concluded that double cycling can improve CT productivity, which minimizes vessel turnaround time with reasonable cost savings.

6.4. Sensitivity analysis

A sensitivity analysis is carried out to modify the model resources. |Only the number of YTs has been implemented to date. The other resources (number of QCs and number of YCs) will be done in future work, as the model requires further development. For instance, to add one more YC, another YC cycle has to be developed and a probabilistic routing element introduced to connect the process. The number of YT changes modifies the number of trucks from 3 to 12 in both single and double cycle. See Table 3

7. CONCLUSIONS

Container terminal customers (shipping companies) believe that "**Vessels do not make money while berthing**", which means that minimizing vessel turnaround time is crucial to satisfy these customers. It is clear that improving the productivity of any container terminal's resources leads to the improvement of the other elements' productivity and of terminal productivity as a whole. QC double cycling has been introduced recently to improve container terminal productivity and minimize vessel turnaround time. This work introduces a new strategy that implements double cycling of YTs to improve container terminalproductivity.

Table 3: YT single and double cycling sensitivity analysis results

No. of YTs	Single Cycle					Double Cycle					Single	Double
	No. Hrs	Productivity rate TEUs/hr	Hourly cost $/hr	Unit Cost $/TEU	Cost Index	No. Hrs	Productivity rate TEUs/hr	Hourly cost $/hr	Unit Cost $/TEU	Cost Index	Total cost ($)	Total cost ($)
3	658.04	48.62	510	10.487	0.21	421.96	75.83	760	10.02	0.132	335603.46	320689.6
4	543.04	58.92	560	9.503	0.16	338.26	94.60	810	8.56	0.090	304102.40	273989.79
5	502.06	63.73	610	9.57	0.15	297.38	107.60	860	7.99	0.074	306259.65	255745.94
6	494.02	64.77	660	10.189	0.15	281.02	113.87	910	7.99	0.070	326053.20	255730.93
7	494.60	64.69	710	10.974	0.16	275.72	116.06	960	8.27	0.071	351170.97	264688.32
8	494.30	64.73	760	11.739	0.18	276.96	115.53	1010	8.74	0.075	375668.76	279733.64
9	494.66	64.69	810	12.521	0.19	275.64	116.09	1060	9.13	0.078	400681.89	292182.64

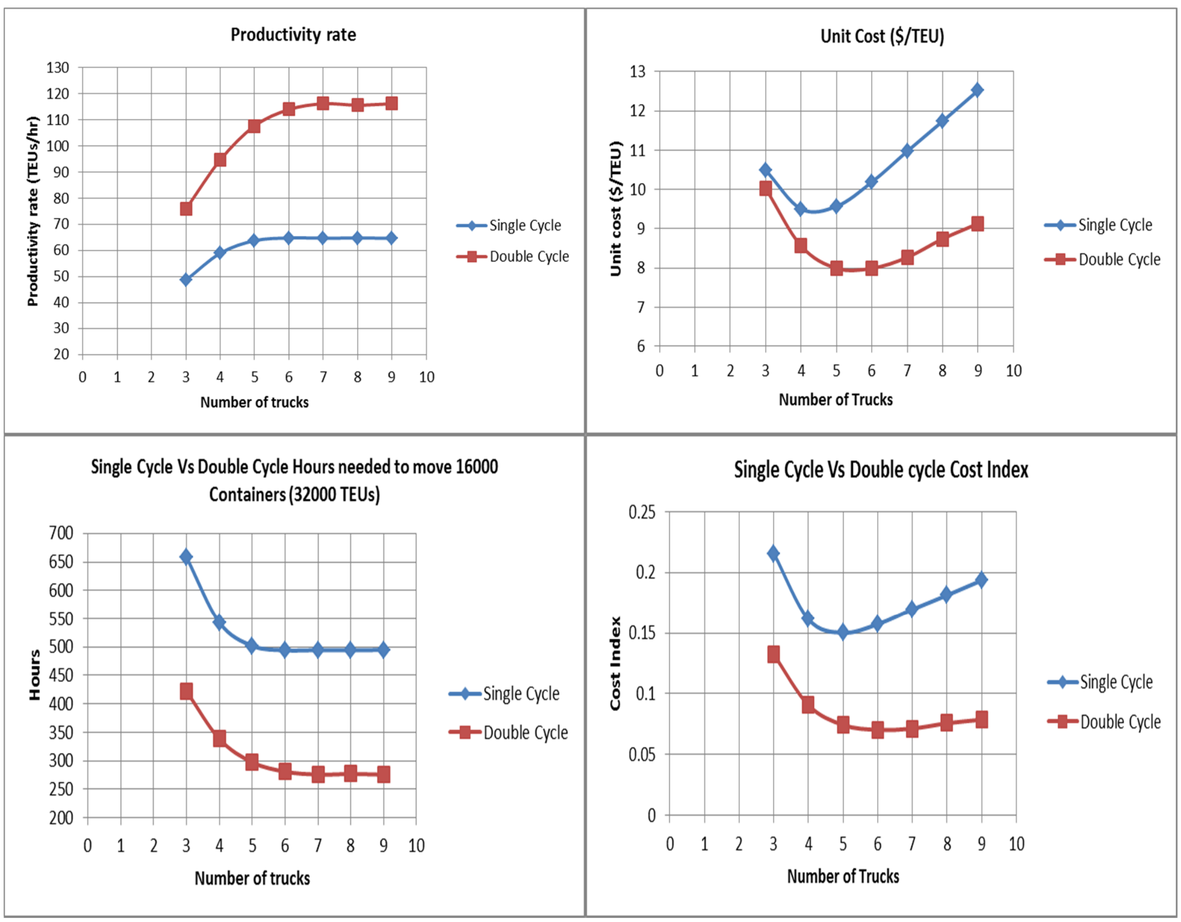


Figure 4: Sincetivity analysis comparision between YT single and double cycling

This new strategy of handling containers has been modeled, tested andThe simulation indicates a reasonable improvement in productivity while reducing hourly and unit costs. The simulation models reveal a productivity improvement of about 68% in terms of (TEU/hr) or about 34% in terms of (TEU/hr/QC), and cost savings of about 16% in both unit cost and cost per vessel of 16000 TEUs capacity.The sensitivity analysis shows the use of 6 trucks is more productive and les cost when using double cycling comparing to the use of 4 trucks in single cycling.

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MODELING TRANSPORTATION OPERATIONS IN THE SUPPLY CHAINS BASED ON JIT MODEL

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ABSTRACT

Transportation is a key logistic function, which determines the dynamic nature of material flows in logistic systems. At the same time, transportation is a source of uncertainty of logistics operations performance in the supply chain. Obviously, the development of a new approach for evaluation of the duration of delivery just in time will improve the efficiency of supply chains in accordance with one of the major criteria, namely customer satisfaction. The paper is devoted to the formation of analytical and simulation models, which allow obtaining the probabilistic evaluation of the implementation of unimodal and multimodal international transportation "just in time"; the developed algorithm takes into account main indices of transportation and various constraints (technical, organizational, administrative); performed calculation examples prove the legitimacy of the developed approach.

Keywords: supply chain management, logistic operations, reliability, modeling

INTRODUCTION

The need for new approaches to improve companies organizational and economic sustainability, maintain their competitiveness and efficiency is due to growing competition in various sectors, increased dynamism of the companies environment and dominating idea of "buyer's market". Given that the issues of cost estimating in the supply chain mainly related to logistics functions, such as inventory management and storage, are developed in sufficient detail, the methods for assessing reliability and quality of customer service have been paid little attention to. This is partly due to the fact that the duration of one of basic logistical operations, namely, transportation, is a random variable and the probability of satisfying delivery "just in time" according to JIT model depends on a number of factors (technical, organizational, administrative-legal, etc.). Obviously, further development of a common methodology for evaluating the effectiveness of supply chains requires developing a complex of decision support methods, which are a synthesis of key logistics operations, namely, inventory management, warehousing and transportation.

1. LITERATURE REVIEW

The "Just in time" (JIT) is a modern concept (technology) of the construction of a logistics system as a whole or the organization of a logistics process in individual functional areas of business, based on the synchronization of material resources delivery processes in the required quantities by the time, when the elements of the logistics system need them, in order to minimize the costs associated with warehousing of reserve stock (Ballou 1999, Bowersox and Closs 1996, Christopher 2011, Sergeev 2014).

JIT concept was used yet in the beginning of last century in the factories of Henry Ford, but has been developed and successfully implemented only in the 1960-1970 years. According to (Stock and Lambert 2001, Waters 2003, Jonsson 2008, Christopher 2011, Kraejewskiy, Ritzman, and Malhotra 2013) is an inventory management philosophy that allows minimizing inventories by eliminating insurance stocks. The purpose of JIT concept is to ensure the delivery of materials directly by the time of performance of specific operations, whereby stocks are practically eliminated.

Some experts (Waters 2003) believe that JIT model successfully works only in certain types of organizations, such as high-power assembly factories that produce a homogeneous product. At the same there is the tendency of expansion of the influence zone of JIT concept on the entire supply chain under different names:

- Quick response, QR.
- Continuous replenishment planning, CPR.
- Efficient consumer response, ECR.
- Lean production, LP, etc.

Modern trends of the application of JIT concept require close correlation of queries of various functional areas (e.g., logistics - production - marketing) as well as with other members of the supply chain (cargo company - supplier).

Obviously, great demand for JIT concept is dictated by the need to reduce the uncertainty of logistic cycles, because the synchronization of logistic functions and operations is becoming increasingly important. It should be emphasized that with the problem of estimating the uncertainty in logistics systems managers meet in the following situations:

- When evaluating the performance and reliability of supply chains, in particular the quality of services (Wolfgang and Thorsten 2006, Bowersox and Closs 1996, Lukinskiy, Lukinskiy, and Churilov 2014).
- When describing and evaluating logistic cycles quantitively (Bowersox and Closs 1996, Stock and Lambert 2001, Lukinskiy et. al. 2007).
- When calculating key performance indicators KPI when considering the balanced scorecard (BSC) and in SCOR – models (Sergeev 2014).

Consider mentioned situations in more detail.

1.1. Uncertainty when evaluating supply chain reliability

Analysis of various sources showed that the present stage of development of logistics and SCM is associated with the appearance of number of new concepts: “durability”, “flexibility”, “adaptability”, “response time” and, of course, “reliability”. In accordance to one of definitions the reliability is a property of the supply chain to keep within the prescribed limits the values of all its indicators and elements that characterize the supply chain ability to perform its functions in accordance with the terms of the contract between its members.

Table 1 shows the systematized data of number of companies (Nissan, Siemens, EMS, Saturn, etc.), that reflect actual reliability indices of performance of transport operations.

Table 1: Reliability Indices Of Performance Of Transport Operations

Indicator's name	Value	Reliability of transportation
Delivery time to consumer	1,0 hour	0,95
Total delivery time	No more than 24 hours	0,90
Permissible delay in delivery	0,25 – 0,50 hour	0,985
Delivery performance	-	0,98-0,995

The analysis of table 1 shows that:

- Quantitative and probabilistic indicators can be used to evaluate the transport operations on the basis of JIT concept (model).
- Each indicator can be taken as an independent criterion. At the same time, the index “permissible delay of indicator” requires information about the index “delivery time”.
- Question about the relationships between the values of temporal and probabilistic parameters remains open, as the distribution function of terms of delivery is not given.
- Indicators should be complemented by estimates of costs for calculating the reliability of the supply chain using discrete-continuous model (Lukinskiy, Lukinskiy, and Churilov 2014).

1.2. Uncertainty when evaluating logistic cycles

One of the basic concepts necessary for the integrated consideration of logistics operations and functions, is the logistic cycle or functional cycle of logistics. The logistic cycle is understood to be the time interval between placing an order and the delivery of the ordered products to the final consumer (receipt of order by the consumer).

There are several kinds of functional cycles; the most important among them are the “cycle of physical distribution” and “functional cycle of procurement” (Bowersox and Closs 1996, Stock and Lambert 2001). So logistic cycle of physical distribution includes five operations (stages):

1. Preparation of an order and its transfer.
2. Order processing.
3. Order picking or production.
4. Transportation.
5. Receipt of an order by the consumer (delivery to the consumer).

According to some experts the first two operations are quite stable; the third operation - order picking - depends on the availability of stocks. If products are not available, then the term of this operation will depend on the time of production or delivery to a distribution center, warehouse.

The greatest uncertainty is typical for the fourth operation (transportation) and to a lesser extent - to the fifth operation (delivery to the consumer). It is known that the transport operations in global (international) and internal supply chains differ significantly. For example, according to (Bowersox and Closs 1996), if at domestic market the transit time is 3-5 days, and the entire functional cycle takes from 4 to 10 days, then at the international level the functional cycle often takes weeks or months. For example, table 2 presents results based on statistical data on the minimum and maximum duration of each operation of logistic cycle as well as their expected (obviously modal) values.

Table 2: Duration Of Logistic Cycle Components

Logistic cycle stage	Duration of logistic cycle stage, days			
	Bowersox and Closs (1996)		Stock and Lambert (2001)	
	Range of values	Anticipated value	Range of value	Anticipated value
Stage 1	0,5 – 3	1	0,5 – 1,5	1
Stage 2	1 – 4	2	1 – 3	2
Stage 3	1 – 20	2	0,5 – 9	1

Logistic cycle stage	Duration of logistic cycle stage, days			
	Bowersox and Closs (1996)		Stock and Lambert (2001)	
	Range of values	Anticipated value	Range of value	Anticipated value
Stage 4	2 – 10	4	1 – 5	3
Stage 5	0,5 – 3	1	0,5 – 1,5	1
Total	5 – 40	10	3,5 – 20	8
Note: *anticipated value of logistic cycle general time is 15 days				

Analysis of the data in table 2 allows us to conclude that:

- Most of distribution functions are asymmetrical and only a few functions are symmetrical and can be approximated by the normal law.
- Operation “order picking” and partly “transportation” cannot be described by a single distribution function and obviously represent superposition (mixture) of the two distribution functions, for example, of the normal law and the uniform density.
- Total distribution function, which is the sum of random variables, is of asymmetric nature that is especially important to consider when assessing the reliability of supply chains.

1.3. Uncertainty when calculating key performance indicators of supply chains

Without going into detail on the nature of SCOR-model (Sergeev 2014), we note that of the five categories effectiveness evaluation (metrics) SCOR-model, two are directly related to the concept of JIT. The first metric “supply chain reliability” include KPI “execution of delivery by a certain date”. The second metric “the rate of supply chain response” includes two KPI: “order fulfillment duration” and “duration of certain logistic cycles” (procurement, production, delivery).

For example, table 3 shows the fragment of the strategic map of SCOR-model of company “Delta” (Sergeev 2014).

Table 3: KPI Of “Delta” Company (Fragment)

Metrics	Indicator of supply chain functioning	Fact	Industry average	Competitor	Leader
Supply chain reliability	Execution of delivery by a certain date, %	90	75	87	95
Supply chain response	Order fulfillment duration, days	1-4	2	1	1

The analysis of tables 1-3 shows that all the above kinds of uncertainties are closely related and, therefore, problems of assessing the duration of execution of logistics operations and functions are identical.

Real way out of this situation requires the development of a new approach based on analytical (numerical) methods and supply chain modeling using information technologies (Bruzzone et al. 2004, Curcio and Longo 2009, Ivanov, Sokolov, and Käschel 2011, Taha 2011).

Thus, the following can be stated, firstly, sources of uncertainty are random variables associated with performing the following operations of logistic cycle: transfer of an order, order processing and order picking (or production), transportation and delivery to the consumer. Secondly, it is believed that when making management decisions it is more difficult to quantify the operations that are related to international multimodal (combined) transportation. Thirdly, the most promising tool to solve the problems connected with reducing uncertainty in the supply chain is JIT model and its modifications. Fourthly, whereas most experts consider JIT concept at the conceptual level and some attempts to bring a conceptual approach to the calculation model have not found wide application, it is necessary to develop a new methodical approach for evaluation the transport process quantitatively (in the broad sense) in the form of analytical models and the use of simulation modeling.

2. FORMATION OF TRANSPORTATION MODEL ACCORDING TO JIT CONCEPT

Transportation is a key logistical operation, a description of which is characterized by a large number of indicators and factors. As mentioned previously the most complex in the preparation and decision-making in supply chain management are transportation operations. This is due to the fact that the external environment of these operations is characterized by the uncertainty, which in turn is associated with a variety of risks that differ in frequency and in nature. The main classification criteria of transportation include modes of transport (road, sea, etc.) and the type of transportation (direct, combined, unimodal, multimodal, etc.).

When developing the transportation model the main attention was focused on road transport that does not diminish the importance of other species. At the same time it is known that for the last fifteen years the share of road freight transport compared to other modes of transport of Eurozone (25 countries) increased by almost 10%. During the same period, the share of rail and inland waterway (river) transport decreased by 25%. This suggests that the increase in the share of transportation by road was due to the reduction of transportation by rail and water.

Time characteristic of overcoming complicated circumstances and observing the requirements to international road transport are random and should be taken into account while designing delivery of cargo, planning and arranging freight transportation just in time.

The main source of uncertainty is a route that is characterized by certain length, the type of road surface, restrictions imposed by different countries and other parameters.

International road transport is a more complex process from the point of view of organization, technology and as a result – management, as compared with the domestic (in-land) transportation. Complexity of the international traffic is predetermined by the necessity to cross the borders and be involved in cargo traffic customs regulation, be aware of peculiarities of the national paper turnover, inspection of the technical conditions of a vehicle, observance of weight, overall dimensions and environmental restrictions, as well as the necessity to obey drivers' work-rest schedule and other things.

If the components of transportation process are random values, then the quantitative assessment is made with the help of probabilistic characteristics.

Taking mentioned features into account, the total time of transportation can be determined by means of formula:

$$T_o = \sum_{i=1}^{A} t_{i,i+1} + \sum_{j=1}^{B} \tau_j + \sum_{k=1}^{C} \Theta_k \, , \qquad (1)$$

where $t_{i,i+1}$ – travelling time between *i* and *(i+1)* points; τ_j – time of preparation of customs documents in j-point (in the country and at the borders); Θ_k – time for loading, unloading and warehousing in *k*-point; *A,B,C* – the number of sections of the roads a car moves, customhouses and loading/unloading points.

Transportation initial time (start) T_{it} is determined by means of formula

$$T_{it} = T_{JIT} - T_o \, , \qquad (2)$$

where T_{JIT} – "just in time" delivery time.

Assuming that average driver's working hours when he performs the international carriage is Tw, the calendar run time is determined by a number of working days and is computed by means of formula:

$$T_L = \frac{T_o}{T_w} \, . \qquad (3)$$

It should be emphasized that similar formulas considering specificity can be used for calculating the time of transportation by other modes of transport; formula (1), taking into account $t_{i,i+1}$ and Θ_k allows evaluating the time of performance of domestic transportation; when considering the multimodal transportation, such as by road and sea transport, the formula (1) should be adjusted by adding summands reflecting the specificity of the respective mode of transport.

The formulas, used for computing average time of transportation and average number of trip days, show the vehicle continuous time on the route, but does not take into account all the peculiarities of the international transportation determined:

- Firstly, by the restrictions of driver's or crew's work-rest regime required by AETR.
- Secondly, by the restriction imposed on heavy haulers in some European countries on Sundays and holidays.
- Thirdly, by the necessity to arrange repair and maintenance activities, particularly, emergency maintenance and other reasons of traffic delays on the road, for example, checking up the axle weight by the road police which are the part of driver's work during his working day besides driving.

Then, taking into account peculiarities of the international transportation, the formula of calculation of the total time on the route should be adjusted and presented as follows:

$$T_o = \sum_{i=1}^{A} t_{i,i+1} + \sum_{j=1}^{B} \tau_j + \sum_{k=1}^{C} \Theta_k + \sum_{l=1}^{D} \varphi_l + \sum_{m=1}^{E} \psi_m + \sum_{n=1}^{F} \eta_n \, , \qquad (4)$$

where φ_l – random component, showing the increase of the trip time for repair and maintenance activities and other reasons; ψ_m – random component reflecting constraints connected with AETR; η_n – random component reflecting bans on the use of heavy-load vehicles; *D*, *E*, *F* – the number of cases of standing idle (considering the mentioned reasons).

When forming the model 4 we took into account characteristics of modes of drivers' work and rest; these characteristics are associated with the accumulation of working time of the driver for the day, week, two weeks that leads to an uneven increase of route time without change of traversed path. This causes the addition the variable ψ to the model. Further specification requires the introduction of a variable in the model of two inequalities-restrictions for each day of driving during the route. The first of them reflects the time of driving:

$$\sum t_{i,i+1} < T_d \, , \qquad (5)$$

where T_d – normalized driving time per day (T_d = 9h.).

The second inequality is related to the duration of the daily rest T_r:

$$\sum \left(t_{i,i+1} + \Theta_k + \tau_j + \varphi_l + \eta_n \right) < 24 - T_r \, . \qquad (6)$$

Peculiarity of application of constraints (5) and (6) is that the general model of delivery time is formed based on the probability of two events (hypotheses). The first hypothesis – H_1 – movement occurs on the route according to the dependence (1), the second hypothesis H_2 – movement occurs on the route according to the dependence (4). Consequently, the distribution function of the total time of delivery may be presented as:

$$F_\Sigma(T) = \sum P(H_i) \cdot F_i(T)\,, \quad (7)$$

where $P(H_i)$ – the probability of the i-th event; $F_i(T)$ – the distribution function according to the i-th hypothesis.

Thus, the generated model that comprises dependence (1) - (7) allows evaluating execution of transport operations in terms of JIT concept.

2.1. Analytical dependences for calculation of delivery time

Evaluation of the distribution function of delivery time according to the generated model is the sum of random variables t_i, i.e.:

$$T = t_1 + t_2 + \ldots + t_n = \sum_{i=1}^{n} t_i\ . \quad (8)$$

If t_i are independent, then one should use the following dependence to calculate the density of distribution $f_\Sigma(T)$:

$$f_\Sigma(T) = f_1(t_1) \cdot f_2(t_2) \ldots f_n(t_n) = \prod_{i=1}^{n} f_i(t_i)\,, \quad (9)$$

where $f_i(t_i)$ – density of distribution of the execution time of i-th operation.

In the general case, the dependence (9) reduces to the recurrence formulas (Ventsel and Ovcharov, 1983). Analysis of several studies has shown that dependences for calculation of $f_\Sigma(t)$ and $F_\Sigma(T)$ were obtained only for several laws of distribution with different parameters, they include normal, exponential and the Poisson distribution laws.

The probability of delivery “just in time” is estimated by using the following formula:

$$P(T) = \int_0^{T_o} f_\Sigma(T)dt\ . \quad (10)$$

For example, in case of normal distribution law the formula for $P(T)$ can be written as:

$$P(T) = \Phi\left(\frac{T_o + T_\Sigma}{\sigma_\Sigma}\right), \quad (11)$$

where $T_\Sigma = \sum_{i=1}^{n} \overline{t_i}$; $\sigma_\Sigma^2 = \sum \sigma_i^2$, $\Phi(\ \ )$ – normal distribution function (Ventsel and Ovcharov, 1983).

Another approach to the calculation of statistical parameters T_0 is based on the theorems of numerical characteristics of random variables. So the average value of the sum of random variables is calculated by the formula:

$$M\left[\sum t_i\right] = \sum_{i=1}^{n} M[t_i], \quad (12)$$

and the variance with regard to correlations t_i:

$$D\left[\sum t_i\right] = \sum_{i=1}^{n} D[t_i] + 2\sum_{i\langle j} k(t_i, t_j)\ . \quad (13)$$

Formulas for the third and fourth central moments also can be found in literature.

To determine the type of distribution laws $F_\Sigma(T)$ in the first approximation we can use the correlation coefficient:

$$\nu = \frac{\sqrt{D\left[\sum t_i\right]}}{M\left[\sum t_i\right]}\ . \quad (14)$$

After checking the correctness of the choice of the distribution law on the basis of tests of fit, the next step is calculation of the probability $P(T)$ by the formula (11).

Considered analytical dependences make possible to obtain the required evaluation of the execution of transport operations according to JIT: average transportation time; the probability of performance of delivery by the time T0 or delivery time with a given probability. The adequacy of these estimates will depend on the number of constraints and their values. But despite that, the presented formulas can be applied during the design of supply chains or in cases of their reengineering.

2.2. Simulation model to estimate the time of transportation in supply chains

Since the application of analytical dependences for evaluating the transportation time is limited, there is an objective need for other versatile tools, such as Monte Carlo method (MCM). It is known that the use of Monte Carlo method lies in reproduction of probabilistic mathematical model, which is being studied, in the form of appropriate “realizations” or “testing”. In this paper we propose to perform modeling of each transportation in the form of a consistent set of realizations in accordance with the route of movement of vehicles and taking into account the various constraints. Following statistical processing allows determining the parameters and the kind of the distribution law of delivery time.

Figure 1 shows a basic block diagram for modeling transport operations on the example of international road transport. Consider some blocks in more detail.

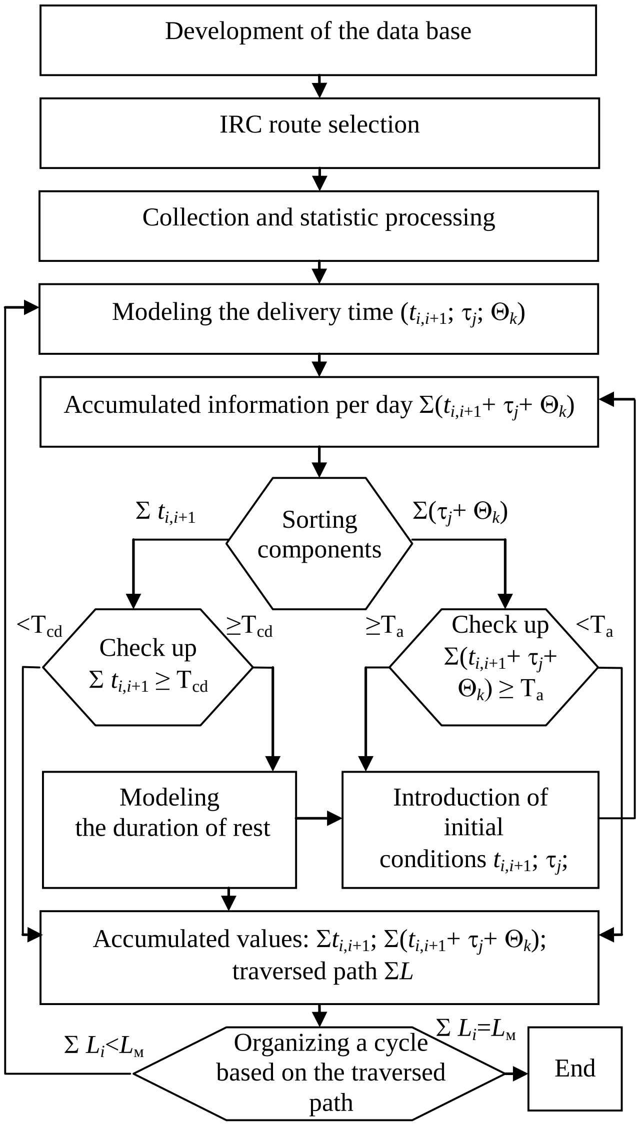

Figure 1: Basic Block Diagram For Modeling Transport Operations (On The Example Of International Road Transport)

In block 2 the type of transportation (unimodal, combined, etc.) and the modes of transport (road, sea, etc.) as well as route options (points, distances, customs, borders crossing, etc.) should be selected.

In block 3, the database of the parameters that are included in the transportation model (such as distribution laws of movement time, idle time, delays due to restrictions, etc.) is formed.

In blocks 4 and 5 simulation of basic transport operations is performed in accordance with the selected distribution laws and three arrays of information are formed: the movement time per day, the time of movement and downtime per day, the total time on the route subject to restrictions. Next in several blocks the analysis is carried out and decision is made in accordance with the restrictions (5) and (6) as well as the array of output data is formed.

The next stage involves the statistical processing of the simulated values and the evaluation of delivery indicators in accordance with the concept of JIT. Obviously, when simulating combined transportation one should include additional blocks in block diagram that take into account the movement time, handling and customs operations as well as particular restrictions, such as the regularity of sending ferries, etc.

3. EXAMPLES OF PERFORMANCE OF DELIVERY "JUST IN TIME"

For approbation of the developed approach the calculations for different routes were made. Given that transportation options are very diverse, for comparative calculations and the refinement of the algorithm two international routes were selected: the first one is a unimodal road transportation and the second one is a multimodal transportation (road and maritime transport).

The data, which are necessary for calculations, were collected on the basis of official information (e.g. tachograph data, etc.), special questionnaires filled out by drivers on real routes and survey results of managers responsible for organizing the international road transport. All simulation results were subjected to statistical processing, that comprises:

- Checking the extreme values of the samples (Arley method).
- Calculation of statistical parameters (means, variances) and the choice of the laws of distribution.
- Determination of the coefficient of correlation between the various transport operations.

3.1. Example 1

The table shows the input data for modeling transportation on the first route. This route includes: the point of departure A - the border B - the point of destination C (loading) - the border D - the point of unloading E.

Table 4 shows that the approximation of statistical data can be made with the help of different distribution laws: for transport operations associated with the movement the normal law is used; for operations related to border crossings and customs procedures, usually asymmetric distribution laws are used such as exponential or Rayleigh laws.

Table 4: Temporal Characteristics Of Transportation On The First Route

Points of the route*	Average value, h.	Root-mean-square deviation, h.	Distribution law
Point A – customs B; M	3,8	1,0	Normal
Customs B; BC + PC	1,8	1,8	Exponential (parameter h=0,55)
Customs B – point C; M	3,0	0,7	Normal
Point C; L + PC	4,9	2,5	Rayleigh (parameter σ_r =3,93)

Points of the route*	Average value, h.	Root-mean-square deviation, h.	Distribution law
Point C – customs D; M	4,2	1,0	Normal
Customs D; BC + PC	3,5	1,8	Rayleigh (parameter σ_r =2,83)
Customs D – point E; M	4,6	0,8	Normal
Point E; U + PC	3	1,0	Normal
*M – movement; BC + PC – border control and procedure of customs; L + PC – loading and procedure of customs; U + PC – unloading and procedure of customs			

Table 5 shows the results of statistical processing of the duration of transportation on the first route. As expected the total delivery time is subject to a normal distribution law. For comparison, calculations were performed using Monte Carlo method and the dependencies for the numerical characteristics of random variables, formulas (12) and (13). Since the correlation coefficients between the transport operations were within 0.1-0.15, the correlation in (13) was not taken into account.

The results of calculations were presented in the form of average values $\overline{T}$ and root-mean-square deviations σ_t; the time of delivery "just in time" with probability P = 0.98 (formula (11)) and the probability of execution of transportation during the time T_g guaranteed by a carrier (in our case, T_g = 55 hours).

Table 5: The Results Of Calculations For Performance Of Transportation "Just In Time"

Route	Calculation method	Distribution law	Parameters, h.		Delivery time (at P= =0.98), h.	Probability of guaranteed delivery
			T	σ_t		
1	Modeling MCM	Normal	49,5	3,5	56,7	0,94
1	Numerical (formulas 12, 13)	Normal	50,7	4,1	59,1	0,85
1 (considering the delays)	Modeling	Different from normal	52	7,0	66,4*	0,5*
2	Modeling	Different from normal	77,5	13,0	104,0	0,92*
*when approximating by the normal law						

3.2. Example 2

Consider such option of route 1, for which in some trips for some reasons there are delays (congestion, traffic accidents, control of weight parameters by the traffic police, etc.). The analysis showed that delays should be attributed to rare events and the probability P of their occurrence in specific realizations adheres to the law of binomial distribution. So for the given route we can take P=0.1. As for the duration of delays, they can be described by the normal distribution law with parameters such as mean value of $\overline{T_l}$ =3.0 hours and root-mean-square deviation σ_l =0.7 hrs. The simulation results are shown in table 2. A characteristic feature of this option is that the distribution of total delivery time differs from the normal law in that it has a "tail" and resembles a superposition of two distributions.

3.3. Example 3

Consider the combined transportation by road and sea transport. It should be pointed out that compared to route 1 in point C the car is placed on ferry, after ferry arrival to point C* car moves to the point of loading, then returns by ferry to point C and continues the movement to point E. The peculiarity of this multimodal transportation is that ferries from points C and C* are sent on a regular schedule at 8.00 and 18.00 each day. Total time of handling and ferry movement adheres to the law of normal distribution with parameters: $\overline{T_f}$ =10.3 h. and σ_f =1 h.

Thus, JIT concept should be applied three times - taking into account the arriving for placing on ferry at point C and C* (on return) as well as to the final point considering the total time of delivery. The table 5 shows the results of modeling, from which it follows that increased deviation from the normal law and increasingly clear display of the superposition of distribution are typical for multimodal transportation.

In conclusion, we note that the results of calculations confirm the validity of the hypothesis of the possibility of describing transportation using random events and random variables. The analysis of the table 5 shows that for some options (especially for unimodal transportation) analytical dependences and simulation results give similar results. For combined multimodal transportation, taking into consideration various constraints, preference should be given to methods of simulation modeling. Comparison of the obtained results with empirical data from tables (1) - (3) is uniquely assesses the reliability of supply chains with relation to transportation. This allows reducing the uncertainty of the entire logistic system.

4. CONCLUSION

1. The developed technique allows obtaining probabilistic estimates of transport operations in supply chains in accordance with JIT concept. The model differs from the existing empirical approach in that it allows decomposing the transportation process into separate components and describing them as separate elements with the use of statistical parameters. The next stage of the development of JIT model is the synthesis of individual transport operations for the transportation

process of the given configuration and subsequent evaluation based on the results of simulation modeling of random processes of delivery "just in time".
2. To implement the proposed approach it is necessary to organize the collection, analysis and systemization of materials, reflecting the statistical nature of the logistics operations in order to create the database that will be subsequently used in the calculations. Since the average size of motor transport enterprise, which is performing international road transport, according to the IRU is 10-12 vehicles, then in case of performing 5-7 routes a month the statistical information needed for calculations can be collected on the major routes for 3-4 months.
3. Developed approach allows us to describe the process of transportation, taking into account the various limitations (technical, organizational, administrative) and go to the reasoned development of measures to improve the effectiveness of efficiency of individual operations.
4. The obtained dependences allow moving from operational to situational management in case of deviation from a planned target considering the confidence intervals of movement process. In turn, this will require the development of matrix of decision making (fast border passage, selection of toll highways, replacement of crew, etc.) to improve the reliability of performance of transportation "just in time".

Further research on the development of the proposed approach can be implemented in the following areas.

It is necessary to consider the possibility of using the developed approach for different types of transportation, modes of transport, route options, taking into account the specifics of the transported goods , etc.

Increasing complexity of the description of processes in logistics systems, which are associated with the requirement to increase the reliability, adaptability, flexibility of supply chains, requires the active development of analytical methods and models based on information systems and information technologies. Obviously, the developed approach can be used to form an integrated model combining the capabilities of such software products as Autoroute, navigation system GPS (for quick response and corrections) and the Internet for operational decisions.

One of the promising directions of development of the proposed model is the introduction of economic parameters associated with supply chain management. A detailed analysis of transport operations and their impact on the final result (delivery "just in time") will allow not only identifying bottlenecks in the supply chain, but also evaluating the costs associated with their removal.

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INVESTIGATION OF ECONOMIC STABILITY OF LOGISTIC PROCESS USING STATISTICAL DYNAMIC MODELLING

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ABSTRACT

Crucial component of the successful performance of all participants of logistic process as an economic system is maintenance of an optimality of functioning of all industrial and economic criteria of the given system. The purpose of the given work is stochastic modelling of the stability of transport logistics system (TLS). The process of deterministic and stochastic modelling of TLS stability is considered in the conditions of uncertainty using bootstrapping and dynamic programming method by Bellman.

It is well known that random character may be an attribute inherent to the majority of economic events and processes of TLS. Modelling of logistical processes in conditions of uncertainty is complicated due to the lack of trustworthy information describing the conditions of uncertainty, and also in view of the random character of occurrences of deviations in the course of processes researched.

Ignoring the evaluation of effect of certain factors during the research of processes occurring in transport logistics system frequently expands "zone of risk", entailing mistakes and discrepancies in the real time situation that, in turn, may finally result in significant material losses.

Keywords: logistics process, financial stability, statistical dynamic modelling, bootstrapping

1. INTRODUCTION

Steady position of TLS in the market is understood as TLS ability to keep or increase the tendency of positive development, that is to keep the volume of the goods or services sold and the profit received from sales of the given goods and services in changing external and internal environment of TLS. The principal objectives of this research work are:

- to consider an option of modelling the financial stability management of TLS participants in conditions of uncertainty;
- to model "zones of risk" of the financial performance of TLS participants in conditions of uncertainty.

The structure of TLS is shown in figure 1.

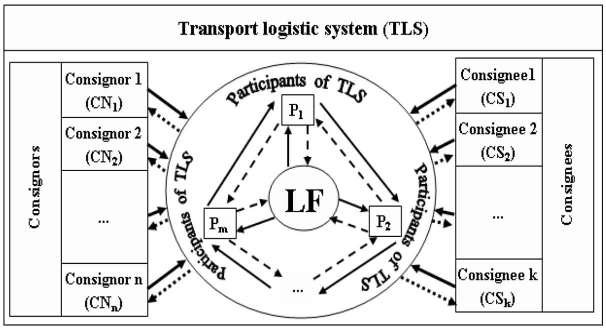

Figure 1: Structure of TLS

Modelling of behaviour of the criterion of TLS stability is based on establishing alternative strategies which are introduced during definite moments of modelling time, thereby supporting stable TLS performance. Thus, the concept „criterion of stability" has been introduced. The primary goal of management of TLS stability is maintaining the criterion of stability with regard to the given interval of allowable values of the chosen criterion of stability. Uncertainty in TLS is understood as a situation when there is incomplete or no information at all about the possible conditions of the system itself and the environment in which the system functions.

2. PROBLEM DESCRIPTION

Conditions of uncertainty are understood as various unexpected fluctuations of some factors of external and internal TLS environment. Steady performance of TLS is the ability of all TLS participants to perform a complete set of functions and also maintain (or even increase) the services to be rendered for a long period of time in the conditions of uncertainty. Ignoring the evaluation of effect of the influence of variable factors during the research of the processes occurring in TLS frequently expands the "zone of risk", thereby leading to mistakes in the real time situation that, in turn, may finally result in significant material losses. The economic stability of TLS is the capability of all participants of TLS to implement their financial liabilities in full on the timeframe set by the contract.

For the evaluation of TLS economic stability it is offered to use:

- complex variable C^F of the financial stability of TLS;
- complex indicator C^Q of the production stability of TLS;
- integral indicator of the stability of the system J, which is the function of several variables and is aggregating the complex evaluation indicators C^F, C^Q of the TLS stability.

The integrated criterion of TLS stability $J^{(t_i)}$ is a function of complex criteria $C^{F(t_i)}$ and $C^{Q(t_i)}$:

$$J^{(t_i)} = f(C^{F(t_i)}, C^{Q(t_i)}) \qquad (1)$$

For the establishment of complex and integrated criteria of TLS stability local criteria of stability of separate TLS participants are used, for example, the criterion of stability of activity of one of the transport companies of TLS, or criteria of stability of some kinds of TLS performance. Complex criteria of stability of TLS must be investigated in a dynamic as well as

Introduction of an integrated criterion of stability of TLS assumes the analysis of all industrial and financial processes in the system, i.e., the internal and external processes of TLS.

The complex criterion of TLS financial stability $C^{F(i,j)}$ is the financial stability of j-th participant of TLS at the moment of time t_i. Under favourable conditions of TLS performance at the moment of time t_i, in the system the issue of insolvency of TLS participants should not arise. That is the balance (B_{ij}) of any TLS participant at the moment of time t_i is a positive value:

$$B_{i,j} > 0 \qquad (2)$$

The complex criterion of the TLS financial stability may be presented as a function:

$$C^{F(i)} = f_1(V_{(-)}^{i,j}, n_{(-)}^{i,j}, \omega) \qquad (3)$$

where: $C^{F(i)}$ - complex criterion of financial stability of TLS at the time moment t_i;

$V_{(-)}^{i,j}$ - normalized criterion of the insolvency of j-th TLS participant at the time moment t_i, should satisfy the inequalities:

$$-1 \le V_{(-)}^{i,j} \le 0 \qquad (4)$$

$n_{(-)}^{i,j}$ - number of insolvent TLS participants at the time moment t_i;

w – random factor.

In real logistics systems there are problems with holding payments in the case of transactions between TLS participants. The breach of the contract and/or partial fulfilment of financial contracts by one of the participants of TLS lead to breaking of the financial stability of the whole system. Thus, it is offered to create and use the financial reserves of the system (Res^{ij}**)** for ensuring the financial stability of TLS. The complex criterion of financial stability of TLS, taking into account the financial reserves $C_{\mathrm{Res}}{}^{F(i)}$, may be presented as a function:

$$C_{\mathrm{Res}}{}^{F(i)} = f_1(V_{(-)}^{i,j}, n_{(-)}^{i,j}, \omega, \mathrm{Re}\, s^{i,j}) \qquad (5)$$

The financial reserves of the system are used for ensuring the limited production resources in the volume required for the TLS performance. The scheme of the use of financial reserves for ensuring the financial stability of TLS is presented in figure 2.

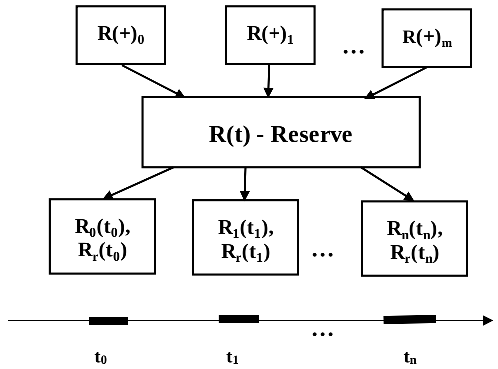

Figure 2: The Scheme of Using and Replenishment of Financial Reserve for Maintenance of TLS Stability in Modelling Time

where R(t) – the total amount of resources in TLS at the moment of time t;

$R(+)_i$ – the value of i[th] replenishment of financial reserve in modelling time, i=0,1,2, … , m;

$R_j(t_j)$ - the value of financial reserve at the moment of time t_j, j=0,1,2, … ,n;

$R_r(t_j)$ – the requirement value of financial reserve for maintenance of the TLS stability at the moment of time t_j, j=0,1,2, … ,n.

Values R(t), $R(+)_i$, $R_j(t_j)$, $R_r(t_j)$, m, t_0, t_1,…,t_n at every time moment t are random with unknown probabilities distribution. For evaluation of distributions of all this parameters we have used the bootstrapping method.

3. BOOTSTRAP METHODOLOGY

Bootstrapping is a general approach to statistical inference based on construction of distribution for a statistic by resampling from the given sample. Suppose that we draw a sample S={s_1, s_2,…, s_n}from a population P={x_1, x_2, …, x_N} and N >> n (N is very much larger than n). Now suppose that we are interested in some statistic T=t(S) as an estimate of the corresponding population parameter θ=t(P). θ could be a vector of parameters and T the corresponding vector of estimates. A traditional approach to statistical inference is to make assumption about the structure of the population (e.g., an assumption of normality), and, if we have condition of random sampling, to use these assumptions to derive the sampling distribution of T, on which classical inference is based. Nonparametric bootstrap allows us to estimate the sampling distribution of a statistic empirically without making assumption about the form of the population, and without deriving the sampling distribution explicitly. The essential idea of the nonparametric bootstrap is as follows: we proceed to draw a sample of size n from among the elements of S, sampling with replacement. Call the resulting bootstrap sample:

$$S_1^* = \{s_{11}^*, s_{12}^*, ..., s_{1n}^*\} \tag{6}$$

It is necessary to sample with replacement, because we would otherwise simply reproduce the original sample S. In effect, we are treating the sample S as an estimate of the population P; that is, each element s_i (i=1,2,…,n) of S is selected for the bootstrap sample with the probability p=1/n, modelling the original selection of the sample S from population P.

We repeat this procedure a large number of times M, selecting many bootstrap samples. Denote the j[th] bootstrap sample as:

$$S_j^* = \{s_{j1}^*, s_{j2}^*, ..., s_{jn}^*\} \tag{7}$$

Then the distribution of T^*_j around the original estimate T is analogous to the sampling distribution of the estimator T around the population parameter θ. For example, the average of the bootstrapped statistics:

$$\overline{T}^* = \frac{\sum_{j=1}^{M} T_j^*}{M} \tag{8}$$

Estimates the expectation of the bootstrapped statistics; then $\Delta^* = \overline{T}^* - T$ is an estimate of the bias of T:

$$\hat{V}^*(T^*) = \frac{\sum_{j=1}^{M}\left(T_j^* - \overline{T}^*\right)^2}{M-1} \tag{9}$$

Similarly, the estimated bootstrap variance of T^* evaluates the sampling variance of T. There are several approaches to constructing bootstrap confidence intervals. The *normal-theory interval* assumes that the statistic T is normally distributed , and uses the bootstrap estimate of sampling variance (perhaps bias) to construct a confidence intervals with confidence level a of the form:

$$\theta = \left(T - \Delta^*\right) \pm z_{1-\alpha}\sqrt{\hat{V}^*\left(T^*\right)} \tag{10}$$

where $z_{1-\alpha}$ is the 1-α/2 quantile of the standard-normal distribution. We can use an alternative approach, called the bootstrap percentile interval, is to use empirical quantiles of T^*_j to form a confidence interval for θ:

$$T^*_{(lower)} < \theta < T^*_{(upper)} \tag{11}$$

where $T^*_{(1)}$, $T^*_{(2)}$, …, $T^*_{(M)}$ are the ordered bootstrap replicates of the statistic; lower = [(M+1)*α/2]; upper = [(M+1)*(1-α/2)].

The square brackets indicate rounding to nearest integer. For example, if α = 0.05, corresponding to a 95-percent confidence interval, and M=1000, then lower = 25 and upper = 975.

The method of Monte-Carlo with bootstrapping is used for management of TLS stability. Bootstrapping is a method used in investigation process for evaluation of possible fluctuation zones for TLS parameters. This allows organizations to develop plans on how to adopt such best practice, usually with the aim of increasing some aspects of performance. Now using bootstrap estimation for values R(t), $R(+)_i$, $R_j(t_j)$, $R_r(t_j)$, m, t_0, t_1,…,t_n we can evaluate the main statistics and in modelling process take into account distributions of parameters.

4. MODELLING OF TLS ECONOMIC STABILITY

The complex criterion of the production stability $C^{Q(i)}$ of TLS characterises the ability of all TLS participants to ensure the performance of material flows in accordance with the contracts signed. The complex criterion of TLS production stability is a function of several variables:

$$C^{Q(i)} = f_2(R^{i,j}, n_{(<1)}^{i,j}, \omega) \tag{12}$$

where $R^{i,j}$ - normalized criterion which characterizes the real amount of TLS resources in comparison with the amount of resources needed for ensuring stable TLS performance in accordance with the contract liabilities.

The value $R^{i,j}$ is defined in the intervals [0, 1]:

$$0 \le R^{i,j} \le 1 \tag{13}$$

The condition of production stability of TLS is violated in the case if for any of TLS participants the criterion $R^{i,j} > 1$. The value of the complex criterion of production stability of TLS $C^{Q(i)}$ is defined in the intervals [0, 1]:

$$0 \le C^{Q(i)} \le 1 \tag{14}$$

The integrated criterion of TLS stability $J^{(i)}$ is a function of complex criteria $C^{F(i)}$ and $C^{Q(i)}$:

$$J^{(i)} = f_3(C^{F(i)}, C^{Q(i)}) \tag{15}$$

For the establishment of complex and integrated criteria of TLS stability local criteria of stability of separate TLS participants are used, for example, the criterion of stability of activity of one of the transport companies of TLS, or criteria of stability of some kinds of TLS performance. Complex criteria of stability of TLS must be investigated in a dynamic as well as complex mode.

The modelling process of TLS economic stability is implemented applying a set of alternative strategies of TLS performance by using the dynamic programming and bootstrapping method. The introduction of a set of alternative strategies supports stable functioning of TLS in the conditions of uncertainty. Thus, the integrated criterion $J^{(i)}$ changes its values in the feasible region:

$$\min J_{ij}(t) \le \sum J_{ij}(t) \le \max J_{ij}(t) \tag{16}$$

The change of criteria of TLS stability is a signal for adjusting the functioning strategy of TLS. Taking into account the TLS infrastructure, and also the character of interaction of internal and external factors of the environment of TLS performance and the integrated criterion of stability, it is natural to estimate the integrated criterion of the profit which can be presented as:

$$P(t_0,t_n)=\int_{t_0}^{t_n} \mathrm{Re}v(t)dt - \int_{t_0}^{t_n} C(t)dt \ge K \tag{17}$$

where: (t_0, t_n) - modelling time of functioning of TLS;
$P(t_0, t_n)$ - criterion of the integrated profit from TLS performance for the period of modelling time of TLS performance;
K - minimal value of integrated criterion of the TLS profit for the period of modelling time.

Integrated criterion of the revenue (Rev) of TLS performance for the period of modelling time of TLS performance can be presented as:

$$\mathrm{Re}v(t_0,t_n)=\int_{t_0}^{t_n} \mathrm{Re}v(t)dt \tag{18}$$

The integrated criterion of the expenses of TLS performance for the modelling time of TLS performance can be presented as:

$$C(t_0,t_n)=\int_{t_0}^{t_n} C(t)dt \tag{19}$$

In this paper we shall consider the problem of dynamic modelling of TLS stability in the feasible zone which looks like:

$$\begin{aligned} & P(t_0,t_n)=\int_{t_0}^{t_n} R(t)dt - \int_{t_0}^{t_n} C(t,dt \ \ge \ K \\ & \sum_{t=t_0}^{t_n}\sum_{i=1}^{n} Q_{i,t}c_{i,j,t} \ \le \ s_j; \ j=1,2,\dots,n \\ & p^{\min}{}_{i,t} \ \le \ p_{i,t} \ \le \ p^{\max}{}_{i,t}; \\ & Q^{\min}{}_{i,t} \ \le \ Q_{i,t} \ \le \ Q^{\max}{}_{i,t}; \\ & C_{i,j,t} \ \le \ c_{i,j,t}; \\ & i=1,2,\dots,n; \ t=t_o,\dots,t_n. \end{aligned} \tag{20}$$

where: $P(t_0, t_n)$ - integrated profit of TLS at modelling time (t_0, t_n);
$P^{min}_{i,t}$ - minimal value of integrated profit of TLS at the moment of time t (set by conditions of modelling);
$P^{max}_{i,t}$ - maximal value of integrated profit of TLS at the moment of time t;
$Q_{i,t}$ - volume of production (services) of TLS sold (executed) at the moment of time t;
$Q^{min}_{i,t}$ – minimal volume of production (services) of TLS sold (executed) at the moment of time t (set by conditions of modelling);
$Q^{max}_{i,t}$ – maximal volume of production (services) of TLS sold (executed) at the moment of time t (set by conditions of modelling on the basis of information describing the real capacity of the market segment);
$C_{i,j,t}$ – price of a unit of production (service) of TLS sold (executed) at the moment of time t;
$c_{i,j,t}$ – ceiling price of a unit of production (services) of TLS sold (executed) at the moment of time t (set by conditions of modelling on the basis of information about the prices for similar production at the market);
R – amount of resources of TLS considered during modelling time;
t – modelling time;
t_0 – initial time of modelling TLS performance;
t_n – time of ending the modelling process.

Conditions (20) set limits for the integrated profit P changes during the period of modelling time t.

Taking into account the casual character of interaction of internal and external factors of the environment of TLS performance, the necessity arises to include the model of casual parameter w and to have an approximated distribution function. The condition (17) is transferred into (21):

$$P(t_0,t_n,w)=\int_{t_0}^{t_n} R(t,w)dt-\int_{t_0}^{t_n} C(t,w)dt \geq K \qquad (21)$$

where: w – stochastic parameter with a set distribution exerting influence on the TLS under investigation;
$P(t_0, t_n, w)$ – criterion of the integrated profit of TLS performance for the period of the modelling time t;

In this case the stochastic modelling of TLS stability during the modelling time of TLS performance is considered. The problem of stochastic modelling of TLS stability can be formulated as follows:

$$P(t_0,t_n)=E\{\int_{t_0}^{t_n} R(t,w)dt-\int_{t_0}^{t_n} C(t,w)dt\} \geq$$

$$\sum_{t=t_0}^{t_n}\sum_{i=1}^{n} Q_{i,t}c_{i,j,t} \leq s_j; \; j=1,2,...,n;$$

$$p^{\min}{}_{i,t} \leq p_{i,t} \leq p^{\max}{}_{i,t}; \qquad (22)$$

$$Q^{\min}{}_{i,t} \leq Q_{i,t} \leq Q^{\max}{}_{i,t};$$

$$C_{i,j,t} \leq c_{i,j,t};$$

$$i=1,2,...,n; \; t=t_o,...,t_n.$$

The set of allowable optimum trajectories of functioning of TLS is defined by using the statistical method of bootstrapping and the method of dynamic programming by Bellman.

5. MAIN STAGES OF TLS STABILITY INVESTIGATION

Research of system can be divided into some main stages.

I. Stage. Logistic system description. Construction of model of interrelations between the participants of TLS. Main stages of investigation see in figure 3.

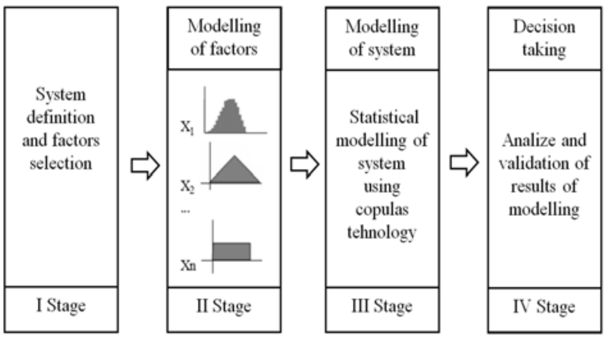

Figure 3: Main Stages of TLS Stability Investigation

II. Stage. Notification of the conditions of TLS financial stability and parameters to provide the TLS stability.

III. Stage. Assessment of feasible regions of changes for TLS parameters to provide the TLS stability, using statistical dynamic modelling, see figure 4.

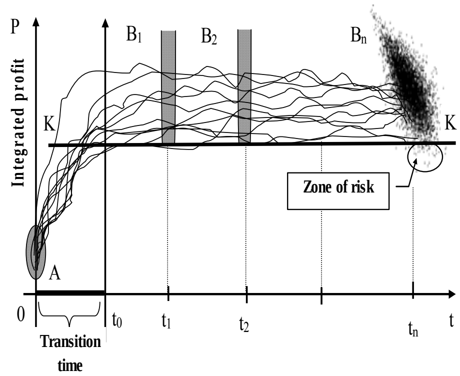

Figure 4: Feasible Regions of Changes for TLS Parameters to Provide the TLS Stability

TLS financial stability means that the trajectory of integrated criterion of TLS stability $J^{(t_i)}$ of system doesn't fall below the line K, see figure 5.

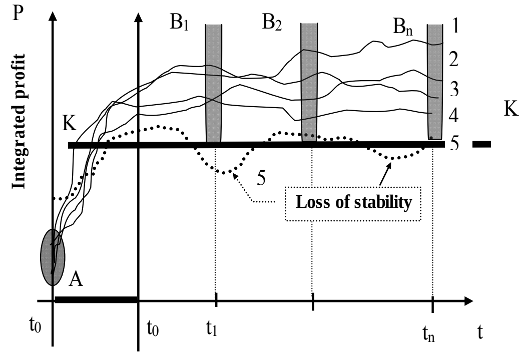

Figure 5: Illustration of the Stability of TLS

IV. Stage. Modelling of financial stability of TLS with financial reserve, using multidimensional statistical method Monte-Carlo with bootstrapping, see figure 6.

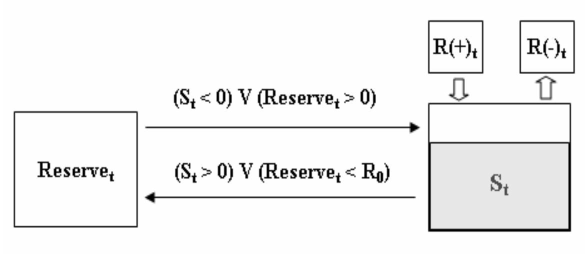

Figure 6: Use of financial reserves for maintaining the stability of TLS

The principal scheme of using of financial reserve for maintenance of TLS financial stability for every time period is shown in figure 7.

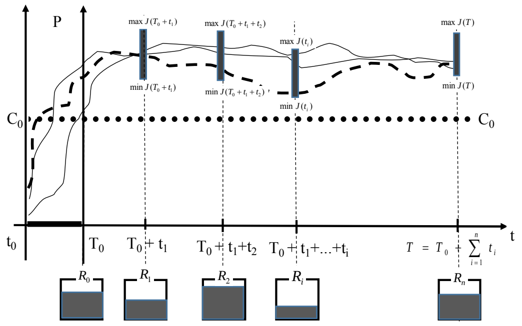

Figure 7: Use of Financial Reserves for Maintaining of TLS Stability

V. Stage. Assessment of feasible regions of changes of financial reserve in providing the stability of TLS.

CONCLUSION

The application of modelling is connected with the fact that frequently it is not possible to provide a definite analytical description of the behaviour of the economic system being investigated. When investigating the dynamic behaviour of the economic system, i.e. by making definite stochastic changes of parameters of the system under investigation, we frequently observe the existence of incidental factors affecting the character of the behaviour of the system. The modelling process of TLS stability is implemented using a set of alternative strategies of TLS performance applying the dynamic programming and bootstrapping method. The introduction of a set of alternative strategies supports stable functioning of TLS in the conditions of uncertainty. Bootstrapping is a powerful statistical tool for investigation the possible range of stability of investigated system.

By using dynamic programming and bootstrapping as well as the Monte Carlo method for modelling of TLS financial stability it has become possible:

1) to set alternative strategies of TLS performance;

3) to model TLS stability using multimodal and nonparametric technique;

2) to model the “risk zones” in which the financial stability of TLS has been distorted;

3) to identify the amount of the financial reserves required for TLS stability in the “risk zones”.

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THE USE OF CONSTRUCTIVE SIMULATION TO TEACH PORT MANAGEMENT

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ABSTRACT
Current use of constructive simulations to teach port managers skill sets is in large missing. The fast pace of change in the maritime industry requires similar adaptation on teaching institutions. Old Dominion University (ODU) began development of a unique curriculum for a port management undergraduate course that integrates a GIS-based simulation environment with the traditional course curriculum. This paper explores requirements and options for teaching port management aided by constructive simulation. A sample case study based on a real world problem is presented. Additionally, a survey was developed and administered to determine whether utilizing a simulation tool gave students a better understanding of the course material and if they gained additional understanding through such a format as compared to classes where constructive simulation was not used. The results indicate that the use of constructive simulation can aid port management students to develop domain relevant problem solving skills, stimulate creativity, and critical thinking.

Keywords: simulation-based teaching, port management, logistics, and manager skill set

1. INTRODUCTION

Multiple terms, such as simulation, simulation game, or educational game, are used to convey the idea of using simulations as an aid in teaching (Ezz, Loureiro-Koechlin, & Stergioulas, 2012). The main goal of this paper is to investigate the importance and effectiveness of a constructive simulation tool in teaching undergraduate-level port management curricula to students at ODU. Current approaches to using constructive simulations in education can intersect three main groups: 1) domain learning; 2) problem solving, and 3) computer simulation concepts related to computer sciences. The first group pertains to the use of the simulation to teach domain specific phenomena and knowledge without getting into simulation knowledge. This focuses on using simulation to drive an educational game, allowing students to view the behavior of simulated systems and analyze output to reinforce concepts learned in the classroom (Ezz et al., 2012). The second group is a middle ground approach and pertains to teaching using computer simulations with a focus on solving problems in different domains. For instance, Saltzman and Roeder (2013) explored the challenges and opportunities to teaching computer simulation to less technical business students as compared to engineering students. Finally, the third group consists of simulation-oriented education programs, which dive deeply into modeling and simulation (M&S) concepts, including simulation theory and formalisms, modeling methods, and software development. This paper discusses an approach at the intersection of the first and second groups. It explores using a GIS based constructive simulation tool to teach domain specific knowledge, in particular, port management skills. The challenges of using a constructive simulation tool to teach non-simulation savvy students port management skills includes hiding unnecessary simulation development details, while taking advantage of a high fidelity modeling environment for developing complex system representation of ports, one that captures both their structure and behavior.

The authors' literature search did not identify any published reports or papers that discuss teaching port management with the aid of constructive simulations. Therefore, our review of literature focused on related maritime areas, such as supply chain management, operations management, business, and transportation. The primary goal of our literature review was to capture the state of the art in applying constructive simulation tools to teaching. Siddiqui, Khan, and Akhtar (2008) developed simulation-based training for supply chain concepts using Macromedia Flash. They noted that visualization features are an important factor for faster learning when using simulation. Additionally, if the engaging character of simulations is supported with competitive game-based learning concepts, students develop a desire to perform better, which can contribute to improved teaching effectiveness. According to Ezz et al. (2012), critical thinking and decision-making were mentioned as specifically applicable to using simulation for learning as they stimulate student's diverse cognitive skills, providing active learning by generating insight into systems that are captured in constructive scenarios together with various decision strategies. Moreover, the feedback from an exercise can be generated quickly and without harm to the actual system. Ezz et al. (2012) reported that in the last decade many types of simulation games were developed for different areas of management. For instance, Shapiro and McGougan (2003) developed web-based marketing simulation games of differing length and complexity. Uhles (2008) described a live simulation version of financial management training, and Chua (2005) proposed a template for designing constructive knowledge management simulation games using MS Excel as a platform. He considered three dimensions: content, gaming, and learning during development of a knowledge management simulation game. Grabis and Chandra (2010) developed a process simulation environment that supports teaching operations and supply chain management. They used case studies that included scenarios allowing students to encounter different problems related to management decision (e.g. increasing demand, process redesign, and system variability). The authors noted the difficulty in taking advantage of modeling features of simulation tools to experiment with model configurations and the consequences of changes as seen in simulation results. This problem pertains to the time required versus time allowed to introduce M&S basic concepts to trainees having traditionally less quantitative backgrounds. The use of constructive simulations to teach a specific domain skill set is limited, and primarily relates to simple simulation games.

The remainder of this paper is organized as follows. Section 2 discusses port management teaching challenges and simulation environment requirements necessary to improve teaching of undergraduate level port management curricula. Section 3 introduces important features of simulation software used, proposes lesson development process, and presents a sample case study scenario for teaching using a constructive simulation environment. Section 4 presents research method. Section 5 discusses survey results and instructor's insights. Finally, Section 6 concludes the paper.

2. PORT MANAGEMENT TEACHING CHALLENGES

Instructors should challenge students to acquire cognitive skills that support proactive thinking habits. The inherent limitations of traditional forms of learning can limit an instructors' ability to properly prepare students for changing port management practices. This section focuses on describing challenges relevant to teaching port management. The complex interactions between terminals, ports, ships and intermodal service providers must be clearly understood by students in order to facilitate their mastery of decision-making skills. The learning of the concepts related to a complex system can be difficult using standard techniques. On the other hand, when a student is tasked to create a port facility and to design its operational policies and procedures, then execute them within a simulated environment, they experience a "learning by doing approach". This in turn will help students to better understand structure, behavior, and the scope of their roles as a decision-maker or analyst responsible for a port or its subcomponents. Simulation tools enable dynamic what-if analysis of different scenarios which can be integrated within a course curriculum.

Alderton (2008) pointed out that modern port managers and transportation professionals must be able to adapt and manage change using forecasting. Depending on the type, simulation tools can facilitate different levels of knowledge learning according to Bloom's taxonomy. Usually the three lower levels such as knowledge, comprehension and application are easier to capture and support by simple game simulation. The upper levels such as analysis, evaluation and especially creation are limited within simple simulation games. These levels require more flexibility, allowing hands-on practice in developing accurate system structure and behavior, and providing valid feedback from scenarios. This can be especially true for undergraduate and graduate courses, like port management, where more fidelity in modeling domain specific representations and creativity in solving problems is required.

Port managers are required to know the system and its behavior in order to be able to evaluate them and critique possible benefits and problems with proposed solutions by examining them in what-if scenarios. This examination must include system structure, scheduled and emergency operations, and resources planning. Lastly, enabling creativity and proactivity in students is facilitated in the process of developing a virtual port model, one that involves determination of its location, designing terminals and operational areas, like berths, staging areas, inspection stations, adding needed resources, and designing schedules.

Light weight simulation games may not be flexible enough to support student creativity and proactivity in the management of a complex system, like a seaport. The requirements for teaching future port managers call for using conceptualization aids in the form of computer simulation environments. Next generation port managers should be able to envision operating as port managers or in a similar relevant authority role. Simulations will support this in a more tangible manner than afforded to them by academic exposure to theoretical concepts.

Development of virtual seaports that model their main components, like terminals, operational areas and resources ensures that students understand structure and exercise. Testing and evaluation of proposed new designs or changes to a port using simulation experiments enables proactive thinking. This must be supported by a highly usable simulation tool that present to students relevant information and hide unnecessary details. Moreover, if rigid scenarios are scripted within simulation games, teachers have no options to improve curriculum based on their teaching experience. Using a flexible and reconfigurable simulation environment that allows a change of elements that will support new exercises related to advancements within the area of study. Simulation tools should be flexible so the teacher can easily improve their curriculum, adding new scenarios and teaching concepts. For instance, if new ship designs with different characteristics are developed in the real world, it should be possible to model them using an existing simulation environment.

The time required to learn simulation skills and how to apply them to build simulation models can be prohibitive for non-programmers and non-simulation oriented audiences, especially in cases of general purpose, commercial off-the-shelf (COTS) simulation products. Development of a multi-level simulation model that includes ports with multiple terminals, and many interconnected operational areas within the terminals requires significant modeling skills and time when generic simulation tools are used. This is a problem when the simulation itself is not the subject of the instruction, but rather an aid in teaching domain specific knowledge.

Using simulation environments to learn domain related knowledge, in our case port management, should require minimal knowledge about simulation and teach only required concepts as students are gaining proficiency about the subject matter. The university undergraduate port management course is traditionally several months long and includes a significant amount of domain specific information, which makes it prohibitive to also teach simulation technology in detail. Simulation tools must be simple to use and appropriate for the students' background, with a focus on accessibility to domain knowledge relevant to the system of interest. This places more stringent requirements on the user interface than those in a generic simulation tool. In summary, non-technical students should be able to develop, visualize, and simulate complex port facilities, providing them a unique learning environment which enables the application of creativity and proactivity superior to traditional instructional methods.

3. A SAMPLE CASE STUDY LESSON

The purpose of the case study is to demonstrate the potential of a high fidelity simulation environment when applied to a higher education port management curriculum. First, we provide a brief introduction to Scalable End-to-End Logistics Simulation (SEELS) environment. Next, a proposed framework showing how M&S based lessons can be developed is concisely described. Finally, a simple case study in the lesson format is described.

3.1. Brief Introduction to Simulation Environment

The SEELS interface allows for a design of highly configurable models that are defined using the provided GIS graphical interface based on ArcGIS map and polygons representing infrastructure. The GUI is designed to match the scalability of the SEELS simulation core (Mathew, Mastaglio, & Lewis, 2012). SEELS enables representation of a logistical network that can be composed of multiple ports. Through a network, entire seaports can be represented within a hierarchal structure of multiple terminal areas, which in turn consist of operational areas as shown in Figure 1. Moreover, cargo and transport profiles can be defined as needed to represent appropriate metrics.

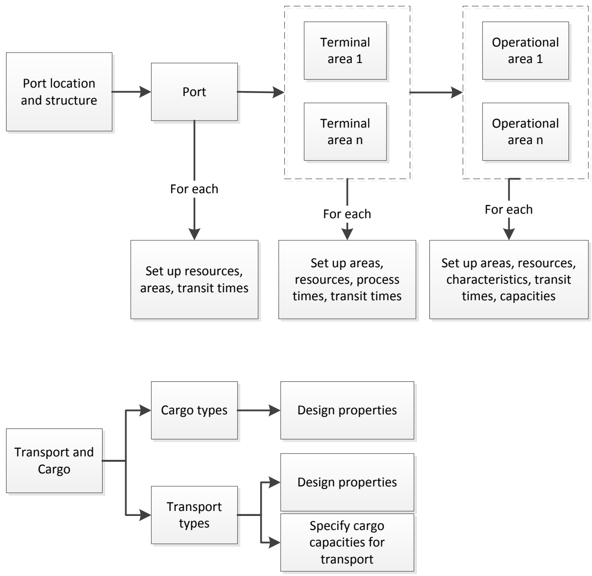

Fig 1. Port design in SEELS

After the development of model components it is necessary to design simulation scenarios that describe a desirable experimental frame. This involves developing a schedule of transport arrival events, the arrival times, transport quantity, and destination of each cargo load for each individual transport item (see Figure 2).

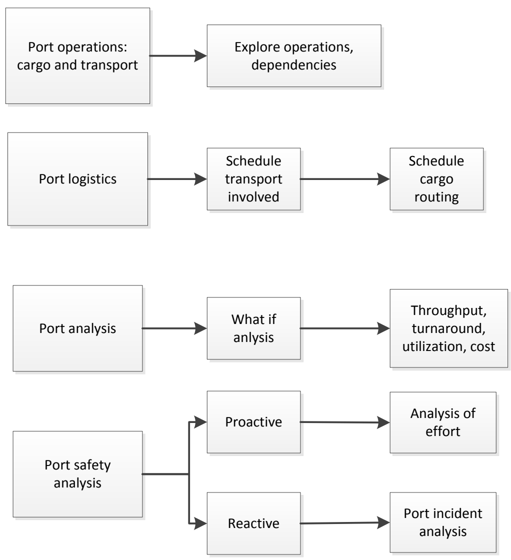

Figure 2. Port and safety scenarios in SEELS

The interface provides an instructor with flexibility to develop learning objectives that enable students to explore ports structure, and requires critical thinking by having multiple paths and options to explore the same problem. Proactive security analysis can be conducted by inserting proposed inspection stations anywhere within the port facilities to assess the impact that they will have on cargo flow. Reactive analysis consists of developing response strategies to disruptive incidents when they occur. Transports can arrive empty or loaded with a mix of cargo headed for different destinations (Mathew et al., 2012). A simulation run consists of a single scenario that can consist of multiple profiles, which can be mixed and configured to work (toggled) with one of multiple network configurations (structure, resources) providing experimental flexibility for end users (see Figure 3).

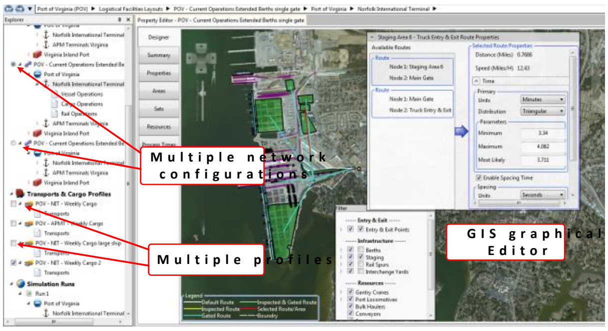

Figure 3. View of SEELS GUI

3.2. Lesson Development

Figure 4 provides a proposed technical approach to developing M&S-based lessons.

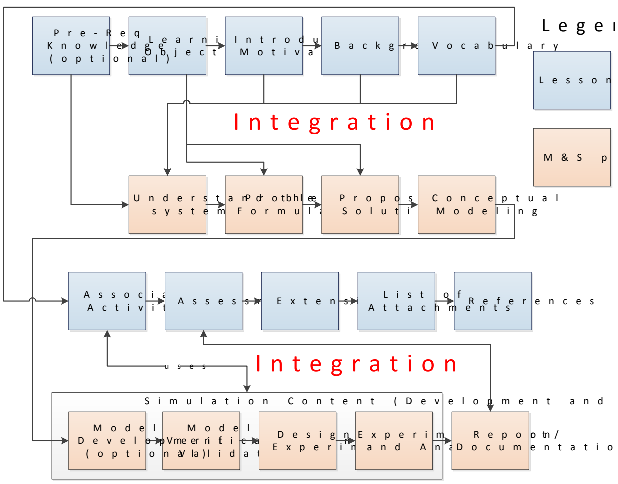

Figure 4. Technical approach to develop an M&S-based lesson

M&S processes adapted from Kelton, Sadowski, and Sturrock (2007) and Law (2007) were overlaid onto STEM-like lesson development sections. Instructors design objectives for the lesson based on real world problems. Depending on lesson objectives, basic theoretical understanding of port operations may be necessary up front. Some problems may require development of port, terminals, and their networks, while other lessons can focus on experimentations using already created models. If development of a model is a part of the lesson, students can use SEELS to visualize possible layouts of terminal areas. This way, conceptualized structure can be developed into simulations by adding resources, specifying processing times, and profiles within the modeled environment. Instructors should introduce implications of model validity and provide necessary relevant data (e.g. processing times to ensure output relevancy) with the lesson objectives. One of the advantages of SEELS for teaching is its embedded domain specification, which allows student to focus on the lesson activities and not time consuming aspects of model coding and related V&V. For instance, statistical output analysis may not be a crucial element of the lesson but a secondary aspect, which is different in comparison to the M&S curriculum. Finally, a student prepares a final report and/or presentation about an insight or a solution to a problem including necessary concepts, models, simulation results, and recommended decisions.

3.3. Background and Objectives of a Sample Lesson

The concentration of container volumes when mega-ships are used is more profitable to the container shipping industry as compared to using smaller vessels, but cargo surges can strain vessel, yard and gate operations at marine terminals Mongelluzzo (2013). This situation can be investigated by students using a simulation model. A model of a terminal for this lesson would be provided to a student. Figure 5 shows a sample model representing Norfolk International Terminal including; berths (blue), staging areas (green), rail spurs (violet), and gates (blue circle) based on Mathew et al. (2012).

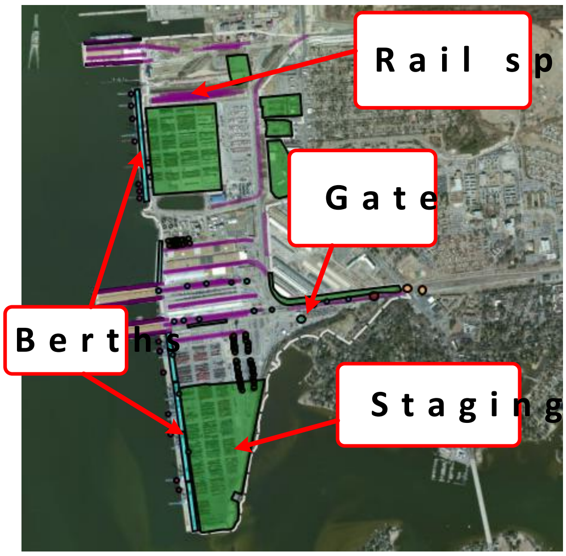

Figure 5. A layout model of Norfolk International Terminal (NIT) developed in SEELS

Students would utilize the provided model to process 10,000 40 ft. containers: 5,000 for import and 5,000 for export. Two types of vessels should be considered:

Panamax vessels capable of carrying up to 5000 40 ft. containers and Feedermax vessels with capacities up to 1,000 40 ft. containers. Import cargo should be processed out of the terminal by 3,500 trucks and the rest of containers should be handled by trains. All exported cargo will be delivered by trucks and shipped out in empty vessels. The objective of the lesson is to expose students to the effect of ship size and schedule options on performance. Students would be tasked to design and conduct simulation experiments to analyze tradeoffs depending on ship type and schedule as a potential for a better outcome in terms of resource cost per container processed and total processing time of cargo. The instructor provides the following types of data: modeled areas included in analysis, number of resources available, operational times, and cost of main resources per hour. Detailed description of all parameters is out of the scope of this paper because it could easily encompass the entire paper. The most important parameters as determined by the authors are provided in Table 1.

Table1. Sample model data

Sample areas	counts	measure
Berths	17	14634 ft
Staging areas	8	8422087 sq ft
Rail Spurs	60	79680 ft
Gates	1	2 inbound and 2 outbound lanes
Sample resources	**utilized**	**cost per hour $**
Straddle carriers	83	80
Container cranes	16	300
Gantry cranes	17	80
port locomotives	6	80
harbor pilot and tugs	5+5	80+80
Sample processing parameters	**minutes**	
berth time	20	
deberth time	20	
crane load and unload time in berth	2	
crane load time	2	
container load and unload time in staging	2	
gates processing time in/out	2/2	

It should be noticed that deterministic values for processing times are assumed in this exercise to simplify analysis and focus in this lesson more on port management learning objectives and less on M&S concepts related to statistical output analysis.

3.4. Design of experiments

Students should have enough freedom to design specific scenarios so the design of experiment (DOE) permits them to examine the problem space. For instance, four sample scenarios are shown in Table 2. Different transport arrival times are considered for the cases with five smaller ships and a single large ship. For instance, Scenario 1 can be read as follows; five ships arrive at time 0, carrying 1000 40ft containers each (import), which are processed out by 3500 trucks and 30 trains that each consist of 50 railcars arriving at time 0. Additionally, 5000 export trucks arrive, each carrying a single 40 ft. container that will be all loaded on five ships also arriving at time 0. Scenario 2 spreads the arrival of transports within five day period for ships, trucks and trains. Scenario 3 is similar to Scenario 1 but single large ship arrives, while Scenario 4 resembles Scenario 2, but only arrival of trucks and trains can be spread in time.

Table 2. Sample Scenarios

	Direction of cargo	Arrive	Contaners picked up by	Arrive
Scenarios 1	Import (five ships) 1000 containers each	at time 0	3500 trucks	at time 0
			30 trains x 50 railcars	at time 0
	Export (5000 Trucks) each with a container	at time 0	five ships	at time 0
Scenarios 2	Import (five ships) 1000 containers each	one a day	3500 trucks	700 a day
			30 trains x 50 railcars	6 a day
	Export (5000 Trucks) each with a container	1000 a day	five ships	1 a day
Scenarios 3	Import (single ship) 5000 containers	at time 0	3500 trucks	at time 0
			30 trains x 50 railcars	at time 0
	Export (5000 Trucks) each with a container	at time 0	single ship	at time 0
Scenarios 4	Import (single ship) 5000 containers	one a day	3500 trucks	700 a day
			30 trains x 50 railcars	6 a day
	Export (5000 Trucks) each with a container	1000 a day	single ship	1 a day

The main output of interest required consists of average throughput of the facility related to processing time of cargo in the terminal, and average cost per container based on resources utilized; however, students can use additional measures.

3.5. Case Study Results and Discussion

Table 3 provides a set of results from sample scenarios.

Table 3. Results from simulations

SCENARIO	1	2
days to process cargo	12	12
average daily throughput	833	833
straddle carrier cost	$1,243,360	$ 1,171,900
container crane cost	$ 292,900	$ 240,313
gantry crane cost	$ 21,173	$ 23,733
port locmotive cost	$ 2,920	$ 2,739
harbor pilot and tugs cost	$ 8,820	$ 8,840
Total considered cost	$1,569,173	$ 1,447,525
cost per container (40ft)	**$ 157**	**$ 145**
average daily cost	130764	120627
SCENARIO	**3**	**4**
days to process cargo	17	17
average daily throughput	588	588
straddle carrier cost	$ 979,372	$ 986,847
container crane cost	$ 191,945	$ 191,894
gantry crane cost	$ 25,550	$ 19,893
port locmotive cost	$ 2,752	$ 2,751
harbor pilot and tugs cost	$ 1,232	$ 1,242
Total considered cost	$1,200,851	$ 1,202,627
cost per container (40ft)	**$ 120**	**$ 120**
average daily cost	$ 70,638	$ 70,743

Processing time of Scenarios 1 and 2 is 5 days less than Scenarios 3 and 4. This difference is a result of the large amount of cargo that arrives at a single berth in Scenarios 3 and 4, which strained berth operations and subsequently increased total processing time. For instance, the worst cargo turnaround time at berth area for Scenario 1 did not exceed 35 hours, while for Scenario 3 it reached over 70 hours. The overall cost per container is higher for Scenario 1 and 2. This is due to more ships processed by harbor pilots and tugs in Scenarios 1 and 2, but also the high cost of processing cargo by various resources within a terminal. Lower cost per container in Scenario 2 as compared to Scenario 1 pertains to ability to divide ships arrival time, hence allowing avoidance of a lumpy demand within the terminal. Five smaller ships allow for more flexibility in scheduling, which can prevent lumpy demand in the terminal, resulting in savings without compromising the processing time. The division of truck and train arrivals did not make any significant changes in Scenarios 4 in comparison with Scenario 3. Scheduling of large ships is more constrained. On the other hand, the tradeoffs between cost and time should be also considered. Constrained to single berth operations in Scenario 3 and 4 was a bottleneck to the whole process within the terminal, which on the other hand decreased the resource operating cost.

Overall, the results from simulations of complex systems should not be considered as generalizations of the system behavior but observations of its particular configuration. Different configurations create different cases related to characteristics of areas, number of resources available, and business rules. Changes made to a single point of system can drastically change the results.

3.6. Report/presentation and student evaluation

The assessment should measure whether the participants achieved the pedagogical/androgogical objective, which is a better understanding of port management concepts. The evaluation can assess whether students were able to make sound business decisions by using the SEELS environment. This can be measured objectively by taking into account the decisions leading to actual simulation output (e.g. financial or operational performance) of the ports or terminals. Moreover, the students should be able to explain the output performance they achieved during the simulation. The presentation given to the class and/or report students submit at the end of lesson could provide additional measures for evaluation. Performance during the simulation needs to be explained based on results. Students should provide an explanation about how the simulation-based decision improved performance.

4. RESEARCH METHOD

A survey was administered to evaluate the undergraduate port management course that integrates a GIS-based simulation environment into a traditional course curriculum. This gauges the current approach, allowing to analyze it and determine whether the possible application of SEELS to support different undergraduate and graduate level maritime courses is feasible. The research question examines whether the use of SEELS benefited students during acquiring port management knowledge and allowed them to experiment with a synthetic environment provided a value-added experience to a traditional curricula. The survey content is provided in the Appendix A. A total of 14 responses were obtained from the MSCM 472 class of 30 students, hence almost half of the class responded.

In addition to the survey, the MSCM 472 instructor will qualify the training strategy. This will include a comparison of the class where the simulation was used with the previous class without using simulation. This evaluation will also provide the instructor insight into what can be learned using this strategy in the context of port management and how competent learners can become. For instance, would they perform better in real life and attain superior results using the learning strategy that includes simulation?

5. ANALYSIS OF SURVEY RESULTS AND DISCUSSION

5.1. Survey Results

Table 4 displays results of the survey. The results are discussed in the context of enabling constructive simulation integration with port management domain knowledge tailored for students not acquainted with M&S. Question 1 and 2 aimed at identifying students' experience and formal training in the M&S. The results in large indicated that the audience was not advanced and have limited experience in M&S concepts. This is important as a baseline to determine possible benefits, limitations, and attitudes of using advanced M&S software such as SEELS for domain learning and problem solving activities by students inexperienced in M&S concepts. Question 3 clearly shows that students had to think critically when using SEELS (4.63, 4.93), which in turn indicates that SEELS assisted the instructor to develop the exercise allowing students to observe, conceptualize, apply, and reason. This is important because it immerses students in the complexity of port management decision making. For instance, question 6, 7, 8, 9, and 10 explored different aspects of SEELS such as development and analysis of simulated data, port capacity and planning, handling equipment allocation, terminal constraints, and terminal modifications respectively. The responses to these questions were highly rated; showing diversity of port management concepts that can be supported by SEELS, and showed enhanced domain learning capability in the case of port management. The challenging aspect of port design and modifications is indicated by results of question 10 (3.5, 4.65), where one student did not agree and three students neither agreed nor disagreed with the question. Question 11 shows that using SEELS benefited students in gaining understanding of the relationship between port operations and supply chain efficiency (4.12, 4.88). Question 4 indicated a high complementary value of using SEELS to the Port Management course, confirmed by question 12 that reflected general perceived benefits of using SEELS.

Table 4. Results from survey

Question Number	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Mean	95% CI - lower bound	95% CI - upper bound
1	4	4	0	4	1	2.5	1.7	3.4
2	9	2	0	3	0	1.8	1.1	2.5
3	0	0	0	5	9	4.6	4.4	4.9
4	0	0	0	1	13	4.9	4.8	5.1
5	0	0	0	7	7	4.5	4.2	4.8
6	0	0	0	4	10	4.7	4.4	5.0
7	0	0	0	5	9	4.6	4.4	4.9
8	0	0	0	6	8	4.6	4.3	4.9
9	0	0	0	6	8	4.6	4.3	4.9
10	0	1	3	4	6	4.1	3.5	4.6
11	0	0	1	5	8	4.5	4.1	4.9
12	0	0	0	3	11	4.8	4.5	5.0
13	0	0	1	10	3	4.1	3.8	4.5
14	0	0	0	5	9	4.6	4.4	4.9

Results of questions 13 (3.83, 4.45) and 14 (4.36, 4.93) indicated that user interface features allowed students critical thinking processes during creating port layouts. First, the SEELS user interface allows for easy visualization and manipulation of port and terminal components that overlay GIS. Second, separation of structure, behavior, data, and visualization allows for hiding unnecessary computer science details. Both characteristics could be beneficial by allowing for a student unexperienced in M&S concepts to jump right into domain learning and learn faster about a terminal and its layout dependencies despite its complex structure and behavior.

Full transcript of open ended questions 15 and 16 is provided in Appendix B. Question 15 provided insight into aspects of the SEELs software that contributed to learning. The responses pointed at importance of hands on experience that can complement books and lectures to gain better understanding of port layout, operations, scope of decisions, through easy to handle visual and analytical representation. Question 16 equivocally supported or even commended SEELS as allowing creativity, being fun, interesting, and educational; the only complaint was a wish to have more time to spend using it.

5.2. Instructor's evaluation

Throughout Port Management lectures students learn and discuss the various mechanisms that ports utilize to improve operating efficiency; however, with the SEELs technology, the students gain the ability to work hands-on with a selected port. By manipulating quay, yard and rail operations students can identify the optimal handling needs and resource requirements for specific terminals. In previous classes where SEELs was not incorporated into the curriculum, students merely heard about simulation technology and planning mechanisms or watched online demonstrations. More questions were raised in the classrooms without SEELs as to how ports administrators accurately forecast changes in vessel calls; adjust to changing vessel sizes and plan infrastructure needs or intermodal projects. The class that utilized SEELs also raised such hypothetical scenarios, but took the questions and used SEELs to simulate the environment and identify solutions.

Moreover, the hands-on application and the ability to actually create a model and simulate a facility showcased how terminal handling operations can be optimized. As an example, by personally adjusting the number of cranes located on the quay or the number of straddle carriers used within the yard, the students gained better insight into how cargo handling equipment influenced port productivity; i.e. how many additional containers were moved per hour with the addition of another crane. Moreover, the students could then analyze the financial side of the operations, as to whether additional equipment and additional labor improved port performance ratios and had a significant return on investment for the organization. Accompanying the analysis, students could further discuss how a change to yard operations could lead to a greater competitive advantage for the selected terminal as compared to a neighboring terminal.

With additional training, it is predictive that students could also utilize these scenarios and solve port planning problems related to supply chain disruptions. These could include simulated weather disturbances and cargo backlogs and cargo diversions or labor-related issues such as union lockouts or strikes. As students transition from the university setting to port-related careers, the students with the SEELs knowledge have the potential to perform better in port planning and terminal operation positions. Their familiarity with existing modeling and simulation tools will provide them with a competitive advantage over students who have not been exposed to hands-on applications. They also have the ability to influence terminal management buying behaviors as they relate to port planning technology since they have experienced the tools in the classroom and recognize the applicability to real-world port situations.

6. CONCLUSIONS

The use of a constructive simulation environment to enhance learning port management has not been previously investigated. The paper discussed challenges related to teaching port management. Brief guidelines to development of lessons that utilize simulation models were proposed, and a sample lesson/case study was described. The study used a survey that examined the effectiveness of initial phase of a port management curriculum development that included constructive simulation as a learning aid. The results provided a strong support for the learning strategy adopted.

In future work, a transformative learning environment that supports students' collaboration within lessons should be considered. This could further enhance motivation and stimulate learning, enabling the execution of exercises that require teamwork as one of port management skills. This can be achieved by developing problems scenarios divisible into roles or tasks that constitute a larger effort, enabling students to develop and examine concepts working in teams via modeling and simulation experiments.

APPENDIX A

1-Strongly Disagree
2-Disagree
3-Neither Agree nor Disagree
4-Agree
5- Strongly Agree
N/A- Not applicable

Student

1. I have previously used modeling and simulation software in other business courses.
2. I have had formal modeling and simulation training in the past.

Content

3. The SEELs module in MSCM 472 required me to think critically.

4. The SEELs module complimented the in-class course lectures and/or added value to the Port Management course.

5. The SEELs software allows for the analysis of real world data (i.e. cargo volumes, ship calls, truck deliveries and railroad operations).

6. I gained a better understanding of terminal design and layouts with the use of the SEELs software. For example, with the use of the software, I understand how a terminal's design influences the volume of cargo that can be handled on an hourly, daily and monthly schedule.

7. I gained a better understanding of port capacity (i.e. vessel scheduling and berth allocation) and planning with the use of SEELs software.

8. I gained a better understanding of cargo handling equipment and asset allocation with the use of the SEELs software.

9. The output report provided me with an understanding of terminal constraints.

10. I used the output report to modify the port design model and incorporated changing port services demand.

11. With the use of SEELs software, I have a better understanding of how port operations affect the supply chain and its efficiency.

12. Overall, I learned or benefited from using the SEELs software.

Navigation

13. The SEELs software provided a user-friendly interface.

14. Creating a port layout required critical thinking

Open Ended

15. Which aspects of the SEELs software exercise contributed most to your learning?

16. Would you recommend using Modeling and Simulation software to learn about port operations and planning?

APPENDIX B

Question 15 responses (10):

- Learning about port development and how critical they are to operate efficiently.
- Felt like it was more of a hands on experience. Books and lectures can sometime miss this element.
- The output of the port productivity and throughput was key. With that I was able to make decisions on what needs to be changed. Therefore, I believe that was the most important part of the SEELs program.
- The SEELS exercise was very helpful in my understanding of ports and port operations.
- Being able to see how a layout of a port looks
- SEELs is a great learning tool that allows you to see what it takes to create a port and how to maximize its use.
- I learned how ports need to be set up in order to function properly, and also to prevent accidents and unauthorized entry into the facilities. I also realized that to have a successful port, location is everything. There are just so many things to consider if a person wants to design a new port. I

now see how unbelievably complex the whole operation is. But I also learned what many of those operation are and how they work, so overall, I'd say I learned a good amount of useful information.

- The layout of the ports and all the other things around it that are necessary. A port needs a lot more than just a berth basically.
- Visual representation of cargo capacity and constraints; could adjust size of port area and amount of equipment to see changes in throughput, congestion etc.
- allocation of equipment and resources, capacity and time constraints of various port operations.

Question 16 responses (13):

- Absolutely.
- Yes. I thought it was very interesting. Wish I would have had more time with SEELS. One session didn't give me enough inside to master the program.
- Yes, I would suggest it because a hands on approach and first person experience is key to understanding a ports operations.
- Yes, I believe that there should be more use of Modeling and Simulation software in MSCM and related classes.
- yes I would
- Yes
- Yes, absolutely. It adds a feel of "real world" application.
- Yes, I think having/ being able to use the SEELs program was very beneficial to the course. It provided a great tool that allowed us (the students) to be creative and design a port. Being both fun and educational I think the SEELs program is a must for the port management class!
- Yes, absolutely
- Yes
- Yes; an excellent tool
- Yes
- Yes, it is a great way to visualize a port and its operations that way. At least I think so.

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RECONFIGURATION MODEL FOR PRODUCTION-INVENTORY-TRANSPORTATION PLANNING IN A SUPPLY NETWORK

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ABSTRACT
Optimization problem for planning the reconfiguration of a production-inventory-transportation network in a supply chain is studied. A dynamic multi-commodity planning model is presented to support the reconfiguration of a production-inventory-transportation network in a supply chain under conditions of uncertainty and structure dynamics.

Keywords: production-inventory-transportation network, structure dynamics, reconfiguration, supply chain, optimal control.

1. INTRODUCTION

Production-inventory-transportation network (PITN) planning is a referenced research problem that is vital in many supply chains in order to successfully meet the customer needs while improving the performance efficiency. Given a location structure from facility planning, customer demand from forecasting, and order quantities from inventory management and sourcing planning, the aggregate transportation volumes between suppliers and customers need to be determined for a middle-range period of time (e.g., one month) so that the total costs (e.g., transportation and inventory) and service level are improved (Amiri, 2006; Chopra & Meindl, 2012; Hinojosa, Kalcsics, Nickel, Puerto, & Velten, 2008; Mula, Peidro, Diaz-Madronero, & Vicens, 2010; Tayur, Ganeshan, & Magazine,1999). The problem is typically constrained by limited capacity of nodes and arcs in the network, given service level, reverse flows, product quality, etc. (Akkermann, Farahani, & Grunow, 2010; Chen, 2010; Costantino, Dotoli, Falagario, Fanti, & Mangini, 2012; Liang, 2008; Mula et al., 2010).

PITN is a form of business organisation, which contains the following specific features: network and enterprise collaboration are organised project-oriented, supply chains in the PITN are formed customer-oriented without predetermined long-term suppliers structures and product programmes, each network participant specialises on certain functional competencies, network participants are independent and act autonomously and self-goal-oriented, for each project a coordinator exists, who is responsible for the project success (customer side) and coordinating network participant activities (supply side). The PITN must be configured according to the project goals and reconfigured in dynamics according to the current execution environment. In practice, PITN redesign decisions are centered on adapting and rationalizing the supply chains in response to permanent changes of network itself and its environment (Harrison et al., 2005). Efficient supply chain reconfiguration is a critical source of competitive advantage given that as much as 80% of total product cost may be fixed by these decisions (Harrison et al., 2005). About 75% of operative costs in value chains are caused by supply chains (Wannenwetsch, 2005).

That is why we consider the problem of PITN dynamical reconfiguration as a critical point in the PITN research. Subject of this contribution is to elaborate a methodological basis of reconfiguration for the PITN in the settings of adaptation. The focus lies on the PITN, which are characterized by high structure dynamics due to flexible customer-oriented networking of core competencies.

The goal of this study is to develop a DN planning and analysis model and to apply it for a concrete case-study and based on an original methodical approach called structure dynamics control (SDC) (Ivanov et al. 2010).

Modern SCM (Supply Chain Management) is a complex system consisting of various objects, including plants in the structure to distribute, distribution centres with the capabilities of physical transformation products. Key elements of the supply chain are often presented (Ivanov, Sokolov, 2010) as the diagram shown in Fig. 1.

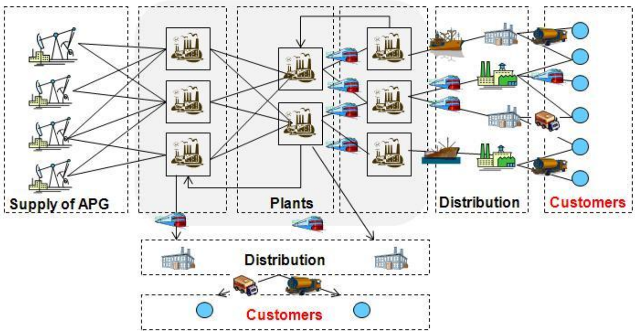

Fig. 1. The main elements of the supply chain.

The task of research production-inventory-transportation network (PITN) is vital for the effective functioning of the various supply chains (Ivanov, Sokolov, 2010). The nodes of this network represent objects interconnected transport links. In the most general case, each such PITN object can perform following operations: receiving the raw materials and storage of raw materials, production of finished products (processing of raw materials), storage of finished products, transportation of raw materials and finished products, delivery of finished products to the consumer . It should be noted that PITN nodes can perform some or all of the above operations.

Logical interconnection of process operations performed in PITN nodes is shown in Fig. 2.

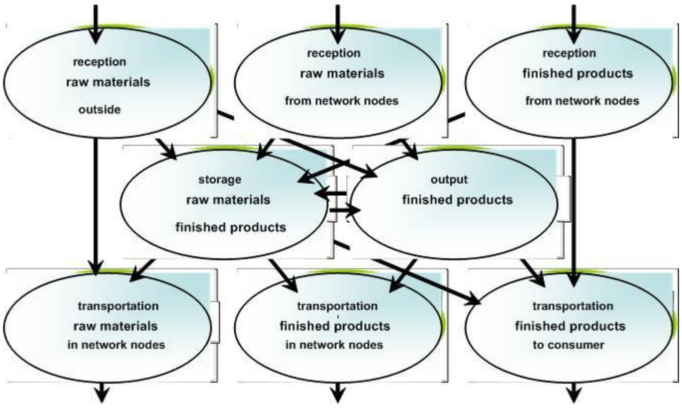

Fig. 2. Logical interconnection technology operations.

2. PROBLEM STATEMENT AND MODEL

As an example, let's consider the production-inventory-transportation network of SCM.

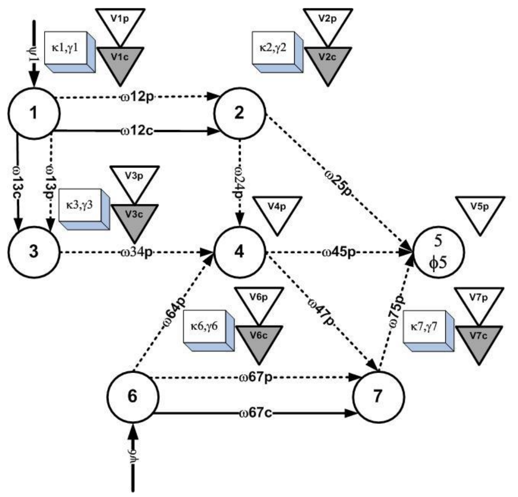

Fig. 3. Production-inventory-transportation network of SCM.

The triangles in Fig. 3 characterize the warehouse of the network nodes for raw materials (gray triangles), for finished products (light triangles). The rectangles in Fig.3 characterize the manufacturing process in the nodes. The supplier delivers various types of raw materials through the nodes 1 and 6. Node 4 is the central node of distribution of finished products. Node 5 is the regional centre of distribution of finished products. Raw materials can be processed in nodes 1 and 6, and in intermediate terminals 2, 3 and 7. In order to take into account possible problems with channel 4-5, 7 terminal outsourcing is used as an alternative route for supplies to distribution centre 5. In addition, you can move finished products, in small quantities, from terminal 2 into centre 5 directly.

We assume that as a result of the destructive effects of the different nature, the structure and parameters of PITN can change, but, at that, they can be constant in some time intervals (Ivanov et al., 2013; Pavlov, 2013). Version of such structural reconfiguration is shown in Fig. 4.

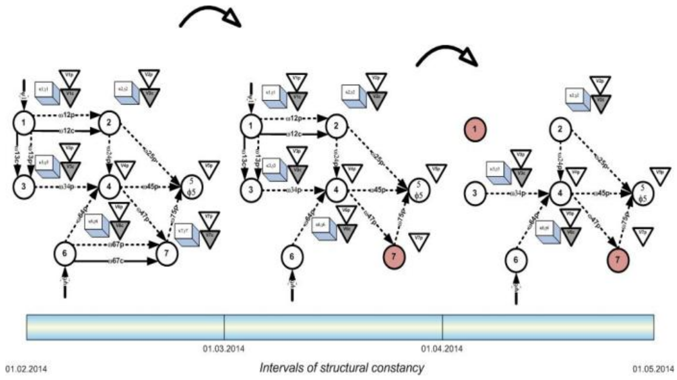

Fig. 4. Structural reconfiguration of PITN.

Meaningful statement of a task for PITN planning has the following features. If the volumes of raw materials exceed PITN capabilities of processing, transport, storage, then unclaimed raw material is sent back to the warehouse outside of PITN. In addition, if the volume of finished products exceed PITN capabilities of transportation, warehousing and customer demand, the unclaimed finished products are disposed. All of this requires additional costs. It is also necessary to consider the constant transportation and storage costs, variable costs for the transportation, storage, processing of products. As a whole, the problem consists of finding a plan for the production, storage, transportation of supplied products with the purpose of meeting consumer demand with minimal total cost.

To formalize the proposed problem, we introduce the following functions describing the peculiarities of the supply, production, storage, transportation, and delivery of raw materials and finished products:

$V_{i\rho}{}^{c}(t)$ - volume of the warehouse of raw materials of ρ type in each A_i node in the PITN;

$V_{i\tau}{}^{p}(t)$ - volume of a warehouse of finished products of τ type in each A_i node in the PITN (or $V_i^m(t)$ - volume of multipurpose warehouse of raw materials and finished products in each A_i node of PITN);

$\psi_{i\rho}(t)$ - intensity of deliveries of raw material of ρ type in A_i node of PITN;

$\gamma_{i\tau}(t)$ - intensity of output of finished products of τ type in A_i node of PITN;

$k_{i\rho\tau}$ - the ratio of raw material consumption of ρ type (the ratio of consumed raw material volume to volume of the resulting finished products) for output of the finished product unit of τ type in A_i node of PITN;

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$\omega_{ij\rho}{}^{c}(t)$ - intensity of transportation of raw materials of ρ type between nodes of PITN;

$\omega_{ij\tau}{}^{p}(t)$ - intensity of transportation of the finished product of τ type between nodes of PITN;

$\phi_{i\tau}(t)$ - intensity of delivery of finished products of τ type from A_i node of PITN to the consumer.

From substantial statement of the PITN planning problem, it follows that the dynamics of changing the quantity of raw materials and finished products passing through A_i node of PITN can be described by the following relations

$$\dot{x}^{+c}_{i\rho}(t) = \dot{x}^{-c}_{i\rho}(t) + \dot{y}_{i\rho}{}^{c}(t) + \dot{z}_{i\rho}{}^{c}(t), \quad i \in N = \{1,2,...,n\},\ \rho \in \mathrm{P}. \tag{1}$$

$$\dot{x}^{+p}_{i\tau}(t) = \dot{x}^{-p}_{i\tau}(t) + \dot{y}_{i\tau}{}^{p}(t) + \dot{z}_{i\tau}{}^{p}(t), \quad i \in N = \{1,2,...,n\}, \tau \in \Theta. \tag{2}$$

In these expressions (1)-(2), designated via $\dot{x}^{+c}_{i\rho}(t),\ \dot{x}^{+p}_{i\tau}(t)$ is, respectively, intensity of deliveries of raw materials and finished products in A_i node of PITN, $\dot{x}^{-c}_{i\rho}(t),\ \dot{x}^{-p}_{i\tau}(t)$ - intensity of reduction of raw materials and finished products in A_i node, $\dot{y}_{i\rho}{}^{c}(t),\ \dot{y}_{i\tau}{}^{p}(t)$ - intensity of accumulation (transportation of raw materials and finished products) in (from) warehouse of A_i node in PITN, $\dot{z}_{i\rho}{}^{c}(t),\ \dot{z}_{i\tau}{}^{p}(t)$ - intensity of return of unclaimed raw materials and disposal of finished products in A_i node of PITN.

In accordance with the designation introduced in a meaningful statement of the problem, intensity of the supply of raw materials into A_i node can be described by the following relation (3):

$$\dot{x}^{+c}_{i\rho}(t) = \psi_{i\rho}(t) + \sum_{j=1}^{n} e_{ji}(t)\cdot\omega_{ji\rho}{}^{c}(t)\cdot u_{ji\rho}{}^{c}(t), i \in N, \rho \in \mathrm{P}, \tag{3}$$

where $u_{ji\rho}{}^{c}(t) \in \{0,1\}$ - management of transportation of raw materials on PITN. If $u_{ji\rho}{}^{c}(t) = 1$, then raw material of ρ type is transported from A_j node to A_i node, and if $u_{ji\rho}{}^{c}(t) = 0$, then the raw materials are not transported.

The intensity of the raw material reduction in A_i node of PITN can be described by the relation (4)

$$\dot{x}^{-c}_{i\rho}(t) = \sum_{\tau\in\Theta} k_{i\rho\tau}\cdot\gamma_{i\tau}(t)\cdot\vartheta_{i\rho\tau}(t) + \sum_{j=1}^{n} e_{ij}(t)\cdot\omega_{ij\rho}{}^{c}(t)\cdot u_{ij\rho}{}^{c}(t),\ i \in N, \rho \in \mathrm{P}, \tag{4}$$

where $\vartheta_{i\rho\tau}(t) \in \{0,1\}$ - management of finished products output in A_i node. Here, if $\vartheta_{i\rho\tau}(t) = 1$, then the costs of raw materials of ρ type for the finished products of τ type in A_i node of PITN, otherwise $\vartheta_{i\rho\tau}(t) = 0$.

Accordingly, the intensity of supply and the finished products reduction can be described by relations (5) - (6):

$$\dot{x}^{+p}_{i\tau}(t) = \sum_{\rho\in\mathrm{P}} \gamma_{i\tau}(t)\cdot\vartheta_{i\rho\tau}(t) + \sum_{j=1}^{n} e_{ji}(t)\cdot\omega_{ji\tau}{}^{p}(t)\cdot u_{ji\tau}{}^{p}(t),\ i \in N, \tau \in \Theta, \tag{5}$$

$$\dot{x}^{-p}_{i\tau}(t) = \phi_{i\tau}(t)\cdot\upsilon_{i\tau}(t) + \sum_{j=1}^{n} e_{ij}(t)\cdot\omega_{ij\tau}{}^{p}(t)\cdot u_{ij\tau}{}^{p}(t),\ i \in N, \tau \in \Theta, \tag{6}$$

where $u_{ji\tau}{}^{p}(t) \in \{0,1\}$ - management for finished products transportation on PITN, $\upsilon_{i\tau}(t) \in \{0,1\}$ - management of finished products delivery to the consumer from A_i node of PITN.

Relations (1)-(6) describe the dynamics of production, transportation, delivery, storage, and additional operations with raw materials and finished products on PITN. It should be noted that $\psi_{i\rho}(t),\ \gamma_{i\tau}(t), \omega_{ij\rho}{}^{c}(t),\ \omega_{ij\tau}{}^{p}(t), \phi_{i\tau}(t)$ are prescribed functions, $e_{ij}(t)$ describes structural reconfiguration of PITN on the appropriate script in the management interval $T = (t_0, t_f]$, while the functions $y_{i\rho}{}^{c}(t),\ y_{i\tau}{}^{p}(t), z_{i\rho}{}^{c}(t), z_{i\tau}{}^{p}(t), u_{ij\rho}{}^{c}(t), u_{ij\tau}{}^{p}(t), \vartheta_{i\rho\tau}(t), \upsilon_{i\tau}(t)$ are unknown quantities, and management $u_{ij\rho}{}^{c}(t), u_{ij\tau}{}^{p}(t), \vartheta_{i\rho\tau}(t), \upsilon_{i\tau}(t)$ uniquely define the operations of return of unclaimed raw materials $z_{i\rho}{}^{c}(t)$ and disposal of finished products $z_{i\tau}{}^{p}(t)$, dynamics of accumulation and transportation of raw materials $y_{i\rho}{}^{c}(t)$ and finished products $y_{i\tau}{}^{p}(t)$ from the warehouse of A_i node in the PITN.

Therefore, the functions $y_{i\rho}{}^{c}(t),\ y_{i\tau}{}^{p}(t), z_{i\rho}{}^{c}(t), z_{i\tau}{}^{p}(t)$ can be considered as the dynamic system state.

In these conditions, the PITN planning model will include the following main elements. Model of the PITN planning process is prescribed by relations (1)-(6). Restrictions for the possible managements and states can be described as follows

$$0 \le y_{i\rho}{}^{c}(t) \le V_{i\rho}{}^{c},\ 0 \le y_{i\tau}{}^{p}(t) \le V_{i\tau}{}^{p} \quad \forall\, i \in N, t \in (t_0, t_f], \rho \in \mathrm{P}, \tau \in \Theta, \tag{7}$$

$$0 \le \sum_{\rho\in\mathrm{P}} y_{i\rho}{}^{c}(t) + \sum_{\tau\in\Theta} y_{i\tau}{}^{p}(t) \le V_i^m \quad \forall\, i \in N, t \in (t_0, t_f], \tag{7'}$$

$$u_{ij\rho}{}^{c}(t), u_{ij\tau}{}^{p}(t) \in \{0,1\}, \vartheta_{i\rho\tau}(t), \upsilon_{i\tau}(t) \in \{0,1\}$$
$$\forall i, j \in N, t \in (t_0, t_f], \rho \in \mathrm{P}, \tau \in \Theta, \quad (8)$$

$$z_{i\rho}{}^{c}(t) \geq 0, z_{i\tau}{}^{p}(t) \geq 0, \dot{z}_{i\rho}{}^{c}(t) \geq 0,$$
$$\dot{z}_{i\tau}{}^{p}(t) \geq 0 \forall i \in N, t \in (t_0, t_f], \rho \in \mathrm{P}, \tau \in \Theta. \quad (9)$$

The boundary conditions look as follows:

$$y_{i\rho}{}^{c}(t_0) = y_{i\tau}{}^{p}(t_0) = z_{i\rho}{}^{c}(t_0) = z_{i\tau}{}^{p}(t_0) = 0$$
$$\forall i \in N, \rho \in \mathrm{P}, \tau \in \Theta,$$
$$y_{i\rho}{}^{c}(t_f) \geq 0, y_{i\tau}{}^{p}(t_f) \geq 0, \; z_{i\rho}{}^{c}(t_f) \geq 0,$$
$$z_{i\tau}{}^{p}(t_f) \geq 0 \; \forall i \in N, \rho \in \mathrm{P}, \tau \in \Theta. \quad (10)$$

Admissible managements $u_{ij\rho}{}^{c}(t), u_{ij\tau}{}^{p}(t), \vartheta_{i\rho\tau}(t), \upsilon_{i\tau}(t)$, that satisfy equations (1)-(6), describing change of the state along the trajectory (7)-(9) and boundary conditions (10), can be evaluated according to various quality indexes for PITN functioning.

Such indexes can be:

$$J_1 = \int_{t_0}^{t_f} \sum_{\rho \in \mathrm{P}} \sum_{i=1}^{n} v_{i\rho}{}^{c}(t) \cdot z_{i\rho}{}^{c}(t) dt + \int_{t_0}^{t_f} \sum_{\tau \in \Theta} \sum_{i=1}^{n} v_{i\tau}{}^{p}(t) \cdot z_{i\tau}{}^{p}(t) dt$$

- the costs of return of the unclaimed raw materials and disposal of finished products;

$$J_2 = \int_{t_0}^{t_f} \sum_{\tau \in \Theta} \sum_{i=1}^{n} h_{\tau}(t) \cdot \phi_{i\tau}(t) \cdot \upsilon_{i\tau}(t) \, dt$$

- cost of the finished products delivered to the consumer;

$$J_3 = \int_{t_0}^{t_f} \sum_{\tau \in \Theta} g_{i\tau}(t) \cdot \gamma_{i\tau}(t) \cdot e_{ii}(t) \, dt + \int_{t_0}^{t_f} \sum_{\substack{\# \in \{\rho, \tau\} \\ \rho \in \mathrm{P}, \tau \in \Theta}} \sum_{* \in \{c, p\}} \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij\#}{}^{*}(t) \cdot \omega_{ij\#}{}^{*}(t) \cdot e_{ii}(t) dt + \int_{t_0}^{t_f} \sum_{\tau \in \Theta} \sum_{i=1}^{n} d_{i\tau}(t) \cdot \phi_{i\tau}(t) \cdot e_{ii}(t) dt + \int_{t_0}^{t_f} \sum_{\substack{\# \in \{\rho, \tau\} \\ \rho \in \mathrm{P}, \tau \in \Theta}} \sum_{* \in \{c, p, m\}} \sum_{i=1}^{n} f_{i\#}{}^{*}(t) \cdot V_{i\#}{}^{*}(t) \cdot e_{ii}(t) dt$$

- fixed manufacturing, transport and storage costs;

$$J_4 = \int_{t_0}^{t_f} \sum_{\substack{\# \in \{\rho, \tau\} \\ \rho \in \mathrm{P}, \tau \in \Theta}} \sum_{* \in \{c, p\}} \sum_{i=1}^{n} \sum_{j=1}^{n} r_{ij\#}{}^{*}(t) \cdot \omega_{ij\#}{}^{*}(t) \cdot u_{ij\#}{}^{*}(t) dt + \int_{t_0}^{t_f} \sum_{\substack{\rho \in \mathrm{P} \\ \tau \in \Theta}} \sum_{i=1}^{n} \lambda_{i\rho\tau}(t) \cdot \gamma_{i\tau}(t) \cdot \vartheta_{i\rho\tau}(t) dt + \int_{t_0}^{t_f} \sum_{\tau \in \Theta} \sum_{i=1}^{n} \pi_{i\tau}(t) \cdot \phi_{i\tau}(t) \cdot \upsilon_{i\tau}(t) dt + \int_{t_0}^{t_f} \sum_{\substack{\# \in \{\rho, \tau\} \\ \rho \in \mathrm{P}, \tau \in \Theta}} \sum_{* \in \{c, p\}} \sum_{i=1}^{n} \delta_{i\#}{}^{*}(t) \cdot y_{i\#}{}^{*}(t) dt$$

- the costs of production, transportation, delivery, and storage of products.

3. EXPERIMENTAL RESULTS

The presented model falls into the class of optimal program control (OPC) models. The structure dynamics (i.e., the execution scenarios according to different structural states), inventory dynamics, and transitions between the intervals can be modeled in the proposed dynamic OPC model. However, the detail degree of the OPC model is too high for aggregate planning. Besides, in this model the right parts of the differential equations undergo discontinuity at the beginning of interaction zones. Piecewise functions $e_{ij}(t)$ are contained in the right parts of Eqs (3)–(6) in order to describe the structure dynamics. The considered problems can be regarded as control problems with intermediate conditions. Another feature is the form of time-spatial, technical, and technological non-linear conditions that are mainly considered in control constraints and boundary conditions. This is why the application of known direct methods for solving the above-stated OPC problem becomes complicated.

However, the structure and the parameters of PITN undergo changes at discrete time points $(t_0, t_1, ..., t_k)$. These points divide the planning interval $(t_0, t_k]$ into sub-intervals L, $T = \{(t_0, t_1], (t_1, t_2], ..., (t_{k-1}, t_k], ..., (t_{L-1}, t_L = t_f]\}$. The PITN structure does not vary at each k-sub-interval $T_k = (t_{k-1}, t_k]$. The assumption on the intervals of structural constancy allows transit from the dynamic to static models (Ivanov et al., 2013). Analysis of the static problem showed that in spite of its high dimensionality it could be efficiently solved via special decomposition procedures and the method of successive improvement of plans for LP problems with two-sided constraints. For experiments with only the static model, computations can be performed in commercial optimization software that supports simplex method.

Let us consider the scenario defined in Fig. 5. The PITN is composed of two mega-hubs (nodes 1 and 6), a central distribution hub (node 4), two intermediate terminals (nodes 2 and 3), an outsourcing terminal (node 7), and a regional distribution centre as the strategic inventory holding point (node 5). The execution in each of the nodes and transportation arcs is limited by maximal warehouse capacity, processing intensity, and transportation intensity respectively.

The triangles refer to the warehouse capacity, and numbers on the arcs refer to maximal transportation intensity. The suppliers first deliver goods to the mega-hubs 1 and 6. Then, the goods will be processed in the central distribution hub 4. The goods from hub 1 are additionally processed at intermediate terminals 2 and 3. From hub 4, the goods are moved to the regional distribution centre 5, which has a certain demand in each of the periods (i.e., 100 units). In practice, a number of the regional distribution centres are in the PITN. Without loss of generality, we are reducing this formulation in this particular paper to only one centre. This is the centralized PITN structure. In order to take into account possible problems with the channel 4→5, an outsourcing terminal is used as an alternative way for deliveries to reach the distribution centre 5. Besides, it is possible to move small quantities (maximal 30 units) directly from terminal 2 to centre 5. Three intervals of the structural constancy are considered. The problem is to maximize the service level under the assumption of the demand of 300 units for the planned period of three months (i.e., 100 units each month) while minimizing the costs as composed of the storage, transportation, return, sourcing, and fixed costs. For simplification, processing costs and capacities are not considered in this example.

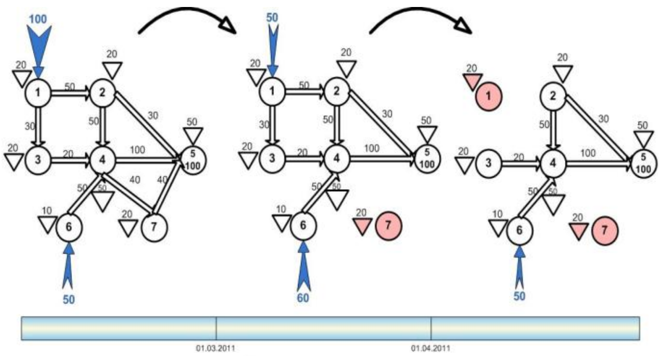

Fig. 5. Scenario of reconfiguration.

In Fig. 6, results of optimal planning subject to the data from Fig. 5 are presented.

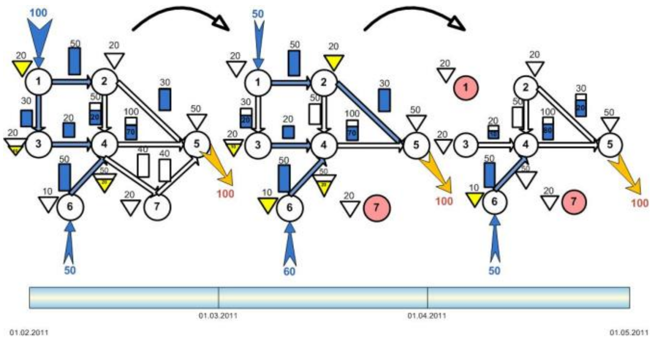

Fig. 6. Distribution plan for scenario of reconfiguration.

The same example has been calculated with greedy algorithm. A greedy algorithm is an algorithm that follows the problem solving heuristic of making the locally optimal choice at each stage with the hope of finding a global optimum. The corresponding plan is presented in Fig. 7.

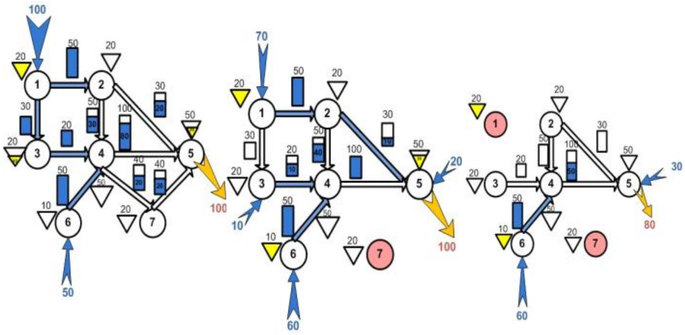

Fig. 7. Distribution plan calculated with greedy algorithm.

The yellow triangles show the warehouse capacities and their actual utilization. The blue rectangles represent transportation channel capacities and the actual transportation quantities. In Table 1, planning results subject to key performance indicators are presented.

Table 1. Planning results

Indicator	**Proposed model**	**Greedy algorithm**
Volume of delivered goods	300.0	280.0
Volume of returned goods	0.0	0.0
Volume of inventory total	120.0	150.0
Transportation costs	30.0	26.6
Inventory costs	8.4	10.5
Fixed costs	90.0	90.0
Sourcing costs	124.0	124.0
Total costs	252.4	251.1
Total revenue	300.0	280.0
Profit	**47.6**	**28.9**

4. CONCLUSIONS

The problem of optimization of production-inventory-transportation network (PITN) supply chain has been investigated. Some extensions of this model in future can be considered. First, it is possible to extend the developed model to operative detailed decisions on transportation planning. The possibility of addressing decision components of different time horizons and levels of detail arises from a combination of a static LP and dynamic OPC models. This combination can result in a hybrid multi-period distribution–transportation model that can be investigated in detail in future research. Second, in comparing the presented approach with the literature, dimensions of agility and flexibility as well as environmental performance can be integrated subject to the trade-off “efficiency-flexibility-resilience”. Different data, e.g., fuzzy representation, can be considered. Additional restrictions, e.g., total budget with time value or other optimization objectives, e.g., minimizing delivery times, can be included in future analysis. On-line adaptation can be the next possible future research direction. Here different adaptation options (e.g., flow re-direction, capacity adjustment, and structure adjustment) and their costs can be compared. In addition, a comparison between investments in robustness vs. costs of adaptation can be made.

ACKNOWLEDGEMENT

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A STUDY ON THE OPIMAL CONFIGURATION OF BERTHS USING SIMULATION
-BASED ON THE WHARF IN GWANGYANG PORT-

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ABSTRACT

A port is an important asset of the country and a national facility requiring lots of budget. Presently, approx. 900 berths of 31 ports are in operation in Korea and about 1 trillion Won is required for building the ports each year. The purpose of this study is to evaluate the appropriateness of berth configuration of the port and also evaluate whether scale of the berth built on the basis of estimated cargo volume at time of construction shall be still appropriate after a significant length of time. This study targets 11 steel berths of Gwangyang Port and desires to evaluate if configuration and scale of such berths are properly supporting the cargo handling. In order to evaluate configuration of the steel berths in Gwangyang Port, the author has collected Port-MIS data from 2011 to 2013 and analyzed the data for 3,591 cargo handling events out of 3,687 events except 96 events which did not intend to load or unload cargo.

According to result of the optimal berth configuration using Arena Simulation, a configuration with 7 berths was proved to be the optimal configuration. That is, building 1 berth of class 50,000 ton, 3 berths of class 30,000 ton, 2 berths of class 5,000 ton and 1 berth of class 3,500 ton was confirmed to provide an efficient operation and service.

It is expected to have an effect of saving national expenses by planning an optimal berth configuration in development of the berths through cargo volume estimation by establishing an optimal operation system through this study.

Keywords: Arena, Simulation, Gwangyang Port, Berth Optimal Design, Cargo Capacity, Waiting ratio

1. INTRODUCTION

The port is an important national asset which supports distribution of export and import cargos and is also a national facility requiring lots of investment.

Efficient use of the port is an important matter in view of cost saving. In Korea, about 900 berths are in operation in 31 ports and approx. 1 trillion Won is required for construction of the port every year.

The function of the port changes continuously according to purposes of background industrial zones. For example, even the berth which was developed as a general merchandise berth in early time shall change its purpose to handle steel products if the enterprises which produce ship blocks are located in the background site of the port. With such a reason, efficient use of the berth is available only when the port function is adjusted to business change every year.

A problem concerning configuration of appropriate berths is that it would cause a tremendous economic loss if the scale of berth is too big comparing with cargo volume handled in the berth due to overestimated cargo volume at time of building the berth.

The goal of this study is to evaluate the appropriateness of berth configuration of the port. That is, it shall evaluate if scale of the berth built on the basis of estimated cargo volume at time of construction would be still appropriate after passing a significant length of time. This paper targeted 11 steel berths of Gwangyang Port. Thus, the ultimate goal of this study is to figure out an optimal berth configuration by evaluating whether the configuration and scale of the steel berths support the cargo handling appropriately.

The purpose of this study is to evaluate the appropriateness of present berth configuration targeting steel berths of Gwangyang Port, thus this study needs to develop a simulation program which may demonstrate the ships entered, movement, docking, loading and unloading and departure of the ships. The simulation model shall support 11 berths and describe number of ships and cargo handling volume of the berths exactly. Occupation and Waiting ratio of the berth shall be calculated as for evaluation criteria of berth performance. An appropriate berth configuration has a purpose to figure out the optimal berth configuration required for handling the present cargo volume and shall satisfy an appropriate occupancy ratio and allowable Waiting ratio. In order to achieve the goal of this study, a method which may check whether the berth configuration satisfies an appropriate occupancy ratio through repeated simulation tests by eliminating the berth which lacks cargo handling capacity is used. Following 3 procedures shall be used in order to figure out the optimal berth configuration:

The 1st procedure is to design a simulation system which may represent the ships entered and cargo handling of the ships appropriately, and to verify if such simulation system developed describes the present situation well enough.

The 2nd procedure is to figure out what kind of berth configuration would meet an efficient occupation and waiting ratio of the berth which are the evaluation criteria after completing the verification of such validity.

The 3rd procedure is to verify if the present situation could be properly dealt with even when the number of berths decreased by adjusting number of berths

This paper intends to verify that even such decreased number of berths shall be able to handle the present cargo volume smoothly by finding out an appropriate scale and number of berths through above 3 procedures.

2. LITERATURE REVIEW

There are several the results to apply the simulation method to find PPI of port terminals. Legato and Mazza (2001) focused on the berth and allocation of berths to arriving ships with queuing network based on the model which is simulated by Visual SLAM software in various scenarios. Their model was tested with data from Gioia Tauro container terminal. Key issues of the application of modeling and simulation for the management of the Malaysian Kelang container terminal are discussed in paper by Tahar and Hussain (2000). Nam et al. (2002) examined the optimal size of the Gamman Container Terminal in Busan, in terms of berths and quay cranes using the simulation analyses which were performed in four scenarios, representing different operational patterns. Shabayek and Yeung developed simulation model employing the Witness program to analyze the Hong Kong's Kwai Chung container terminal performance. It is shown to provide good results in predicting the actual operation system of the terminal. Kia et al. (2002) investigated the role of computer simulation in evaluating the container terminal performance in relation to its handling techniques and their impact on the capacity of terminal. Pachakis and Kiremidjian (2003) presented a ship traffic modeling methodology based on statistical analysis of container ship traffic and cargo data obtained from a port in the United States. Sgouridies et al. (2003) focused on the simulated handling of incoming containers. Results on the service level, i.e., service times, utilization factor, and queues, are generated for analysis. Demirici (2003) developed simulation model to analyze port operations and was run especially for investment planning. This paper discussed the simulation model results of Trabzon port. Bielli et al. (2005) proposed simulation model which can improve ports efficiency and they gave the architecture components that are implemented with Java. Simulator calibration and validation were also presented in the paper at the Casablanca container terminal. van Renzburg et al. (2005) described a computer simulation model of ocean container carrier operations. Their simulation is called SimSea. Ali Alattar et al. (2006) simulated different condition to find out the queue of containers at the port and also analyses the effect of increase in the facilities at the port to reduce this queue. Dragović et al. (2005a) gave the simulation model results for ship berth link of the Pusan East Container Terminal (PECT). They developed simulation model which can be used by the port management to improve different operations included in the process of ship service at the ship-berth link. Dragović et al. (2005b) developed simulation models of ship-berth link with priority service in container port. The ship berth-link performance for five alternative strategies was evaluated, and system behavior observed. The results revealed that simulation modeling is a very effective method to examine the impact of introducing priority, for certain class of ships, on the ship-berth link performance at PECT.

3. PORT FACILITY AND CARGO HANDLING SITUATION OF STEEL BERTHS OF GWANGYANG PORT

1) Port Facility Situation of Steel Berths

Steel berths of Gwangyang Port consists of total 11 berths including 1 berth of 50,000 ton class, 3 berths of 30,000 ton class, 1 berth of 20,000 ton class, 5 berths of 5,000 ton class and 1 berth of 3,500 ton class.

The depth of water is 14 m for 50,000 ton class, 12m for 30,000 ton class, 11m for 20,000 ton class and 7 m for 5,000 ton and 3,500 ton class.

The length of quay of each berth is 280m for 50,000 ton class, 240m for 30,000 ton and 30,000 ton class, 126.6m for 5,000 ton class and 107m for 3,500 ton class and all of 11 berths handles steel products.

Details are specified on <Table 1>.

<Table 1> Facility Situation by Berth of Steel Terminal of Gwangyang Port

Terminal	Berth No.	Docking Capacity	Depth of Water(m)	Length (m)	Handling Cargo
Steel Terminal	41	50,000	14	280	Steel Products (HR, CR)
	42	30,000	12	240	
	43	30,000	12	240	
	44	30,000	12	240	
	45	20,000	11	240	
	46	5,000	7	126.6	
	47	5,000	7	126.6	
	48	5,000	7	126.6	

	49	5,000	7	126.6
	4A	5,000	7	126.6
	4B	3,500	7	107

2) Number of Ships by Size by Berth

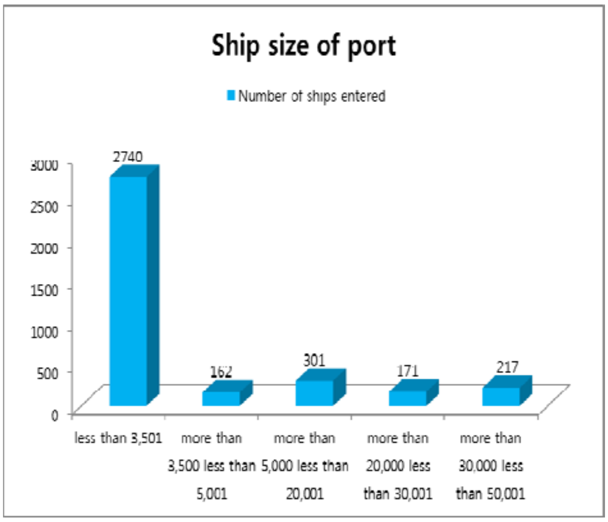
The author has collected Port-MIS data of steel terminal of Gwangyang Port for 2011 –2013 in order to find out number of ships entered and DWT (Dead Weight Tonnage) and the average value for 3 years shall be used in this paper. The items of the data collected include port name, terminal name, berth name, ship name, ships entered date and time and total tonnage.

Total number of data collected is 3,687 data of ships entered and departure for 3 years, but 96 data which did not handle the cargo, for example refueling, repair, commodities for ship, crew shifting and others were excluded.

<Table 2> Number of ships entered and cargo volume handled

Berth name	Specification and operation situation of the terminal				
	Berth length (m)	Depth of water (m)	Berth size (DWT)	Number of ships entered	cargo volume handled
Berth 41	280	14	50,000	243	4,221,687
Berth 42	240	12	30,000	391	4,691,573
Berth 43	240	12	30,000	345	1,893,038
Berth 44	240	12	30,000	842	1,177,284
Berth 45	240	11	20,000	447	1,456,745
Berth 46	126	7	5,000	360	1,075,221
Berth 47	126	7	5,000	268	844,858
Berth 48	126	7	5,000	258	946,662
Berth 49	126	7	5,000	223	715,460
Berth 4A	126	7	5,000	12	30,336
Berth 4B	107	7	3,500	202	566,648

The size of ships were classified to below 3,500 ton class, over 3,051 ton below 5,000 ton class, over 5,001 ton below 20,000 ton class, over 20,000 ton below 30,000 ton class and over 3,0001 ton below 50,000 ton class based on steel of port, and total 3,591 ships have entered and departed for 3 years.



[Figure 1] Ship size of port

4. SIMULATION MODELING

1) Outline for development of simulation system for ship entered

It needs a simulation which may describe the reality of ship entered as well as cargo handling in order to measure the evaluation criteria for 11 berths of steel terminal of Gwangyang Port, such as cargo handling volume, waiting ratio, occupancy ratio and number of ships. Thus, in this section, this paper intends to design a simulation model which may describe situation of the reality well enough.

☐ Definition of waiting ratio

The waiting ratio in port means that the ships arrived at the terminal wait for cargo handling due to lack of berths and waiting ratio is obtained by dividing average waiting time by average service time.

☐ Definition of Berth occupancy ratio

The issue to utilize the berth at an appropriate level without waiting of the ship has a relation with arrival schedule of the ship. If the arrival schedule of the ship is well established, the waiting time of the ship shall be reduced and the occupancy ratio of the berth shall be significantly risen. However, such schedule become delayed due to unexpected bad weather during sail, the waiting shall occur due to other ships entering at the same time.

The berth occupancy ratio is calculated the ships berthing time divided by berth available time for a year. <Table 3> shows the relationship between average berth occupancy ratio and waiting ratio of major international ports. In the case of for 11 berths of steel terminal of Gwangyang Port, the criteria for finding optimal berth configuration is considered 65% of berth occupancy ratio and less than 9%.

<Table 3> Average berth occupancy ratio and waiting ratio [%]

Number of berth	Appropriate berth occupation rate	Container terminal		General terminal	
		Tw / Ts	Tw / Ts	Tw / Ts	Tw / Ts
		K = 4	K = ∞	K = 1	K = 2
1	0.40	0.42	0.33	0.67	0.50
2	0.50	0.22	0.18	0.33	0.26
3	0.55	0.14	0.12	0.22	0.17
4	0.60	0.12	0.10	0.18	0.14
5	0.65	0.12	0.10	0.17	0.13
6 or more	0.70	0.12	0.10	0.19	0.14

Average Waiting ratio= Average Waiting Time/Average Service Time(Tw / Ts)

: UNCTAD, 1986 and Hans Agerschou (2004), “Planning and design of ports and marine terminals”, 2nd edition, Thomas Telford.

When number of berth is 1, appropriate berth occupancy ratio is 40% while average 33%-42% of ship waiting occurs. When number of berth is 2, appropriate berth occupation is 50% and average 18%-22% of ship waiting ratio occurs. When number of berth is 3, appropriate berth occupation is 55% and average 10%-12% of ship waiting ratio occurs. When number of berth is 4, appropriate berth occupancy ratio is 60% and average 10%-12% of ship waiting ratio occurs. When number of berth is 5, appropriate berth occupation is 65% and average 10%-12% of ship waiting ratio occurs. When number of berth is 6, appropriate berth rate is 70% and 10%-12% of ship waiting ratio occurs.

2) Design of port simulation modeling

Actual data collected of steel terminals were utilized in order to find an optimal model for 11 steel berths of Gwangyang Port. Arrival time interval of the ships, TPC (Ton per Call) by ship and handling time of cargo equipment per ton were selected as input variables of the simulation. Number of ships entered and handling tonnage of steel terminal for 3 years were used as for analysis data for the simulation.

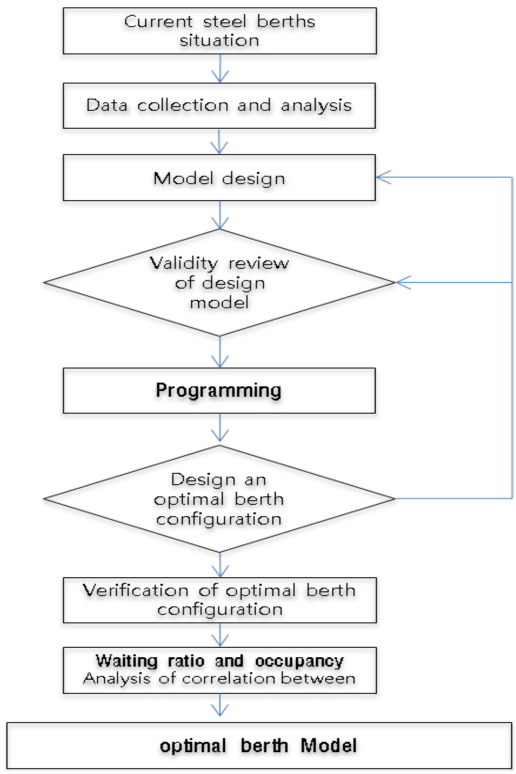
The simulation model was designed based on input data created. The information created from the simulation model includes cargo handling volume by berth, number of ships entered, waiting ratio and occupancy ratio by berth etc.

The actual number of ships entered and cargo volume handled from 2011 to 2013 were compared with those of simulation result in order to verify the validity of the simulation model.

When complete the validity verification of the simulation, check whether the berth configuration satisfies an appropriate occupancy ratio and allowable waiting ratio as varying the present berth configuration. If it does not satisfy the criteria, continue testing with a new berth configuration plan.

For a new berth configuration plan, use a method to reduce number of the berths. The berths targeted to be reduced shall be the berths where the least cargo volume and ships entered occur.

The flow chart for designing the simulation is shown on <Figure 2>.



[Figure 2] Simulation flow chart

☐ Input & Output Variable of Simulation Setting

The raw data were set as input variables after analysis in the simulation and output variables to be created through the simulation shall be set as <Table 4>

<Table 4> Major variables of quay simulation setting

Item	Variable	Description	Remark
Input variables	Ship arrival	Arrival interval time	Probability distribution
	Number of berth	Number of berths	11 berths
	Berth access time	Time from anchorage to arriving berth	Actual value
	Berth leaving time	Time from leaving berth to leaving port.	Actual value
	Idle time before	Time from docking to service	Actual value
	Idle time after	Time after service to leaving quay	Actual value
	Number of group1	Number of berths for Group 1	Two berth

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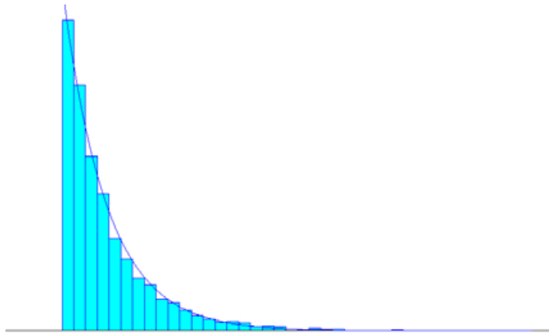
	Number of group2	Number of berths for Group 2	Four berth
	Number of group3	Number of berths for Group 3	Five berth
	Number of group4	Number of berths for Group 4	One berth
	Original no of ships	Actual number of ships entered	Actual value
	Original throughput of cargos	Actual cargo volume handled	Actual value
	Ship DWT	Distribution of ship Size occurrence	Probability distribution
	Sub TPC classify1	TPC assignment distribution	Percentage
	First class1	TPC occurrence distribution	Probability distribution
	Cargo handing time	Cargo handling time per 1 ton	Actual value
Output variables	Waiting ratio	ship waiting ration	Average ship waiting time ratio comparing to average ship docking time
	Occupancy ratio	Berth occupancy ratio	Docking time ratio comparing to ship docking available time
	Total no of ships berthed	Number of ships entered per 1 berth	Calculated value
	Total number of cargos handled	Cargo handling volume per a berth	Calculated value
	Entity number out	Number of ships which completed service	Number of ships departed port after completing service
	Ship queue TAVG	Average waiting time of the ships in queue line	Average ship waiting time
	Aver service time	Average service time in a certain berth	Calculated value
	VarShipProc1	Number of ships docked in berth No. 1	Calculated value
	Total varShipProc	Number of total ships entered	Calculated value
	Total throughput	Total cargo volume handled (ton)	Calculated value
	Avg wait Time group1	Average waiting time by Group	Calculated value
	Today	Date and time of today' Days to base time(TNOW)	Calculated value

□ Creation of Ship Arrival Interval Distribution

As result of the analysis of 3,591 ship's activity for three years, ship arrival interval distribution is expressed by <table 5> and <Figure 3>.

<Table 5> Ship Arrival Distribution of Steel Terminal of Gwangyang Port

Terminal Type.	Number of ships entered	Distribution Type	Distribution
Steel Terminal	3,591	Exponential Distribution	-0.001 + EXPO(7.31)



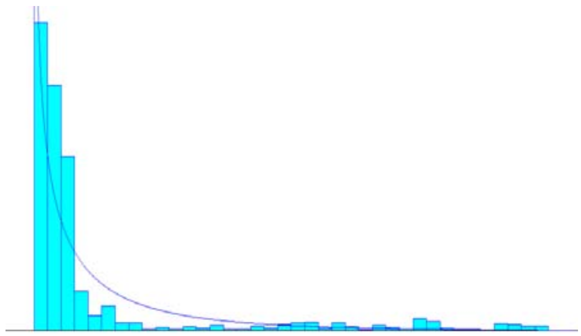
[Figure 3] Ship Arrival Distribution

□ Creation of Ship Size Distribution

As result of the analysis of 3,591 ship's size for three years, ship size distribution is expressed by <table 6> and <figure 4>

<Table 6> Size distribution of the ships entered the steel terminal

Terminal Type.	Distribution Type	Distribution
Steel Terminal	Weibull Distribution	36 + WEIB(4.38e+003, 0.681)



[Figure 4] Ship size Distribution

□ Creation of Cargo Volume Distribution by Berth

As result of the analysis of ton per call(TPC) of each berth for three years, TPC is expressed by <table 7> .

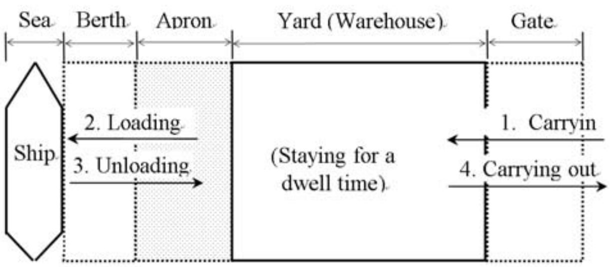
<Table 7> Function Formula of Estimation Distribution by Berth

Berth.	TPC1	TPC2	TPC3	TPC4
Berth 41	8 + 9.39e+003 * BETA(0.545, 1.4)	UNIF(1.02e+004, 3e+004)	3.01e+004 + 4.85e+004 * BETA(0.85, 2.4)	n/a
Berth 42	5 + 3e+003 * BETA(0.473, 0.827)	3.02e+003 + 1.2e+004 * BETA(0.478, 0.916)	UNIF(1.51e+004, 2.99e+004)	TRIA(3.04e+004, 3.36e+004, 6.3e+004)
Berth 43	7 + WEIB(546, 0.802)	TRIA(2.03e+003, 3.45e+003, 4e+003)	4.02e+003 + WEIB(2.42e+003, 1.26)	1.01e+004 + GAMM(1.37e+004, 0.676)
Berth 44	9 + 391 * BETA(0.971, 1.29)	410 + GAMM(50.7, 2.36)	820 + 2.18e+003 * BETA(0.86, 1.14)	3.1e+003 + WEIB(2.55e+003, 0.706)

Berth 45	16 + 1.98e+003 * BETA(0.185, 0.237)	2e+003 + 1.3e+003 * BETA(0.682, 0.391)	3.3e+003 + LOGN(1.19e+003, 5e+003)	6.04e+003 + EXPO(3.64e+003)
Berth 46	35 + 1.97e+003 * BETA(0.365, 0.283)	2.1e+003 + 1.1e+003 * BETA(0.709, 0.476)	3.22e+003 + ERLA(122, 2)	4.05e+003 + 9.97e+003 * BETA(0.803, 2.42)
Berth 47	16 + 1.98e+003 * BETA(0.392, 0.277)	2.05e+003 + 1.25e+003 * BETA(0.844, 0.47)	3.31e+003 + EXPO(215)	4.01e+003 + 4.59e+003 * BETA(0.76, 0.545)
Berth 48	TRIA(16, 1.89e+003, 2.4e+003)	2.57e+003 + 732 * BETA(0.677, 0.374)	3.31e+003 + GAMM(184, 1.14)	NORM(7.17e+003, 3.87e+003)
Berth 49	37 + 1.96e+003 * BETA(0.347, 0.348)	2e+003 + 1.3e+003 * BETA(0.707, 0.344)	3.3e+003 + GAMM(104, 1.16)	3.8e+003 + WEIB(812, 0.522)
Berth 4A	60 + WEIB(270, 0.338)	2.35e+003 + EXPO(1.92e+003)	n/a	n/a
Berth 4B	TRIA(20, 2.04e+003, 2.2e+003)	2.24e+003 + 1.06e+003 * BETA(0.853, 0.457)	3.3e+003 + 100 * BETA(0.842, 0.106)	3.4e+003 + WEIB(610, 0.566)

☐ Logic of the Model

The system was set as queuing system and designed as the events with a flow of ship arrival, assignment of ship size, berth assignment, TPC assignment by berth, cargo handling time per 1 ton and departing the port after loading service <figure 3>.



[Figure 5] Flow of quay simulation

5. VERIFICATION AND VALIDITY OF SIMULATION MODEL

It needs to verify if the simulation designed by this paper reflects the reality in order to figure out the optimal berth configuration.

For verification, the author conducted verification through developing anchorage-berth-yard link simulation model and checking ship arrival, queuing in case of berth occupied, cargo handling and ship leaving activity and simultaneously yard stocking and leaving activity.

After verification task, the authors try to validate simulation model through checking accuracy ratio between the actual data and the result values of simulation for 3 years. The results of actual data and simulation are as follows:

<Table 8> Validity Test Result of Simulation

Terminal Name	Data of calling ship and cargo handling of Steel Terminal for 3 years		Simulation Result				Accuracy Ratio	
	Number of ships entered	Cargo Volume handled	Number of ships entered	Waiting ratio (%)	Occupancy Ratio (%)	Cargo Volume Handled	Number of ships entered	Cargo Volume handled
Steel Terminal	3,591	17,619,512	3,584	23%	46%	16,920,385	99.8%	96%

The simulation of this study premised that all 11 berths of the steel terminal operate simultaneously and intended to verify the simulation by number of ships entered and cargo volume handled of the whole terminal.

Total 3,591 ships entered the steel terminal for 3 years and the cargo volume handled was 17,619,512 ton. According to simulation result, total 3,584 ships was entered the steel terminal and cargo volume handled was 16,920,385 ton. The accuracy ratio shows 99.8% for number of ships entered and 96% for cargo volume handled.

The simulation could not show the correct matching ratio because number of ships entered and cargo volume handled may cause an event as distribution but reflects the reality within ±5% error range.

6. PROPOSAL OF AN OPTIMAL BERTH CONFIGURATION

Now, there are 11 berths in the steel terminal consisting of 1 berth of 50,000DWT class, 3 berths of 30,000DWT class, 1 berth of 20,000DWT class, 5 berths of 5,000DWT and 1 berth of 3,500DWT class.

Number of ships entered and cargo volume handled for 3 years in 11 berths are as <Table 9>.

<Table 9> Number of ships entered and cargo volume handled for 3 years

Berth Name	Specification and Operation situation of the Terminal				
	Berth length (m)	Depth of Water (m)	Berth size (DWT)	Number of ships entered	cargo Volume handled (RT)
Berth 41	280	14	50,000	243	4,221,687
Berth 42	240	12	30,000	391	4,691,573
Berth 43	240	12	30,000	345	1,893,038
Berth 44	240	12	30,000	842	1,177,284

Berth 45	240	11	20,000	447	1,456,745
Berth 46	126	7	5,000	360	1,075,221
Berth 47	126	7	5,000	268	844,858
Berth 48	126	7	5,000	258	946,662
Berth 49	126	7	5,000	223	715,460
Berth 4A	126	7	5,000	12	30,336
Berth 4B	107	7	3,500	202	566,648

As a result of carrying the simulation in order to find out an optimal berth configuration in this study, it was found that number of total ships and total cargo volume handled are same as those of actual data but there was a change in occupancy ratio and waiting ration of the whole berths.

For finding optimal the berth configuration, we tried to select the number of berths while eliminating the berths which handles the least volume of cargo and the number of calling ships. The result of simulation test will be shown on the <Table 10>.

Considering the criteria of 60% of proper berth occupancy rate and less than 5% of permissible ship waiting ratio, the optimal alternative of berth configuration is found 8 berths consisting of a 50,000 dwt berths, three 30,000 dwt berths, three 5,000 dwt berths and a 3,500 dwt berth. If we consider lower operation cost and higher occupancy ratio, the 7 berths consisting of a 50,000 dwt berths, three 30,000 dwt berths, two 5,000 dwt berths and a 3,500 dwt berth will be selected as an alternative even if its waiting ratio and occupancy is a little higher than the former alternative.

<Table 10> Result Values of Simulation for New Berth Configurations

Simulation Result					
Number of Berths	Berth Configuration	number of ships entered	Waiting ratio (%)	Occupancy Ratio (%)	Cargo Volume Handled
10	50,000 x 1 30,000 x 3 20,000 x 1 5,000 x 4 3,500 x 1	3,576	1.5%	49.7%	16,865,693
9	50,000 x 1 30,000 x 3 5,000 x 4 3,500 x 1	3,570	1.7%	55.4%	17,401,828
8	50,000 x 1 30,000 x 3 5,000 x 3 3,500 x 1	3,583	2.1%	62.0%	17,688,794
7	50,000 x 1 30,000 x 2 5,000 x 3 3,500 x 1	3,450	51.7%	78.3%	20,995,582
7	50,000 x 1 30,000 x 3 5,000 x 2 3,500 x 1	3,596	7.9%	69.6%	19,166,586
6	50,000 x 1 30,000 x 3 5,000 x 2	3,514	44.9%	76.5%	19,116,760

7. CONCLUSION

This study intended to figure out the optimal berth configuration analysing Port-MIS data of 11 steel berths of the Gwangyang Port for 3 years. The author presents the optimal berth configuration based on UNCTAD standard through its own designed simulation premising that the optimal berth configuration is the results showing 65% of berth occupancy ratio and less than 9% of ship waiting ratio and presents the optimal berth configuration out of several berth configurations simulated earlier. The optimal berth configuration would be 7 berths configuration instead of 11 berths for handling the present cargo volume.

The optimal berth configuration consisting of a 50,000 dwt berths, three 30,000 dwt berths, three 5,000 dwt berths and a 3,500 dwt berths, total 8 berths is proposed as the optimal berth configuration for the cargo volumes of the steel terminal and it is expected to have an effect to save the operation and construction cost by establishing such optimal berth configuration.

The contribution of this study is to suggest the method for finding optimal configuration of existing berths using simulation technique without interrupting the handling capacity of current cargo volume under proper berth occupancy rate and permissible ship waiting ratio.

Acknowledgements

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"WHAT TO" APPROACH FOR THE OPTIMIZATION OF A LOGISTICS PLATFORM

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ABSTRACT
The paper proposes a "what to" approach in order to optimize the receiving activities in a logistics platform operating in the food sector.

The aim is the minimization of the receiving makespan, the time between the arrival and the exit of the inbound trucks at the node.

The approach is based on a dynamic, stochastic, discrete-event micro-simulation model, that is properly specified, calibrated and validated.

The simulation model allows the evaluation of the efficiency and functionality of the receiving activities. It can be applied to existing logistics platforms or to logistics systems in project phase, by offering managers summary indicators to support decisions related to planning receiving activities at different levels.

Finally, a test application is proposed showing the optimal configurations of the system through the adjustment of the layout characteristics and the resources employed to serve inbound trucks.

Keywords: Logistics platform, micro-simulation model, optimization.

1. INTRODUCTION
A logistics platform, like a warehouse, "is a facility, which provides the services about material storage and management to a manufacturing firm or customer". Its efficiency depends on many factors and is important because costs affect the production or distribution accounts and ultimately fall on the consumer.

The paper proposes a "what to" approach in order to optimize the receiving activities in a logistics platform operating in the food sector.
The aim is the minimization of the time inbound trucks spend at node. A discrete event, stochastic, dynamic micro-simulation model was specified and calibrated to solve the problem and it was implemented by using WITNESS software.

The simulation model allows to evaluate the efficiency and functionality of the receiving area of logistics platforms, already existing or to be built, by offering managers summary indicators to support decisions related to the planning of receiving activities at different levels (strategic, tactical and operational).

Through "what to" procedures, the model provides the analysis of the receiving area performance in relation to the node working conditions and the managerial policy adopted by the terminal operators. The proposed model is a useful decision support tool for operators of existing logistics platforms, since it enables them to make operational evaluations (space organization, resources utilization, etc.) that can direct the planning of tactical and strategic actions. Furthermore, in the case of platforms still to be built, the proposed simulation model allows to test scenarios and to make informed choices about the provision of space and resources and about the management approach to be taken in planning phase.

After a brief review of the studies about inbound vehicles scheduling, the description and the mathematical formulation of a model is proposed in order to optimize receiving activities in the logistics platform.

Finally, the paper proposes a test of the above-mentioned model to a logistics platform operating in the north of Italy.

2. LITTERATURE REVIEW
The trucks scheduling problem takes into account temporal constraints and determines where and when trucks should be processed. In literature sector, this problem is faced in different ways in relation to the presence of temporary storage during the goods transfer from inbound doors to outbound doors.

Tsui and Chang (1992) study the problem without considering temporary storage of incoming goods, the objective is to minimize the distance traveled by handling means in warehouse. They use a traditional formulation for the problem (bi-linear programming) and Branch & Bound algorithm for resolution. The model is a reference point in the litterature sector, in fact many authors propose a integration or adaptation of it (Bermudez et al., 2001; Rong Zhu et al., 2009; Cohen and Karen, 2009; Guignard et al., 2012).

Also Boysen et al. (2010), in the case of direct goods transfer without temporary storage, propose a procedure to schedule inbound and outbound trucks. The used approach is dynamic and the problem is resolved by using heuristic methods. The objective is to minimize the total time spent at node.

Instead Chen and Lee (2009) develop a polynomial approximation algorithm and a branch-and-bound algorithm to minimize the makespan for products going through a crossdocking facility without temporary storage. In particular, the authors propose to sequence the unload/upload and degroupage/groupage operations for the inbound/outbound goods to minimize the makespan. They formulate this problem as a two-machine flow shop problem.

Yu and Egbelu (2008) study the scheduling issue of inbound and outbound trucks in a crossdocking systems with temporary storage. They try to find the scheduling sequence for both inbound and outbound trucks to minimize the total operation time when a storage buffer to hold items temporarily is located at the shipping stock. Boloori Arabani et al. (2011) deal with the same problem and propose an implementation of a genetic algorithm for the resolution.

Other researches concern the study of the trucks scheduling through the simulation, for instance McWilliams et al. (2008) cover a specific trucks scheduling problem at a parcel hub. They propose a simulation-based scheduling approach with an embedded genetic algorithm.

The trucks scheduling problem is related to vehicle routing problem and internal resources scheduling problem. In fact, the arrival times of the inbound trucks are determined by the route travelled on the network. The arrival time is an important parameter influencing the assignment of the inbound trucks to the unloading doors. In addition, the assignment of the trucks to the doors determines the handling activities inside the platform, in other words, the distance that the workers and the handling means have to travel to transfer the goods from inbound doors to outbound doors.

In function of last consideration, the paper proposes the resolution of trucks scheduling problem by using a simulation approach. The supply variables are clearly considered in the problem formulation. They characterize a logistics platform and influence the system performance and the service level offered to clients, therefore the efficiency and the speed with which the inbound trucks are served. The objective is to minimize the inbound trucks makespan through the optimization of the infrastructural and superstructural resources of a platform, without defining the best sequence of inbound trucks.

3. MATHEMATICAL MODEL FORMULATION

The aim of the proposed model is to optimize the receiving activities by minimizing the total time spent by the trucks at the node, from their arrival to their departure.

The receiving area of a logistics platform has a gatehouse; one or several docks equipped with doors for unloading operations and for the reloading of rejected goods; an area where the inbound goods are subject to the qualitative and quantitative checks and, then, are sorted into the storage area. Generally, the docks of a logistics platform correspond to specific warehouse zones and are used to receive only certain types of goods so that the following operations of handling and storage of inbound goods can be simplified.

The receiving process concerns the activities carried out to handle inbound trucks and involves the receiving area and the corresponding operational areas. In detail, once the conformity of the amount and type of goods transported by a truck is checked, following the order of arrival, the gatehouse assigns a dock and a serial number to the inbound vehicle. Generally, the dock is assigned according to the type of goods, in order to optimize the following unloading and storage operations, while the serial number is assigned on the basis of the arrival time and registration at the gatehouse. Thus, the truck remains waiting for the service and, when one of the doors of the assigned dock becomes available, it is let in. Then, the unloading operations start and, finally, they are followed by check operations (Transport Document: TD). It is important to notice that the qualitative and quantitative check is carried out by priority, i.e. if the inbound goods are not immediately required in the warehouse, the check is postponed. When checking operations end, if goods are deemed suitable, they are stored, otherwise they are reloaded on the truck, which leaves the door at the end of all operations.

In relation to the operational and functional characteristics of the receiving area of a logistics platform, the optimization problem of the makespan of inbound trucks (T_I) can be formulated as follows:

$$Min\ T_I \tag{1}$$

Subject to:

$$\begin{cases} x_{ij} - 1 \le y_{ik} - y_{jk} \le 1 - x_{ij} \\ i, j = 1, \ldots, n+1 \quad i \ne j \quad k = 1, \ldots, m_k \end{cases} \tag{2}$$

$$0 < \sum_{k=1}^{K} m_k \le N \tag{3}$$

$$0 < \sum_{k=1}^{K} a_k^{unload} \le A^{unload} \tag{4}$$

$$0 < \sum_{k=1}^{K} a_k^{c} \le A^{c} \tag{5}$$

$$x_{ij} \in \{1,0\} \quad \forall i, j = 1, \ldots, n \tag{6}$$

$$y_{ik} \in \{1,0\} \quad \forall i = 1, \ldots, n \quad k = 1, \ldots, m_k \tag{7}$$

where:

- x_{ij} binary variable equal to 1 if the truck i and truck j carry the same type of goods, 0 otherwise;
- y_{ik} binary variable equal to 1 if the truck i carries the goods that will be unloaded at dock k, 0 otherwise;
- n total number of inbound trucks;
- m_k number of doors operating at the k-th dock;
- K total number of operating docks;
- N total number of operating doors;

- a_i^{unload} number of workers for goods unloading at *i*-th dock;
- A^{unload} total number of workers for goods unloading;
- a_i^c number of workers for goods checking at *i*-th dock;
- A^c total number of workers for goods checking.

Constraint (2) requires that the trucks carrying the same type of goods are served at the same dock.

Constraint (3) considers the node layout and imposes that the numbers of operating doors in every docks does not exceed the total number of doors available at the logistics platform. Constraints (4) and (5) are budget constraints related to human and superstructural resources that are necessary for the functionality of the receiving area. In particular, constraint (4) ensures that the workers or the handling vehicles dedicated to unloading activities at each dock do not exceed the number of workers/vehicles available for unloading operation. Similarly, constraint (5) requires that the resources employed in checking activities at each dock do not exceed the number of workers available for this activity. Finally, constraints (6) and (7) ensure that x_{ij} and y_{ik} are binary variables.

Specifically, the receiving makespan can be defined through the following function:

$$T_I = T_W + T_{Service} \quad (8)$$

where T_W is the waiting time of the trucks at the collect point and $T_{Service}$ is the service time.

The service time is the sum of three elements: the time necessary for unloading operations (T_{unload}), the time spent to perform the first qualitative and quantitative checks on incoming goods (T_c), the time spent on docking/undocking operations at the door and the time lost waiting for the go-ahead by the logistics platform management (T_{extra}):

$$T_{Service} = T_{unload} + T_c + T_{door} + T_{extra} \quad (9)$$

Generally, T_{door} is negligible and it can be considered as included in the last term, thus the following is the simplified form:

$$T_{Service} = T_{unload} + T_c + T_{extra} \quad (10)$$

4. SOLVING APPROACH

The problem described above was solved by using a simulation approach.

In particular, a discrete-event, stochastic, dynamic micro-simulation model was specified, calibrated, validated and implemented through the WITNESS software.

The phases of the model specification and calibration were based on a statistic procedure for the evaluation of the time/cost variables. The methodological approach is schematized in Figure 1.

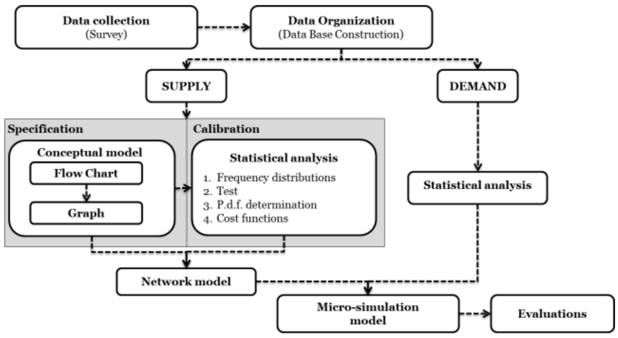

Figure 1: Methodological approach (Gattuso and Cassone, 2012)

4.1. Micro-simulation model

The model specification consisted in the definition of the conceptual model and in the identification of the system variables (Gattuso and Cassone, 2012).

The conceptual model was built by consecutive steps, through gradually increasing the details of representation, defining first the flow chart of nodes and then their graph. The system variables considered are the time variables that define the makespan of inbound trucks.

The calibration of the micro-simulation model consisted in identifying the distribution of the system variables and in evaluating the corresponding characteristic parameters.

The calibration of the simulation model was based on the statistical analysis of the data collected through direct surveys at existing logistics platform.

Table 1 specifies the average and the standard deviation for each system variables.

Table 1: Statistics related to system variables

Variable	Goods type/ Dock	Average (min)	Standard dev. (min)
T_w	Cross	72,61	51,15
	k_B	65,11	53,97
	k_C	66,78	59,64
	k_D	73,71	64,11
	k_E	76,78	62,69
T_{unload}	Cross	6,91	2,34
	k_B	10,78	4,51
	k_C	10,71	4,65
	k_D	11,68	4,54
	k_E	11,50	4,63
T_c	Cross	10,15	7,83
	k_B	32,77	19,63
	k_C	33,09	23,04
	k_D	33,58	17,66
	k_E	45,69	31,05
T_{extra}	Cross	34,36	28,04
	k_B	37,69	36,27
	k_C	38,24	37,12
	k_D	40,26	33,36
	k_E	57,63	61,61

k_B: detergents; paper products; hygiene and personal care products; k_C: beers, wines and liqueurs, plastic/glass drinks; high value perfumes; k_D: oil and vinegar; conserves; pasta, rice and similar products; k_E: water, milk, biscuits, bread and similar products; early childhood products; controlled temperatures and flammable goods.

Instead, Table 2 shows the calibration results referred to the type of goods or to operating docks (each dock is equipped to handle specific types of goods).

Table 2: Calibration results for each goods type

Variable	Goods type/ Dock	Distribution	Parameters
T_w	*Cross*	Beta (α; β) α: shape par. β: scale par.	(1,00; 3,00)
	k_B		(1,80; 7,50)
	k_C		(0,95; 3,50)
	k_D		(1,26; 6,60)
	k_E		(1,20; 3,90)
T_{unload}	*Cross*	Poisson (μ)	6,91
	k_B	Weibull (r; β) r: shape par. λ: scale par.	(1,7; 12,08)
	k_C		(1,4; 11,66)
	k_D		(2,0; 13,78)
	k_E		(1,8; 12,93)
T_c	*Cross*	Weibull (r; β) r: shape par. λ: scale par.	(1,1; 10,52)
	k_B		(1,8; 36,85)
	k_C		(1,6; 37,9)
	k_D		(1,7; 37,64)
	k_E		(1,6; 50,96)
T_{extra}	*Cross*	Exponential(θ)	0,0291
	k_B		0,0265
	k_C		0,0261
	k_D		0,0248
	k_E		0,0174

4.2. Optimization Algorithm

The optimization of the receiving activities in the logistics platform is developed by using the Adaptive Thermostatistical algorithm, also known as Simulated Annealing (SA). It is a research methodology fitting any no-convex optimization problem which is based on statistical mechanics. The SA originated as a simulation method of the tempering of solids (annealing).

In the annealing process, a solid is first brought to the fluid state by heating to high temperatures and then it is brought back to the solid or crystalline state, at low temperatures, controlling and gradually reducing the temperature. At high temperatures, atoms are in a highly disordered state in the system and, therefore, the energy is high. To give these atoms a highly ordered crystalline configuration (statistically), the system temperature should be lowered.

Fast reductions of the temperature can cause defects in the crystal lattice resulting in metastability, with cracks and fractures of the lattice (thermal stress). Annealing avoids this phenomenon by gradually cooling the system and leading to a globally optimal stable structure (Lacagnina, 2014).

The system is in thermal equilibrium at temperature T if the probability $P(E_i)$ of a state having energy E_i is governed by the Boltzmann distribution:

$$P(E_i) = \frac{\exp\left(-\frac{E_i}{k_B \cdot T}\right)}{\sum_i \exp\left(-\frac{E_j}{k_B \cdot T}\right)} \qquad (11)$$

where k_B is the Boltzmann constant.

Note that, at high temperatures, all the energy states are probably possible, while, at low temperatures, the system is definitely in the states of lowest energy.

For optimization problems, the SA works as follows: at high temperatures, the algorithm behaves more or less like a random search. The search jumps from one point to another in the solution space by identifying the characteristics and thus the directions or areas where it is more likely to find the global optimum. At low temperatures, the SA is similar to the methods of steepest descent. Solutions are in the area of the most promising domain. This means that the analyst should decide to implement the method with a large number of parameters allowing greater freedom of choice and therefore high applicability. However, there is a price to pay: the calibration of a large number of parameters causes an initial hard work to make the method converge. A key advantage of SA is that the analyst can adopt it for not well-known optimization problems.

The simulation of the annealing process applied to optimization problems requires several preparatory steps. First, in the optimization problem, the similarities with the physical concepts have to be identified: energy becomes the cost function; the configuration of particles becomes the configuration of the parameters (decision variables) of the problem; the search for a minimum energy state becomes the search for a solution minimizing the cost function; temperature becomes a control parameter. Hence, an appropriate annealing scheme has to be chosen, which consists in the adjustment of the parameters on which the optimization process depends. That means the temperature decay law and the time duration required to reach thermal equilibrium at each temperature have to be defined. Finally, a perturbation method of the system has to be introduced to explore the search space by generating new configurations.

Metropolis et al. (1953) developed an algorithm to simulate the behaviour of a set of atoms in thermal equilibrium at a particular temperature. The essential feature of this algorithm is that it generates a set of configurations, for each temperature T, whose energies can be represented by the Boltzmann distribution. The algorithm starts from a given initial atoms configuration in a system with energy E_0. Then, successive configurations are generated through small random perturbations of the current configuration. The difference between the energy of the current configuration and that of the new configuration (candidate configuration) allows accepting or rejecting the new configuration. The energies of the accepted system configurations have to follow a Boltzmann distribution if the thermal equilibrium is reached.

Metropolis algorithm always accepts a candidate solution if its energy E_j is lower than that of the current configuration E_i. On the other hand, if the energy E_j of the candidate configuration is higher than that of the current configuration, then the candidate is accepted with the following probability:

$$P(\Delta E) = \exp\left(-\frac{\Delta E}{k_B \cdot T} \right) \qquad (12)$$

where $\Delta E = E_j - E_i$.

For an optimization problem, the SA algorithm can be summarized as follows:

1. An initial configuration or solution x_0 is given with energy or value of the objective function E_0. Select an initial value for the temperature T_0.
2. Perform the following steps for each temperature stage:
   Generate a new valid configuration through a small random perturbation of the current configuration. Evaluate the energy difference ΔE between the two configurations;
   If $\Delta E \leq 0$, the objective function of the new configuration has a value lower than that of the current configuration. Accept the new solution and change the current one. If $\Delta E > 0$, the objective function of the new configuration has a value higher than that of the current configuration. Accept this solution with a probability $P(\Delta E)=exp(-\Delta E/k_B \cdot T)$ and update the current configuration if it is necessary;
   If the thermal equilibrium is not reached, return to Step 2.A. Otherwise, go to Step 3.
3. If the annealing process is incomplete, reduce the temperature and return to 2.

5. APPLICATION

A test application is proposed to optimize the efficiency of the receiving area of a logistics platform.

The considered platform is located in the north of Italy and operates in the food sector. Table 4 shows both the layout characteristics of the receiving area and the resources employed to serve inbound trucks.

In order to simplify the following activities of storage, picking and composition of the outbound loads, inbound trucks are sorted at docks in relation to transported goods.

For this reason, the efficiency analysis of the receiving area was carried out considering the operating dock (or the type of goods).

Table 4 and table 5 respectively show the values of reference variables and the values of the objective function in the current system configuration.

The results of the considered optimization problem are shown in table 6.

The analysis of the optimization results shows an clear reduction in the makespan of inbound trucks due to the reorganization of the docks and to the redistribution of the human resources at each dock.

The reorganization of docks implies 28 doors (compared to 34 current doors), 10 workers for the unloading activities and 9 workers for the checking activities (1 unit less than at present).

In particular, the optimal configuration of the dock 1 has 9 doors (5 more than current state), 5 workers for unload activities (3 more than current configuration) and 2 workers for checking activities, so the makespan is cut by 27.69%. The optimal configuration of dock 2 is very similar to current state: 8 doors for goods unloading (1 door less than the 9 doors of current state) and 3 workers (1 worker less for goods unloading), this means a reduction in the makespan of about 3.89%.

Table 4: Reference variables in the current system configuration

Reference variable	Description	Value
n	Total number of inbound trucks	130
m_1	Number of doors operating at dock 1	4
m_2	Number of doors operating at dock 2	9
m_3	Number of doors operating at dock 3	3
m_4	Number of doors operating at dock 4	9
m_5	Number of doors operating at dock 5	9
K	Total number of operating docks	5
N	Total number of operating doors	34
a_i^{unload} $i=1,2,..,5$	Number of workers for goods unloading at i-th dock	2
A^{unload}	Total number of workers for goods unloading	10
ai^c $i=1,2,..,5$	Number of workers for goods checking at i-th dock	2
A^c	Total number of workers for goods checking	10

Table 5: Objective function value in the current system configuration

Dock	T_I (min)
1 - cross activities	407,13
2 - treatment of k_B goods type	420,78
3 - treatment of k_C goods type	141,63
4 - treatment of k_D goods type	394,32
5 - treatment of k_E goods type	439,18

Instead, for dock 3 the optimal configuration requires a minimum use of resources (1 door, 1 worker for goods unloading, 1 worker for goods checking) and the makespan is cut by 60.66%.

The optimization results require significant changes in the configuration of dock 4. In fact, it has 2 doors for goods unloading (7 less than current state), 1 worker for goods unloading (1 less than current condition), 2 workers for goods checking (equal current state). The makespan is cut by 19.93%.

Table 6: Optimization results

Dock	T_I (min)	m	a^{unload}	a^c
1	294,38	9	5	2
2	404,43	8	1	2
3	55,723	1	1	1
4	315,74	2	1	2
5	343,78	8	2	2
TOTAL AMMOUNT		28	10	9

Finally, the optimal configuration of dock 5 is similar to current state (8 doors, 2 workers for unloading, 2 workers for checking) with a makespan reduction of about 21.72%.

The simulation results recommend a reorganization of the receiving area in order to increase functionality and performances.

6. CONCLUSIONS

The logistics platform is a fundamental component of the supply chain; it is the link between the producers and the consumers and, in general, it accounts for 15-20% of the logistic costs. It plays a double role in the logistics network: it is both a "container" of goods in stock and a "transformer" of inbound flows into outbound flows.

Therefore, there is the tendency to improve productivity and to reduce the total supply chain cost.

The paper proposes a "what to" approach to optimize the activities and functionality of the receiving area in a logistics platform operating in the food sector.

The optimization has the aim to minimize the time spent by inbound trucks at the node through the formulation of a discrete event, stochastic, dynamic micro-simulation model implemented by using the WITNESS software.

The proposed model is a useful decision support tool for operators of existing logistic platforms, since it allows the analysis of the real functionality/efficiency of the receiving area. The aim is to obtain some useful indicators to establish if the current organization of space and distribution of resources are the best possible, or if a reorganization is necessary to offer a better service level to the inbound trucks.

The model allows ex-ante performing evaluations on the receiving area efficiency for the platforms to be built, so that the operators can define the physical structure of the node and identify the resources necessary for the receiving activities by using suitable efficiency indicators.

The proposed optimization procedure has good transferability to similar contexts (cross-docking, urban distribution centres, etc.).

Future developments of research will integrate the proposed model in order to carry out the efficiency analysis of the whole platform. In addition, a few elements considering ITS technologies used to perform the internal activities of the node will be studied.

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SIMULATING BOARDING STRATEGIES FOR MINIMISING PASSENGER AIRCRAFT TURN-TIMES

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ABSTRACT
The airline industry implements many simulation models to optimise its operations, knowing that small changes in the policies of its companies involve significant improvements in the long run. Here, we have developed some simulation models to make a comparison between different boarding strategies for passengers in an A380 aircraft. After suggesting six different strategies (back-to-front, outside-inside, optimization, by blocks, random, and alternative rows) and having performed the apposite simulation models and their corresponding ANOVA analysis, the alternative rows strategy has revealed as superior in relation to the other strategies. Some final considerations have also been discussed about the limitations of each strategy and the goodness of the proposed as the better.

Keywords: Simulation, Boarding Strategy, Turn-time, Passengers Air Transport

1. INTRODUCTION

The airline sector is a highly competitive industry where each airline must struggle to win a suitable position in the market. In order to increase the associated profitability, the greatest efforts are focused on optimising operational processes controlled by the airline companies such as the use of available resources.

The wild competition between airlines (especially between legacy and low-cost airlines) and the current fuel prices generate small profitability margins, being sometimes negative. Therefore, airlines are always interested on maximizing resources usage. Increasing aircraft utilization, for example, allows the airlines to serve more origin-destination routes and to place more frequencies on them, thus serving more passengers and capturing greater revenues. Reducing the time an aircraft spends on the ground increases profit (Ferrari and Nagel, 2004; Van Landeghem and Beuselinck, 2002, Lewis and Lieber, 2005): an aircraft in the ground does not generate any revenue (Van de Briel et al., 2005) but does airport fees. According to Van Landeghem and Beuselinck (2002) the turn-time of an aircraft (i.e., the elapsed time in ground with the chocks placed) is about 30-60 minutes (i.e., it depends on the aircraft size). Each minute an airline spends during the boarding process costs \$30: for an airline operating a flight network with 500 daily flights, a decrease of a single minute for all the turn-times results in annual savings of \$5,475,000 (Nyquist et al., 2008).

Therefore, the process of passenger boarding is a key step during the turn-time of an aircraft. Based on the airline tradition and the level of service it wants to offer, a specific boarding strategy is chosen (Van de Briel et al., 2005). Factors such as the speed of passengers, the amount of hand luggage they carry on, and the interference that may exist for each strategy should also be taken into account in order to be efficient. Furthermore, the robustness of the strategy should not be neglected because many of them are efficient but few are robust when implemented. The most common strategies among legacy airlines are *back-to-front* and *outside-inside*. They are also used in a hybrid way.

This paper focuses on the study and comparison of different strategies used for boarding passengers in medium to long haul flights operated by the A380 fleet type. We focus on the optimization and improvement of the boarding process, neglecting the events out of control of the airline. There are two main reasons why this study is carried out: (1) there are few studies on boarding strategies for large aircraft types since other authors have focused on optimizing the process for smaller fleet types; and, (2) we think it is more important to study boarding strategies for larger aircraft types due to the number of passengers, the existence of more than one aisle and boarding gates and sometimes two decks. These factors make the boarding process more complex: more interference arise as compared to smaller aircraft types such as those ones with a single door, aisle and deck. Furthermore, as passengers may usually carry on more than one hand luggage in the flights served by this fleet type, the difficulty for reaching an efficient and smooth boarding process is greater.

2. STATE OF THE ART

The passenger boarding process has been studied by many other researchers. Most of the past studies focus on the simulation rather than in an analytical approach. Marelli et al. (1998) developed a simulation model in order to study different strategies under different configurations of a Boeing 757 for boarding and deboarding of passengers. Van Landeghem and Beuselink (2002) explored different patterns of boarding; Van den Briel et al. (2003, 2005) studied the boarding problem using integer programming, non-linear assignment models and simulation models with real data samples. Ferrari (2005) used different schemes to evaluate different boarding strategies and designed a new model consisting of boarding small groups; they concluded that the most efficient strategies were separating groups traveling together, thus decreasing passenger satisfaction. Van Landeghem and Beuselinck (2002) reached similar conclusions to those ones in Ferrari and Nagel (2005).

Bazargan (2007) analyzed the interferences between passengers causing greater boarding times and designed an integer programming model to minimize these interferences. Nyquist and McFadden (2008) analyzed the most effective boarding strategies in terms of costs while also accounting for customer satisfaction. Steffen (2008) used simulation to study the sequencing of passengers to minimize the boarding time. Steiner and Philipp (2009) built a simulation model and used samples of observations drawn from the Zurich airport to calibrate the model; they accounted for various actions carried out in and out of the aircraft.

Thus, the main contributions of this paper are summarized as follows: (a) we have developed a simulation model to replicate the different boarding strategies in an A380 aircraft with the purpose of finding the lowest boarding time strategy; and (b) we have tested the previous optimal strategy with realistic instances in the aforementioned A380. In this way, we use simulation models to make decisions with optimization objectives.

3. PROBLEM DESCRIPTION

In this section, the boarding problem is described in detail. First, the boarding process is presented. Then, the different boarding strategies are introduced.

3.1. The Boarding Process

The boarding process is one of the processes included in the set of activities that are performed during the turnaround of an aircraft; the turnaround begins when an operator puts ramp chocks and finishes when the aircraft pushback starts.

During the turnaround of an aircraft, besides the passenger boarding process, other activities are carried out, such as baggage unloading and loading, visual inspections of the aircraft, cleaning, fuelling, and catering. The handling of these services may be done by the airport itself, or by specific companies specialized in handling services (which may be owned by the airline, the airport or any other entity). The speed, accuracy and efficiency provided by these handling companies are key factors to minimize the overall turn-time. Most of these activities can be made while other activities are being performed. However, there are activities such as deboarding and boarding of passengers that cannot be performed in parallel. Figure 1 shows the different activities to be carried out during the turnaround.

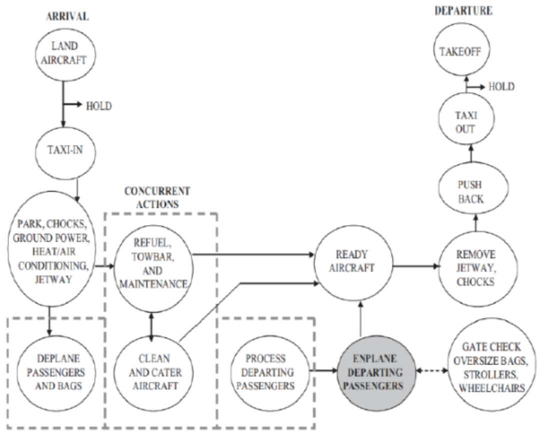

Figure 1: Turnaround process for a passenger aircraft

The total boarding time depends on factors such as the size of the aircraft, airport infrastructure, ground handling services, human resources workload, hand luggage or passenger behaviour. Some of them are controllable while others not.

The boarding process is composed of three different steps:

1. announcement: the boarding start is announced to the passengers and passengers queue at the gate;
2. check in: an airline agent checks all boarding passes and registers passengers into the system;
3. and access: passengers access to the aircraft through the finger or by bus. In the latter case, passengers arrive at the door of the aircraft in large batches. Once inside the aircraft, passengers queue in a straight line in order to reach their assigned seat.

There are several causes of delays during the boarding process such as late arrival of passengers (e.g., delayed connecting passengers), malfunction of electronic systems used during the boarding, removal of excess baggage in the gateway (due to the strengthening of control over luggage limits) and passenger behaviour (i.e., storage of hand luggage and sitting down). Some of these delays are increased due to the nature of some flight networks such as hub-and-spoke networks.

3.2. Boarding Strategies

There is no a universal strategy which is efficient for every boarding that is performed around the world.

Each airline must ensure that its strategy reaches a trade-off between the multiple different objectives, such as the level of service offered to the passengers, the flexibility to the characteristics of the aircraft, the load factor of the flight and the early and/or late arrival of the passengers. Furthermore, there are also external factors affecting the suitability of each one of the strategies such as the availability of fingers and multiple aircraft doors.

The most employed strategies by legacy airlines are: *back-to-front* and *front-to-back*, *outside-inside*, *optimization*, *by blocks*, *random* and *alternating rows*. We describe each of the strategies in the following subsections.

3.2.1. Back-to-front and front-to-back

Back-to-front is the most often used strategy by the majority of the small and large fleet sized airlines. In this strategy, first class boards first and then the rest of the passengers are called to board by groups, following a sequence from the back to the front of the aircraft.

It is the most common strategy due to its simplicity and ease to be understood. Also, it allows groups of passengers traveling together to board at once. As disadvantages, there is no evidence that it is the most efficient strategy and there are large interferences between the passengers.

Front-to-back is the opposite strategy, i.e. first class boards first and then the rest of the passengers are called to board by groups, following a sequence from the front to the back.

3.2.2. Outside-inside

The *outside-inside* strategy, also known as *Wilma* (window-middle-aisle), consist of boarding passengers as follows: first class passengers, passengers who are assigned a seat next to the window, then middle seats and finally aisle seats. The advantages of this strategy are that it has less interference and if the boarding is successfully conducted, seat interferences are completely eliminated. The main disadvantage is that this strategy forces passengers traveling together to board separately and during different time periods.

3.2.3. Optimization

It consists of first boarding passengers with a window seat, followed by those in the middle and finally the aisle seats; passengers board diagonally in this strategy. Thus, it can be considered a hybrid strategy between *back-to-front* and *Wilma* strategies. This strategy boards passengers traveling together at once.

3.2.4. By blocks

This strategy consists of boarding passengers sitting in the middle of the aircraft at the last place. The passengers are grouped by areas and are boarded as follows: first the area of the front, then the one at the rear and again an area from the front and so on; therefore, the strategy rotates from the front to the rear. The first class is always boarded first.

3.2.5. Random

The *random* strategy accommodates passengers randomly so there is only one area. The first class passengers board first, and then the rest of the passengers with assigned seats are boarded. This strategy is known as FIFO (first in-first out).

3.2.6. Alternating rows

In this boarding strategy, first, all passengers sitting in the window seats on one side of the plane board at once, in alternating rows (rows 1, 3, 5, etc.). Then the same is done on the other side of the plane. Then the middle seats, still in alternating rows, board on the first side of the plane. That continues with the other side's middle seats, then aisle seats (first one side and then the other one). Then, the process is repeated for the even-numbered rows.

It is simple, but very efficient; alternating rows gives everyone enough elbow room; taking careful notice of seat position it reduces bottlenecks from aisle-passengers having to stand up all the time.

4. SIMULATION MODEL

The simulation model makes the following assumptions:

1. passengers are assigned to seats randomly;
2. seats are classified into different groups;
3. and passengers within the same group board the aircraft randomly.

The following subsections describe the passenger behaviour and the aircraft and load factor influences on the process.

4.1. Passenger Behaviour

Once inside the aircraft, each passenger goes to his/her seat based on his/her walking speed (walking time per seat row). Obviously, he/she will stop if another passenger obstructs his/her way. We assume that passengers are not mistaken about their seats and, therefore, they go the right way when reaching their seats. In addition, passengers have an associated delay time to get to the seats because they need a certain time to locate their hand-luggage in the upper compartments (hand-luggage time); we assume every passenger carries hand-luggage. Moreover, when a passenger reaches the seat row where he/she is sitting, if there is another sitting passenger, we assume that some time is needed to wait for this passenger to clear the way for the incoming person (interference seating time).

We have relied on the study by Mas et al. (2012) in order to determine the passengers' parameters. They observed several real boarding processes and obtained realistic values for parameters such as the walking time per row, delays caused by passengers' interferences, or the time associated with luggage handling inside the plane. We assume the following values are constant and read as follows:

1. walking time per row equals to one time period (i.e., one time period represents half a second);

2. interference seating time equals to ten time periods;
3. and hand-luggage time equals twelve time periods.

Interferences among passengers are considered in our simulation model, i.e., we implemented in the code a logic such that whenever a passenger stops in the aisle, the passengers behind him/her are forced to wait (unless available space exists between the stopping passenger and them). Likewise, similar logics have been implemented to account for interferences related to luggage handling or seat movements.

4.2. Aircraft and Load Factor

We represent the aircraft with a grid (see Figure 2 for an example). Each highlighted cell in the grid represents a seat. The load factor of a flight represents the percentage of seats occupied by passengers. This parameter is important because the more passengers, the more interference will exist and, therefore, it will take longer to complete the boarding.

We consider two levels of occupation, medium-high (load factor of 90%) and high (load factor of 100%). The level of passenger interference will be lower for lower load factors; therefore, we are not interested in studying low occupancy levels: the different boarding strategies will behave similarly.

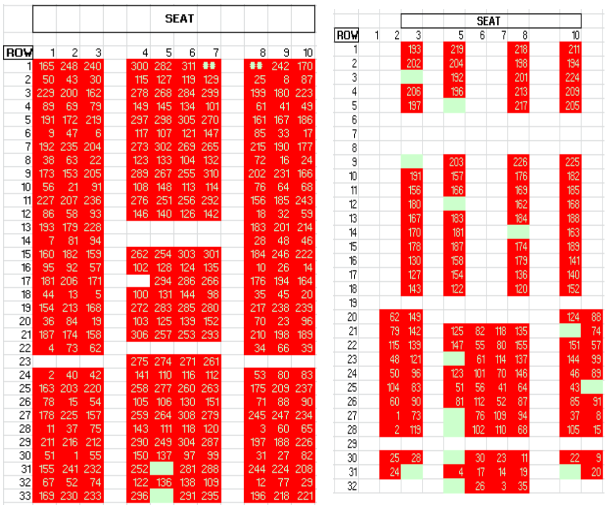

Figure 2: Aircraft grid for the simulation model: lower (left) and upper (right) decks.

5. COMPUTATIONAL RESULTS

Each aircraft type is classified according to the number of passengers that it can carry and the distance it can cover. The aircraft studied here is an Airbus 380-800 used by Singapore Airlines SQ with 471 seats on two decks: 12 Suite Class seats and 311 Economy Class seats on the main deck, and 60 Business seats and 88 Economy seats on the upper deck. There are three gates: two for the main deck (one for the Suite Class) and one for the upper deck of the aircraft.

We have developed an ad-hoc simulator using VBA inside Excel. With this software, we have performed simulations independently for the main deck and the upper deck. As we study 6 different boarding strategies and 2 different load factors, we carry out 12 simulations for the main deck and 12 for the upper deck; from each of the 12 simulations, 6 (one for each strategy) at a load factor of 90% and the other 6 at a load factor of 100%. We run 30 iterations for each simulation in order to have 30 different observations. The assignment of passengers to seats is randomly changed at each iteration. The Suite Class, which consists of 12 seats, has not been modelled since it has a self-boarding gate and is the area that requires the least boarding time.

The main objective is to observe the boarding time at the two decks. For each of the six strategies, the total boarding time will be the maximum time between the two decks.

5.1. Load Factor of 90%

In this subsection, we study the different boarding strategies for a load factor of 90%. We conduct the simulations independently for the main and upper decks.

5.1.1. Main deck

In order to be able to visually detect the differences between the six boarding strategies studied, we use a boxplot. Figure 3 shows a boxplot with the obtained results. The y-axis shows boarding times in time periods and the x-axis the strategy used (i.e., *Rand* for *random*, *BF* for *back-to-front*, *FB* for *front-to-back*, *ALTROW* for *alternating rows*, *BLOCKS* for *by blocks* and *RP* for *optimization*). The circle inside each box represents the average boarding time.

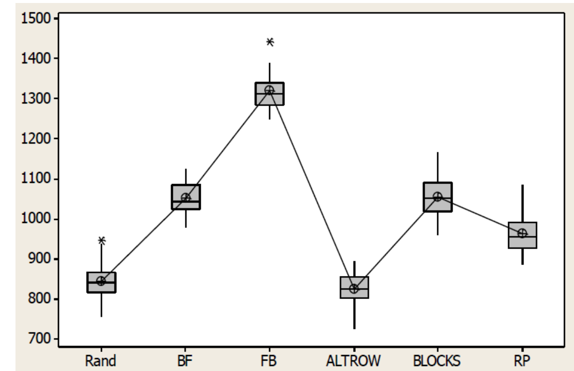

Figure 3: Boxplot for the main deck and load factor of 90%

Notice that there are two outliers, which are the extreme values of the data set (within the 30 observations, 2 have had a larger value than the average one). These values are represented by an asterisk in Figure 3. Regarding average values, the boarding times for *alternating rows* strategy appear to be the lowest, although the *random* strategy also provides low boarding times. The *front-to-back* strategy clearly provides the worst boarding times.

In order to examine whether there are significant differences between the average boarding times provided by the studied strategies we make an *Analysis of Variance (ANOVA).* Figure 4 shows the results. According to the p-value, which in this case is 0.000<0.005, we reject the null hypothesis: not all the (expected) boarding times are equal. The boarding times of *random* and *alternating rows* strategies and the *back-to-front* and *by blocks* are overlapping strategies: there are not many differences between them. For the other strategies there is no overlapping: the differences between them are significant.

We can conclude that the boarding strategy which works best on the main deck for a load factor of 90% is the *alternating rows* strategy.

```
Source   DF       SS      MS       F      P
Factor    5  4921282  984256  518,42  0,000
Error   174   330353    1899
Total   179  5251635

S = 43,57   R-Sq = 93,71%   R-Sq(adj) = 93,53%

Individual 95% CIs For Mean Based on
Pooled StDev
Level    N    Mean  StDev  ------+---------+---------+---------+---
Rand    30   843,6   44,6   (*)
BF      30  1051,7   35,2                (*)
FB      30  1319,6   45,5                                 (*)
ALTROW  30   824,6   38,2  (*)
BLOCKS  30  1055,4   49,6                (*)
RP      30   961,5   46,6          (*)
                           ------+---------+---------+---------+---
                               900      1050      1200      1350

Pooled StDev = 43,6
```

Figure 4: ANOVA for the main deck and load factor of 90%

5.1.2. Upper deck

The obtained results for the upper deck are similar to those ones for the main deck.

Figure 5 shows a boxplot so as to see the differences between the six boarding strategies studied. Figure 5 can be read the same way as Figure 3.

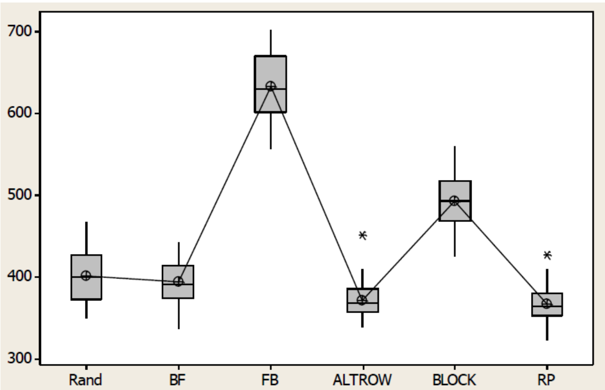

Figure 5: Boxplot for the upper deck and load factor of 90%

Again, there are two outliers, which are represented by asterisks. Regarding average boarding time values, *alternating rows* and *optimization* strategies provide the lowest ones. The *random* strategy also yields a low average boarding time. The *front-to-back* strategy is clearly the worst one; moreover the box is considerably wider as compared with the ones for the rest of the strategies.

Figure 6 shows the *ANOVA* results for the upper deck. According to the p-value, which equals to 0.000<0.005, we reject again the null hypothesis (homogeneity of expected boarding times). The average boarding times provided by the *random* and *back-to-front* strategies and, the *alternating rows* and *optimization* strategies overlap, which means that there are not significant differences between them.

Having a load factor of 90%, the *optimization* strategy is the one which works best on the upper deck.

```
Source   DF       SS      MS       F      P
Factor    5  1610375  322075  356,62  0,000
Error   174   157144     903
Total   179  1767519

S = 30,05   R-Sq = 91,11%   R-Sq(adj) = 90,85%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level    N    Mean  StDev  ----+---------+---------+---------+----
Rand    30  400,47  31,44     (*)
BF      30  393,73  25,29    (*-)
FB      30  632,97  38,28                               (*)
ALTROW  30  371,53  23,91  (*-)
BLOCK   30  492,57  34,58                (-*)
RP      30  366,90  23,62  (*)
                           ----+---------+---------+---------+----
                              400       480       560       640

Pooled StDev = 30,05
```

Figure 6: ANOVA for the upper deck and load factor of 90%

5.2. Load Factor of 100%

In this subsection, we study the different boarding strategies for the main and upper decks for a load factor of 100%. The obtained results are very similar to those ones for a load factor of 90%.

5.2.1. Main deck

Figure 7 shows the *ANOVA* results. The differences between the different strategies are statistically significant: the boarding time intervals of the strategies are separated from each other. We note that not all the boarding strategies produce the same boarding times (the p-value is 0.000).

The *alternating rows* strategy average boarding time is the lowest one, while the strategy *front-to-back* yields the greatest average boarding time. Therefore, the results are the same as those ones for a load factor of 90%.

```
Source   DF       SS       MS       F      P
Factor    5  6011086  1202217  731,62  0,000
Error   174   285920     1643
Total   179  6297006

S = 40,54   R-Sq = 95,46%   R-Sq(adj) = 95,33%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level    N    Mean  StDev  -+---------+---------+---------+--------
Rand    30   928,0   36,7    (*)
BF      30  1201,6   40,9                    (*)
FB      30  1444,0   51,1                                 (*)
ALTROW  30   905,8   34,6  (*)
BLOCK   30  1193,5   41,3                    (*)
RP      30  1089,7   36,4             (*)
                           -+---------+---------+---------+--------
                           900      1050      1200      1350

Pooled StDev = 40,5
```

Figure 7: ANOVA for the main deck and load factor of 100%

5.2.2. Upper deck

Figure 8 shows the boxplot for the upper deck and for a load factor of 100%. We note that there are no outliers. The best boarding strategy is the *alternating rows* one; moreover, its boarding times vary within a small range (see its box narrowness). The *front-to-back* strategy is the worst one.

The *ANOVA* analysis (Figure 9) shows the differences between the boarding strategies regarding boarding times. According to the p-value (0.000), the expected boarding times are not equal among the strategies. According to our experimental results, the *alternating rows* strategy is the most efficient one.

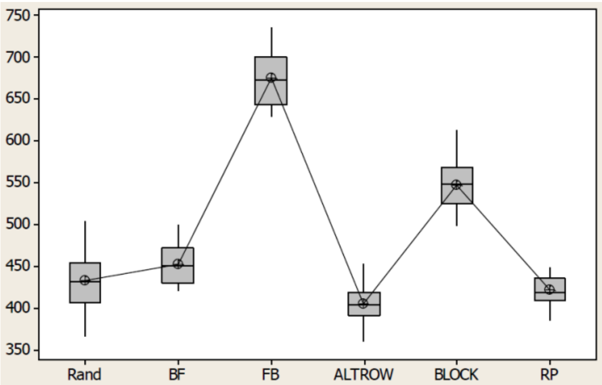

Figure 8: Boxplot for the upper deck and load factor of 100%

```
Source    DF       SS       MS       F       P
Factor     5  1624641   324928  476,61   0,000
Error    174   118625      682
Total    179  1743266

S = 26,11   R-Sq = 93,20%   R-Sq(adj) = 93,00%

                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev
Level     N    Mean   StDev  --+---------+---------+---------+--------
Rand     30  432,60   32,94       (*)
BF       30  452,80   22,85         (-*)
FB       30  675,07   32,10                                   (*-)
ALTROW   30  404,90   21,73  (-*)
BLOCK    30  548,00   26,52                    (-*)
RP       30  422,00   16,65     (*)
                             --+---------+---------+---------+--------
                             400       480       560       640

Pooled StDev = 26,11
```

Figure 9: ANOVA for the upper deck and load factor of 100%

5.3. Summary of the Computational Results

The *alternating rows* boarding strategy is the most efficient strategy for both load factors of 90% and 100%. For a load factor of 90%, the *optimization* strategy works better in the upper deck; however, it provides little significant difference as compared to the *alternating rows* boarding strategy.

The computational results show that it takes more than twice the boarding time for the upper deck to board the main deck. This is due to the distribution of the seats in the upper deck: it provides less interference between passengers; moreover, the total number of seats is much lower in the upper deck than in the main deck.

Figure 10 shows boarding times for load factors of 90% and 100%. The total boarding time is significantly lower for the case where the load factor is 90%.

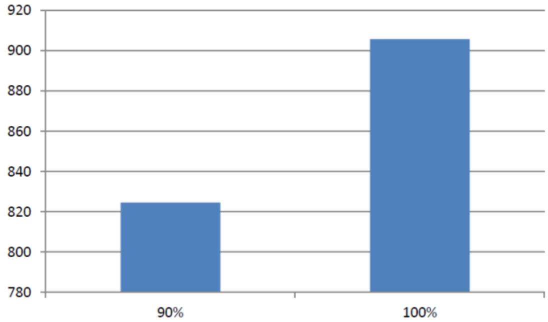

Figure 10: Boarding times for load factors of 90% and 100%

6. CONCLUSIONS

Conducting an efficient boarding process is a key step in order to minimize the total turn-time of an aircraft in an airport. We have demonstrated that different boarding strategies produce significant different boarding times.

One of the most important factors affecting the boarding times is the interference between passengers. Obviously, it depends on the number of seats and its distribution over the deck.

We show how for high load factor flights, small variations on it (i.e., within the range of 90-100%) do not have significant impacts on the boarding times and on the choice of the best boarding strategy.

The *back-to-front* boarding strategy, which is the traditional and most common strategy used by airlines (Herbst, 2007), is not the most efficient one for the aircraft studied in this paper: we have demonstrated that the one which works best is the *alternating rows* strategy. We acknowledge that this strategy may be confusing for the passengers. However, these negative effects may be alleviated if passengers are properly split into different passenger groups according to the strategy.

ACKNOWLEDGMENTS

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CONCEPTUAL MODEL OF SUPPLY CHAIN NODE FOR SIMULATION BASED RISK ANALYSIS

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ABSTRACT

The Supply Chain comprising of distribution centres, plants, terminals and stores in the product flow, and Information and Communication Technologies platforms in the information flow face a lot of risks in today's competitive world. As SCs are highly complex dynamic multi-state systems, such systems as well as their individual nodes are exposed to numerous random factors in the form of various risks, which include natural disasters, terrorism, cyber attacks, credit crunch, and what is more is the impact of demand risk due to optimistic forecasts that turn out to be a disaster due to organizations' ineffective and inefficient information flow. These risks could yield to a drastic loss in productivity, revenue, competitive advantage, profitability etc, if not managed appropriately. This article discusses the risks typical to the supply chain as well as the conceptualization of risks for subsequent simulation-based analysis. In addition, the development of a generic conceptual model of a retail node is described and relevant performance measure indicators are introduced.

Keywords: resilience, simulation, risk analysis, supply chain

1. SUPPLY CHAIN NODES

Before analysing the supply chain (SC) nodes, it is necessary to define the supply chain itself.

1.1. Defining the Supply Chain

Over the past 50 years, the supply chain has greatly evolved from traditional to modern innovative companies that are actually outsourcing almost all the processes in the supply chain unlike the traditional companies that were wholly and solely responsible for supplies, manufacturing and distribution. This has somehow affected the definition of the supply chain and currently it has many definitions consisting of overlapping terminology and meanings. Hence, several authors have come up with different definitions that tend to overlap in many cases with the supply chain being defined, for example, as 'a group of inter-connected participating companies that add value to a stream of transformed inputs from their source of origin to the end products or services that are demanded by the designated end-customers' (Lu 2011), or 'a general description of the process integration involving organizations to transform raw materials into finished goods and to transport them to the end-user' (Pienaar 2009). Furthermore, it is also defined as 'a sequenced network of business partners involved in production processes that convert raw materials into finished goods or services in order to satisfy the consumers' demand' (Mensah and Merkuryev 2012).

Although the aforementioned definitions lacks the terminology 'nodes and links', they do refer to them indirectly. The authors have discussed nodes and links below.

1.2. Nodes and Links

Nodes and Links build up the supply chain where nodes are factories, distribution centres, warehouses, stores that are engaged in product flow. As far as the information flow is concerned the nodes are mainly Information and Communication Technologies (ICT) platforms. In addition, nodes can also be described as fixed spatial points where goods are stored or processed. The links which are mainly roads, rails, waterways, airways etc, represent the transportation network and connect the nodes. Figure 1 below illustrates an example of a supply chain with its nodes and links.

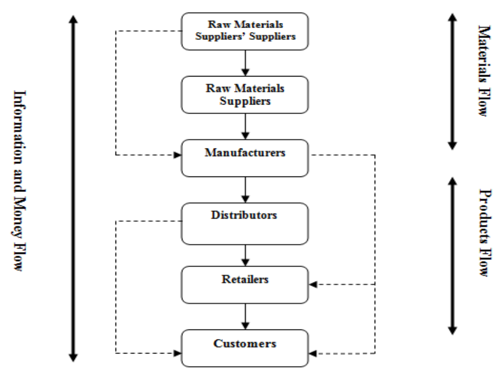

Figure 1: Supply Chain Nodes (Mensah and Merkuryev 2013)

With reference to Figure 1, the nodes represented in boxes include raw materials suppliers' suppliers, raw materials suppliers, manufacturers, distributors, retailers and customers are linked by arrows. The nodes are in stages within the upper stream and lower stream of the supply chain. All of these stages involve the 'flow of materials, information and money through a business network, all the way from the suppliers to the customers' (Croker 2003) and vice versa.

The links are also illustrated in Figure 1 connecting the nodes by arrows. For example, in the upper stream of the supply chain, materials flow from the raw materials suppliers' suppliers to the raw materials suppliers and then down to the manufacturers through transportation network consisting of roads, rails, waterways, airways etc. After production, the products flow from the manufacturers to the distributors that distributes to the retailers through a network of transport. The retailers finally supply the customers in stores. However, the supply chain does not end there as an ICT platform communicates the flow of information, products, money and materials between the upper and lower limits of the supply chain. As the network within the nodes and links is complex, any part of the supply chain is vulnerable to risks that could disrupt the whole system. The risks are discussed in the next section.

2. RISKS IN THE SUPPLY CHAIN

'In today's uncertain and turbulent markets, supply chain vulnerability has become an issue of significance for many companies' (Christopher 2004, Peck 2004).

Risks including natural disasters, terrorism, cyber attacks, credit crunch shrinking product lifecycles, volatile and unpredictable markets and many more, could yield to a drastic loss in productivity, revenue, competitive advantage, profitability etc, if not managed appropriately. As the numbers of threats that can undermine a supply chain are now greater, organizations are facing greater challenges in managing risks (Sheffi 2005). According to the results of the 4th Annual Survey of the Business Continuity Institute in Supply Chain Resilience in 2011, where more than 550 organizations from over 60 countries were surveyed, 'Supply chain incidents led to a loss of productivity for almost half of businesses along with increased cost of working (38%) and loss of revenue (32%)' (The Business Continuity Institute 2011).

Another survey by the Independent Risk Consulting Company, Protiviti, about Understanding Supply Chain Risk Areas, Solutions, and Plans (Protiviti 2013), highlights that the risks in operational supply chain are many. Hence, organizations should therefore be always alert as these risks, could hinder their performances leading to a loss in profits and competitive advantages. These risks are given in bullet points below:

- A variety of supply interruption risks
- Demand and supply planning and integration risks
- Purchase price risks
- Inventory and obsolescence risks
- Regulatory and compliance risks
- Information privacy and security risks
- Customer satisfaction and service risks
- Contract compliance and legal risks
- Process inefficiency risks
- Employee and third-party fraud risks
- Product introduction and cycle time risks
- Human resource skills and qualifications risks
- Project management risks
- Corporate culture and change management risks
- Information integrity

Managing all the above risks is a concern especially in small and middle size organizations. However, the authors have considered a few according to their importance, namely:

- Demand and supply planning and integration risks
- Inventory risks
- Customer satisfaction and service risks
- Information integrity

Taking the retail sector into consideration, today most retailers spend lots of time and money in forecasting where they hope to get the 'right figures' so that their forecasted demand will meet with their actual demand. Unfortunately, in many cases the figures are not accurate. This could be because the retail supply chain in not linked and every node is forecasting for itself. This actually leads to 'retail out-of stock' affecting retailers and their partners. Doherty, Harrop and Martin point out that retail stores are the weakest in the retail supply chain as far as out-of-stocks are concerned. In addition, 'retail store out-of-stocks (usually in the 5 percent to 8 percent range) are indeed much worse than the percentage of out-of-stocks that occur elsewhere across retail supply chains. Even worse, those numbers balloon to almost 15% during promotions' (Doherty, Harrop and Martin 2012).

In the current competitive business world, customers' preferences are dynamic and changes most of the time. Consequently, it is quite challenging to sustain customers' satisfaction as they can easily switch. Developing a platform where constant feedback is obtained from current customers with organizations reacting accordingly whilst trying to gain new customers could be the answer.

Integrity risks occur due to miscommunication and lack of transparencies which can only be dealt with through accurate flow of information, materials, and product along the supply chain as this would ensure visibility, integrity and transparency. All of these are a stepping stone in developing a supply chain resilient strategy which is discussed in the next section.

3. DEVELOPING A SUPPLY CHAIN RESILIENT STRATEGY

3.1. Defining Resilience

Resilient Strategy in the supply chain is a new area that still needs thorough research.

Some research papers have defined supply chain resilience as, ‘the ability of a system to return to its original or desired state after being disturbed’ (Cranfield School of Management 2003) or ‘the ability to bounce back from large-scale disruptions’ (Sheffi 2008), where as the dictionary definition of ‘resilience’ states that it is the ability of a substance to return to its original shape after it has been bent, stretched or pressed (Oxford Advanced Learner’s Dictionary 2013).

3.2. Resilient Strategy

As the risks discussed in the former section could disrupt the supply chain if they occur, it is now essential for organizations to have a resilient strategy as part of their strategic plans in order to avoid the occurrence of these risks or if they do occur, organizations would be able to bounce back speedily after disruptions. By planning and implementing lean production, six sigma practices, flexibility and a strong corporate culture, the capabilities to speed up the process of bouncing back after deformation on any part along the supply chain is very possible. This is where the role of ICT in the supply chain is significant as a shared ICT infrastructure consisting of six sigma software, Enterprise Resource Planning (ERP) and Social Intranet Software is implemented. This would facilitate lean production, a strong corporate culture is developed that would engage management and employees on the activities of the organization through online communication and collaboration. This will result in improved services, reduced logistics costs and faster communication between customers and their suppliers. In addition, organizations will also make accurate and quick decisions after deformation of its supply chain that will eventually bounce it back to normal activities in the shortest possible time.

From another perspective, Modelling and Simulation could be used as an application technique to support supply chain design, management and optimization (Longo 2012) as any network of supply chain (Klimov et al. 2010) can be easily represented by a simulation model.

Furthermore, simulation can be used as decision support tool in order to improve the supply chain management, reduce risks and vulnerability (Longo 2012).

4. RETAIL SIMULATION AND RETAIL RISK SIMULATION

Usually the risk concept is discussed in the context of applications of simulation models in finance and insurance. The statement can be proved by the analysis of the publications from one of the most authoritative sources in the field of modelling and simulation – the Winter Simulation Conference (WSC). Only in 2011 the section “Risk Modelling, Assessment, and Applications” arrived in WSC proceedings. This fact reflects the tendency to use simulation in the analysis and mitigation of influence of risk factors on the behaviour of complex artificial systems, e.g. supply chains.

Starting from the 60s of the 20th century many articles were published in the area of supply chain simulation. One of the first researches was famous Jay Forrester Industrial Dynamics introducing a macro level supply chain simulation model and experiments with it. Forrester had described a three-echelon supply chain model and analyzed the impact of demand variations (Forrester 1961). Actually this simulation was the beginning of system dynamics.

In one of the first publications of WSC 1968 in the area of SC modelling, the author described the purpose of modelling, including how far can some of the dynamic instabilities and adaptive patterns can be explained within an abstract simulation model. (Pfaff 1968). The simulation model was used to study the influence of changing consumer demand on the behaviour of all links of the logistics chain. The particular interest is a conceptual model of the retail node of the supply chain, proposed by the author. The experiments were held using different scenarios with multiple demand patterns. The random demand, or demand with rare significant fluctuations that are peculiar for events associated with risks were not investigated.

The same volume of WSC 1968 proceedings contains another paper devoted to SC simulation but using the different concept (Dulchinos and Hill 1968). The simulation model implements a discrete-event approach and is implemented as a micro model with detailed operation description. The input of the lowest level SC node is a random demand for a specific item whilst the outputs are orders from the wholesaler and deliveries to the consumers.

Since these studies, the use of simulation analysis of supply chain functioning continues to develop in these traditional – system dynamics and discrete event approach – directions. Recently, the agent-based modelling in this area has become topical.

5. CONCEPTUAL MODEL OF RETAIL NODE IN RISKY ENVIRONMENT

Accepting the idea of a conceptual model as ‘a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model’ (Robinson 2004), one introduces the conceptual model of a retail node for the purposes of simulation both as a single, separate object of interest and as a node of a complex SC. The conceptual model forms the hypothetically complete description of the original system (Becker and Parker 2011). Conceptual modelling is the abstraction of a simulation model from the real world system that is being modelled (Robinson et al. 2012).

In this context, the objective of creating a SC simulation model is getting a tool for assessing the performance of the supply chain in the process of long, medium or short-term decision making. The inputs of the simulation model of a retail node of SC are deliveries from the wholesalers, consumer demand and outputs – orders to the wholesalers, deliveries to the consumers or sales, the main state variable – inventory. Additional state variables and performance measures may be considered, e.g. sales, costs and customer service level. The controllable experimental factors include the order and assortment parameters, customer parameters, inventory management strategy. Uncontrollable experimental factors are unpredictable environmental factors and risk events. As a retail node is a part of a multi echelon supply chain, the model should implement an information feedback between nodes of different levels. A characteristic feature of each model is the mechanism of time advance, which allows us to classify the computer model as a model system dynamics or discrete-event simulation model. The choice of an approach depends from the purpose of a concrete project.

Figure 2 provides an outline of the reasonable content of a conceptual model of a retail node according the approach suggested by Robinson (2004). The more detailed content is determined by the goal of the particular research. The simulation model is accepting the inputs (on the left) – experimental data and events and provides outputs (on the right) – performance measure estimates.

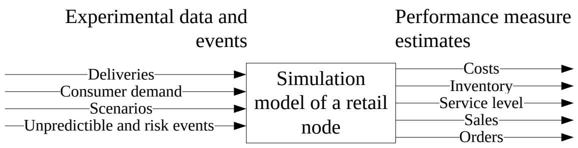

Figure 2: Conceptual Model Content of a Retail Node

The modelling objectives are stated by the problem and define inputs, outputs and the content of the model. The simulation model provides data for statement whether modelling objective is achieved or not. In case of failure, the reasons of failure are revealed. As risks in a supply chain should be measured, valued and managed by costs, the performance measures may be expressed in monetary units. For example, Klimov et al. (2010) introduces a case study where only two types of possible local costs are considered namely, inventory holding costs and backordering costs. Such choice gives possibility to analyze both inventory management efficiency and customer service level. The risky environment in this concept may be simulated using scenario approach and risk events simulation, using approaches together or separately.

Supply chain risks may be categorized as external or internal ones. The retail node is affected by process risks internal to the company, demand and supply risks external to the company and internal to the supply chain, and environmental risks external to the supply chain (Longo and Ören 2008). The goal of the model development is to provide computer experiments to study the adaptive behaviour of the SC nodes and to provide relevant information to decision makers.

After the identification of the risk factors, for simulation purposes we need to (a) describe their variability, (b) probability of occurrence, (c) the set of nodes and arcs that they affect and (d) the duration of the disruption that they cause (Deleris and Erhun 2005). This approach incorporates external events to evaluate uncertainty in supply networks.

The randomness of the demand itself may be interpreted as risk: “risk is any uncertainty that affects a system in an unknown fashion” (Klimov et al. 2010). The impact of this risk factor on the whole SC may be one of the causes of the Bullwhip effect (Longo and Ören 2008). Unnecessary costs associated with demand risks are observed when the demand exceeds the supply and the customers are disadvantaged or when the supply exceeds the demand, the company stockholders are disadvantaged (McGarvey and Hannon 2003).

An example list of risks associated with customers and customer demand is provided by Bendža (2014). The list is based on the study of a business process of a small Latvian retail enterprise. Only high end extreme level risks are included into the list:

- Return of an online purchase
- Latvia’s economic crisis of 2008/2009 effects
- difficulty to forecast the demand accurately
- current financial crisis in the United States
- customer failure to pay for the item/s
- decrease of interest in paper format editions
- competitors among other field related retailers

It is clear that some of the risk factors mentioned above are described as events (return or failure event), some as trends (decrease of interest) and some are in “free format”. Free format risk factor description should be formalized for the purposes of modelling and simulation using realistic assumptions and simplifications and included or not into the simulation model.

Finally, risk analysis of retail nodes of SC simulation is used to describe the dynamic behaviour of a given supply chain structure and to assess the benefits of supply chain policies, such as inventory policies, taking into account the initial state of the node, and order fulfilment rules and algorithms as well as inventory management strategies.

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MARITIME TRAFFIC CO-SIMULATION FOR ANALYSES OF MARITIME SYSTEMS

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ABSTRACT
Analyses of maritime systems are necessary to improve the efficiency and safety of the worldwide shipping lanes. Distributed simulations provide a flexible and extensible testbed for these analyses. This paper describes a HLA-based maritime co-simulation to provide and analyze data about vessel traffic motions. The co-simulation focuses on a flexible configuration, high extensibility and reusability. It comprises of an analysis component as well as simulators for the environment, human behavior and the physics of vessels. The common semantic model enables the communication of these components with its consistent set of concepts and data types. The MTS is based on a physical model for vessel motions with four degrees of freedom. Three agent types are implemented on the base of the generic agent model to show its extensibility and practical use. The evaluation of the generated vessel traffic motion data is done by comparison with real AIS data.

Keywords: Flexible Analysis, Distributed Simulation, Maritime Traffic Co-Simulation, Extensibility, Semantic Model, DOF, HLA, RTI, MASON

1. INTRODUCTION

According to a 10 years survey there are significant challenges regarding a safe and efficient maritime traffic on the worldwide shipping lanes (Gale 2007). According to Gales survey 60 % of collisions and groundings are primary caused by human errors. The analysis of maritime systems like vessels can help to optimize their reliability and eNavigation equipment so that e.g. a single person's navigation error can be easier handled by such systems (IMO 2012). Consequently, the analysis of maritime systems can serve the improvement of the efficiency and safety of shipping lanes.

Distributed simulations are an appropriate way to run scenarios for the analysis of maritime systems (Läsche et al. 2013). Therefore this paper describes the architecture, components and semantic model for a flexible maritime traffic co-simulation. Moreover it describes the efficiency and safety on the same level above the micro models which include the full vessel dynamics and exact maneuvers. It supports a large selection of usage scenarios for the analysis of maritime systems like:

1) Testing of new algorithms for the planning and optimization (e.g. regarding the performance of maritime traffic routes)
2) The efficiency evaluation of shipping lanes with input parameters like the number of vessels and their goal ports
3) Testing of platooning to check its effect for the efficiency of shipping lanes
4) Evaluation of traffic management systems like VTS to evaluate and improve their reliability and usability
5) The evaluation of risks like grounding and collisions with different input parameters like the number of vessels and environment conditions
6) Testing of maritime traffic collision avoidance systems to check the precision of their algorithms

2. CO-SIMULATION INFRASTRUCTURES

Frydman et al. (2002) and Zini et al. (2004) presented a HLA-based approach for distributed environments. But Zini et al. (2004) focused mainly on the analyses in the military, maritime domains. Focusing on the same domain, the HLA-based approach of Bruzzone et al. (2008) takes human behavior into account. Longo et al. (2012) introduced an approach for traffic controllers and ships pilot training in marine ports environments. Massei et al. (2013) developed a HLA-based real time distributed simulation of a marine port for training purposes which considers also safety and efficiency aspects. IWRAP is a modelling tool for the evaluation of risks like groundings and collisions (IWRAP 2014). Beschnidt (2010) presented a simulation environment for traffic flows on inland shipping lanes which supports usage scenarios like the evaluation of navigation systems.

Our approach considers exclusively civilian usage scenarios like the risk and efficiency analysis of whole shipping lanes.

3. CO-SIMULATION ARCHITECTURE

The developed testbed is realized as a co-simulation allowing the components like simulation systems for vessel traffic, environment, human behavior and analytical proposes to work together in an appropriate way.
The simulation components exchange data in an inter-process communication. This is done by the open source runtime infrastructure (RTI) certiRTI. It implements the standard High Level Architecture (HLA) (s. Figure 1). Therefore it is able to enable the communication among all components and synchronizes them to ensure a common awareness of their shared environment (Noulard et al. 2009). The implementation requires a description of the communicated data in form of an Object Model Template (IEEE 2010).

3.1. Architecture Overview

The co-simulation-based testbed for the analysis of maritime systems comprises of the *Scenario Importer*, *Maritime Traffic Simulation (*MTS*), Environment Simulation* and the *Analysis Component* as well as the *Semantic Model* for the co-simulation. Furthermore *Controllers* role with commands like start, stop and *Observers* role are described.
The *Scenario Importer* is able to read Scenario Description files to set up co-simulation scenarios. The MTS provides vessel traffic data. The *Environment Simulation* provides the environment state for the MTS by HLA / RTI. The *Analysis Component* is able to generate key performance indicators (KPIs) that are intended to measure the efficiency and safety of shipping lanes.

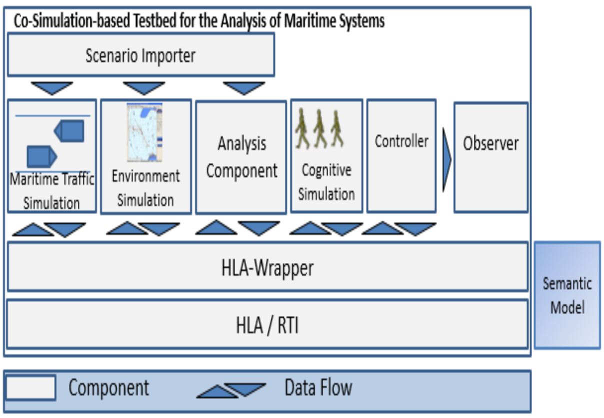

Figure 1: Co-Simulation-based Testbed for the Analysis of Maritime Systems

The *HLA-Wrapper* is used to simplify the usage of HLA as described in Puch et al. (2012) and Läsche et al. (2013).
The *Cognitive Simulation* provides simulation of human actors like nautical personnel. This component allows considering possible human errors in the co-simulation. Described detailed description can be found in Wortelen et al. (2006). In the following, the other components are explained in depth.

3.2. Scenario Importer

The *Scenario Importer* reads XML-based scenario configuration files. A scenario configuration file includes values to configure e.g. the MTS for the determination of properties like length, draught, MMSI, GPS start position etc. Moreover the *Scenario Importer* is able to import scenario configuration data for the *Analysis Component* which is explained in section 3.5.

3.3. MTS with its Physical Model

The MTS is based on the physical model from Fossen (2011) reduced to three degrees of freedom (DOF).
DOF are individual variables which define the position and orientations of a vessel (s. Figure 2 and Table 1).

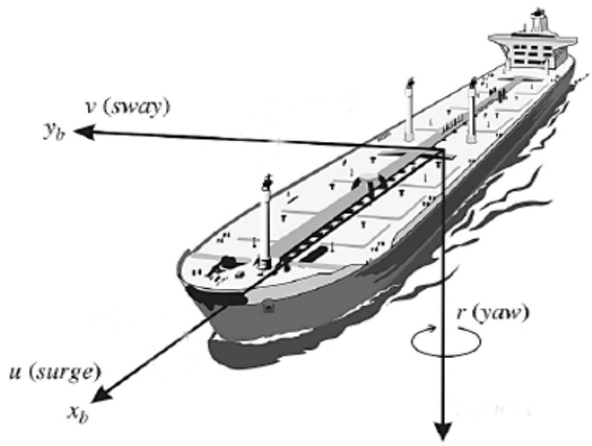

Figure 2: Movement in three DOF (Fossen 2011)

Table 1: Notations for marine vessels (SNAME 1950)

DOF		Forces and moments	Linear and angular velocities	Positions and Euler angles
1	Motions in the x direction (surge)	X	u	x
2	Motions in the y direction (sway)	Y	v	y
3	Rotation about the z axis (yaw)	N	r	ψ

The "horizontal plane model" with three DOF (surge, sway and yaw) is defined as follows:

- **Surge**: Describes the sum of all forces that have an impact on the forward and backward movement of the vessel. This comprises of all environmental parameter of the physical simulation as well as the propulsion of the vessels.
- **Sway:** Describes the sum of all forces that move the vessel to the right or left. All environment factors must be considered for the sway.

- **Yaw:** Describes the sum of all forces that have an impact on the rotation of the vessel. The environment parameters are considered together with the rudder.

The forces acting on a ship (level and torque) can be defined by the model from Abkowitz (1964); Fossen (2011); Gronarz (1997). Furthermore the physical simulation considers the moment of inertia for each of the three DOF.

In the realized physical simulation, the current draught of a vessel depends only on its loading condition. This means that movements influenced by environment factors like waves of a vessel are not considered.

3.3.1. Architecture of the MTS

The implementation of the MTS is based on MASON. It is a framework for multi-agent simulations which is based on the Java platform (Luke 2013). MASON implements an event-oriented simulation (discrete event simulation). This means that the simulation activities are implemented through a sequence of incoming events.

The *Visualization Component* is able to display simulated vessel traffic motions from the connected *Physics Engine*. The *Visualisation Component* and *Physics Engine* are split into two-layers and are part of the MTS (s. Figure 3, 4). Their split allows to exchange the *Physics Engine* as well as the *Visualization Component* in a simplified way (Luke 2013).

GeoMason allows the loading of geospatial data from various formats and provides corresponding data spaces for MASON (Sullivan et al. 2010). GeoMason is used to provide map data like the depth and buoys of waterways.

3.3.2. Agent Logic and Types

The *MTS* is an agent based simulation. The agent logic describes the behavior of each agent. The MTS allows a simple extension and changing of the agent logic. Furthermore the generic approach enables to specify all agent types based on one agent model. Any changes of this generic model are then automatically inherited by all derived agents.

By now, three agent types are realized with the generic agent model of the MTS: the non-interactive agent, interactive agent and automated agent. Each agent type has a different logic and is able to control vessels.

The scenario configuration file defines which agent type relates to which vessel.

The *non-interactive agent* can receive a list of steering commands (s. Figure 3). This agent moves according to the received steering commands and the physical characteristics of the vessel(s). The steering commands come from the MTS and external components over the HLA / RTI. Moreover the non-interactive agent sends information about its state (e.g. position data, velocity data etc.) in a parameterized interval over the HLA / RTI to external components like a collision avoidance system. At the beginning of the simulation, the *interactive agent* receives a start point over the HLA / RTI.

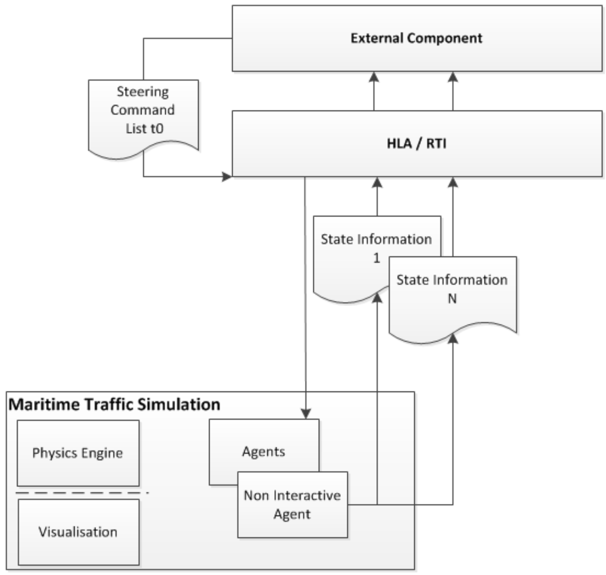

Figure 3: Steering Command List for the Non-Interactive Agent

During the simulation, the *interactive agent* receives new steering commands step by step from an *external component* like a keyboard, joystick, ship console or other components which are connected by the HLA / RTI (s. Figure 4). This enables the *interactive agent* to change the trajectories of the related vessel during the simulation depending on its physical characteristics. These characteristics depend e.g. on the defined velocity for the movement of the rudder.

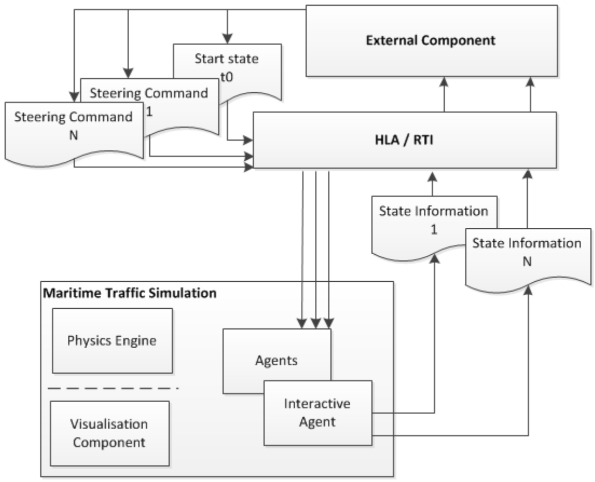

Figure 4: Steering Commands for the Interactive Agent

The *interactive agent* is also able to send information about its state in a parameterized interval over the HLA / RTI on *external components*.

A practical scenario for this agent type is e.g. the test of collision avoidance systems: Users with a keyboard or ship console are able to change the course of vessels so that a collision with other vessel(s) is possible.

A correct collision avoidance system of the other vessel(s) will try to change their course in a direction were the probability for a collision is as low as possible (Hornauer & Hahn 2013).
The *automated agent* receives a traffic route by HLA with at least two GPS points (start and goal). It is able to automatically calculate steering commands under the consideration of the physically possibilities. This enables the generation of realistic traffic situations. The *automated agent* can be realized with different artificial intelligence, regarding the wayfinding and driving behavior. The currently realized *automated agent* uses the A* algorithm (Nosrati 2012) and the Taxicab geometry (Janssen 2007) to reach its destination.
This geometry is used to evaluate the costs under the consideration of the way. The route between the start and destination point is rasterized in squares. The standard grid-size is 2500 m². Thereby each square requires the following conditions:

1. the water depth [m] of each square has to be deeper than the required depth [m] of the vessel.
2. the square is in areas were vessels are allowed to drive.

Each square includes a value which increases proportionally to the distance of the start point. The way is described as a spatial sequence of squares. The optimal way is the one where the target square contains the lowest value. The surrounding squares are sampled in the case of barriers. The square which is nearer to the target square is selected as the optimal square in an incremental sequence. A vessel route over all squares is set after the identification of all optimal squares. The vessel route calculation has the sense to smooth the found way of individual squares so that the vessel is able to move adequate. This includes in particular the avoidance of many closely spaced course changes. Furthermore the planning of routes considers the vessel dynamics to ensure that the calculated routes can be followed by the individual vessel.

3.4. Environment Simulation

The *Environment Simulation* provides the environment state for the MTS by HLA / RTI. Beschnidt (2010) considered for his environment simulation the factors wind and stream. Our *Environment Simulator* provides the current, wind, sea level and wave data to have more realistic conditions. The maps used in this component are based on the S-57 standard. This is a transfer standard for hydrographical data which includes e.g. the GPS positions of buoys and draught information. The environment can be set up by two scenarios: the static scenario or the dynamic scenario.

The static scenario defines a fixed environment state for the whole map or a selected area. This scenario can be configured in the GUI in Figure 5. The configuration comprises of the following factors:

- the current speed (= *Current speed [m/s]*)
- the current direction (= *Current direction [degrees]*)
- the wind speed (*Wind speed [m/s]*)
- the wind direction (*Wind direction [degrees]*)
- the sea level (*Sea level [m]*)

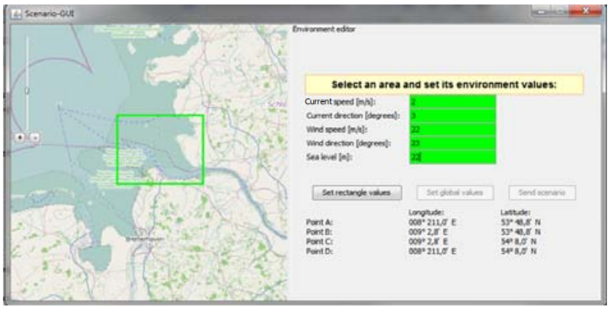

Figure 5: GUI for the Static Environment Scenario

The definition of a fixed environment state is sensible to examine waters regarding the possible risks during user defined environmental conditions. This can be e.g. a storm and a strong current.

The dynamic scenario provides a dynamically interpolated environmental state. The calculation is based on a linear interpolation function which takes the factors defined in the configuration file or GUI as a first start point. Furthermore it gets historical data to make an approximation to the real environment conditions. The historical data of the stream is read from GRIdded Binary (GRIB) files.

3.5. Analysis Component

The analysis component allows to set up scenarios on shipping lanes to analyze the effect of different input parameters like strong wind. They are passed to the simulation component which executes the scenario, while it returns all relevant data back to the analysis component. The analysis component analyzes the data and creates an assessment of e.g. the efficiency of vessel traffic in the form of key performance indicators (KPIs).
The co-simulation can answer the following two exemplary questions:

- Can the traffic efficiency be improved by platooning maneuvers?
- Can a dredged shipping lane with a deeper water level be used for a denser traffic and thus contribute to increasing transport efficiency in estuaries?

Input Parameters

The user has the possibility to define input parameters describing the initial situation of the scenario. The input parameters are passed to the simulation component at the start of the scenario. The parameters to be considered are listed below:

- The number of vessels

- The start point of each vessel [GPS]
- The orientation of each vessel [°]
- The type of vessel (length, width, depth, [m], etc.)
- The agent type of each vessel
- The waterway section which is relevant for the efficiency or safety review
- The characteristics of the waterway
- The environmental situation (e.g. strong wind, high current, low sea level)

Output Parameters
During the execution of the simulation scenario, the simulation component sends all relevant data to the analysis component. These are:

- MMSI of each vessel
- Position [GPS]
- Orientation [°]
- Speed over ground (SOG) [m/s]

The analysis component creates KPIs based on this information. Exemplary KPI are:

- The number of vessels that can pass through the stretch per unit of time
- The transport tonnage of these vessels
- The type and number of violations of navigation rules as provided by the simulation

The definition of KPIs is done through queries. Moreover the necessary evaluation of KPIs depends on the particular analytical question(s). It follows, that it is the responsibility of the user to carry out the assessment and apply an appropriate evaluation function. For this purpose external programs such as Excel can be used.

The KPIs are provided after a simulation run. KPI data can be exported to text files or to a relational database.

Comparison with real AIS data
Another objective of the analysis component is to provide a basis for the validation of the simulated vessel traffic motions e.g. by comparison to AIS data. Nevertheless it has to be considered that the AIS signals do not contain information about the environmental influences like current during a period. Therefore recorded environment data has to be taken from exactly the same period. In this case, the *Environment Simulation* would be able to provide realistic environment conditions. Furthermore the situation around the vessel during that period has to be considered.

A first evaluation concept considers a part of the route from Hamburg to Bremen. The input parameters describe a typical cargo vessel with a length of 270 meters and a gross tonnage of 61870 m^3. The simulated vessel is visualized in yellow triangle in the bottom right corner of the map in Figure 6.

Currently, the authors implement a surveillance platform at the Elbe to get sufficient data to calibrate the system.

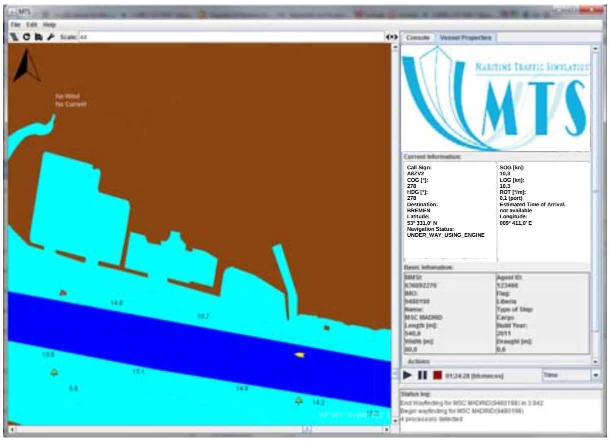

Figure 6: Visualization of the Simulated Vessel

3.6. Observer
The *Observer* is a passive component which does not influence the simulation during its processing but can observe each aspect of the simulation. Therefore it is able to recognize predefined events like hazards and failures. A hazard is defined as: “A potential source of harm. Harm is a physical injury or damage to the health of people“ (Esposito 2010). A failure can be defined as: “The termination of the ability of an element or an item to perform a function as required.” (Esposito 2010). In the case of maritime systems, an example of a failure is the grounding of a vessel in a curve caused by the vessels engine damage (a hazard).

3.7. Controller
The simulation can be started and stopped by commands from the *Controller* before and during runtime over the HLA / RTI. Furthermore the controller can execute a save and resume command (Läsche et al. 2013). Then the maritime co-simulation states can be persisted and resumed at a specific point in time (e.g. near a collision of vessels or during a high density on shipping lanes).

Moreover environmental conditions can be influenced from the *Controller* over the HLA / RTI (Läsche et al. 2013). This means in the case of the *Environment Simulation* the possibility to change the factors wind, current and sea level during runtime. This enables the dynamic evaluation of shipping lanes regarding their safety and efficiency under different weather conditions and traffic density.

3.8. Semantic Model
The common *Semantic Model* is necessary to provide the concepts and data types for a formally described semantic and to enable the communication between the components of the presented testbed. This enables

among others the common awareness of these components. The semantic model is structured in five layers (s. Table 2).

Table 2: Five Semantic Model Layers

Content	Name
Ecore, OWL, …	0: Languages
Unit, Graph, Math, 3DGeometry, …	1: Universal
Physics, Geography, …	2: Engineering
TrafficSystem, Vehicles, Sense, HMI, Environment, …	3: Application
Maritime, …	4: Domain

The basic layer covers all languages which are necessary to describe the *Semantic Model*. The concepts and data types are described using the metamodel Ecore which is based on the Meta Object Facility standard for metamodeling (Steinberg et al. 2008). This allows the usage of the EMF tool chain for further development based on the *Semantic Model*. Moreover the data types, which are defined in Ecore can be transformed into the Object Model Template (OMT). OMT files are necessary to configure the certiRTI regarding the data types which are the base for the communication between the co-simulation components. The transformation into OMT is done by an automatic model transformation as explained in Dibbern et al. (2014). The Web Ontology Language (OWL) will be used to describe the concepts of the model to improve knowledge management (W3C 2014b).

The layers one to four comprise of model packages. Each model package encapsulates topic specific concepts and data types and follows the design rationale high coherence. In addition, loose coupling is realized to other model packages. This simplifies the exchangeability and maintainability of model packages if e.g. a new standard has to be considered.

The *Universal* layer comprises of concepts and data types which have a general meaning for all layers below with model packages like Unit (common definition of Time, Engineering Unit), Graph, Math and 3DGeometry. The *3DGeometry* model package contains concepts and data types from the ISO19125 and the S100 Simple Geometry (ISO 2004; IHO 2010). It is used to describe geometrical data. Therefore it comprises of data types like 'GeoPoint', 'Curve', 'Surface' and 'Polygon' that could be both two- or three-dimensional.

The *Engineering* layer includes model packages for physics and geography. The model package *Physics* contains concepts and data types from the Bullet Physics library like RigidBody and EnvironmentFactor (Real-Time Physics Simulation 2014). The package *Geography* comprises of concepts and data types from the S100 Feature Catalog to describe e.g. buoys on a shipping lane like the Weser. Examples for buoys are shown in Figure 6 on the left and right side of the fairway.

The *Application* layer includes all concepts and data types to integrate different applications like Sensor Simulation and Cognitive Simulation. It comprises of the model packages TrafficSystem, Vehicles, Sense, Human Machine Interaction and Environment. The *TrafficSystem* model package includes data types like 'WayPoint' and 'Trajcetory'. The *Vehicles* model package is necessary to define concepts and data types like MMSI and the dynamics of a vessel.

The model package *Sense* is necessary to integrate sensor simulators. In case of maritime systems, it is e.g. required that this package includes concepts and data types like GPS so that the MTS is able to communicate the vessel positions to a radar simulation. Because of that the *Sense* model package contains concepts and data types from the *SensorML* (Open Geospatial Consortium Inc. 2007) and *Semantic Sensor Network Ontology* (W3C 2014a). The Sensor Modelling Language is a XML based standard which is used to describe sensors as well as their measurement process. It also includes models to describe observations of these devices. The *Human Machine Interaction* model package includes concepts and data types like Display and InformationObject to be able to integrate *Cognitive Simulations* as shown in Figure 1. The current concepts and data types of the model package *Environment* are shown in Figure 7. It is necessary to integrate *Environment Simulations* like explained in section 3.4.

Figure 7: Model Package for the Environment Simulation

The *Domain* layer comprises of model packages of different domains like maritime, aviation and automotive. The model package *Maritime* is realized to provide additional concepts and data types like specific vessel types such as HighSeaVessel and InlandVessel.

4. CONCLUSION

This paper describes a HLA-based co-simulation for the analysis of maritime traffic systems. The co-simulation integrates the following simulators and components: The mathematical model is the base for the MTS and considers four degrees of freedom to provide a realistic physical behavior for analysis purpose. Its agent model supports the flexible configuration, extensibility and reusability of the co-simulation by its generic construction. The environment simulator provides a static and dynamic behavior so that wind, waves, current and sea level can be generated based on the historical data with an interpolation function. The analysis component is connectable by HLA / RTI and is able to get the required data for efficiency and safety analyses from the environment, maritime traffic and cognitive simulation. It supports the definition of individual queries to allow flexible analysis of maritime systems. The MTS and Environment Simulation can be influenced by the Controller so that the co-simulation states can be saved and set up again. Furthermore errors can be inducted and environment parameters like the wind can be changed to analyze the effect of rare events. The MTS is able to communicate broken traffic rules by HLA / RTI so that observers can recognize such rare events. The common semantic model enables the communication between the co-simulation components with its set of consistent data types. The evaluation of the MTS will be realized with a comparison of recorded AIS data from the Elbe. The challenges to use AIS for evaluation purposes of the MTS were explained.

Furthermore it is planned to extend the simulation logic regarding traffic rules with more rules of "The International Regulations for Preventing Collisions at Sea" (Lloyd's Register 2005). By now, the agents are able to follow the rule to move on the right side of the fairway, to hold an adequate distance to other vessels and to make overtaking maneuvers.

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SIMULATION AND OPTIMIZATION OF A CAPILLAR THIRD GENERATION CAR SHARING SYSTEM

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ABSTRACT

The paper concerns a capillar third generation car sharing system for urban pedestrian environments. The following specific services are provided: instant access, open ended reservation and one way trips; vehicles can be accessed not only at stations, but also along the roads. All these features provide users with high flexibility, but create a problem of uneven distribution of vehicles. Therefore, relocations of vehicles must be performed. Different relocation procedures exist in literature. In this paper, a management scheme is proposed where vehicles automatically relocate and reach the users positions, thanks to their degree of automation. In order to provide transport managers with a useful tool to test the proposed system in different realities, an object-oriented simulator has been developed. An optimization algorithm has also been developed for assessing the fleet dimension and the transport system parameters. The proposed car sharing system has been simulated for Genoa historical city centre, Italy.

Keywords: third generation car sharing, capillarity, object oriented micro simulation, optimization

1. INTRODUCTION

The paper concerns a new generation car sharing system for urban pedestrian environments, which involves a fleet of automated personal vehicles, called PICAV. PICAV vehicles are specifically designed for areas where usual public transport services cannot operate because of the width and slope of the infrastructures, uneven pavements and interactions with high pedestrian flows. Some details on characteristics and performances of PICAV vehicles are reported in Cepolina and Cepolina (2014a).

New generation car sharing systems overcome some restrictions of traditional car sharing (first generation) where members need to book cars beforehand and the time the car will be dropped off should be specified (fixed-period reservation); besides, cars must be returned to the same station where they were picked up (two-way trips).

New generation car sharing systems are aimed at providing users a higher degree of flexibility, and in particular the following specific services:

- instant access: users can access directly to an available vehicle, without the need to make a reservation;
- open-ended reservation: users can keep the PICAV vehicle as long as needed;
- one way trips: users can drop the vehicle off at any station.

The main problem of these systems is that they may quickly become imbalanced with respect to the number of vehicles at the stations. Due to uneven demand, some stations during the day may end up with an excess of vehicles whereas other stations may end up with none.

New generation car sharing systems often resolve the balancement problem through operator based relocation. But operator based relocation has shown to be extremely expensive in terms of staff and management costs, therefore some systems have turned out into a failure, while others only remained pilot projects and have never been settled on a wide scale. A full description of the main characteristics, advantages and problems of new generation car sharing systems has been provided in Cepolina and Farina (2012b) and Cepolina et al. (2014b).

The *third generation of car sharing systems* aims to add capillarity to the new generation car sharing systems. The capillarity of the system, i.e. the possibility of having shared vehicles available at several points of the area, ideally at any point, improves the quality of the service provided to users. In this scenario vehicles can be accessed and returned not only at stations but also along the roads.

Several third generation car sharing systems, such as Car2go, DriveNow and Greenwheels, have been planned, and some of them have also been applied on the field. Users have an interactive map where they can reserve, with short advance, the vehicle closest to their position. This however can create some impedance to users because they may have to travel also for long to reach the closest available vehicle. In these systems, a large number of vehicles and a balanced demand are required, in order to keep limited the user waiting times.

2. THE PROPOSED RELOCATION STRATEGY

A trip by PICAV vehicle may have, as origin or destination, either a station or any position along the roads within the intervention area. When in the origin of the user's trip there are no available PICAV vehicles, a PICAV reaches the user position in a fully automatic way.

In the proposed transport system, relocations are required:

1. In the stations, when the number of vehicles available at stations is below the low critical threshold. This criterion is adopted to prevent user waiting times. In this case, the request for a vehicle could be addressed:
   (a) firstly to the stations where the number of vehicles is above the low buffer threshold. Among the stations to which the vehicle request could be addressed, the providing station is selected according to two criteria: the closest station (shortest time criterion) and the station having the highest number of vehicles (inventory balancing). The shortest time criterion relates mainly to service levels, while the inventory balancing mainly focuses on cost efficiency. Therefore, an appropriate choice of relocation technique should be made according to the current system situation: in periods of low usage, the most appropriate relocation technique is by inventory balancing while in periods of high usage, then the shortest time technique performs best.
   (b) secondly, to the available vehicles parked along the road. In this last case, the nearest vehicle automatically relocates towards the station in shortage.
2. Not in the stations, when a user calls for a vehicle. In this case, the criterion is to limit the user waiting times along the roads as much as possible. The system manager assigns to the user the available vehicle nearest to the user's position. If the nearest vehicle is in a station, it can be provided only if the number of vehicles available in the station is greater than the low critical threshold of the station.

At the end of their trip, the user can leave the vehicle at any position along the roads within the intervention area. When a vehicle is returned, if the level of battery charge is below the minimum charge level, the vehicle automatically reaches the nearest station to recharge the battery. As soon as it reaches the minimum charge level, it becomes available and if not required, continues the charging process.

An object oriented micro simulator of the proposed transport system has been developed. The simulator is described in detail in section 3.

An optimization algorithm has been developed to optimize the proposed transport system's performances. The optimization algorithm is described in section 4.

3. THE MICRO SIMULATION OF THE PROPOSED TRANSPORT SYSTEM

The micro simulator receives in input: a simulation time period, a road network, a PICAV fleet, the PICAV transport demand and the parameters related to the relocation strategies (the low critical and the low buffer thresholds). The simulator allows to track the second-by-second activity of each user, as well as the second-by-second activity of each PICAV vehicle.

The micro simulator provides in output the user waiting times t_{wi} (i is the i^{th} user) and the relocation times t_{rj} (j is the j^{th} relocation).

The proposed transport system has been modelled according to an object-oriented logic. The language chosen for writing the code is Python 2.5.

3.1. Input data

The micro simulator input data are: the simulation time period, the road network, the transport demand, the PICAV fleet characteristics, the relocation strategy parameters. All these inputs are deterministic. The only stochastic input is the transport demand, as it concerns the user arrival time instant.

3.1.1. The simulation time period

The simulation time period starts when the car sharing system opens to users and ends when the last user returns the PICAV. In the following we refer to a daily simulation time period. The simulation time period could be characterised by peak and off peak phases: for each phase, an average pedestrian density k in the pedestrian area, from which the PICAV vehicles speed depends, and a PICAV transport demand, should be specified.

3.1.2. The road network

The road network includes stations, provided with charging stations, and the roads in which PICAV vehicles are allowed to travel. The road network has been defined using OpenStreetMap.

Stations have been represented through nodes. Each road is divided into sections and each section has been modeled again by a node.

Between each pair of nodes, we take into account only one path, which could be the shortest one or the one which contains a high concentration of shops, museums and other attractions. The overall length and the average upslope for each of the paths were charaterised using GoogleMaps (Cepolina et al. 2011a). These data are necessary to determine the battery discharging law: in particular the quantity of discharge is assessed from the average upslope, as it contributes heavily to the resistances to motion encountered by the PICAV vehicle. If the path is instead descending the recovery in battery charge is so slight that it is neglected, therefore for each path the downslope parts are considered as flat in the calculation of the average upslope. The overall length of a path is required in order to determine the trip duration.

The path lengths and the average upslope are assessed through a routing algorithm written in javascript, which interacts with OpenStreetMap. These data are given as input in the simulator in the form of two matrixes. The matrixes are squared and the number of rows (or columns) equals the number of nodes in the network. In the first matrix, the cell *ij* represents the path length between the origin node *i* and the destination node *j*. In the second matrix, the cell *ij* represents the average upslope of the path between the origin node *i* and the destination node *j*.

The minimum charge level is calculated as a function of the average upslope and of the length of the most battery consuming path in the road network.

The vehicle speed is assessed from the pedestrian density according to the following model:

PICAV user driven: $v = -1.45\,k + 1.58$ (1)

PICAV automatically driven, relocation trip:

$$v = -1.45\,k + 1.38 \quad (2)$$

where *k* is the *pedestrian density* expressed in pedestrians per square meters; *v* is the PICAV vehicle speed expressed in m/s. The model for assessing the vehicle speed from the pedestrian density is described in detail in Cepolina et al. (2011b). The model has been implemented in the micro simulator.

3.1.3. The transport demand

The transport demand refers to a given phase of the simulation time period and it is given to the simulator in the form of an OD matrix. Each row refers to a node of origin, and each column to a node of destination. Each cell gives the hourly number of trips from the node the row refers to, to the node the column refers to.

We consider two trip typologies: a direct trip, or a sequence of shorter trips (multitask trip) where one accomplishes a number of short tasks that require short term parking along the street, before finally returning the vehicle. In both cases what is of interest for the proposed study is the overall duration of the trip. Given an origin, a destination, the path between them, and an average pedestrian density, the trip duration changes according to the trip typology.

Therefore each OD matrix refers to a given phase of the simulation time period and to a trip typology. In the simulation PICAV users are generated with the following characteristics: the origin of their trip by PICAV, the destination, the time at which they appear in the origin and the trip typology. These data are assessed according to the OD matrixes. The time at which a user appears in their origin is randomly generated: if X users have to be generated between 8 and 9 a.m. in a given origin, X casual numbers are extracted within the given time interval and these casual numbers are the exact arrival instants of the X users in the origin.

3.1.4. The PICAV fleet characteristics

The PICAV fleet characteristics are: the fleet dimension, the number of PICAV vehicles at each station at the beginning of the simulation time period, the battery capacity, the battery charging and discharging laws.

A lithium-ion battery has been selected by MAZEL, the partner of the project consortium dealing with the electric engine and battery development. The battery is composed of 15 blocks connected in parallel, each composed of 27 cells connected in serial, and provides 202Ah and 48V DC.

The battery charging technique is the *opportunity charging*. The term opportunity charging refers to the charging of the batteries wherever and whenever power is available. The *minimum charge level* is the quantity of charge necessary to the vehicle to perform the longest trip or relocation journey. Every time a PICAV is returned in a station, a check on its charging level is performed. If the vehicle has a level of charge which is more than minimum charge level, it is available to users and to relocations, otherwise it starts the charging process.

3.1.5. The relocation strategy parameters

The relocation strategy parameters are described by two vectors. Their dimension equals the number of stations in the area, the value of each vector component is the station’s *low critical threshold* for the first vector and the station’s *low buffer threshold* for the second vector.

A high value of low critical threshold gives rise to a high number of required relocations and to low waiting times, if the fleet is consistent and therefore there are vehicles available for relocation.

The low buffer threshold is greater than the low critical threshold. If the low buffer threshold is much greater than the low critical threshold, the number of satisfied requests for relocations is low because often no stations can provide the vehicles required: this results in an increase of the users waiting times.

If the low buffer threshold is slightly greater than the low critical threshold, the number of satisfied requests for relocations is high; on the other hand, it may occur that at a given time instant a station provides a vehicle and at a following time instant the same station is in shortage of vehicles. This results in an increase in the number of required relocations.

As a result, it is necessary to optimize the low critical and low buffer thresholds values for each scenario under study.

3.2. Output data

3.2.1. Level of Service (LOS)

LOS measurement are assessed based on the statistical distribution of users waiting times. Castangia and Guala (2011) proposed a new LOS measurement scale (shown in table 1) using as reference the 50th, 90th and 95th percentiles of waiting time. The LOS measurement scale ranges from LOS from A (perfect service) to F (completely poor service). All the constraints on the three percentiles of users waiting times should be met to achieve a given LOS. LOS measurements could be assessed for each station or for the overall area, referring specifically to the waiting time of users.

Table 1: The LOS assessed according to the percentiles of users waiting time expressed in seconds

LOS	Waiting time (minutes) not greater than:		
	50th percentile	90th percentile	95th percentile
A	0.5	1	1.5
B	1	2	3
C	1.5	3	5
D	2.5	5	8
E	4	8	10
F	worse	worse	worse

3.2.2. Efficiency

An explicit expression to assess the transport system efficiency does not exist. However, according to Barth and Todd (1999) and Kek et al. (2006), we assess the efficiency according to the following variables:

- fleet dimension;
- number of required relocation trips;
- percentage of vehicles available, with reference to the total fleet dimension, at each simulated time instant.

The values of the first two variables are assessed offline at the end of the simulation; the value of the last variable is assessed online, i.e. during the simulation run.

3.3. Stochastic effects

As the input data are stochastic regarding the users arrival times, the output data, in terms of users waiting times and relocation time, are stochastic as well. According with the criteria given in Law and Kelton (1991), 30 runs of the microscopic simulator resulted sufficient to reduce these stochastic effects.

4. THE OPTIMIZATION OF THE PROPOSED TRANSPORT SYSTEM

An optimization algorithm has been developed to optimize the proposed transport system's performances. More in detail, it optimizes:

- the low critical thresholds,
- the low buffer thresholds,
- the fleet dimension and its distribution among stations at the beginning of the simulation time.

4.1. The cost function

The cost function f to minimize is composed of:

- the user cost, given by the total users waiting time in a simulation day
- the operator cost, given by the daily amortization cost of the fleet and by the daily cost of relocation.

The cost function has the following expression:

$$f(\mathbf{s}) = n_v c_v \left[\frac{r(1+r)^{lt}}{(1+r)^{lt}-1} \right] \frac{1}{365} + c_w \sum_{i=1}^{m} t_{wi}(\mathbf{s}) + c_r \sum_{j=1}^{n} t_{rj}(\mathbf{s}) \quad (3)$$

Where:

- **s** is an array which has three components:
  - the overall fleet dimension;
  - the low critical threshold, taken the same in all stations;
  - the low buffer threshold, taken the same in all stations;
- m is the number of users; n is the number of relocations that have taken place in the simulated day;
- n_v is the fleet dimension and c_v is the purchase cost of each vehicle;
- r is the discount rate and lt is the vehicle lifetime;
- c_w is the cost of each minute of users waiting time and t_{wi} is the user i's waiting time;
- c_r is the cost of each minute of relocation and t_{rj} is the relocation time;
- j is the j^{th} relocation; i is the i^{th} user.

We have decided to consider only the total fleet dimension, and not its distribution among stations at the beginning of the simulation time, because this last aspect is not relevant as it is compensated by the relocation. Therefore, at the beginning of the simulator, the same number of vehicles is assigned to all stations.

We have taken an unique value for all stations regarding low critical and low buffer thresholds as the cost function is not very sensitive if different values are taken. This highly simplifies the procedure as a low number of variables is necessary.

The three components of the vector **s** are determined through a micro simulator.

The problem constraints are the following:

$$g(\mathbf{s}) = \begin{cases} t_w^{50\%} - 4 < 0 \\ t_w^{90\%} - 8 < 0 \\ t_w^{95\%} - 10 < 0 \end{cases} \quad (4)$$

Where $t_w^{50\%}$, $t_w^{90\%}$, $t_w^{95\%}$ are the 50th, 90th and 95th percentiles of users waiting times.

These constraints are imposed in order to avoid the system to incur into LOS F. However, the results have shown that the constraints are automatically satisfied by minimizing the cost function.

We transform the constrained minimization problem into a single unconstrained problem using penalty functions. The constraints are placed into a new objective function $h(\mathbf{s})$ via a penalty parameter $\hat{\mu} > 0$ in a way which penalises any violation of the constraints:

$$h(\mathbf{s}) = f(\mathbf{s}) + \hat{\mu} \cdot \Sigma_i \left[\max\{0, g_i(\mathbf{s})\} \right]^2 \quad (5)$$

where: g_i is the i^{th} constraint.

Since there is no analytical expression for h (**s**), we cannot exclude the need to deal with a multi-peak function and the risk of reaching a local minimum, without being able to find the global minimum, is high (Cepolina and Farina 2012a). To combat this issue and the fact that the search space is extremely large, Simulated Annealing (SA) has been chosen to solve the minimization problem.
At each iteration of the SA algorithm the cost function $h(\mathbf{s})$ is evaluated through the micro simulator.

The procedure for solving the minimisation problem through the Simulated Annealing is described in the following section.

4.2. The solution algorithm

The chosen solution algorithm is based on Simulated Annealing (SA).

The Simulated Annealing (SA) scheme is a stochastic method currently very popular for difficult optimization problems. The term Simulated Annealing is motivated by an analogy to annealing in solids searching for minimal energy states. This procedure starts with the metal at a liquid state and at a very high temperature. In this state the atoms are quite free in their movements. The temperature of the metal is then slowly lowered. If the metal is cooled slowly enough, the atoms are able to reach the most stable orientation. This slow cooling process is known as annealing and so the method is known as Simulated Annealing.

The method is an iterative process that searches from a single point moving in its neighbourhood and allows sometimes to accept worse solutions. This is meant to avoid to get stuck in a local minimum in the optimization procedure. Worse solutions are accepted according to a probability, which depends on a parameter, i.e. the temperature, which decreases with the number of steps.

The algorithm evolves through an iterative cycle, in which the search space is explored. This search depends on a control parameter called temperature T which decreases as the number of the iteration of the cycle increases. In each iteration, a new point $\mathbf{s_n}$ is reached from $\mathbf{s_o}$, according to the transition rule. At the new point, the value of the cost function $h(\mathbf{s})$ is checked.

Since the cost function does not have an explicit formula, at each step of the Simulated Annealing algorithm, the microscopic simulator is recalled to calculate the users waiting times and the relocation times from which the cost function value depends.

The updating happens according to:

a) if $h(\mathbf{s_n}) \le h(\mathbf{s_o})$ → $\mathbf{s_n}$ substitutes $\mathbf{s_o}$, i.e. $\mathbf{s_o} := \mathbf{s_n}$

b) if $h(\mathbf{s_n}) > h(\mathbf{s_o})$ → $\mathbf{s_n}$ will become the current solution $\mathbf{s_o}$ with a probability given by:

$$p = \exp\left(- \frac{h(\mathbf{s_n}) - h(\mathbf{s_o})}{T} \right) \quad (6)$$

This is the core of Simulated Annealing and is known as the Metropolis algorithm. T is the value of the temperature for the current cycle (Laarhoven and Aarts 1987). Given that $r \in [0,1]$ is a pseudo random number, the updating happens according to the following:
if $r \le p$ → the new solution $\mathbf{s_n}$ substitutes $\mathbf{s_o}$,
if $r > p$ → the new solution $\mathbf{s_n}$ is rejected and therefore $\mathbf{s_o}$ will not be updated.

Therefore the algorithm needs the definition of the cooling schedule, the local search and the starting and stopping conditions.

4.2.1. The cooling schedule

The cooling schedule is defined by the initial temperature, the law of its decrease and the final temperature. The starting temperature has been determined according to Laarhoven and Aarts (1987).

An initial acceptance ratio p_0 of the worse solution, e.g. 0.5, is fixed at the first step of the algorithm. From this point, the initial temperature T_0 is determined from the acceptance ratio p_0 in this way, according to Laarhoven and Aarts (1987):

$$0.5 = p_0 = \exp\left(- \frac{h(\mathbf{s_n}) - h(\mathbf{s_o})}{T_0} \right) \quad (7)$$

The choice of the initial acceptance ratio has the purpose of performing a quite good exploration of the search space without slowing down too much the algorithm.

As in Cepolina (2005), the geometric temperature reduction function has been used: $T_{k+1} = \alpha \cdot T_k$ where T_k and T_{k+1} are the temperatures in two consecutive iterations of the algorithm. Typically, $0.7 \le \alpha \le 0.95$. In order to have a good exploration of the search space but not a too slow algorithm, α has been assumed equal to 0.9. The final temperature scheme of the cooling schedule is replaced by a stopping condition. The algorithm is stopped when 100 iterations without accepting any more new solutions is reached, according to the stopping criteria given in Laarhoven and Aarts (1987).

4.2.2. The transition rule

The transition rule regards the exploration of the search space: from a given vector $\mathbf{s_o}$, a new vector $\mathbf{s_n}$ is selected in the neighbourhood of $\mathbf{s_o}$.

The transition rule is probabilistic: it passes from $\mathbf{s_o}$ to $\mathbf{s_n}$ changing only one component of the vector $\mathbf{s_o}$. The algorithm randomly determines the component of the vector to modify. In our case, each component has the same probability to be selected. The algorithm also determines whether to increase or decrease the chosen component: it is increased with a probability of 50% and it is decreased with the same probability. More specifically, the first component of $\mathbf{s_o}$, i.e. the fleet dimension, if selected, is increased or decreased by m, where m is the number of stations in the intervention area. The second and the third component of $\mathbf{s_o}$, the low critical and low buffer thresholds, if selected, are increased or decreased by 1. Moreover, the algorithm avoids the situation where, in a given iteration, the vector component to change is the same as the one that has been changed in the previous iteration. In this way, it is guaranteed that the new vector $\mathbf{s_n}$ is taken in the neighbourhood of the previous vector $\mathbf{s_o}$. Keeping the neighbourhood that small allows to reach faster the optimum solution but, on the other hand, it cuts down the possibility of great improvements.

5. APPLICATION ON THE FIELD

The proposed transport system, together with the simulation and optimization methodology, has been applied to the case study of the historical city centre of Genoa, Italy. The historical city centre of Genoa has an area of about 1.13 km^2. This area is one of the most populated in Europe and the population density is equal 19,000 inhabitants/km^2. Also the density of commercial activities is high in this area. The proposed car-sharing system successfully integrates with conventional public transport, which cannot operate in the study area because of the narrowness and slope of roads. We consider as simulation time period the PICAV service during a reference working day: the service starts at 8 a.m. and ends at midnight. From the data collected in the field (Cepolina et al. 2011a), an off-peak phase in the morning (starting at 8 a.m. until 4 p.m.) and a peak phase in the afternoon (from 4 p.m. to 8 p.m.) were identified. From 8 p.m. to midnight no PICAV trips start.

The localizations of bus stops and underground stations were identified from Genoa public transport website (www.amt.genova.it). We have identified as well the localization of hotels, museum, offices, schools and commercial activities (food shops, clothes shops, handicraft shops and other shops) from the internet and from surveys performed in the field (Cepolina et al. 2013a). We designed 7 stations, all of which are on the border of the area, placed in correspondence of the main public transport stops. Each road has been divided into 50 m long sections and therefore 120 units resulted. The characteristics of the intervention area and the position of stations are shown in figure 1.

We assume that 1% of people that currently enter the historical city centre by foot will use the PICAV car-sharing systems. From surveys performed on the field (Cepolina et al. 2011a), it has been assessed that, in Genoa historical city centre, the pedestrian density in the afternoon (i.e. peak) period is on the average 1.45 times the density in the morning (i.e. off-peak) period. The peak transport demand is therefore assumed almost 1.45 times the off-peak demand. The overall PICAV travel demand in the reference time period is 1644 trips.

Trips having an origin or destination on the area border, are assumed to have had an origin or destination at a station; whereas trips having an origin or destination inside the area, are assumed to have had an origin or destination at a road section.

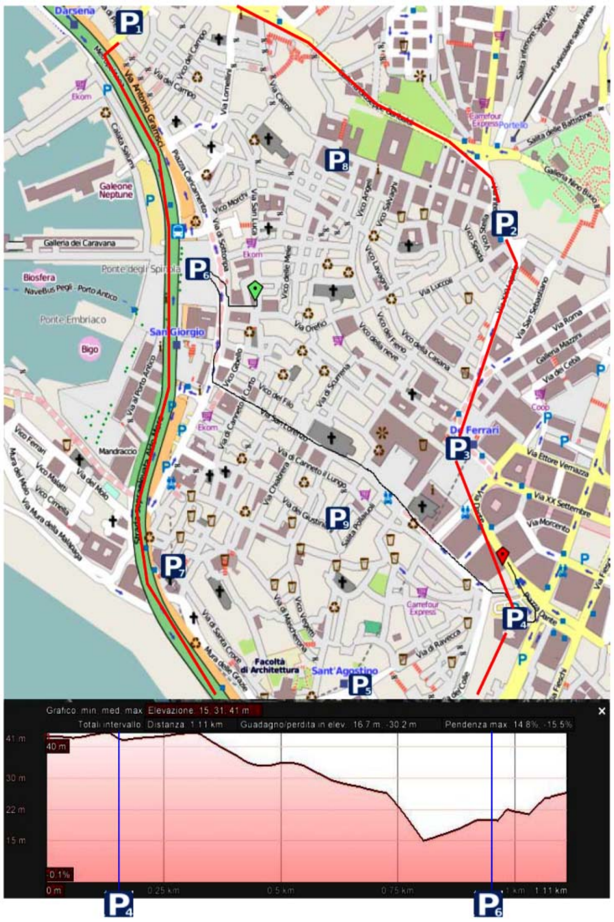

Figure 1: The intervention area and the stations positions (above). Longitudinal profile of the path between stations 4 and 6 (below).

About 100 people waiting for the bus on the area border have been interviewed (Cepolina et al. 2013a), in order to know the characteristics of the trips performed in the historical city centre. From the collected data, the duration of a multitask trip was found to be about 5 times the length of a similar direct trip.

The minimum charge level has been assumed equal to 10%, since this is the quantity of charge necessary to perform the longest trip, among the ones simulated in the area of study.

The optimization procedure has provided the optimum fleet dimension and the low critical and low buffer thresholds. The optimum fleet dimension is equal to 77 vehicles.

This fleet dimension seems reasonable, since it is in accordance with the outcomes from Barth and Todd's research (1999). Barth and Todd found that, for all the various travel demand cases they analysed, the best number of vehicles ranged from 3 vehicles per 100 trips to 6 vehicles per 100 trips. We have 1644 trips per day therefore, according to these authors, the fleet dimension should range between 49 and 98 vehicles. The fleet has been assumed equally distributed among the stations at the beginning of the time period, as the different demand at the various stations is compensated through automatic relocation. The low critical thresholds were set to 2 and the low buffer thresholds to 3 vehicles for each station: these values have been determined again through optimization. The relocation technique used in the simulator is the shortest time.

The total value of the cost function is 485.61 €; the cost of users waiting time is 117.37 €, the cost of the fleet is 337.83 € and the cost of relocation is equal to 30.41 €.

The performance of the proposed car sharing system for the case study of Genoa has been assessed.

The trend of the cost function and its components with respect to: fleet dimension, low critical thresholds and low buffer thresholds, is represented in figures 2,3 and 4 respectively. The values reported are averaged over 30 simulator runs.

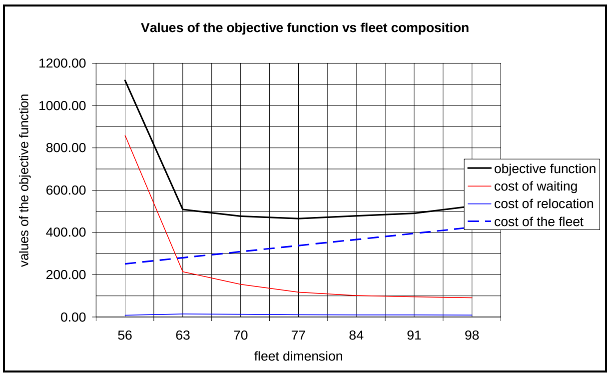

Figure 2: The trend of the cost function and its components (cost of waiting, cost of relocation and cost of the fleet) against the fleet dimension.

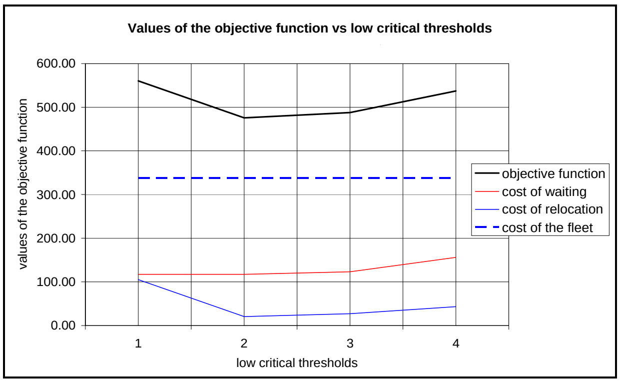

Figure 3: The trend of the cost function and its components (cost of waiting, cost of relocation and cost of the fleet) against the low critical thresholds.

In Figure 5 the number of PICAVs in each state is plotted against time. This figure refers to only one simulation run. The states taken into account are:

- available,
- occupied by users,
- required but not available because in charge,
- relocating,
- redirected because there is not free space in the destination station (FPT occurrences).

Time is expressed in hours, starting from 8 a.m. to midnight, when the last user returns the PICAV unit. The diagram in Figure 5 shows that the selected charging technique (opportunity charging) is suitable for the case of study, since the vehicles' charge levels always remain above the minimum.

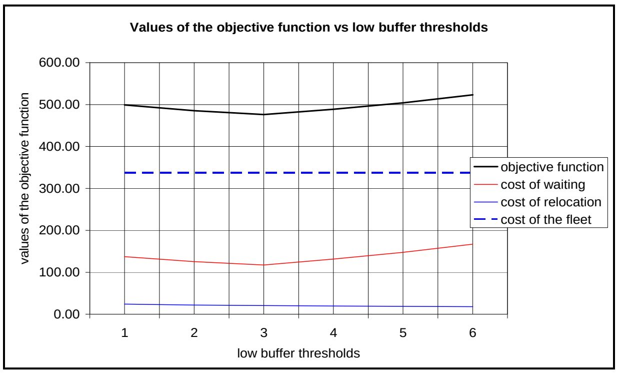

Figure 4: The trend of the cost function and its components (cost of waiting, cost of relocation and cost of the fleet) against the low buffer thresholds.

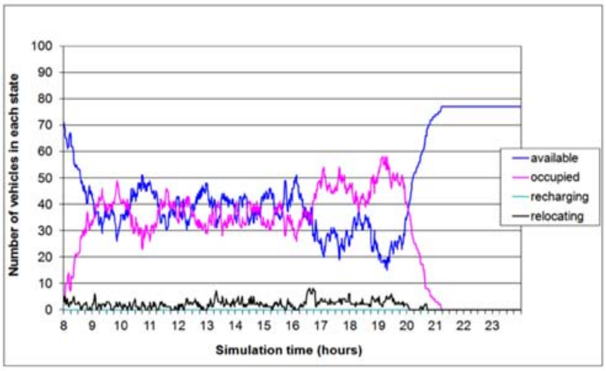

Figure 5: Number of vehicles in each state against time

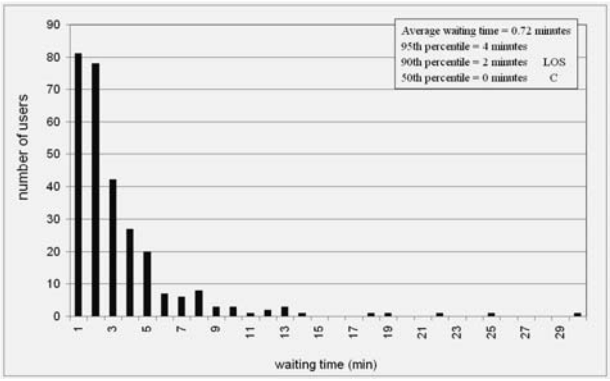

Figure 6: Distribution of users waiting time

If we consider the vehicles available to users which are occupied or available at stations, in the PICAV transport system, in the peak phase, about the 96% of the fleet results available to users and about 4% is therefore relocating. This means that the simulated relocation strategy works quite well for the case of study, since the number of vehicles subtracted to users for relocation is low.

The distribution of users waiting times is shown in figure 6. The reported values are averaged over 30 simulation runs. The average waiting time is equal to

0.72 minutes, and, according to the percentile values, the level of service is C.

6. CONCLUSIONS

The paper concerns a third generation car sharing system for urban areas. It is based on a fleet of intelligent vehicles which can be rented for short term periods (usually a couple of hours) and are shared through the day by different users. Vehicles can be accessed not only at stations, but also at any point of the intervention area. It is worth to underline that capillarity (i.e. the possibility that vehicles are available also along the roads) is a very good way to better satisfy user demand.

The car-sharing system has been planned and modelled in order to guarantee open ended reservation, instant access and one way trips. In the proposed system, a fully vehicle based relocation strategy is adopted, because the level of automation of PICAV vehicles allows them to move in an automatic way.

In order to plan such a vehicle sharing system for a given pedestrian area, an optimization procedure is presented in the paper which allows to assess the relocation strategy parameters that minimize the system cost, both in terms of level of service provided to users (that depends on waiting times) and the efficiency from the management point of view (that depends on relocation time and fleet dimension).

Since there is not an explicit expression for the cost function, the distribution of users waiting times and the total amount of time spent by vehicles in relocation, from which system cost depends, are assessed by microscopic simulation. The microscopic simulator follows an object oriented logic. The simulator follows each user and each vehicle within the simulation period, and gives the actual users waiting times and the relocation time.

As illustrative problem, the proposed transport system has been planned for the historical city centre of Genoa, Italy. The results of the simulation clearly show the effectiveness of the proposed car sharing system, because, with low staff costs, it allows users a high level of satisfaction. The model has been validated through a comparison of the simulation output data with those available in the body of knowledge.

Existing systems, such as Car2Go, DriveNow and Greenwheels, exploit the benefits of capillarity to avoid relocations. Actually, because of the widespread of vehicles, it is quite easy that the user finds an available vehicle quite close to his position. However, these systems do not work in cases of unbalanced demand and small cities. For example, if car sharing systems are used for trips to/from work, in the morning peak hour, it may happen that at a certain moment people who want to go to work cannot find anymore available vehicles. In this case, the only alternative is the automatic relocation.

As stated in Cepolina and Farina (2013b), the automatic relocation of PICAV vehicles still cannot be applied on the field because of legal problems in case of accident. To reduce the impact of automatically driven vehicles, also at legal level, it could be explored relocation by platooning. The operator drives the first vehicle of a platoon and the other vehicles follow the leader through automatic distancing. This relocation technique, however, increases the staff costs, as some operators to perform the relocation are needed. Moreover, because of the high level of capillarity, therefore vehicles should be redistributed all over the area, the relocation trips may be highly time consuming, therefore the staff needed is huge.

ACKNOWLEDGMENTS

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A DYNAMIC MODEL AND AN ALGORITHM FOR SUPPLY CHAIN SCHEDULING PROBLEM SOLVING

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ABSTRACT
We present a new model and algorithm for optimal scheduling of a supply chain (SC) with multiple customers and suppliers. The formulation assumes that suppliers can dynamically allocate jobs and schedule their resources in a coordinated manner so that all the suppliers are equally utilized and jobs are accomplished without interruptions and scheduled subject to maximal customer service level and minimal delays. This problem is represented as a special case of the job shop scheduling problem with dynamically distributed jobs. The approach is based on a natural dynamic decomposition of the problem and its solution with the help of a modified form of continuous maximum principle blended with combinatorial optimization.

Keywords: supply chain, scheduling, dynamic model, optimal program control, continuous maximum principle, combinatorial optimization.

1. INTRODUCTION

We present the scheduling model and algorithm where an SC (Ivanov, Sokolov, 2010) is a networked controlled system that is described through differential equations based on a dynamic interpretation of the job execution. The studies by Holt, Modigliani, Muth, and Simon (1960), Hwang, Fan, and Erikson (1967), Zimin and Ivanilov (1971) and Moiseev (1974) were among the first to apply the optimal program control (OPC) and the maximum principle to multi-level and multi-period master production scheduling that determined the production as an optimal control with a corresponding trajectory of the state variables (i.e., the inventory). This stream was continued by Kimemia and Gershwin (1983), who applied a hierarchical method in designing a solution procedure to the overall model, and by Khmelnitsky, Kogan, and Maimom (1997) for planning continuous-time flows in flexible manufacturing systems.

The study (Sarimveis, Patrinos, Tarantilis & Kiranoudis, 2008) showed a wide range of advantages regarding the application of OPC to production and logistics. They include, first of all, a non-stationary process view and accuracy of continuous time. In addition, a wide range of analysis tools from control theory regarding stability, controllability, adaptability, etc. may be used if a schedule is described in terms of control. Recent studies (e.g., Subramanian, Rawlings, Maravelias, Flores-Cerrillo, & Megan 2013) discussed the possibilities to translate the MP scheduling models into a state-space form and the design of rescheduling algorithms with the desired closed-loop properties.

However, although the OPC was widely applied to flexible manufacturing system scheduling, it cannot be directly applied to the flow or job shop scheduling level as a computational procedure. The continuous time models are not applicable in their direct form to discrete assignment problems due to the continuous values of the control variables from 0 to 1. In addition, such problems as numerical instability, non-existence of gradients, and non-convexity of state space should be mentioned. The calculation of the OPC with direct methods of the continuous maximum principle has also not been proved efficient. It can be concluded that the application of OPC to scheduling is not a trivial problem for two reasons. First, a conceptual problem consists of the continuous values of the control variables. Second, a computational problem with a direct method of the maximum principle exists. In this paper we present a new model and algorithm for optimal scheduling of a SC with multiple customers and suppliers. In this case the job execution is characterized by (1) execution results (e.g., volume, time, etc.), (2) capacity consumption of the resources, and (3) supply flows resulting from the delivery to the customer. We propose to use a two-stage scheduling procedure in line with Chen and Pundoor (2006). A job control model (M_1) is first used to assign jobs to suppliers, and then a flow control model (M_2) is used to schedule the processing of assigned orders subject to capacity restrictions of the production and transportation resources. The basic interaction of these two models is that after the solving the job control model, the found control variables are used in the constraints of the flow control model. In additional models of resource and channel control, the material supply to resources and its consumption as well as setup times are represented.

2. PROBLEM STATEMENT AND MODEL

2.1. Dynamic Model of Job Control (model M$_1$)

We consider the mathematical model of job control. We denote the job state variable $x_{i\mu}^{(o)}$, where (o) — indicates the relation to jobs (orders). The execution dynamics of the job $D_\mu^{(i)}$ can be expressed as (1).

$$\frac{dx_{i\mu}^{(o)}}{dt} = \dot{x}_{i\mu}^{(o)} = \sum_{j=1}^{n} \varepsilon_{ij}(t) u_{i\mu j}^{(o)} \tag{1}$$

where $\varepsilon_{ij}(t)$ isan element of the preset matrix time function of time-spatial constraints, $u_{i\mu j}^{(o)}(t)$ is a 0–1 assignment control variable.

Remark 1. The economic sense of (1) consists of the job dynamics representation in which process non-stationary and time consumption are reflected.

Let us introduce equation (2) to assess the total resource availability time:

$$\dot{x}_j^{(o)} = \sum_{i=1}^{\bar{n}} \sum_{\substack{\eta=1 \\ \eta \neq i}}^{\bar{n}} \sum_{\mu=1}^{s_i} \sum_{\rho=1}^{p_i} (u_{i\mu j}^{(o)}) \tag{2}$$

Equation (2) represents resource utilization in job execution dynamics. The variable $x_j^{(o)}$ characterizes the total employment time of the *j*-supplier. The control actions are constrained as follows:

$$\sum_{i=1}^{\bar{n}} \sum_{\mu=1}^{s_i} u_{i\mu j}^{(o)}(t) \leq 1, \forall j; \ \sum_{j=1}^{n} u_{i\mu j}^{(o)}(t) \leq 1, \forall i, \forall \mu \tag{3}$$

$$\sum_{j=1}^{n} u_{i\mu j}^{(o)} [\sum_{\alpha \in \Gamma_{i\mu_1}^-} (a_{i\alpha}^{(o)} - x_{i\alpha}^{(o)}) + \prod_{\beta \in \Gamma_{i\mu_2}^-} (a_{i\beta}^{(o)} - x_{i\beta}^{(o)})] = 0 \tag{4}$$

$$u_{i\mu j}^{(o)}(t) \in \{0,1\}; \tag{5}$$

where $\Gamma_{i\mu_1}^-$, $\Gamma_{i\mu_2}^-$ are the sets of job numbers which immediately precede the job $D_\mu^{(i)}$ subject to accomplishing of all the predecessor jobs or at least one of the jobs correspondingly, and $a_{i\alpha}^{(o)}, a_{i\beta}^{(o)}$ are the planned lot-sizes. Constraint (3) refers to the allocation problem constraint according to the problem statement (i.e., only a single order can be processed at any time by the manufacturer). Constraint (4) determines the precedence relations; more over, this constraint implies the blocking of operation $D_\mu^{(i)}$ until the previous operations $D_\alpha^{(i)}, D_\beta^{(i)}$ have been executed. If $u_{i\mu j}^{(o)}(t) = 1$, all the predecessor jobs of the operation $D_\mu^{(i)}$ have been executed. Note that these constraints are identical to those in MP models.

Proposition 1. *The constraints (4) ensure that all the scheduled jobs from one customer should be fully fulfilled, i.e. the planned service level can be reached.*

Corollary 1. *The analysis of constraints (4) shows that control* $\mathbf{u}(t)$ *is switching on only when the necessary predecessor operations have been executed.* $\sum_{j=1}^{n} u_{i\mu_j}^{(o)} \sum_{\alpha \in \Gamma_{i\mu_1}^-} (a_{i\alpha}^{(o)} - x_{i\alpha}^{(o)}(t)) = 0$ *guarantees the total processing of all the predecessor operations, and* $\sum_{j=1}^{n} u_{i\mu_j}^{(o)} \prod_{\beta \in \Gamma_{i\mu_2}^-} (a_{i\beta}^{(o)} - x_{i\beta}^{(o)}) = 0$ *of at least one of the predecessor operations.*

According to equation (5), controls contain the values of the *Boolean variables*. In order to assess the results of job execution, we define the following initial and end conditions at the moments $t = T_0$, $t = T_f$:

$$x_{i\mu}^{(o)}(T_0) = 0; \ x_{i\mu}^{(o)}(T_f) = a_{i\mu}^{(o)}; \tag{6}$$

Conditions (6) reflect the desired end state. The right parts of equations are predetermined at the planning stage subject to the lot-sizes of each job.

According to the problem statement, let us introduce the following performance indicators (7)–(9):

$$J_1^{(o)} = \frac{1}{2} \sum_{i=1}^{\bar{n}} \sum_{\mu=1}^{s_i} [(a_{i\mu}^{(o)} - x_{i\mu}^{(o)}(T_f))^2] \tag{7}$$

$$J_2^{(o)} = \sum_{i=1}^{\bar{n}} \sum_{\mu=1}^{s_i} \sum_{j=1}^{n} \int_{T_0}^{T_f} \alpha_{i\mu j}^{(o)}(\tau) u_{i\mu j}^{(o)}(\tau) d\tau \tag{8}$$

$$J_3^{(o)} = \frac{1}{2} \sum_{j=1}^{n} (T - x_j^{(o)}(T_f))^2 \tag{9}$$

The performance indicator (7) characterizes the accuracy of the end conditions' accomplishment, i.e. the service level of an SC. The goal function (8) refers to the estimation of an job's execution time with regard to the planned supply terms and reflects the delivery reliability, i.e., the accomplishing the delivery to the fixed due dates. The functions $\alpha_{i\mu}^{(o)}(\tau)$, assumed to be known, characterizes the fulfilment of time conditions for different jobs and time points of the penalties increase due to breaking supply terms respectively. The indicator (9)estimates the equal resource utilization in the SC.

2.2. Dynamic Model of Flow Control (model M$_2$)

We consider the mathematical model of flow control in the form of equation (10):

$$\dot{x}_{i\mu j}^{(f)} = u_{i\mu j}^{(f)}, \ \dot{x}_{ij\eta\rho}^{(f)} = u_{ij\eta\rho}^{(f)} \tag{10}$$

We denote the flow state variable $\dot{x}_{i\mu j}^{(f)}$, where (f) indicates the relation of the variable *x* to flows.

Remark 2.*The economic sense of the first part of equation (10) consists of the representation of flow consumption of the resource $C^{(j)}$. The second part of (10) describes the delivery to the customer $\bar{B}^{(\eta)}$.*

The control actions are constrained by maximal capacities and intensities as follows:

$$\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i} u_{i\mu j}^{(f)}(t) \le \tilde{\tilde{R}}_{1j}^{(f)}, \sum_{\rho=1}^{p_i} u_{ij\eta\rho}^{(f)}(t) \le \tilde{\tilde{R}}_{1j\eta}^{(f)}, \quad (11)$$

$$0 \le u_{i\mu j}^{(f)}(t) \le c_{i\mu j}^{(f)} \cdot u_{i\mu j}^{(o)}, 0 \le u_{ij\eta\rho}^{(f)}(t) \le c_{i\eta\rho j}^{(f)} \cdot u_{i\eta\rho j}^{(o)}, \quad (12)$$

where $\tilde{\tilde{R}}_{1j}^{(f)}$ is the total potential intensity of the resource $C^{(j)}$, $\tilde{\tilde{R}}_{1j\eta}^{(f)}$ is the maximal potential channel intensity to deliver products to the customer $\bar{B}^{(\eta)}$, $c_{i\mu j}^{(f)}$ is the maximal potential capacity of the resource $C^{(j)}$ for the job $D_\mu^{(i)}$, and $c_{i\eta\rho j}^{(f)}$ is the total potential capacity of the channel delivering the product flow $P_{<s_i,\rho>}^{(j,\eta)}$ of the job $D_\mu^{(i)}$ to the customer $\bar{B}^{(\eta)}$.

The end conditions are similar to those in (6) and subject to the units of processing time. The goal functionals of the flow control model are defined in the form of equations (11) and (12):

$$J_1^{(f)} = \frac{1}{2}\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}[(a_{i\mu j}^{(f)} - x_{i\mu}^{(f)}(T_f))^2, + \sum_{\substack{\eta=1\\ \eta\ne i}}^{\bar{n}}\sum_{\rho=1}^{p_i}(a_{ij\eta\rho}^{(f)} - x_{ij\eta\rho}^{(f)}(T_f))^2] \quad (13)$$

$$J_2^{(f)} = \frac{1}{2}\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}\int_{T_0}^{T_f} \beta_{i\mu}^{(f)}(\tau)u_{i\mu j}^{(f)}(\tau)d\tau. \quad (14)$$

The economic meaning of these performance indicators correspond to equations (7) and (8). With the help of the weighting performance indicators, a general performance vector can be denoted as (15):

$$J(x(t),u(t)) = \left\| J_1^{(o)}, J_2^{(o)}, J_3^{(0)}, J_1^{(f)}, J_2^{(f)} \right\|^T. \quad (15)$$

The partial indicators may be weighted depending on the planning goals and SC strategies. Original methods (Gubarev et al. 1988) have been used to transform the vector $\mathbf{J}$ to a scalar form J_G.

The job shop scheduling problem can be formulated as the following problem of OPC: this is necessary to find an allowable control $\boldsymbol{u}(t)$, $t \in (T_0, T_f]$ that ensures for the model (1)–(2), and (10) meeting the vector constraint functions $\boldsymbol{q}^{(1)}(\boldsymbol{x},\boldsymbol{u}) = 0$, $\boldsymbol{q}^{(2)}(\boldsymbol{x},\boldsymbol{u}) \le 0$ (3)–(5) and (10–11), and guides the dynamic system (i.e., job shop schedule) $\dot{\boldsymbol{x}} = \boldsymbol{\phi}(t,\boldsymbol{x},\boldsymbol{u})$ from the initial state to the specified final state. If there are several allowable controls (schedules), then the best one (optimal) should be selected in order to maximize (minimize) J_G. In terms of optimal program control (OPC), the program control of job execution is also the job shop schedule. We will refer to this problem of OPC as *PS*.

The formulated model is a linear non-stationary finite-dimensional controlled differential system with the convex area of admissible control. Note that the *PS*is a standard OPC problem; see (Lee and Markus 1967). In fact, this model is linear in the state and control variables, and the objective is linear. The transfer of non-linearity to the constraint ensures convexity and allows using interval constraints.

3. COMPUTATIONAL PROCEDURE AND ANALYSIS OF THE ALGORITHM

The computational procedure for the developed model is based on the integration of the main and conjunctive equation systems subject to the maximization of the following Hamiltonian (16)–(18):

$$H(\boldsymbol{x}^*(t), \boldsymbol{u}^*(t), \psi(t)^*) = \max_{\tilde{u}\in\tilde{\tilde{Q}}(x)} \sum_{z=1}^{2} H_l(\boldsymbol{x}(t), \boldsymbol{u}(t), \psi(t)) \quad (16)$$

$$H_1 = \sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}[\psi_{i\mu}^{(o)} \cdot \varepsilon_{ij} + \psi_j^{(k)} + w_2^{(o)}\alpha_{i\mu j}^{(o)}]u_{i\mu j}^{(o)} \quad (17)$$

$$H_2 = \sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}[\psi_{i\mu j}^{(f)} + w_5^{(f)}\beta_{i\mu}^{(f)}]u_{i\mu j}^{(f)} \quad (18)$$

where $\boldsymbol{\psi}(t)$ is the conjunctive vector.

The maximization of the Hamiltonian H_1 for model (1) in combination with the constraints (3)–(5) solves the assignment problem. The maximization of the Hamiltonian H_2 for model (10) in combination with the constraints (11)–(12) solves the LP problem. At each time instant, only those jobs and constraints from the "active scheduling zone" are considered in the models M_o and $M_f$which meet the requirements (3)–(5), (11), and (12). By a dynamic switching of the constraints (4) from inequalities to equalities, the size of the scheduling problem at each time point is reduced. The Hamiltonians (17) and (18) can be maximized when the constraints (4) satisfy the corresponding variables $u_{i\mu j}^{(o)}$ and $u_{i\mu j}^{(f)}$. In this case, only a part of the constraints (4) is considered for the current assignment problem since, when the control in (4) is switched to zero, then it becomes active in the right-hand part of the equations (12). Therefore, the reduction of the problem dimensionality at each time instant in the calculation process is ensured due to the recurrent operation description.

A methodical challenge in applying the maximum principle is to find the coefficients of the conjunctive system, which change in dynamics. One of the contributions of this paper is that these coefficients can be found analytically (Boltyanskiy, 1973, Ivanov, Sokolov, 2010). The coefficients of the conjunctive system play the role of the dynamical Lagrange multipliers as compared with MP dual formulations.

In accordance with the maximum principle, the following conjugate system can be written:

$$\frac{d\psi_{i\mu}^{(o)}}{dt} = \dot{\psi}_{i\mu}^{(o)} = -\sum_{j=1}^{n}[\psi_{i(\mu+1)}^{(o)}\varepsilon_{ij} + \psi_j^{(k)} + \lambda_2^{(o)}\alpha_{i(\mu+1)j}^{(o)}]u_{i(\mu+1)j}^{(o)}, \quad (19)$$

$$\frac{d\psi_j^{(k)}}{dt} = \dot{\psi}_j^{(k)} = 0\,, \quad (20)$$

$$\frac{d\psi_{i\mu j}^{(f)}}{dt} = \dot{\psi}_{i\mu j}^{(f)} = 0\,. \quad (21)$$

The transversality conditions can be formulated in the following way:

$$\psi_{i\mu}^{(o)}(T_f) = \lambda_1^{(o)}(a_{i\mu}^{(o)} - x_{i\mu}^{(o)}(T_f)), \quad (22)$$

$$\psi_j^{(k)}(T_f) = \lambda_3^{(k)}(T - x_j^{(k)}(T_f)), \quad (23)$$

$$\psi_{i\mu j}^{(f)}(T_f) = \lambda_5^{(f)}(a_{i\mu j}^{(f)} - x_{i\mu j}^{(f)}(T_f)). \quad (24)$$

The basic peculiarity of the boundary problem considered is that the initial conditions for the conjunctive variables $\psi(t_0)$ are not given. At the same time, an OPC should be calculated subject to the end conditions. To obtain the conjunctive system vector, we use the Krylov–Chernousko method of successive approximations (MSA) for an OPC problem with a free right end, which is based on the joint use of a modified successive approximation method (Krylov&Chernousko, 1972). We propose to use a heuristic schedule $\bar{\boldsymbol{u}}(t)$ to obtain the initial conditions for $\psi(t_0)$. Then, the algorithm DYN can be stated as follows:

Step 1. An initial solution $\bar{\boldsymbol{u}}(t), t \in (T_0, T_f]$ (a feasible control, in other words, a feasible schedule) is selected and $r = 0$.

Step 2. As a result of the dynamic model run, $\boldsymbol{x}^{(r)}(t)$ is received. Besides, if $t = T_f$ then the record value $J_G = J_G^{(r)}$ can be calculated. Then, the transversality conditions (22)–(24) are evaluated.

Step 3. The conjugate system (19)–(21) is integrated subject to $\boldsymbol{u}(t) = \bar{\boldsymbol{u}}(t)$ and over the interval from $t = T_f$ to $t = T_0$. For the time $t = T_0$, the first approximation $\boldsymbol{\psi}_i^{(r)}(T_0)$ is obtained as a result. Here, the iteration number $r = 0$ is completed.

Step 4. From the time point $t = T_0$ onwards, the control $\boldsymbol{u}^{(r+1)}(t)$ is determined ($r = 0,1,2,...$ denotes the number of the iteration). In parallel with the maximization of the Hamiltonian, the main system of equations and the conjugate one are integrated. The maximization involves the solution of several MP problems at each time point.

The assignments (i.e., the control variables $u_{i\mu j}^{(o)}$) from the model M_o are used in the flow control M_f (10)–(12) by means of the constraints (12). At the same time, the model M_f influences the model M_o through the transversality conditions (22)–(24), the conjunctive system (19)–(21), and the Hamiltonian function (16).

4. EXPERIMENTAL ENVIRONMENT

Continuous optimization is a challenging calculation task. Thus any sensible judgments on the models and algorithms can be made only by application of special tools. For the experiments, we elaborated the model in a software package. Because of the limited size of this paper, we cannot describe this package in-depth here, but will sum up the main experiment design features. The software has three modes of operation with regard to scheduling and an additional mode to analyse stability of the schedules. This mode is beyond the scope of this paper.

The first mode includes the interactive generation/preparation of the input data. The second mode lies in the evaluation of heuristic and optimal SC schedules. The following operations can be executed in an interactive regime:

- multi-criteria rating, analysis, and the selection of SC plans and schedules;
- the evaluation of the influence that is exerted by time, economic, technical, and technological constraints upon SC structure dynamics control;
- the evaluation of a general quality measure for SC plans and schedules, and the evaluation of particular performance indicators.

The third mode provides interactive selection and visualization of SC schedule and report generation. An end user can select the modes of program run, set and display data via a hierarchical menu.

The first step is the input data generation. These data create SC structure and the environment on which scheduling will be performed. The data can also be input by a user. After setting up SC structures, planning goals and environment parameters (customer orders and possible uncertainty impacts), the scheduling algorithm is then run. The algorithm of dynamic control is programmed by us; for the optimization of problems (16)-(18) under the presence of constraints (3)-(5) and (11)-(12) at each time point by means of MP techniques, the OPC algorithm addresses the MP library of the MS Excel Solver.

The schedule can be analyzed with regard to performance indicators. Subsequently, parameters of the SC structures and the environment can be tuned if the decision-maker is dissatisfied with the values of performance indicators. More than 15 parameters can be changed to investigate different interrelations of schedule parameters and SC planning goals (e.g., service level and costs) achievement. E.g., there is an explicit possibility to change:

- the amount of resources, their intensity, and capacities;
- the amount and volumes of customers' orders and operations within these orders (including key customer orders and bottleneck operations);
- the priorities of orders, operations, and resources;
- the lead times, supply cycles, and penalties for breaking delivery terms;
- the perturbation impacts on resources and flows in the SC;
- the priorities of the goal criteria.

Of course, these 15 parameters should not be tuned all at once. The tuning depends a great deal on the SC strategy. In the case of a responsive strategy, the increase in the amount of resources and capacities leads in the direction to improving the values of service level and to increasing the amount and volumes of customers' orders. In the case of an efficient strategy, resource consumption and penalties should be reduced as much as possible even if the lead times and supply cycles would increase and the service level decrease. With regard to perturbation impacts, an SC planner can also analyse different alternative SC plans, fill these plans with reliability and flexibility elements to different extents, and then analyse how these changes influence the key performance indicators. In the current version of the software package, this tuning is still performed manually; hence we are still unable to provide either justified conclusions of recommended settings of parameters or established methods for tuning. However, the extension of the software prototype in this direction is under development. The conducted experiments showed that the application of the presented dynamic scheduling model is especially useful for the problems where a number of operations are arranged in a certain order (e.g., technological restrictions). This is the case in SC planning and scheduling.

The building of the scheduling model within the proved theorems and axioms of the optimal CT (Lee and Markus 1967) allows us to consider the found solutions as optimal (see the proofs of the maximum principle in Pontryagin et al. (1964) and the application of maximum principle to economic problems by Sethi and Thompson (2006). Based on the optimal solutions, we can also methodically justify the quality of different heuristics that have launched the optimization procedure (see Step 1 Section 3) (see Fig. 1).

Fig. 1 depicts the idea that having calculated optimal solutions for several points, it is possible to validate the decision to use either dynamic or one of the heuristic planning algorithms (for simplification, we consider here only FIFO, LIFO and Zimin-Ivanilov-Moiseev (ZIM) algorithms).In ZIM algorithm priority of each job depends on quantity of following jobs. It can be observed that, in the case of a number of processes between 10 and 12, the quality of the heuristic and optimal solutions does not differ by more than 4%. In area 2, the DYN algorithm is preferable to the heuristics. If still using the heuristics, the FIFO algorithm is preferable to the LIFO and ZIM. The most benefit from using the DYN algorithm is achieved in area 3. In this area, the ZIM algorithm is preferable to the LIFO and FIFO algorithms. These data are provided only to depict the idea of using an optimal solution for the evaluation of different heuristics. Of course, for other data structures, the interrelation may be different.

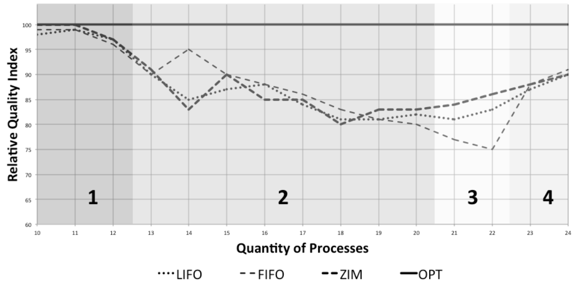

Fig. 1 Comparison of heuristic algorithms' quality with regard to an optimal solution

3. CONCLUSIONS

In this paper, we considered deterministic issues in SC scheduling where scheduling is interconnected to the control function.

In this study, an original approach to a dynamic decomposition of an NP-hard combinatorial SC scheduling problem has been presented. The decomposition is based on the developed model and an algorithm for the optimal control of the execution of the operations blended with mathematical programming (MP). The proposed dynamic decomposition is supported both with an algorithm of local coordination with the help of MP (i.e., at each time instant) and an algorithm of global optimization (i.e., upon the whole planning horizon). This results in the formulation and solution of partial combinatorial problems of lower dimensionality.

In light of this result, the theoretical contribution of this study is directed towards increasing the scheduling quality with the help of a sophisticated scientific methodology. The proposed novelty of this study consists of a detailed theoretical analysis of the time-based decomposition and computational complexity with an application to flow-shop scheduling with continuous flows and discrete assignments. A dynamic model and an algorithm have been developed for the simultaneous solution of the assignment and SC control tasks.

The main idea of the proposed modification of the classical OPC model is to implement and update (e.g., due to dynamic changes in capacity availability) non-linear constraints on a convex domain of feasible control inputs rather than in the right-hand sides of differential equations. In this case, the coefficients of the conjunctive system (i.e., the dynamic Lagrange coefficients), keeping the information about the operational and logical constraints, can be explicitly defined via the local cut method (Boltyanskiy, 1973).

Furthermore, we proposed to substitute the relay constraints by interval ones, i.e., instead of the relay constraints $u_{i\mu j}(t) \in \{0,1\}$ less strict ones $u_{i\mu j}(t) \in [0,1]$ can be considered. Nevertheless, the control takes Boolean values as it is caused by the linearity of the differential equations and the convexity. The proposed substitution enables us to use fundamental scientific results of the OPC theory in scheduling.

The formulated model is a linear non-stationary finite–dimensional controlled system of differential equations with a convex area of feasible control. This is the essential structural property of the proposed approach, which allows applying methods of discrete optimization for the OPC calculation and ensuring the required consistency between OPC and LP/integer programming (IP) models. Although the solver works in the space of piecewise continuous functions, the control actions (i.e., the assignments) can be presented in a discrete form as in LP/IP models.

The continuous time representation allows analyzing the execution of the operations at each time point, and therefore, to obtain additional information about the execution of the SC operations and the flow control. The analysis showed that, since the complexity of the IP/LP problem at each cut is polynomial and the number of integration steps and iterations increase linearly, the computational complexity of the proposed DYN algorithm is also polynomial.

Among the limitations of this study, the strong orientation on centralized SC control and the lack of software tools for a comparative analysis with the existing benchmark solutions can be mentioned. This is the focus of our future efforts. As the convergence speed of the proposed algorithm depends on the selection of the heuristic solution to the vector of the conjunctive system, further research in this direction is needed, e.g., an application of higher-level heuristics.

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ROUTE COST EVALUATION MODEL OF CONTAINER SHIPPING

-FOCUSED ON NORTH CHINA PORTS AND BUSAN PORT-

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ABSTRACT

Asian container routes are the area where world 10 big ports are concentrated including Busan Port based on container cargo handling records in 2013 and the competition to attract container cargos between such ports is very tough. This paper has developed an economy evaluation model corresponding to change in transshipment cargo volume of neighbor ports in North East Asia classifying to Route 1 and Route 2 with Busan Port as a starting point and carried out an economy evaluation of the sea route, an important data for deciding sea routes and calling ports of the shipping companies by applying this model. As a result of analyzing such 2 routes, the shipping company can develop a more profitable route and the port related government authority or operational institution of each country can figure out the threshold of feeder cargo volume in economic viewpoint.

Keywords: Container, Sea Route, Transshipment Cargo Volume, Feeder, Economy Evaluation Model

1. INTRODUCTION

UNCTAD Secretariat (2013) announced all of world 10 big ports(Shanghai, Singapore, Hong Kong, Shenzhen, Busan, Ningbo, Guangzhou, Qingdao, Dubai and Tianjin) based on container cargo handling volume were concentrated in East Asia from 2010 to 2012. In addition, since the rank of ports has been changed from time to time due to the difference in competitiveness according to the service cost and level of each port, maintaining the competitiveness of port according to service level is a very important point. Especially, for each port under competition relation, not only for the container cargo volume but also attracting the transshipment cargo volume becomes a significant variable (Chung and Gak 2002; Kim, Shin and Chang 2012).

While Notteboom and Vernimmen (2008) carried out an economy analysis in order to lower the fuel cost in recession period, considering such important variables, this study developed an evaluation model to figure out which route is more economic corresponding to change in transshipment cargo volume in neighbor ports of East Asia with 2 container routes starting from Busan port. This study carried out an economy evaluation of the port, which is a major data for deciding the sea route and calling port by shipping companies, in particular, could find a more economic model according to size of cargo volume of feeder from viewpoint of shipping company.

Gilman (1999) conducted an analysis to compare One Port Calling Strategy with Several Ports Calling Strategy based on Rotterdam in order to compare and evaluate the costs between the existing End to End service and Hub and Spoke service. In addition, it stressed that it takes significantly long time to tranship the cargos to feeders and is difficult to secure a stable and efficient feeder transportation system for feeders which are essential for sailing of supersized ships. Nevertheless, the shipping companies may develop the better profitable sea routes if they could figure out a proper size of feeder cargo volume of neighbor ports based on such economy evaluation models. Further, if port related central government or operational agency of each country could obtain a marginal value of feeder cargo volume exactly from economic viewpoint and reflect it to the port policy, it shall be able to carry a correct policy to make a prompt decision making and secure the port competitiveness than other competition countries.

2. STATUS OF MAJOR PORTS OF EAST ASIS

Container volume in major ports of East Asia and ship size of major container routes are important variables to decide the sailing routes of container ships. In addition, change in transshipment cargo volumes of container ships in Busan Port, a research object of this study, is also an important factor to consider. Therefore, it shall be possible to foresee how the major container routes shall be changed and to develop our port operation policies favorably coping with those of competition countries by reviewing the process of changes for such important factors.

2.1. Chronology of Major Hub Ports

Major hub ports in East Asia includes Singapore(SG), Hong Kong(HK), Kaohsiung (Taiwan, KHH), Kobe (Japan, KB), Shanghai (China, SHA) and Busan (South Korea, PUS) from 1980S to 2010S and Tsingtao(China, TAO) and Tianjin(China, TSN) are expected to be included in major ports in future.

Major hub ports in 1980's were SG, HK and KB as Figure 1 and the factor to decide the hub port was the shortest distance of sailing route.

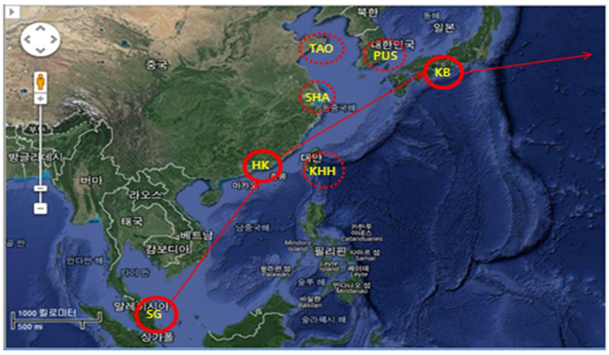

Figure 1: 1980's Main Hub Ports

Major hub ports in 1980's were changed to SG, HK, KHH and PUS as Figure 2, the major factor of change was that KB was eliminated from a hub port due to Great Earthquake in Kobe 1995 and KHH and PUS have been emerged as hub ports alternatively.

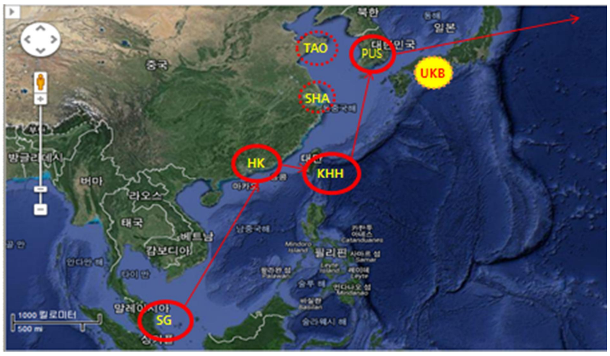

Figure 2: 1990's Main Hub Ports

Major hub ports in 2000's were changed to SG, HK, SHA and PUS as Figure 3 and the major factor of change was that existing KHH, Taiwan was replaced by SHA, China due to increase of cargo volume by rapid development of economy in China.

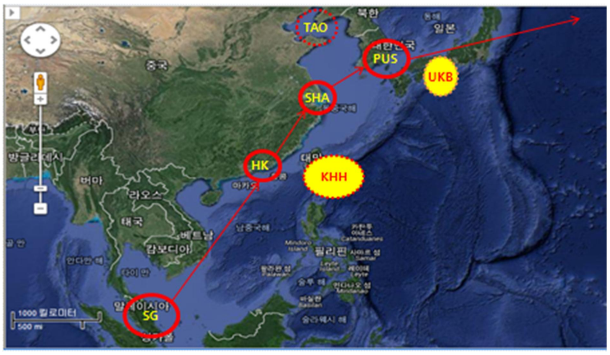

Figure 3: 2000's Main Hub Ports

Major hub ports in 2010's have been maintained same as 2000's but are most likely to be changed due to sudden increase of container cargo volume in Q'TAO and TSN of China that it became an important issue if PUS could still maintain its position as a hub port.

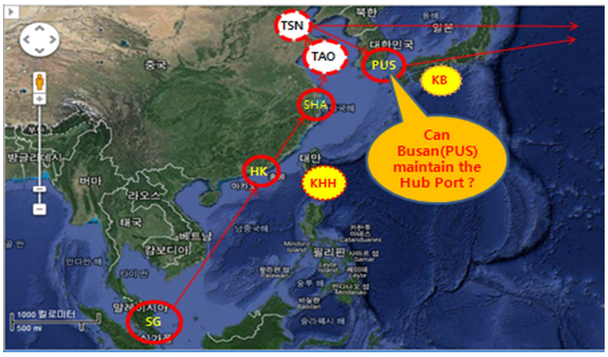

Figure 4: 2010's Main Hub Ports

2.2. Change of Ship Size in Asia Sailing Route

ICF GSK (2014) reported the size of container ships by route starting from Asia has been increased as Figure 5 based on 2013.

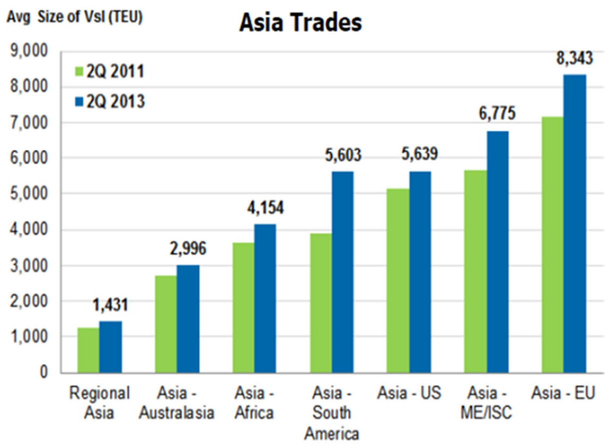

Figure 5: Asia Trades

Especially, the size of ships in Asia-South America routes has been suddenly increased from less than 4,000TEU to 5,603TEU in 2011 as well as Asia-EU routes from 7,000TEU to 8,343TEU. According to Alphaliner and Lloyd's List (2014), such phenomenon appeared to be P3 11,600TEU, G6 11,300 TEU, CKYHE 10,300TEU in average container ship size of FE-N EU based on Feb. 2014.

Such increase of container ship size could be a factor to accelerate the inflow of transshipment cargo volume to hub ports from adjacent ports according to future routes of Asia-America and Asia-EU routes and a big change in maintaining as a hub port is expected according to attraction of transshipment cargo volume.

2.3. Change of Transshipment Container Cargo Volume in Busan Port

According to BPA (2012), 31% of transshipment cargo volume in Busan Port was from China and it steadily increases from 27% in 2004 to 31% in 2012 as shown on Table 1.

Table 1: Container T/S Rank in Busan Port

Rank	Port	Country	T/S (1000TEU)	Ratio (%)
1	Tianjin	China	839	10.3
2	Qingdao	China	556	6.8
3	Dalian	China	427	5.2
4	Shanghai	China	247	3.0
5	Los Angeles	USA	235	2.9
6	Vancouver	Canada	199	2.4
7	Long Beach	USA	172	2.1
8	Seattle	USA	172	2.1
9	Ningbo	China	148	1.8
10	Vladivostok	Russia	131	1.6

In addition, out of big 10 transshipment ports of Busan, 5 are Chinese ports and located in places within 1.5 days sailing distance, so transshipment to China is one of essential factors to keep Busan Port as a hub port. Figure 6 shows transshipment status by country.

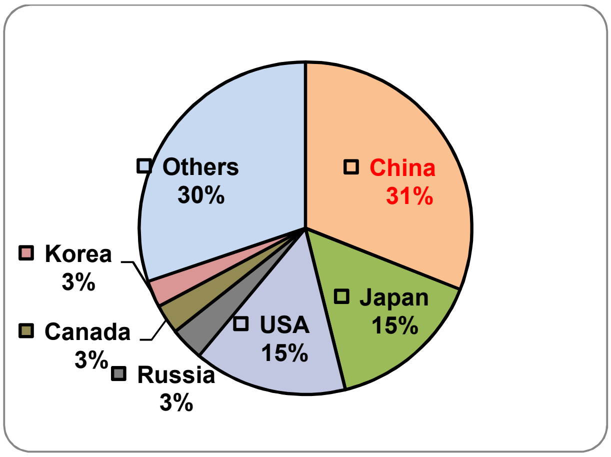

Figure 6: T/S Statistics per country in Busan Port

3. DESIGN OF ECONOMY EVALUATION MODEL

In order to design an economy evaluation model of container routes, a procedure to calculate the economy evaluation model and an equation to apply to such evaluation model shall be defined.

3.1. Calculation Procedure of Evaluation Model

Calculation procedures of evaluation model shall be implemented according to total 12 steps as Figure 7.

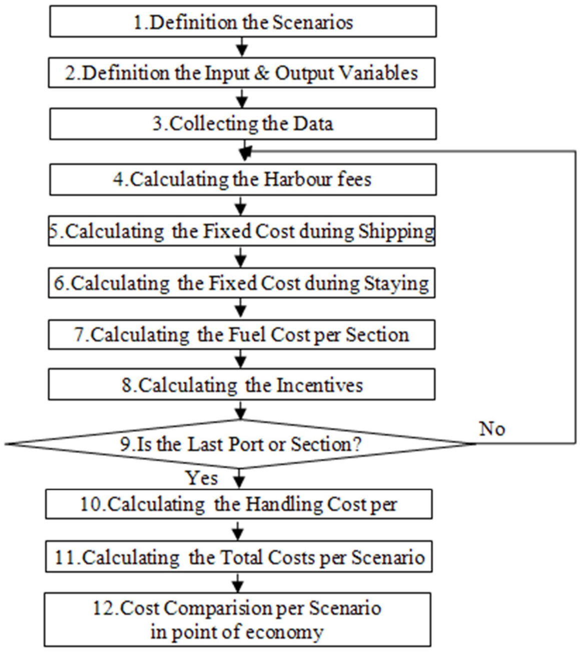

Figure 7: Calculation Procedures of Economy Evaluation Model

Detailed processes by each step are as follows:

1. Number and types of scenarios to be applied to evaluation model shall be defined.
2. Input variables and output variables to be applied to the scenarios shall be defined.
3. Correct financial data to be applied to the scenarios shall be collected and its accuracy shall be verified.
4. Harbor fee of each port shall be calculated by scenario
5. Fixed sailing cost by scenario shall be calculated.
6. Fixed staying cost by scenario shall be calculated.
7. Fuel cost of each section by scenario shall be calculated.
8. Incentives provided by individual port by scenario shall be calculated.
9. When the costs of each port by scenario are calculated, proceed to the next step; otherwise repeat the calculation of harbor fee of item 4.
10. Cargo handling cost by scenario shall be calculated.
11. All costs by scenario shall be aggregated.
12. Costs by scenario shall be compared in viewpoint of economy.

3.2. Definition of Input Variables and Output Variables

Number of input variables to be applied to evaluation model was 7 variables and were defines as Table 2.

Table 2: Definition of Input Variables

Input Variables	Description	Unit
Port Name	Busan(PUS) Long Beach(LGB) Oakland(OAK) Tianjin(TSN)	(code)
Distance	Nautical Mile	(miles)
Shipping time	Time to be consumed during shipping	(days)
Staying Time	Time to be consumed during staying	(days)
Average Speed	Average speed of ship (15 Knot)	(Knot)
Fuel Consumption	HFO(Heavy Fuel Oil) MDO(Marine Diesel Oil) MGO(Marine Gas Oil)	(LT/day)
Currency	USD:KRW=1$:1,072.00₩ CNY:KRW=1¥:175.17₩ EUR:KRW=1€:1,453.95₩	2013, 11th October

Number of output variables to be applied to evaluation model was 7 variables and were defined as Table 3.

Table 3: Definition of Output Variables

Output Variables	Description	Unit
Harbor fees(1)	Tonnage due Harbor due Pilotage Towage Dockage Husbanding fee Quarantine Line handling Entrance/clearance Pilot boat Light due Other port charge	(KRW)
Fixed Cost during Shipping(2)	Shipping duration * 1 Day charterage * Currency	(KRW)
Fixed Cost during Staying(3)	Staying duration * 1 Day charterage * Currency	(KRW)
Fuel Cost(4)	1 Day fuel consumption * Shipping duration * Fuel cost(HFO) * Currency	(KRW)
Incentive(5)	Loading Amount(TEU) * Incentive per port per TEU	(KRW)
Handling(6)	Loading Amount (TEU) * Handling cost per TEU	(KRW)
Total(7)	(1)+(2)+(3)+(4)-(5)+(6)	(KRW)

3.3. Formula of Evaluation Model

The formula of evaluation model using Input Variable of Table 2 and Output Variables of Table 3 shall be as follows:

Calculus of Harbor Fee (1) is as follows:

$$C_{hf} = \sum_{i=1}^{n}\left(C_{tdi} + C_{hdi} + C_{twi} + C_{dki} + C_{hf} + C_{qri} + C_{hi} + C_{eci} + C_{pbi} + C_{ldi} + C_{etci} \right) \quad (1)$$

i : 1 = port 1, 2=port 2, ... n=port n

C_{tdi} : Tonnage due of Port i
C_{hdi} : Habor due of Port i
C_{twi} : Towage of Port i
C_{dki} : Dockage of Port i
C_{hf} : Husbanding fee of Port i
C_{qri} : Quarantine of Port i
C_{hi} : Line handling of Port i
C_{eci} : Entrance / clearance of Port i
C_{pbi} : Pilot boat of Port i
C_{ldi} : Light due of Port i
C_{etci} : Other port charge of Port i

Calculus of Fixed sailing Cost (2) is as follows:

$$C_{fs} = \sum_{j=1}^{n}\left(D_{shj} * C_{ch} * R_{cu} \right) \quad (2)$$

j : 1 = Section 1, 2= Section 2, ... n= Section n

D_{shj} : Shipping duration of Section i
C_{ch} : 1 Day charterage
R_{cu} : Currency

Calculus of Fixed Staying Cost (3) is as follows

$$C_{fst} = \sum_{i=1}^{n}\left(D_{sti} * C_{ch} * R_{cu} \right) \quad (3)$$

i : 1 = port 1, 2=port 2, ... n=port n

D_{sti} : Staying duration of Port i
C_{ch} : 1 Day charterage
R_{cu} : Currency

Calculus of Fuel Cost (4) is as follows:

$$C_{fu} = \sum_{j=1}^{n}\left(Q_{1dj} * D_{shj} * C_{hfo} * R_{cu} \right) \quad (4)$$

j : 1 = Section 1, 2= Section 2, ... n= Section n

Q_{1dj} : 1 Day fuel consumption of Section j
D_{shj} : Shipping duration of Section j
C_{hfo} : Fuel cost(HFO)
R_{cu} : Currency

Calculus of Incentive (5) is as follows:

$$C_{ic} = \sum_{i=1}^{n}\left(Q_{ldi} * C_{ipi} \right) \quad (5)$$

i : 1 = port 1, 2=port 2, ... n=port n

Q_{ldi} : Loading Amount(TEU) of Port i
C_{ipi} : Incentive per port per TEU of Port i

Calculus of Cargo Handling Cost (6) is as follows:

$$C_{hc} = \sum_{i=1}^{n} (Q_{li} * C_{hpi}) \quad (6)$$

i : 1 = port 1, 2=port 2, ... n=port n
Q_{li} : Loading Amount(TEU) of Port i
C_{hpi} : Handling cost per TEU of Port i

Calculus of total cost (7) could be made by aggregating calculus (1) to (6):

$$C_t = C_{hf} + C_{s} + C_{f} + C_{fi} - C_{i} + C_{hc} \quad (7)$$

4. CASE STUDY

The evaluation model was applied to the route between PUS and USA in order to evaluate the economy of the container route. In particular, two types of models; operating feeders from PUS to TSN and calling directly at TSN out of the route between PUS and USA via TSN were evaluated.

4.1. Definition of Scenarios of Applicable Routes

Applicable routes were developed by 2 scenarios. Route-1 is to start from PUS and return to PUS via TSN, PUS, LGB and OAK. Route-2 is to start from PUS and return to PUS via LGB and OAK but operate feeders between PUS and TSN.

4 types of feeders including 1000TEU, 2000TEU, 3000TEU and 4000TEU were assumed to be operated between the feeder section of Route-2.

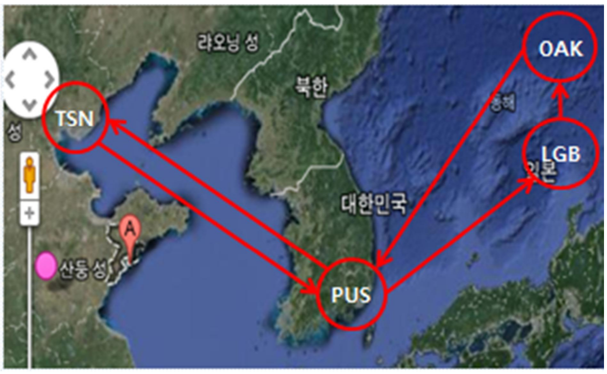

Figure 8: Route 1 Scenario

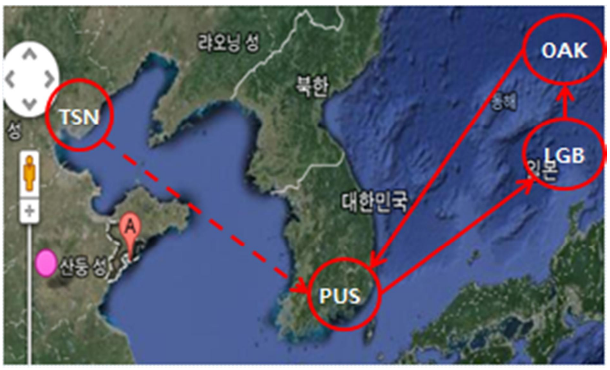

Figure 9: Route 2 Scenario

4.2. Assumption of Application by Scenario

Scenarios of two routes were applied as Table 4. Especially, Mother ship was assumed to be 5,300TEU class and sail at average 15knot speed.

Table 4: 2 Scenarios per Route

Items	Route-1	Route-2
Mother Ship	5,300 TEU	5,300 TEU
Shipping duration	33 days	29 days
Staying Time	4.00 days	2.55 days
Avg. Speed	15 Knot	15 Knot
Fuel Consumption	3,275 tons	2,911 tons
Feeder Ship	n/a	1,000/2,000/3,000 /4,000TEU

4.3. Result of Applying the Evaluation Model

As a result of analysis applying the evaluation model by 2 objective routes, the cost by item was appeared to be as Table 5.

Table 5: Evaluation Results per Items (Unit : 1,000 USD)

Items	Route-1(a) TSN-PUS-LGB-OAK	Route-2(b) PUS-LGB-OAK	Cost Differences (b-a)
Harbor fees(1)	91	37	-54(-59.3%)
Fixed Cost during Shipping(2)	270	240	-30(-11.1%)
Fixed Cost during Staying(3)	21	8	-13(-61.9%)
Fuel Cost(4)	1,966	1,747	-219(-11.1%)
Incentive(5)	3	3	0(0%)
Handling(6) :1,000TEU	599	730	+131 (+21.9%)
Handling(6) :2,000TEU	842	1,089	+247 (+29.3%)
Handling(6) :3,000TEU	1,084	1,452	+368 (+33.9%)
Handling(6) :4,000TEU	1,327	1,816	+489 (+36.9%)

5. INTERPRETATION OF RESULT AND COUNTERPLAN

5.1. Interpretation of Results

The results of economy evaluation according to feeder sizes by scenario were arranged as Table 6 based on Table 5. Namely, aggregation of (1) + (2) + (3) + (4) – (5) + (6) of Table 5 may obtain the result of (7) by feeder size of Table 6

2 scenarios based on Table 6 could be shown by graph as Figure 10. Namely, operating feeders between TSN and PUS as Route-2 is more economical than directly calling at TSN as Route-1 when the container

cargo volume is 1,000TEU or 2,000TEU. On the other hand, a direct calling at TSN and PUS is more economical when the container cargo volume exceeds 3,000TEU at side of shipping company.

Table 6: Evaluation Results per Feeder Ship (Unit : 1,000 USD)

Feeder Ship	Route-1(a) TSN-PUS-LGB-OAK	Route-2(b) PUS-LGB-OAK	Cost Differences (b-a)
1,000TEU(7)	2,944	2,759	-185(-6.3%)
2,000TEU(7)	3,208	3,118	-90(-2.8%)
3,000TEU(7)	3,472	3,481	+9(+0.0%)
4,000TEU(7)	3,736	3,845	+109(+2.9%)

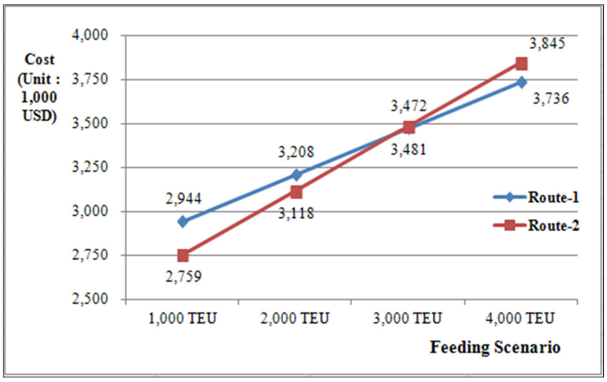

Figure 10: Cost Graph per Scenario

5.2. Counterplan

For the competitiveness of transshipment based container port, the weight of export and import containers of domestic enterprises is important but the competitiveness of port mostly depends on how much they could attract the transshipment cargo volumes of neighbor ports. Thus, a counterplan to maintain the competitiveness in terms of port operating agency and shipping company could be investigated as follows:

First, the transshipment based port operating agencies, for example, government agency or Port Authority under Government shall provide a policy providing a strategic service with which shipping company shall not move their cargos to neighbor ports. According to IMP (2009), the fuel cost which takes the biggest weight out of operational cost of shipping company could be saved by 20% if sailing speed is reduced by 10%. So, they shall reconstruct the ship sail in slow speed. If the symptom of slow steaming by shipping company is found, we need continuously to monitor the shipping liner to choose “Route 1” instead of ”Route 2” .

Furthermore Port Authority has to considering install the fueling facilities which may provide the fuel at cheaper price than those in neighbor ports (Nam, Song and Kim 2006). In other aspect, they need to operate the cargo handling system strategically in order to offer the cheaper cargo handling price. Further, they also need to maintain the docking and storage facilities which may save the waiting time in aspect of service because such systems and services, in turn, may bring an effect to lower the fixed costs of shipping companies by raising the ship usability of shipping companies.

According to Lee and Chang (2011), it was found out that when H shipping company operated the ships at slow steaming of economical speed by adding a ship to 9 ships from 8 ships in Asia-Europe sea route in 2008, the saving effect of sailing cost according to fuel cost saving was bigger than the increase of fixed cost according to additional charterage in case the fuel price is over USD200/ton, HFO average price.

In addition, in aspect of shipping company, they need to prepare and operate a decision making system whether to maintain a direct calling or feeder transportation according to size of feeder cargo volume by closely reviewing the cost system such as the service cost and the fuel cost of transshipment port and neighbor ports. Through this, an implementation of a strategy to select the competitive ports and to operate the ships at slow steaming for saving the fuel shall be important.

The economy evaluation model developed and presented by this study could be utilized as a decision making tool to maintain the optimal service in terms of economy and select the optimal calling ports in order to keep the competitiveness of port operating agencies or shipping companies which operate the ships.

6. CONCLUSION

The world 10 big ports based on container cargo handling volume are concentrated in East Asia container routes and the container handling capacity of each port is rapidly changing. Since the attraction of transshipment cargo volumes between the neighbor ports is directly related to survival and maintaining the competitiveness, such changes are the most significant and interesting matters. Thus, it is very important to decide which port as a transshipment port at the side of port operating agency and shipping company.

This paper developed a model which evaluates the economy for the container routes based on financial data and carried out an economic analysis applying such model to the container routes between PSU and America in East Asia.

According to result of economic analysis, as a result of analyzing the economy between the route which uses TSN as a transshipment port from PUS and a route which uses PSU, TSN, LGB and OAK as direct calling ports, direct calling at PUS and TSN was more economically advantageous in case the transshipment cargo volume at TSN is handled at 3,000TEU ship.

This study also presented a strategic alternative concerning the method to maintain the competitiveness of shipping company utilizing the calculation result by item of this economy evaluation model based on such results. As seen above, applying the economy evaluation model to the container routes shall be helpful for implementing the reasonable and prompt decision making.

Besides, it is, above all, very important to secure the data used as input variables such as harbor fee, cargo handling system and fuel cost timely in order to obtain the correct result from this economy evaluation model.

The economy evaluation model in this study was developed using an offline tool but it shall be possible to make a decision more promptly if the future study establishes an economy evaluation model in online system and utilizes it applying the most recent data in real time. Further, it could be utilized quite favorably in raising the business competitiveness of port operating agencies and shipping companies.

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ANALYZING THE PRACTICAL USE OF LOAD PLANNING MODELS IN INTERMODAL RAIL TRANSPORT

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ABSTRACT
The train loading problem involves determining the positions of outbound containers on trains. This paper analyzes the applicability of load planning models described in scientific literature to the real life situation of an intermodal rail operator. A novel train planning model is presented, combining theoretical models from literature with problem characteristics from practice. Results of the train planning model are compared with the current manual planning process of the intermodal rail operator. Next, the load planning model is adapted to a rolling time horizon. Results demonstrate the added value of an automated planning method as a supporting tool for the planning department of the intermodal rail operator. Applying the train planning model in a rolling horizon approach offers an initial load plan for the whole week and enables the manual planners to have a longer term view.

Keywords: intermodal rail transport, load planning problem, case study, multiperiod planning

1. INTRODUCTION

A further stimulation of intermodal transport is expressed in multiple communications of the European Commission (2009, 2011). An increased use of intermodal rail transport for long-haul transport distances can relieve congested highways and increase the sustainability of our transport system. Bontekoning, Macharis and Trip already emphasized in 2004 the upcoming research field of intermodal rail transport. Many research efforts have been focused on increasing the efficiency and competitiveness of intermodal transport (Caris et al. 2008). An up-to-date overview of current topics in decision making models for intermodal transport can be found in Caris et al. (2013).

According to Boysen et al. (2013) the market share of rail freight transport may be expanded by establishing an efficient freight handling in intermodal terminals. At the operational decision level, the train loading problem involves determining the positions of outbound containers on trains. The following research papers are related to the train loading problem. Feo and González-Velarde (1995) are the first to study the problem of optimally assigning highway trailers to railcar hitches (‘piggyback’ transport) in intermodal transportation. The problem is defined as a set covering problem. The authors apply a branch-and-bound algorithm and a Greedy Randomized Adaptive Search Procedure. Instead of only considering the local trailer assignment problem at a single yard at a single point in time, Powell and Carvalho (1998) introduce network level information to improve decisions made at a local level. The problem is formulated as a logistics queuing network which can handle a wide range of equipment types and complex operating rules. The repositioning of railroad-owned equipment is integrated in this problem formulation. Corry and Kozan (2006) develop a load planning model to dynamically assign containers to slots on a train at an intermodal terminal. The objectives are to minimize excess handling time and optimize the mass distribution of the train. Because truck arrival times are not known in advance, the model needs to be applied over a rolling horizon. The simplifying assumption is made that all containers have equal length. In an adapted version of their model, the authors minimize the weighted sum of number of wagons required and equipment working time (Corry and Kozan 2008). A local search algorithm and a simulated annealing algorithm are proposed to find solutions in a short time span. Constraint programming is applied by Aggoun et al. (2011) to optimize the assignment of containers of various sizes to wagons of a train. Additional constraints related to the handling of dangerous goods and incompatibilities between families of containers are taken into account. Bruns and Knust (2012) introduce additional weight restrictions for the wagons and the whole train in their train loading model. The objective function is a weighted sum which maximizes the utilization of the train and minimizes setup and transportation costs in the terminal. The authors extend their model taking into account uncertainties about input data concerning the wagons of the train and the load units that should be placed on to the train (Bruns et al. (2013). A robust optimization approach is described to increase the reliability of solutions in an uncertain planning environment.

In this paper we analyze the applicability of load planning models described in scientific literature to the real life situation of an intermodal rail operator. Section 2 summarizes factors which determine the efficiency of a load plan. In section 3 a case study is presented in which scientific models are tested and adapted to a practical context in intermodal rail transport. Concluding remarks are given in section 4.

2. EFFICIENT LOAD PLANNING

This section gives an overview of factors that may play a role in drawing up an efficient load plan. First, for each type of wagon, a given number of load patterns are possible (Corry en Kozan, 2008). Each wagon can be divided in a single or multiple slots. The number of slots in a load pattern is equal to the number of containers on the wagon. Each load pattern defines certain length restrictions and weight limits per slot. Also a limit is placed on the entire length and weight of the train. Second, avoiding a double handling of containers can increase the efficiency of a load plan. Double handling arises when a load unit cannot immediately be placed onto another transport mode and needs to be stacked in a temporary buffer location or when changes are made to the load plan in a dynamic context. However, a reduction in double handling may lead to a worse weight balance of the entire train (Corry and Kozan 2006). Thirdly, a load plan may be efficient in terms of wear of the breaks, by minimizing the distance between the centre of gravity and the front of the train.

3. CASE STUDY

The applicability of theoretical models found in literature is explored in a practical case study in which an intermodal rail operator offers daily services along continental connections throughout Europe. In subsection 3.1 the planning context of this intermodal rail operator is first described. Next, in subsection 3.2 a novel train planning model is presented, combining theoretical models from literature with problem characteristics from practice. In section 3.3 this train planning model is applied to the planning operations on a daily and weekly basis.

3.1. Planning context

This case study considers the load planning operations of an intermodal rail operator offering connections between Italy, the Benelux countries, the United Kingdom and the Rhine-Ruhr area. The train planning at a single intermodal rail terminal in their service network is studied.

The company owns and manages its own trains to be able to offer a high service degree to its customers. Only when its own capacity is insufficient or when a certain connection is not offered by the company itself, it will make use of external rail operators. Around 1800 load units of seven different types are available, as summarized in Table 1. The second and third column mention the available number and length of each type of load unit.

Table 1: Type of load units

Type	Nb	Length (metres)
Coil flat – 20 ft and 25 ft	195	6.10; 6.58 or 7.15
Bulk container – 30 ft B	950	9.12
Curtain side swap body – 30 ft	100	9.29
Curtain side swap body – 45 ft	335	13.72 or 13.95
Pallet wide box container – 45 ft	175	13.71
Mega huckepack trailer – 45 ft	10	13.62
Trailer with coil well – 45 ft	15	13.95

For the intermodal connection under study, the company makes use of three different wagon types: 60-feet wagon with four axes, 90-feet wagon with six axes and 104-feet wagon with 6 axes. Each wagon type is characterized by a number of load patterns.

The company offers a daily service on this intermodal connection from Monday until Saturday. The train planning is performed by experienced planners, who take into account the following restrictions. The total weight of a train, including wagons, load units and load content may not exceed 1600 tonnes. The train length is limited to 520 metres. The order of the wagons and wagon types are fixed, as the train is composed first for the intermodal connection in the opposite direction.

The train planners apply a number of rules of thumb. Priority is given to most urgent transport orders with the shortest due dates. Secondly, large transport orders of 45 feet are assigned to 90-feet wagons. Each train also needs to carry a number of containers of a specific customer. These are identical transport orders without a fixed due date. Transport orders for which the load type is not yet known, are planned in advance as a 45-feet load unit and are assigned to a 90-feet wagon. If all 90-feet wagons are already occupied, these transport orders are assigned to 60-feet wagons. If afterwards it appears that these transport orders have been given different load types, the train planning needs to be revised. Bulk containers of 30 feet and 30-feet swap bodies are allocated as much as possible to 60-feet wagons. If this is not possible anymore, they are placed on 90-feet wagons. Load units of 20 and 25 feet are preferably not placed onto 90-feet wagons. The train planning is a dynamic process. The emergence of more urgent transport orders, the fact that planned load units may not arrive in time at the intermodal terminal and new information on the type of load unit of a transport order all lead to changes in the initial train planning.

3.2. Train planning model

In this subsection a binary programming model is proposed for the train planning in this case study. The model formulation is partly based on Corry and Kozan (2008) and is adapted to the specific problem context.

Concerning the objective function, the intermodal rail operator aims to maximize the loading degree of its trains. A minimization of train length is not pursued, as the company prefers to carry an additional transport order with a later due date instead of uncoupling wagons. A minimization of handling costs (cfr. double handlings) is not considered by the planners, as handling operations are the responsibility of the terminal operator and not of the intermodal rail operator. Handling costs are also estimated to be much lower than the cost of an additional wagon set. Therefore the intermodal rail company focuses on the minimization of the number of wagon sets and thus the maximization of the loading degree of each departing train.

The following notation is used to formulate the train planning model:

Indices

i	load unit i (i = 1,… , n)
j	wagon j (j = 1,… , m)
a	load pattern a (a = 1,…, c_j)
k	slots k per load pattern (k = 1,… s_{ja})

Parameters

s_{ja}	number of slots in pattern a of wagon j
c_j	number of possible patterns for wagon j
d_{ijak}	equals 1 if load unit i has same dimension as slot k in pattern a of wagon j, zero otherwise
g_i	weight of load unit i (empty weight and weight of the load)
h_j	empty weight of wagon j
mwg_j	maximum allowed weight loaded on wagon j (excluding h_j)
P_{ja}	priority of load pattern a on wagon j

Variables

U_{ijak}	equals 1 if load unit i assigned to slot k in pattern a of wagon j, zero otherwise
y_{ja}	equals 1 if pattern a is chosen for wagon j, zero otherwise

$$\text{Maximize} \quad 1000 * \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{a=1}^{c_j} \sum_{k=1}^{s_{ja}} U_{ijak} + \sum_{j=1}^{m} \sum_{a=1}^{c_j} (P_{ja} * U_{ijak})$$

Subject to

$$U_{ijak} \leq d_{ijak} \qquad \forall i, \forall j, a = 1, \dots, c_j, k = 1, \dots, s_{ja} \tag{1}$$

$$\sum_{i=1}^{n} U_{ijak} \leq 1 \qquad \forall j, a = 1, \dots, c_j, k = 1, \dots, s_{ja} \tag{2}$$

$$\sum_{j=1}^{m} \sum_{a=1}^{c_j} \sum_{k=1}^{s_{ja}} U_{ijak} = 1 \qquad \forall i \tag{3}$$

$$\sum_{a=1}^{c_j} y_{ja} \leq 1 \qquad \forall j \tag{4}$$

$$\sum_{i=1}^{n} \sum_{k=1}^{s_{ja}} U_{ijak} \leq s_{ja} * y_{ja} \qquad \forall j, a = 1, \dots, c_j \tag{5}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{a=1}^{c_j} \sum_{k=1}^{s_{ja}} g_i * U_{ijak} + \sum_{j=1}^{m} h_j \leq 1{,}600{,}000 \tag{6}$$

$$\sum_{i=1}^{n} \sum_{a=1}^{c_j} \sum_{k=1}^{s_{ja}} g_i * U_{ijak} \leq mwg_j \qquad \forall j \tag{7}$$

$$U_{ijak} \in \{0,1\} \qquad \forall i, \forall j, a = 1, \dots, c_j, k = 1, \dots, s_{ja} \tag{8}$$

$$y_{ja} \in \{0,1\} \qquad \forall j, a = 1, \dots, c_j \tag{9}$$

The objective function maximizes a weighted sum of the loading degree of the train and the use of optimal load patterns. Optimal load patterns receive a high priority P_{ja}, as they make to a maximum use of the available capacity. For these load patterns, P_{ja} is set to 10, while the train utilization receives a weight of 1000. A high loading degree remains the main objective of the company.

The first group of constraints (1) ensure that a load unit is assigned to a slot with a matching dimension. Constraints (2) and (3) guarantee that slots are allocated to at most one load unit and that each load unit is assigned to a single slot. The next group of constraints (4) state that a single load pattern may be chosen for each wagon. Load units may only be assigned to selected load patterns, taking into account the number of available slots in a selected pattern (constraints (5)). A limit of 1600 tonnes is imposed on the total weight of the train by constraint (6). Furthermore, the total weight of all load units assigned to a wagon should be less than the maximum allowed weight for this wagon type (constaints (7)). Finally constraints (8) and (9) define the decision variables as binary variables.

The intermodal rail operator does not take the balancing of weight on the total train into consideration, as wear of the breaks is seen as of minor importance compared to the cost savings of a higher loading degree. The company realizes that a higher degree of cooperation with the terminal operator could lead to an integrated decision making, taking also the minimization of handling costs at the terminal into account when drawing up a train loading plan. A higher degree of integration with the terminal would offer the opportunity to integrate data flows, leading to real-time information. An online status update of the load units at the terminal can further improve the planning process. Currently, the intermodal rail operator can consult a status update of the terminal only every two hours.

3.3. Case study results

Results of the train planning model are compared with the current manual planning process of the intermodal rail operator. This analysis is performed for the planning process of a random day, with the historic data given in Table 2. The first part of table 2 summarizes the number of wagons of each wagon type available on the train. The composition of the train is fixed and depends on the earlier made composition of the train in the opposite direction along the same transport corridor. The second part of table 2 mentions the type and number of load units which were loaded onto the train in the manual planning process. For each wagon type, multiple load patterns are possible. The available number of slots in each load pattern is also an input into the train planning model. The optimal load pattern *a*, allowing a maximal load on wagon *j*, needs to be identified by setting the corresponding parameter P_{ja} to the value of 10.

Table 2: Data day 1

		Nb
Wagon type	60 ft	13
	90 ft	3
	104 ft	4
	Total	**20**
Type of load unit	20 ft	7
	25 ft	5
	30 ft B	14
	30 ft	2
	40 ft	1
	45 ft	11
	Total	**40**

Table 3 compares the manual train planning of day 1 with the exact solution of the train planning model as described in section 3.2. This automated planning is calculated with the optimization software Aimms (www.aimms.com).

Table 3: Train planning day 1

		Manual			**Automated**			
		Slot			Slot			
Wagon	ft	1	2	Opt	1	2	3	Opt
1	60	20	25	0	45			0
2	60	25	20	0	20	20		0
3	60	30	30	1	30	30		1
4	60	30	30	1	30	30		1
5	60	30	30	1	25	30		0
6	60	30	30	1	30	30		1
7	60	20	25	0	45			0
8	60	20	20	0	30	30		1
9	104	45	45	0	20	25	25	0
10	104	45	45	0	20	25	45	0
11	104	45	45	0	30	45		0
12	60	30	20	0	20	20		0
13	60	30	30	1	30	30		1
14	90	30	20	0	45	45		1
15	90	40	45	0	45	45		1
16	90	45	45	1	45	45		1
17	60	30	30	1	30	30		1
18	60	30	30	1	30	30		1
19	104	45	45	0	20	25	40	0
20	60	25	25	0	45			0

Each line in table 3 represents a wagon. The columns indicate the wagon type expressed in feet (ft) and the type of load unit placed in the first, second and third slot in the manual and automated planning. The columns 'Opt' show whether an optimal load pattern is chosen for this type of wagon or not. As the train planning is based on historic data, the same number of load units is planned in the automated planning as in the manual planning. Thus train utilization remains the same. However, the automated planning chooses the optimal load pattern for 10 wagons, compared to 8 times an optimal load pattern in the manual planning. Also time savings are achieved in the planning operations. The manual planning takes around 30 minutes, whereas the exact solution of the train planning model is generated in a few seconds. In the dynamic context of the intermodal rail operator, this time gain can be crucial when changes in the train planning are required.

In table 4, the same comparison is made for a train with an almost ideal composition and high degree of utilization. Both the manual and automated planning select an optimal load pattern for 15 out of 18 wagons. Results for days 1 and 2 indicate that the binary program of section 3.2 adequately solves the train planning problem and may result in considerable time savings for the intermodal rail operator.

Table 4: Results day 2

		Manual			**Automated**		
		Slot			Slot		
Wagon	ft	1	2	Opt	1	2	Opt
1	90	45	45	1	45	45	1
2	90	45	45	1	45	45	1
3	60	30	30	1	20	20	0
4	60	30	30	1	30	30	1
5	60	30	30	1	25	30	0
6	60	20	30	0	30	30	1
7	60	30	30	1	30	30	1
8	60	30	30	1	30	30	1
9	60	25	20	0	30	30	1
10	90	45	45	1	45	45	1
11	60	30	30	1	30	30	1
12	90	45	45	1	45	45	1
13	90	45	45	1	45	45	1
14	90	45	45	1	45	45	1
15	90	45	45	1	45	45	1
16	60	25	30	0	30	30	1
17	60	30	30	1	25	30	0
18	60	30	30	1	30	30	1

In the previous two examples historic data of a manual train planning is used. No changes in train utilization can be measured as the number of available load units is given. In the next analysis, the load planning model is investigated with a rolling time horizon. Historical data of one week are used as a list of available load units that need to be transported. Priorities PD_i are assigned to each load unit *i*, according to its due date. Load units that need to be shipped on the present day receive a priority value of 100. Load units which have to be shipped one day later, get a priority value of 10. All other transport orders with a later due date in the same week, receive a priority value of zero. The automatic planning is run for each day of the week consecutively and priority values are modified after each day. The objective function of the binary programming model is adapted as follows, to incorporate the handling of these priorities.

$$\text{Maximize} \quad \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}}(l_i * U_{ijak}) + 0.1 * \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}}(PD_i * U_{ijak})$$

In the first part of the objective function the train utilization is maximized. However, in this formulation the sum of the length l_i of all loaded units is maximized. In this way optimal loading patterns are already favoured and the second part of the previous objective function becomes redundant. The handling of priorities is maximized in the second part of the new objective function. A weight of 0.1 is assigned to this priority handling. This implies that only if the priority of a load unit is equal to 100, a larger importance is given to urgent transport orders than to maximizing the loading degree of the train. The rolling horizon model also requires a change in constraints (3). Each load unit should now be assigned to at most one slot, as stated in the new group of constraints (10). All other constraints remain the same.

$$\sum_j \sum_{a=1}^{c_j}\sum_{k=1}^{s_{ja}} U_{ijak} \leq 1 \qquad \forall i \qquad (10)$$

Historical data of a single week is used to analyze the use of the train planning model in a rolling horizon approach. Table 5 gives an overview of the number and type of wagons available on each day of this week.

Table 5: Available wagons in rolling horizon approach

Wagon type	Mon	Tue	Wed	Thu	Fri	Sat
60 ft	8	10	14	8	13	11
90 ft	5	7	4	5	5	5
104 ft	5	2	2	5	1	2
Total	18	19	20	18	19	18

The train planning model is run for each day of the week. Load units assigned to a wagon slot are each time removed from the list of available load units for the next planning day. Tables 6 and 7 summarize the results of the manual and automatic train planning. The first row in both tables mentions the number of load units assigned to the train. The unused weight and unused length of the train are given in the second and third row as a percentage of the available capacity. In the automated planning a higher train utilization is realized from Monday to Friday. This results in fewer load units left and thus a high remaining capacity on Saturday (40% unused weight and 70% unused length). The largest difference between both planning methods is observed on Monday. This may be partly explained by the fact that the planners on the first day of the week may not dispose of all information on some load units that will become available later on.

Table 6: Results manual planning of one week

	Mon	Tue	Wed	Thu	Fri	Sat
Nb of load units	31	38	40	36	38	36
Unused weight (%)	22.1	0.7	1.8	10.7	6.3	7.9
Unused length (%)	25.2	8.9	14.1	13.1	9.3	7.1

Table 7: Results automatic planning of one week

	Mon	Tue	Wed	Thu	Fri	Sat
Nb of load units	45	40	42	38	37	17
Unused weight (%)	0.01	0.67	0.48	0.02	0.94	40.29
Unused length (%)	1.7	1.3	1.3	4.1	3.7	70.4

Table 8 gives a detailed analysis of the number of assigned load units in each priority class on each day.

Table 8: Number of assigned load units

Day	PD_i	Manual	Automated
Mon	100	18	24
	10	10	10
	0	3	11
Tue	100	11	23
	10	24	12
	0	3	5
Wed	100	22	14
	10	0	0
	0	18	28
Thu	100	26	18
	10	7	7
	0	3	13
Fri	100	15	15
	10	15	17
	0	8	5
Sat	100	18	7
	10	16	0
	0	2	10

In current practice, the manual planners only look two days ahead. Therefore, fewer load units with a zero priority are observed in the manual planning. Only on Wednesday less urgent load units are shipped to guarantee that these will arrive at the latest on Saturday. Table 8 also shows that the automated planning assigns a higher number of urgent load units to trains on the first days of the week. Results in tables 6, 7 and 8 demonstrate the added value of an automated planning method as a supporting tool for the planning department of the intermodal rail operator. Results should still be interpreted with care, as in reality the planning is highly dynamic. New transport orders may be placed on the same planning day and other load units may not reach the terminal in time to be put on the departing train. However, applying the train planning model in a rolling horizon approach offers an initial load plan for the whole week and enables the manual planners to have a longer term view.

4. CONCLUSIONS AND FUTERE RESEARCH DIRECTIONS

In this paper the applicability of train planning models from scientific literature is tested on a case study of an intermodal rail operator in Europe. The company focuses on maximizing the train utilization, at the expense of handlings costs at the terminal. Load patterns and weight restrictions are taken into account. The company does not consider double handlings, transportation costs of rolling stock at the terminal or changes in pin settings of wagons. A new train planning model is proposed and compared with the manual planning method currently in practice. The new train planning model can provide the train planners with an immediate and efficient solution.

In future research, the use of this train planning model in a dynamic setting should be further investigated, as the planning operations are continuously subject to changes. Another research opportunity lies in the integration of train planning decisions with the other operational decisions at the intermodal terminal, taking into account the cost of handling material. A final research track identified in the case study is the joint planning of multiple trains departing from different nearby terminals from which the intermodal rail operator offers services.

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AN EXPERIMENTAL VALIDATION OF SHIP-TO-SHORE GANTRY CRANE SIMULATOR COMPARING WITH REAL DATA DERIVED BY TERMINAL PORTAINER

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ABSTRACT
The objective of this article is to validate a mobile platform of a ship-to-shore gantry crane simulator named "Chameleon". It can be used for both training and R & D activities.

The simulator has been built to provide an environment for high performance training, but also for basic and applied research, analysing operator performance by means of medical instruments.

The validation has been done comparing the vibration spectra recorded in the simulator platform with spectra recorded in a cabin floor of a true crane located in Cagliari Terminal Container port, measured during task executions.

Keywords: crane simulator, terminal portainer, vibration spectra

1. INTRODUCTION

The objective of this paper is the validation of a mobile platform of a ship-to-shore gantry crane simulator developed at University of Cagliari; it has been named "Chameleon" because it can be used for both training and R & D activities, changing equipments dedicated to measure performance and medical characteristics of crane operators.

Chameleon has been developed by a team composed by some researchers of University of Cagliari (the authors of this paper) and others of University of Genoa.

The aim of the simulator is double:

- regarding training activity, it is to reduce the error of quayside crane operators through training using virtual reality, improving the performances and thus the competitiveness of the port.
- regarding the Research & Development, it is to study physical and mental effects that the position and the work activity have on crane operator, evaluating thus issues of human factors.

Moreover , in container terminals, the gantry crane operators are strongly exposed to latent sources of stress: it depends by the specific task made and of the continuing advances in crane functionality.

This has led to an increasing demand for highly skilled operators in container shipping, a sector that has been experiencing exponential growth for many years now.

So a ship-to-shore gantry crane simulator allows to improve the performances of crane operators, increasing the quality of task and reducing the effect of physical and mental stress: therefore, simulators as Chameleon have to simulate real world as good as possible, regarding crane movements, vibrations, waves and so on.

The simulator has been designed to provide a full immersion environment for high performance training, but also and above all for basic and applied research, monitoring and analysing operator performance by means of electromedical instruments.. The specific activities conducted with the Cagliari simulator (training, research, technological advance) aim to reduce the possibility of accident occurrence, which are largely caused by the onset of fatigue. In this way, it is possible to obtain vibration spectra of linear and angular accelerations over time.

The objective of this paper is to validate Chameleon comparing the vibration spectra recorded in the simulator platform and in cabin floor in a true crane located in Cagliari Terminal Container port measured during task executions.

2. CHAMELEON SIMULATOR

The quay crane simulator "CHAMELEON", is an innovative system designed for the purpose of solving human factor related problems (sight, ergonomics, anthropometrics etc.) associated with quay crane operator tasks, as well as for conducting advanced training activities

Chameleon simulator is located in a 40 ft High Cube container (purposely chosen for its internal height of 2.70 m, higher than a standard ISO container, allowing more space for designing the main platform). This minimizes the time required to prepare training and research sessions, providing on site training services for container terminal operators.

Figure 1: Traditional dynamic cockpit and graphic interface of the quay crane simulator

Figure 2: Brieda dynamic control station currently installed in the Chameleon simulator

As every kind of existing simulators for training a crane simulator is composed by 5 main components:

1. cabin interface(cockpit): it reproduces with fidelity the real place operator, composed by seat and cockpit (commands, two manipulators, one for movement and the other for elevation of the system spreader-container). It is usually positioned on a motion platform (3 degrees of freedom) that allows the operator to receive, not only visual and audio stimulation, but above all to perceive movement sensation. Platform is build with actuators under the cabin that provide movement based on input from the user and operative conditions. The motion system simulates real vibrations and collisions.
2. highly immersive basic CAVE (consisting of the four display screens-drapes, two side, one in the front and one inclined on the floor to ensure continuity of the virtual image) that provides the trainee with 270° horizontal and 120° vertical fields of vision.

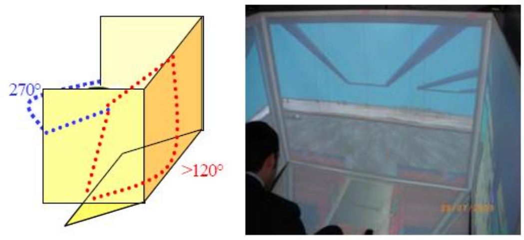

Figure 3: Trainee field of vision

3. Operative trainer interface: it is axternal to the operator cabin, it's provided with monitors to observe the training session phases. From the trainer observatory it is possible:
   - to reproduce different simulation scenario, with several weather conditions (wind, rain, sun, etc.), daytime (day with sunlight, night with artificial light) and general (the selection of the different set up allows to alternate several scenario, with different ships configuration harbors and equipments as different kind of spreaders);
   - for the instructor to repeat the trainee test with the same conditions in case of failed scenario or to analyze mistakes;
   - to provide scenario with growing level of difficulties if the trainee shows improvements.

Figure 4: Instructor workstation

4. visual system: it reproduces the real environment by screens projection.
5. audio system: it reproduces sounds effects produced by vibrations (movement of the crane cabin on the portal), collisions, wind.
6. central operative system: the “brain” of the simulator, it controls operations and provides different simulation scenario

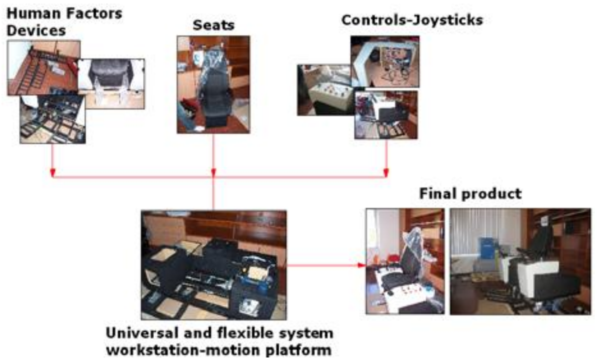

Figure 5: Interchangeability Concept of the Integrated Seat-Pulpit System of the Cagliari portainer simulator

This high-tech and completely original simulator, able to satisfy the real requirements of the cargo handling sector, is equipped with highly versatile and flexible hardware and software and differs from all other quay crane training simulators currently in use in other centres. In fact with the Chameleon, operator training can be tailored to all types of control stations and existing crane types.

Evidence of its great versatility, is its current configuration for accommodating two different types of control stations: the traditional type and the innovative dynamic control station manufactured by Officine Meccaniche Brieda, as shown in fig. n°2.

Figure 6: Electro-medical instruments

The simulator has been designed to conduct three different activities:

- Research: studies of human performance under different operating conditions through objective medical parameters (EEG, ECG, EMG plots, goniometer, Inclinometer, Accelerometers, Eye tracker, etc.) as well as by means of standard procedures already used for fatigue testing in the field;
- Technology advancement: applied research activities and validation of new design options for the crane command and control systems, aimed at enhancing operator performance and thus at optimizing the man-machine interface;
- Training and refresher training for crane and truck-trailer drivers in port terminals.

3. THE METHOD

The measurements were carried out on 6 points of measurement shown schematically in figure below. The use of measurements on three axes is under the operator's seat has allowed to evaluate the absorption by vibration of the mass located between the support structure and the seat.

For the measurements were used six accelerometers; they have been positioned on the support structure of the seat, so as to be able to acquire the values along the three axes and calculate the rotation values with simple arithmetic operations.

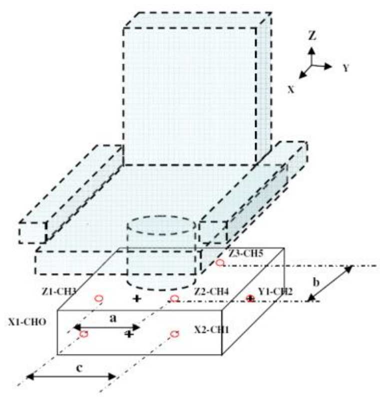

Figure 7: Location of six accelerometers

First analysis was performed of the work cycle of loading-unloading of the crane gantry, thus identifying four basic stages:

- Phase 0: positioning of the spreader, locking and lifting the container from the dock
- Phase 1: Progress of the spreader, coupled with the container from the quayside to the ship
- Phase 2: Place the container, releasing the spreader
- Phase 3: Return of the spreader toward the dock and the beginning of the next cycle

The data were obtained with a scanning speed of 2000 data / s; for each linear and angular acceleration component have been reported the maximum values obtained and the RMS values refer to successive samples of data in 1000 and evaluated for an entire work cycle. In this way it was possible to highlight the critical values of the accelerations during the various stages.

For data acquisition we have used six single-axis accelerometers, IEPE cubic Dytran series 3097; it is a cube miniature titanium from 0.4 inches to the side, weight 4.3 grams, low noise electronics JFET, circuit TEDS.

During two days tests, a set of data about the movements of a portainer cabin have been collected: using six Accelerometers IEPE (Integrated Electronic Piezoelectric), all vibrations spectra along three axes: x, y and z, have been recorded. They have been placed at the crane operator seat base, for measuring the accelerations along:

- X axis for cabin frontal movement;
- Y axis for cabin lateral movement;
- Z axis for cabin vertical movement.

Data have been collected respect to wind speed, crane movements, container weight and so on. Tests have been made at the beginning of the work shifts of Cagliari terminal container: each test session is gone on for two hours and 30 minutes. The details of test are:

- Test 1: from 7,00 a.m. to 9,30 a.m.;
- Test 2: from 3,00 p.m. to 5,30 p.m.;
- Test 3: from 7,00 p.m. to 9,30 p.m.

Globally, 103 cycles have been measured: each cycle represents a complete movement to load or unload one container from ship to shore.

The acquisition of data in separate periods of the day and in different shifts allowed the assessment of any changes in the results caused by different "styles" of work of operators and crane operators from different environmental conditions (eg day / night or intensity of the wind).

Regarding data collected in Chameleon simulator, data have been acquired with the same methodology, placing the 6 accelerometers symmetrically in groups of three along the three main axes X, Y, Z, positioned at the base of the chair of the operator.

4. RESULTS

First of all, for each measured cycle , it has been recorded the RMS (Root Mean Square) for each axis, defining the minimum and the maximum of the acceleration wave; then, the mean between maximum acceleration values of X, Y and Z have been calculated.

The minimum and maximum values of three axes, have been reported in the table below:

Table 1: Min and Max acceleration wave for crane

	acceleration wave $\frac{m}{s^2}$		
	X	**Y**	**Z**
Min	0.02	0.02	0.01
Max	1.68	2.11	2.71

Same survey has been made in Chameleon simulator for recording same data at the same way. The minimum and maximum values of three axes, have been reported in the table below:

Table 2: Min and Max acceleration wave for Chameleon

	acceleration wave $\frac{m}{s^2}$		
	X	**Y**	**Z**
Min	0.01	0.02	0.01
Max	0.35	0.39	0.83

The results show as the platform of Chameleon simulator repeats quite well all movements of a real gantry crane.

The results show some interesting issues, particularly regarding the comparison of average of values of acceleration for each axis:

- comparing of spectra shape and so the profiles of wave recorded during simulator and quay crane tests are well fitting and very similar. The waveform shapes are similar, the points of minimum and maximum are located in the same position and there are the same proportions between peaks. The qualitative drawing of single spectra wave for three axes (X, Y and Z) are quite similar with the work cycle structure of a portainer.
- regarding the real values of spectra acceleration for medium wave, the simulator platform has a similar behaviour respect to real cabin crane; analysing each axes.
  - for X axis, the differences between simulated and real acceleration are low and not more than 0,2 m/sec^2; the spectra of Chameleon are regular instead the spectra of true crane have irregular shape.

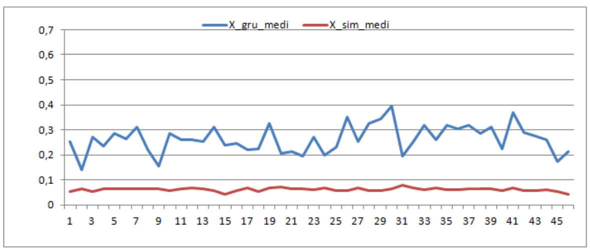

Figure 8: Comparison of spectra for X axis;

  - for Y axis, the differences are smaller than X axis and differences of real values are less than 0,1 m/sec^2; looking the profiles of spectra for chameleon and true crane, there is nearly a coincidence of values in the shape: in some points two lines coincide.

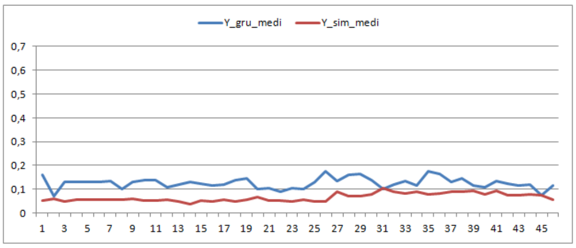

Figure 9: Comparison of spectra for Y axis;

– for Z axis, the differences are bigger than two previous cases (medium values about 0,25-0,3 m/sec^2). Infact, in the first part of spectra, there is little difference between the real and simulated acceleration, but in the second part they increase. The differences between the two spectra are less than 0. m/sec^2 in the first part, while in the second part the trend is similar except for some cycles where the differences reach 0.3-0. m/sec^2. The evolution of the spectra is quite similar in both cases: it is rather uneven.

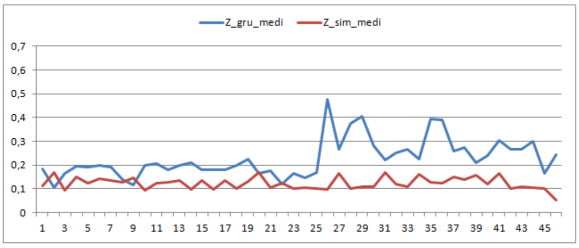

Figure 10: Comparison of spectra for Z axis;

Comparing the average of maximum values of each cycle, obviously the differences between real and simulated accelerations are higher than medium values:

- for X axis, the waveform shapes are similar and differences between real and simulator values are about 0,7-0,8 m/sec^2;
- for Y axis, differences are smaller than the previous case(less than 0,3-0,4 m/sec^2, but some cycles present high peaks);
- for Z axis, there are some differences evaluated in 0,4-0,5 m/sec^2.

There are many reasons for explaining these differences between real and simulator data:

- high values of the acceleration data recorded for cabine crane can be caused by wind: infact during registration only the average wind speed has been observed, not the peak values;
- the cranes used for real tests are fifteen years old: during movements for loading/unloading containers, they suffer high vibrations caused by work use. Probably using a new crane, those high acceleration values would be lower.

5. CONCLUSION

The work carried out has allowed us to deepen the basic knowledge and the trend of the spectra of vibrational waves that develop in the cockpits of the gantry crane of the industrial port of Cagliari during the course of loading and unloading. As for the simulator, it was the first test and thus made it possible to gather information necessary for its future development and improvement.

The spectra of vibrations produced by the simulator have a trend similar to the real (referring to a single work cycle) ; if one considers the qualitative trend of the spectrum (ie, the trend of the peaks and the design of the spectrum), for both the X axis and for that of Y and Z, the shape can be considered very close to the real performance. In the transition from one phase to another is maintained the right proportion in the sequence of lows and highs and keeps track of the maximum (for all three axes), as well as on the real crane, in moments of "loading" and "unloading".

The simulator encounters some difficulties as regards the intensity of the accelerations to be produced: the average of the oscillations vibrational force was lower for a delta of 0.4 m/sec2. This difference is visible to the X and Y axes while the Z axis of the delta difference is smaller.

Therefore, it is suggested, first, to calibrate the platform of the simulator with the new spectra. Also it would be useful to provide the mechanism or a fifth horizontal piston or of a system of sub-woofer in order to make more marked oscillations along the horizontal (ie, along the axes X and Y).

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DIRECT MODELING OF QUEUING SYSTEMS AND NETWORKS

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ABSTRACT
Queuing theory has numerous applications in the organization of production, analysis of information processes, transport problems, health care, military-technical tasks, etc. This report shows a clear lack of traditionally used GPSS simulation technology for the purposes indicated and features that are useful for direct imitation.

Keywords: queuing theory, simulation.

1. INTRODUCTION

In various areas of technology, in the organization of production and in the military there is a need to solve peculiar probability problems related to queuing systems of different types of requirements. This concept involves multiple recurrence of situations (many arrivals in and served requirements, a large number of using similar systems) and the statistical stability of the situation. The scope of its potential applications, in particular, include:

- in communications technology - the design of telephone and computing networks, analysis of communication protocols;
- in transport problems - analysis of traffic passing through a tunnel, the technical inspection of motor vehicles, the formation of trains, airport takeoff and landing, loading and unloading of ships at the sea and river ports;
- in the industry - the planning of assembly operations, flexible automated production, organization of equipment repair;
- in automated systems - evaluating waiting time of demands for computational work and preparation of data, processing the results of experiments, technology control;
- in health care - in determining the required number of hospital beds, stations and ambulances, doctors and nurses, needs in diagnostic and therapeutic equipment;
- in the judiciary - its staff size, capacity of corrective labor institutions, investigative staff headcount and operatives;
- in the field of science and education - the study of certain types of physical processes (registration of elementary particles, filtration, diffusion), launch the satellites, satellite data processing, calculation of the number of laboratory facilities; design and analysis of large libraries working;
- in the military - design of air-defense systems (each target can be regarded as "demand" on the service, i.e. firing), the organization of border security, based patrol outfits and in many other cases, such as those described above in relation to daily activities and combat troops .

Immediately, we emphasize that these types of problems have to be solved not only in the design of the newly created queuing networks and systems (QN, QS), but also in the available service - with increasing load; changing complexity of the processing; of failure, degradation or upgrading technology; reducing staff; revising requirements for expediting the processing of demands, etc.

2. SIMULATION MODELING IN GENERAL

Simulation modeling is the computer playing of the simulated system "life". It discusses its behavior by the set of algorithms for each type of event. The control program monitors the events preserving the sequence of their occurrence in modeling time, and then processes the accumulated statistics.

With the ability to sufficiently complete reality reflection (for example, a multi-stage service, inhomogeneous flows, channel locks because of the buffer limited capacity, a complex systems of priorities and other service disciplines, heterogeneous resources) simulation is applicable to problems irreducible to analytical and numerical methods, and complexity of the problem does not create any principal difficulties. Simulation is indispensable for testing new numerical and analytical techniques. In particular, author used it when developing approximate numerical methods for the analysis of systems with random selection from queue, of multi-level priority queues with a quantized service, as well as for systems and networks with "negative" demands and with impatient ones. The disadvantages of simulation are:

- high consumption of computer time;
- low accuracy of the probabilistic characteristics of rare events;
- difficulties of the system optimization (search of the optimum is conducting in the presence of random errors in the results);
- difficulty in obtaining general conclusions and recommendations.

Very popular belief that the problems of accuracy and optimization can be solved by increasing the number of tests. The table 1 shows his insolvency by calculating the number π using statistical tests – as a fraction of points in the circle inscribed in the unit square.

Table 1. Error in determining the number π by statistical tests

N	δ	N	δ	N	δ
1 000	9.8e-2	50 000	2.8e-3	2 000 000	-1.4e-4
2 000	8.6e-2	100 000	8.3e-3	5 000 000	-1.0e-5
5 000	5.6e-3	200 000	4.3e-3	10 000 000	2.9e-4
10 000	1.8e-2	500 000	4.3e-3	20 000 000	4.2e-5
20 000	2.2e-3	1 000 000	2.0e-3	50 000 000	1.2e-4

Simulation modeling on high level languages PL/1 and FORTRAN is very time consuming for the following reasons:

- due to the increasing complexity of the simulated systems the number of elements and monitored processes is constantly increasing;
- simulation models are difficult to debug because of the rich logic, mutual dependence of the algorithm branches, very time consuming runs and low accuracy of the results, in some cases able to hide an error;
- even minor changes in the model may require many corrections to the program and its debugging nearly over.

The solution may be using some standard schemes as models for general classes of systems. Modeling languages allow to write the simulation program in a form that resembles the description of the simulated system, and in such a way that small changes in the system behavior correspond to small changes in the program. It provides, having a minimum experience, fast writing and debugging of the simulation programs. The most known such systems are GPSS and its analogs. Undoubted advantages of modeling languages are:

- Simplification of the model description.
- Avoiding the programmer from many technical details.
- Automatic control of input program syntax correctness.

Established in the early 1960s. general-purpose simulation system GPSS to this day remains the most popular language in the world of simulation. It was used in the learning process by more than 100 Russian universities. GPSS program is a description of the trajectory of the message ("TRANSACT"). It contains the names and the order of used "facilities" (service devices) or "memories"; delays; logical conditions governing promotion of transacts; waypoints, where data collects about waiting time, etc.

The general rule of new software using is its testing on the problems with the known solution (preferably - analytic). For the M/M/1 system the theoretical queue length is $q = \rho^2 / (1-\rho) =$ 0.9^2 / (1-0.9) =8.1. Average waiting time *w* according to a Little's formula must be q / λ and in this case ($\lambda = 1$) is numerically equal to the average length of the queue. Theoretical probability of the idle system is $1 - \rho = 0.1$. Therefore, on average a tenth of the applications should receive services without delay.

Table 2.Testing GPSS / W on the M/M/1 model

Index	Theory	Thousand of tests		
		50	200	500
Load factor	0.900	0.896	0.897	0.899
Average service time	0.900	0.899	0.902	0.901
Number of inputs		49843	199042	499032
Of them with zero expectation		5340	21001	50691
Average queue length	8.100	5.132	5.757	6.690
Average waiting time	8.100	5.148	5.785	6.703

Results associated with the expectation are improper. The reason for this can be only one: an insufficient quality of the pseudorandom numbers generator.

Finally, we discuss the temporal characteristics of the compared model realizations. To achieve the level of the timer 500 000 (and approximately the same number of served transacts) it was needed 187 seconds. The run of relevant FORTRAN program for the same raw data gave an average queue length 8.683 - much closer to the theoretical estimate, than the best of the results in Table 2. The run took only 6.26 seconds. Such a large difference is the natural price to pay for the versatility of GPSS interpreter.

The mentioned system is a very valuable tool simulation, free from the constraints of analytical and numerical methods, rather "transparent", allowing non-standard data processing and removing from the programmer the set of nontrivial problems of program writing and debugging. It has, however, several serious drawbacks:

1. The cumbersome of the system and excessive manifold primitives.
2. Lack of conceptual unity. In confirmation, we refer to the difference in treatment the elements of the matrix with a simple link and value changing.
3. Unsuccessful designations for relational operators L, G, E (it would be better to concord them with FORTRAN); SQR function is used for the square root (in Pascal this designate “square”); the state of logical keys is described as SET and RESET (literal translation - "installed" and "re-set") instead of ON, OFF; operand RE (the traditional meaning - the repetition of an action) means the removal, and it would be better to use DEL.
4. Prohibition to interrupt "the memories" (they can be used to model multi-service devices and, therefore, will be subject to interruptions).
5. Non-possibility to change the type and layout of graphs scales, as well as color and texture of the lines, making them indistinguishable from each other and/or the background in black-and-white output.
6. The argument of graphs may be the time only, so that the probability distribution of the system states can’t be presented automatically. By the way, this will necessarily require a logarithmic scale, the implementation of which is missing.
7. Opportunities of the formal optimization models are of questionable value because in real-world problems solving:
    - the number of channels in the network nodes is integer;
    - channels productivity is selected from a finite set of allowed values;
    - restrictions are imposed on the elements of a routing matrix numerous, reflecting processing technology.

3. DIRECT SIMULATION

Simulation environments solve the limited range of opportunities in principle, but due to excessive claims of the developers to universality they form the redundant programs with big time consuming. However, any simulation algorithm can be written on the usual procedural oriented programming language. Hence, there remains the need to write direct modeling programs on the languages such as modern FORTRAN. This applies in particular to learning in higher education, the purpose of which should be not the mastering of technologies, but the clarification of principles. Benefits of direct modeling are:

- no need for special software and its studying;
- «transparency» of model logic;
- the availability of built-in functions, library routines, statistical analysis tools, editing output and other features usually provided by a general-purpose programming systems;
- no restrictions on the model composition and logic;
- possibilities to control the experiment - in particular, to implement methods to reduce results variance.

Direct simulation model allows the developer to supplement the typical model logic by the special techniques that increase modeling efficiency. Of these, we consider the following:

Hierarchy of chains of events.

- Using the SELECT operator.
- Creation of specific models.
- Looped chain of events.
- Separate random number generators (RNG).
- The logarithmic scale of outputs.
- Variance reduction methods.

Chain of planned events include moments of various kinds of events: the arrival of demands (perhaps, from several independent sources); arrival of "negative" demands changing the logic of current services; service ending; exhausting application patience, etc. Note that the ordering within the chains is generally not necessary. Hierarchy of the chains of events is administered by the separately chains for each species, the choice of the nearest for each type and then comparing the lows to control the SELECT statement to assign option for nearest event processing. This further reduces the total redundancy, since each type of event is associated with processing of only a few chains. Using of SELECT greatly simplifies the program logic, eliminating complex structures with conditional statements.

An example of a specific model is the multi-channel system with interrupting priorities, which is beyond the capabilities of GPSS. Its feature is the need for a demand’s passport which contains demand type, moment of its arrival, needed service time (for interrupted ones - residual duration), moments of the service completion (for being serviced), etc. - depending on the purpose of modeling. First n positions of the array of passports present the demands in the service channels, the rest ones – in the queue. In the n-th position of the array of passports whenever you update the situation in the channels for full buzed system is convenient to put the "least respected" demand - the first candidate to interrupt. This simplifies the handling of the respective event.

Looped chains of events are convenient because when retrieving service requests do not need to shift array of passports stored in the queue: it is enough to adjust the pointers to the head and tail of the queue (when arriving application - only on the tail). Of course, this is required the overflow control using the current values of the number of entities in the system. It must be compared with a maximum length of the queue defined before the model is run.

Important condition for the correctness of the simulation is the independence of random variables of each type - the interval between applications, service time, type of applications, the successor node in the network of service, etc. The independence is achieved by using for their generation the separate RNG. For the convenience of a software implementation, it should be a kind of multiplicative generators with a common factor, but different initial values. It is required to guarantee the disjointness generated series, but constructive advices on the matter are missing in the literature. Mentioned problem can be solved by dividing the period of the generator (for a good RNG it is 2^{m-2}, where m is the number of bits) for the required number of generators and take as the initial values the corresponding numbers. To obtain these properties an algorithm can be applied which accelerates getting a random number p, based on the binary representation of its number k:

```
subroutine fastrand(k,p)
   integer k,p
   integer x0, z, j, j1 ,j2
   data x0 /57539/
   j=k; p=x0
   z=1220703125
   do while (j>0)
      j1=j/2; j2=j=2*j
      if (j2==1) p=p*z
      if (p<=0) then
         p=(p+2147483647)+1
      end if
      z=z*z
      if (z<=0) z=(z+2147483647)+1
         j=j1
   end do
end
```

In it as the current “prefabricate” p, and the degree of the factor z are dividing up on the generator module 2^{31}. Exponentiation is performed at each step, and the multiplication by p - an average of half steps, which gives the estimate of complexity the k-th number obtaining $\frac{3}{2}\log_2 k$ of multiplications. Note that the logarithm of a billion does not exceed 30. Algorithm is applicable to any initial values and multipliers and (after an obvious modification) – to any generator module. The formed integers are divided into generator module to receive the standard $\{U_i\} \in [0,1)$.

Simulation modeling is usually associated with a progressive build-up of the number of trials - preferably in a single run with the issuance of the test results in the points of logarithmic scale. Typical construction of a simulation model is the cycle WHILE which contains the choices controlling. Immediately before the end of said cycle the fragment can be inserted which multiplies after completing each order interval for m by 10:

```
if (n>n1) then
   k=mod(n,m)
   if (k==0) then
      k=n/m
   if (k==1.or.k==2.or.k==5.or.k==10)
then
      print *, ' n = ', n
      <  output  t  of  the  desired
      results >
      n1=n
      if (k==10) m=10*m
      end if
   end if
 end if
```

Promising research in the field of simulation is the application of results variance reduction. Here we will discuss the most effective ones.

We illustrate the use of estimates with the smallest variance by two examples. With a Poissonian flow input the calculation of the stationary probabilities of the system states can be done by counting the multiplicity of states observation or through the total time spent in them (according to theorem PASTA, the received estimates must match). The latter option is preferable already by "philosophical" reasons. Another object of this kind - the calculation of moments of distribution of demands sojourn time in the network, either directly or as a convolution of the statistical moments of waiting and reliably known a priori service time distribution. In the second method one of the sources of statistical error is eliminated.

The method of antithetic variables is to use random number generators with negatively correlated results that can be obtained in different ways:

- through the "somersaulting unit" (the alternating use of *U* and 1-*U*);
- using complementary initial settings of the generators,
- by the crossing (in different runs) use of generators for intervals between arrivals and service times.

Authors did not deny the appropriateness of popular simulation environments in practical problems of particular complexity. However, in our opinion, in the fields of university education and research the using of direct modeling with the languages like modern FORTRAN is preferable. The techniques described above will help make it easier and more efficient.

3. CONCLUSION

Authors did not deny the appropriateness of popular simulation environments in practical problems of particular complexity. However, in our opinion, in the fields of university education and research the using of direct modeling with the languages like modern FORTRAN is preferable. The techniques described above will help make it easier and more efficient.

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NETWORK DEA APPROACH TO ASSESSING THE EFFICIENCY OF SHIPS PROCESSING AT A CONTAINER TERMINAL

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ABSTRACT
The processing of ships at a container terminal is divided into two stages, namely Berthing and Loading/Unloading. Both stages use labor and time as inputs. The Loading/Unloading stage also uses other resources, such as Quay and Stacking Cranes and other material handling equipment. Each stage has its own outputs. Thus, the outputs of the Berthing stage are the ship characteristic data, such as the Tonnage, Length and Depth. The single output of the Loading/Unloading stage is the number of TEUs loaded and unloaded. An input-oriented, parallel-process network DEA model is proposed to compute the overall system technical efficiency together with labor and time targets. A cost minimization network DEA model is also proposed so that the cost efficiency of previous ships processing can be assessed and a minimum cost resource allocation can be computed for an arriving ship. The proposed approach is illustrated on a real-world dataset.

Keywords: ship calls, time in port, network DEA, cost efficiency

1. INTRODUCTION

Data Envelopment Analysis (DEA) is a non-parametric technique widely used to assess the relative efficiency of a set of comparable units referred as Decision Making Units (DMUs). DMUs use certain inputs to produce certain outputs. There are many studies that have used DEA to study the efficiency and productivity change of seaports and container terminals (e.g. Barros 2006; Wang and Cullinane 2006; Lin and Tseng 2007; Lozano 2009; Lozano et al. 2011; Barros et al. 2012, Bang et al. 2012; Chang 2013; etc). DEA has also been used to measure the efficiency and productivity change of shipping companies and container shipping lines (Managi 2007, Gutiérrez et al. 2014) as well as the performance of shipbuilding yards (Pires and Lamb 2008). There are not however, to the best of our knowledge, DEA studies of the efficiency with which individual ships are processed at container terminals.

In this paper a DEA approach is proposed to assess the efficiency of these port operations. Specifically, a network DEA approach is used. Contrary to conventional DEA, which considers a DMU as a single, aggregated process (like a black box), network DEA considers different stages or sub-processes within the DMU, each stage consuming its own inputs and producing its own outputs and, in some cases, with internal flows between the stages. The literature on the theory of network DEA has grown rapidly in the last few years (e.g. Kao 2009a, 2009b; Tone and Tsutsui 2009, 2014; Fukuyama and Weber 2010; Lozano, 2011; Lozano et al. 2013, etc). The applications of network DEA have also increased, including transportation, with the most relevant being the two-stage supply chain model for measuring container terminal efficiency of Bichou (2011) and the two-stage network DEA approach to container shipping lines of Lozano et al. (2012).

The structure of the paper is the following. In Section 2, the proposed parallel-processes network DEA approach is presented and the corresponding technical efficiency model formulated. In Section 3, a minimum cost network DEA model is also introduced with the aim of estimating the optimal resource allocation and time-in-port for an arriving ship. Section 4 presents the results of the application of the proposed approach to a real-world dataset. Finally, in Section 5, the main conclusions of the study are drawn and further research outlined.

2. PROPOSED PARALLEL-PROCESSES NETWORK DEA APPROACH

In this section, a parallel-processes network DEA approach to container ships processing is presented. It considers that the processing of a container ship consists of two stages: Berthing (B) and Loading/Unloading (L/U). Although these two stages occur sequentially within the temporal dimension the corresponding network approach is deemed a parallel-processes one in the sense that the two stages have common inputs but there are no intermediate products that are produced in one stage and consumed in another. Thus, as shown in Figure 1, both Stages B and L/U use LABOR and TIME inputs. In addition, Stage L/U uses Quay Cranes (QCRANES), Stacking Cranes (SCRANES) and Automated Guided Vehicles or similar Shuttle Vehicles (SHUTTLES). In addition, Stage L/U consumes storage space. This is included through a non-discretionary input that represents Storage Space Availability (AVAILSS). Other resources used in either stage may be included if the corresponding data are available although that is not necessary if the amount of the resource consumed by a ship is constant for all ships (e.g. if one tug is used by every ship). With respect to the outputs of each stage, those of Berthing are the main data about the characteristics of the ship such as Gross Register Tonnage (TONNAGE), LENGTH and DEPTH while the output of Loading/Unloading is the total number of TEUs loaded and unloaded. The outputs of both stages are non-discretionary and, together with the non-discretionary input AVAILSS, can be handled as proposed in Banker and Morey (1986).

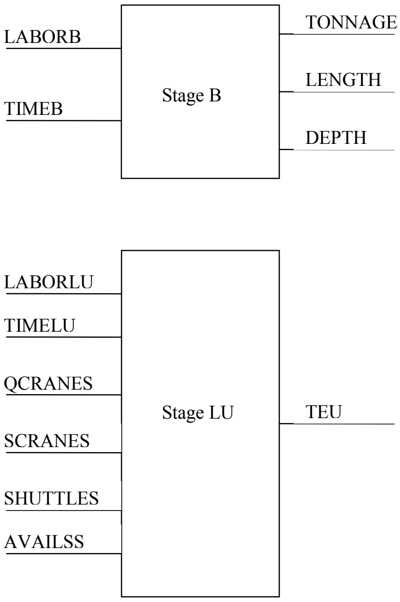

Figure 1. Inputs and outputs of Berthing and Loading/Unloading stages of a ship call

A conventional DEA approach would consider a single, aggregate process as shown in Figure 2 where LABOR and TIME correspond respectively to the total labor and time inputs of a ship, i.e. the sum of those of its two stages.

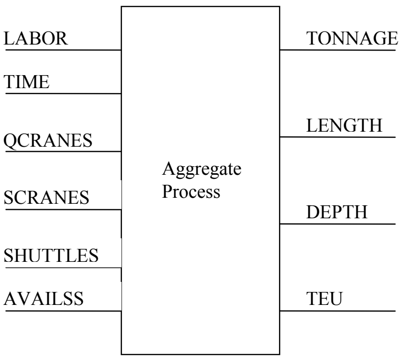

Figure 2: Inputs and outputs of a ship call considered as a single process

Before formulating the proposed input-oriented relational DEA model, let

n number of DMUs
$j,J=1,2,\ldots,n$ indexes on the DMUs
$LABORB_j$ input LABOR of stage B of DMU j
$TIMEB_j$ input TIME of stage B of DMU j
$LABORLU_j$ input LABOR of stage LU of DMU j
$TIMELU_j$ input TIME of stage LU of DMU j
$QCRANES_j$ input QCRANES of stage LU of DMU j
$SCRANES_j$ input SCRANES of stage LU of DMU j
$SHUTTLES_j$ input SHUTTLES of stage LU DMU j
$AVAILSS_j$ non-discretionary input AVAILSS of stage LU of DMU j
$TONNAGE_j$ non-discretionary output TONNAGE of stage B of DMU j
$LENGTH_j$ value of the non-discretionary output LENGTH of stage B of DMU j
$DEPTH_j$ value of the non-discretionary output DEPTH of stage B of DMU j
TEU_j value of the non-discretionary output TEU of stage LU of DMU j

The corresponding input-oriented Variable Returns to Scale (VRS) single-process (SP) DEA model for a certain DMU 0 is

SP DEA model

$$\text{Min} \quad \theta_0^{SP}$$

s.t.

$$\sum_{j=1}^{n} \eta_j \cdot LABOR_j \leq \theta_0^{SP} \cdot LABOR_0$$

$$\sum_{j=1}^{n} \eta_j \cdot TIME_j \leq \theta_0^{SP} \cdot TIME_0$$

$$\sum_{j=1}^{n} \eta_j \cdot QCRANES_j \leq \theta_0^{SP} \cdot QCRANES_0 \qquad (1)$$

$$\sum_{j=1}^{n} \eta_j \cdot SCRANES_j \le \theta_0^{SP} \cdot SCRANES_0$$

$$\sum_{j=1}^{n} \eta_j \cdot SHUTTLES_j \le \theta_0^{SP} \cdot SHUTTLES_0$$

$$\sum_{j=1}^{n} \eta_j \cdot AVAILSS_j \le AVAILSS_0$$

$$\sum_{j=1}^{n} \eta_j \cdot TONNAGE_j \ge TONNAGE_0$$

$$\sum_{j=1}^{n} \eta_j \cdot LENGTH_j \ge LENGTH_0$$

$$\sum_{j=1}^{n} \eta_j \cdot DEPTH_j \ge DEPTH_0$$

$$\sum_{j=1}^{n} \eta_j \cdot TEU_j \ge TEU_0$$

$$\sum_{j=1}^{n} \eta_j = 1$$

$$\eta_j \ge 0 \quad \forall j \qquad \theta_0^{SP} \text{ free}$$

An alternative DEA approach would be to consider the two stages B and LU separately and assess their efficiency as if they were independent processes. The corresponding input-oriented DEA models would be

Stage B DEA model

$$\text{Min} \quad \theta_0^{B}$$

s.t.

$$\sum_{j=1}^{n} \lambda_j \cdot LABORB_j \le \theta_0^{B} \cdot LABORB_0$$

$$\sum_{j=1}^{n} \lambda_j \cdot TIMEB_j \le \theta_0^{B} \cdot TIMEB_0$$

$$\sum_{j=1}^{n} \lambda_j \cdot TONNAGE_j \ge TONNAGE_0 \qquad (2)$$

$$\sum_{j=1}^{n} \lambda_j \cdot LENGTH_j \ge LENGTH_0$$

$$\sum_{j=1}^{n} \lambda_j \cdot DEPTH_j \ge DEPTH_0$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \ge 0 \quad \forall j \qquad \theta_0^{B} \text{ free}$$

Stage LU DEA model

$$\text{Min} \quad \theta_0^{LU}$$

s.t.

$$\sum_{j=1}^{n} \mu_j \cdot LABORLU_j \le \theta_0^{LU} \cdot LABORLU_0$$

$$\sum_{j=1}^{n} \mu_j \cdot TIMELU_j \le \theta_0^{LU} \cdot TIMELU_0$$

$$\sum_{j=1}^{n} \mu_j \cdot QCRANES_j \le \theta_0^{LU} \cdot QCRANES_0$$

$$\sum_{j=1}^{n} \mu_j \cdot SCRANES_j \le \theta_0^{LU} \cdot SCRANES_0 \qquad (3)$$

$$\sum_{j=1}^{n} \mu_j \cdot SHUTTLES_j \le \theta_0^{LU} \cdot SHUTTLES_0$$

$$\sum_{j=1}^{n} \mu_j \cdot AVAILSS_j \le AVAILSS_0$$

$$\sum_{j=1}^{n} \mu_j \cdot TEU_j \ge TEU_0$$

$$\sum_{j=1}^{n} \mu_j = 1$$

$$\mu_j \ge 0 \quad \forall j \qquad \theta_0^{LU} \text{ free}$$

Finally, the proposed parallel-processes network DEA approach jointly considers the B and LU stages, aiming at reducing the total inputs consumed by both stages (see Kao 2009b). The corresponding input-oriented, VRS model is

Network DEA (NDEA) model

$$\text{Min} \quad \theta_0^{NDEA}$$

s.t.

$$\sum_{j=1}^{n} \lambda_j \cdot TIMEB_j + \sum_{j=1}^{n} \mu_j \cdot TIMELU_j \le \theta_0^{NDEA} \cdot TIME_0$$

$$\sum_{j=1}^{n} \lambda_j \cdot LABORB_j + \sum_{j=1}^{n} \mu_j \cdot LABORLU_j \le \theta_0^{NDEA} \cdot LABOR_0$$

$$\sum_{j=1}^{n} \mu_j \cdot SCRANES_j \le \theta_0^{NDEA} \cdot SCRANES_0$$

$$\sum_{j=1}^{n} \mu_j \cdot SHUTTLES_j \le \theta_0^{NDEA} \cdot SHUTTLES_0$$

$$\sum_{j=1}^{n} \mu_j \cdot AVAILSS_j \le AVAILSS_0 \qquad (4)$$

$$\sum_{j=1}^{n} \lambda_j \cdot TONNAGE_j \ge TONNAGE_0$$

$$\sum_{j=1}^{n} \lambda_j \cdot LENGTH_j \ge LENGTH_0$$

$$\sum_{j=1}^{n} \lambda_j \cdot DEPTH_j \ge DEPTH_0$$

$$\sum_{j=1}^{n} \mu_j \cdot QCRANES_j \le \theta_0^{NDEA} \cdot QCRANES_0$$

$$\sum_{j=1}^{n} \mu_j \cdot TEU_j \ge TEU_0$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\sum_{j=1}^{n} \mu_j = 1$$

$$\lambda_j \ge 0 \quad \forall j \quad \mu_j \ge 0 \quad \forall j \qquad \theta_0^{NDEA} \text{ free}$$

On the one hand, although this model decreases the total LABOR and TIME inputs of the two stages, as does the SP DEA model (1), it uses different intensity variables for each stage (λ_j,μ_j) instead of just one set of intensity variables (η_j) as in the SP DEA model. On the other hand, although the proposed NDEA model uses different intensity variables for each stage as do the separate models of each stage (2) and (3), it computes a single efficiency score for the whole system (as does also the SP DEA model) instead of two efficiency scores, one for each stage. Therefore, in some sense, the NDEA model is in between the other two approaches. Note also that all three models treat the non-discretionary input and outputs in the same manner.

3. MINIMUM COST NETWORK DEA MODEL

In this section the network DEA approach is extended so that a minimum cost model is formulated. It is assumed that the unit cost of each input of each stage is known so that the model computes the optimal resource level for each stage given the value of the outputs, i.e. given the ship characteristics and the number of TEUs to be loaded/unloaded. In particular, since the durations of the two stages are among the inputs that are computed, the model determines the optimal time-in-port value. The idea is to apply this model to plan in advance and optimally allocate the resources required for the processing of an arriving ship whose characteristics and cargo requirements are known.

Let

Data

LABORCOST cost per unit of input LABOR (LABOR measured in man•hours)
TIMECOST cost per unit of input TIME
QCRANESCOST cost per unit of input QCRANES per unit of time
SCRANESCOST cost per unit of input SCRANES per unit of time
SHUTTLESCOST cost per unit of input SHUTTLES per unit of time
AVAILSS value of the non-discretionary input AVAILSS of arriving ship
TONNAGE value of the non-discretionary output TONNAGE of arriving ship
LENGTH value of the non-discretionary output LENGTH of arriving ship
DEPTH value of the non-discretionary output DEPTH of arriving ship
TEU value of the non-discretionary output TEU of arriving ship

Variables

TLABORB optimal value of input LABOR of stage B for arriving ship
TTIMEB optimal value of input TIME of stage B for arriving ship
TLABORLU optimal value of input LABOR of stage LU for arriving ship

TTIMELU optimal value of input TIME of stage LU for arriving ship
TQCRANES optimal value of input QCRANES for arriving ship
TSCRANES optimal value of input SCRANES for arriving ship
TSHUTTLES optimal value of input SHUTTLES for arriving ship

Note that in the case of the cranes and shuttle vehicles the above cost coefficients are per unit of time. This means that, if the corresponding input data represent the number of cranes and vehicles used, in order to compute the cost incurred due to these concepts it is necessary to multiply by the duration of the L/U stage, which would make the proposed model a quadratic, albeit easy-to-solve, optimization problem. On the contrary, if the corresponding input data already represent cumulative usage time of cranes and vehicles (i.e. cranes•hours and vehicles•hours) then the model is an ordinary Linear Programming optimization problem. Below the two alternative objective functions corresponding to both cases are formulated.

$$\begin{aligned}\text{Min}\ & \text{LABORCOST}\cdot(\text{TLABORB}+\text{TLABORLU})+\\ &+\text{TIMECOST}\cdot(\text{TTIMEB}+\text{TTIMELU})+\\ &+\text{QCRANESCOST}\cdot\text{TTIMELU}\cdot\text{TQCRANES}+\\ &+\text{SCRANESCOST}\cdot\text{TTIMELU}\cdot\text{TSCRANES}+\\ &+\text{SHUTTLESCOST}\cdot\text{TTIMELU}\cdot\text{TSHUTTLES}\end{aligned}$$

or

$$\begin{aligned}\text{Min}\ & \text{LABORCOST}\cdot(\text{TLABORB}+\text{TLABORLU})+\\ &+\text{TIMECOST}\cdot(\text{TTIMEB}+\text{TTIMELU})+\\ &+\text{QCRANESCOST}\cdot\text{TQCRANES}+\\ &+\text{SCRANESCOST}\cdot\text{TSCRANES}+\\ &+\text{SHUTTLESCOST}\cdot\text{TSHUTTLES}\end{aligned}$$

s.t.

$$\sum_{j=1}^{n}\lambda_j\cdot\text{LABORB}_j\le\text{TLABORB}$$

$$\sum_{j=1}^{n}\lambda_j\cdot\text{TIMEB}_j\le\text{TTIMEB}$$

$$\sum_{j=1}^{n}\lambda_j\cdot\text{TONNAGE}_j\ge\text{TONNAGE}\qquad(5)$$

$$\sum_{j=1}^{n}\lambda_j\cdot\text{LENGTH}_j\ge\text{LENGTH}$$

$$\sum_{j=1}^{n}\lambda_j\cdot\text{DEPTH}_j\ge\text{DEPTH}$$

$$\sum_{j=1}^{n}\mu_j\cdot\text{TIMELU}_j\le\text{TTIMELU}$$

$$\sum_{j=1}^{n}\mu_j\cdot\text{LABORLU}_j\le\text{TLABORLU}$$

$$\sum_{j=1}^{n}\mu_j\cdot\text{QCRANES}_j\le\text{TQCRANES}$$

$$\sum_{j=1}^{n}\mu_j\cdot\text{SCRANES}_j\le\text{TSCRANES}$$

$$\sum_{j=1}^{n}\mu_j\cdot\text{SHUTTLES}_j\le\text{TSHUTTLES}$$

$$\sum_{j=1}^{n}\mu_j\cdot\text{AVAILSS}_j\le\text{AVAILSS}$$

$$\sum_{j=1}^{n}\mu_j\cdot\text{TEU}_j\ge\text{TEU}$$

$$\sum_{j=1}^{n}\lambda_j=1$$

$$\sum_{j=1}^{n}\mu_j=1$$

$$\lambda_j\ge 0\quad\forall j\quad \mu_j\ge 0\quad\forall j$$

Note that although in principle the solution to this minimum cost network DEA model gives the same solution that would be obtained solving a separate minimum cost DEA model for each stage, the network DEA approach is more general and allows for the inclusion of additional constraints involving the allocation of the shared resources. Thus, for example, maximum and/or minimum total LABOR and/or TIME constraints can be imposed, i.e.

$$\text{LABORLOWERBOUND}\le\text{TLABORB}+\text{TLABORLU}$$

$$\text{LABORUPPERBOUND}\ge\text{TLABORB}+\text{TLABORLU}$$

$$\text{TIMELOWERBOUND}\le\text{TTIMEB}+\text{TTIMELU}$$

$$\text{TIMEUPPERBOUND}\ge\text{TTIMEB}+\text{TTIMELU}$$

or constraints on the relative allocation of resources to the two stages can be imposed, i.e.

$$RELLABORLOWERBOUND \leq \frac{TLABORB}{TLABORLU}$$

$$RELLABORUPPERBOUND \geq \frac{TLABORB}{TLABORLU}$$

$$RELTIMELOWERBOUND \leq \frac{TTIMEB}{TTIMELU}$$

$$RELTIMEUPPERBOUND \geq \frac{TTIMEB}{TTIMELU} \leq$$

Take into account, however, that these or other possible joint constraints should only be used when there are enough reasons to impose them, since they generally reduce the feasibility region of the model and therefore increase the minimum cost of the optimal solution.

4. APPLICATION OF PROPOSED APPROACH TO CONTAINER TERMINAL OF BUENAVENTURA

In this section the results of the application of the proposed approach to a dataset comprising 46 ship calls that took place in a two-month period at the container terminal of Buenaventura, Colombia, are presented. The inputs and outputs considered are the ones mentioned in the previous section except that:

- the number of SHUTTLES used was not available and
- since in all cases in the sample two QCRANES were used and since VRS is assumed it was decided to exclude that constant input from the analysis

Therefore, stage B used two inputs and produced three non-discretionary outputs and stage L/U used four inputs (one of them non-discretionary) and produced one non-discretionary output. Tables 1 and show the input-oriented, VRS technical efficiency scores computed using the models of Section 2. Note that the results of the different models are rather consistent, with the SP approach having the least discriminant power of the three DEA approaches. Thus, SP has the highest average efficiency score and labels as many as 29 DMUs as technically efficient. The separate assessment of the efficiency of the two stages identifies 17 cases of stage B efficiency and 15 cases of stage L/U efficiency. Finally, the RN DEA approach identifies just 12 DMUs as technical efficient. Except in the cases of DMUs 25 and 39, min (θ_0^B , θ_0^{LU}) ≤ θ_0^{NDEA} ≤ max (θ_0^B , θ_0^{LU}) with θ_0^{RN} generally closer to θ_0^{LU} than to θ_0^B.

Table 1: Results of Stage B and Stage LU DEA Models

DMU	θ_0^B (%)	θ_0^{LU} (%)
1	**100.0**	72.4
2	95.4	83.3
3	**100.0**	84.6
4	**100.0**	**100.0**
5	69.6	86.5
6	81.6	**100.0**
7	74.4	81.6
8	72.4	83.9
9	75.1	**100.0**
10	89.0	81.3
11	**100.0**	**100.0**
12	92.2	77.7
13	97.5	68.1
14	77.7	84.7
15	76.3	99.0
16	**100.0**	80.9
17	89.9	84.4
18	90.1	**100.0**
19	95.1	63.3
20	78.6	**100.0**
21	100.0	80.6
22	93.2	80.1
23	77.9	84.7
24	**100.0**	62.9
25	88.8	90.6
26	**100.0**	72.6
27	90.9	82.8
28	**100.0**	**100.0**
29	77.7	**100.0**
30	87.9	**100.0**
31	62.4	**100.0**
32	56.3	89.3
33	99.8	77.8
34	**100.0**	**100.0**
35	**100.0**	75.7
36	89.8	99.7
37	**100.0**	81.3
38	**100.0**	**100.0**
39	89.9	82.8
40	**100.0**	**100.0**
41	**100.0**	94.4
42	**100.0**	**100.0**
43	**100.0**	83.9
44	85.9	96.6
45	66.6	84.7
46	71.9	**100.0**
Average	*89.0*	*88.1*

The correlation coefficient between θ_0^{RN} and θ_0^{LU} is 0.974 while that between θ_0^{RN} and θ_0^B is -0.106. The correlation coefficient between θ_0^{NDEA} and θ_0^{SP} is intermediate, 0.589, positive but not too high. Note that θ_0^{NDEA}=1 whenever the two stages are assessed as efficient, i.e. θ_0^B=θ_0^{LU}=1, something which occurs to DMUS 4, 11, 28, 34, 38, 40 and 42.

Table 2: Results of SP and Network DEA Models

DMU	θ_0^{SP} (%)	θ_0^{NDEA} (%)
1	96.5	76.1
2	**100.0**	84.3
3	**100.0**	86.2
4	**100.0**	**100.0**
5	90.0	82.6
6	**100.0**	96.4
7	82.4	80.3
8	93.5	81.2
9	**100.0**	**100.0**
10	88.1	82.7
11	**100.0**	**100.0**
12	85.9	79.4
13	90.8	71.7
14	**100.0**	84.7
15	**100.0**	91.4
16	**100.0**	82.4
17	95.4	85.0
18	**100.0**	99.2
19	70.6	67.2
20	**100.0**	**100.0**
21	91.7	83.0
22	97.8	81.8
23	85.6	83.9
24	**100.0**	70.6
25	**100.0**	88.5
26	**100.0**	79.7
27	87.1	83.5
28	**100.0**	**100.0**
29	**100.0**	**100.0**
30	**100.0**	**100.0**
31	**100.0**	**100.0**
32	91.4	84.6
33	89.3	82.0
34	**100.0**	**100.0**
35	94.4	76.0
36	**100.0**	97.1
37	**100.0**	83.6
38	**100.0**	**100.0**
39	**100.0**	82.3
40	**100.0**	**100.0**
41	95.7	94.6
42	**100.0**	**100.0**
43	**100.0**	87.6
44	**100.0**	96.6
45	**100.0**	81.9
46	**100.0**	98.7
Average	*96.2*	*88.4*

Although it can be concluded that all the models agree that, in general, there are no significant technical inefficiencies, a minimum cost analysis can detect whether cost inefficiencies exist. To that end the minimum cost network DEA model of section 3 has been applied to each DMU. The estimated unit cost coefficients used are 10$/man·hour for LABORCOST, 20$/hour gross Ton for TIMECOST and 25$/hour for SCRANESCOST.

Table 3 Cost Efficiency of Observed DMUs

	Cost		
DMU	Observed	Minimum	Cost Eff. (%)
1	13,666	8,643	63.2
2	22,394	16,451	73.5
3	26,488	12,817	48.4
4	17,195	10,188	59.2
5	14,094	10,930	77.5
6	10,678	10,172	95.3
7	8,934	5,927	66.3
8	11,305	8,478	75.0
9	14,177	13,386	94.4
10	14,681	8,882	60.5
11	26,804	18,122	67.6
12	12,514	8,917	71.3
13	19,890	11,414	57.4
14	18,675	12,126	64.9
15	14,200	11,581	81.6
16	28,155	13,407	47.6
17	14,793	11,361	76.8
18	7,807	7,355	94.2
19	11,479	6,116	53.3
20	11,767	11,155	94.8
21	11,166	8,759	78.4
22	16,881	11,403	67.5
23	22,937	10,817	47.2
24	22,178	12,646	57.0
25	19,717	15,506	78.6
26	19,590	12,577	64.2
27	7,866	5,832	74.1
28	**24,120**	**24,120**	**100.0**
29	22,220	21,531	96.9
30	10,683	10,272	96.2
31	13,027	10,556	81.0
32	11,065	8,397	75.9
33	12,208	8,660	70.9
34	14,604	12,012	82.3
35	28,270	12,661	44.8
36	12,296	9,117	74.1
37	26,668	17,131	64.2
38	23,418	22,566	96.4
39	19,471	14,706	75.5
40	23,638	17,286	73.1
41	24,449	16,559	67.7
42	11,555	10,004	86.6
43	16,913	13,362	79.0
44	11,339	9,998	88.2
45	22,118	13,507	61.1
46	13,316	12,429	93.3
Sum	781,410	559,839	-
Savings = 221,571 *$*			
Savings = *28.4%*			
Savings = 4,817 *$ per DMU*			
Savings = 15.8 *$ per TEU*			

Table 3 shows the costs originally incurred (for the given concepts), the minimum cost computed by the proposed network DEA approach and the corresponding cost efficiency. Note that of the 12 DMUs that were labelled technically efficient only DMU 28 is cost efficient. The average cost efficiency is 73.9%.

Note also that not only this minimum cost model but all the other models compute, in addition to the efficiency scores, appropriate target levels for the controllable inputs. Thus, for example, Table 4 shows the value of the targets computed by the minimum cost network DEA model. Unlike the technical efficiency approach, the minimum cost feasibility region is not constrained to those operating points that use less inputs but it can, if it is cost-effective, increase some inputs and reduce others. In addition, the minimum cost approach exhaust all possible slacks that the input-oriented radial efficiency score usually leaves unaccounted for. As shown in the table, the minimum cost efficiency approach could have obtained a 28.4% cost reduction for the DMUs in the sample, with total savings of 221,571 $ which represents 4817 per ship and 15.8 $ per TEU.

Table 4 Cost Efficiency of Observed DMUs

	Targets				
DMU	LABORB	TIMEB	LABORLU	TIMELU	SCRANES
1	28.9	3.7	360.3	8.4	7.6
2	28.3	4.4	407.4	10.5	10.4
3	29.6	4.0	387.1	8.7	7.2
4	20.7	3.8	325.6	8.1	8.0
5	24.8	3.9	337.3	8.2	7.9
6	25.7	3.6	348.4	10.9	7.0
7	20.6	3.8	206.9	14.0	6.4
8	24.8	3.7	330.5	8.1	7.9
9	29.6	3.9	348.4	10.9	7.0
10	20.6	3.8	430.3	8.0	9.5
11	28.3	4.4	390.4	12.9	9.5
12	35.2	3.3	378.7	8.6	7.3
13	30.3	4.1	327.5	8.1	8.0
14	30.4	4.3	373.3	8.6	7.4
15	29.7	3.9	371.1	8.5	7.4
16	30.6	4.5	407.8	8.7	9.1
17	28.1	3.9	362.4	8.5	7.5
18	20.6	3.8	327.2	8.1	8.0
19	20.6	3.8	245.8	11.8	7.0
20	27.8	3.9	325.6	8.1	8.0
21	35.8	3.2	365.8	8.5	7.5
22	29.9	4.2	325.6	8.1	8.0
23	20.6	3.8	349.0	11.0	7.1
24	53.0	4.5	380.8	8.7	7.3
25	20.6	3.8	491.9	11.8	12.3
26	60.9	4.7	367.9	8.5	7.5
27	20.6	3.8	159.8	15.4	6.0
28	**37.7**	**4.3**	**398.3**	**22.1**	**13.0**
29	30.7	3.8	473.8	17.3	15.0
30	20.6	3.8	611.4	6.3	13.0
31	26.5	3.9	325.6	8.1	8.0
32	20.6	3.8	325.6	8.1	8.0
33	35.2	3.3	357.7	8.4	7.6
34	31.5	4.1	379.9	7.7	9.0
35	30.1	3.9	404.4	8.9	7.0
36	25.7	3.6	343.4	8.2	7.8
37	34.5	6.5	350.6	14.2	7.6
38	30.6	4.5	346.2	22.4	8.0
39	28.9	4.1	406.8	11.3	10.6
40	26.6	4.1	352.1	18.5	8.2
41	20.6	3.8	354.9	17.4	8.3
42	24.6	3.9	359.5	8.4	7.6
43	41.3	5.7	365.5	8.5	7.5
44	28.1	3.9	326.0	8.1	8.0
45	31.7	4.1	365.1	10.3	7.8
46	28.4	3.9	405.3	8.9	7.0

The results in Table 2 corresponds to the observed DMUs, i.e. they perform an ex-post analysis and show the potential cost reduction that might have occurred if the processing of the different ships had been as the computed targets indicate instead of being the one observed. Although interesting, this analysis is not too useful because it looks into the past which cannot be changed. Much more useful is to apply the proposed approach to a ship that is to arrive and thus estimate ex-ante the amount of resources to allocate given appropriate upper bounds on the durations of the two stages. Thus, for example, assume that a ship with TONNAGE=25,000 Ton, LENGTH=200 m, DEPTH=10 and that plans to load and unload a total of 400 TEU. Assume also that when the ship arrives the storage are free capacity is AVAILSS=2,500. Formulating and solving the minimum cost network DEA model it can be estimated that the ship can be processed in TIMEB=4.18 hours and TIMELU=8.88 hours (i.e. a total time-in-port of 13 hours approximately) allocating LABORB=30 man·hours, LABORLU=406 man·hours and SCRANES=7.6 with an estimated total cost (due to the concepts considered) of 12,564 $.

5. CONCLUSIONS

In this paper, a DEA approach to assessing the technical and cost efficiency of the processing of ships at a container terminal has been proposed. Unlike conventional DEA that looks at a DMU as a black box consisting in a single, aggregate process, a parallel-processes network DEA approach has been used. The two stages considered have been Berthing and Loading/Unloading. Each stage has inputs and outputs, the latter being non-discretionary in nature. Not only can the technical efficiency of the operations be estimated but also its cost efficiency. A most practical feature of the latter approach is that not just the potential cost reductions of past processing can be measured but the resources to assign for processing an expected ship can be computed and the cost of its processing estimated. The results show the usefulness of the proposed approach in analyzing the historic (i.e.

observed) inefficiencies of the terminal operations as well as estimating minimum cost resource requirements and time-in-port of arriving ships.

Of course, the proposed approach has limitations like its being a static analysis which means that the feasibility of the computed target operating points need to be checked using for example discrete-event simulation. Another major limitation, which the reviewers kindly pointed out, is the deterministic nature of the analysis, which therefore ignores the stochastic variability (e.g. variance) of the processing times of common port operations.

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MANOEUVRING SIMULATIONS OF THE PERSONAL VEHICLE PICAV

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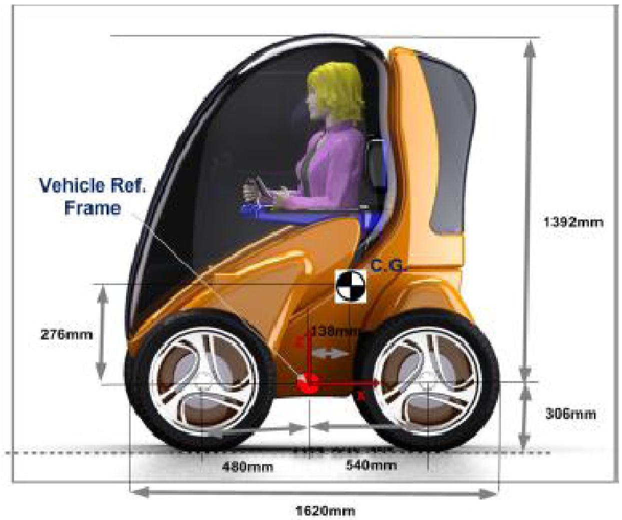
ABSTRACT
The greening of surface transport, ensuring sustainable urban mobility and improving safety and security are the three main paradigms reflecting the present and future urban transport strategic and policy challenges. The PICAV unit is a one person vehicle that is meant to ensure accessibility for everybody and some of its features are specifically designed for people whose mobility is restricted for different reasons, particularly (but not only) elderly and disabled people. Ergonomics, comfort, stability, assisted driving, eco-sustainability, parking and mobility dexterity as well as vehicle/infrastructures and intelligent networking are the main drivers of the PICAV design. The PICAV case is considered, investigating the advantages of four independently powered wheels and exploring how actuation redundancy could be used to grant proper manoeuvrability, at least, within the expected operative conditions and transport modes.

Keywords: Green cars, Personal vehicle, Mathematical model, Simulation

1. INTRODUCTION

In the last ten years governments, organizations and citizens in general have been involved, with great effort, to create green zones in downtown, touristic areas and public parks; ensuring citizens have an economic, social and environmentally sustainable mobility system. A particular effort has been dedicated to the juridical substance of the right to mobility for all people, avoiding any kind of social exclusion and changes in personal habits, culture and quality of life, especially for the less able (elder and handicapped) users who cannot resort to the typical efficient and clean walking and cycling mobility resources powered by human muscles. Taking these paradigms in consideration and having as a primary objective to overcome them; arises then the Personal Intelligent City Accessible Vehicle (PICAV) system funded by the European commission under the 7th framework program.

PICAV, Figure 1, is a small full electric vehicle, able to move in outdoor pedestrian environments, where usual public transport services cannot operate because of the width and slope of the infrastructures, uneven pavements and the interactions with high pedestrian flows.



Legenda	Symbol	Value
Total mass	M	400 kg
Wheel moment of inertia	J	0.8 kgm^2

Figure 1: The PICAV reference make-up: sketch and main parameters

Transport systems for pedestrian areas, based on a fleet of PICAVs have been proposed in (Cepolina and Farina 2012) and (Cepolina and Farina 2014).

The paper considers the manoeuvrability characteristics of this untraditional vehicle with four independently powered wheels (Silva et al. 2008; Esmailzadeh et al. 2001; Shino and Nagal 2003) that are very important in order to assure comfortable and safe travel to the user.

Some brief hints are given on the construction of the vehicle dynamic model moving from the behaviour of a driving wheel (with compliant tire); modelling the group motor wheel suspension and then assembling the four groups to the chassis to find out the motion of the centroid and around it when the four actuators operate while the vehicle moves on varying soil surfaces. The model was modularly implemented in Simulink/Matlab environment.

Simulation results are presented and discussed.

2. MODELING THE PICAV DYNAMICS

The PICAV vehicle is modelled as a multi bodies system (Cho and Kim 1995): the chassis connected, through viscous-elastic joints, to four masses including suspensions and motorized wheels, each one coupled with the road.

Due to the low speed and the comparatively smooth soil, finally, a 14-degrees-of-freedom model is obtained: 6 for the car body (3 of the centroid and 3 around it); 2 for each of the four suspended masses (the linear motion at joints and the rotation of the wheels); namely, in body-axes and assuming small angular deflections, the reference dynamics is set, as in the following sections.

The model refers to the coordinate frames shown in Figure 2.

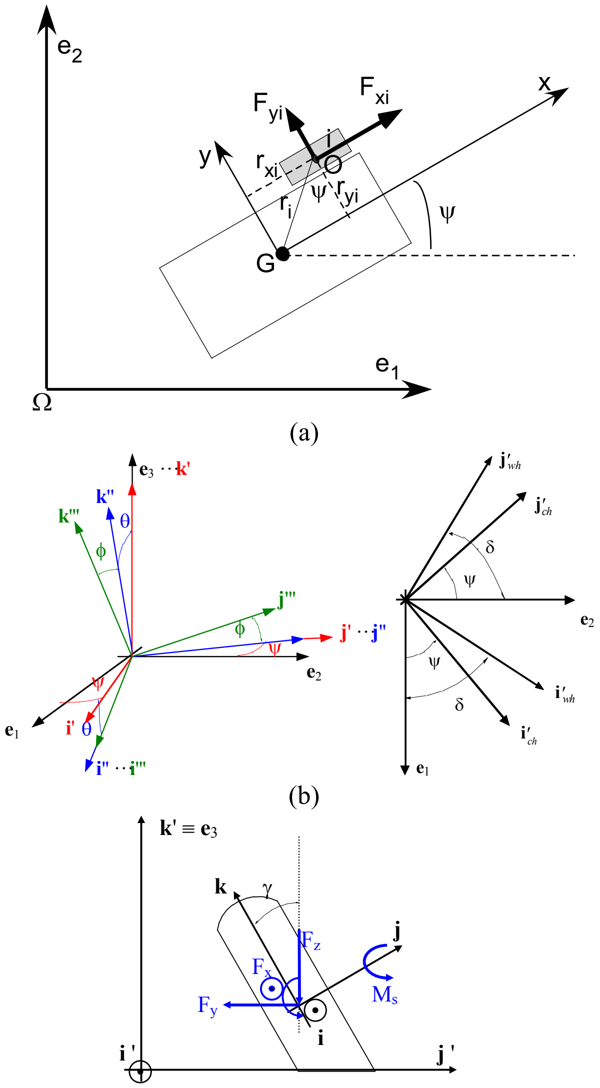


Figure 2: Wheel chassis outline (a). Co-ordinate frames, roll (ϕ), pitch (θ), yaw (ψ) and steering (δ) angles for basic rotations. The subscript ch refers to the chassis, wh refers to the wheel, {e1, e2, e3} is the fixed frame. These frames and angles refer to the general vehicle model. In the case of PICAV (no steering wheels) δ=ψ and $\{i'\ j'\ k'\}_{ch} \equiv \{i'\ j'\ k'\}_{wh}$ (b). Wheel frames (c).

2.1. Tire-soil contact model

The tire-soil contact model is hereafter written for a generic i^{th} wheel. The hypothesis of vehicle with all identical wheels is considered and the geometry and mass parameters are considered the same for all the wheels.

The model of wheel dynamics, including the slip non linear behaviour allows to find the wheel torque T_i and the maximum torque that can be applied to the wheel before creep.

The forces exchanged between tire and soil depend on complex phenomena but the basic technical literature (Pacejka and Besselink 1997; Wong 2001) suggests simple proportionality relations for micro-slip contacts (say, out of extended creep situations):

$$T_i = mR\dot{v}_{xi} + \frac{J}{R}\left(\frac{m}{k_i}\left(\ddot{v}_{xi}v_{xi} + \dot{v}_{xi}^{\,2}\right) + \dot{v}_{xi}\right) \qquad (1)$$

$$\omega_i = \frac{v_{xi}}{R} + m\frac{v_{xi}\dot{v}_{xi}}{k_i R} \qquad (2)$$

Where: m and J arethe mass of the wheel and its moment of inertia referred to the wheel axis, ω_i is the wheel angular velocity, R is the wheel radius, v_{xi} is the wheel longitudinal velocity, k_i is the constant of the i wheel slip law.

2.2. Motorwheel model

The motor wheel dynamic model considers all the degrees of freedom supplied from the rotations around three non-orthogonal axes: spin θ around the current y axis (**j**), corresponding to spinning torque M_S, steering δ around the z fixed axis (**e$_3$**), corresponding to steering torque M_{st}, camber γ around the current x axis (**i**), corresponding to camber torque M_C, see Figures2b and 2c. **R** is the road reaction on the tire and **F** is the force applied to the chassis by the wheel.

The motor wheel model is hereafter written in the general case indicating m' the mass of motor and wheel:

- Translation equilibrium:

$$\begin{bmatrix} R_x + F_x \\ R_y - F_y \\ R_z - F_z \end{bmatrix}_i = m'R\begin{bmatrix} \alpha_{st}s\gamma + 2\omega_{st}\omega_c c\gamma + \alpha_s \\ -\alpha_c c\gamma + \left(\omega_{st}^2 + \omega_c^2\right)s\gamma + \omega_{st}\omega_s \\ -\alpha_c s\gamma + 2\omega_{st}\omega_s c\gamma s\gamma + \omega_c^2 c\gamma \end{bmatrix}_i \qquad (3)$$

- Rotation equilibrium:

$$\begin{bmatrix} M_c + RR_z s_\gamma + RR_y c\gamma \\ M_s c\gamma - RR_x c\gamma \\ M_s s\gamma + M_{st} - RR_x s\gamma \end{bmatrix}_i = I\begin{bmatrix}\alpha_c+\omega_{st}^2 c\gamma s\gamma \\ -\left(\alpha_{st}s\gamma c\gamma - 2\omega_{st}\omega_c s_\gamma^2\right) \\ \left(\alpha_{st}c\gamma^2 - 2\omega_{st}\omega_c s\gamma c\gamma\right)\end{bmatrix} + I_y \begin{bmatrix} -\omega_{st}\omega_s c\gamma - \omega_{st}^2 c\gamma s\gamma \\ \left(\alpha_s c\gamma + \alpha_{st} c\gamma s\gamma + \omega_{st}\omega_c c\gamma^2\right) - \omega_c\left(\omega_{st}s\gamma^2+\omega_s s\gamma\right) \\ \left(\alpha_s s\gamma + \alpha_{st}s\gamma^2 + \omega_{st}\omega_c s\gamma c\gamma\right) + \omega_c\left(\omega_{st}s\gamma c\gamma + \omega_s c\gamma\right)\end{bmatrix}_i \quad (4)$$

Where: ω and α are the wheel angular velocity and acceleration while their subscripts *s, st, c* refer respectively to spin, steering, camber; the mass quadratic moment **I** is diagonal with $I_x=I_z=I$, $I_y=J$; because identical wheels are considered, the variables R, m', I, I_y have no subscript; sε=sinε, cε=cosε.

2.3. Suspension model

The proposed dynamic model of the individual suspension is:

$$\begin{bmatrix} F_{whx} - F_x \\ F_{why} - F_y \\ F_{whz} - F_z - c_{susp}\dot{z}_s - k_{susp} z_s \end{bmatrix}_i = m_{susp}\begin{bmatrix} a'_{Gx} - \ddot{\psi} r'_{GSy} - \dot{\psi}^2 r'_{GSx} \\ a'_{Gy} + \ddot{\psi} r'_{GSx} - \dot{\psi}^2 r'_{GSy} \\ \ddot{z}_s \end{bmatrix}_i \quad (5)$$

$$\begin{bmatrix} z_s F_{why} + M_x - M_{whx} \\ -z_s F_{whx} + M_y \\ M_z - M_{whz} \end{bmatrix}_i = \begin{bmatrix} 0 \\ 0 \\ I_{susp}\ddot{\psi} \end{bmatrix} \quad (6)$$

Where $\mathbf{F}_{wh}$ and $\mathbf{M}_{wh}$ are force and moment due to the motor wheel; m_{susp} and I_{susp} are the mass properties of the suspension, k_{susp} and c_{susp} are the elastic and damping parameters of the suspension; z_s is the quote of the suspension mass m_{susp} considered concentrated; $\mathbf{r'}_{GS}$is the vector between the chassis center of mass G and the suspension contact point S; the superscript indicates the reference frame {**i', j', k'**}.

In the case of stiff suspensions the vertical acceleration is zero: $\ddot{z}_s = 0$

The equations of motor wheels and suspensions can be assembled together to have the model of the group motor wheel suspension.

2.4. Chassis model

The chassis is considered as a rigid body with 6 degrees of freedom.

The dynamic model of the chassis, in the case of PICAV with no steering wheels, is:

$$\sum_{i=1}^{4}\left(F_{xi}\mathbf{i}'_{ch} - F_{yi}\mathbf{j}'_{ch} - F_{zi}\mathbf{k}'_{ch}\right) - m_{ch} g\mathbf{k}'_{ch} = = m_{ch}\mathbf{a}_{Gxyz} + m_{ch}\left(-\dot{\psi} v_{Gy}\right)\mathbf{i}'_{ch} + m_{ch}\left(\dot{\psi} v_{Gx}\right)\mathbf{j}'_{ch} \quad (7)$$

$$\begin{aligned}&\left(r_{y1}F_{z1} + r_{z1}F_{y1} - r_{y2}F_{z2} + r_{z2}F_{y2} + r_{y3}F_{z3} + r_{z3}F_{y3} - r_{y4}F_{z4} + r_{z4}F_{y4}\right)\mathbf{i}'_{ch} + \\ &+\left(-r_{z1}F_{x1} - r_{x1}F_{z1} - r_{z2}F_{x2} - r_{x2}F_{z2} - r_{z3}F_{x3} + r_{x3}F_{z3} - r_{z4}F_{x4} + r_{x4}F_{z4}\right)\mathbf{j}'_{ch} \\ &+\left(r_{x1}F_{y1} - r_{y1}F_{x1} + r_{x2}F_{y2} + r_{y2}F_{x2} - r_{x3}F_{y3} - r_{y3}F_{x3} - r_{x4}F_{y4} + r_{y4}F_{x4}\right)\mathbf{k}'_{ch} \\ &+\sum_{i=1}^{4} M_{xi}\mathbf{i}'_{ch} + \sum_{i=1}^{4} M_{yi}\mathbf{j}'_{ch} + \sum_{i=1}^{4} M_{zi}\mathbf{k}'_{ch} \\ &= I_{zch}\ddot{\psi}\mathbf{k}'_{ch}\end{aligned}$$

where $\mathbf{I}_{ch}$=diag$[I_x,I_y,I_z]_{ch}$ is the inertia matrix of the chassis; m_{ch} is the chassis mass; $[r_x, r_y, r_z]^T_k$isthe arm vectorof the force $\mathbf{F}_k$ applied to the chassis from the motor wheel k, $\mathbf{a}_G$ is the acceleration vector of the chassis center of mass.

3. SIMULATION RESULTS

The PICAV manoeuvring has been studied through two operative conditions: the execution of on spot turn and the execution of a path with large radius. The vehicle model considered neglects secondary effects (at the tire-soil interface) and does not explicitly deal with the control strategies required to compensate unwanted effects. The sketch of the implemented Simulink model is shown in Figure 3.

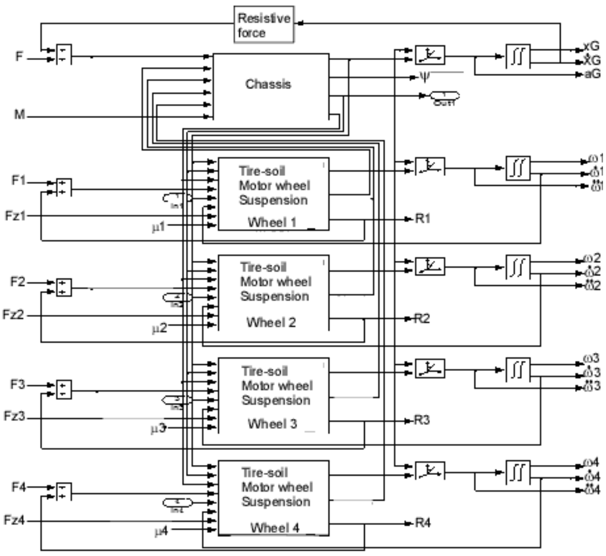
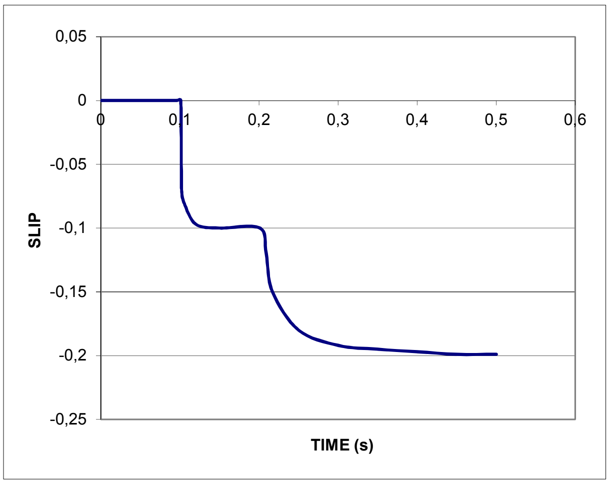


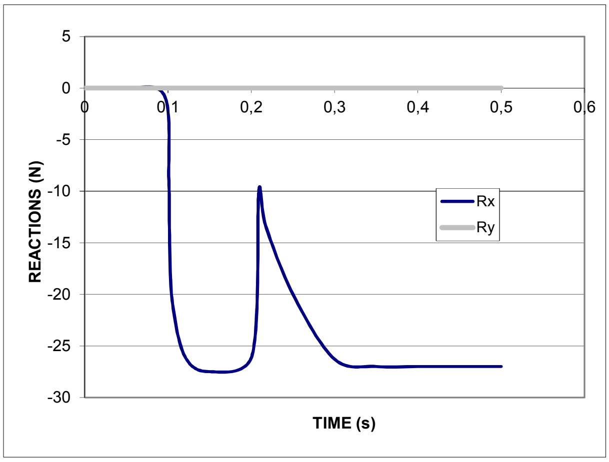
Figure 3: Sketch of the PICAV simplified model in Simulink

A set of simulation trials have been performed, achieving results to assess the usefulness of the proposed (unusual) driving opportunity for 2D motions. As first instance, it has been properly verified that fully balanced actuation leads to straight trajectories while circular paths are tracked when outer wheels rotate at equal speed, faster than inner wheels.

Simulations have been performed to test the effects of a variation of the adherence corresponding to a ground friction varying from 0.7 to 0.2 on a mono-wheel during braking. At 0.1s a braking torque of -6 Nm is applied and taken constant; a adherence coefficient μ=0.7 was applied to the wheel for t<0.2s, then this coefficient was lowered to μ=0.4. Details on the simulation results are shown in Figure 4. In this case the applied torque is lower than the torque corresponding to the adherence limit: the slip grows and then arranges on a new value. In the case of a braking torque higher than the adherence limit, when the adherence lowers the wheel is too much braked respect to the ground conditions and the wheel blocks.



(a)



(b)

Figure 4: Slip (a) and reactions (b) of a mono-wheel undergoing a sudden change of adhesion coefficient.

3.1. PICAV turning on the spot

PICAV is designed to move people in restricted areas sharing it with pedestrians, like city centers, parks, malls. So it is very important the dexterity of the car, allowing the PICAV to reach every position with whatever desired orientation, while minimizing the manoeuvring space. To check the PICAV maneuverability a skid steering manoeuvre (radius zero plane trajectory) has been simulated. During the on the spot path test starting from zero speed and powering by equal torques, +130 Nm outer train forward, -130 Nm backward the other, the velocity and acceleration of the chassis kept zero while the values of the forces applied from the wheels to the chassis varied as shown in Figure5.

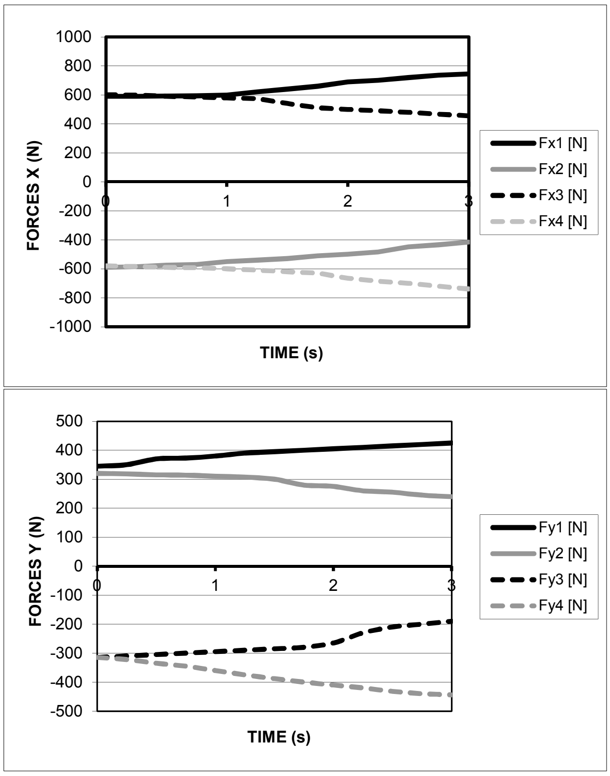


Figure 5: Forces exchanged between wheels and chassis respectively in x and y direction during on-spot turn with reciprocal actuation law (skid-steering)

3.2. PICAV on circular path

The steady state motion along a circular path is characterized by constant yaw velocity and therefore zero acceleration due to the equilibrium between the torques generated by the transversal and longitudinal reactions. Many tests have been performed on PICAV tracking curved path with different local radius (Cho and Kim 1996). In Figure 6 are shown the results obtained applying on the outer train 20 Nm torques and on the inner one 1.2 Nm torques, the reference trajectory is a 100 m radius circle. During this trajectory the chassis yaw is decreasing with constant speed and zero acceleration. Figure 7 depicts the trends of significant variables during this manoeuvre: the forces exchanged between soil and wheels, Figure 7a, the forces applied from the wheels to the chassis, the yaw rate, Figure 7b, the slip angles, Figure 7c. In Figure 7c can be noted that the slip angles on the front wheels are inferior to the rear wheels slip angles resulting in a lightly oversteering behaviour. This is understandable because each wheel velocity is determined by the sum of the velocity of the vehicle center of mass plus the velocity due to its rotation.

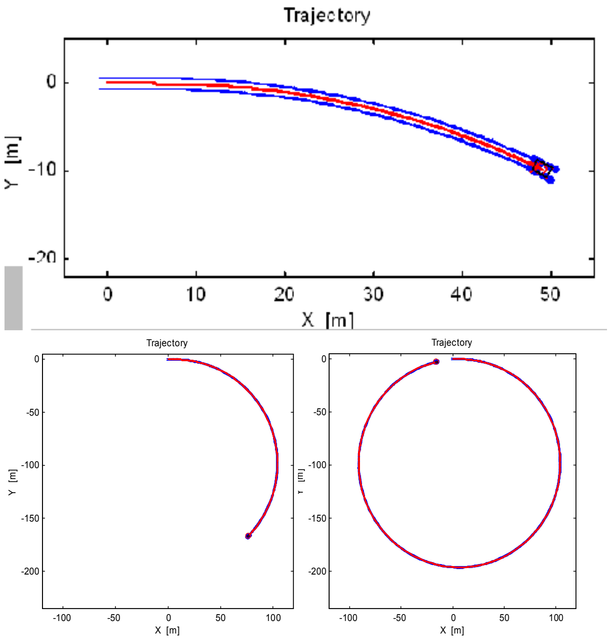
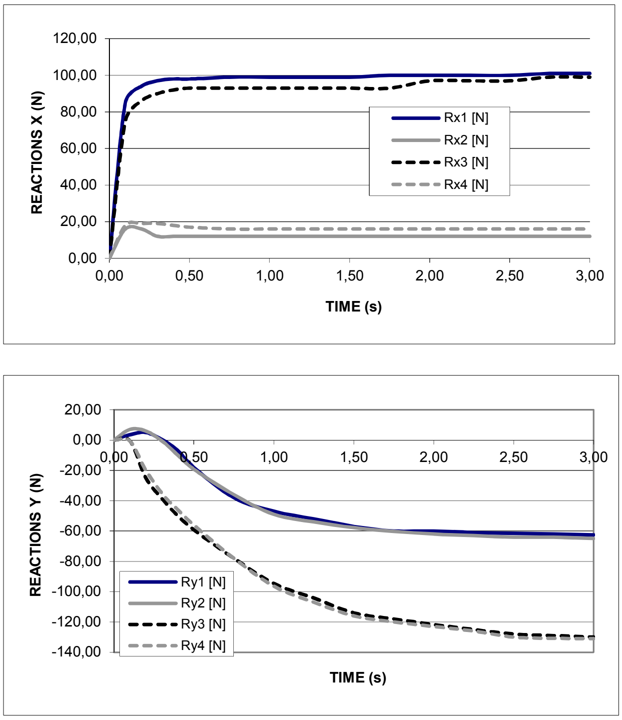
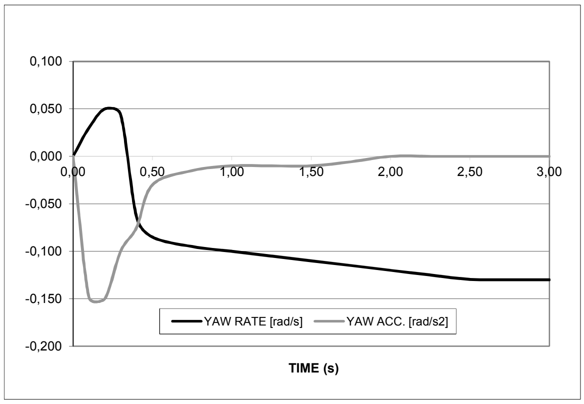


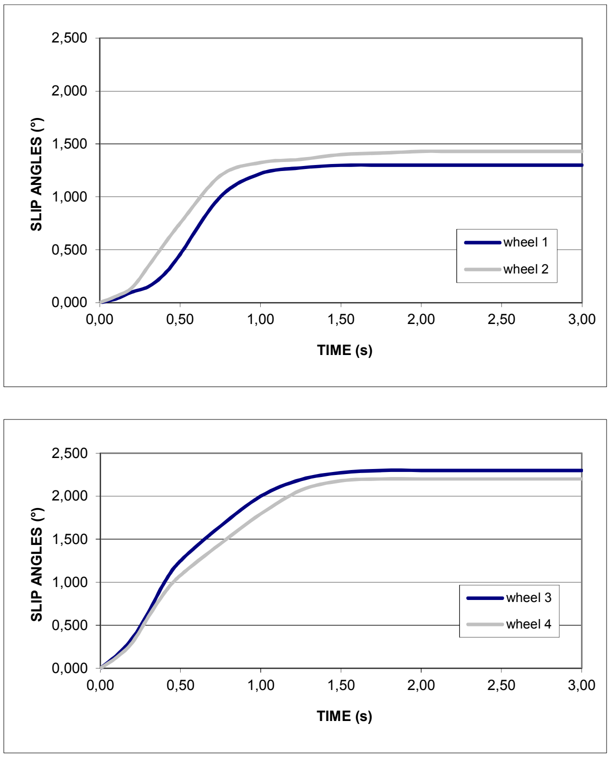
Figure 6: PICAV tracking a circular path at 10s, 50s and 100s



(a)



(b)



(c)

Figure 7: Forces exchanged between wheels and soil (a), respectively in x and y direction; yaw rate (b) and slip angles (c) during a 100 m radius circular path.

It has to be noted that the vehicle forward velocity is lightly reducing because the actuation torques have been computed in open loop trying to estimate the torque distribution guaranteeing a circular path performed at constant speed, balancing beyond the aerodynamic and rolling reactions, the centripetal contribution. In any case the different circular paths close with negligible errors.

4. CONCLUDING COMMENTS

The paper proposes the model for a 4 non steering motor-wheels vehicle. The model is applied to the new personal vehicle PICAV to study its open loop performances about dexterity in manoeuvring and stability. First the general mathematical models are derived for the single modules composing a car with different level of approximation; then the preliminary architecture and geometry mass parameters of PICAV have been used in the simulation to explore its behaviour and results are shown and commented.

PICAV is designed to join semi-autonomous mobility with the basic requirements on technological sustainability. The main results on the vehicle manoeuvrability will be directly transferred to the driving assistant and the dynamic model will be used for implementing a suitable compensator of the non linearities with the aim to achieve a near linearized modelsimplifying and improving the robustness of the control system.

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COST MANAGEMENT IN CAR TERMINALS

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ABSTRACT

Car terminals are important logistic hubs in charge of vessels loading/unloading and car's temporary storage before their routing to the final destination. In this paper terminal operations are described and their costs are defined. A discrete event simulation model is presented to support day-by-day terminal managers' decisions, enabling what-if analysis on the basis of manager's planning and scheduling choices with the objective of minimising the logistic costs and pollutants' emission.

Keywords: car terminal cost, port terminal operations, terminal planning and scheduling

1. INTRODUCTION

The **volume of maritime transportation** in the European Union has reached more than 8 billion of goods in 2012 (UNCTAD 2012) and is expected to continue growing in the near future. In particular, **vehicles** logistics has risen impressively during the last decade (average rate of 4% per year - Platou 2014), leading to the emergence of a world-wide hub-and-spoke network (Drewry, 1999).

Maritime inter-modality of the automotive supply chain takes place in special port terminals called Ro-Ro terminals, where roll-on/roll-off handling of vehicles are performed on/off special vessels called car carriers (Mendonça and Dias 2007). These vessels are "floating parking lots" (Johnson et al. 1999) provided by ramps and large doors, usually distinguished in short-sea carriers, which can transport 1000 vehicles, and deep-sea carriers, which have a capacity of up to 6000 vehicles (Cordeau et al. 2011). Because of their central role in the development of logistic operations, an emergent paradigm in the automotive supply chain considers these port terminals as able to provide economies of scope if they can allow buffering, warehousing with pre-delivery inspections and postponement customization, becoming a new decoupling point between the supply chain forecasts-driven and the demand-driven side (Quaresma et al. 2010).

Nevertheless, these logistic platforms are nowadays in charge of vessels loading/unloading and car's temporary storage before their routing to the final destination. Their **efficiency in planning and performing terminal operations** are of great importance. Indeed, they determine both the waiting time of vessels in queue for accessing/exit the port or the berth (with the consequent high cost involved), and the congestion of the landside road network caused by queues of logistics operators and cars. Moreover, implications such as the duration of the started engines of waiting vessels and vehicles on the degree of environmental pollution and the safety of the actors involved cannot be neglected.

For the abovementioned reasons, researchers highlight the need for more efficient terminal operations in order to transport more vehicles while reducing logistics costs (Kang et al. 2011).

Many studies have addressed the topic of optimization of the operations management in **container terminal** (see, for example, Bierwirth and Meisel 2010), but only a few regards with car terminal (Keceli et al. 2013). Unfortunately, terminal container models cannot be transferred to car terminal for a number of reasons. First of all, containers can be stacked upon one another to increase storage space, may be relocated several times during their stay in a hub, and request several means of transports (cranes, forklifts, reach stackers, etc.). To the contrary, vehicles can't be stacked, are usually not relocated in order to kept at minimum danger or damages (in transhipment, damage levels between 0.5% and 1.0% are considered acceptable according to Drewry 1999), and are handled by drivers (Mattfeld and Kopfer 2003).

Looking at car terminal process resources, one specific characteristic of **drivers** is that they are considered to have infinite capacity, because they can generally be hired flexibly from a port-wide workforce pool (Mattfeld and Kopfer 2003). The leading information, indeed, is the time the ship is willing to stand in the port. Starting from it, the terminal defines the number of drivers needed each shift. Nevertheless, some studies try to balance the allocation of manpower in order to avoid short-term hiring of inexperienced drivers, which would increase damage rates (Mattfeld and Kopfer 2003; Fisher and Gehring 2006).

Moreover, the main limited resource is the **yard**: since vehicles are frequently not directly delivered to clients, they have to be stored in the terminal. The storage capacity, organized in "rows", has to be managed according to the uncertainty about the departure time of the incoming and leaving of seaside and landside vehicles (Fisher and Gehring 2006). In particular, due to the minimization of relocations, vehicles supposed to leave the port together are usually **stored in interconnected parts** of parking areas (Fisher and Gehring 2006) and are generally defined as a group on the basis of the vessel of origin, the model and the brand (Cordeau et al. 2011).

This study aims at assessing the impact of car terminal's managers' decisions on the terminal efficiency in planning and operations, using as performance indicator the total cost related to the traffic generated by transit (both for handling and waiting) of vessels, cars and transporters.

To this extent, the traffic flow of the three principal port activities is depicted, the costs involved in terminal processes are formalized and the management decisions about terminal activities are analysed.

The high complexity of the managerial problem, mostly due to the stochastic nature of the related variables, is dealt with a simulation model.

The rest of the paper is structured as follows: in Section 1 the literature review is presented; Section 2 deals with the description of the main physical and information flows of a car terminal; Section 3 introduces the managerial decisions over the planning horizon; in Section 4 the performance cost function is proposed; Section 5 copes with the simulation model logic and structure; in Section 6 the first validation results are shown; Conclusions and Future Studies follow.

2. LITERATURE REVIEW

As already stated, few studies have been focused on car terminal operations. In the following a brief review is reported.

Keceli et al. (2013) have developed a Discrete Event Simulation (DES) model to identify possible bottlenecks within the area of a Ro-Ro port terminal that serves trucks and trailers. They simulated the four import/export processes and evaluated them in terms of utilization rates (which can detect over-investments) and maximum number of vehicles in queue (which measures congestions).

Mattfeld and Kopfer (2003) coped with vehicle transshipment with the objective of balancing the allocation of manpower among shifts, since car location assignment in the terminal yard and manpower usage are interdependent on the duration of loading/unloading tasks. They stated the stochasticity of the input data and the integration of planning and scheduling tasks but, due to the resulting combinatorial complexity, they set in a static framework a hierarchical problem separation, to be solved by a heuristic procedure as an iterative decision support system.

Fisher and Gehring (2006) matched the manpower management planning with the parking areas' constraints under the objective of minimization of required drivers' time and balancing the manpower usage over the shifts. First of all, they described the car terminal planning processes in a case study. Then, taking advantage on the approach of Mattfeld and Kopfer 2003, they divided the problem into three tasks: quay management (considered as an independent sub-problem), storage allocation and deployment scheduling, completed with the estimation of the vehicle departure time. The first three sub-problems were assigned to three different agent types in a Multi-Agent System (MAS). A further agent was in charge of coordinating the activities in order to reach the minimization objectives.

Longo et al. (2013) evaluated the impact of factors such as inter-arrival time between vessels, loading/unloading time and the total amount of cars and trucks to be handles on the turn-around time, chosen as the main port performance index. To this extent, they simulated the following terminal macro-activities, considering both containers and vehicles to be handled:

- ships arrival;
- possible wait in roadstead due to berth unavailability;
- mooring operations;
- loading/unloading operations.

An interesting contribution has been given by Cordeau et al. (2011), who focus their attention on the scheduling aspect of the assignment of cars to parking rows in the transhipment mode. Under the assumption of deterministic arrival and departure time of cars' groups and on the basis of berth-yard distances, they developed an integer linear programming formulation to assign car groups to adjacent parking areas, minimizing the total handling time. Moreover, they presented some extensions of the model, with the objective of simultaneously minimizing the cars' group fragmentation risk or balancing the manpower usage. Due to the computational complexity of the problem, demonstrated to be an NP-Hard, a meta-heuristic algorithm was proposed.

In summary, literature contributions are oriented to divide the problem in sub-problems and analyse the sub-problems in a deterministic framework or recognise the stochasticity of the environment, proposing a simulation model based on a case study to analyse some specific aspects.

To the contrary, the present study has to objective of presenting an integrated operations management framework and the implementation choices to develop a general car terminal simulation model for day-by-day managerial decisions' support.

3. PHYSICAL AND INFORMATION FLOWS

The traffic flows of the three principal activities of a car terminal taken into account in this research are:

- Import: cars unloading from ship, waiting in storage, loading on transporter;
- Export: cars unloading from transporter, waiting in storage, loading on ship;
- Transshipment: unloading from ship, waiting in storage, car loading on ship.

Each vehicle in transit takes part to specific processes described in the follows, exchanging information and moving in the port area.

Ship arrival and berthing. Usually one week in advance, vessels communicate their expected arrival day-time and the maximum time they are provided for loading/unloading cars. The day before the arrival, they confirm the expected arrival time. According to the quay and the berth planning, ships wait in bay until the entrance is allowed by the terminal staff; as soon as a ship enters the harbour and reaches the assigned mooring position, loading/unloading operations can begin.

Car to be unloaded from ship. Some days before the arrival, the shipping agency sends to terminal the vessel's booking, with the list of cars to be loaded and unloaded. Given the precedence to the discharge, a shuttle leads drivers from the parking areas onto the ship. Unlocked the safety block, drivers bring cars to the planned parking area where the shuttle waits for a new round. In this phase errors can be made in the selection of the vehicles to unload and damages caused during the operations.

Car to be loaded on ship. Once ended the unloading operations, led by shuttle taxi, drivers reach cars to be loaded (according to booking disposals) and drive them onto ship. In ship's hold they lock cars and, by shuttle, return in yard areas for another round. Again, errors and damages can occur. In order to minimize the turn-around time, control activities take place after the vessel leaves the port.

Car Park allocation. The destination area of the parking activities depends on the allocation policy. Cars are assigned to a specific slot within an area and the parking take place in rows, in order to facilitate the consequent withdrawal (FIFO technique). Also here, allocation mistakes can happen. In case of space unavailability, the recourse to an outside yard is made.

From the information point of view, usually only the transshipment cars are provided by a departure date (corresponding to the arrival of the car carrier). If the time between unloading from a ship and loading on another is short, or in case the ship stand is short, drivers can park the cars into some buffer areas located in the proximity of the vessel mooring position.

Transporter unloading: access from landside entrance gate, reaching of a specific location, parking, unloading and transporting, to the indicated storage area, leaving by landside exit gate.

The transporter access to the car terminal is usually orchestrated by logistic operators, which very often do not communicate it to the port stakeholders.

Transporter loading: access from landside entrance gate, reaching of a specific location, parking, identification of cars to load, transporting from the storage area to the carrier, loading, securing, leaving by landside exit gate.

Parked car to be handled: taking out from a storage area and transporting to another area.

4. MANAGERIAL DECISIONS

In order to describe the complexity and the interdependencies among the decisions the car terminal management have to make, the problem has been split into six sub-problems in dependence with the planning horizon the solution refers to.

Yard partition. While some studies propose optimal car allocation oriented to minimum travel length and based on deterministic arrival and departure time, this research, starting from the evidence of the stochastic nature of parking events, consider the virtual labelling of the parking areas according to the access frequency. In the long planning horizon, decisions about the rough cut capacity planning of the terminal yard are made according to:

- the terminal layout (yard points of access/exit, distances with respect to berth and landside gates);
- yard storing capacity;
- parking demand data (quantity, duration and destination of cars stored in the yard for a period of time, for example, in one year).

The mentioned data are used to define:

- capacity of yard sub-areas allocated to each main destination;
- position of these areas according to the access frequency and the average distance from the point of origin of demand (seaside/landside).

The output of this phase is the "static cars' destination labelling" of the yard (which "structurally" reduce the handling costs) and represents one of the inputs of the subsequent optimization steps.

Quay planning. Taking as input vessels' requests and waiting cost, the terminal's management perform a demand aggregation (on a daily basis) and chooses an optimal feasible quay plan according to the mean capacity of workers and yard in order to manage the possible contemporary arrival of two or more vessels.

Note that ports, due to theirs morphology and structure, allow the contemporary entrance/exit of a limited number of vessels (also one) and exit has priority over entry (Longo et al. 2013).

Berth planning. Once the vessel arrival time is confirmed, terminal managers formulate a berth plan in the attempt to minimize the seaside costs, on the basis of:

- yard partition;
- yard-berth distances;
- manpower capacity.

Such assignment is generally defined during a daily meeting with the harbourmaster.

Dynamic yard management. In the daily handling operations, cars' clusters are defined in order to allocate homogenous groups of cars to parking areas taking into account quantity, type, destination and withdrawal time in order to avoid or minimize relocations. Because only transhipment cars are provided by this information, a probabilistic model should be used. For example, Fisher and Gehring (2006) carried out the departure time estimation by means of a learning classifier system.

Drivers plan. According to the previous plans (which give the time windows and the distances to cover) and considering the number of cars to handle, the terminal management has to choose the most convenient number of drivers to hire each shift.

Transporters plan. Finally, taking into account the transporters request to access the port (if available), terminal staff can contract with them an access plan to minimize the handling costs due to internal traffic congestion.

5. PERFORMANCE EVALUATIONS

The relevant costs sustained by the actors involved in the processes in the observed period of time are used to measure the terminal plans' performances. Moreover, some other performance indicators can be provided to the terminal management.

C_{SS}: seaside cost. It is the cost dependent on quay and berth allocation decisions (vessel's access/exit and mooring positions) and includes:

- c_{wb}: ship's waiting in bay cost (hourly cost);
- c_{wh}: ship's waiting in harbour cost (hourly cost).

In the quay planning, the access priority has to be attributed to vessels that ask to enter or leave the bay within the same time bucket; in the berth allocation, the vessels' mooring position choices influences the time to load/unload cars by terminal workers (drivers). In both cases, waiting times reflect on the service level assured by terminal to shipping company. Moreover, both activities are closely related to external constraints such as: the number of vessels crossing port access together, special disposals of the port authorities, depth of seabed, etc. The relevant times are:

- $t_{lu,exp}$: expected ending time for loading and unloading operations, assigned by the ship-owner;
- $t_{lu,eff}$: effective ending time, measured during the process;
- t_{wb}: waiting in bay time, measured during the process.

The cost formulation is:

$$C_{ss} = c_{wb} * t_{wb} + \max\{0, c_{wh} * (t_{lu,eff} - t_{lu,exp})\}. \quad (1)$$

Some performance measures are:

- mooring positions usage, a frequency analysis of the preferred positions for possible re-contracting with the port authority,
- vessel service level, dependent on the waiting times, indicator of the shipping company satisfaction.

C_H: handling cost. It takes into account the costs of:

- drivers to load/unload cars from vessels and re-location in parking areas during the shifts and in overtime;
- shuttle costs;
- cars delivery to outside park (due to storing locations unavailability in the port yard);
- mistakes in vehicle load/unload (due to control postponement after the vessel departure);
- transporters wait, in case the transporter plan is shared/coordinated by the terminal.

The cost formulation is the following:

$$C_H = c_{d_{st}} * n_{d_{st}} + c_{d_{ot}} * n_{d_{ot}} + c_{f_{sh}} * d_{sh} + c_{c_{op}} * \\ * n_{c_{op}} + c_{c_f} * n_{c_f} + c_{c_{fp}} + n_{c_{fp}} + c_{wt} * t_{wt} . \quad (2)$$

where:

- $c_{d_{st}}$: unit driver cost per shift, defined by the drivers company;
- $n_{d_{st}}$: number of drivers employed per shift (car and shuttle drivers), assigned in the dynamic yard management in accordance to the total number of cars to be handled and the distances that drivers have to cover (time required) from/to the mooring positions;

- $c_{d_{ot}}$: unit driver cost per hour in case of overtime;
- $n_{d_{ot}}$: number of drivers hourly employed in the overtime;
- $c_{f_{sh}}$: shuttle fuel cost per unit of distance;
- d_{sh}: covered distances by shuttles;
- $c_{c_{op}}$: cost for daily storage in an outside park of a car;
- $n_{c_{op}}$: number of cars exceeding the port storage capacity (to park outside the port);
- c_{c_f}: cost of failed loading/unloading of a car, due to drivers oversight;
- n_{c_f}: number of cars not loaded/unloaded from ships for driver failure;
- $c_{c_{fp}}$: cost of failed loading of a car caused by unavailability (car parked outside the port and not recalled on time by the management);
- $n_{c_{fp}}$: number of cars not loaded on ship for planning failure;
- c_{wt}: transporters waiting cost (hourly cost);
- t_{wt}: waiting time of the transporters.

The main related performance measures are:

- yard congestion, number of operations in the unit of time;
- shuttles saturation, number of seats occupied divided by the available ones;
- park areas saturation, a measure of the efficiency of the yard partition;
- drivers saturation, a measure of the efficiency of the dynamic yard management and the driver plan;
- transporter service, depending on the waiting time, expressing the respect of the transporters' plan.

$\boldsymbol{C_{ENV}}$**: environmental cost.** It takes into account the emission of pollutants released by vehicles. This cost item represents a "green" side of the model and it is based on the recent European disposals about environmental impact: reduction of pollutants will be rewarded in tax deductions. Cost is a function of the CO_2 emissions from ships (depending on the different vessel states), transporters and cars started engines, and it is proportional to the time the engines works. In particular:

- $c_{e_{ves}}$: average hourly environmental cost of a vessel switched on in the port area (in bay and at the berth);
- t_{ves}: time spent by vessels in the port;
- c_{e_c}: average hourly environmental cost of a car handled in the port area;
- t_c: duration of cars handling;
- $c_{e_{tr}}$: average hourly environmental cost of a transporter moving in the port area;
- t_{tr}: time spent by transporters in the port area.

The cost expression is the following:

$$C_{ENV} = c_{e_{ves}} * t_{ves} + c_{e_c} * t_c + c_{e_{tr}} * t_{tr} \,. \qquad (3)$$

$\boldsymbol{C_{TOT}}$**: Total cost.** Having defined the cost components, the purpose of management is to define the port management plans according to the following cost function:

$$\min \{C_{TOT} = C_{SS} + C_H + C_{ENV}\}. \qquad (4)$$

6. SIMULATION MODEL

In this very complex environment, mostly due to the stochastic nature of the related variables (such as vessels/transporters arrival times, loading lists and handling activity durations), we use simulation to support terminal's managers in their day-by-day decisions by what-if analysis. By means of this tool, management is enabled to test the whole effect of its interdependent plans (Section 4) on the terminal operations, using as main performance indicator the abovementioned cost function (Section 5).

A DES model has been developed in Arena Rockwell simulation software. In this section, a basic simulation model is presented, with the objective of showing the implementation choices of all resources, information, variables and activities. The ongoing researches are focused on developing the simulator for a particular car terminal, validating and testing its ability to support decisions (Figure 1). The Probability Distribution Functions (PDFs) presented later have to be calculated on terminal past data and are given as input to the simulator by means of Monte Carlo Simulation.

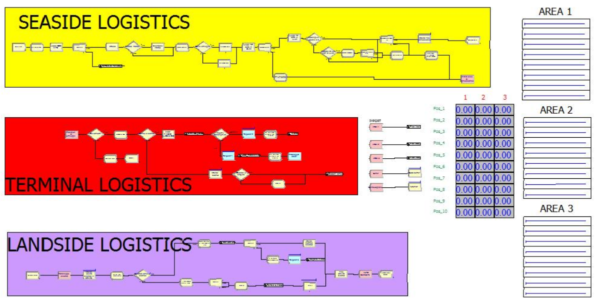

Figure 1: Screenshot of the ongoing Arena simulation model.

Based on the described information and physical flows (Section 3) and with the aim of modelling the daily decisions involved in the car terminal management (Section 4), four main processes have been implemented:

- terminal setting;
- seaside logistics;
- terminal logistics;
- landside logistics.

Entities in the simulation model are vessels (characterized by charging/discharging list, arrival time), transporters (with loading/unloading list), cars (with model, lot number, serial number, arrival time, departure time). The stations blocks are used to model berth positions, car parking areas, transporters parking areas. Car rows in the parking areas are represented by queue sets; transports are used to model the usage and the distances covered by drivers and transporters' drivers.

Terminal setting. The terminal management has to describe the yard partition and capacity, the berth infrastructure and the landside gates. This allows configuring the terminal model in the simulation.

Distances among the physical areas are stored in an excel spreadsheet together with the value of cost's items used in the objective function formula. Time series of arrivals, lateness and handled quantities of vessels and transporters are automatically elaborated to build the related PDF.

For each analyzed scenario, the berth and yard occupation (that is, the terminal current state) has to be recorded in a excel spreadsheet.

Seaside logistics. This process deals with the daily Quay and Berth planning. An excel spreadsheet collects the information that constitutes the input of the simulation. Notwithstanding the arrival plans, variability is attributed to the vessels' Time of Arrival, by means of lateness PDF and delay PDF.

The events of vessel entrance/leaving the port are simulated, the waiting times caused by managerial decisions are measured and C_{SS} is computed.

Terminal logistics. The discharging and loading lists of each vessel are collected in an excel spreadsheet, together with the number of drivers assigned by the managers. As happen in reality, the loading list can be provided of a "load up to the vessel capacity" request for a specified brand. This is reproduced by means of a notice time PDF, vessel request' PDF, a brand request' PDF and a number of requested cars' PDF. The notice time is important information because it can allow cars' recalls from the outside park if needed.

The unloading activities obviously take place before the loading ones. As explained before, the unloaded cars are automatically labelled with the destined parking area thanks to the yard partition. Transshipment cars are always provided by a departure time, the imported ones, instead, are not. This value, fundamental for parking decisions inside an area, is attributed on the basis of the parking duration PDF for each car model. The drivers, modelled as resources' sets, transport the cars from the berth to the parking area, with a time proportional to the covered distance. Different sets of drivers express their different experience level, inversely proportional to the probability of damages or errors which can be added as a simulation input by management. As Mattfeld, D.C. and Kopfer described (2003), the port management wants to leverage the manpower usage in order to always hire skilled drivers.

Finally, when a vessel leaves the port, the possible idle workforce is assigned to moored remaining ships.

Rows of cars in a yard partition are represented by queues. The simulator is provided by a smart algorithm to allocate cars in a parking area according to the characteristics of the incoming lot of vehicle and the others already stored in the area. In particular, the row selection depends on the expected time of withdrawal (probabilistic for import and export flows) of cars already stored, and the new lot is parked where the more attributes match; in case of no attributes matching, the parking row is selected on the basis of the current saturation according to the lot dimension of incoming cars; lastly, if no row is available, cars are moved to a near parking area. If no space is available in the yard, vehicles are delivered to an outside park, and the relative cost is measured. This feature is particularly interesting for terminal management, giving exact indications of how to schedule parking cars on rows.

Ended this process, according to the loading list, cars are withdrawn from yard sub-areas' rows and loaded on vessels. If needed, re-locations in parking areas are performed.

The time needed to carry out the loading/unloading activities is calculated, influencing all the involved costs. Drivers' extra-capacity, indeed, should be needed, causing additional workforce costs, lateness in vessel activity completion and pollutant emissions

Landside logistics. The last process copes with the transporters activities. Because usually no information about their arrival is available, their arrival event is simulated by means of a PDF, as the model to load/unload and its quantity. While the incoming car' attributes are given according to the future charging lists of planned vessels mooring, the selected car to withdrawal are chosen in dependence with the departure time. The tasks are performed by transporters' drivers that cannot interfere with terminal drivers' activities (who have the priority to handle cars in the parking area). Car recalls from the outside park are given as a further input and simulated here.

Once set the number of repetitions for each simulated scenario, the described simulation tool is able to provide ${C_{TOT}}^{scenario}$, its confidence interval and the other performance indexes described in Section 5.

6.1 Model validation

First of all, the process validation was carried out thanks to the involvement in the research project of the management of an Italian car terminal. By this, the sequence of the modelled activities and input data was approved.

Then, the model was validated against real data in a simplified port environment, characterized by 2 mooring positions and 3 parking areas, each one provided by 10 parking rows of 10 cars.

According to the terminal management decisions, the quay, berth, drivers and parking plans for 4 incoming vessels was provided, and the PDF of the other variables and the current inventory level were collected. Then, a two-day simulation was developed. This time horizon was chosen in order to reproduce the impact of the decisions made during the daily harbormaster meeting, without neglecting the effect of possible delays in the execution of the operations that could be postponed to the subsequent day.

The simulation was repeated 200 times in order to accurately reproduce the variability of the input variables and the standard error of the vessel mean completion time of about 4.56% with respect to the real case resulted.

What-if analysis were made varying the input plans in 4 scenarios, one of them recording a reduction of C_{TOT} with respect to the first scenario of about 10%, with a significance level of 5%.

7. CONCLUSIONS

Car terminal has become an important maritime logistic hub, which efficiency significantly influences the performance of the whole automotive supply chain. Nevertheless, only a few studies cope with the terminal operations management optimization or make simplified deterministic assumptions. This paper proposes a simulation tool to evaluate the stochastic performances of a car terminal in the day-by-day decisions, providing a valuable tool for what-if analysis and detection of bottlenecks to terminal management with the objective of minimising the logistic costs and pollutants' emission.

The car terminal logistic processes are described in terms of physical and information flows, managerial decisions and performance measures, and are finally modelled in a simulation environment.

A basic model has been implemented and validated referring to an Italian car terminal data. The ongoing researches are focused on completing the implementation of a real port, also by means of an accurate cost parameters setting and an extensive data collection. Moreover, in order to assess the impact of terminal decisions on a longer planning horizon, a methodological study will be developed to manage the input plans according to their probability of occurrence over the time. Further studies should be oriented to use the resulting simulation model as a testbed for terminal plans' optimizations with heuristic methods.

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SPACE OPTIMIZATION IN WAREHOUSES LOGISTICS

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ABSTRACT
Industrial warehouses are typically composed by multi levels scaffolds holding pallets, each pallet carrying one or more manufacturing item. The paper introduces the problem of the wasted space in industrial warehouses and describes the algorithms implemented in a simulation software able to suggest how to organize the storage of the manufacturing items. The proposed software uses effective and efficient search algorithms to minimize the overall storage lost space. The general structure of the numeric platform and the logics of the solver algorithms are described together with the strategies adopted to reduce the computation time. Typical results obtained in an industrial environment working in the plastics sector are presented and discussed.

Keywords: warehouse management, space optimization, palletized objects, logistics, multi stages optimization

1. INTRODUCTION

One of the main tasks of manufacturing plant organizations is to reduce the storage space dedicated to tools, fixtures and devices and to improve their inbound logistics efficiency by minimizing the displacements and optimizing the positions. The size and weight of the objects to be handled in the production plants can vary widely. Generally sets of these objects are carried by pallets that are displaced using electric lifts; the forks of the electric lifts can quickly load and unload the pallets. The preferred solution is to use ISO standard pallets of the same size in order to facilitate the automation. In effect today many new storages are fully automated (ASRS) and can host several thousands of pallets.

The objects within a warehouse are usually subdivided in categories; each section of storage hosts a different typology of products and tools. It is not always trivial to organize the objects in order to minimize the warehouse wasted area; the correct space optimization allows reducing the overall number of pallets needed to carry goods, allowing maximizing the overall number of objects that a store can hold.

The storage space optimization needs come directly from the industry (Chyuan et al. 2009), the analytical methods used to solve this problem belong to the field of applied research. A review of the optimization methods in shelf space allocation is given in (Bai 2005).

The physical constraints and integrality constraints of the warehouse space allocation problem are very similar to the constraints in bin packing and knapsack problems, which are well-known NP-Hard problems (Martello and Toth 1990a). However, warehouse space allocation problem may be even more difficult because it usually has a non-linear objective function and some additional constraints e.g. weight constraint has to be considered.

In the literature, optimization studies concerning warehouse space allocation problem have been carried out: appropriate models have been developed and optimization techniques proposed. A frame of optimization approaches that were considered by the authors and gave rise to the original approach presented in the paper is hereafter given.

Optimization approaches include exact and heuristics methods.

An exact method seeks the optimal solution to the problem. Exact methods include well-known linear programming (Hillier and Lieberman 2005), dynamic programming (Bellman 1957), branch and bound (Hillier and Lieberman 2005), and Lagrangian relaxation method (Reeves 1995). Although these approaches could obtain optimal solutions, they can be computationally expensive and impractical for many real-world applications.

Heuristics could be used to create a solution or to improve an existing solution by exploring the neighboring solutions based on given appropriate rules or strategies (Reeves, 1995), but these simple heuristic methods are prone to getting stuck in a local optimum. To prevent this risk, many researchers proposed advanced heuristic approaches, called meta-heuristics (Osman and Kelly 1996; Glover and Kochenberger 2003) including single point, population based and hybrid methods.

In the following, references will be given about space allocation problems similar to the one considered in the paper.

The one dimensional bin packing problem refers to a given set of items $I = \{1, \ldots, m\}$ each having an associated size or weight w_i and a set of bins with identical capacities c. The problem is to pack all the items into as few bins as possible, without exceeding the capacity of the bins. This packing problem belongs to the family of NP-Hard combinatorial optimization problems (Martello and Toth 1990b) and there is no known polynomial time-bounded algorithm that can solve every problem instance to optimality. This problem can also be extended to two-dimensional and three-dimensional bin packing, where both the bin and the items have sizes in two or three dimensions. The one-dimensional bin packing problem has been addressed by many researchers and both exact methods and meta-heuristic methods have been applied.

The knapsack problem is similar but the variables weight and profit are introduced for each item. The problem is to select a subset of items such that the total profit of the selected set of items is maximized. Typically exact approaches such as branch and bound algorithm (Martello and Toth 1975) and dynamic programming (Toth 1980) are used. However, due to their significant computational requirements, for very large domains (m>1000) approximate approaches are preferred.

The problem of storage space optimization is non linear and can be solved adopting a heuristic approach following the principles of the dynamic programming (Bellman 1957). The problem is decomposed in nested stages, each corresponding to a sub-problem in only one variable that must be solved before moving to the second stage. The problem can hence be tackled by a recursive procedure, in which each iteration corresponds to a sub-problem. Moving from the first stage to the final one, the model will provide an optimal answer.

As said before, optimization problems are highly computationally expensive when dealing with large size item domains (Hillier and Lieberman 2005). In such circumstances one may refer to some approximation methods which can solve the problems with satisfactory solution quality within reasonable computational time, resorting to heuristic and meta-heuristic approaches. In our case a memory meta-heuristic method using a short term history, including iterative local search, is adopted.

Wasted area of the shelf that is expensive due to the high costs of construction as well as maintenance.

In the paper the problem of storage space optimization has been approached in sequence in two stages: vertical optimization and horizontal optimization.

The first problem deals with the height of items and aims to assess the vertical distance between the shelves: adjustable shelving systems allow varying the distance between the shelves. The vertical wasted area is minimized putting, under the same shelf, moulds having all almost the same height.

The second problem deals with width and length of items and aims to minimize the number of required pallets, and therefore the wasted area on each pallet.

The paper has been structured in the following way: section 2 describes the problem constraints. Section 3 describes the vertical optimization and the algorithm proposed to solve it. Section 4 focuses on the horizontal optimization and on the algorithms that have been developed to solve it. The algorithms have been applied to an illustrative case of study that is presented in section 5. Conclusion follows.

2. BASIC CONSIDERATIONS

In the following the optimization of a specific industrial moulds storage is considered as a reference case; the problem is typical of important industrial sectors such as plastics, shoes, clothing, automotive. The studied warehouses can host over 500 moulds and each year new moulds are added to the warehouse. A good storage exploitation allows saving space and enhances the moulds picking speed as well as the manufacturing plant internal logistics.

The pallets considered belong to the same ISO family and have the same area layout; this hypotheses is widely accepted because it facilitates the use of automated warehouses. Each pallet can accommodate a number of moulds that ranges from 1 to 6, according to their dimension.

The shape of each mould is approximated, by hypotheses, to the enclosing minimum parallelepiped: specific algorithms can be implemented if the objects to place on the same pallet have complex geometries (Schepers and Wottawa, 1996).

Each parallelepiped mould, by hypothesis, can be positioned on the pallet only with bottom edges parallel to the pallet sides; it can be rotated of 90 degrees around the Z axis assuming two possible footprint configurations on the pallet outline (see figure 1).

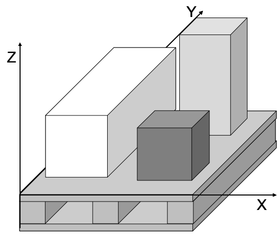

Figure 1: Pallet holding some items

The moulds that can be accommodated on a given pallet has to satisfy constraints on the overall weight of the pallet and on the overall area of the moulds (that should not exceed the pallet area). Only one layer of moulds is admitted on a given pallet.

Moreover nested configurations of moulds on a given pallet, as shown in figure 2, are not allowed.

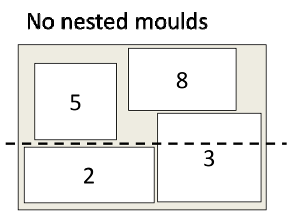

Figure 2: Nested moulds

The displacement of heavy moulds is a delicate operation: nested moulds are forbidden to simplify the factory activities. The condition "no nested moulds" allows the workers to cross the moulds horizontally. The moulds, that weight from 20 kg to 300 kg, need to be handled with care.

The shelving system allows varying the distance between the shelves. A suitable low air gap is needed for pallet loading unloading operations (see figure 3). The depth of the shelves allows to accommodate only one pallet. All the moulds should be easily accessed and no priority in mould loading/unloading operations has been taken into account.

3. VERTICAL OPTIMIZATION

Moulds are clustered according to their heights: the moulds are divided in groups. A given shelf accommodates only the moulds belonging to a group. The distance between shelf *n* and shelf *n+1* depends on the max height of the moulds within the group assigned to shelf *n*, as shown in figure 3.

We call *m* in the following the number of moulds belonging to a given group that should be assigned to pallets.

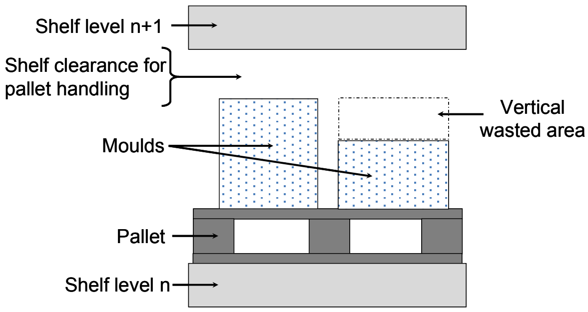

Figure 3: Vertical wasted area

4. HORIZONTAL OPTIMIZATION

The target is to assign all the moulds belonging to a given group to a minimum number of pallets.

The algorithm proceeds by successive steps. A threshold *TH* (that represents the maximum wasted space that we accept on one pallet), is fixed in the process initialization (*TH°* could be for example 10%) and it is sequentially increased (in the external iterations). For a given value of *TH*, the algorithm tries to assign a number *n* of moulds to the pallets. *n* increases from 1 to 6 as the internal iterations increase. Given *TH* and *n*, the algorithm fills as much pallets as possible with *n* moulds sets: for each pallet the algorithm (n MOULDS/PAL procedure deeply described in the section 4.1) finds the *n* moulds, out of the *m* available in the given group, and their orientations (virtual pallet) that satisfy constraints at section 2 and, in the cases of the first two approaches proposed in sections 4.1.1 and 4.1.2, minimize the wasted area on the pallet. If the virtual pallet, output of n MOULDS/PAL procedure, satisfies also the constraint on *TH*: *the wasted area on the pallet<=TH,* the *n* moulds, oriented as they are in the virtual pallet, are assigned to the current pallet.

The proposed methodology is schematically described in the following. The architecture of the solver is shown in figure 4.

1. *TH=critical threshold:=TH°*
2. *p:=1*
3. *n:=1*
4. *n MOULDS/PAL problem →finds the n moulds (out of the m available in the given group)and their orientations (virtual pallet) :*
    a. *that satisfy constraints at section2*
    b. *(that minimize the wasted area on the pallet)*
5. *check if the wasted area in the current virtual pallet is lower than TH*
6. *if yes*
    a. *assign the n moulds to the pallet*
    b. *delete the n moulds from the group →m:=m-n*
    c. *p:=p+1: go to the next pallet*
    d. *go to step 4*
7. *if not*
    a. *n:=n+1increases the number of moulds to be assigned to the pallet*
    b. *go to step 4*
8. *is m=0? Have all the moulds of the given group been assigned to pallets?*
9. *if not*
    a. *TH:=TH+10%TH*
    b. *Go to step 2*
10. *if yes→END*

A multistage solver has been developed and implemented. The core of the algorithm is dedicated to the search of the *n* moulds and their orientations that satisfy constraints in section 2 and, as it concerns the first two approaches proposed in sections 4.1.1 and 4.1.2, minimize the wasted area on the pallet.

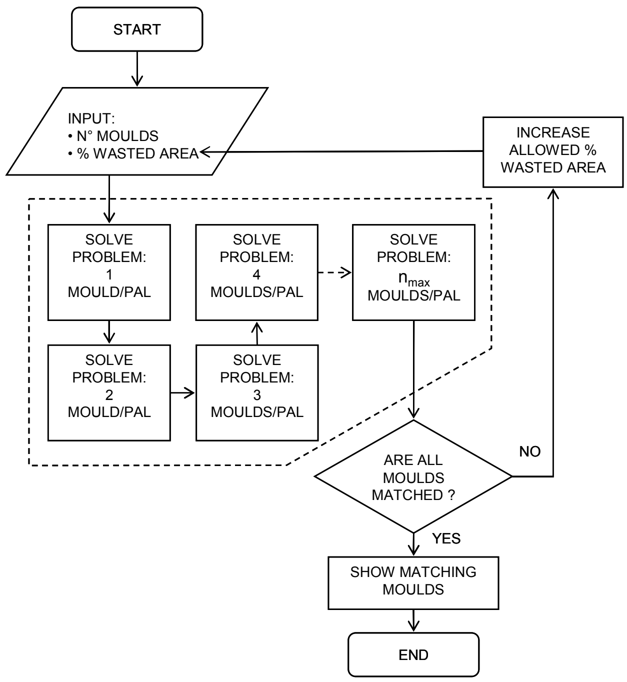

Figure 4: The architecture of the solver

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4.1. The problem: n MOULDS/PAL

The number n of moulds to be assigned to each pallet is given in input to this procedure. The procedure aims at finding the n moulds, out of the m available in the given group, and their orientations (virtual pallet) that satisfy constraints at section 2 and, in the cases of the first two approaches proposed in sections 4.1.1 and 4.1.2, minimize the wasted area on the pallet.

The dimension of the search space is: $= \frac{m!}{(n)!(m-n)!} 2^n$ where:

- $(\frac{m!}{(n)!(m-n)!})$ is the number of combination of m moulds on n positions without repetition and,
- 2^n takes into account that each mould can be loaded on the pallet with 2 orientations.

As an explanatory example we take into account the case of $m=10$ moulds and $n=4$ moulds on a pallet Each mould, out of 10, can be positioned, on a pallet area; the 4 moulds can be horizontally (X) or longitudinally (Y) oriented respect to the pallet outline. It is therefore possible to load the pallet with $\frac{10!}{4!6!} 2^4 =$ 3360 possible configurations.

Three alternative approaches have been proposed and they are schematically represented in figure 5. The first two aim at finding the configuration (virtual pallet) that satisfies the constraints and minimizes the pallet wasted area. The third approach aims at finding a virtual pallet that only satisfies the constraints. All the three approaches have been tested and are reported in the following.

All the three approaches are based on a solver that hosts internally two generators.

The first solver generator (RELATIVE POSITIONS in figure 6) creates all the possible moulds orientations (X,Y) on the pallet. *2m* objects are generated from the *m* moulds.

Then the second solver generator (SET CONFIGURATIONS GENERATION) creates possible combinations of the *2m* objects (virtual pallets).

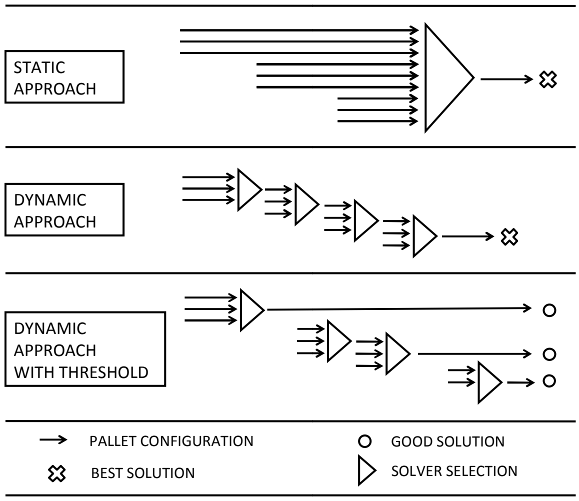

Figure 5: Open loop static and dynamic approaches

4.1.1. Static approach

The second solver generates all the possible virtual pallets (which number is $\frac{m!}{(n)!(m-n)!} 2^n$). Then a check on all the constraints described in section 2 is performed (MATCH CRITERIA in figure 6) for all the generated virtual pallets: all the virtual pallets that do not satisfy the constraints are deleted.

A performance parameter is then assigned to all the remaining virtual pallets. The performance parameter is related to the wasted area: the area of the pallet that is not covered by moulds. The solver finds the virtual pallet that has the best performance parameter (SEARCH OF THE BEST SOLUTION in figure 6).

At the end of the procedure the set of moulds belonging to the best virtual pallet is sent to the check (step 6 of the proposed methodology) on *TH*.

The five basic steps, shown in figure 6, summarize the solver activities.

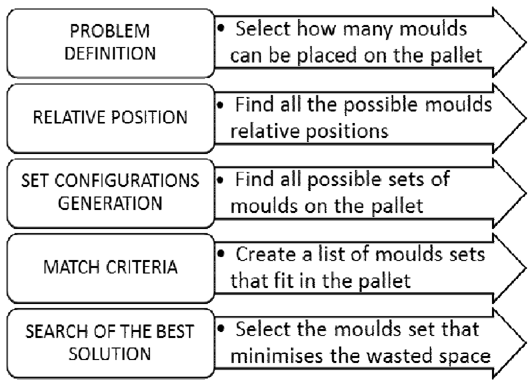

Figure 6: Logical steps of the solver activities

This approach tests all the possible combinations by numeric simulation. This approach is appealing but an important aspect needs to be considered; the number of solutions to explore can be really high.

4.1.2. Dynamic approach

The solver, addressed in the previous paragraph, requires a huge computational effort: it needs about one

week to solve the problem *m=100* moulds and *n=6* positions. Some simplification hypotheses are now introduced in order to speed up the computation time: the logical steps to solve the problem are critically reviewed and improved.
In the dynamic approach, the second solver proceeds by sequential steps. At each step *nb* (not all, as in the static approach) virtual pallets are generated, a check on the constraints is performed (MATCH CRITERIA in figure 6) on the *nb* generated virtual pallets: all the combinations that do not satisfy the constraints described in section 2 are deleted. The performance index is assessed for each of the remaining virtual pallets and the best one is selected. The best solution is added to the *nb* combinations generated in the next step. This procedure is repeated until all the possible virtual pallets are taken into account.

At the end of the procedure the set of moulds belonging to the best virtual pallet is sent to the check on *TH* (step 6 of the proposed methodology).

The complete list of combinations generated by the second solver in the static approach is therefore replaced by a dynamic list that is updated at each step.

4.1.3. Dynamic approach with threshold

A significant boost of quest speed is also offered searching a good solution instead of the best solution (bottom part of Figure 5).

As in the dynamic approach, the third solver proceeds by sequential steps.

At each step *nb* virtual pallets are generated, a check on the constraints is performed (MATCH CRITERIA in figure 6) on the *nb* generated combinations: all the virtual pallets that do not satisfy the constraints described in section 2 are deleted. The first of the remaining combinations is sent to the check on *TH* (step 6 of the proposed methodology).

The threshold solver, allocating in the memory only the current n_b combinations stresses less the computer resources. The dynamic approach with threshold finds good results fast: the best solution is not searched any more.

5. NUMERICAL RESULTS

The solver is written, for portability reasons, on Microsoft Excel 2003 and Visual Basic. The performance of the solver, described in sub-section 3.1.3 has been tested on a workstation IBM Intellistation Z Pro (4 CPU: Intel(R) Xeon(R) 5160 @ 3.00GHz, 16,0 GB RAM). The results are reported in Table 1.

Table 1: Results relative to the threshold configuration

Moulds/ pallet	Overall moulds	Cases analysed	Free surface	Solution s found	Work time
1	100	2.0*10^2	80 %	20	4 s
2	100	4.0*10^4	90 %	12	19 s
3	100	8.0*10^6	36 %	10	46 s
4	100	1.6*10^9	24 %	8	18 min
6	100	6.4*10^13	30 %	15	42 min

Five moulds configurations (1, 2, 3, 4 and 6 moulds/pallet) have been tested. The solver work time increases with the number of the moulds/pallet. The moulds used for the test are relatively small; the 6 moulds/pallet configuration finds better solutions (maximum 30% waste space) than the 1 mould/pallet configuration (maximum 80% waste space). The threshold *TH* has been increased to 80% in order to find some solutions; 80 of the 100 moulds have a base surface smaller than 20% of the area of the pallet (and so are rejected by the solver).

Finally the numeric tool has been used to organize the moulds of a whole factory storage. The 501 moulds of the storage have an height range from 250 mm to 850 mm. The moulds have been sorted by heights in 10 groups: all the height intervals of the groups are selected in order to have about 50 moulds for each group. The average vertical pallet wasted area is 5%. Ten hours of simulations are necessary to position 501 moulds on the pallets of the storage. The average horizontal pallet wasted area is 10%; the geometrical problem allows a 90% of pallet surface. The moulds are disposed on the pallets according to the maximum load limit of the shelves. The configurations, selected by the numeric solver, are graphically displayed by the solver; a different color is assigned to each mould. The graphic output helps to implement easily the solver outputs.

The results are satisfactory. The average height of the pallets from ground has been lowered, enabling a safer moulds management. The use of solver helped to save 51% of space. The electric lifts now follow shorter paths for handling the moulds in the new compact storage. Already 28% of new space created has been used to insert new moulds in the shelves; the 23% space available will be used in the future to host new moulds.

6. CONCLUSIONS

The problem of optimizing the waste space of industrial warehouses has been studied. The numerical approach often implies the comparative evaluation of a very high number of configurations. The heuristic threshold approach introduced gives accurate quality results in a reasonable time.

Each object to store has peculiar characteristics and specific needs: weight, size, inertia, object family, kind of use, frequency of use, maintenance needs, expiration date etc. The rules and constraints, specific to each family of objects, should be considered simultaneously in a multi-objective performance index. The designed and implemented solver can only minimize the waste space. Good sense is necessary to interpret and evaluate the simulator results. Good results are achieved only if the decision process is defined and discussed involving logistic managers, the storekeepers, and the electric lifts drivers. The multi stages numeric solver proposed helped to successfully optimize the space inside an industrial moulds storage; after the optimization, the shelves host 51% more moulds. The same approach can be used to solve several different logistic problems.

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REVERSE LOGISTICS SIMULATION MODELLING

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ABSTRACT
Scientific research regarding reverse logistics systems in developing logistics systems are complex, often not conducted by SMEs and are continuously generating certain logistics costs. Developed logistics systems are analyzing product returns and are tending to detect differences and oscillations in returned product flows. Developing logistics systems, as Croatian, reverse logistics issues, regarding product returns are not observing as issues of priority. Detailed research analysis implicated that majority of products in return is directed from different subjects in supply chains. Paper will detect amounts and processes regarding electric and electronic products directed to service from final consumers and retail chains. Collected relevant parameters will be base for simulation model of centralized service center on the Croatian market.

Keywords: reverse logistics, simulation modeling, process optimization, reverse logistics activities

1. INTRODUCTION

In a today's globalized economy and highly competitive market manufacturers face the challenge of reducing manufacturing cycle time, delivery lead-time and inventory reduction. The rapid development of today's technology and appetite for latest models of goods and products by consumers are fuelling the rate at which new products appear every day. Advancement in information technology results in a shortened product life cycle. This situation, which accompanies consumers developing disposable habits, has caused a large amount of waste, rapid depletion of resources, and serious damage to the environment. To deal with these critical problems, many governments have announced environmental legislation associated with green product designs and encouraged enterprises to implement green supply chains and reverse logistics so as to improve customer satisfaction, extend product life, and decrease resource investment. Reverse logistics is a recoverable system that increases product life by means of recycling, repair, refurbishment, and remanufacturing (Alshamrani, Mathur, and Ballou 2007; Amini, Retzlaff-Roberts, and Beinstock, 2005). In 1998, Stock defined reverse logistics as the processes associated with the flows of product returns, source reduction, recycling, material substitution, material reuse, waste disposal, material refurbishment, repair, and remanufacturing. Hence, the recoverable system deals with the physical flows of products, components and materials from end users to re-users. Reverse logistics is becoming more important in overall industry area because of the environmental and business factors. Planning and implementing a suitable reverse logistics network could bring more profit, customer satisfaction, and a nice social picture for companies. But, most of logistics networks are not equipped to handle the return products in reverse channels.

Environmental management aims primarily to reduce waste volume by moving away from one-time use and disposal to having control of the product's recovery. This encompasses of reuse, remanufacturing and materials recycling, which can be the three end-of-life (EOL) alternatives determined by the product's characteristics at the end of the product life cycle (Rose and Masui, 1998). As these concerns start to affect the customer's purchasing decisions, manufacturers are increasingly forced to consider their product's impact on the environment. This changing trend extends the responsibility of producers beyond the production and distribution to the responsibility for their products at the end of their life cycle. In order to address these problems, producers have to extend the traditional forward logistic distribution chain and consider the total environmental effects of all products and processes until they are returned at the EOL, which is also referred to as reverse logistics (Beomon, 1999, Kooi et al., 1996).

The aim of this paper is to define a model for centralized service centers where items directed to services should be processed with reduced disposition cycling time. Research for simulation model is conducted on the Croatian market by measuring relevant parameters.

2. MAJOR HEADINGS

Reverse logistics is the backward flow of what logistics operators, distributors and manufacturers wish would be a forward-only process. Products, components, materials, equipment and even complete technical systems may go backwards in the supply chain.

Products can be reworked during manufacturing due to unsatisfactory quality, or with good materials or components being returned from the production floor because they were left over after production (manufacturing returns). Defective products may be detected after they have entered the supply chain resulting in a pullback of products through the chain (product recalls). From this stage there are more actors in the chain involved with the reverse flows on the basis of commercial agreements such as returning vs. taking back obsolete stocks of short-life products (B2B commercial returns). In addition, in the business-to-consumer scenery, products may be sent back due to mismatches in demand and supply in terms of timing or product quality (B2C commercial returns). A particular situation is e-commerce where high percentages of returned products are not a surprise. During use and in presence of warranty or service possibilities, products may also be returned to be substituted by others, or to be repaired (warranty and service returns). Ultimately, even after use or product life, products are collected to be e.g. remanufactured, recycled or incinerated (end-of-use and end-of-life returns). At this point both material's hazard and environmental impact have to be taken into account. Concluding, products may reverse direction in the supply chain for a variety of reasons as listed below (see also Dekker and van der Laan, 2002; Dekker and de Brito, 2002):

1. Manufacturing returns
2. Commercial returns (B2B and B2C)
3. Product recalls
4. Warranty returns
5. Service returns
6. end-of-use returns
7. end-of-life returns

Summarizing, a product is developed and goes into production following the supply chain with the purpose of reaching a customer. However, at any moment, the product may go back in the chain. From this moment on, the chain does not deal any longer with supply alone, but also with recovery related activities. This denomination underlines the possible integration of forward and reverse flows. Furthermore, it embraces both the closed loop supply chains, where supposedly the reverse flow goes back to the original user or original function, as well as open loop supply chains.

Reverse logistics is gaining increasing levels of attention because of environmental factors as well as economic reasons (Ginter and Sterling, 1978; Gupta and Veerakamolmal, 2000, Haberland et al., 1997). Unfortunately, reverse logistic systems are more complex than forward logistic systems. This complexity stems from a high degree of uncertainty due to the quantity and quality of the products (Gungor and Gupta, 1999). Although it is desirable to develop an integrated model to incorporate forward and reverse flows of new and used products, one common approach to designing reverse logistic networks is to model reverse distribution independent of forward distribution (Fleischmann et al., 2003; Ginter and Sterling, 1978; Minner, 2001; Klebber et al., 2002; Teunter and van der Lann, 2002).

3. SIMULATION MODELLING IN LOGISTICS

A simulation is a model that mimics reality, defined as:

„*... the imitation of the operation of the real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history is draw inferences concerning the operating characteristics of the real system that is represented*“. (Banks, Carson, and Nelson 1996)

In general, models can be divided in conceptual, mathematical and simulation models. This segmentation refers to the levels of development of individual models. In designing of any model, it is primarily to define a conceptual model, and then this conceptual model can be used as a basis for the development of mathematical and simulation models (Hompel and Schmidt 2007).

Simulation models are models which are used in dynamic systems, systems that change in time and when applying simulation models, solution is obtained by experimenting system model, whereby simulation experiments result in a set of points. For this reason, planning and analysis of simulation experiments requires a statistical approach. When performing simulation elements (parts of model), simulation conditions must be controlled and provide conclusions.

The model is defined as an abstract representation of a system that describes objects systems, their interaction and usually contains a mathematical (i.e. budget period, activities) and logical relations (conditions of the action, the rules for the selection of entities) that correspond to the structure and mode of system operation. Models include objects with specific properties and their interaction causes changes of the system per time unit.

There are two basic groups of simulation models. The first group includes deterministic (those whose behavior is completely predictable) and stochastic models (those whose behavior is unpredictable, but it is possible to determine the probability of a status change). The second group includes discrete models (i.e., manufacturing processes and transportation systems), continuous models (i.e. position and speed changes continuously over time during the flight of the aircraft), and continuous-discrete models (i.e. arrival of tankers with oil in the harbor, where they differ continuing variables such as the level of oil in a tanker and tank and discrete events such as the arrival of the tanker).

Simulation of discrete event is a method for simulation modeling that describes the state changes which occur discontinuously in time, only in some specific moments. The interaction of objects in the system activities is causing changes in system status. These changes or events occur in discrete (discontinuous) time points (Thierry, Thomas, and Bel 2008).

Modeling of logistics system (supply chains) requires an understanding of the types of logistics systems and the objectives and issues associated with each type of system. Logistics systems can be arbitrarily complex and difficult to understand due to large number of data which is necessary to provide supply chain modeling.

In supply chain, decisions taken are usually classified as strategic, tactical, or operational. Strategic decisions are related to the company's strategy and are long term (2-5 years) with involvement of the most partners in the supply chain. Tactical decisions are mid-term (a month to 1 year). Operational decisions are short term, which are related to the day-to-day activities. Tactical and operational decisions are taken in individual area of the supply chain (e.g. plant and warehouse). They deal with issues in demand, procurement, production, warehouse and distribution.

Many researchers are investigating the possibility of creating a simulation-based real time scheduling system that will be able to monitor the system status and make decisions in real-time. To have the capability, it is desirable to have (1) capability to interface with legacy databases to obtain information (2) hardware and software processing capability to run simulation within very short time- at least, pseudo in real time (3) capability to interface with the control system to assign tasks and receive feedback on system status and performance.

Currently there are several commercial simulation tools available. These tools can be divided in three basic classes: general-purpose simulation language (requires that user is proficient programmer as well as competent simulationist), simulation front-ends (are essentially interface programs between the user and the simulation language) and simulators (they offer graphical presentation and animation, easy to use).

In this article authors used "Flexsim" simulation tool for simulation of centralized service center. Mentioned tool is specifically designed to simulate discrete events, primarily when simulating warehouse processes, airports, terminals and manufacturing complexes. Each model simulated in software is a system that consists of queues, certain processes and transportation. It enables the development of 3D models and accurately captures the actual system.

Reverse logistics issues are suitable for simulation modelling regarding to complexity of reorganization on site and focus on forwarding channel. Simulation modelling of directing amounts of products through different processing options in reverse logistics has a benefit of redesigning for an optimal solution. Returned amounts in reverse logistics are significant and need to be observed from supply chain point of view. Paper will present amounts and modelling directing to service centers from subjects in supply chain, including final consumers.

4. REVERSE LOGISTICS CASE STUDY – RETURN TO SERVICE CENTERS

Performed studies on the Croatian market regarding reverse logistics included 19 different companies, i.e. retail chains of a major share on the market, suppliers, producers, distributers and service centers. Companies provided basis for conducting research and insisted on anonymity. Researched infrastructure included detecting processes, warehousing and data regarding reverse logistics and inventories in distribution flow.

Regarding goods in return directed to service centers from retail locations, those are transported in an average of two times a month, according to research conducted at retail locations. Of all products (approximately 16) returned in one day from different reasons at a retail location category III (this means "Retail location assortment of 33000 products"), an average of two will be directed to a service center. The service center employs trained personnel to carry out inspection and repair of the returned product. Time periods required to conduct certain activities are used as input parameters of the simulation model of proposed centralized service center.

Retail locations are in different ways directing the goods in service centers, depending on the organization within the company, but also it depends on the current quantities of goods which are necessary to transport. Although transportation to a service center is secured, the organization is often ununiformed, performed in 20% cases *ad hoc*, when it's noticed that returned goods on service wait too long, and the legal obligation of goods repair should be within "a reasonable time". The goods are transported at the expense of distributors, suppliers or manufacturers, depending on the agreements between the companies. Because of non-uniformed processes, transporting goods for service often is dedicated to salesperson, or any other person to whom specified route this permits, and is operating within retail and service chain or a business associated with it. On the market there are two different returns from retail chains:

- Products intended for the service are collected at retail location, and then by organized transport are directed at service centers.
- Products intended for service are not collected at service centers, and the end users themselves are obliged to deliver the goods to the location of the service center and to collect.

Because of the mentioned above, the double transport processes are detected in handing the goods, as users primarily returning the goods to the location of purchase, and then at the company's expense, because company is contractually bound to the above, the goods are delivered to the service location.

At the level of the service center, the goods are received on a daily basis, and based on semi-annual data of one company that has been involved in the study, in a total of 31,723 orders. The service center, which is one of the major service centers in Croatia, and is a manufacturer and distributor of electronics and consumer goods, goods in return primarily categorize:

- Commercial return which includes goods returned by the end user within 8 days of purchase unpacked and for defects in using, but technically unused goods, used for the purpose of promoting or goods damaged at the retail level.
- Service orders that include only goods that are returned due to a malfunction.

4.1. Amounts and product quality in return

Data collected for the purposes of research have shown that in the six-month period, from August 2012 until January 2013 year, the service center has received a total of 8,500 orders categories of commercial return, and a total of 23,232 service orders, as graphically shown in Figure 1.

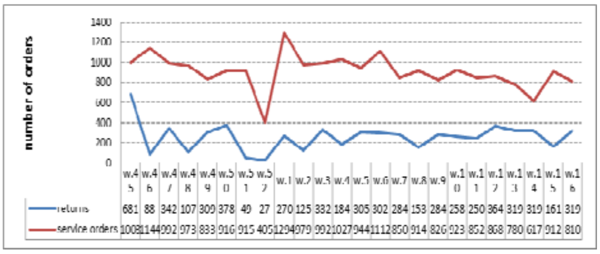

Figure 1: Return of goods to a service center

Service orders in 72% of cases involve the inspection, repair and return to the final consumer, 16% of the products are damaged, but products that can still achieve certain market value, 10% of them are for directing at the disposal, and 2 % to the manufacturer.

Statistical data resulted in the fact that after inspection of the commercial return category by trained employees in the service center, most of the goods are directed in the reverse logistics channel where the goods will be sold at a lower price, then the channel in which the goods will be sold at full market price. Other channels include the disposal at 21% of the cases, the return to the manufacturer in 8.9 % of cases, and a return to the status of an unauthorized in 0.6 % of cases. The study confirms that uniformity in procedures affects the return of unauthorized returns in minimal amounts. Disposed are those products that after control present group for which cost of repair is greater than cost of disposal. Products are destroyed completely, and parts thereof, cannot be reused. Manufacturers are usually insisting on return for the purpose of verifying the status of return processes, where each manufacturer ensures that the product is reviewed in accordance with their terms. The above statistics are shown in Table 1, were processing is at the example of 3445 orders received.

Table 1: Status of commercial return after reviewing by trained employees

	Number of orders	Percentage
Secondary market – sales price	1243	36.1%
Primary market – full price	1149	33.4%
Disposal	725	21%
Return to manufacturer	306	8.9%
Unauthorized return	22	0.6%
Total	**3445**	**100%**

4.2. Necessary time periods for processing

Different categories of return characterize different periods of time necessary for the employee to inspect and repair goods. Studies have confirmed that the average period of time required for treatment depends on the condition of the product. At total of 31,732 orders observed in six month period, it was found that the product inspection by employees requires time period from 1.96 to 2.06 working days. The differences are reflected in the time required for repair, where the products include fewer failures and are categories of commercial returns, and require much less time to repair, ie 4.7 compared to 7.81 workday for service orders product category. The above data are shown in Table 2.

Table 2: Time periods necessary for inspection and repair

Category of non-defective defectives (product is

	Time period for product inspection (calendar days)	Time period for product inspection (working days)	Time period for product repair(calendar days)	Time period for product repair(working days)
Commercial return	2,74	1,96	6,58	4,7
Service order	2,88	2,06	10,96	7,81

properly working), which is one of the strategically important categories, and the categories that need to be reduced when entering the reverse logistics system, are analyzed on the basis of service orders and status after a review of the product in return. From a total of 23,232 service orders in the period of August 2012 until January 2013, 3.14% are orders whose status confirms that the product has been tested and is fully correct. Share of non-defective defectives at a service center is not considered significant, while the cause of the quantity of returned products in this category are considered uneducated users, and unused instructions.

As relevant parameters for comparison with the output parameters of the simulation model are defined:

- Number of employees in charge and their cost.

During the research it has been noticed that at every level of the supply chain there are employees solely responsible for processing goods in return. Respondents pointed that disburden of the distribution flow employees could reduce costs and/or provide additional resources to handle the distribution of goods.

- Average disposition cycling time.

Disposition cycling time is important indicator of the return flow quality. Reducing the disposition cycling time, organization allows returned product directing to the secondary market in a shorter period of time and increases the possibility of achieving maximum market value.

All costs and presented as an approximate value for employee salary on the Croatian market in January 2014, while disposition cycling time is measured at researched locations for products in return. Mentioned parameters are presented in Table 3.

Regarding service centers and retail locations, during the research, necessity for reduction of costs was continuously highlighted. Costs that are considered as issues include unnecessary transport process, employee occupation with return and number of employees provided for returned items, especially at retail locations. Disposition cycling time generates costs from product point of view, where prolonged processing reduces the value of the product and the possibility to gain maximal possible profit.

Table 3: Research results regarding disposition cycling time and expenses at retail locations and service center

	Number of employees /hours a day	**Expenses brutto/day**	**Total expenses / day**	**Disposition cycling time**
Retail location	3/16	25 EUR	75 EUR	5-10 days
Service center	38/8	30 EUR	1140 EUR	10-14 days

5. SIMULATION MODEL OF CENTRALIZED RETURN TO SERVICE CENTER

Simulation model is made in simulation tool “Flexsim” that is used for simulation modeling of logistics processes. Due to unnecessary transport processes, ununiformed procedures and prolonged disposition cycling time organizational model for centralized service center is proposed.

Conceptual model is based on presumption that service center is formed on the market as an business subject that is processing facility for inspection, repair and other reverse logistics activities. Service center is formed for the benefit of reducing the disposition cycling time and prompts the positioning of returned products on the secondary market containing reverse logistics channels in form of outlet and internet sales. Model contains activities that are triggered when item is returned, if unauthorized return appears it will be rejected, positioned in the shipping zone for directing to producer or back in chain. If authorized, inspection is obligatory. Detailed inspection provides individually based information regarding product in return and necessity for repair. Temporary location is provided while ordering parts and/or repair. Educated personnel evaluate products and its disposition to proper in-house or another reverse logistic channel. If product is consumer return it is positioned on temporary location while collection by consumer.

Mentioned structure is presented in Figure 2.

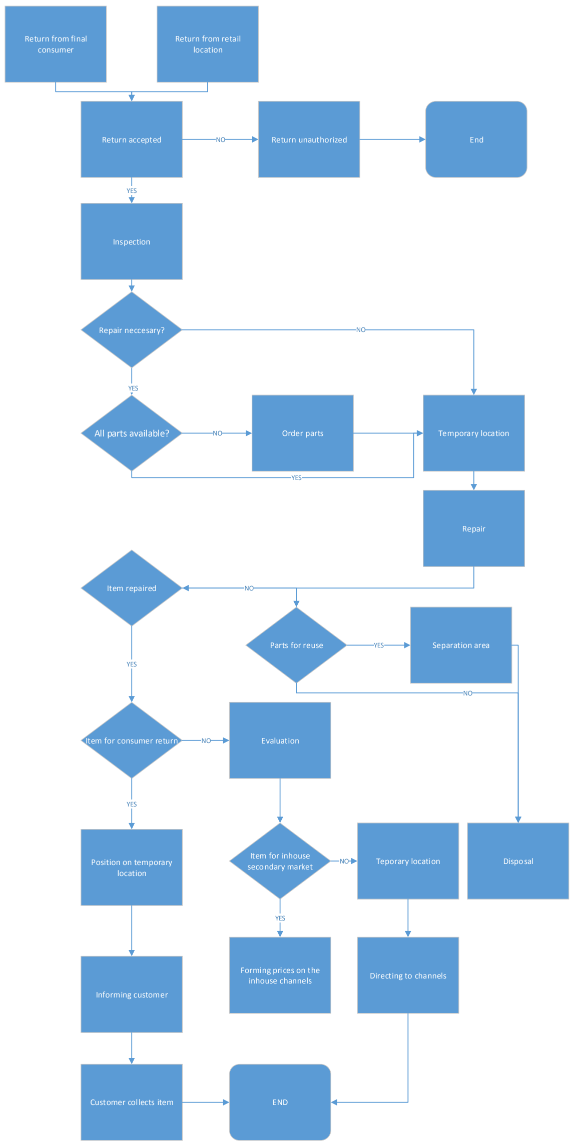

Figure 2: Model of centralized service center

Simulation model contains of processing objects and three modules, receiving area, processing and directing to secondary markets.
Simulation modeling included:

- Objects formation from the simulation software tool library.
- Defining the relationship between objects by setting connection.
- Objects parameters (variables) input.
- Simulation runs with the execution of simulation experiments.
- Summary Statistics.

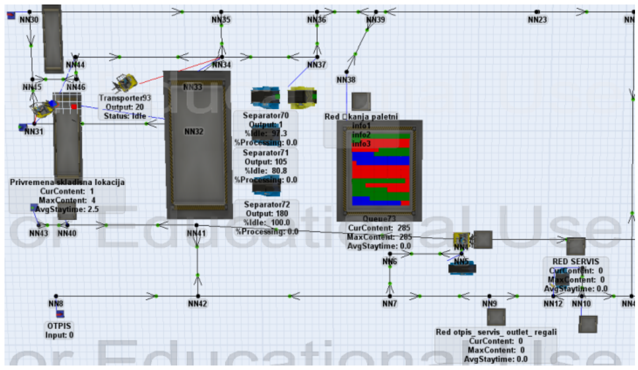

Figure 3: Simulation model proccesing modul of centralized service center

For the purpose of verification of the simulation model, testing of individual activities was conducted, objects, their conditions and interrelationships. Procedures, planned events, the association of fixed and mobile objects and their defined variables, and the movement of the entities within the conceptual model, were tested in the form of modules, where one module is a closed function of the observed system. In this manner modules are individually verified and after for simulation model was defined the limited time period of replication in the range of 10,080 rpm.

After 120 replication of limited time duration in the range of 10,080 rpm, different output variables were observed. Model of the service centers, has resulted in direct benefits for critical points related to the business in return of goods. Reducing the disposition cycling time at averaged 280.85 minutes, or goods are in the house after arrival processed within one business day, which significally shortened the disposition. The disposition cycling time on the Croatian market for products directed to service centers in its minimal share is 15 days and in its maximum 24 days after the products is received. The disposition cycling time in centralized service model directly depends on the number of service workers and can be prolonged by reducing the number of employees with parallel reducing of the costs. The cost of employees was reduced at each retail location category III for approximately 2000 EUR per month. Channels of reverse logistics in a simulation model include outlet and internet sale which is significant for electric and electronic devices because of their continuous value loss, and positioning items in short period of time on the market.

Except mentioned, evaluation of products on retail level results in ununiformed values, processes and provided activities (if existing), while processing products in return in the service center results in evaluation by educated personnel.

6. CONCLUSION

Reverse logistics is the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. To achieve this objective, companies need to have better visibility into the entire reverse logistics system of their own plans as well as those of their suppliers and customers. Companies today should be agile enough to adjust and rebuild plans in real time, to take care of unexpected events in the supply chain. These needs have propelled the application of discrete event simulation for analyzing entire supply chain process.

When developing reverse logistics simulation models, first of all a good understanding of the overall supply chain is most important. Good understanding of the business characteristics (e.g. performance measures, make to-stock or make-to-order) is also essential since every industry has different business characteristics and supply chain management processes.

Organizational issues of reverse logistics, including reverse logistics problems in all aspects of the supply chain, need to be researched continuously. Detailed analysis of processes, reasons of return and specifications of products in return can be fundaments for reorganizing the reverse part of chain for the economic, ecological and sociological benefits.

Specific part of logistics should be often simulated due to uncertainty and often impossibility to reorganize processes to measure optimization. Except in-house simulations, reverse logistics issues very often become issues of other parts of chain where they generate certain logistics costs in form of warehouse, transport and manipulation costs. Because of mentioned subjects of supply chain should coordinate their business to optimize reverse logistics processes.

For the same reason simulation model was formed regarding centralizing the goods aimed for service from final consumer and retail locations. For directing those products in return it is necessary to provide specific activities. In the service center is necessary to define the activities that will be in accordance with the needs of the customer service or own business and specifications of the products that will be directed to a service center.
Primer activities should be the core of the centralized service center defined for the purpose of the offer and to short disposition cycling time as repair, dismantling of the components, reuse and disposal. Activities of repair and re-use are provided by trained employees and service workers, while these activities imply that the product needs for specific (and in some cases very small) changes. Depending on the contract, it is necessary to provide activities to replace worn out or dysfunctional components of the product or packaging, in order to re-use products.

Also, it is necessary to provide possibility for packaging original state by conducting activities such as cleaning, polishing, painting, etc. if a manufacturer or supplier requires. If this is not the case, after evaluating, products will be repaired or renewed in the manner prescribed by the service center, with the aim of adding value in order to achieve the maximum possible value of the potential markets and in-house reverse logistics channels.

ACKNOWLEDGMENTS
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A ROBOTIC VEHICLE FOR FREIGHT DELIVERY IN URBAN AREAS

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ABSTRACT
The authors present new concept architecture of light duty full electrical vehicle for efficient sustainable urban freight transport that allows the movement of two Euro Pallets 800x1200 mm (or boxes with similar bottom part). Following a sustainable and efficient mobility approach, a robotic handling device has been designed and positioned on-board of the vehicle. The handling device realizes the loading-unloading operations on the right side of the vehicle and from the ground to the vehicle platform. Active suspensions of the vehicle have been designed to adapt the stiffness to the payload and at modifying the chassis height on the ground for travel and loading-unloading tasks.

Keywords: Freight Transport, Urban Areas, Robotic Vehicle, Electric Vehicle

1. INTRODUCTION

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

As urban freight transport deals primarily with the distribution of goods at the end of the supply chain (Power 2005), many deliveries tend to be made in small loads and in frequent trips, thus resulting in many vehicle kilometres (Cepolina and Farina 2013).

Consuming behaviours have changed rapidly in the past years and they have transformed the way people travel for shopping. Surveys show that home deliveries are not marginal anymore and are growing at fast rate. Many householders have their groceries delivered at home on a regular basis. Many of them do it after online shopping. According to latest APAC and America forecast report, global e-commerce sales Business to Consumer, B2C, will surge up to 50% in the next 5 years, see Figure 1. Many transport companies are reluctant to serve householders: they consider home deliveries to be a difficult market, because of the high dispersal of delivery points, a high proportion of missed appointments, difficult delivery schedules and a large number of upper floor deliveries (Dablanc 2014).

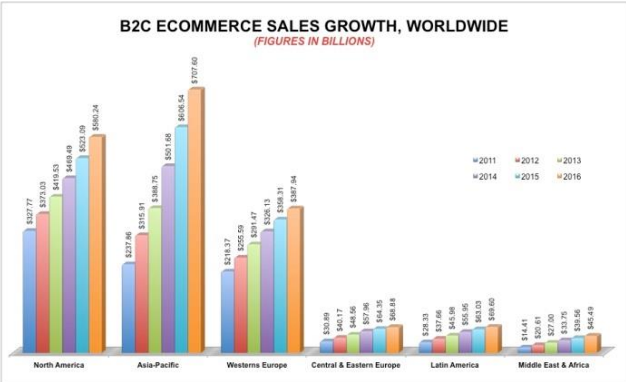


Figure 1: B2C e-commerce sales statistics and forecast (courtesy Amit Misra, July 2013)

As a result the scope of urban freight focuses on vehicles that visit many destinations, picking up and delivering many separate consignments (Muñuzuri 2009).

These urban freight movements cause problems within cities, e.g. due to: the lack of suitable infrastructure for deliveries, the conflicts with other users during freight delivery operations, the accessibility of these vehicles to pedestrian areas and historic city centres, environmental and noise pollution, generation of accidents in the urban areas and compromising the mobility of citizens.

The primary focus of urban transport planners in recent years has been to address the demand for people movement, and more specifically, to reduce the collective dependence on motorcars and on fossil fuels. As a result, we have seen the gradual conversion of road and street networks towards the inclusion of bus lanes, larger footpaths, cycle lanes, etc. and the reduction of road space available for cars. So the road space available for the freight distribution, both in terms of available road lanes and loading space has been reduced (Crainic at al. 2004).

2. FURBOT MAIN FEATURES

The vehicle architecture is conceived modularly: the main modules are the cab and the chassis. The payload is assumed to be packaged in freight boxes and Euro pallets. The vehicle integrates electrical modules for power generation and supply together with the relative software control modules. The power is used either for the vehicle motion or for the loading/unloading operations; this is also a safety measure, because in this way it will not be possible to move the vehicle during the loading/unloading operation.

FURBOT is environmentally cleaner and less noisy than traditional vehicles. This allows it to operate in urban center without any access restriction in term of zones and time windows. For instance, thanks to the low noise emissions, off-peak and night-time deliveries can be performed.

Great attention has been devoted to improve the energy efficiency of the system (Amjadi and Williamson 2010) by exploiting different aspects: a new power train layout specially designed and suitably integrated in the chassis design; a new battery and energy management system; last generation lightweight, direct drive electric motors; regenerative braking on the four driving wheels; reduced mass of the vehicle due to a by-wire transmission that allows the realization of the active driving controls via software instead of using heavy mechanical components; and driver-assistant or autonomous-guidance software able to minimize power use.

The freight loading/unloading operations are performed automatically through robotized procedure. Freight boxes have been specially designed together with the architecture of the FURBOT vehicle: the boxes have standard size and their bottom is shaped exactly as a Euro pallet in order to be handled by the robotized forklift. The FURBOT unloads these boxes in specific locations in the urban area. In this way the conflicts with other road users during the loading and unloading operation, and the resulting congestion due to urban freight movements, are limited. The number of stops for the loading/unloading operations is kept low because many parcels, with small volumes and near-by destinations, are aggregated in a single box. Once the delivery is made, the consignee will open the door containing his/her parcel. This is done within a predefined time window, scheduled in advance during the purchase of the item. When the time window expires, the empty boxes will be collected by FURBOT, leaving the urban space free again for other land uses (such as parking).

The FURBOT vehicle is kept very small in size and in the amount of transported freight. It represents a transport agent that can be used by alone but that better exploits its power if used in a fleet as a multi-agent system yielding a new sustainable and adaptable urban freight transport system (Cepolina et al. 2013).

3. THE FURBOT VEHICLE

The dominant paradigms of the new vehicle design were life-cycle approach and high energy efficiency. The first required to take into account, at the design level, of the manufacturing processes, the modularization of subsystems, the standardization of components, functionality performance, the maintenance, repair, and reconfiguration issues, as well as the disassembly and recycling needs, while targeting low cost figure. The second required the right selection and sizing of all the electric supply system components, the definition and set up of suitable rules for the battery management system, the automatic regenerating of the braking energy and its use to charge the batteries, the definition of logics managed by the driving assistant.

Great attention was devoted to the optimization of the vehicle layout in order to increase the freight-payload to vehicle-weight ratio and improve crashworthiness.

3.1. The Structure

The main innovative characteristics are: (a) a light-weight agile frame equipped with active suspension wheels (this novel architecture will allow a better usability in urban environment and improve intrinsic stability and safety); and (b) the adoption of standardized freight boxes dedicated to different categories of cargo and (c) the integration of a robotic module responsible for the loading/unloading operations.

The vehicle body was designed with the aim to tightly envelop the maximum freight volume consisting of two Euro pallet or dedicated boxes (800x1200 mm footprint). The freight weight is supported by a minimalist network of welded stainless steel tubes with square and rectangular section, Figure 2. The body frame cage was optimized through static and dynamic computational analyses and simulations.

The vehicle mobility is realized by two traction wheels located in the rear part of the chassis; the two electric motors are mounted near to the wheels, due to the lack of in-wheel motors with suitable diameter and power available in the market. The two front wheels are steering.

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

Figure 2: The FURBOT vehicle body and structure

The structural design of the frame has been developed through two sets of analyses: static for the first definition of the geometry and sections; dynamic with time variant external loads at the interfaces of the suspensions to minimize the mass of the structure.

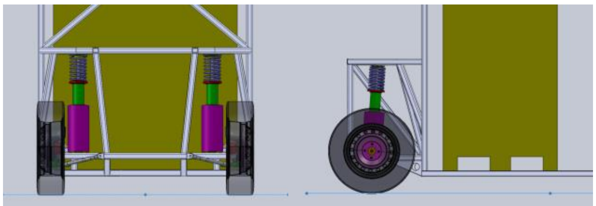
3.2. The Freight Handling Robotic System

A new robotic device, supplied by on-board electricity, is developed and integrated in the platform of the vehicle (Dinale et al. 2013). The kinematic architecture is specially targeted for service tasks, with minimized mass and degrees of freedom, thus simplifying the control system and allowing for an intuitive Human Machine Interface (HMI). The pallet/box loading/unloading tasks are performed by moving the whole pallet/box to and from the chassis-frame side, so this operation can be done very quickly reducing the parking manoeuvres. The main features of the robotic module are: (a) full flexibility and ability to handle (in particular load and unload) automatically the freight modules; (b) sensorization to prevent errors and accidents while performing the operations without compromising timing; (c) ability to determine automatically the mass and inertial properties of the package (typically by reading an RFID tag) and to optimize the handling operations according to the specific need.

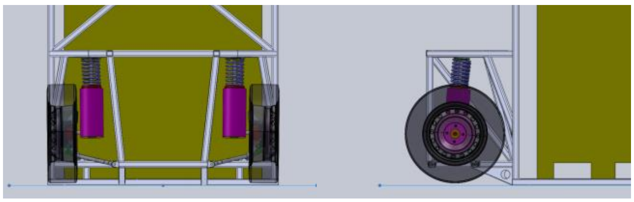
The actuation system of the robotic handling device is constituted of two DOFs: a horizontal (Y direction) and a vertical (Z direction) motion (see Figure 2). These movements are generated by two hydraulic motors with telescopic elongation.

The actuation system of the vehicle contributes with one DOF in Z (see Figure 2 and Figure 3) direction during loading/unloading operations. The movement is generated by active suspensions mounted on the wheels of the FURBOT vehicle.

More information on the freight handling device could be found in (Muscolo et al 2014).



(a)



(b)

Figure 3: Driving configuration (a) and loading/unloading configuration (b) of the FURBOT vehicle

3.3. The Body Embedded Sensorial System

A suitable distribution and intelligent use of exteroceptive sensors plays a key role in the implementation of the driver-assistant and automated-driving functions (Pollard et al. 2014). This will contribute to: (a) safe behaviour within city environments; (b) vehicle steering, accelerating and braking by wire; and (c) a more efficient use of electric power for vehicle propulsion, freight handling and regenerative braking. Figure 4 shows the main sensors equipping the vehicle body.

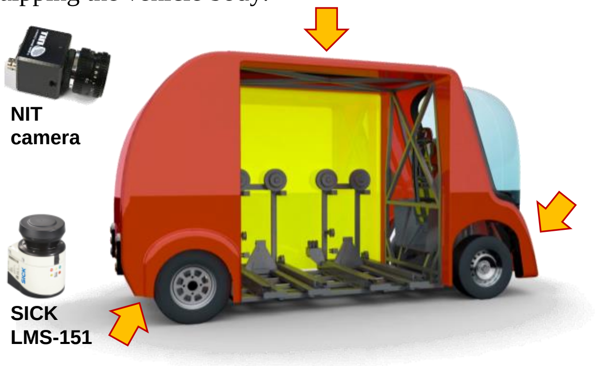


Figure 4: Main exteroceptive sensors positioning

3.4. The Electronic Power System

A fully electrical power train that allows to overcome the low fuel efficiency of traditional gasoline engines or diesel engines has been adopted. Furthermore, the energy efficiency of present-day electrical vehicles (about 60%, taking into consideration the efficiencies of all power chain components charger, battery, power control, motors, transmissions) has been improved in three ways: (a) by regenerating braking energy and using it to charge the batteries; (b) by using intelligent power management rules within the driving assistant; and (c) by targeting the conversion efficiency of standard electric vehicles to obtain a satisfactory power system for small light weight vehicles.

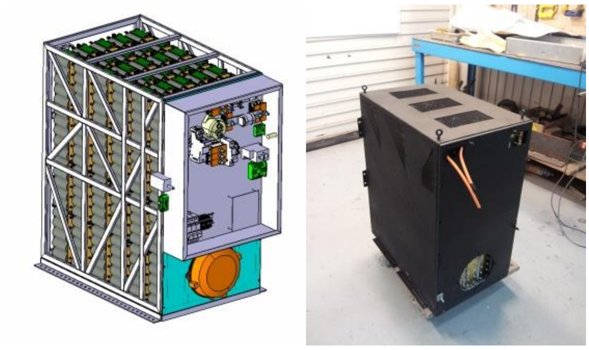


Figure 5: Battery model and box (Courtesy Mazel Ingenieros)

The battery box includes the cells, the monitoring and balancing system. The communication is obtained via can bus.

3.5. The Loading/unloading operation

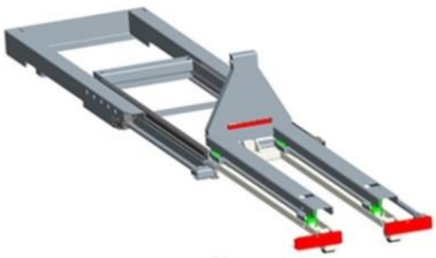
Hereafter the loading/unloading cycle is described. Once the vehicle has been positioned correctly, the following steps are applied:

1. check that the distance between box/pallet is less than 500 mm and all other position tolerances are satisfied;
2. use the active suspensions to move the loading deck until the proper height with respect to the pallet/box to load is reached; the frame with forks translates with

respect to the base and a short lift is available (120 mm), sufficient to move the bottom face of the pallet/box above the floor surface of the loading deck;
3. move outward the forks in lower configuration, insert them in the slots of the pallet/box, lift up the forks, retract the forks, translate down the forks to position the pallet/box on the loading deck;
4. lift up the suspensions to driving height.

The unloading is done analogously in reverse order. Figure 6 shows the two robotic handling devices: the digital mock-up and the real prototype of the robotic handling device. Figure 7 shows frames explaining the motion of the forks during a loading cycle.

(a)



(b)

(c)

Figure 6: Robotic Handling Device: a) digital mock-up closed configuration; b) digital mock-up open and lifted configuration; c) real prototype open and lifted configuration.

Figures 8, 9 and 10 show the complete realized vehicle (without cover), respectively in a frontal, rear, and side view.

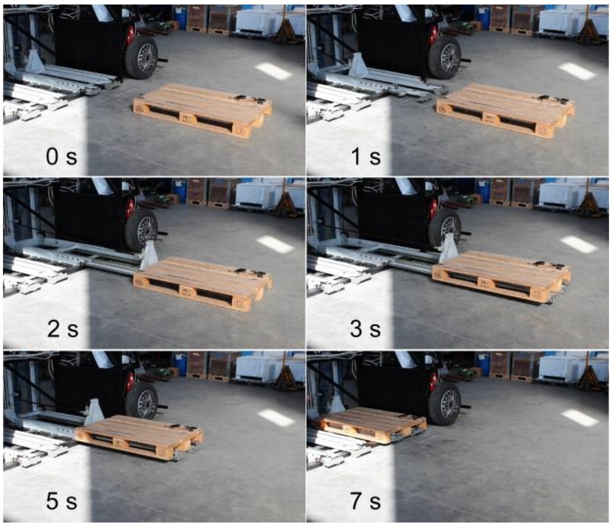


Figure 7: FURBOT loading cycle (from top to bottom, from left to right): intermediate positions of the fork loading an empty pallet.

4. THE FURBOT PROTOTYPE

The different modules of the vehicle are realized and tested stand alone. The assembly and cabling operations are in progress.

The frame is made of welded AISI304 square hollow pipes. The floor of the loading bay uses four 100 mm x 40 mm x 2 mm thickness pipes with transversal connection beams (see Figure 8).

The four suspensions span 180 mm vertical translation and let move the loading deck from driving height (maximum height) to any intermediate loading/unloading height up to deck laying on the ground (minimum height). Each suspension comprises a hydraulic ram with gas spring and a shock absorber in series; this assembly pivots on a ball joint on the chassis and is hinged to the wheel assembly. This original solution transforms the vehicle in a platform with the ability to adjust its height from the ground continuously.

The steering of the front wheels is operated by a servo electric motor driving a mechanical commercial steering bar. The traction power is 15 kW at wheels (tire size 165/75 R14). Full loaded, the vehicle negotiates slopes up to 10% and the max speed is 30 km/h. These speed and slope data have been collected during the delivery simulations in Lisbon (Portugal) and Genoa (Italy), where typical delivery path have been considered.

A view of the vehicle from the rear shows the battery and electronics housing, Figure 9.

The two freight handling robotic systems can be seen on the side view of the vehicle in Figure 10.

Figure 8: FURBOT Vehicle: frontal view

Figure 9: FURBOT Vehicle: rear view

Figure 10: FURBOT Vehicle: side view

5. CONCLUSION

The paper addresses the main features of the FURBOT vehicle. This vehicle has been designed with the aim to offer an innovative platform for freight delivery in urban areas with full respect of the inhabitants and the local environment. In few months, the FURBOT prototype will be ready for testing in real cities that will request its use.

ACKNOWLEDGMENTS

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SYSTEM IDENTIFICATION MODELING OF ROTORS BEHAVIOUR

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ABSTRACT
The prediction of the rotor behavior in its turbo machine final housing is a crucial problem for turbo machinery manufacturers and very complex to solve using classical approaches. The authors, in other works, proposed an innovative method for the determination of a transfer function (MTF) between the rotor responses on a balancing machine (HSB) and on turbo machinery (SP). The proposed method uses a particular formula (MTF), calculated with a black/box approach and based on the application of the theory of System Identification. MTF was determined by a regression analysis of the responses in HSB and SP of 10 rotors; subsequently it was tested and validated on other 15 rotors. The results demonstrate that the proposed MTF simulates a rotor behavior in SP with a satisfactory overlapping of the measured output. In the last presented works, only some results were shown. In this paper all results on prediction and simulation of rotors behavior are presented. An analysis on all graphs allows underlining the repeatability of the proposed method.

Keywords: Rotor Dynamics, Balancing, System Identification, Vibrations, Black-Box, Transfer Function, MTF

1. INTRODUCTION

The statoric parts and the rotors of turbo machines, such as compressors, steam, and gas turbines, are usually realized in an independent way. The rotor is balanced several times on a high speed balancing machine (HSB) in order to reduce the gap error between the theoretical simulation and the real behavior of the rotor during the high speed rotation, thus it is positioned within the turbo machine (SP). The vibration limits of rotors and turbo machinery for proper operation are defined by ISO (2002) and API (1996a; 1996b).

A very important problem, in the field of turbo machinery testing, is the prediction of rotor behaviour (Darlow 1989) in HSB and SP. Some rotors, with a stable behavior in rotation, during theoretical simulation and balancing in HSB, have an unstable behavior during rotation tests in SP.

In engineering problems, often the physical behavior of a system cannot be fully described (either for lack of baseline data or for excessive complexity of the system). In these cases it is necessary to use an experimental approach in order to define the mathematical model.

System identification is utilized to solve this kind of problems (Ljung 1994, 1999; Bittanti 1992a, 1992b; Söderström and Stoica 1989). The identification techniques generate a mathematical model using a regression analysis of the input or input-output data of a system (Natke 1988; Droper 1998).

In the papers (Muscolo 2008; Muscolo, Casadio, and Forte 2012), the authors proposed a new method based on a black-box approach to find a transfer function, called MTF, between the rotor responses on the High Speed Balancing machine (HSB) and in the turbo machine (SP). MTF allows to predict the vibration amplitude of the rotor in SP, already during the balancing steps in HSB. The black-box approach was used because of the high complexity of the two systems and for the unavailability of all the data required to define accurate and realistic white-box models using classical approaches. The research has been conducted in collaboration with a competitive Oil & Gas company, and the MTF represents a first relation between HSB and SP.

In this paper, the authors show other results obtained using the MTF formula and not presented in last papers. Graphs of measured, predicted, and simulated model output are shown in this paper underlining the repeatability of the MTF used model. The future planned steps are focused on the optimization of the formula (MTF) using a non-linear system identification approach.

The paper is so structured: section two presents the problem and the black-box used approach based on the system identification; section three shows the MTF formula and some graphs underlining the repeatability of the model. Section four presents the validation of the MTF and the paper ends with conclusions and future works.

2. SYSTEM IDENTIFICATION MODELING: BLACK-BOX APPROACH

Figure 1 shows a graph of vibration amplitude in micrometres peak-to-peak of an analysed rotor. One graph contains the vibration responses of four probes (A, B, C, D) in HSB overlapping to the four vibration responses in SP. A and B are the responses of the 2 probes mounted on the bearing of the support near to the motor transmission joint; C and D are the responses of the 2 probes mounted on the bearing on the other support (see Figure 2).

Table 1 shows the characteristics of the 25 rotors considered in the analysis. All of them respect the run-out limit. Run-out is a noise relative to probes (API 1996a) as defined in (Weaver, Timoshenko, and Young 1990) (Ehrich 1992; Bently, Hatch 2002).

The test performed in the turbo machinery lab (SP) is passed if the vibration amplitude of the rotor is below the threshold of 25 micrometres peak-to-peak in proximity of the first or second critical speed as in HSB (Darlow 1989).

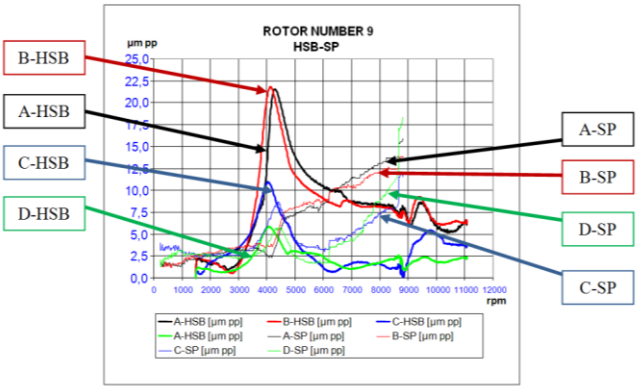

Figure 1: Vibration amplitude in micrometres peak-to-peak of rotor n° 9, in HSB and SP. A, B, C, D represent the vibration responses measured by 4 probes on bearings in HSB e in SP.

Table 1: Characteristics of the 25 analysed rotors.

Values	MAX	MIN
Rotor masses(kg)	1900	244
Diameter of impellers(mm)	600	350
Number of impellers	8	5
MCS = Maximum Continuous Speed (rpm)	13027	8167
OS = Over Speed (rpm)	14850	9310
TS = Trip Speed (rpm)	13678	8657

Statistical and physical approaches have been presented in (Muscolo 2008; Muscolo, Casadio, and Forte 2012), and have highlighted the difficulties of representing the complex relation between the HSB and SP systems and the need to use other tools to find a relation.

The new method proposed in the articles (Muscolo 2008; Muscolo, Casadio, and Forte 2012) allows determining the transfer function between HSB and SP for rotors with the characteristics listed in Table 1, within the range of rotational speed from 1000 rpm to 12000 rpm.

A black-box approach, based on the theory of system identification (Ljung 1994, 1999; Bittanti 1992a, 1992b; Söderström and Stoica 1989), was utilized in order to determine the transfer function. In the proposed method, the rotor responses in HSB and SP were considered, respectively, as an input (H) and output (S) signal; a mathematical model, using a regression analysis of input-output data of the system H-S, was created. The transfer function linking these two signals (H and S), for each single rotor, was a particular solution. The general formula, valid for all rotors, relating H and S (and then HSB and SP), called MTF (Muscolo 2008; Muscolo, Casadio, and Forte 2012), was constructed from the subsequent analysis of many particular solutions.

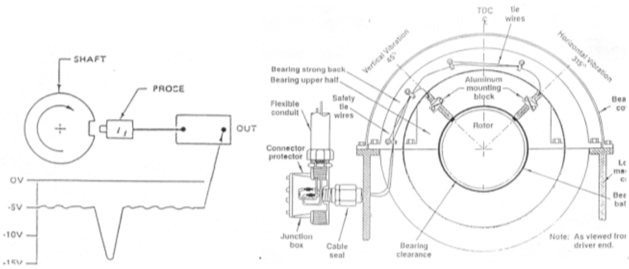

Figure 2: Classical position of the two probes in a machine with horizontal rotor axis

2.1. Analysis and Processing of Experimental Data

25 rotors different by weight, length, number of impellers, etc. (see Table 1) were considered for the determination and validation of MTF.

Instead of the rotational speed in rpm, the following variable was adopted:

$$i = \frac{rpm - 1000}{100} \qquad (1)$$

For each rotor it is possible to get two signals, H and S (as input and output), for each probe (A, B, C, D), expressed as a function of variable i ranging from 0 to 110 corresponding to a range of rotational speed from 1000 to 12000 rpm.

The signal was sampled from 1000 *rpm* (0*i*) to 12000 *rpm* (110*i*) (period Ti = 110), with spaces of variable $\Delta i = 1$, satisfying the sampling theorem (Shannon theorem). Eight data vectors [111x1] were created for each rotor, corresponding to the eight signals of the probes (Figure 1). Four input data vectors (in HSB (H)) and four output data vectors (in SP (S)) were considered. Each vector is formed by a column of values and by 111 lines of sampling. The signal analysis was carried out on the data vectors [111x1]. The process of analysis of 10 rotors is described in the following sections with reference to probe A; for the other probes the procedure is the same. 10 input and 10 output vectors were constructed; three systems of data were built: one system was obtained without data filtering, one was obtained with constant detrend (removing mean value) and another system was obtained using linear detrend.

2.2. Identification Process, Optimal Model, and Its Validation

The first step of identification techniques should define what family models can describe the data. The analysis was limited to five linear family models: ARX, ARMAX, OE, BJ, PEM (Natke 1988). The second step of identification techniques is the determination of the complexity of the model by varying its order. The Final Prediction Error (FPE) and the Akaike Information Criterion (AIC) were used as prediction error (Ljung 1999; Natke 1988). The optimal order of a model corresponds to the lowest calculated values of AIC and FPE. Each rotor was analysed using Matlab System Identification Toolbox and the validation was done using Simulink.

In order to determine the transfer function, tests and simulations were performed on 10 rotors using parametric models (arx, armax, oe, bj) and models for signal processing (or prediction error (PEM)), with different polynomial order. For both models (parametric and pem) 3 types of analysis of values were carried out: without detrend, with average detrend (order 0) and with linear detrend (order 1).

The comparison of all models and the subsequent simulation allowed choosing model bj22221. Among all families the bj model best describes, with the lowest percentage error, the sequence of data of H and S (HSB and SP) for all 10 rotors. The bj22221 model, among the stable models, has the lowest values of AIC and FPE, respectively equal to 0.0963 and 2.3401.

3. MTF FORMULA: DETERMINATION

MTF is the proposed transfer function between HSB and SP defined by the determination of coefficients, $\alpha(q)$, $\beta(q)$, $\gamma(q)$ and $\delta(q)$, of model bj22221:

$$\underline{\underline{MTF}} : S(i) = \frac{\alpha(q)}{\delta(q)} \cdot H(i) + \frac{\beta(q)}{\gamma(q)} ; \qquad (2)$$

where:

$\alpha(q) = 2.12q^{-1} - 1.9q^{-2}$;

$\beta(q) = 1 - 0.17q^{-1} + 0.39q^{-2}$;

$\gamma(q) = 1 - 0.74q^{-1} - 0.27q^{-2}$;

$\delta(q) = 1 - 0.35q^{-1} - 0.56q^{-2}$;

The elements of vectors *H(i)* and *S(i)* are the vibration amplitude values of 4 probes (see Figure 1) respectively obtained in HSB and SP varying the value of the variable i ($0 \le i \le 110 \Rightarrow 1000 \le rpm \le 12000$). Equation (2) is based on a BJ family model (Ljung 1994, 1999; Bittanti 1992a, 1992b; Söderström and Stoica 1989) and with MTF it is possible to obtain the simulation of vibration amplitude values of the rotor in the turbo machinery bench SP (*S(i)*), giving vector *H(i)* as input. In conclusion, by using MTF it is possible to obtain the simulation of the trend of vibration amplitudes in SP knowing the vibration amplitude values in HSB at the end of the rotor high speed balancing.

3.1. Results and Discussion

MTF was determined by analysing the trends of 10 rotors and it was validated on other 15 different rotors.

The following Figures show measured, predicted and simulated output graphs. The Figures predict the output of the identified model, MTF, 5 steps ahead using input-output data history, and simulate the output signal (MTF) using only input data history (H).

Figures also display the percentage of the output that the MTF reproduces (*Best Fit*), computed using the following equation:

$$BestFit = 100 \times \left(1 - \frac{\|MTF - S\|}{\|S - \bar{S}\|}\right) \qquad (3)$$

MTF is the simulated or predicted model output, *S* is the measured output and $\bar{S}$ is the mean of *S*. 100% corresponds to a perfect fit, and 0% indicates that the fit is no better than guessing the output to be a constant ($MTF = \bar{S}$).

Because of the definition of *Best Fit*, it is possible for this value to be negative. A negative best fit is worse than 0% and can occur for the following three reasons:

- The estimation algorithm failed to converge.
- The model was not estimated by minimizing $|S - MTF|$.
- The validation data set was not preprocessed in the same way as the estimation data set.

It was noted, by comparison between the predicted and simulated output, that with only 5 steps ahead using input-output data history, the goodness of the identified model using MTF respect to the measured one improves the Best Fit value from 10% to 40%.

Figures 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 show real (S) and simulated or predicted (MTF) responses respectively of rotors n° 1, 2, 3, 4, 5, 6, 7, 9, 10, and 11. Trends of 10 rotors, used in order to determine the MTF, have not all the same fit, but in all rotors the simulated signal with the MTF follows the real one. By analysis of graphs, the MTF is able to simulate the signal for its entire length.

From the graphs of the following Figures it is possible to note also the difference of rotors behavior in the SP: the rotor 1 (S1 in Figure 3) has a maximum limit at the first critical speed of 20 micrometers peak-to-peak and has a value lower than 5 micrometers peak-to-peak at the second critical speed; in the rotor 2 (S2 in Figure 4) the first critical speed has a value of 10 micrometer peak-to-peak and the second critical speed has a value of 20 micrometers peak-to-peak

The other rotors have different responses as index of the non-linearity of the system.

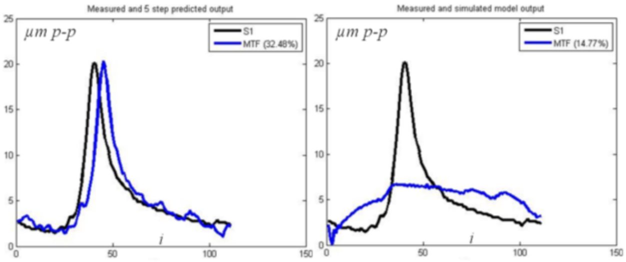

Figure 3: Determination of MTF: measured (S1), predicted and simulated model output (MTF) of the rotor 1.

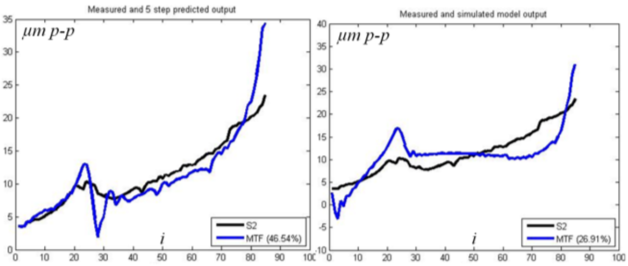

Figure 4: Determination of MTF: measured (S2), predicted and simulated model output (MTF) of the rotor 2.

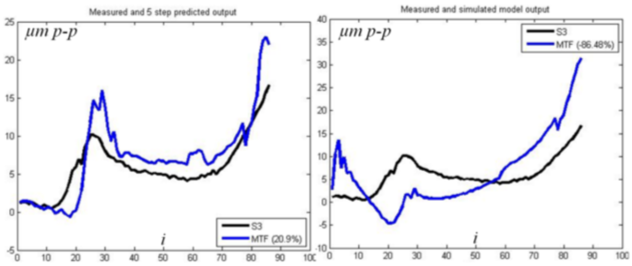

Figure 5: Determination of MTF: measured (S3), predicted and simulated model output (MTF) of the rotor 3.

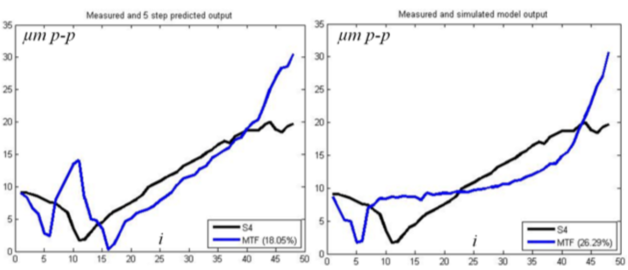

Figure 6: Determination of MTF: measured (S4), predicted and simulated model output (MTF) of the rotor 4.

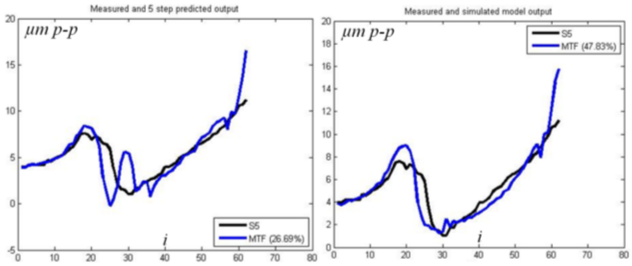

Figure 7: Determination of MTF: measured (S5), predicted and simulated model output (MTF) of the rotor 5.

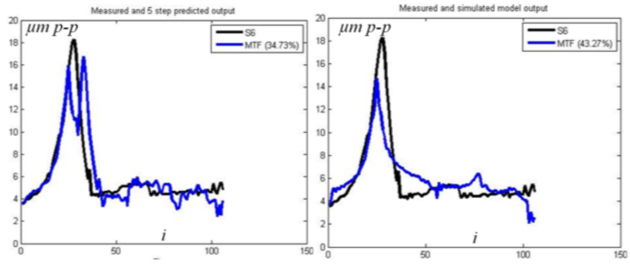

Figure 8: Determination of MTF: measured (S6), predicted and simulated model output (MTF) of the rotor 6.

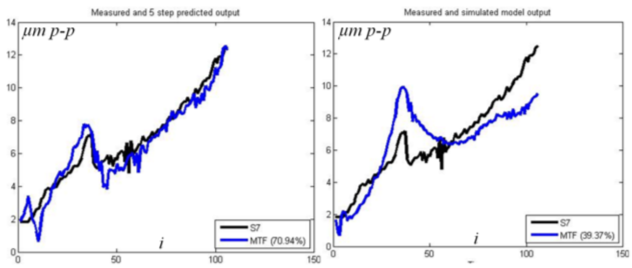

Figure 9: Determination of MTF: measured (S7), predicted and simulated model output (MTF) of the rotor 7.

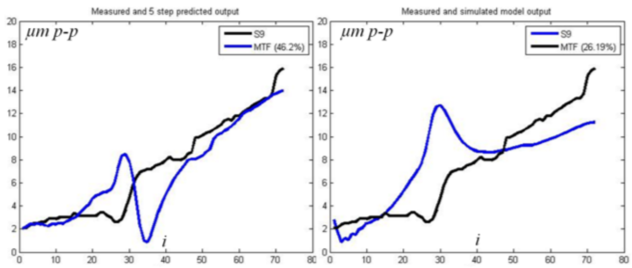

Figure 10: Determination of MTF: measured (S9), predicted and simulated model output (MTF) of the rotor 9.

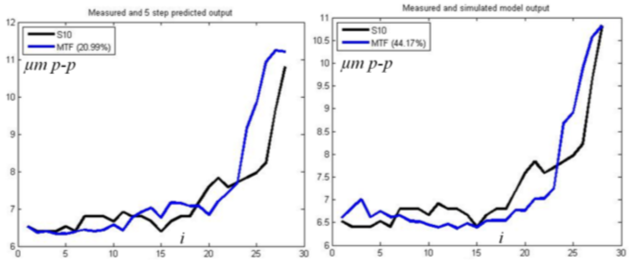

Figure 11: Determination of MTF: measured (S10), predicted and simulated model output (MTF) of the rotor 10.

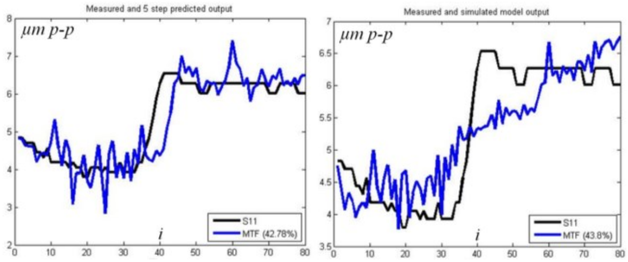

Figure 12: Determination of MTF: measured (S11), predicted and simulated model output (MTF) of the rotor 11.

The MTF was constructed for 10 rotors and from presented results is underlined as an optimization of the formula using non-linear identification systems is necessary. Figure 3 shows, in the simulation graph, a low value of best fit equal to 14.77%. However this value has been higher respect to the stable linear family models considered. Figure 4 shows a best fit in simulation of 26.91%. The rotor number 3 of the Figure 5 has a best fit predicted value of 20.9% and the simulated best fit value of -86.48%. The rotor number 4 (Figure 6) has 18.05% and 26.29% respectively in prediction and simulation. Figures 7, 8, and 9 show respectively a best fit in simulation of 47.83%, 43.27% and 39.37%. The best fit values of the other rotors are, respectively in prediction and simulation, equal to: 46.2% and 26.19% for the rotor number 9; 20.99% and 44.17% for the rotor number 10; 42.78% and 43.8% for the rotor number 11.

It is interesting to evidence that for rotor numbers 10 and 11 the MTF simulated values are bigger respect to the MTF predicted values. The best fit negative value of the rotor number 3 indicates that the estimation algorithm failed to converge using linear identification systems and it is necessary to explore a non-linear identification systems field.

4. MTF FORMULA: VALIDATION

The transfer function MTF was tested on 10 rotors (rotors number: 1, 2, 3, 4, 5, 6, 7, 9, 10, 11) and was validated on the other 15 different rotors (rotors number: 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 and 25) with characteristics presented in Table 1.

Figures from 13 to 22 show the measured, predicted and simulated model output using the MTF.

Predicted and simulated best fit values of the rotors are respectively shown in the Table 2.

The rotors with negative predicted and simulated best fit values are shown in the Table 3

Table 2: Predicted and simulated Best Fit values

Predicted %	Simulated %	Rotor number	Figure
41.53	22.37	12	13
43.6	36.11	13	14
56.2	57.48	15	15
30	47.95	17	16
67.54	32.85	22	17
43.66	23.13	25	18

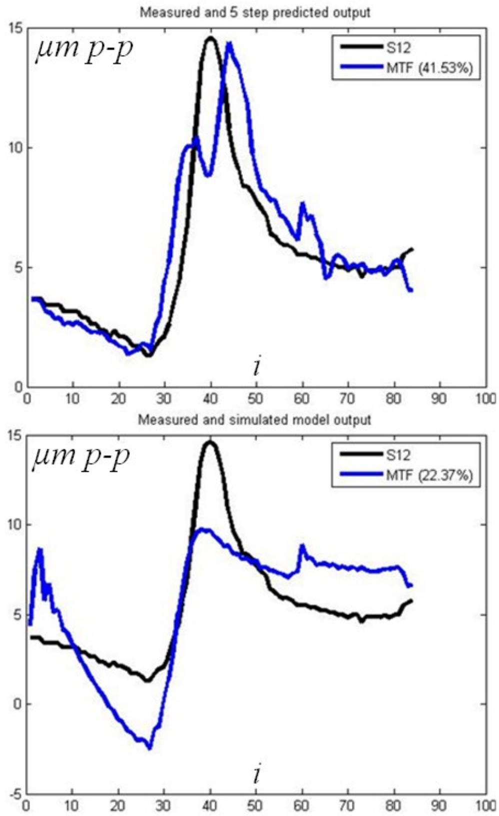

Figure 13: Validation of MTF: measured (S12), predicted and simulated model output (MTF) of the rotor 12.

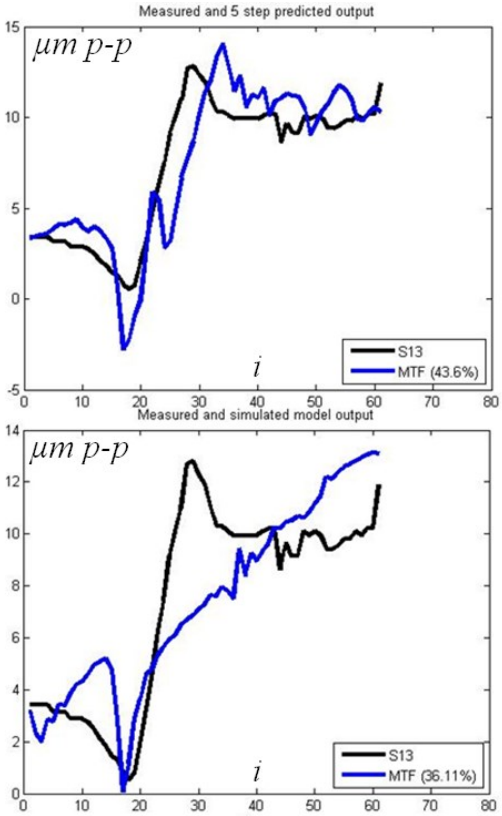

Figure 14: Validation of MTF: measured (S13), predicted and simulated model output (MTF) of the rotor 13.

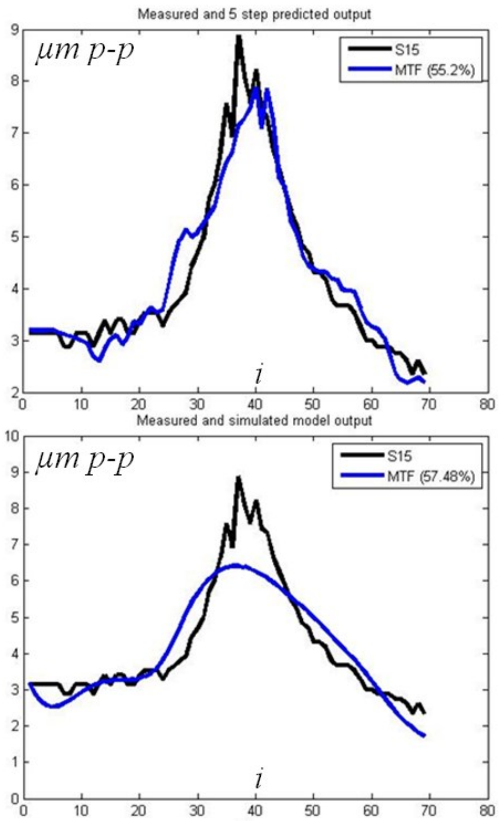

Figure 15: Validation of MTF: measured (S15), predicted and simulated model output (MTF) of the rotor 15.

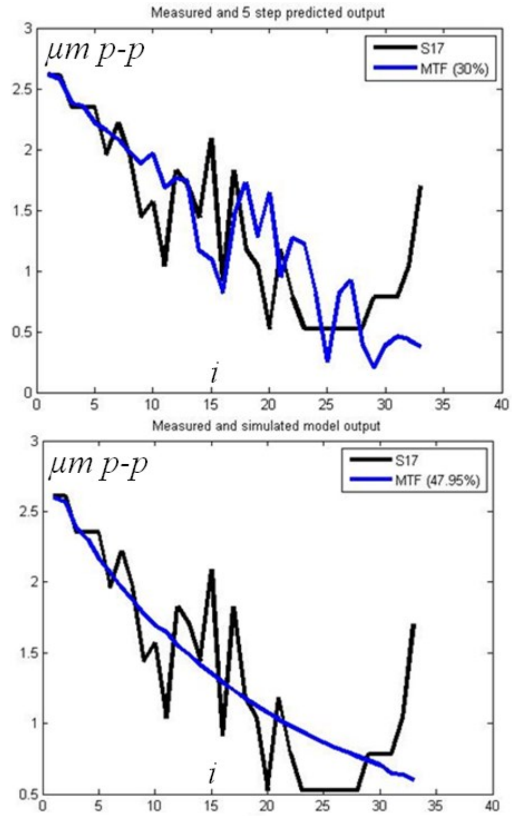

Figure 16: Validation of MTF: measured (S17), predicted and simulated model output (MTF) of the rotor 17.

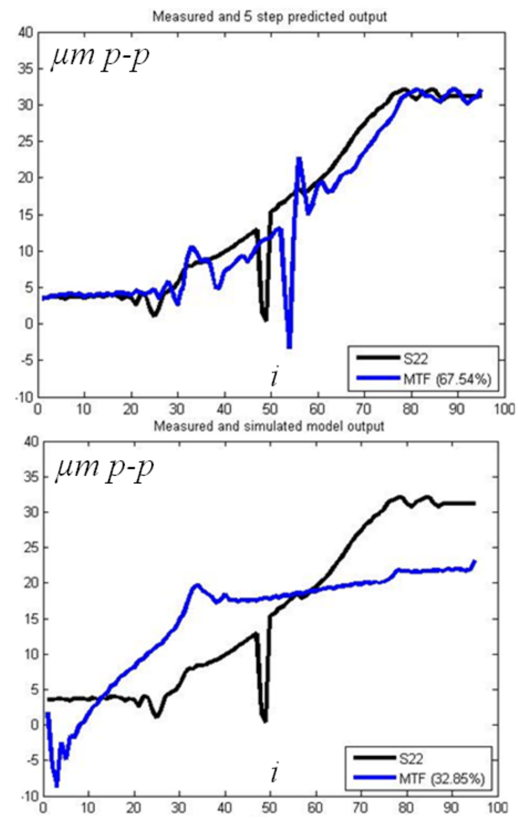

Figure 17: Validation of MTF: measured (S22), predicted and simulated model output (MTF) of the rotor 22.

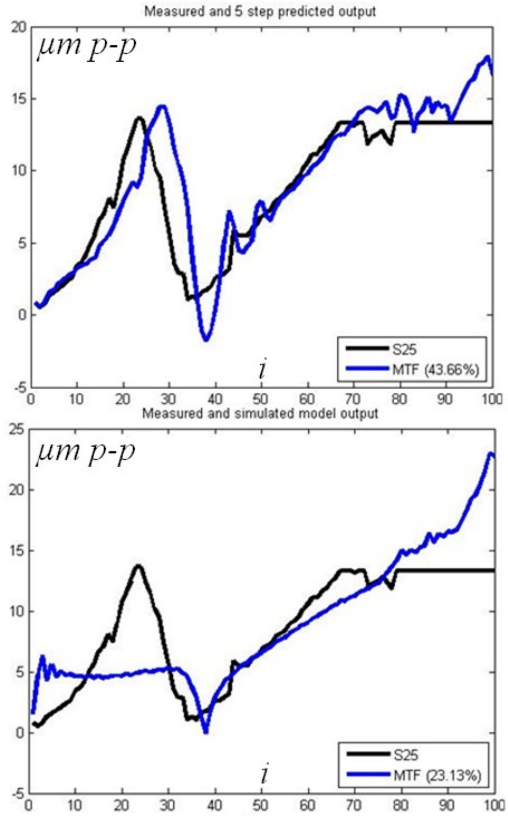

Figure 18: Validation of MTF: measured (S25), predicted and simulated model output (MTF) of the rotor 25.

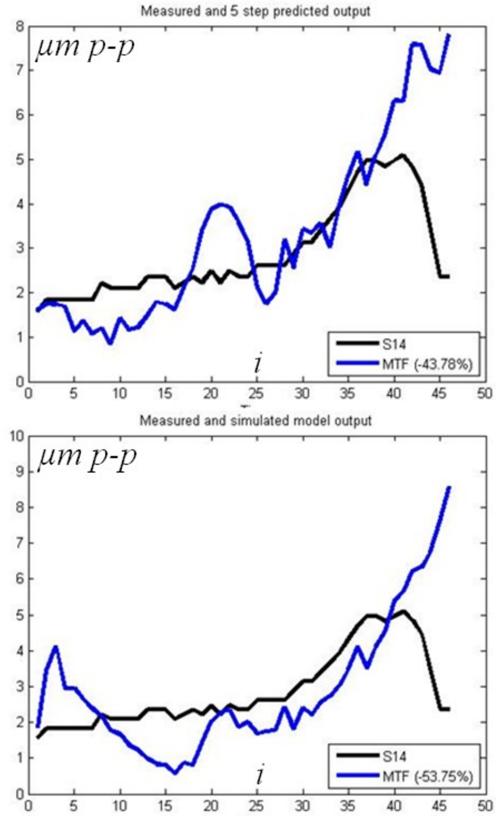

Figure 20: Validation of MTF: measured (S14), predicted and simulated model output (MTF) of the rotor 14.

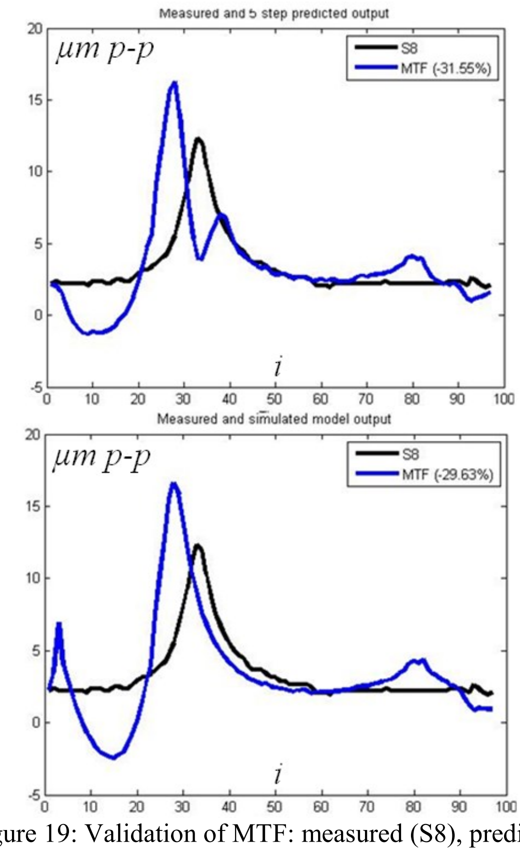

Figure 19: Validation of MTF: measured (S8), predicted and simulated model output (MTF) of the rotor 8.

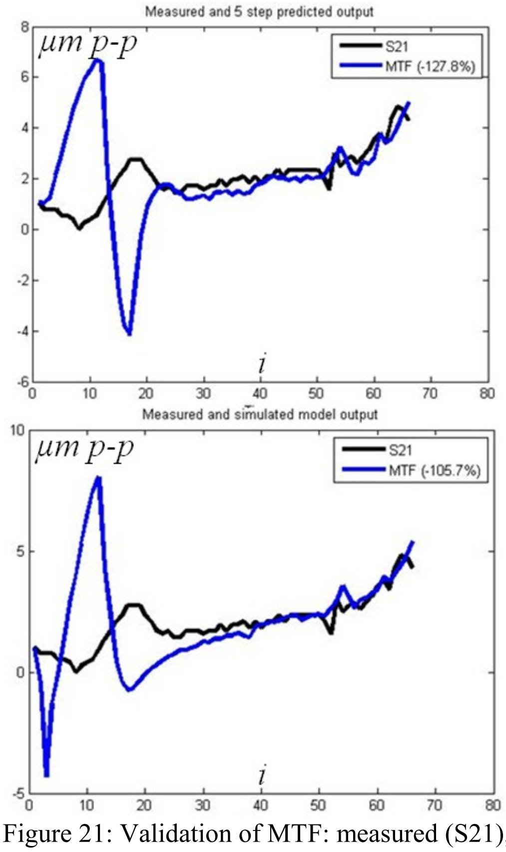

Figure 21: Validation of MTF: measured (S21), predicted and simulated model output (MTF) of the rotor 21.

Table 3: Negative predicted and simulated Best Fit values

Predicted %	Simulated %	Rotor number	Figure
-31.55	-29.63	8	19
43.78	53.75	14	20
-39.06	-32.8	16	
-155.8	-255.4	18	
-89.17	-146.1	19	
-80.46	-298.7	20	
-127.8	-105.7	21	21
-3.2	-17.96	23	
-7.87	-20.31	24	

The predicted MTF model of rotors 12, 13, 15, 17, 22, 23 and 25 confirms that the MTF reproduces the experimental response of rotors as seen for rotors number 2, 5, 6, 7. The predicted graphs of rotors 8, 14, 16, 18, 19, 20, 21 and 24 overestimate the maximum limit of vibration in the first and second critical speed, respect to the experimental graphs.

The prediction of the response of rotor 21 (Figure 21), using MTF, generates a trend similar to the real signal S21, but a peak precedes the first critical speed of the signal S21.

However, the maximum value of the predicted response is lower than the allowable value of 25 micrometers peak-to-peak and the predicted signal with the MTF represents a good safety factor. As can be seen from Figures, also with no bigger best fit values, all simulated or predicted models follow the real trends of the rotor. In particular, the rotor number 21 of the Figure 21 has a negative best fit value in prediction and simulation, but by graphs analysis it is possible to evidence the similarity between S21 and MTF after the 20 i (3000 rpm) of the rotor.

In conclusion, the MTF can be used also as a first step for studying a non-linear rotor behavior underlining non-linear rotor behavior zones respect to the linear one.

A comparison between the experimental graph of the rotor 9 (Figure 10) used for determination of the MTF and the graph of the rotor 8 (Figure 19), used for the validation of the MTF shows that the real signal S9 is different respect to the real signal S8 even if two rotors (8, and 9) are structurally and functionally the same.

Thus, the non-linearity of the system is not only correlated to the structural and manufacturing characteristics of rotors, but also to other factors that cannot be described using classical approaches and as described in (Muscolo 2008).

The validation of the MTF was also confirmed in the prediction and simulation of the trends of other 3 remaining probes. It was conducted the validation of the MTF also considering the probes B, C and D (relating to the other six lines of the graphs of Figure 1 in addition to the probe A).

The analysis of validation of the formula MTF for the three probes B, C, D, gave the following results:

The probe B, for all 25 rotors has the same trends of the probe A, at least in the proximity of the first critical speed. In proximity to the second critical speed seems that the probe B reproduces, in some cases, responses similar to rotors of the probe C.

The trends of the probe C are predicted with the same goodness which predicted with the probe A.

For most of the rotors the probe D has the same trends in prediction of the probe C. For some rotors near of the second critical speed the probe D follows the probe A, when the probe B follows the probe C.

The transfer function MTF is representative for the probe that has the largest number of resonances (probe A).

5. CONCLUSIONS

In this paper the authors used a black-box approach based on system identification to find a transfer function, called MTF, between the rotor responses on a high speed balancing machine (HSB) and in turbo machinery (SP).

MTF has been presented in past works having considered the limitations of the classical (physical and statistical) approaches, the high complexity of the systems, and the unavailability of the necessary data.

In this paper some graphs on prediction and simulation using MTF were presented and discussed. MTF was determined by a regression analysis of the responses in HSB and SP of 10 rotors; subsequently it was tested and validated on other 15 rotors.

The first tests have been carried out in the labs of GE Oil & Gas Company. Only the rotors of compressors were considered because they have more problems in balancing (maybe related to impellers) compared to rotors of steam and gas turbines.

The first research started because some of these rotors presented a stable response in HSB and an unacceptable response in SP. MTF should allow to predict the vibration amplitude of the rotor in SP, already during the balancing steps in HSB.

The proposed formula is the first attempt to find a relation between the two systems (HSB and SP) and must be considered preliminary. The linear system identification models, studied in (Muscolo 2008; Muscolo, Casadio, and Forte 2012), are actually a first step of this research.

The best fit negative value obtained for some rotors indicate that the estimation algorithm failed to converge using linear identification and that it is necessary to apply non-linear identification methods.

Moreover, the formula was obtained on the basis of the signals of one probe but with some additional work it could be optimized on the responses of all the other probes.

Improvements could be made also differentiating the formula for classes of rotors or for ranges of operating conditions. The future planned steps are therefore focused on the optimization of the formula using a non-linear system identification approach.

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VARIABLE NEIGHBORHOOD SEARCH FOR THE BLOCK RELOCATION PROBLEM

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ABSTRACT
In container yards, containers are stacked in several tiers due to space limitation. In order to retrieve a container from a container yard, it is necessary to relocate containers stacked on it. The aim of the block relocation problem, which is also known as the container relocation problem, is to minimize the number of relocations required for retrieving containers according to a specified order. This study will propose a variable neighborhood search algorithm for the problem and its effectiveness will be examined by numerical experiments.

Keywords: container terminal, block relocation problem, variable neighborhood search

1. INTRODUCTION

Container terminals in ports play an important role as a temporary storage for container transshipment between maritime and land transports. Containers in a container terminal are stacked in container yards to reduce space requirements. The containers compose multiple bays in a container yard, and each bay consists of several stacks. Containers are retrieved by a gantry crane that travels between bays and within a bay (Fig. 1). Since only containers on the top of stacks are accessible from the crane, those above the target container should be relocated to other stacks before it is retrieved. This relocation should complete within a bay because the crane travel from one bay to another is time-consuming compared to that within a bay. The purpose of the block relocation problem, which is also known as the container relocation problem, is to minimize the number of relocations necessary to retrieve all containers in a bay according to a specified retrieval order.

Formally, the problem considered in this study is described as follows.

Suppose a container bay composed of S stacks whose maximum height (the maximum number of tiers) is restricted to T. Blocks (containers) are stored in tiers and the number of blocks in stack i is given by $N_i (\le T)$. The total number of blocks is denoted by $N = \sum_{i=1}^{S} N_i$. The block in the j th tier of stack i from the bottom is referred to as block (i, j). Each block (i, j) is given a distinct integer priority P_{ij} $(1 \le P_{ij} \le N)$ where a smaller value means a higher priority (an earlier retrieval order). Figure 2 illustrates an example of a block layout with $S = 4$ and $T = 4$. The number in each block denotes the priority P_{ij}.

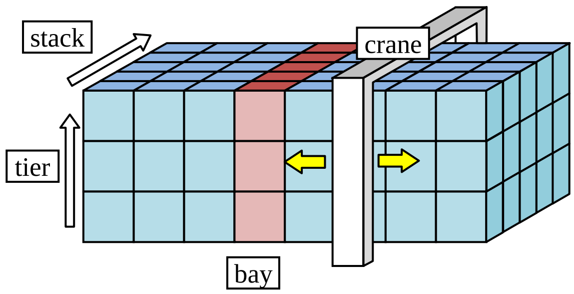

Figure 1: Containers in Container Yard

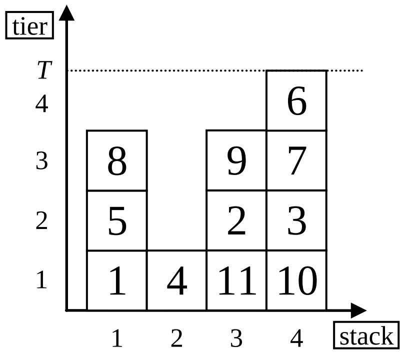

Figure 2: An Example of Block Layout ($S = 4, T = 4, N_1 = N_3 = 3, N_2 = 1, N_4 = 4$)

The following two operations are available for retrieving all the blocks from the bay according to their priorities:

1. Relocation
   A block on the top of a stack is moved to the top of another stack whose height is less than T.
2. Retrieval
   A block with the highest priority is retrieved from the bay if it is on the top of a stack.

The objective of the block relocation problem is to find an optimal sequence of these two operations that minimizes the number of operations required. In practice, the objective function of the block relocation problem is the number of relocation operations because the number of retrieval operations is identical to the number of blocks and hence is constant.

There are two types of problem settings for the block relocation problem. In the restricted problem, the relocatable blocks are restricted to the one on the top of the stack that includes the block retrieved next, i.e. the block with the highest priority. In the layout of Fig. 2, block (1, 3) is the unique relocatable block because block (1, 1) has the highest priority and should be retrieved next. On the other hand, such a restriction is not imposed on relocatable blocks in the unrestricted problem. Hence, blocks (1, 3), (2, 1), (3, 3), and (4, 4) are all relocatable in this problem. This study will consider the restricted problem. In the following, the highest priority of the blocks in stack i, namely, $Q_i = \min_{1 \le j \le N_i} P_{ij}$ is referred to as the priority of stack i.

There have been several studies on heuristic algorithms for the block relocation problem (eg. Caserta and Voβ 2009; Caserta and Voβ 2011; Forster and Bortfeldt 2012; Petering and Hussein 2013; Jin et al. 2013). However, to the best of the author's knowledge, algorithms based on local search have not been studied extensively so far. The purpose of this study is to construct a local search algorithm and to examine its effectiveness by numerical experiments.

2. PROPOSED ALGORITHM

The proposed algorithm is a variant of the variable neighborhood search (Mladenović and Hansen 1997; Hansen et al. 2010). The constructive greedy heuristics by Caserta et al., 2011 is utilized for both computing the initial solution and representing solutions.

2.1. Constructive Heuristics

Suppose that the relocatable block in the current block layout is block (i, j) $(i = \arg\min_k Q_k)$ .This heuristics relocates block (i, j) to stack k^* determined as follows:

1. If there exists a stack whose height is less than T and whose priority is lower (larger) than P_{ij}, $k^* = \arg\min_{N_k < T, P_{ij} < Q_k} Q_k$.
2. Otherwise, $k^* = \arg\max_{N_k < T} Q_k$.

In the block layout in Fig. 2, the relocatable block (1, 3) is relocated to stack 2 according to the first condition.

2.2. Solution Representation

In the proposed algorithm, a solution is represented by destination stacks of relocatable blocks, which form a $(N-1)\times(T-1)$ matrix $X = (x_{ij})$. Each element x_{ij} is associated with a relocatable block as follows. Suppose that all the blocks with priorities higher than i have already been retrieved and that the block with priority i is block (k,l) $(P_{kl} = i)$. Since this block is to be retrieved next, the blocks above it should be relocated to other stacks, whose destination stacks are determined by x_{ij}. More specifically, the destination stack of the j th block $(k, l + j)$ is determined by x_{ij}.

Instead of encoding the destination stack directly, the proposed method encodes into x_{ij} the relative position of the destination stack in order to take advantage of the constructive heuristics. More specifically, the candidate destination stacks (the stacks other than stack k whose heights are less than T) are sorted in the increasing order of their priorities, and the positions of the destination stacks are denoted by their differences from that of the stack determined by the constructive heuristics. In the block layout of Fig. 2, for example, the block to be retrieved next is block (1, 1) and the relocatable block is (1, 3), which is associated with x_{12}. The candidates for its destination stack are stacks 2 and 3 whose priorities are 4 and 2, respectively. Therefore, 3, 2 is the sorted sequence of stacks. Since the destination stack determined by the constructive heuristics is stack 2, x_{12} should be either -1 or 0, which means that the destination stack is stack 3 or stack 2, respectively. Obviously, a zero solution matrix in this encoding always represents the solution by the constructive heuristics. Therefore, it will be easy to search around the heuristic solution intensively under this encoding method.

2.3. Variable Neighborhood Search

Based on the representation of a solution explained in the preceding subsection, a variable neighborhood search algorithm is applied. The initial solution is computed by applying a local search from the solution obtained by the constructive heuristics. The neighborhood of the incumbent solution in the local search is defined by those generated by changing the value of an element of the solution matrix. The incumbent solution is updated by the first improvement rule: it is updated immediately when a better solution is found in the neighborhood.

Next, the incumbent solution is perturbed randomly. The following three types of perturbations are employed in turns:

1. Insertion/Deletion
   An element is inserted into or deleted from a row of the solution matrix with an equal

probability of 0.5. In the case of insertion, an element with zero is inserted.

2. Modification
   The value of an element x_{ij} is changed randomly.
3. Interchange
   Values of two elements x_{ij_1} and x_{ij_2} in the same row are interchanged.

One of these perturbations is applied to randomly chosen rows and/or positions. Then, the local search is started again from this new incumbent solution. After these are repeated for some number of iterations, the incumbent solution is replaced by the current best solution, and then it is perturbed so that the local search can be started again from it.

It is possible that no destination stack exists for some value of x_{ij}. In this case, the feasibility of a solution is ensured by modulo operation.

The pseudocode of the proposed algorithm is summarized in Fig. 3. InsertionDeletion(X , p) in line 8 perturbs the solution matrix X by the insertion and deletion operations, and p specifies the total number of insertion and deletion operations applied, which is given by $p\lceil N/8 \rceil$. Similarly, Modification(X , p) and Interchange(X , p) apply the modification and interchange operations, respectively, and the total numbers of operations applied are $p\lceil N/16 \rceil$ and $p\lceil N/4 \rceil$, respectively. After these perturbations are applied 9nrepeat times, the incumbent solution is replaced by the best solution in line 23. If the best solution is not updated successively for 8 times, nrepeat is increased by 1, whose maximum value is restricted to 6.

All the parameters in the algorithm were determined by preliminary experiments.

```
1: Obtain an initial solution matrix X^incumbent.
2: X^best ← X^incumbent, i ← 1.
3: nrepeat ← 1, notupdated ← 0.
4: while True do
5:   for j = 1 to nrepeat do
6:     for k = 1 to 9 do
7:       case ⌈k/3⌉ of
8:         1: InsertionDeletion( X^incumbent, k )
9:         2: Modification( X^incumbent, k − 3 )
10:        3: Interchange( X^incumbent, k − 6 )
11:      endcase
12:      Apply the local search from X^incumbent.
13:      if X^incumbent is better than X^best then
14:        X^best ← X^incumbent
15:        notupdated ← −1
16:      endif
17:      if i = maxiter then
18:        Output X^best and terminate.
19:      endif
20:      i ← i + 1
21:    endfor
22:  endfor
23:  X^incumbent ← X^best
24:  notupdated ← notupdated + 1
25:  if notupdated = 8 then
26:    notupdated ← 0
27     nrepeat ← max(nrepeat + 1, 6)
28:  endif
29: endwhile
```

Figure 3: Pseudocode of the Algorithm

3. NUMERICAL EXPERIMENTS

The proposed algorithm was applied to the 12500 benchmark instances by Zhu et al. (2012). The algorithm was coded in C and the experiments were conducted on a desktop computer with an Intel Core i7-2700K CPU (3.5GHz) by changing the maximum number of iterations (maxiter) from 100 to 5000. To examine the effectiveness of the algorithm, the results are compared with optimal or best solutions obtained by the exact algorithms (Zhu et al. 2012; Tanaka and Takii 2014).

Table 1 summarizes the results. T and S denote the maximum height of stacks and the number of stacks, respectively, and n denotes the number of instances. "obj" and "time" are the average objective value and the average CPU time in seconds, respectively. In addition, "best" denotes the average objective value of optimal or best solutions found by the exact algorithms (Zhu et al. 2012; Tanaka and Takii 2014) as well as the proposed algorithm, and "heur" the average objective value of the constructive heuristics in 2.1, "ini" the average objective value of the initial solution (the solution obtained by applying the local search from the solution shown in "heur". Boldface in the "obj" columns means that all the solutions yield the best objective values. The average CPU time for the initial solution is omitted because it was less than 0.01s. From this table, we can observe that the proposed algorithm is able to find good solutions quickly. Indeed, the best solutions for 85 instances among 180 unsolved instances by the exact algorithms were updated by the proposed algorithm.

4. CONCLUSION

This study proposed a variable neighborhood search algorithm for the block relocation problem. Numerical experiments showed that the algorithm is able to find good solution in a short time. We will be able to improve the performance of the local search in more sophisticated frameworks such as the tabu search algorithm, but it is left for future research. Extending the algorithm for the unrestricted problem is also left for future research.

Table 1: Computational Results for the Instances by Zhu et al. (2012)

T	S	n	best	heur	ini	100		500		1000		5000	
						obj	time	obj	time	obj	time	obj	time
3	6	300	**6.64**	6.71	**6.64**	**6.64**	0.00	**6.64**	0.01	**6.64**	0.02	**6.64**	0.06
	7	300	**7.77**	7.85	7.78	**7.77**	0.00	**7.77**	0.02	**7.77**	0.02	**7.77**	0.09
	8	300	**8.93**	9.01	8.93	**8.93**	0.01	**8.93**	0.02	**8.93**	0.03	**8.93**	0.14
	9	300	**10.37**	10.46	**10.37**	**10.37**	0.01	**10.37**	0.03	**10.37**	0.04	**10.37**	0.20
	10	300	**11.59**	11.73	11.60	**11.59**	0.01	**11.59**	0.03	**11.59**	0.06	**11.59**	0.27
4	6	400	**12.51**	12.91	12.57	**12.51**	0.01	**12.51**	0.02	**12.51**	0.03	**12.51**	0.13
	7	400	**14.50**	14.96	14.57	14.51	0.01	**14.50**	0.03	**14.50**	0.05	**14.50**	0.21
	8	400	**16.72**	17.35	16.83	16.73	0.01	**16.72**	0.04	**16.72**	0.07	**16.72**	0.32
	9	400	**18.46**	18.98	18.53	**18.46**	0.02	**18.46**	0.05	**18.46**	0.10	**18.46**	0.49
	10	400	**20.54**	21.21	20.69	20.55	0.02	**20.54**	0.07	**20.54**	0.14	**20.54**	0.71
5	6	500	**19.01**	20.24	19.26	19.04	0.01	19.01	0.03	19.01	0.05	**19.01**	0.25
	7	500	**22.52**	24.01	22.86	22.56	0.01	22.53	0.05	22.52	0.09	**22.52**	0.41
	8	500	**25.73**	27.45	26.10	25.78	0.02	25.73	0.07	25.73	0.14	**25.73**	0.68
	9	500	**28.31**	30.16	28.81	28.38	0.02	28.33	0.10	28.31	0.20	**28.31**	0.99
	10	500	**31.45**	33.44	31.98	31.53	0.03	31.47	0.14	31.45	0.28	**31.45**	1.43
6	6	600	**26.96**	29.68	27.67	27.09	0.01	26.98	0.05	26.98	0.09	**26.96**	0.45
	7	600	**31.00**	34.27	31.91	31.16	0.02	31.04	0.08	31.02	0.15	31.01	0.76
	8	600	**35.31**	38.89	36.30	35.54	0.03	35.38	0.12	35.34	0.24	35.32	1.20
	9	600	**39.52**	43.49	40.70	39.82	0.04	39.62	0.18	39.58	0.36	39.54	1.85
	10	600	**43.31**	47.80	44.66	43.68	0.05	43.46	0.25	43.40	0.51	43.34	2.62
7	6	700	**35.45**	40.29	36.94	35.83	0.02	35.56	0.08	35.51	0.15	35.46	0.74
	7	700	**41.10**	46.94	42.92	41.58	0.03	41.30	0.12	41.24	0.24	41.17	1.23
	8	700	**46.25**	52.80	48.33	46.87	0.04	46.51	0.20	46.43	0.40	46.33	2.06
	9	700	**51.93**	59.16	54.33	52.64	0.06	52.26	0.29	52.17	0.59	52.05	3.04
	10	700	**57.04**	65.14	59.72	57.91	0.08	57.49	0.43	57.37	0.86	57.19	4.49

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MULTIMODAL FREIGHT TRANSPORTATION: A SERVICE OPTIMIZATION ALGORITHM

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ABSTRACT
Most of the initiatives in terms of transportation promote multimodal transport, trying to decrease the road transport flows. In general a multimodal option is more efficient in terms of cost, fuel consumption and congestion than road transportation. One example of this initiative is the Transport White Paper 2011. In this paper the idea of multimodality and the actions to support it are reinforced. The optimization of the multimodal chain performance is one of these actions. This paper shows an optimization approach for the maritime service, taking into account the multimodal network. In this case the objective of the optimization is to maximize the value of the internal rate of return of the maritime service. To evaluate it, a multimodal transportation model, developed in a previous work by the research group, is used. This model, the optimization algorithm and some results will be shown in this paper.

Keywords: optimization, transportation, multimodal, Internal rate of return

1. INTRODUCTION

The current situation is the ideal framework for all the initiatives that promotes more efficient and sustainable transportation systems. Nowadays the roads are very congested: it is an important problem for transportation companies but also for the inhabitants of areas near the road, and actually for all the people. This is because this transportation mode produce high greenhouse gases emissions and its accidents or incidents have high impact over the population.

There are some initiatives in Europe that promote the use of other transportation systems in order to transfer movements of freight and passengers that usually use road transportation to other transportation systems.

For example, the European Transport White Paper (European Transport Commission, 2001) pays attention to the multimodality in order to obtain more sustainable transportation modes. Another initiative is, for example, the MARCO POLO Program. It indicates that road transportation depends on fossil fuel that produces high CO_2 emissions, and also congestion problems. Further, it underlines the need of integrating the railroad, short ship shipping, and river transportation in the transportation chain to decrease the road flows. Another project like Motorways of the sea or the improvement of the connections between ports and railroad follows the same idea.

Another White Paper (European Transport Commission, 2011) published in 2011, indicates the goal to reach, that is an absorption of the 50% from road transportation to other transportation modes. The way to obtain it is to optimize the multimodal chain in different terms (profitability, energy efficiency…). But the services that cover this have to be attractive for the shippers. To do so, these services have to be profitable.
All these reasons give an ideal framework to develop algorithms that optimize these services or the complete supply chain.

In this paper we propose an algorithm to optimize the maritime services as part of a multimodal transportation chain. This work is a continuation of a previous work presented in the HMS 2012 in Wien (Vienna) whose title is *A parameterized model of multimodal freight transportation for maritime services optimization* (R. Rios Prado, Crespo Pereira, Bastida Sardiña, del Rio Vilas, & Rego-Monteil, 2012).

Section 2 presents a brief review of optimization and simulation related with transportation. Section 3 explains the transportation model used. Section 4 shows the algorithm developed and the last section presents some results.

2. BACKGROUND

One of the tools best suited to transportation problems is simulation and optimization because it allows the establishment of systems with higher performance and/or with lower environmental effects.

The different levels of resolution and problems that the transportation presents mean that this kind of solutions are appropriated. There are some examples that we can use to illustrate this importance. In 2010 Longo (Longo, 2010) used this tool to improve the terminal operations, or Frick in 2011 (Frick, 2011) that explains the importance of simulation of a transportation network and proposes their own implementation. Also works like

Juan et al. in 2010 (Juan et al., 2010) shows how to use optimization to solve some transportation problems.

In terms of models for transportation planning there are two main groups. There are models for passengers and for freight transportation. The first ones are more developed, it means, there are more works about it. In most of them the method used is the Classical Model of the Four Stages (Ortúzar & Willumsen, 2011). This model is based on the movement of passengers between zones. These zones are called Traffic Analysis Zones, or TAZ, which are zones capable of generating and attracting movement of passengers. The four stages of the model are the following:

1. Trip generation: Trips generated in each TAZ.
2. Trip distribution: Generate trips between origin and destinations.
3. Modal split: Choose the transportation mode.
4. Traffic Assignment: Gives the links of the network used for a trip.

This model, despite being widely used for passengers' transportation, can be adapted for commodities transportation.

The difficulty to obtain a mode choice for freight transportation is the reason for fewer of these works. Decisions about transportation in companies follow complex criteria. More than a couple of variables have to be taken into account. For example Kreutzberger in 2008 (Kreutzberger, 2008) identified cost, reliability or frequency as important factors that affect the choice of mode.

In terms of optimization there are many works applied to transportation modeling, using Dynamic Programming and Operation Research techniques. Many of these works are referring to the Vehicle Routing Problem (VRP) in all its forms. Most of these papers are about a single transportation mode, meaning that they do not take into account the multimodality of the transportation.

In contrast, there are some works that search the optimization of transportation services. In 2010 Fagerholt (Fagerholt, Christiansen, Magnus Hvattum, Johnsen, & Vabø, 2010) presents a methodology for the strategic planning of a shipping company; he solves a route planning problem considering a "rolling horizon", updating information, to obtain the optimization. Another example is the work of Chou et all (Mabel Chou, n.d.) that optimizes shipping routes taking into account the two subproblems that it presents, direct and transfer services. For rail transportation we can cite the paper of Mu and Dessouky (2011) which optimizes the time plans for rail transport combining local search heuristics with heuristics that optimize the overall total delay.

It is important to mention the work of Yamada et al in 2009 (2009) where they show the optimization of a particular network of multimodal freight transportation. In 2009, Andersen et al. presents an optimized model for tactical design of service networks. It pays special attention to the effects of timing and coordination of services for improvement.

As we said before, there is an important factor that affects transportation planning. This factor is the cost, so not only infrastructure and operational configuration affect the performance of the service. The economic aspect, like fares or price policies, has to be taken into account. They are often treated separately from other design factors, as could be seen in the reviews of this kind of works made by Ortúzar and Willumsen (2011).

3. TRANSPORTATION MODEL

Before optimizing a transportation service, it is necessary to develop a transportation model that takes into account all the transportation modes available in the system. In this case the network has road and maritime links, because we want to optimize the maritime service taking into account the freight flow rates between road and the multimodality road-sea.

The transportation model developed comes from a previous work of the research group (Rosa Rios Prado, Crespo Pereira, del Rio Vilas, & Rego-Monteil, 2011) and a parameterization described in the paper of Rios (2012).

3.1. Input Data

The transportation model needs a set of information to develop the model, and also for the experimentations in order to obtain the results. The elements of this set are:

- Traffic analysis zones (TAZ). They are the zones capable of attracting and generating freight flows. In the case of our model these zones are areas of Spain. In Figure 1 you can see the TAZs of the model (the red areas). The model takes into account the Atlantic and Mediterranean areas of Spain.

Figure 1: TAZs of the model

As much in the model as in the algorithm the subscript for origin is ***i*** and for destinations ***j***.

- OD matrices. A transportation model is useful for evaluating how freight flows through the different transportation systems. The origin destination matrices (OD matrices) represent the total cargo in tons that have to be moved between each origin-destination pair. We represent the flows by $F_{t,i,j}$ where t is the period of time considered (in this case, a year).

- Cartography. A GIS contains all the links and nodes necessary to define all the transportation systems. It allows to obtain the real distances and travel times between nodes, and also the associated costs. The transportation modes are identified by the subscript ***l***.
- The fare and cost chain of each transportation system.

3.2. Network

The network of the model has to include all the transportation systems that we want to evaluate or that compete between them.

In this case we uses a GIS that represents the main roads of Spain and the maritime routes that can be used. As main roads, the roads and highways available for freight transportation are used. For maritime transportation, the model uses some regular routes available when the model was built. It also have a node layer that contain all the origin and destination points, and other singular points as the ports for the maritime routes.

The GIS is important because some elements of the model are based on the distance or the links used.

3.3. Transport model

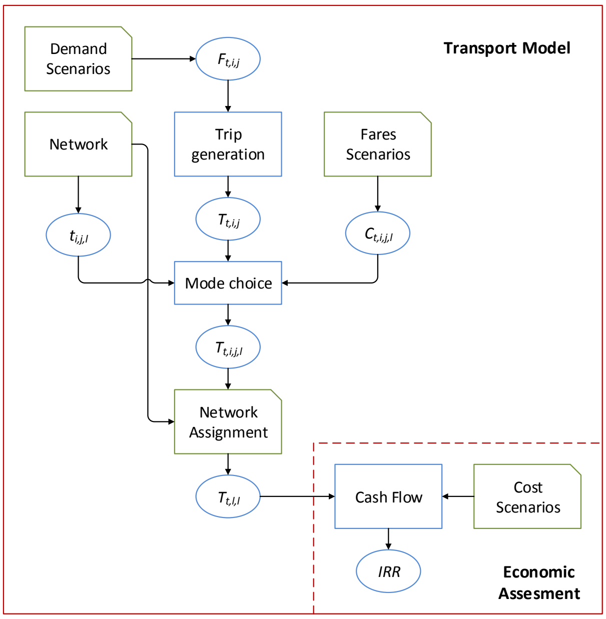

Figure 2: Transport model.

The model was developed using the Classical Four Stage Method for transportation modelling (Figure 2). In this case the OD matrices are inputs of the model, so we did not develop the first two steps. However, a modification should be made in the OD matrices for the Trip Generation Step.

- **Trip Generation**. This first step transforms the OD matrices units of tons into OD matrices of trips. We consider a standardized twenty feet container (TEU) as the transportation unit, because it is an element that can be carry by road and by sea. The TEU is a standardized unit of transportation, which represents a high intake of the global trades. This assumption simplify the model, because we do not have to take into account different handling systems due to different cargo. An average weight of the containers is used to transform tons in TEU.
- **Modal Split**. This step give us the freight flows between each OD pair by each transportation mode considered in the model. This is the most important step of the model because it gives how competitive a transportation mode is compared with the other modes considered in the model. The competitiveness could be evaluated by the freight flows that each transportation mode is capable to attract under some operational characteristics.
  There are several models developed to solve this step (Ortúzar & Willumsen, 2011), it means to predict the freight shippers choice. In this model a Multinomial Logit Model is used (MNL). It is one of the model widely used for shipper's choice.

$$P_{i,j}(l) = \frac{e^{V_{i,j,l}}}{\sum_{l \in A_L} e^{V_{i,j,l}}} \quad (1)$$

  Where:

  $P_{i,j}(l)$ Probability of the alternative ***l*** for a trip between ***i*** and ***j***.
  $V_{i,j,l}$ Utility for ***l*** travelling from ***i*** to ***j***. In this case the variables are cost and time.
  A_L Set of transportation modes. In this case road and multimodal (road-sea).
- **Network Assignment**. This step calculates the total freight flow for each link of the network. The "all or nothing" assignment method is used, because congestion effects in the network can be omitted or are not significant due to the analysis period of time considered. The freight flows are assigned by the shortest path method, minimizing the time, the cost, a generalized cost, or the length.

3.4. Parameterization

This model was developed for freight analyses but also for optimization purposes. An important aspect is to define the parameters needed for freight analysis and also for the optimization algorithm.

One of the first parameters that it is necessary to define is the **Number of Routes**. As we said before they are defined in the network.

Another parameter is the **Number of Vessels** because it was related with the capacity of the service. In our case the type of vessel is fix, as the more common vessel in the routes considered.

The **Total freight flow** ($T_{t,i,j}$) represents the total freight between origin and destination in TEUs, and using the model they have to be converted in freight flows between origin and destination for each transportation model ($T_{t,i,j,l}$). These OD matrices are obtained:

$$T_{t,i,j,l} = P_{i,j}(l) \times T_{t,i,j} \tag{2}$$

When these matrices are assigned to the network we obtain the freight flow of each link of the network, $n \in network$,($T_{t,l,n}$).

The mode choice model depends on the utility functions. The variables of these functions are **Time** ($t_{t,i,j,l}$) and **Cost** ($C_{t,i,j,l}$), because are the most important ones that affects the shippers choices (Kreutzberger, 2008)

- Road time: It take into account the travel time (function of the length and the speed) and the legal rest time of the drivers.
- Multimodal time: It has a haulage time (by road) that is calculated as it was said before. For sea links the time is a function of length and speed, but we also have to take into account the waiting times in ports.
- Road cost: The cost of road transportation comes from the data of the Freight Road Transport Observatory (Ministerio de Fomento Gobierno de España, 2012). It considers the total cost of the transportation chain by road (crew, car tires, amortization, etc.)
- Multimodal cost: For road haulage we use the same data of the observatory. For maritime option we built a cost chain similar to the road one, taking into account the costs of fare or taxes in port, port operation costs and inventory costs.

The objective is to optimize the maritime services in terms of the Internal Rate of Return (IRR). For this, we consider the **Fare** of the maritime service, because it allows to obtain the Incomes of the company.

The **Intermediate Stops** should be considered in solving the problem because they are associated with obtaining the shipping costs.

4. OPTIMIZATION ALGORITHM

After the multimodal transportation model has been built, the optimization problem could be defined. In this case the optimization search maximizes the maritime service profitability. The objective function is the Internal Rate of Return, according to the following formulas:

$$Fare = Costs + Net\ Profit \tag{3}$$

$$Income = Fare\ \times \textstyle\sum_{n \in MR} T_{t,l,n} \tag{4}$$

$$Earnings\ Before\ Taxes\ = Income - Costs \tag{5}$$

$$Earnings\ \ After\ Taxes\ = (Income - Costs) -\ Taxes \tag{6}$$

$$Cash\ Flow = Earnings\ After\ Taxes + Depreciation \tag{7}$$

$$\textstyle\sum_{t=0}^{10} \frac{CF_t}{(1+IRR)^t} = 0 \tag{8}$$

$\boldsymbol{CF}$ is Cash Flow, and $\boldsymbol{t}$ the time period. $\boldsymbol{MR}$ is the set of links of the network that belong to the maritime route considered.

In this case the tax rate is 30% of the profits (common rate of Spanish Corporate Income Taxes). A life time of the vessel of 20 years and a residual cost of the 15% are assumed.

The calculation of some parameters of the function comes from the evaluation of the multimodal transportation model, so simulation approaches are required for its calculation.

The decisions of the model are:

- The number of maritime routes
- The sequence of ports in each route
- The fares of each route. It must be greater that the cost per km.

Some variables are fixed in the model, as the characteristics of the ships of the routes, and also their number is high enough to cover all the freight flows of the maritime links. The costs and the times are calculated in the transportation model.

As the objective function shows, the optimization problem is quite complex, because its characteristics gives a combinatorial nature to the problem. The objective function has continuous decision variables (the fares), integer variables (number of routes, vessels…) and port sequences. There are different mythologies that can be applied to this kind of problems as metaheuristics (Dullaert, Maes, Vernimmen, & Witlox, 2005), hyperheuristics (Dowsland, Soubeiga, & Burke, 2007) or hybrid approaches (Mahjoub Dridi,Imed Kacem, 2004). The characteristics of the problem means that we cannot adopt some previous solutions and we had to develop our own algorithm.

The solution adopted in this case is a combination of heuristics and metaheuristics specifically developed for this problem, and that takes into account the combinatorial nature of the problem and the complexity of the objective function.

The solution uses an evolutionary algorithm, for the metaheuristics. In this case a Differential Evolution algorithm is used (Storn & Price, 1997), it gives a general and robust optimization method, and it shows good performance in problems with a low number of dimensions (Caamaño, Bellas, Becerra, & Duro, 2013).The genes include the parameter of the constructive algorithm and the route fare. The heuristics is specifically developed for the problem. The flowchart of this algorithm is shown in Figure 3.

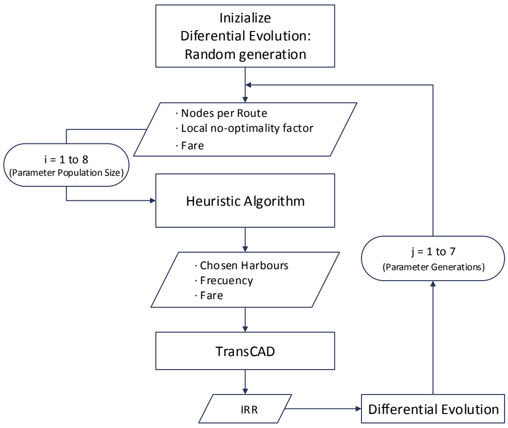

Figure 3: Optimization algorithm.

1. Initialize Differential Evolution:
   Random generation of the initial population
   Number of individuals = Population Size parameter
   Three dimension individuals
2. Evaluation of the individuals by the heuristic
3. Calculate the IRR of each individual
4. New population
5. Loop repeat

4.1. Evolutionary Algorithm.

The Differential Evolution algorithm used in the work was implemented in the Evolutionary Algorithms Framework (EAF), developed by Caamano et al (Caamano, Tedin, Paz-Lopez, & Becerra, 2010).

The parameters used in this case are the ones in the Table 1:

Table 1: Parameters settings.

Parameter	Value
Population size	8
Number of Generations	8
Parameter F	0.5
Parameter CR	0.5

The Evolutionary Algorithm is used to optimize the parameters of the heuristic. The decision variables of Evolutionary Algorithm are the parameters of the heuristic in 4.2:

- Number of nodes per route: Between 2 and 5. It have to be an integer.
- Local No-optimal Factor (***L***): Integer. It makes that a harbor has not been selected twice or more in a route.
- Fare: For each route. Its value goes from 0.3 to 0.7 euros per kilometer.

As it was said before, the first generation is a random generation. At the beginning of the execution of the search, the initialization is made. The break criterion is the number of generations. The quality function is the internal rate of return.

4.2. Heuristic Algorithm.

The Evolutionary Algorithm gives individuals with three dimensions: nodes per route, Local non-Optimality Factor and Fare.

These values feed the heuristics algorithm, and they are evaluated to obtain the ports sequence.

The flowchart of the heuristic algorithm is shown in Figure 4.

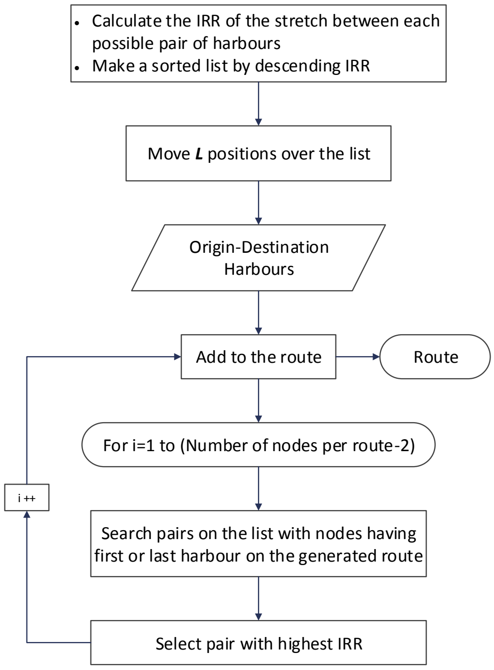

Figure 4: Heuristic algorithm.

A TransCAD macro calculates the IRR of each link between each pair of harbors. A list of this links is created and ordered by descending IRR. After that, ***L*** positions are moved over the list, giving the Origin-Destination pair of harbors. These pair of harbors are added to the route.

Now from 1 to the number of nodes per routes minus 2, the algorithm searches the link that has an end point in the origin or destination harbor previously selected. From all of them, the one with higher IRR is chosen and the other node of this link is added to the route.

These steps have to be repeated to obtain the predetermined number of routes.

When the sequence with all the ports is obtained, the IRR can be estimated. Then it is sent back to de Differential Evolution for further exploration.

5. CASE OF STUDY.

Two scenarios are proposed to evaluate the effectiveness of the optimization mixed algorithm. These scenarios are a problem with a single route and the second one is a scenario of two routes. Both scenarios are represented in the Figure 5.

Figure 5: Maritime routes for the case of study.

In this evaluation some assumptions are made. One of them is the frequency of the vessels, we considered a travel each week, 50 travels per year. This frequency minimize the number of vessels, but the algorithm checks if they are enough, if it isn't the algorithm increases it.

Table 2: Scenario 1.

Decision Variables (Genetic Algorithm)		
Number of ports in a route		4
Non-Local Optimality Factor		3
Fare per Route		0.67 €/Km
Decision Variables (Optimization Problem)		
Routes Solution		Valencia-Barcelona-Marín-Cartagena
Frequency		50
Fares		0.67 €/Km
IRR	VAL-BCN	9.54%
	BCN-MAR	35.34%
	MAR-CART	30.67%
	CART-VAL	-2.72%
IRR Overall		18.12%
Computation Time		40 minutes

Table 3: Scenario 2.

Decision Variables (Genetic Algorithm)		
Number of ports in a route	5	
Non-Local Optimality Factor	4	
Fare per Route	0.57 €/Km	0.62 €/Km
Decision Variables (Optimization Problem)		
Routes Solution	Huelva-Barcelona-Cartagena	
	Cadiz-Barcelona-Marín	
Frequency	50	
	50	
Fares	0.57 €/Km	
	0.62 €/Km	
IRR	HUELV-BCN	20.85%
	BCN-CART	-2.97%
	CART-HUELV	12.83%
	CAD-BCN	13.82%
	BCN-MAR	4.47%
	MAR-CAD	1.89%
IRR Overall		8.48%
Computation Time		3 hours 30 minutes
Absorption Rate		6.40%

As the tables show, the algorithm is capable to obtain good solutions in terms of profitability of the services.

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A COMBINED SIMULATION APPROACH FOR THE EFFECTIVE INTEGRATION OF OPERATIONAL AND STRATEGIC LEVELS FOR INTERMODAL TRANSPORT MODELLING

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ABSTRACT

Transport modelling is a fundamental tool for planning and economic assessing of transport infrastructures. To provide reliable results, models should be able to deal with the complexity of the transport system. This is traditionally faced using aggregated models that are incapable of analysing the operations taking place in terminals, even though their performance is crucial for the global competitiveness of any transport system. In this paper a combined approach consisting of a traditional transport modelling –encompassing both tactical and strategic levels- and discrete event simulation –to study terminals at the operational level- is presented. Along with an expected improvement in the level of accuracy of results, this increased-scale approach makes it possible to gain a better understanding of the project as a whole, connecting macroeconomics and microeconomics. This approach has been initially developed for the early design and analysis stages for the Central Bioceanic Railway Corridor (CFBC) project in Bolivia.

Keywords: transport modelling, discrete event simulation, rail-road terminals, transport infrastructure projects

1. INTRODUCTION

The design and development of transport infrastructures, or extension to an existing one, is a big undertaking. There are huge financial, environmental, political, regulatory and practical aspects to be considered and carefully weighed. These projects take a great deal of time and effort in the design and approval phases. Further, infrastructure projects typically demand large capital investments and tend to suffer significant deviations in deadlines and total costs (Maravas and Pantouvakis 2013; Sözüer and Spang 2014).

Simulation provides with a natural framework for the conducting of "what if" analysis that essentially serve as a means of capturing managerial flexibility during the planning, execution and operation of infrastructures, which is otherwise difficult to attain. This modelling and analysis looping methodology provides a natural framework for the effective economic consideration of the wide set of solutions simulation allows to explore. With a well built and validated simulation, a range of different alternatives and situations –options- can be analysed for potential improvements (Nembhard and Aktan 2010). Simulation has been increasingly used as a cost-effective way to understand how various resources (berths, storage areas, cranes, etc.) interact with each other under different operational configurations (Bierwirth and Meisel 2010) and how they are affected by random factors - weather, breakdowns, etc.- (Pani et al. 2014). Ultimately, simulation serves for anticipating the expected return of both capital and operational expenses scenarios throughout the entire life-cycle of the infrastructure, providing a valuable tool for those involved in the decision-making process (Moon and LeBlanc 2008).

However, projects are usually assessed and conducted on a linear fashion (Cruz and Marques 2013). Thus, decisions taken at the strategic stage directly and rigidly affect those made at tactical level, which in turn affect those made at operational level, leaving little room for a more than necessary fine-tuning feedback.

Moreover, when planning the allocation of considerable amount of public and private financial resources in intermodal infrastructures, a sort of biased decision making is generally adopted; yet affording tremendous –and futile- efforts in forecasting the evolution of typical macroeconomic variables –GDP, population, sort and trends of goods demand, etc.- for the typical long planning horizons of infrastructures –up to 50 years-, pretending demonstrate the rationale and general utility and fitness of the investment decision, planners maintain a frozen picture of a certain state of the art during those time horizons regarding the more than plausible evolution of technological level – developments in Material Handling Systems, Terminal Operating Systems, Information Technologies, vessels dimensions, etc.-

The solution lies in finding a way to provide useful information to the principal decision-makers, which should lead to an increase in the degree of certainty. This type of feedback can be carried out in a sort of preliminary exploration and therefore, can be used to minimise the risk of bad investment.

In this paper, we focus on the development of a discrete event simulation (DES) model intended to analyse a generic rail-road intermodal terminal performance within an innovative approach that combines macro-modelling and DES for an improved transport infrastructures assessment. A thorough description of the transport model can be found in (Rios et al. 2013).

In the following section the conceptual modelling of the DES model is described. Section 3 presents the collection and analysis of data whereas in Section 4, the generic Intermodal Node Model is outlined and its verification and validation presented. In Section 5, the combined simulation approach is precisely explained. This paper concludes with a case of successful implementation and the corresponding conclusions.

2. CONCEPTUAL MODEL

The development of any conceptual model demands to acquire a thorough understanding of the actual operations being studied (Robinson 2004). To do so, a research and analysis of such operations as well as simulation models proposed for similar cases was carried out. The conclusions of the literature review were used to identify:

- The elements that most often appear in rail-road terminal models.
- Parameters and results usually defined as input and output data.
- Logic, simplifications, and assumptions typically included.

These results are of great importance since any conceptual model must define the content, input and output data, the logical relationships between components that are going to be modelled and the assumptions and simplifications of the model (Robinson 2004).

At the very end, the rationale behind employing simulation to aid in the design of intermodal terminals is that either their execution or operation demand both huge planning and investment efforts. Terminals should be able to sufficiently cope with peaks in demand avoiding undesirable congestion effects which spread throughout entire transportation networks; but terminals capacity and investment must be balanced.

Three main factors determine the capacity of rail-road terminals; namely, rail tracks capacity, storage area capacity and gates capacity. Rail capacity refers to the number and length of rail tracks, which is directly proportional to the turnaround index, i.e., the faster the loading and unloading operations, the higher the rail capacity is. The storage area determines the maximum number of freight units that can be stored in a terminal. This is the critical factor when containers residence times grow. Last, gate operation determines the number of trucks per unit of time entering and abandoning the terminal. Gate times mostly depend on administrative processes regarding the operational identification of containers (loader, origin, destination, etc.) as well as on the number of lanes, hence highly sensitive to the level of technological deployment involved in order to manage administrative burden and queues.

The model development took into account the number and length of rail tracks, the number of handling equipment, and the number of lanes and corresponding tellers attending trucks, as experimental input factors. However, the storage area is not considered as an input but as an output thus allowing further implementations of tactical concepts like capacity analysis and conceptual pre-engineering deployment design.

2.1. Content

For the sake of generic modelling and analysis, rail-road terminals can be divided into three main subsystems, i.e., (i) gates (interface), (ii) train loading/unloading area, and (iii) storage area (Rizzoli, Fornara, and Gambardella 2002). The main terminal components are as follows:

- The *road gate*, where trucks enter and exit the terminal.
- The *rail gate*, where trains enter and exit the terminal. The rail gate is connected to the rail network and to the transhipment tracks inside the terminal.
- The *loading/unloading area*, composed by a set of transhipment tracks –also known as handling tracks- and a set of lanes for service and driving purposes. A transhipment track is a rail track that can be served by the terminal handling equipment.
- The *yard* or *storage area*, where intermodal terminal units (ITUs) are temporary stored.

Figure 1 presents an outline of a rail-road terminal where the aforementioned components and a waiting area for trucks are identified.

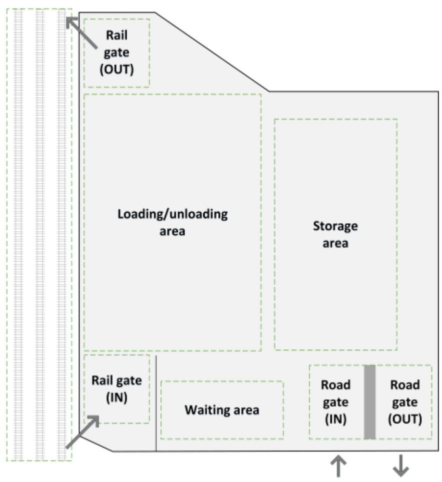

Figure 1: Outline of a Rail-Road Terminal

In addition, the main processes to be modelled are the following:

- Transhipment of ITUs from road to rail.
- Transhipment of ITUs from rail to road.
- Storage of ITUs on the yard.

The complete transhipment process includes the arrival and departure process of ITUs by train and truck.

2.2. Input data

The input parameters that feed the model can be classified into the following types:

- Terminal Design: This category includes the characterization of rail and road gates (number of lanes and rail tracks), handling equipment (number of gantry cranes and reach stackers) and number of transhipment tracks.
- Terminal Operation: Information regarding inbound trains (schedule, size), outbound trains (schedule, destination), pick-up trucks (a number of parameters that connect their generation with the generation of inbound trains) and delivery trucks (theoretical arrival time -that is later randomized- and associated outbound train).
- Internal Calculations: This category includes values (function arguments) the program requires to generate random delays and process times.

Since input data refers to data that feed the DES model, the format in which it is provided is a key issue, in terms of integration, computing efficiency, and above all, conceptual integrity. In this case, the transformations that allow the model to use data from the transport model –which typically handles data from statistical databases and/or market research studies, presenting a high level of both spatial and time aggregation- are explained in detail in Section 5.

2.3. Output data

Output data definition involves identifying the desired information for the assessment of the results. It is possible to define three sets of performance indicators: throughput and lifting performance, system capacity and service level (Benna and Gronalt 2008).

In this model, the key variable is the average container dwell time. Additionally, the model has the capacity to gather a number of key indicators concerning the three groups of parameters described above; namely, container throughput per week (a replication simulates the terminal operation for a period of one week), usage rate of resources (crane and reach stacker utilization), average and maximum number of stored containers (along with storage area occupation graphs), total time for unloading and loading a train, gate queue length (average and maximum length) and gate delay times (average waiting time for trucks delivering and picking up containers). For the sake of summarizing, the variables mentioned in this paragraph are listed and presented in a structured way in Table 1.

Table 1: Model Output Variables

Performance	**Capacity**	**Service level**
ITU dwell time	Utilization	Road gate (IN)
– Average – Minimum – Maximum	– Crane – Reach stacker – Storage area	– Avg. length – Max. length – Waiting time
ITU throughput	Occupation time	
– Inbound – Outbound	– Unloading – Loading	

Some of these variables were especially useful for model testing (verification and validation).

2.4. Logical relationships

The interconnections of the model components allow the main processes of the terminal to be represented.

In order to identify the key interconnections, it is of high interest to analyse and understand the nature of tasks involved in rail-road transhipment processes and the physical movements derived from them.

The rail to road unloading sequence is dictated mainly by the truck arrivals at the terminal. Crane operations start following arrival of the train and they are performed in such a way that a higher priority is given to direct transhipment (train to truck) over indirect transhipment (train to storage and storage to truck).

The road to rail loading sequence also follows this rule. However, the entire process of loading a train is mainly governed by predefined management policies –controlled by terminal managers- based on the definition of the following four events (Kulick and Sawyer 2001):

- *Set time*: time when the train loading starts.
- *Cut-off time*: Last allowable time that an outbound unit is allowed to enter the loading process. Units arriving after the cut-off time are re-allocated to the next outbound train with the same destination.
- *Release time*: Target time when the train is scheduled to be fully loaded.
- *Depart time*: Time when the train physically leaves the loading/unloading area.

In summary, the most important logical relationships of the model may be classified in three large groups: routing, resource allocation and transhipment track assignment.

Routing procedures allow the model to simulate the rational decisions behind some of the truck and train movements within the terminal, such as the movement of a pick-up truck after passing the road gate.

Resource allocation logic refers to real-time decisions regarding handling equipment allocation. This includes not only the allocation of available equipment when requested, but also the allocation of equipment (in accordance with certain pre-established priority rules) when there are several outstanding tasks.

Finally, transhipment track assignment logic covers how real terminal operators direct trains to available handling tracks or force them to queue until the availability condition is satisfied.

2.5. Assumptions and simplifications

Most of the assumptions of the model are due to data unavailability, however, they also respond to an attempt of developing a generic and scalable base for further particularisations. In order to estimate process times it was necessary to study existing systems similar to those represented (see Section 3).

The simplifications made in this model suppose that inbound trains always arrive at the scheduled time and only a single type of container is considered. In addition, introducing unexpected shutdowns (such as human errors or mechanical failures) and designing a highly detailed storage area layout were considered to be beyond the required scope. In the same vein, labour requirements were deemed as unnecessary constraints in such a preliminary exploration.

3. DATA COLLECTION AND ANALYSIS

To develop, validate, and run the model, all three types of input data (see Section 2.2) were proposed, including resources, process times and terminal configuration, amongst others. Therefore, an initial sizing of terminal resources was carried out.

Activities whose temporal distributions are needed for input data can be divided into four groups. The first group includes those activities whose process times are marked by the performance of the terminal and its workers (i.e. aggregated times concerning gates –both road and rail– and non-transhipment activities that are indispensable for the terminal operation). The second group includes operations that do not depend on the terminal itself but on the behaviour of trucks (both pick-up and delivery trucks). Finally, activities carried out by cranes and reach stackers are included in the third and fourth group, respectively.

It is necessary to point out that conceptual terminal designs were proposed as there are no actual terminals in Bolivia that could be taken as a reference. This, indeed, was not a problem given the generic approach of the model.

First, a literature review focused on small and medium sized rail-road terminals was carried out. Results achieved included values and appropriated statistical functions to represent process times (Cartenì and Luca 2010; Ferreira and Sigut 1995; Lee and Kim 2010). This work was completed with the analysis of transhipment operation videos recorded in European medium-sized terminals. Finally, results were compared with information found in technical documents from handling equipment manufacturers present in South America (such as Konecranes and Terex).

4. INTERMODAL NODE MODEL (INM)

The model conception and design pursues its further integration with the aggregated transport model. Calculating container dwell times was of great interest so that total travel time could be estimated with greater accuracy. As dwell times are a consequence of events that can only be studied at an operational level, the intermodal node model (INM) had to represent the main processes that would take place in the terminals that are nodes in the aggregated model. In order to accurately represent these processes, the resolution of the model was designed at the level of a single ITU movement. This led to the selection of the discrete event simulation paradigm. Furthermore, we sought to reapply the INM at other terminals with different demand levels. In other words, the INM needed to be quite generic to be able to model a variety of different terminal configurations.

To ensure the flexibility and the future usability of the model, an interface using Microsoft Excel was created to enter input data and to organize output data.

The INM allows experimentation with different terminal layouts under different scenarios and/or operating conditions due to its modular architecture that represents different elements of the model separately. The modular architecture (see Figure 2) was naturally chosen since it is ideal for developing generic models of considerable size and makes future improvements easier.

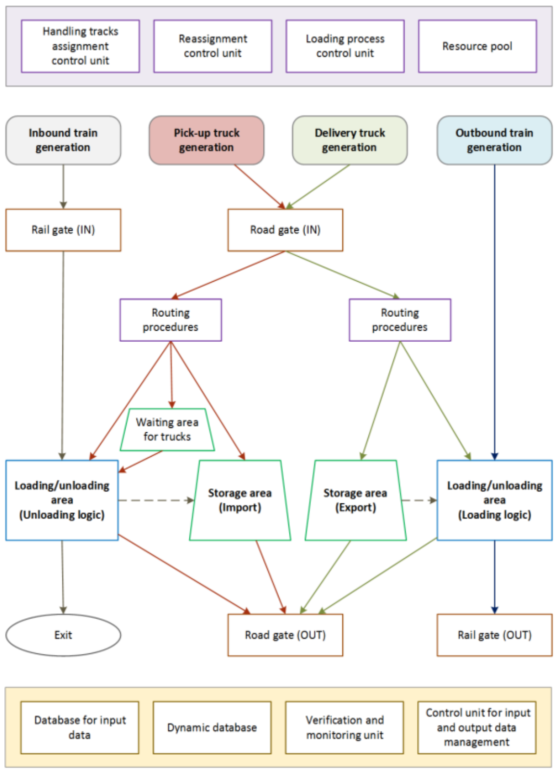

Figure 2: Schema of the INM Architecture

This model has the capacity to represent events like the arrival of a pick-up truck or the movement of a container between two areas of the terminal.

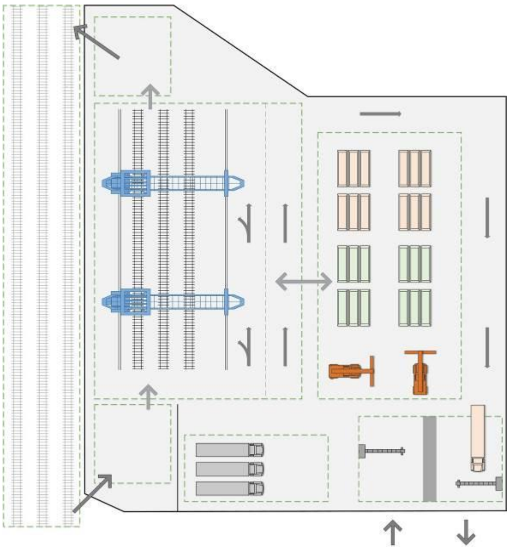

Figure 3: Final Layout Chosen for the Terminals

Figure 3 shows the final layout chosen for the terminals according to their forecasted demand. The transhipment area is served by a set of rail mounted gantry cranes (RMG), spanning the platform length and serving the transhipment tracks for loading and unloading purposes. The reach stackers serve the storage area. They serve trucks directed to the storage area and additionally move ITUs from this area to the loading/unloading area and vice versa.

The model was implemented in ExtendSim 8.0.2, and its interface was created in MS Excel.

Model verification and validation were carefully carried out since they are critical in the development of any simulation model. Verification may be defined as "*assuring that the simulation model has been implemented according to the simulation model specification*" (Sargent 2001). In this project, verification was carried out as an ongoing task, which was naturally and easily done thanks to the modular approach. Whenever a new module or algorithm was completed, guided experiments and analysis of the values obtained with –and during– the execution were conducted to ensure that the computer programming of the conceptual model was correct.

Validation is "*the process of ensuring that the model is sufficiently accurate for the purpose at hand*" (Carson 1986). Since the intended purpose of the model was to support an existing transport model with valuable information to aid strategic and tactical decision-making, its validity was determined for that specific purpose. A number of tests were conducted to explore model behaviour and evaluate if the INM was able to provide reasonable results as well as reasonable variations when changes in the input data were introduced. A number of tests were conducted to explore model behaviour and evaluate if the INM was able to provide reasonable results as well as reasonable variations when changes in the input data were introduced.

As regards the practical application explained in Section 6, the client was able to validate the model due to the credibility the model had acquired during the whole model development process as well as the tests explained above. Clients were involved in the validation of the input data and the conceptual model and found the proposed layout appropriate.

A "final" validation has not been considered since the model is expected to be used and upgraded in the future and a periodic review of the model's validity will be necessary.

5. APPROACH

In order to represent and analyse a transport system, the approach presented in this paper assumes that an aggregated freight transport model has been developed in the first place. This aggregated model is based on the Classical Model of the Four Stages and employs macroeconomic variables as input data (Ortúzar and Willumsen 2011). However, specific adaptations have been done in order to be employed for freight transport simulation (Rios et al. 2013). These stages are generally known as follows:

1. Trip Generation
2. Trip Distribution
3. Modal Split
4. Traffic Assignment

Despite of being able to work at a strategic level, these models have an inherent disadvantage: they are not able to analyse nodes in the operational level, even though the performance of these infrastructures is crucial in the global competitiveness of the transport system. Thus, a generic and flexible DES model enables the analysis at different levels of aggregation.

When integrating the transport model and the INM, it is necessary to adapt the different levels of resolution so each model receives data in the appropriate units and format, corresponding to their respective time and space frameworks. While the transport model works with average annual freight flows rates across a regional transportation network, the INM represents and handles every single ITU within the terminal. Data must be disaggregated through successive conversions (from tons to TEUs) and transformations that can be based both on peak indexes (year to month distribution; month to week distribution) and random or empirical distributions (week demand is finally converted in individual trains). Accordingly, a breakdown system programmed in Excel and partially coded in ExtendSim is responsible for converting the different input and output data.

Output data is also automatically processed. In any case, the transmission of results to the transport model is quite simple as data re-aggregation is not required. Despite the adopted freight transport models handle long time horizons (decades), the mode choice problem is solved by defining utility functions that use -among other data- total travel times (in hours). The coexistence of such different time scales in the very conception of transport models suggests the adequacy of this combined simulation approach.

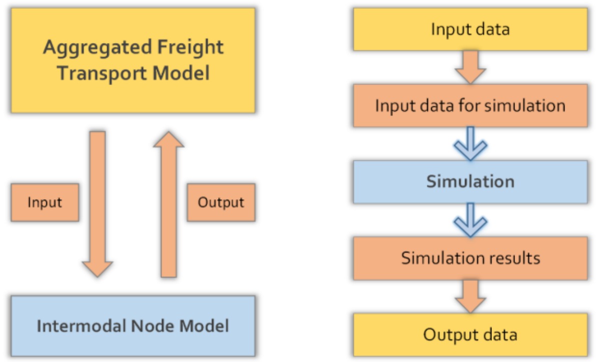

Figure 4: Conceptual Communication Schema between the two Models

The general approach of the way the two models communicate is depicted in Figure 4.

6. IMPLEMENTATION

This combined simulation approach has been applied to provide traffic absorption forecasts as part of a study to determine the future profitability of the Central Bioceanic Railway Corridor (CFBC) in Bolivia.

The CFBC is a railway corridor infrastructure project promoted by the Bolivian government and funded by the Inter-American Development Bank (Iniciativa para la integración de la infraestructura regional suramericana 2013). It will link the Atlantic and Pacific coasts of central South America.

To assess the competitiveness of the CFBC against that of other existing alternatives such as the Paraguay-Parana Waterway, a transport model was developed. Once the transport model was ready to use, the development of a rail-road terminal simulation model began. Figure 5 shows the most important terminals of the corridor from Bolivia's point of view.

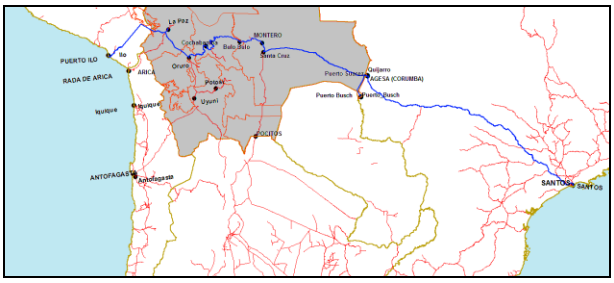

Figure 5: The CFBC Modelled in the Transportation Planning Software TransCAD.

To automate the hierarchical integration of the models, macros were programmed in GISDK, the proprietary programming code of TransCAD, connecting with Excel. Consequently, the INM is executed whenever a new calculation of container dwell time is requested by the transport model. The implementation for the case study led to the calculation of values that fed the aggregated transport model.

Providing a rough and preliminary estimation of resource requirements to deal with peak activity months -in the future terminal of La Paz- that would affect transport system performance and reliability was another important finding. This analysis was performed taking into account the expected volumes of activity for that node -with a timeframe up to the year 2025- which had been calculated with the aggregated transport model. Numerical results and findings are not shown in this paper due to confidentiality issues.

Future work will focus on characterization of input and output data, with the objective of increasing model and integration complexity if sufficient computational power is available.

7. CONCLUSIONS

A combined approach for intermodal freight transport modelling has been presented. It involves integrating an aggregated transport planning model and a generic terminal discrete event simulation model.

As a result, the total travel time, one of the key parameters to assess the competitiveness of transport infrastructures and systems, can be more accurately calculated compared with typical approaches. It is also possible to assess the impact of variations of terminal design parameters, such as handling equipment, or any other operation parameters like train timetables.

Finally, the complexity and level of detail accomplished make this model a useful tool in the planning and design of new CFBC terminals.

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MODE CHOICE MODELLING FOR THE ASSESSMENT OF AN INTERNATIONAL RAILWAY CORRIDOR

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ABSTRACT
When developing a model for multimodal transport planning, the mode choice component is a critical element since it estimates the shares of traffic flow which are absorbed by each competing alternative. This paper describes the steps followed in the mode choice modelling phase in the development of the transport model for the assessment of the Bolivian Central Bioceanic Railway Corridor (CFBC). The model integrates different levels of geographical resolution, alternatives from four competing modes of transport and different categories of freight.

Keywords: Multimodal Transport, Freight Transport, Discrete Choice Model.

1. CASE INTRODUCTION

The CFBC (Central Bi-Oceanic Railway Corridor) is a railway corridor infrastructure project promoted by the Bolivian Government and funded by the Inter-American Development Bank. It will link the Atlantic and Pacific coasts of the central part of South America, from the port of Santos in Brazil to a port in the coast of Peru (Figure 1). Its construction is expected to save both costs and time of transporting cargo and passengers through the great natural barrier which are the Andes. As of nowadays, the only way to cross them is by narrow mountain roads that lead to high logistics costs and difficult the economic development of the region.

Figure 1. Proposed CFBC map.

This paper describes the steps followed for choosing and calibrating the discrete modal choice component of the transport model (Figure 2) developed for strategic planning. The transport model is a M&S tool developed as part of the analysis of prospective trade, market and logistics alternatives. It seeks to forecast the levels of passenger and freight demand and the CFBC's flows absorption among Bolivia, its neighboring countries and the rest of the world. The goal is to analyze its competitiveness compared to other existing alternatives such as the Paraguay-Parana Waterway or the Panama Channel. Import and export trades are regarded as one of the most promising sources of demand and thus accurate international transport modelling is considered a major challenge in the project development.

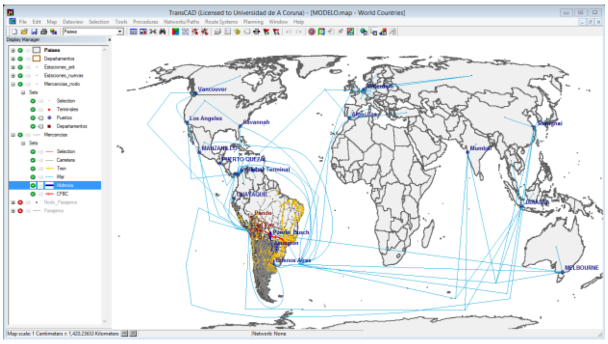

Figure 2. Screenshot of the whole transport model.

The model developed is based on the classical four steps methodology. A full description of the modelling methodology is given by Rios-Prado et al. (2013). The components of the model are:

- Freight generation and consumption. It estimates the total flows of freight produced and demanded in each Traffic Analysis Zone (TAZ).
- Freight generation and distribution. It estimates the flows of freight from each origin to each destination. It is performed for both the flows between regions within Bolivia and for the international import/export flows between Bolivia and the rest of the world.
- Modal choice. It calculates the share of load that uses each transport alternative.
- Network assignment. It estimates the total cargo that uses each link of the road.
- Discrete events simulator of train terminals. This complementary model estimates the

residence times in the terminals of the railway network depending on traffic congestion and terminal design parameters Figure 3.

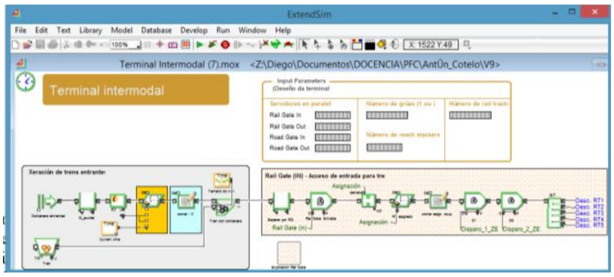

Figure 3. Screenshot of a part of the discrete events model implemented in ExtendSim for the simulation of train terminals.

The transport network included in this model spans:

- Main roads infrastructure in Bolivia and neighboring countries.
- Railway network in Bolivia and neighboring countries.
- Paragay-Parana waterway.
- Major shipping routes departing from the most representative ports in the region.

Although there are many types of cargo that can be considered at the large scale of this model, they were grouped in four categories:

- "Dirty" dry bulk cargo (mainly minerals).
- "Clean" dry bulk cargo (mainly soy).
- Liquid bulk (mainly fuels).
- Containerized cargo (mainly manufactured products).

This paper is focused in the data collection and calibration steps for obtaining the modal choice component of the model. Section 2 presents a brief introduction to discrete choice models and bibliographic review. Section 3 presents the discrete choice model fitted.

2. DISCRETE CHOICE MODELS

One of the key aspects of a transportation model is to estimate how modal choice is made from a set of available alternatives. Discrete choice models aim at capturing how some individuals or groups select a mode weighting some factors that affect the decision (Ortúzar and Willumsen, 2011).

In freight transport, it has been well established in the literature that the best option in terms of a single factor (such as cost or time) is not always chosen by all the users. Hence, probabilistic decision models are preferred to deterministic ones. The main goal of the choice model is to predict the share of trips for each origin and destination pair transported by each mode.

There are some different models that can be adopted such as logistic regression, Bayesian networks or neural networks. The most popular ones applied in practice are the logit models, which can be subdivided in many types. Linear regression models are discarded because the assumptions of ordinary least squares are violated (Aldrich and Nelson, 1995). The main logistical models are Multinomial Logit Model, Binary Logit Model and Nested Logit Model.

Discrete-choice models are based on random utility theory. Its assumptions can be summarized as follows (Ortúzar and Willumsen, 2011):

- There is a homogenous population formed by a set of individuals who have perfect information.
- A set of alternatives is available (it is assumed in general to correspond to each transport mode).
- Each transport alternative (*j*) has a net utility for individual (*p*), U_{jp}. The utility is then assumed to be the sum of two components, a measurable function of certain factors that affect the transport choice (V_{jp}) and a random component which reflects the idiosyncrasies and particular tastes of each individual as well as measurement and observational errors (ε_{jp}).

$$U_{jp} = V_{jp} + \varepsilon_{jp}$$

Logit models are a family of discrete choice models that can be obtained by considering different assumptions about the nature of the stochastic component. In particular, the Multinomial Logit Model (MNL) is a very popular one in practice due to its simple assumptions and robustness (Domencich and McFadden, 1975). It relies on the assumption that the random errors are Gumbel IID distributed, which leads to the well-known equation of a MNL for calculating the share of kth alternative (P_k):

$$P_k = \frac{e^{V_k}}{\sum_j e^{V_j}}$$

The utility function (V) is generally modelled as a linear function of a set of alternative dependent factors and/or individual related factors. Two common decision factors considered in practice are the cost and the time incurred by using each transport alternative. These two factors usually determine modal choice (Kreutzberger, 2008). The preference for an alternative given equal cost and time conditions can be captured in the linear model by means of a constant parameter. For instance, a simple utility function form would be:

$$V_k = \beta_k + \beta_C \cdot c_k + \beta_t \cdot t_k$$

Where β_k stands for alternative preference utility, β_C stands for the cost unitary utility (it must be negative since utility is reduced by increases in cost), c_k stands for the cost of choosing alternative k, β_t stands for the time unitary utility and t_k stands for the time of choosing alternative k.

Multinomial logit models (MNL) have found many applications to transportation problems in practice. For instance, they have been applied to analyzing the mode choice behavior in the Oresund region (Rich et al., 2009), for vehicle choice modelling in Colombia (Holguin-Veras, 2002) or joint mode and vehicle choice in the US (Pourabdollahi et al., 2013).

Other logit models of practical interests are the Nested Logit Model (NLM) and the Mixed Logit Model (ML). The NML (Daly and Zachary, 1978) takes into account that when there are groups or hierarchies of the choice alternatives the random errors IID assumption is no longer valid. The paper by Jiang et al (1999) presents a case of application for analyzing the relation between the freight characteristics and the shipper's choice. The model considered two great transport groups such as public and private, and three subgroups in the public one, road, train and multimodal. Another example of application is the analysis of mode choice in India for containerized cargo (Ravibabu, 2013).

The Mixed Logit Model assumes that the parameters of the utility function are not constant but random variables themselves. Mixed logit models (ML) are suitable for cases in which the population of decision makers is very heterogeneous and weights the decision factors differently (Fadden and Train, 2000). This greater model flexibility comes at the expense of greater model complexity since parameters distributions need to be specified.

Another approach considered in this project was the use of neural networks for choice modelling, which is a promising technique for mode choice modelling (Hensher and Ton, 2000; Karlaftis and Vlahogianni, 2011; Nijkamp et al., 2004). Neural networks can fit to complex non-linear data (Karlaftis and Vlahogianni, 2011), although they generally require large datasets, might be subject to overfitting and model parameters have not a direct interpretation. They were discarded in this work because the size of the available datasets was limited and it was desired to provide an interpretation of the model parameters.

3. THE MODEL CALIBRATION

3.1. Alternatives identification

The first step for calibrating the mode choice model was to identify the set of transport alternatives. The relevant alternatives depend on the geographical distances covered. For interregional transport within Bolivia or transport to the neighboring countries, road and train are the only relevant modes.

However, for long distance import/export flows maritime transport is required and the Paraguay-Parana waterway is used as a link to the port of Buenos Aires in Argentina, from where goods can be transported to the rest of the world. Thus, the hardest case for identifying transport alternatives is the export/import to far destinations. All the countries which are not neighbors of Bolivia will be included in the category of "distant TAZs".

The mode choice model will thus operate differently for this two types of transport:

- Short distance transport for interregional flows and import/export to neighbouring countries.
- Long distance transport to "distant" TAZs.

For short distance transport only two options were considered in this case: road and multimodal road-train modes.

For long distance transport, the available alternatives can be grouped following two criteria:

- Alternatives related to the port used for import/export. There are many ports available on both the Atlantic and Pacific coasts. Port selection is important because it is conditioned by ports facilities, connections to the hinterland and it determines the maritime routes followed.
- Alternatives related to the mode of transport employed for reaching the port. There can be used road, multimodal road-train and the waterway along with its combinations with road and train.

Although if all the options of ports and modes combinations were taken into account the number of alternatives would be large, in practice some of the combinations can be disregarded due to their practical infeasibility or lack of use. Also, although the waterway is actually a transport mode that competes with road and train for some of the flows, the only port available is Buenos Aires so other ports get discarded. Thus, the waterway option does not need to be accounted for in both categories of alternatives and it was dealt with as if it was a "port" alternative. Finally, not all the alternatives of transport are valid for all types of cargo, so further constraints can be applied.

Once the relevant alternatives were filtered, the set of following options was established as shown in Table 1.

For different types of cargo, criteria for mode choice are usually different. Thus, at this step of the model development it was decided to calibrate a separate model for each cargo category. For instance, containers have usually higher added value than bulk cargo so travel time is a more important factor for the first category.

Table 1: Available alternatives in the model.

Alternatives			
Port	Mode	Bulk	Containers
Arica	Road	Yes	Yes
Arica	MM	No	No
Peru port	Road	Yes	Yes
Peru port	MM*	Yes	Yes
Iquique	Road	Yes	Yes
Antofagasta	Road	Yes	No
Antofagasta	MM	Yes	No
Pto. Busch (waterway)	Road	Yes	Yes
Pto. Busch (waterway)	MM	Yes	Yes
Pto. Suarez (waterway)	Road	Yes	Yes
Pto. Suarez (waterway)	MM	Yes	Yes
Buenos Aires	Road	Yes	Yes
Santos	Road	Yes	Yes
Santos	MM	Yes	Yes

* This alternative is not available as of nowadays but it is part of the future part of the CFBC so it is considered in the model.

3.2. Dataset

Data for model calibration was mainly gathered from the international trade databases of the Bolivian Ministry of Foreign Affairs. Although interviews with exporters and importers were available, they did not provide useful information for model calibration. The data required for model calibration must have information of costs and times by using each alternative as well as the actual choice made by the shipper or stated preferences. However, the data available only had information about the chosen alternative but not the other options.

On the contrary, the international trade database contains extensive data on the imports, exports and modal choice. The fields of information contained in this database are:

- Origin and destination for each import/export flow.
- Type of cargo.
- Mode of transportation (train, road and waterway).
- Entry/Exit point to Bolivia.
- Year and month.
- Tons of transported flow, along with its CIF and FOB values.

Combining this information with the estimated transport costs of each mode, it was possible to obtain a dataset with the required fields to calibrate the choice model. The process followed for obtaining this dataset can be summarized as follows:

1. Download data from the international trade database. The registries include origin/destination, mode, cargo type and entry/exit point. This data constitutes the "observed flows dataset".
2. Obtain and debug the GIS cartography for the model network.
3. Estimate the average transit unitary costs per mode and average velocities from a market survey.
4. Employ the GIS cartography along with the unitary costs and velocities to estimate the total costs and travel times from each origin to each destination by mode.
5. Add the total costs and times per mode as additional fields to the "observed flows dataset".

However, the maximum likelihood methods employed for calibrating a MNL model require discrete observations of selected mode along with mode attributes. In order to obtain such a sample, Monte Carlo simulation was adopted using the "observed flows dataset" to weight the probability of each simulated trip. The goal of this procedure is to generate a sample of observations that match the observed pattern of mode share present in the data.

A sample of 800 simulated trips was generated for each freight category following the next procedure in order to obtain the "Simulated Trips Survey Table":

1. The probability of generating a trip from an origin to a destination using a certain mode is given by the total freight flow from the origin to the destination divided by the total freight.
2. A sample of 800 combinations of Origin-Destination-Alternative is randomly generated from the "observed flows dataset" using the probabilities calculated in the previous step. A row in the "Simulated Trips Survey Table" is added for each possible alternative and the selected Origin-Destination. The field "Selected Alternative" is set equal to True for the row that matches the observed alternative and False for the others.
3. For each Origin-Destination-Alternative combination generated, the cost and time by each mode are obtained from the "observed flows dataset".

The dataset thus obtained could then be used for model calibration.

3.3. Results

The model was calibrated for the sample obtained as indicated before. R software was employed for this purpose. A separate model was fitted for each cargo type. The variables included in the utility function varied from one type to another depending on the statistical significance of the fitted parameters. Also, some alternatives for cargo transport were not included in the model depending on the actual constraints as explained before.

The values of the fitted parameters are omitted due to confidentiality issues. The presented values are the parameters included in the model along with their p-values for the parameters significance tests. Table 2 shows the models parameters.

Table 2: Utility function parameters along with their statistical significance.

Cargo Type	Parameter	p-value
Container	Arica Preference	0.0000
Container	Cost	0.0000
Container	Time	< 2.2e-16
"Dirty" dry bulk	Cost	0.0000
"Dirty" dry bulk	Time	0.0000
"Clean" dry bulk	Cost	0.5331
"Clean" dry bulk	Time	0.0001
Liquid bulk	Cost	0.0000

The following conclusions are derived from them:

- For containers, both cost and time were significant parameters to be included in the model. It was also found that including an alternative dependent parameter for the Arica Port increased the prediction power of the model. This result can be explained taking into account that the Arica Port offers attractive facilities for containerized freight. Santos port in Brazil is also a port with a large volume of containers, although it is less attractive for Bolivian cargo since it is more far away and it is a highly congested port.
- For "dirty" dry bulk, both cost and time factors were included in the model.
- For "clean" dry bulk, time was found to be the most significant variable. This result makes sense if we take into account that most of this cargo is soy. Soy exports are nowadays conditioned by the seasonal variations of soy prices. Exporters are mainly interested in minimizing travel times to reach their destination markets when prices are high.
- For liquid bulk, it was found that the cost factor could account for the observed share and including the time factor would not contribute to increase the predictive power of the model.

The calibrated MNLs were implemented in the transport model so that assignments of freight flows to each mode and the network could be obtained. Figure 4 shows an example of the kind of results that could be achieved before the CFBC is operating and Figure 5 shows the results once the CFBC is operating.

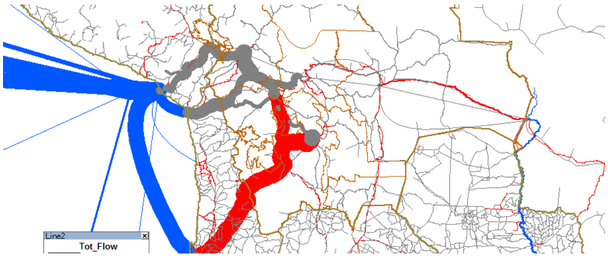

Figure 4. Screenshot of the model results displaying the assignment of freight flows for a certain type of cargo before the CFBC is operating (red is used for rail mode and grey for road).

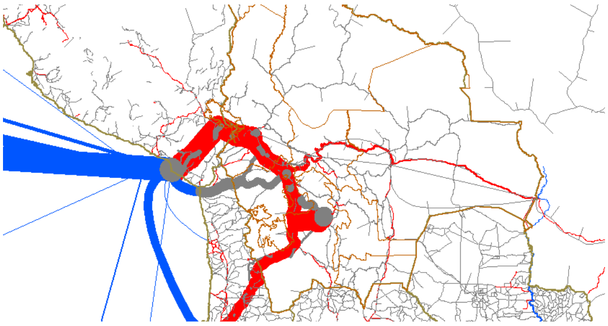

Figure 5. Screenshot of the model results displaying the assignment of freight flows for a certain type of cargo once the CFBC is operating (red is used for rail mode and grey for road).

4. CONCLUSION

This paper describes the process of developing the mode choice component of a large transport model employed for the assessment of a new railway corridor. Multinomial Logit (MNL) models were used for estimating the shares of freight flow that are absorbed by a wide range of transport alternatives which span various ports in the Pacific and Atlantic coasts of South America and combine four different transport modes.

The models were fitted using data from the International Trade Database developed and maintained by the Bolivian government, which provided the widest and most valuable data source available in this project. The model includes the main variables necessary to estimate the distribution of cargo among competing alternatives. The MNLs calibrated were implemented in the transport model so that it was possible to forecast the absorptions of flow by the future CFBC service given the designed conditions and proposed fares.

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RISK ANALYSIS FOR SUPPLY CHAIN NETWORKS

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ABSTRACT

The research is focused on the development of an integrated generic supply chain risk-, crises and performance management and monitoring system under the aspect of a comprehensive approach. Building on existing results from previous research activities we created a generic, integrated and systemic supply chain network model. Based on this model we described various scenario portfolios and single scenarios. We developed a risk assessment and analysis process model. The research results should create a unique risk rating and crises management monitoring system for decision making under the systemic view and criteria of:

- event orientation
- organisational orientation
- cause/trigger orientation
- time frame
- region
- level of abstraction

Beside the generation of the systemic supply chain network model, the scenario development, the risk assessment and analysis process and the risk rating and crises management monitoring model our research result can be used as well as for organizational development and strategic and operational decision making.

Keywords: enterprise risk management, risk rating, integrated supply chain risk- and performance management, supply chain networks.

1. INTRODUCTION

Over the past decade, the awareness of the importance of risk management for supply chains has risen continuously. Recent incident, such as the catastrophic floods in the Bangkok region in 2011 (BKK 2011) have demonstrated the high interdependency of international supply chains, in this special case the high dependence of the worldwide hardware industry on disks manufactured in the flooded region. This and other similaraly disastrous events have led to a renewed interest in robustness and resilience of supply chains (Wilding 2011).

This discussion is ongoing, especially in relation to how future supply chain network-infrastructures should be structured in a centralized or decentralized way. Of primary interest and in some cases even vital importance is the discourse of all horizontally and vertically integrated interactions and dependencies between the different supply chain networks for providing uninterrupted services. This has a direct influence on the development and the use of future smart solutions options, not only in the context of energy supply, but even more so in the context of ICT infrastructures.

Compliance constitutes a other field of discussion and research. Legal and corporate compliance should ideally guide risk management efforts of organisations and build the basis for the implementation of an Integrated Supply Chain Risk- and Performance Management and Monitoring System. While the majority of laws and regulations relevant for this research are based on European regulations, directives and guidelines, US and austrian national legislation and international and national standardizations and agreements (e.g. ISO 31000, ISO 31010, ISO 28000ff, ON ISO 31000, ONR 49000ff) also play a major role.

2. MOTIVATION

Consequently, society and economy, i.e. enterprises, governments, NGOs and individuals, have to address a wide range of issues:

- The development of a robust interaction mechanism for controlling increasingly complex and interdependent supply chain networks (Wilding 2011).

- The relation between global, supranational, regional and local supply relevance and density under resilient conditions.
- The prediction and anticipation of potential disruptions of centralized and decentralized supply chain networks in relation to potential events, space, time and level of abstraction in order to design adequate avoidance and mitigation strategies, and emergency plans both for the public and the private sector based on accumulated knowledge and empirical best-practices (Goellner, Kienesberger, Peer, Schoenbacher, Weiler, Wurzer 2010; Goellner, Meurers, Peer, Langer, Kammerstetter 2014).
- The provision of robust and reliable communication and logistics for all involved stakeholders, especially for the purpose of adequate status information (Goellner, Meurers, Peer, Povoden 2011; Peer, Göllner, Haberfellner, Bauer 2014).

Advanced concepts for future risk analysis of supply chains should therefore support and improve the above issues, which sometimes needs to be done in ways not anticipated before. Risk analysis concepts, models and methods should ideally allow for the speedy aggregation and presentation of data, information and knowledge supported by effective and efficient communications in new ways, offering improved interpretation, assessment and decisions.

3. AIM/SCOPE

One of our core research goals is to follow an integrated approach consisting in the core of contributions from logistics, risk analysis, performance management and information and communications technology including the Human factor rsp. The structured basis on the issue given in Fig.1, which is developed by Göllner, Peer (2012), builds the background of the research approach presented in this paper.

It clearly arranges critical infrastructures, sectors in society and economy, actors and events that may lead to a threat in a specific supply chain (Goellner, Kienesberger, Peer, Schoenbacher, Weiler, Wurzer 2010).

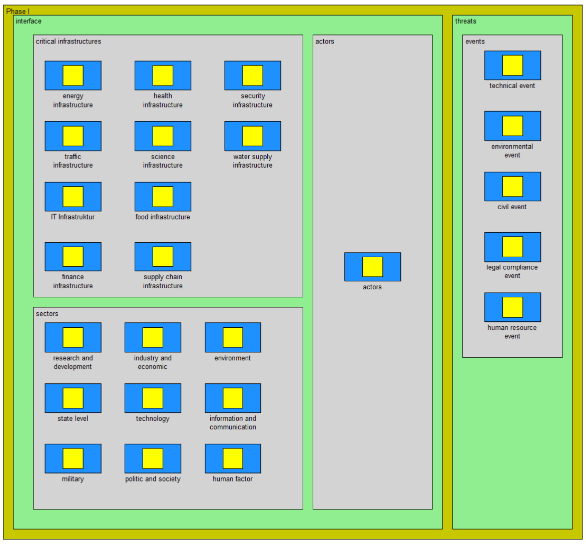

Figure 1: Structure and interface for comprehensive risk analysis

The design of complex supply chain networks will profit most from this research, while our current research in risk models and meta models, IT & network resilience, critical infrastructure risk, knowledge development & decision support form the basis for the development of an integrated supply chain risk- and performance management approach (Goellner, Meurers, Peer, Povoden 2010a-c; Christopher and Peck 2004).

Industrial applications, especially in the chemical industry, insurance companies, transport & logistics, finance, strategic resource planning, information and communication technology & energy, architecture & urban planning, information and big data analysis and network analysis can serve as case studies for testing the viability of our research (Goellner, Meurers, Peer, Povoden 2010a-c; Goellner, Meurers, Peer, Povoden 2011).

Enterprise risk management and business continuity need to be discussed in the context of a meta supply chain model, which is currently under development. Building on an identification of requirements for the envisaged meta supply chain model the model itself is described, followed by an enterprise risk management (ERM) approach based on this model, including business continuity aspects (Goellner, Meurers, Peer, Povoden 2010a-c; Bossel 2007; Buzan, Waever, Wilde 1998; Buzan, Waever 2008).

The following figure 2 was developed by Göllner J. and Peer A (Goellner, Peer 2012). This figure shows the relation between the enterprise risk management of a reference organisation and the supply chain networks.

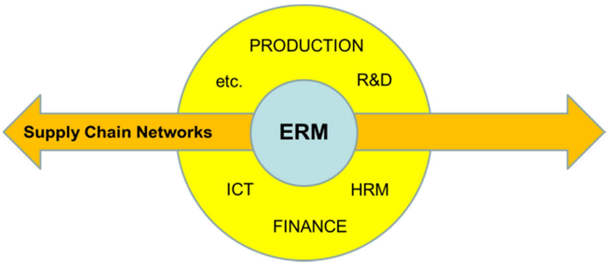

Figure 2: Relation between organisation-supply chain networks and enterprise risk management

4. RESEARCH AGENDA & PROCESS

The research follows the agenda:

1. Process representation of a selected supply chain
2. Identification and systematization of the strategic / critical supply chain networks focused on an integrated supply chain concept
3. Design and develop a "state of the art" - Network typology to generate a risk map-catalogue, which is representing the relevant risk-events
4. Verification of the relationships and interfaces along the Supply Chain Networks for presentation in a supply chain risk map and in relation to the example relevant endogenous and exogenous risk factors, according to point 1-3
5. Development of a risk rating model for the evaluation and assessment of centralized and decentralized "critical infrastructure networks" and in relation to the associated event / event portfolio (framework scenarios, scenarios portfolios and individual scenarios)
6. Development of a crisis management model for business continuity especially under the focus of chemical, biological, radiological and nuclear threats (CBRN threats) in the industrial context
7. Use Case discussion

The ongoing research process is divided into 4 phases:

1. The first element (figure 1) deals with the identification of the interfaces of critical infrastructures, sectors and actors under various threats and the analysis of strategic / critical supply chain networks in the sense or on the basis of an integrated supply chain concept is generally finished and tested.
2. The second element deals with a referenced global acting pharmaceutical enterprise, which is used for validating our comprehensive approach during various test cases.
3. The third element consists of a scenario development and the following risk management model to design and development a "state of the art" - Network typology to generate a risk map – catalogue (Howard 2009; Vester 2008). Therefore various models are still tested and a meta model is finally designed and tested.
4. In the last element the research approach is divide up into both the development of

    a. a risk rating model and
    b. a crisis management model

    including the verification and validating under the systemic view of the 5-stage-model during 2 use cases. The 5-stage-model is shown in Fig. 3 (Backfried, Göllner, Quirchmayr, Rainer, Kienast, Thallinger, Schmidt, Peer 2013).

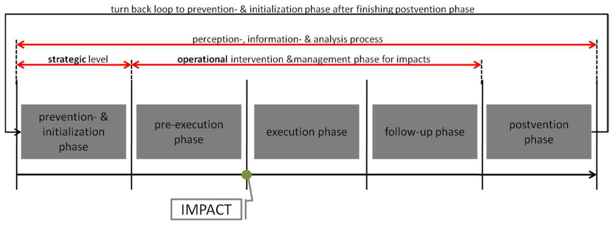

Figure 3: 5-stage-model

So with this activities the various influencing topics are documented and further on categorized. Then the interdependencies and correlations are identified and described.

5. RESULTS

Based on the research agenda and the research process we created a generic integrated systemic supply chain network model.

Various unique scenario portfolios and single scenarios were described in relation to the generic integrated systemic supply chain network model.

Further on we developed a risk assessment and analysis process and model, including the identification of the relevant and corresponding key performance indicators and key risk indicators.

Those indicators are necessary for the designed risk rating model for future trend analysis and also as well as the implementation of a effective and efficient crises management on demand.

The result of the research can be used for centralized or decentralized strategic or critical supply chain networks as well as for the crisis management.

The unique result for an organisation is at least an integrated supply chain risk-, crises and performance management and monitoring system which depends on the relevant rating elements.

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IMPROVING RAIL ROAD TERMINAL OPERATIONS IN THE FOREST WOOD SUPPLY CHAIN – A SIMULATION BASED APPROACH

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ABSTRACT

Advanced logistics and transportation concepts are required to improve the forest-wood supply chain. In this paper some terminal concepts are analyzed that show a strengthening of the railway timber transport and synergies between rail and road transport chains. A discrete event simulation model is developed in order to analyze different prevalent terminal layout configuration and to disclose potential improvements of the timber railway transportation system by proposing new terminal layouts and new railway transport options. We conduct comprehensive simulation experiments of the wood supply network with several terminals and industry sites to find out system's bottlenecks and appropriate railway operation schedules. As a result we can show that by changing the railway operation from a single wagon load to a shuttle system we can nearly double the amount of round wood to be transported.

Keywords: forest-wood supply chain, rail terminal, scenario analysis

1. INTRODUCTION

It is often claimed that the rail transport system should preferable be used for heavy and bulk materials. Austria processes approx. 25 Mio. of solid cubic meter roundwood per year and it operates more than 200 wood loading and transshipment points and a good quantity of wood industries have sidings in use. On the other hand the portion of road transport is rather high and cost pressure on railway forces railway companies to rethink their wood terminal network.

In this paper a few terminal concepts are analyzed in particular that show a strengthening of the railway timber transport and the possibilities of synergy between rail and road intermodal transport chains. For this purpose, already existing concepts in timber logistics are analyzed and the role of the railway is shown during timber transport. In a first step we carry out a detailed process analysis of roundwood (i.e. sawlogs and pulpwood) transport and its handling on dedicated wood terminals. Further, we give special emphasis on the communication interfaces of the involved actors. Through a mass flow analysis the structure of the timber transportation, both in terms of transport mode as well as the actual spatial distribution of the wood transports are evaluated. A discrete event simulation model is developed in order to analyze different prevalent terminal layout configuration and to disclose potential improvements of the timber railway transportation system by proposing new terminal layouts and new railway transport options. We conduct comprehensive simulation experiments of the wood supply network with several terminals and industry sites to find out system's bottlenecks and appropriate railway operation schedules. As a result we can show that by changing the railway operation from a single wagon load to a shuttle system we can nearly double the amount of round wood to be transported. If it is moreover possible to change the terminal layout (i.e. loading track length) we can further increase railway transport volumes.

2. TIMBER TRANSPORTATION SYSTEMS AND WOOD TERMINAL OPERATIONS

Round wood transportation may be either directly from forest to industry by truck or for some reason like long distances or high volume transport units are transshipped on dedicated wood terminals. In this case we are talking about multimodal transport (Wolfsmayr and Rauch 2014, Zazgornik et al. 2012). The log truck driver is using a truck crane to unload the logs in the terminal. If there are appropriate rail wagons available to use, which further on transport the logs to the industry, there will be a direct transhipment from truck to rail wagon. This is denoted as synchronous transhipment. However in standard operation a direct transhipment is rarely possible, so that the logs are unloaded by using some certain storage areas at the terminal. When the freight train arrives an additional operation is required for loading the freight wagons. The activities of this multimodal transport chain are shown in Figure 1.

Railroad terminal transhipment volume is mainly determined by existing infrastructure like number and length of loading tracks, storage area and handling equipment. We will describe a simulation based scenario approach for analyzing a railway based wood supply network. For a given number of industry plants we evaluate the capacity of such a network and study the effects of infrastructural changes at the terminals, different railway operational concepts and fluctuations of the available wood supply in the catchment area of the terminals.

In intermodal wood transport chains, terminals proofed to provide good services (Gunnarsson et al.

2004) and large buffer storage area is also essential for rail transport, as high volumes can be unloaded and stored in a short time slot (Rauch and Gronalt 2011). Supply chains including terminals increase year round availability resp. supply security (Ranta et al. 2012) and are seen as prerequisite to fulfill significantly increasing wood demand.

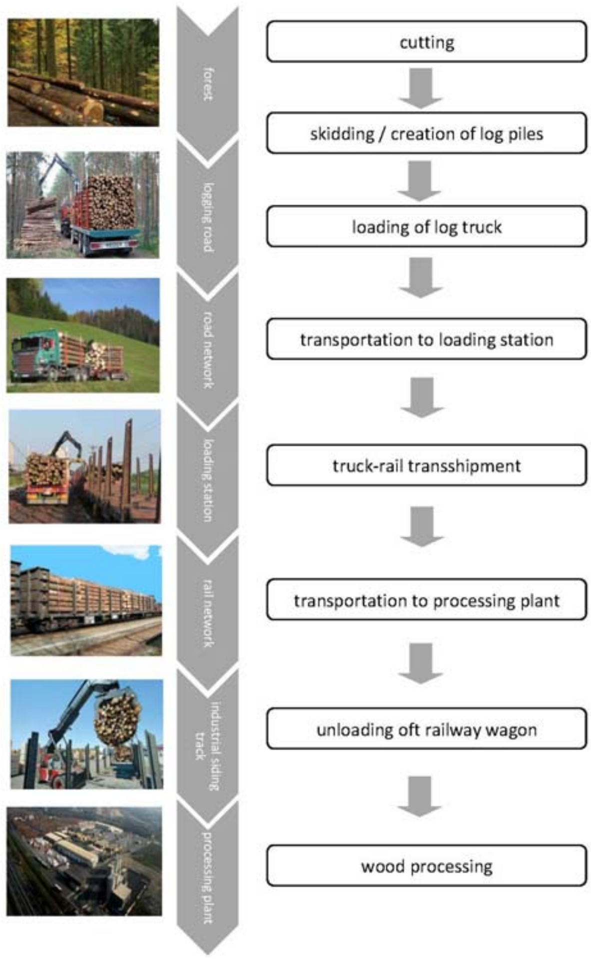

Figure 1: Multimodal round wood transport and synchronous transshipment

Next to transshipment, a train terminal can fulfill additional logistical functions or services and therefore terminals differ in terms of location, storage capacity and specific services provided (Benna and Gronalt 2008; Gronalt et al. 2012). Optimal storing capacity of a terminal is determined by seasonality of both, timber supply and plant demand, leading to a minimum amount of timber to be stored at a certain time of the year in order to ensure supply security. In Finland, domestic roundwood transport via train terminals becomes competitive at a distance of at least 200 km, from there on total costs for truck transport to the terminal, terminal costs and rail transport to the plant are lower than for direct truck transport (Tahvanainen and Anttila 2011). If an additional post road transport is included in the roundwood supply (e.g. since the plant has no own rail access), break-even point of rail transport compared to direct truck transport is reached at a distance of 300 km (Chesneau et al. 2012). Additionally, cost cutting potential of a terminal varies depending on specific timber supply chain parameters like total timber volume or regional wood harvest seasonality (Rauch and Gronalt 2010). Critical success factors for rail terminals proved to be length of loading rail, capacity and characteristic of storage area (Ranta et al. 2012), number of trains despatched per week and utilising maximum payload for each train or wagon.

The aim of the simulation model and simulation study described in the following section is to simulate a wood supply chain including four wood terminals and four wood processing plants. Two of them are sawmills, requiring the delivery of sawlogs and two are papermills which process pulpwood. We want to compare the transport chain as it is currently in use in Austria with a different approach that uses terminals for asynchronous truck-train transshipment and employs a concept of shuttle trains in contrast to the single wagon system that is used now.

We assess the two approaches under the current real life situations and develop a number of scenarios to see how the analyzed approaches react to changed transport volumes and how infrastructural adaptions influence the performance. Since there is no information about the actual capacities of the existing terminals we want to evaluate the current capacity, compare it to the capacity when a different operational concept is applied and subsequently analyze how changes in infrastructure and train concepts affect the capacity of the terminals and the whole wood supply chain network.

3. SIMULATION MODEL DEVELOPMENT

The simulation model developed covers the precarriage of round timber to wood terminals, round wood storage in terminals, transshipment to rail cars and final transport to and unloading at woodworking plants. The simulation model is used for several issues in order to improve the efficiency of this supply chain. These contain the determination of transshipment time / cycle time of round timber, stock levels at terminals over time, utilization of terminal infrastructure (storage capacity, transshipment equipment), network capacity with given terminal sizes and configurations and required terminal sizes and configurations to achieve a given network capacity. The model must be able to cope with the effects of short term fluctuations in timber supply and capacity constraints of specific terminal layouts. The simulation study includes therefore various terminal specifications and their effect on the supply network and also the effects of applying different train concepts (single wagon, shuttle train) for picking up the wood at the terminals.

To achieve the level of detail in the simulation results that is necessary to derive valid conclusions requires our model to be process-centric and on a detailed operational level. Therefore we developed and implemented a discrete-event based simulation model by using AnyLogic. In the discrete-event simulation approach, continuous real world processes are divided into an ordered sequence of events, where each event occurs at an instant in time. This simplification allows for better analysis of the modeled processes.

3.1. Model description, structure and components

The simulation model consists of four basic components that are interrelated with each other in order to represent the specific supply chain network. These components are (1) forest and precarriage, (2) terminal modules, (3) railway network and (4) plant modules. The behavior of each component depends both on its process and infrastructural input parameters, stochastic effects and the other model components. The components and their input and output parameters are schematically shown in Figure 2. All components except the railway network follow a modular principle so that they can be duplicated as often as required in order to reflect the studied supply chain. Since the railway network already presents the whole network, there is only one railway network in the model.

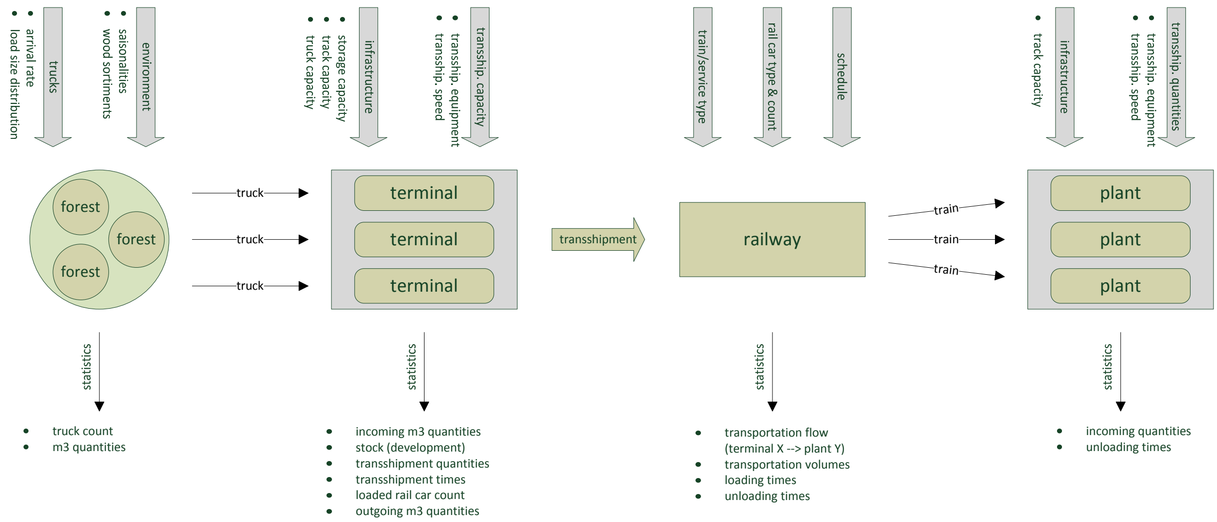

Figure 2: model components and input/output relations

(1) Forest and precarriage module

This module constitutes the starting point of the model. Its main purposes are to generate the wood supply and simulate the precarriage of the generated log-entities to its assigned terminal. All log-entities that have to be handled in the wood supply chain are generated here. Consequently all external effects that affect the wood supply and their stochastic behavior are implemented in this part of the model. These effects represent environmental impacts on the wood supply and include seasonality and weather conditions that influence the accessibility of the forest sites which serve as source for the log-entities. On creation of the log-entities, the forest module also assesses the assortment of the generated entity. The approach for the log generation works in that way, that it does not create single logs, but truckload sized batches of coherent log assortments. The batch size is determined by a truck load generator function that applies a triangular distribution to generate truck load sizes corresponding to realistic truck loads in the setting of Austrian forestry.

So the output of the forest module are log trucks that carry logs of one assortment and are associated with a certain departure time and a stochastic travel time to the terminal. Since we assume that no truck arrives at a terminal outside of its hours of operation, the arrival rate of the log creation process is set to zero if the truck leaving the forest can't reach the destination terminal within the opening hours.

(2) Terminal module

The terminal module contains all processes that take place in the terminal and therefore includes all multimodal interactions between trucks and railcars. The main functions of the terminal module are the unloading the incoming log trucks, if necessary storage of logs at the terminal and the loading of the outgoing railcars. Every terminal module has a respective forest/precarriage module assigned.

The model considers two types of wood terminals and consequently includes two types of terminal modules. While type A represents the most common type of wood terminals in Austria and the according synchronous multimodal loading processes we model asynchronous loading with shuttle train traffic as terminal type B.

Type A:

In terminal modules of type A we modeled Terminals that are used for synchronous multimodal transshipment for single wagon traffic as it is common practice in Austrian wood supply chains.

The processes in the terminal module are designed as follows. When a log truck from the assigned forest module arrives at the terminal, first it is checked if the truck can enter the terminal or the transshipment area respectively. Since most current terminals are quite small and don't have a lot of space it can be impossible for a truck to enter a terminal when there are a couple of other trucks unloading or waiting to unload. So if a truck can't enter a terminal or estimates the waiting time too long to wait it leaves and tries again at a later time.

In case no waiting is necessary the truck enters and starts to transship the logs to the wagons provided by the railway network. Since we included a uniform distributed probability that the required wagons for the transshipment are not provided on time there is a chance that the truck has to put the logs into interim storage at the terminal area. In this case the truck unloads, leaves the terminal and returns again after a stochastic generated period of time to load the previously stocked logs onto the wagons, if now provided. The loaded wagons are then dispatched by train at the next scheduled time of service for single wagon traffic and therefore are passed from the terminal to the railway network within the simulation model.

Type B:

In contrast to type A, terminal type B is served by shuttle trains rather than single wagon traffic and therefore also has to allow for asynchronous transshipment of the round wood. Hence we modeled the layout of a type B terminal as shown in Figure **3**. Next to the traffic lane for the trucks there are loading boxes arranged (T-section shaped storage racks made of steel) that can hold the amount of round wood necessary to fill a block train. In the adjacent area between the loading box lane and the exiting traffic lane there is additional storage space for storing logs that exceed the capacity of the loading boxes.

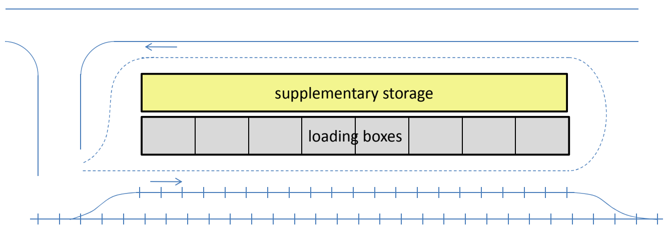

Figure 3: layout of type B terminals

The arrival and potential impossibility of entering the terminal because of too many trucks inside is modeled as in the type A module.

When a truck enters the terminal it drives to an empty loading box and unloads the logs into it. In case another truck is unloading at the same time and therefore is blocking the traffic lane, the incoming truck has to use an empty box rear to the truck already standing in the lane so it can be reached without passing the blocking truck. If that is not possible because all the reachable boxes are full the truck has to wait until the other, already unloading, truck is done and the traffic lane is cleared.

The terminal is served by shuttle trains that arrive and depart according to a fixed schedule specified in the railway network.

While the shuttle train is waiting at the siding track of the terminal, its wagons are loaded with the logs of the wood assortment assigned to this shuttle train. Which assortment has to be loaded is determined by the industrial site the shuttle train is headed for (saw logs for sawmills, pulpwood for paper mills, dummy assortment for external destinations outside of the modeled network).

For the process of loading the train, wheel loaders or log trucks with cranes are present at the terminal to load the wood from the loading boxes to the railway wagons. The loading time is modeled by a stochastic probability distribution dependent on equipment used for the transshipment.

In order to show how the entity flow is modeled, in Figure **4** a fraction of a terminal module is depicted. The grey box in the upper left corner is the connection of the module to the rest of the simulation model. Via the left and the right nodes in the box, the train entity enters, respectively departs the terminal module, whereas the log truck entity is passed on to the terminal by the bottom node. The entering truck goes to the "queueEntry" where the check if the truck can enter the terminal or has to wait is conducted. Subsequently, the truck either waits, leaves to returns at a later point in time (executed by the processes in the lower white box) or continues to the actual terminal and is set up for the transshipment process at "setupTruck". This is followed by the check whether the truck can access an available loading box or is blocked by another truck in the traffic lane and has to wait until this truck is finished unloading (processes in the upper left box). Providing that the truck is not blocked it proceeds to a loading box, unloads the logs and leaves the terminal. During the unloading process the truck entity is separated from the carried wood which subsequently is splitted into flow units each representing one solid cubic meters of a specific wood assortment.

In case a shuttle train with empty wagons is currently present at the siding track when the truck is at the terminal and the wood assortment the truck carries matches the assortment assigned to the train, the truck transships directly to the a wagon of the shuttle train. These processes are performed in the upper right white box together with other areas of the terminal module that are not shown for reasons of clarity.

(3) Railway network.

The terminal and plant modules are embedded in the railway network which generates trains and controls the routing between the particular terminals and plants according to schedule. When a train arrives at a specific terminal or plant, it is forwarded to the corresponding module and passed back to the railway network after finishing operations at the terminal or plant module.

The railway network also controls all railway related parameters like number of trains in the network, number of railcars per train, the wood assortment the train is going to pick up at a terminal depending on the plant it is routed to next and travel times.

(4)Plant module

Since our study focuses on the processes at the terminals and the rail based shipping, there is not much emphasis on an extensive modeling of an entire industrial site. So the focal point of the plant module is the siding track of the facility. Therefore we model the arrival and departure of the trains as well as the unloading of the logs and the log storage at the facility. The unloading speed and the storage capacity are being controlled by parameters representing the transshipping equipment and the storage area available at the modeled industrial site.

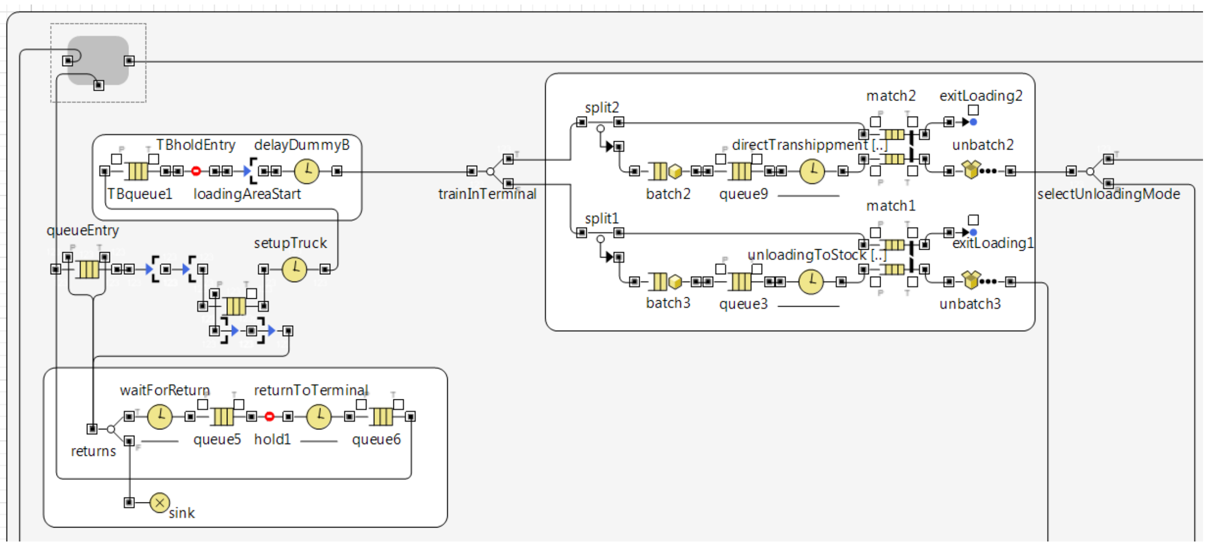

Figure 4: example for the modeling of the entity flow within a terminal module

Beyond that, the plant modules merely serve as sink for the modeled flow entities i.e. the logs. So we don't simulate the log processing at the plants. Nevertheless we included an aggregated manufacturing process, so when the parameters of the throughput of logs per unit of time at the facility are known it is possible to monitor the inventory and determine shortages of wood supply or a lack of size of the available storage area.

3.2. Simulation Study

In our case study for analyzing the competitiveness of the wood terminal network we consider four wood terminals and four production sites of the wood processing industry, specifically two saw mills and two paper mills. We deliberately consider different types of processing plants since it makes sense for wood processing companies to cooperate with each other in the area of raw material procurement (Zazgornik et al 2012). The overall procurement cooperation is realized via common buying agents.

3.2.1. Data basis and model parameters

The data we use were gathered from three sources. The quantity of logs that is handled at the terminals was provided by the operating railway company whereas the data about the quantity of wood supply that is delivered to the considered wood processing plants was provided by the buying agent of the plant operators. The information, regarding the infrastructure at the terminals as well as the processes that take place during terminal operations where either collected on site or also provided by the operating railway company.

For the parameterization of the simulation model we made following assumptions:

- There are three types of logs in our model. Two types correspond to the different wood assortments that are processed in the industrial sites. Those two types are saw logs, which have to be transported to one of the two sawmills in the model and pulpwood which is bound for one of the paper mills.
- Additionally we introduce a third assortment that doesn't represent an actual type of wood, but is a dummy assortment for logs which are assigned to demand outside of our considered supply network. These logs are transshipped in the terminals of our system but are not transported to one of the modeled industrial sites. Therefor they occupy resources at the terminals, but not in the railway network or the wood processing plants.
- In case a log truck can't enter a terminal to deliver the logs because the terminal has reached its maximum capacity, either in terms of trucks inside the terminal or in terms of storage capacity, it will wait outside the terminal for some time. This is only possible if there are not so many trucks waiting that the public street gets blocked. If the truck still can't enter the terminal after this waiting period, it leaves and comes back once after a time span which is determined by a triangular probability distribution. Is the terminal blocked again on return, the log truck will leave and deliver the logs directly to the industrial site the logs are bound for.
- Shuttle trains have fixed arrival and departure times at the terminals. Since railway

companies have to reserve the rail tracks on the whole route well in advance for a specific time window it is not possible to adjust the waiting time to the actual loading time. Therefore in the simulation it can happen, that the train is either waiting at the terminal for some time even if the loading process is already completed. The other way round if the transshipment capacity at a terminal is not sufficient it is also possible that the train has to depart before all logs could have been transshipped.

3.2.2. Scenario generation

The simulation model is used to analyze several scenarios in order to evaluate the network capacity of the supply chain under various configurations. For the definition of the different scenarios used for the numerical experiments we first identify four dimensions that influence the performance of the modeled supply chain. These dimensions are the quantity of wood that has to run through the network (volume dimension), the infrastructural dimension (available storage space, length of rail tracks and hence the maximum number of wagons at a terminal), the transshipment dimension (quantity and type of transshipment equipment) and the train concept dimension (type of railway production system). For every dimension we then define a number of one dimensional scenarios where only the parameters of this dimension are changed. This leads to following scenario types:

- Base scenario (current "real world" infrastructure and volumes).
- Volume scenarios (volume dimension).
- Infrastructure scenarios (infrastructural dimension).
- Storage capacity scenarios.
- Rail track scenarios.
- Transshipment scenarios (transshipment dimension).
- Train concept scenarios (train concept dimension).

Finally, for the scenarios that are used in the simulation runs of the numerical experiments, multidimensional scenarios are derived by combining different variations of the one dimensional scenarios.

We start our analysis with a base-scenario where the configuration of the model represents the actual state of the network i.e. the actual infrastructure at the terminals and run through the defined volume scenarios with this configuration. The results of this simulation runs provide the basis for measuring the effects of infrastructural changes considered in the later scenarios. The further scenario plan is not fixed in advanced but developed in a recurring iterative process of scenario selection, simulation run and performance evaluation. This cycle is illustrated in Figure **5**.

So after every simulation run the results are analyzed with respect to the performance of the network and the terminals and the next scenario is picked accordingly.

This is done to avoid the simulation of scenarios that are already known to provide no further information, based on the evaluation of the outcome of previously simulated scenarios.

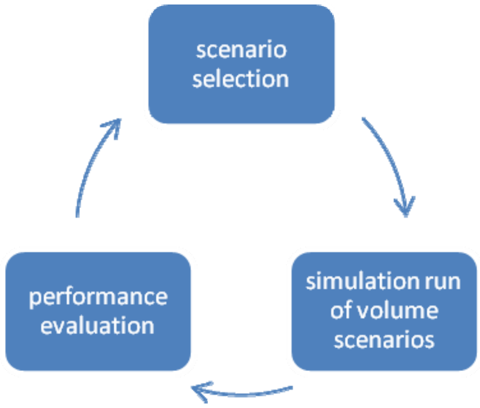

Figure 5: scenario plan definition process

Based on the "real world" transportation volume data the volume scenarios range from -20% to +320% of the actual quantities that where supplied by the analyzed network.

The infrastructural scenarios consist of different capacities of the storage space for logs and different railway track lengths at the terminals. In the transshipment scenarios different transshipment capacities are defined in dependence of the used equipment at the terminals. Finally, the train concept scenarios define different approaches regarding the rail concept and the frequency of the train schedule. The parameter for the simulation scenarios are listed in Table 1.

supplied wood	infrastructure	transshipment	train concept
actual volumes	current infrastructure	synchronous	single wagon
- 20%	upgrade 1	log truck	block train - 48h
- 10%	upgrade 2	log truck - variation	block train - 24h
+ 10%	target volume coverage	wheel loader	2 block trains
+ 20%			
+ 40%			
+ 80%			
+ 160%			
+ 320%			

Table 1 : parameter for simulation scenarios

4. NUMERICAL EXPERIMENTS AND RESULTS

In order to be able to evaluate the performance of the supply chain setting, we identify all relevant performance measures and collect all required data and statistics during the course of a simulation run. 2 lists the selected scenarios and the most important results.

The performance of the supply chain is evaluated primarily based on the throughput of the terminal network. Throughput here is defined as the percentage of generated wood volumes that can be handled by the terminal network. Correspondingly the dismissed volume is the quantity of wood that cannot be delivered via a terminal but has to be brought to the industrial site by truck because of a lack of capacity at a terminal or in the railway network.

Base-scenario

As mentioned before, the base-scenario represents the current "real world" state of the analyzed supply chain network which is composed of four terminals and four industrial sites, more specifically two saw mills and two paper mills, with the actual infrastructure and equipment.

The volume scenarios for the basic network configuration show, that volumes up to 180% of the initial quantity can be handled quite well. Just 3% of the generated wood cannot be covered by the terminal network but have to be delivered to the industrial sites by truck. Beyond the 180% the network gets noticeable overstressed.

An important foundation for the evaluation of a new supply chain concept is the finding under which configuration the same volumes of wood can be handled as in the standard concept. Simulating the same volume scenarios with the new terminal concept of asynchronous transshipment and a shuttle train service (terminal module type B) instead of synchronous transshipment an single wagon traffic (terminal module type A) in scenario 1 shows that the base volume as well as an increase by 10% can be handled quite well (98.2% and 97% throughput respectively). But with further increasing volumes, the throughput drops significantly. The higher throughput at increased volumes in the base scenario can be explained with the higher frequency of service with single wagon traffic (30 times a week in the base scenario in comparison to 14 times a week in scenario 1).

So the base volume can be handled at less effort in terms of train service with the new supply chain concept. This is also evident when looking at the average train load, which rises from 98 solid cubic meters of wood in the base scenario to 214 in scenario 1. The following scenarios analyze at what configuration higher volumes can be handled by new supply chain concept too.

Covering 180% of the base volume.

Deploying a second shuttle train in the network (scenario 2) results in a significant higher throughput than without any infrastructural modifications. The limit for an effective network operation is now at 180% of the initial volume like in the base-scenario and the development of the throughput over the volume scenarios is now very similar to the one in the base scenario. Whereas the number of performed train services is still lower (23 vs. 30).

Covering 320% of the base volume

Another interesting question is where the limits of the new supply chain concepts in terms of the handled volume are with adapted infrastructure. In scenario 3 the rail track and storage capacities at the bottlenecks are increased. This leads to an acceptable throughput of 98.2% at the 260% volume scenario, compared to a throughput of 88% in the base scenario and scenario 2. However, the network is still not very effective at 320% of the base volume (93% throughput). The throughput also hardly improves with further increases in rail track and storage capacities. This is due to the fact, that at this

		base-scenario			scenario 1			scenario 2			scenario 3		
m²-volumes	scenario	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)
80%	S1	11	0,998	78,18	6	0,991	173,82	3	0,996	110,32			
90%	S2	68	0,998	89,38	60	0,990	194,88	12	0,996	122,12			
100%	S3	120	0,997	97,63	902	0,982	213,52	33	0,995	136,21			
110%	S4	197	0,997	106,88	3.219	0,969	229,52	74	0,995	146,96			
120%	S5	410	0,996	115,85	10.191	0,928	237,69	117	0,995	159,45			
140%	S6	1.491	0,991	135,23	28.552	0,849	253,47	578	0,993	183,60			
180%	S7	7.542	0,970	169,88	71.979	0,723	276,35	5.636	0,975	231,01			
260%	S8	47.589	0,878	222,42	159.871	0,584	319,81	46.520	0,876	299,45	5.260	0,982	334,39
320%	S9	94.332	0,803	248,87	231.665	0,516	348,69	109.219	0,772	325,73	31.711	0,930	390,33
train concept		single wagon traffic			1 shuttle train			2 shuttle trains			2 shuttle trains		
capacity increase of infastructure		terminal	track	storage	terminal	track	storage	terminal	track	storage	terminal	track	storage
		T1			T1			T1			T1		
		T2			T2			T2			T2	+1	+40%
		T3			T3			T3			T3	+3	+20%
		TSQ1			TSQ1			TSQ1			TSQ1		

		scenario 4			scenario 5			scenario 6			scenario 7		
m²-volumes	scenario	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)
140%	S6				0	0,995	156,09						
180%	S7	473	0,994	237,09	1.907	0,986	197,96						
260%	S8	3.585	0,987	337,09	41.549	0,867	248,57	0	0,995	285,82	0	0,995	285,52
320%	S9	22.018	0,952	399,03	96.720	0,757	265,66	3.317	0,985	346,85	169	0,994	349,19
train concept		2 shuttle trains			2 shuttle trains			2 shuttle trains			2 shuttle trains		
capacity increase of infastructure		terminal	track	storage	terminal	track	storage	terminal	track	storage	terminal	track	storage
		T1			T1			T1			T1		
		T2	+3		T2			T2	+2	+40%	T2	+3	+20%
		T3	+6		T3			T3	+5	+20%	T3	+6	+20%
		TSQ1			TSQ1			TSQ1			TSQ1		
					no truck blocking			no truck blocking			no truck blocking		

Table 2: simulation results

high volumes trucks are unloading at the terminals very frequently and therefore also block each other more often. So in scenarios 5 to 7 we assume that the terminals are designed in a way that an unloading truck doesn't block the traffic lane. Now with the same parameters as in scenario 3 and a slightly increased rail track capacity, a throughput of 98.5% can be achieved at 320% of the base volume handled by the supply chain network.

The results of the numerical experiments show that the proposed train concept of asynchronous transshipment and shuttle trains connecting terminals and industrial sites instead of single wagon traffic combined with adaptations in the infrastructure at the terminals can increase the network capacity significantly.

The simulation study also indicates that it is important to increase railway track and storage capacities in a way so that they match each other. An enlarged storage doesn't have much of a positive effect if the rail tracks limit the throughput too much and therefore just cause non-productive expenses. On the other side can a storage that is too small not provide the required buffer function in order to maximize the effectiveness of the given railway tracks, hence network capacity is lost.

An interesting finding is that the redesign of terminals in a way so trucks don't block each other while unloading can boost the throughput at terminals with high utilization even with unchanged infrastructure.

ACKNOWLEDGMENTS
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INTELLIGENT TRANSPORTATION SYSTEM TO ENHANCE THE SUSTAINABILITY OF THE AIR FREIGHT TRANSPORT

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ABSTRACT
When addressing the transport problem in isolation from production, the object is to obtain the lowest total cost of transport. Thinking the production and the distribution as a linked system, the optimisation goal should balance between production and transport costs, considering the minimization of the total distribution cost (TDC) instead of considering only the minimization of the transport costs.
In this paper it is presented the commercialization of passenger airline bellies for freight transport purposes under a business model approach.

Keywords: freight transport booking, turnaround, business model, air transport logistics.

1. INTRODUCTION

From the logistic point of view, Industry is trying to devise a goods creation and distribution system that creates greater value than its costs. Improvements in the efficiency of the global supply chain are essential to increase the overall levels of demand for Just-In Time (JIT) logistics services. Costs related to inventory (ie. depreciation, spoilage, obsolescence, good insurances, bay hiring cost, etc) plays an important role when designing the supply chain architecture.

Air cargo is an important sector of the airline industry. Cargo can be carried in cargo holds of passenger airlines or on aircraft designed exclusively to carry freight. Cargo carriers in this industry do not provide door-to-door service. Instead, they provide only air transport from an airport near the cargo's origin to an airport near the cargo's destination. Companies that provide door-to-door delivery of parcels either across town or across the continent are classified in the couriers and messengers industry, and are known as integrators.

Cargo airlines can provide a critical link in any supply chain consortium to reduce stocks while reducing transport times, supporting different type operations "hub and spoke" or providing ad hoc transportation of freight from point to point.

Cost of transport usually is split into two parts:

- Direct Operating Cost: Fuel, crew, vehicle depreciation, maintenance, etc.
- Indirect Operating Cost: sales, cargo handling, administration, profit, etc.

With regards to direct operating cost, it is easy to see that ship transport is much less expensive than airplane transport, however for the indirect operating cost, there are several aspects related to cargo handling, such as ship mechanized loading and large containers versus some manual air load and balancing operations that nowadays increases the air cargo transport cost and time, but that in a near future "low cost cargo airline" could tackle in a more efficient way without affecting safety aspects.

Traditional air cargo business must deal with strategic, tactical and operational changes in order to give a proper answer to the growing air cargo expectations. Too many trouble spots should be re-designed not considering only logistic at operational level but also the proper planning of infrastructures in which the non-added-value operations could be removed or minimized.

Since a structural change is inevitable for a competitive, reliable and low cost air cargo it is important to evaluate the different emerging scenarios from a sustainability perspective instead of only considering economical or operational aspects.

Based on a deep analysis of Intelligent Transportation Systems (ITS) tools in the air cargo sector, developed in the European FP7 T-Trans project, in this paper it is presented the development of a technology commercialization model for the use of passenger aircraft bellies to satisfy cargo industrial purposes, considering the sustainability aspects of the ITS applications.

Due to the huge number of resources and operators that should be properly coordinated, a system engineering approach would help to design a methodology focussed on process simplification, verification and audit, while also meeting increasing security demands. This new methodology should tackle air cargo agility, flexibility & adaptability, plus visibility from an integrated perspective considering always the cost and yield aspects of any decision.

Section 2 presents the main components to be considered in the FTB system, while section 3 summarizes the identifier enablers of the business model.

2. SYSTEM DESCRIPTION

One of the main difficulties to deal with a competitive and cost effective air transport system rely ion the proper coordination of the different actors, considering the available transport and handling capacities together with the different technologies and procedures through which goods should flow. In this section it is described the main components to be considered.

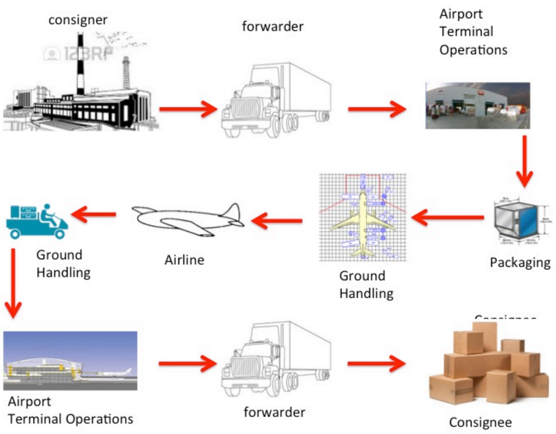

Figure 1: Aircargo supply chain

In Figure 1 it is summarized the main actors through which the cargo flows, while in Figure 2 the technologies required for seat booking are highlighted, most of which should be adapted for freight belly booking.

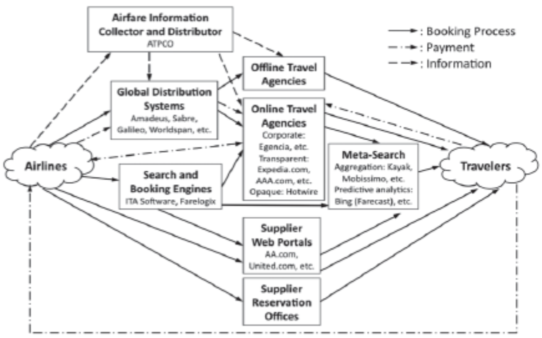

Figure 2: Travel Distribution value (Granados et al., 2011)

2.1. Actors

To deal with a sustainable approach to the use of passenger aircraft bellies it is essential to understand the role and functionalities of the different actors handling the freight in order to remove the non-added-value operations and understanding the value change.

Consigner is the person or company that is physically and administratively responsible for shipping the goods. Consigners can either directly contact the Air Cargo Carrier either can pass through a third party provider, e.g. the Freight Forwarder. The Air Cargo Carrier who is providing to both the service plays the central role.

Passenger/Cargo Airlines have contracts with passenger airlines that allow them to ship items via passenger service. Passenger flights have such high frequencies they can offer shipping rates that are competitive to the cargo only airlines. Many may be surprised to find out that even if everyone on board their airplane checked a bag, there would still be a large amount of space in the baggage compartment left unused. That's where cargo makes the airline some extra money. Standard aircraft almost always carry some cargo in the baggage hold - in the aircraft belly. These companies operate passenger services and cargo services simultaneously. These airlines can combine the advantages of destinations and frequencies supplied by passenger services with the benefits of power and specialization of cargo network.

Freight Forwarders are persons or companies that organizes shipments for individuals or to get goods from the producer to a market, customer or final point of distribution acting therefore as an expert in supply chain management. Freight forwarders arrange the best means of transport, taking into account the type of goods and the customers' delivery requirements. They use the services of shipping lines, airlines and road and rail freight operators. In some cases, the freight forwarding company itself provides the service. A distinction can be made between Forwarder out (expeditor) and forwarder in. The expeditor operates by buying space at the airline's sales or customer service department, or in case of a foreign airline, to the General Sales Agent. The Forwarder in manages the shipment from its arrival at the airport up to the delivery to the final customer or consignee.

Airport Terminal Operator: it provides the required infrastructure to receive the freight form the land side, inspect and pack in ULD's and send to the air side, and also receive freight from the air side, unpack and forward to the land side after the required administrative processes.

Ground Handling: It is a company, which provides all the services required by the aircraft while it is in the ground for the next fly. Speed, efficiency, and accuracy are important in ground handling services in order to minimize the turnaround time (the time during which the aircraft must remain parked at the gate).

Consignee: is the person or company that is physically and administratively responsible for receiving the goods.

2.2. Technologies

In order to evaluate the sustainability of a Freight Transport Booking (FTB) system, it is of outmost importance to understand how the booking is performed within the air passenger segment and to establish similarities and differences between air passenger and air cargo segment. It is worthwhile to note that the core technologies in which FTB applications rely on are at a maturity level.

ISP: Internet Service Providers, referring to the companies that provide internet services to large companies, providing a direct connection from the company's networks to the Internet.

IBE: Internet booking engines are applications that help travel and tourism industry support reservation through the Internet. By installing them in the home page of an airline, they enable easy access for customers. Once customers enter their travel preferences, the IBE contacts the GDS or CRS to receive the relevant information but displaying it in an appropriate and user friendly interface. With the growing online travel booking, companies developing and integrating online booking engines have multiplied.

Data management platforms are the back-bone of data-driven marketing, serving as unifying platforms to collect, organize, and activate first and third party audience data from any source, including online, offline and mobile. A Data Management platform should collect unstructured data from any source, including mobile web and app, web analytic tools, CRM, and points of sale.

PSP: E-commerce and payment service providers are companies specialized in offering webshops online services for accepting electronic payments by a variety of payment methods. A PSP manages the technical connections to multiple acquiring banks, card and payment networks, offering also risk management services.

GDSs: Global Distribution Systems are the link between travel agents and airlines in the passenger sector. In particular, in the cargo context, capacity exchanges are implemented in the form of an electronic cargo-booking system, allowing a forwarder to see the schedules, available capacities, and prices of all airlines serving a particular route, and to make the best selection for its customers (Schwarz, 2006). There are a set of available tools owned by different providers of e-freight business solutions for air cargo, which implement separately the steps for booking (see for example (www.calogi.com).

GSSA: General Sales and Service Agency provides a valuable role in assisting Airline to achieve a cost-effective presence in a market where it may be uneconomical for an airline to maintain its own sales force and premises. The GSSA works on behalf of their Airline Principals providing the freight forwarding community with the full range of cargo services within the specified territory .

2.3. Processes

Among the different process that could affect drastically the implementation of the FTB there 2 processes which requires a deep understanding of the FTB dynamics to avoid over costs and poor competitivity:

Fast turnaround times. A crucial issue for the successful exploitation of such a large unused belly capacities is the possibility for airlines to maintain their current turnaround times, and then the high aircraft utilization rate. This is mostly true for low cost airlines that show very fast turnaround times (25 minutes for Ryanair) and then cannot afford disruptions due to the cargo operations, such as the processing of the appropriate cargo papers. Hence the capability of handling paperless documentation is a key enabler for the actual implementation of transporting cargo in passenger flight bellies, in particular e-Air Waybill (e-AWB). The Air Waybill (AWB) is a critical air cargo document that constitutes the contract of carriage between the "shipper" (forwarder) and the "carrier" (airline). e-AWB removes the requirement for a paper AWB, significantly simplifying the air freight supply chain process. IATA's target is 100% penetration for e-AWB shipments by 2015.

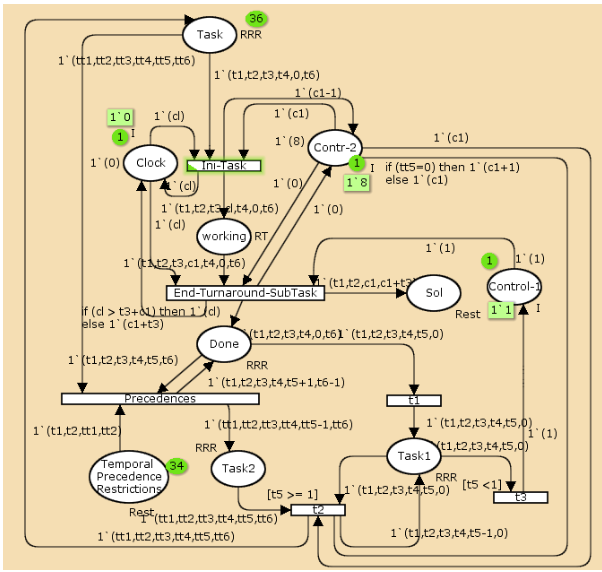

Figure 3 Turnaround CPN model

Clearly, optimised ground holding operations (such as cargo loading/unloading to/from the aircraft belly) are also mandatory to maintain fast turnaround times. In (Fernandez, 2014) it is presented the use of a CPN model (see Figure 3) to analyse the different interdependencies which affects the turnaround process, with special attention to introduce ULD palletized freight tasks designing also mitigation mechanisms to the propagation of disturbances between freight, passenger and aircraft tasks.

In Figure 4 it is represented the critical path of a turnaround obtained with the CPN developed, in which some delays appeared in de-boarding and in the catering tasks

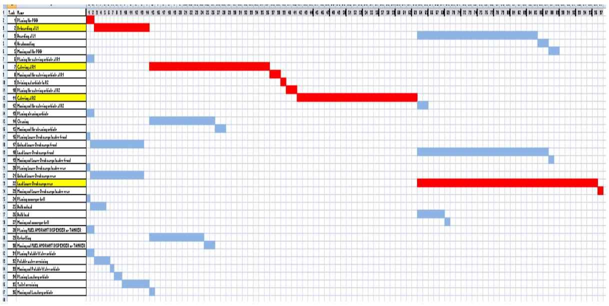

Figure 4: Critical path of the turnaround process considering delays

Revenue Management: to increase an airline's profitability based on customer insight. The RM techniques applied to the commercialization of the bellies should consider:

- *Capacity Forecasting (CF)* – evaluation of the space available on future flights
- *Demand Forecasting (DF)* - aims at estimating how much cargo will tender for a particular flight
- *Overbooking* - the practice of selling more cargo space than what is physically available, in order to compensate for no-shows, cancellations or variable tendering
- *Capacity Management (CM)* - deals with how to optimally allocate the booking requests in the forecasted cargo capacity for a particular flight
- *Allotment Management (long-term sale)* – deals with a long-term agreements (typically 6-12 months) between a freight forwarder and an airline
- *Free Sale Space Management (short-term sale)* – deals with decision of selling the capacity when a request comes in, or to save it for a potential later sale at a higher price
- *Routing Optimisation* – supports the decision about delivery route of the cargo from origin to destination
- *Freight Transport Booking* – reservation of space by customer and payment of transportation fee
- *Freight Tracking* - allows a customer (and the airline) to know in real time the (approximate) location of a shipment

2.4. Present Shortages

Despite most technologies for FTB are at a mature stage, there are some aspects which should be properly considered for the sustainability of the freight transport in the passenger airline bellies:

- Product capacity definition: In passenger each entity is well-defined: a passenger. In cargo, each item is more complex: length, width, and weight define each entity, and the most constrained resource between volume and weight should be considered to predict the "rest capacity".
- Booking time-frame: short term booking is highly dependent on medium-term allocations. Allocations in pure cargo airlines are sold usually twice per year in which customer agreements are issued to guarantee capacity on specific flight/weekday. The cargo delivered by customers every week usually fluctuates with respect to the agreement signed.
- Booking process is subject to considerable volatility: The kilograms and cubic metres of cargo demand often depend on extraneous factors that make demand more difficult to anticipate. As example, consider industrial freight forwarders do not know what shipments they will consolidate until the last minute, usually shippers may only know the approximate size of their shipments at time of booking since the task of accurately estimating weight, volume and density is not always feasible.
- Forecast Demand Models for short term booking are unviable since the time efficiency inherent to air cargo transport usually is required by manufacturers to overcome unpredicted inventory shortages or demand fluctuations (ie. stochastic events).
- It is very difficult to compare fares among different carriers. Most airlines allow registered users only to check on the internet prices and associated service conditions. And, to the best of our knowledge, there are not websites, such as Expedia or Travelocity for passengers, simultaneously showing several options from different airlines for a given shipment.
- Business models incompatibilities: Air cargo carriers are subordinated to the passenger marketing requirements, which unable cargo requirements to influence on schedules, frequency, destinations and equipment. Cargo capacity at departure is often the leftover space in aircraft bellies after passenger baggage loading.
- Hidden Logistic Costs: The cost of the full cargo chain cannot be easily modelled due to the diversity of intermediate agents and operations that must be coordinated from the shipper location until the destination customer, which usually can require different van-truck transport agents, more than four warehouse operations and different cargo packing and consolidation tasks.
- Aeronautical taxes: The major part of aerial cargo within Europe is transported by feeding surface

service (RFS or also known as the aerial truck). The truck shipments are done with the code IATA (International Air Transport Association) reflected on the air waybill including the company and flight number detailing the operation was carried out by RFS. Airlines usually opt for this service to connect major European airports, used as hub airports, with secondary airports to power and operate the first flight with a greater load factor.
- Bureaucracy: According to IATA, every air cargo shipment carries up to 30 paper documents. With this volume of documents could fill eight Boeing 747 aircraft each year. This entails an increase administrative burden of waiting time and therefore a higher total transportation time. This extra time results in additional costs to the actors as they must maintain a safety stock in the supplier chain.
- Lack of operational flexibility due to an undesirable interaction between documentation flow and physical flow: The documentary portfolio (ie. documentation required by the destination airport, customs, transportation companies, etc.) is prepared in the airport cargo terminal once one knows exactly the goods that can be transported on a particular flight. During the belly loading operation it is not possible manage the cargo containers by removing a small part of the weight due mainly that the full documentation should be prepared again in the cargo terminal.

3. BUSINESS MODEL

A business model is a formal description of an opportunity that incorporates four elements: the product or service being offered, the customer definition, the value proposition (the benefits to the customer), and the means by which the benefits will be delivered to the customer (the distribution channel).

Among the main difficulties in the past to enhance the use of belly cargo of short and medium range passenger aircraft against dedicated freighter was mainly because freight operations use to be secondary to the passenger business in some airlines with potential penalties slowing turnaround times for example and because on some routes, demand for air cargo transportation far exceeds belly capacity: for example belly space alone is far from being able to cope with the demand.

Once at this point in which aircraft companies are introducing extra capacity for passenger bellies, airlines are looking for new incomes to compete with the increment of fuel prices and other taxes, and production industries and wholesalers are always trying to reduce stocks through faster and cheaper transport means for replacement, it seems obvious that a new website platform that could fit the cargo transport demand from one side into the passenger bellies, would provide a challenging and competitive solution to present transportation market.

Regarding the extra cost of flying with freight, it has been estimated by means of BADA model and also from empirical data that the extra fuel per each Tone of cargo use to affect in an increment of 4% of kerosene for a short/medium range route. Thus, the transport of 2 Tones would affect only on 80 Kg of kerosene. It can be assumed no extra cost regarding Airport fees and ATC fees meanwhile the aircraft do not exceed the MTOW (maximum take off weight) declared, which is independent of the freight transported in each particular flight. Handling costs are not considered since some companies have a flat rate independently of the amount of ULD to be managed.

A macro approach to the cost of freight transport by trucks is estimated by:

Total Cost Truck= distance* road price (0.69 €/Km) * ULD
Total Time = International transport (3 days aprox)

The freight transport cost considering the use of passenger airline bellies is estimated by:

Total Cost = (distance to airport (0.69 €/Km) * ULD) + Belly Cost + (distance from airport to destiny (0.69 €/Km) * ULD)
Total Time = maximum 1 day

Despite different scenarios could be considered, just a rough comparative considering the shipper and the consignee close to the origin and destination airport would provide a difference of transportation costs for a 1000 km distance around 600 € per ton.

By considering that all key technologies for develop a FTB in the air sector are nowadays in a mature stage, and the competitive trade-off between time and cost estimated,, the main break-even risk is the critical mass of commercial passenger airline bellies that could satisfy not only the predicted demand to each particular destination, but also an extra capacity at zero cost to support problems related to late shipments and off-loads.

In order to enhance the use of passenger airline bellies and increase the frequency of flights to the freight destination, a strategic model analysing the hinterland characteristics of the airports is proposed. An analysis at macro level of the different routes to satisfy the freight demand will provide a picture of those airports which tends to run short of bellies for freight, those airports which tends to offer more bellies than, together with its relationship with the hinterland characteristics, with special emphasis about the different airports from which freight could be send or received. Note that freight forwarders arrange the best means of transport, taking into account the type of goods and the customers' delivery requirements. Thus, they can collect the freight from a warehouse and transport to the more convenient airport by surface transport.

In Figure 5 it has been represented the different combination to transport freight from a consigner to a consignee. A circle is used to represent the hinterland of the different airports, each one with a surface leg with several airports. The blue circle denotes a hinterland with a clear consigner capacity while the green circle denotes a hinterland with a clear consignee capacity, while red and yellow describes hinterland with consigner and consignees. The specific airline, and departure and destination airports are in principle irrelevant to the customer provided that the freight is picked up in O and delivered in D within the agreed time windows.

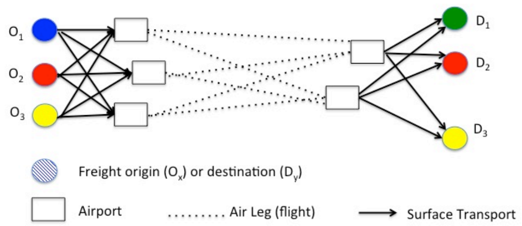

Figure 5: Surface and air leg combinations

The commercialization of a critical mass of passenger airline bellies is one of the main enablers to support air cargo routing optimisation at leg level, segment level, or origin and destination (O/D) level, depending on the structure of the network. Furthermore, an excess of bellies with respect to predicted demand should be the right target of a business model to support over sale (ie. overbooking) which somehow is a mandatory approach to implement revenue management tools and pricing algorithms that could compete with better established transport means such a road surface transport in which freight forwarders are few and they are strongly positioned in the value chain. Note, that an excess of empty bellies do not repercute at all in a negative impact on the sustainability of the business, since bellies are inherent to the commercial passenger airlines.

In the airline industry (e.g., Bell, 2009). there are empirical studies in which it can be observed a trend of convergence of strategies and structures ("business models"), in which a best-practice initiative developed by one airline, is implemented by the rest of airlines in the same sector as a booming effect. Trend convergences have positive effects if it reflects the diffusion of efficient processes and practices among firms. Thus, it can be expected that the right integration of the different DSS used by the FTB actors, and a minimum amount of bellies that could be achieved by the combination of surface and air legs would provide the seed for a sustainable air freight transport system.

CONCLUSIONS

This paper focuses on the advantages of commercializing the passenger airline bellies considering the use of ULD palletized cargo to avoid any extra time in aircraft turnaround process and the airport KPI's.

A review of actors, technologies and procedures to be considered for the FTB has been described, in which it has been identified the critical process, and the technologies which are at mature stage. A business model has been also considered to deal with the critical mass required to overcame present air freight transportation shortages, such as the well known off-load problem.

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DEVELOPMENT OF INTELLIGENT TRANSPORTATION SYSTEM IMPLEMENTATION IMPACT EVALUATION METHODOLOGY: CASE-STUDY OF RIGA

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ABSTRACT

The goal of current paper is to present the results of development of Intelligent Transportation Systems (ITS) implementation impact evaluation methodology, which is based on applying traffic flow simulation approach. The proposed methodology allows to solve vivid problem of making more reliable decisions on introducing ITS solutions into transport system. The proposed methodology was approbated based on Riga (capital of Latvia) case study. The results obtained during approbation allow to conclude that methodology could be used in in real projects related with integrating of new technologies into transport system by decision makers.

Keywords: sustainable development, transport system, simulation model, impact evaluation

1. INTRODUCTION

According to the definition of sustainable development, following general definition could be provided "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The definition underlines that development of the sustainable system is a complex problem which involves many internal and external factors.

For many countries (including Latvia) transport is a key element of the national economics that is why European Commission puts a lot of attention on development of sustainable transport systems. According to document published by European Commission (EC 2011) a modern transport system must meet following 3 requirements: ecological requirements; safety and effectiveness. The report of United Nations department of Economic and Social Affairs (Bongardt et al. 2011) declare that more sustainable transportation system is the system that: 1) allows the basic access and development needs of people to be met safely and promotes equity within and between successive generations; 2) if affordable within the limits imposed by internalization of external costs, operates fairy and efficiently, and fosters a balanced regional development; 3) limits emissions of air pollution and GHGs as well as waste and minimizes the impact on the use of land and the generation of noise (Bongardt et al. 2011). In general all 3 points are reference on social, economic and environmental aspects of transport.

All aspects are important and that is why in order to develop a sustainable transport system a balance between them should be found. A number of sustainable transport system development tools could be mentioned here: use of Intelligent Transportation Systems (ITS); use of P&R (Park and Ride); optimization of existing transport infrastructure; development of intermodality; implementation of new transport infrastructure elements base on strict analysis of development consequences; use of sound tax policy, use of modern technologies; application of more environment friendly technologies etc. The range of tools is wide and varies from political issues (T-TRANS 2013a) to issues related with commercialization of innovative technologies for transport sector (T-TRANS 2013b).

The most perspective and supported by European Commission issue is related with implementation of ITS. According to the definition (Miles and Chen 2004) Intelligent Transport System is integrated application of communications, control and information processing technologies to the transportation system.

ITS development process often faces difficulties. Character of these problems may be financial, technical or political. Nowadays more and more cities are trying to divide risks and financial obligations among government, local administration and stakeholders who are interested in this process. ITS requires large investments in infrastructure, hardware and software and involving the use of fast developing technologies..

Successful ITS deployment requires systematic approach. And in this aspect Public Authorities can create framework according to the national strategy of development, urban planning and according individual ITS applications.

According to the Handbook of ITS there are four key simple rules that can influence on successful project implementation (Miles and Chen 2004):

- ITS should be incorporated into the mainstream transportation planning and investment cycle;
- Use innovative procurement methods in the public sector, involving multiple evaluation criteria to secure best value;
- Project finance needs to be on a whole-life basis, including maintenance and operational costs as well as capital for start-up investment;

- Where appropriate, the private sector can be involved in partnerships and out-sourcing, both for the investment in ITS infrastructure and for ITS operations and delivery of ITS services.

As it was mentioned previously, before starting ITS development process it is necessary to understand regional transportation needs that covers all issues of sustainable development. And when key actors are identified and all priorities and requirements are stated the documentation for the project implementation could be prepared.

The basic cycle for ITS development could be presented in figure 1.

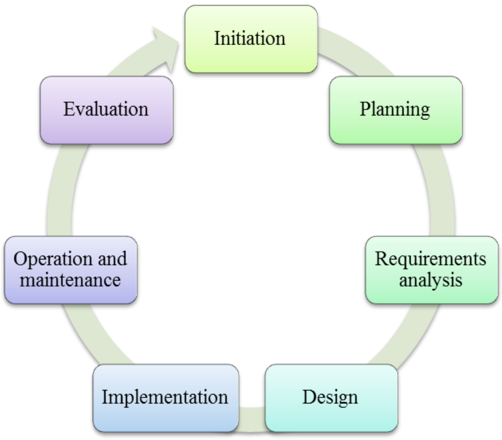

Figure1. ITS Development Cycle

The narrow step in ITS development cycle is an evaluation of the impact on social, economic and environmental issues. As could be seen from figure 1, the usual case is when we do evaluation after implementation. The main problem here is related with post evaluation of the ITS impact. That is why the presented ITS development life cycle must be upgraded with pre-evaluation phase (ex-ante assessment).

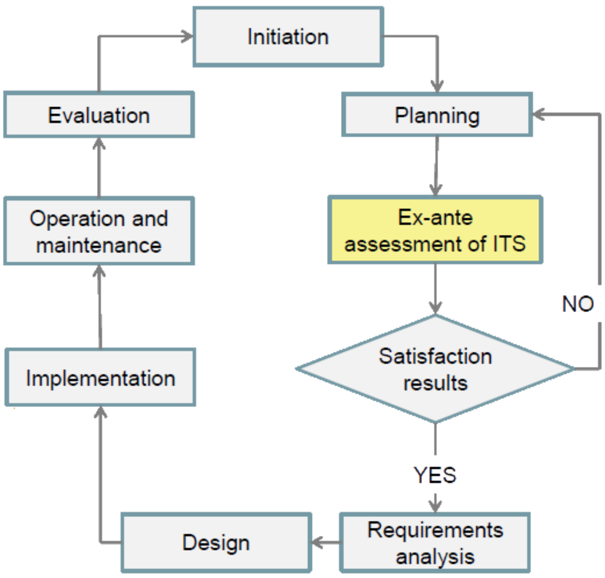

Figure 2: ITS Development Cycle Extended With Ex-ante Assessment

Introduction of ex-ante assessment in ITS development life-cycle allows to support decision makers by quantitative information about impact of the proposed solution (more to say in monetary equivalent). The next chapter is dedicated to the development of the evaluation methodology (ex-ante assessment).

2. DEVELOPMENT OF THE EVALUATION METHODOLOGY

2.1. Review of ITS assessment methodologies

It is obviously, that nowadays when transportation plays one of the leading roles in human life is presented broad and impressive list of different approaches in transportation projects assessment. In transportation field the bulk of assessments appear because of the lack of information for taking reasonable, adequate and suspended decisions. ITS as one of representatives of transportation field projects as well can be assessed using different methods. There are several directions of ITS evaluation: impact assessment, technical assessment, socio-economical evaluation, users acceptance evaluation, financial assessment and market assessment.

During technical assessment we can evaluate system performance and reliability. Technical assessment is realized with different methods, such as: field observation, field trials, pilot tests and other. Impact assessment includes evaluation of safety, transport efficiency, user behavior, modal split etc. Impact assessment as well as technical assessment can be carried out using different methods like before-after observations, field trials and pilot tests, modelling and simulation. User acceptance evaluates users' opinions, their preferences and willingness. Basic methods that are used for this evaluation includes surveys, interviews, questionnaires. After users acceptance evaluation we can distinguish socio-economic evaluation. Socio-economic evaluation allows understanding benefits and costs of system implementation. In the core of this evaluation are laying two basic methods: cost-benefit analysis and multi-criteria analysis. This two methods are quite popular in transportation assessment and will be discussed deeply bellow. Other two assessment approaches are financial assessment and market assessment. Market assessment allows understanding demand and supply, and financial assessment, using different business models, considering investment and risks can evaluate initial and return costs, rate of return, payback period and other essential economic indicators.

Each project has its own characteristics, features and limitations. The use all approaches at once is not necessary to evaluate a project. Selection of few of them which can help to assess exactly what is important to achieve the objectives for which the project was developed. Choosing correct method for evaluation is the first and significant moment for future results of evaluation. Onwards are presented two methods of evaluation that indeed become very popular in transportation projects assessment. Both methods are referred to socio-economic evaluation. Using these methods we can not only evaluate project but as well compare different alternatives in the project.

2.1.1. Cost- Benefit Analysis (CBA)

Cost-Benefit Analysis (CBA) is one of the most popular methods for transportation project evaluation. In 1960 it was first time introduced in transport project in UK. This method involves comparing the total expected cost of each option against the total expected benefits. This is done to see whether the benefits outweigh the costs, and by how much. By decision makers CBA is used for two main purposes: first, is to gain knowledge about return of investment and the second, to provide a basis for comparing projects. In CBA costs and benefits are presented in money terms. Usually this is a complex problem, but CBA use the time value of money in order to do recalculation. So, all flows of benefits and flows of project costs over time, which tend to occur at different points in time, are expressed on a common basis in terms of their net present value (NPV).

For each alternative, a single aggregate measure of economic worth is formed by adding the different impacts, considering benefits as positive and costs as negative, and taking account of the time when these occur. The definition and quantification of benefits and costs depend on the stakeholders for whom the analysis is performed. The alternative with the highest worth is preferred.

The bellow variables are present in CBA and are usually evaluated using market prices, when available (Cascetta 2009):

- **CC** Difference between the construction costs of the project and the costs of construction and other major works (reconstruction, rehabilitation), if any, required for the nonproject alternative.
- **CVT** Difference between investment costs in vehicles and technologies for the project and nonproject situations.
- **CMO** Difference between maintenance and operating costs for the project and nonproject situations.
- **REV** Difference between direct (sale of transportation services) and indirect (commercial activities) revenues in the project and nonproject situations.
- **TR** Difference between government revenues from taxes and duties in the project and non-project situations.
- **DS** Change in transportation system user perceived surplus in the project and nonproject situations, expressed in monetary units. This is typically obtained by adding up the changes in perceived surplus for different user classes
- **UNPB** Change in benefits not perceived by the users between the project and nonproject situations. These benefits might include costs changes due to accidents or vehicle operations (lubricants, tires, etc.). And other non out-ofpocket costs not perceived by the users in their travel-related choices. All these benefits are expressed in monetary units; the variable has a positive sign if there is a reduction in these costs.
- **NUI** Change in the nonuser impacts between the project and nonproject situations. Impacts on the environment (e.g., reduction of pollutant emissions) and on the economy and land use system can be included in this variable after conversion to monetary units. These impacts are sometimes referred to as indirect benefits and are positive if the benefits increase.

It is important to stress that the variables considered and the way they are computed both depend on the viewpoint from which CBA analysis is performed. The evaluation must avoid double counting of an individual project effect by quantifying its impacts with different variables having the same sign (Cascetta 2009).

Several synthetic indicators have been proposed for comparing the time streams of benefits and costs of different projects. The Net Present Value (NPV) is the equivalent value in year 0 of the time stream of annual project costs and benefits. NPV can be calculated using variables described above.

$$NPV_i(r) = \sum_{t=1}^{T} \left(\frac{DS_i^{(t)} + UNPB_i^{(t)} + NUI_i^{(t)} + TR_i^{(t)} + REV_i^{(t)} + CC_i^{(t)} + CVT_i^{(t)} + CMO_i^{(t)}}{(1+r)^t} \right),$$

where:

T – is the number of years included in the time stream;

r – is the applicable discount rate per year.

The Internal Return Rate (IRR) is defined as the value of the discount rate, such that the NPV calculated over a period of *T* years.

2.1.2. Multi-Criteria Analysis (MCA)

Usually in transportation projects decision maker have a lot of goals, and system or application may produce a variety of impact types. Often, goals conflict with each other, for example the maximization of users' surplus might conflict with the reduction of noise and air pollution. That is why good decisions need clear objectives. These objectives should be specific, measurable, agreed, realistic, and time-dependent.

MCA can help to decision makers to answer questions about project impact on different objectives. It is undertaken to make a comparative assessment between projects or heterogeneous measures. In a MCA one does not try to express all effects in one dimension – money. But several dimensions are used at the same time (monetary units, minutes, grams etc.). The overall assessment of a project or the ranking of different projects, using all the criteria, takes place by using criterion weights. MCA establishes preferences between options by reference to an explicit set of objectives that have been identified, and for which performance indicators (that measure the degree to which an objective is attained) have been defined.

To compare the contribution of different options towards given objectives, it is necessary to have criteria that reflect the options' performance in meeting those objectives. In simple situations, the process of identifying and assessing objectives and criteria may alone provide enough information for decision-makers. However, where a level of detail broadly akin to cost-benefit analysis is required, MCA offers a number of ways of aggregating the data on individual criteria to provide indicators of the overall performance of each available option (Communities and local Government 2009).

A key feature of MCA is its emphasis on the judgment of the decision-making team in establishing objectives and criteria, in estimating relative importance weights, and, to some extent, in judging the contribution of each option towards each evaluation criterion. Its foundation, in principle, is the decision maker's own choice of objectives, criteria, weights, and her assessments of the options' performance towards achieving the objectives, although "engineering" data such as times and costs can of course also be incorporated in this process. MCA can bring a degree of structure, analysis, and openness to classes of decisions that lie beyond the practical reach of cost-benefit analysis. In general, a MCA consists of the following main steps presented on the figure 3:

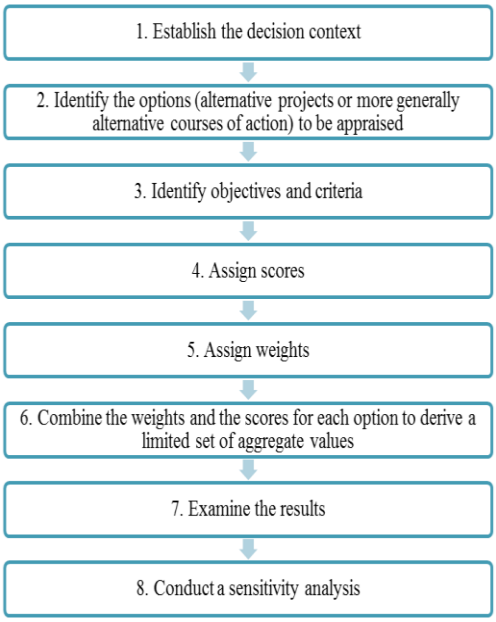

Figure 3. Steps in MCA

In the evaluation field, multi-criteria analysis is usually used as an ex-ante evaluation tool. MCA is particularly used for the examination of the intervention's strategic choices. In ex-post evaluations, multi-criteria analysis can contribute to the evaluation of a programme or a policy through the appraisal of its impacts with regards to several criteria (EU 2014).

In ex-ante or intermediary evaluations MCA can be useful (EU 2014):

- To evaluate the ability of various activities of a programme to fulfil a given objective. This assessment can take place to collect the opinions of decision-makers and beneficiaries about the effectiveness of the activities.
- To structure the views of project or programme managers about on-going activities.
- To discuss the content of the programmes, and the funding of various activities during the drafting of strategies and programmes.

In ex-post evaluations, in beneficiary countries, interventions in fields such as poverty alleviation, maintaining security, immigration control, or trade development can benefit from this type of analysis which formulates judgements on these complex strategies.

2.2. Methodology of ITS implementation impact assessment for Riga

In this subchapter the methodology for ITS impact assessment before the implementation of the real system is proposed.

This methodology can be used as a supporting tool for decision makers and transportation professionals. The methodology is proposed to help to decision maker understand the influence of proposed ITS application before it was implemented in the real transport system.

The methodology is divided into three main parts:

1. Preliminary part (analysis of the transport system for further improvement);
2. Tactical part (conceptual solution identification, impact and measures identification0
3. Main part (assessment based on the simulation).

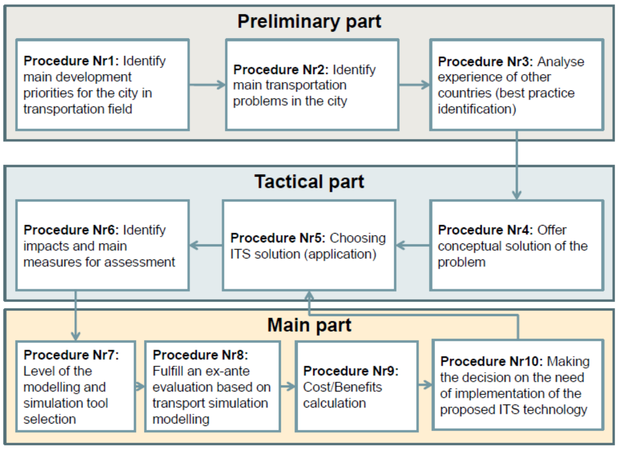

Figure 4: Ex-ante Assessment Methodology

Preliminary part consists from the steps that should be done before real assessment process, like analysis of the transportation system development priorities and problems. On the tactical part should be done the decisions which cover: conceptual solution how the problems can be solved and what technology to choose, as well impact and measures should be identified. Main part of the methodology consists of evaluation steps based on simulation and it gives the understanding of the modelling application for ITS impact assessment. If we distinguish main milestones (Figure 4) the methodology will have 3 steps in the first and in the second part and 4 steps in the main part ending with decision about proposed ITS technology.

Procedure 1: Identify main development priorities for the city in transportation field

The procedure is targeted on clearing the strategic and operational goals of TS development. This could be done by completing following:

- Analysis of different policy documentation. First of all, the documentation of the development of the city as a unified system and particularly transportation system development.
- Defining the main priorities and future trends of transportation technology, infrastructure and fleet should be taking into account.
- Defining strategic and operational goals. For that two different time periods: strategic (3- 5 years) and operational (1-3 years). Usually, short-term and long-term development priorities have one common trend. That leads the situation when long-term goal combines different short-term goals.
- When all priorities of the city transport system development are identified it should be distinguished measures to evaluate where and for how much we deviate from the priorities.

Procedure 2: Identify main transportation problems in the city

The procedure includes following sub-steps:

- Review of transportation statistics and main indicators of the goals conformity assessment. Characteristics like crashes and injuries, traffic jams and air pollution should be analysed.
- Identify the problems based on the analyses in the previous step.
- Propose different solutions for these problems. When problems were identified different solutions of how to eliminate them should be considered. These solutions may be connected with political decision or exactly with transport infrastructure or fleet. For example, if the problem is congestions in the city center political decision can be – paid entrance to the city. If the problem is dissatisfaction among users about public transport frequency, the solution may be – increase in public transport frequency by increase in rolling stock.

Procedure 3: Analyse experience of other countries (best practice identification)

The procedure 3 is targeted on following sub-steps:

- Analysis of ITS implementation process.
- Analysis of legislation aspects.
- Analysis of architecture solutions.
- Analysis of user needs.

At this procedure the goal for future improvement of transportation system experience of different countries should be analysed. Different approaches in ITS should be discovered. In ITS implementation basic parts like legislation, architecture and user needs should be analysed. Also procedure covers review of different technologies of ITS.

Procedure 4: Offer conceptual solution of the problem

The conceptual solution should be done together with transportation professionals due to this decision should be comprehensive accordingly to the priorities and be a best solution for the proposed problem.

Procedure 5: Choosing ITS solution (application)

The procedure is targeted on proposal different ITS solutions, which are able to solve existing problem. The list could be generated based on analysis of experience of other country or based on own experience.

Procedure 6: Identify impact and main measures for assessment

This procedure is targeted on identifying measures which will be used further. The measures range should be wide in order to cover three types of benefits: 1) economic; 2) social; 3) environmental.

Procedure 7: Level of the modelling and simulation tool selection

At this step the level of modelling (macroscopic, microscopic, mesoscopic) should be identified and the tool (software application) should be selected based on the future results and goal that was set before analysis. As well tool selection depends on the resources that are available at the moment. Price and functionality is the key factors in selection.

Procedure 8: Fulfil an ex-ante evaluation based on transport simulation modelling

The procedure defines of how simulation model is used within frame of the assessment methodology. The steps of simulation model application are described in figure 5. Main steps are:

- Development of a model with the baseline scenario "as is"
- Identification of measures that can be gained using results of simulation
- Preparation of the model for the experiment "as is"
- Experiment realization and necessary data collection.
- Measures assessment (experiment “as is”).
- Transport model implementation with the proposed ITS technology.
- Preparation of the model for the experiment with implemented ITS technology into the model.
- Experiment realization and necessary data collection.
- Measures assessment (experiment with implemented ITS technology).

- Results comparison before and after ITS technology implementation (benefits calculation).

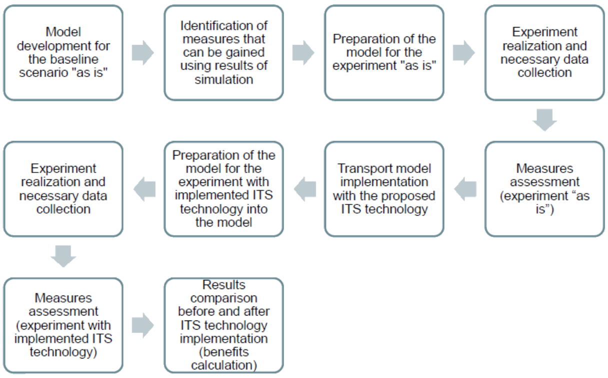

Figure 5: Evaluation Based on Transport Modelling

Procedure 9: Benefits calculation

Benefits that bring implementation of new solution should be calculated. After benefits are estimated the last step of the methodology – decision of the need of new transportation solution comes. Besides this part it is important to know not only benefits, but as well the cost of implemented application. In this work cost question is put off, but in the methodology it is distinguished as one separate step.

Procedure 10: Making the decision on the need of implementation of the proposed ITS technology

This decision should take into account the whole methodology and be comprehensive during before and after benefits comparison.

3. APPROBATION OF THE EVALUATION METHODOLOGY

The proposed methodology was approbated on Riga city. The approbation results are described in brief, to give the general view of how developed methodology is applied.

Procedure 1:

In this procedure the analysis of strategic documents for Riga city was completed. The main finding (priorities) are presented below.

The National Development Plan of Riga 2007 – 2013:

- ecology,
- accessibility,
- safety,
- efficiency.

Long-term Development Strategy of Riga until year 2025 (RDPAD 2005):

- mobility,
- reliability,
- public transport.

Procedure 2:

Analysis of statistical data about transport system of Riga gives following vivid problems:

- congestions,
- large number of traffic accidents,
- increased environmental pollution.

Procedure 3:

The analysis of European and United States experience in overcoming of mentioned above problems was analysed (study of scientific publications, books, white paper etc).

Procedure 4:

Based on previous procedures results, it could be confirmed, that in this case the ITS application could be a possible solution.

Procedure 5:

Moreover it is proposed to apply a green wave approach for traffic signals deployment as an ITS solution.

Procedure 6:

Following performance criteria and measures are used:

Performance criteria:

- mobility,
- efficiency.

Measures:

- average speed by mode,
- average speed for selected Origin-Destination,
- average delay by mode,
- total delay by mode,
- total travel time by mode,
- average travel time for selected Origin-Destination,
- network total average delay.

Procedure 7:

Microscopic simulation model of Riga transport network fragment developed in frame of project focused on pedestrian and transport flow analysis (TTI 2011). The models developed using PTV VISION VISSIM simulation software.

Procedure 8:

This step defines of how simulation model is used within frame of the assessment methodology. The steps of simulation model use are described in figure 5.

Procedure 9:

Table 1: Cost/Benefits Calculation

Measure/Transport mode	Car	Tram	Pedestrian	Bike	Trol	Light HGV
Increase in average speed	6,52%	7,46%	3,03%	0%	0,18%	6,67%
Decrease in average delay	-23,11%	-19,37%	-5,65%	3,03%	-5,82%	-24,1%
Decrease in total delay	-17,46%	-16%	3,15%	-1,58%	100%	-16,79
Decrease in total travel time	-10,17%	-9,49%	2,91%	3,22%	100%	91,45%

Measure/Origin-Destination	AB	BA	CD	DC
Increase in average speed	1,45%	5,34%	4,95%	0%
Decrease in average travel time	-2,52%	-7,54%	-7,37%	0,66%

Measure	Network total
Decrease in average delay	-1,53%

Procedure 10:

Results of Cost/Benefits calculation with recalculation to monetary value show that implementation of ITS (green wave approach) gives monetary economy from the time perspective for one peak hour is a more than 48 EUR. In average 1 year has 52 weeks. By multiplying number of weeks by 5 working days and by estimated monetary benefit of 48 EUR gives us 12480 EUR per year. The costs are not considered here as the traffic

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light management is done by dedicated enterprise which has supporting contract with Riga city council.

4. CONCLUSIONS

- The main attention of this research was concentrated on impact assessment that leads ITS implementation in the city. In particular work an ex-ante approach was considered. The goal of the research – development of ITS impact evaluation methodology based on ex-ante approach considering the vital factors for Riga transportation system was fully achieved.
- Review of ITS assessment theory was done and different ITS impact assessment methods like CBA and MCA.
- ITS ex-ante impact assessment methodology using microscopic simulation for Riga was developed and approbated on Riga case study. During Riga case study main goals for Riga transportation system development, main problems and main measures for impact assessment were identified. And based on the results from simulation modelling proposed measures and benefits were estimated and the decision for ITS green wave technology was done.
- The potential users of this methodology are decision makers. This methodology can help to understand the influence of proposed ITS solution for the city before the real system implementation. In turn, it may lead for deployment different ITS applications with the best positive effect on the transport network and save money and time.

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SIMULATION-BASED FITNESS LANDSCAPE ANALYSIS AND OPTIMISATION OF COMPLEX SYSTEMS

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ABSTRACT
The research is dedicated to the development of methods and algorithms for a simulation-based fitness landscape analysis and optimisation of complex systems. Research is motivated by a wide spread of hard optimization problems nowadays and a relevance of improvement of their solution methods. Application of the fitness landscape analysis methods in the engineering field and tasks of simulation-based optimisation are reviewed and analysed in the paper. A formalised scheme of simulation-based optimisation enhanced by fitness landscape analysis is developed. Strength and weakness of the fitness landscape analysis is researched on the benchmark landscapes, both with relations between efficiency of the optimisation algorithm and structural features of the corresponding fitness landscapes. The prototype of a software tool for the fitness landscape analysis of simulation optimisation problems is developed. Approbation of the developed methods is performed in optimisation of vehicle schedule and routes in the delivery planning task. Various metaheuristic optimisation scenarios with application of the fitness landscape analysis are investigated.

Keywords: simulation, optimisation, fitness landscape analysis, metaheuristic methods, vehicle scheduling

1. INTRODUCTION

In various cases, traditional optimisation methods (linear programming, integer programming, stochastic optimisation, etc.) could not be applied to solve hard optimisation problems. These methods may lead to ineffective solutions for such problems due to a high number of parameters of an optimised system, existence of stochastic parameters and a large solution search space. A number of metaheuristic optimisation techniques are applied for the optimisation of these tasks. To choose an appropriate technique, fitness landscape analysis of an optimisation problem can be performed. At the present time, simulation optimisation technology is a necessary tool in optimisation of complex systems, where solution evaluation can be complicated. Simulation-based fitness landscape analysis provides an efficient approach to analysis of suitability of the optimisation algorithms.

Nowadays, fitness landscape analysis methods are used for the determination of the problem hardness for the metaheuristic algorithms (Stadler et al. 2002, Pitzer and Affenzeller 2012). However, there are few researches on fitness landscape analysis within simulation optimisation of complex systems. Simulation-based fitness landscape analysis will allow better selection of optimisation algorithms, as well as allowing for construction and adjustment of the most appropriate algorithm. The research is aimed at developing methods for the simulation-based fitness landscape analysis and optimisation of complex systems.

The structure of the paper is as follows. Section 2 gives formal definitions of fitness landscape and its analysis techniques. The problem of the simulation-based fitness landscape analysis is defined. Section 3 discusses the landscapes of the benchmark problems. Section 4 presents a procedure of the simulation-based fitness landscape analysis. A case study problem is given. Section 5 describes application of metaheuristic optimisation methods in solving of a combined vehicle routing and scheduling task.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

2.1. Simulation-based Optimisation for NP-hard Problems

Modern optimisation problems in logistics and industry are characterized by large dimensions, uncertainty and nonlinearity. A factor that strongly influences the hardness of the optimisation problem is computational complexity of the problem. The research focuses on the NP-hard problems. Other factors that strongly influence the hardness of the optimisation problem can be the stochastic nature of the optimised system and the hardness of obtaining the analytical form of the objective function. To find solutions of such complex, large-scale, stochastic optimisation problems simulation-based optimisation is applied.

Numerical optimisation methods form a natural choice in solving complex stochastic optimisation problems, where the closed form of the objective function is frequently unknown (Gosavi 2003). These methods include metaheuristic optimisation methods, which facilitate finding good solutions to large and complex optimisation problems in a reasonable time with the application of different heuristic and stochastic methods. Although metaheuristic methods don't guarantee to find the optimal solution of the problem, there is a high interest for such methods in the applied optimisation of real life problems (Glover and Kochenberger 2003). These methods include such examples as the *Genetic Algorithm* (GA) (Goldberg 1989) and *Evolution Strategy* (ES) (Schwefel 1995). The application of the metaheuristic and other numerical methods becomes more important for especially hard optimisation problems such as NP-hard combinatorial optimisation problems (Dreo et al. 2006).

To make the selection and adjustment of an optimisation method more reasonable, a fitness landscape analysis offers methods for the investigation of the problem's search space.

2.2. The Concept of Fitness Landscape Analysis

The fitness landscape analysis provides methods and techniques for a mathematical analysis of a search space of optimisation problems. It can be applied as a support tool to enhance optimisation of complex systems, and it is widely considered in literature (Weinberger 1990, Jones and Forest 1997, Stadler 2002). The fitness landscape is interpreted as a combination of a fitness function of the optimisation problem and the relationships or a distance metric between the solutions in the search space (Reeves and Rowe 2002).

It was proposed that the structures of a fitness landscape affect the way, in which a search space is examined by a metaheuristic optimisation algorithm. The fitness landscape analysis would allow getting more information on the problem's properties dependent on a specific optimisation method, which will guide the optimisation process (Reeves and Rowe 2002). With the landscape analysis it is possible to get measures of the problem's difficulty, and the recommended configuration of an optimisation algorithm. Searching for better problem subclass specific algorithms and configurations will provide useful knowledge on the problem solution scenarios (Pitzer and Affenzeller 2012).

Formal definitions of fitness landscapes are provided in the literature. In the following definition (Jones 1995) a *representation space* $\boldsymbol{R}$ defines a set of representations and the *search operator* ϕ is defined as a function $\phi: \boldsymbol{M}(\boldsymbol{R}) \times \boldsymbol{M}(\boldsymbol{R}) \to [0, 1]$, where $\boldsymbol{M}(\boldsymbol{R})$ is a multiset of representations. A value of $\phi(v, w) = p$ for $v, w \in \boldsymbol{M}(\boldsymbol{R})$ defines a probability p that v will be modified to w by application of the operator ϕ. The fitness landscape is defined as the 5-tuple:

$$\boldsymbol{L} = (\boldsymbol{R}, \phi, f, \boldsymbol{F}, >_{\boldsymbol{F}}), \quad (1)$$

where f is a fitness function; $\boldsymbol{F}$ is the fitness space with a partial order $>_{\boldsymbol{F}}$. The landscape can be represented as a directed labelled graph $G_{\boldsymbol{L}} = (V, E)$, where vertices are $V \subseteq \boldsymbol{M}(\boldsymbol{R})$, and edges are $E \subseteq V \times V$. In this representation, a vertex $v \in V$ is labelled as $f(v)$, and edge (v, w) is labelled $\phi(v, w)$. Similar to structures of nature landscapes hill ridges, valleys and other structures can be identified in the fitness landscape. Following structures are formalised in the literature: *peak* (or *maximum*), *global-optimum*, *local-optimum*, *plateau*, *basin of attraction* (Jones 1995).

The major highlighted factors, which affect the hardness of the optimisation problem, are: the m*odality*, which defines a number and density of optima in a search space (Reeves and Rowe 2002); *ruggedness* that characterizes the impact of all landscape structures on the hardness of the search (Merz and Freisleben 2000); and *neutrality*, which characterizes a number of plateaus (Reidys and Stadler 1998).

2.3. Fitness Landscape Analysis Techniques

Different techniques have been developed for a fitness landscape analysis by evaluating its structural characteristics (Jones and Forest 1997, Vassilev et al. 2000, Smith et al. 2002, Collard et al. 2004).

Fitness landscape analysis techniques apply different strategies for data collection based on simple moves, which generate a trajectory through the landscape. In the *Random Walk*, a solution candidate is randomly modified repeatedly. In the *Adaptive Walk*, a certain number of mutations are performed to generate a set of neighbours, and then the best one is selected from this set (Kauffman 1989). The *Up-Down Walk* is similar to the adaptive walk, but the direction of the walk is reversed when a local optimum is reached (Vassilev et al. 2000). *Neutral Walks* explore "flat" areas (Reidys and Stadler 1998).

The *statistical analysis* proposed by Weinberger (1990), calculates the autocorrelation function in the random walk to measure the ruggedness of the landscape. In case of a high correlation between fitness values the landscape is considered less rugged. In the first step a time series of fitness values $\{f_t\}^N_{t=1}$ is obtained in a landscape walk of N moves. Then, an autocorrelation function $\rho(\Gamma)$ is calculated:

$$\rho(\Gamma) \approx \frac{E(f_t f_{t+s}) - E(f_t)E(f_{t+s})}{V(f_t)}, \quad (2)$$

where $E(f_t)$ the expectation and $V(f_t)$ is the variance of a sequence $\{f_t\}^N_{t=1}$. For smooth landscapes the autocorrelation of a random walk is close to 1 and tends to zero for rugged (Reeves and Rowe 2002). Another statistical measure is correlation length, which defines a distance beyond which two sets of fitness points becomes uncorrelated. A longer correlation length indicates a smooth landscape.

The ***information analysis*** interprets a fitness landscape as an ensemble of objects, which are characterized by their form, size and distribution. These objects consist of a point in the fitness landscape and the nearest neighbours of this point. The information analysis is based on the information theory, and four information measures are proposed by Vassilev et al.

(2000). The *information content* $H(\varepsilon)$ is a measure of entropy in the system. In case of high information content, the landscape is more rugged. *Partial information content* $M(\varepsilon)$ characterizes the modality of the obtained fitness string. The *information stability* ε^* characterizes a magnitude of optimums in the obtained landscape fitness path. The *density-basin information* $h(\varepsilon)$ analyses the variety of flat and smooth sections in the landscape. Information measures are calculated with notice to a calculation accuracy which is defined by a parameter ε, which defines a threshold of slopes in the fitness path (Vassilev et al. 2000).

2.4. Problem Setup of the Simulation-based Fitness Landscape Analysis and Optimisation

To extend the concept of the fitness landscape analysis for its application in simulation-based optimisation, the concepts of the simulation-based fitness landscape analysis are introduced in (Bolshakov 2013). The formal definition of the simulation fitness landscape $\boldsymbol{L}'$ with an assumption that a simulation model provides real value output is:

$$\boldsymbol{L}' = (\boldsymbol{R}, \phi, S), \tag{3}$$

where $\boldsymbol{R}$ is a representation space, ϕ is a search operator and S is a simulation model with one output variable.

To apply the fitness landscape analysis in the simulation optimisation, the following three-level formalised scheme is introduced (Bolshakov 2013) (see Fig. 1). At the *benchmarking level*, information on landscape measures and on the performance of the optimisation algorithms on benchmark landscapes is collected. At the *landscape analysis level*, the landscape analysis procedure is defined. The trajectory on the landscape is generated with different walking strategies, the time series of fitness values are obtained and landscape analysis measures are calculated by using statistical and information analysis techniques. The obtained collection of data is used to select and adjust an appropriate optimisation algorithm. At the *optimisation level*, the selected algorithm is used to optimise the investigated system by using the simulation-based metaheuristic optimisation approach.

Landscape walk module LW can be interpreted as follows:

$$\vec{x}_{t+1} = LW(\vec{x}_t, \phi, \hat{y}), \tag{4}$$

where t is a number of completed walk iterations, $\vec{x}_{t+1}$ is a vector of simulation model input variables for a current iteration, $\vec{x}_t$ are input variables at the previous iteration and $\hat{y}$ is an output of a simulation model. Output of the landscape walk module is a vector $\vec{x}$ = $(x_1, x_2,..., x_k)$, $\vec{x} \in \boldsymbol{R}$.

Simulation model S evaluates the performance of a system. Its output is estimated by $\hat{y} = \mathrm{E}[y]$, where $y \in \mathbb{R}$ is simulation output in each replication and $\mathrm{E}[\cdot]$ is the mathematical expectation. As a result of process integration of modules LW and S, a number of time series $\{\hat{y}_t\}^N_{t=1}$ are generated.

The module of **statistical and information analysis** performs analysis of fitness values time series, and calculates the landscape statistical and information analysis measures. A set of measure values is obtained for different values of Γ and ε.

The module of **construction and tuning of an optimisation algorithm** allows selecting the appropriate optimisation algorithm and adjust its parameters for optimisation of a complex system, which is simulated by S. Selection of the algorithm, its components and parameters is based on the data from simulation-based fitness landscape analysis and the data on benchmark landscapes. The module output defines the selected metaheuristic optimisation algorithm and its configuration: the representation $\boldsymbol{R}$ and a set Φ of search operators which form the optimisation algorithm. The selection of the algorithm and its configuration is based on the rules and recommendations which are applicable for known values of the landscape measures.

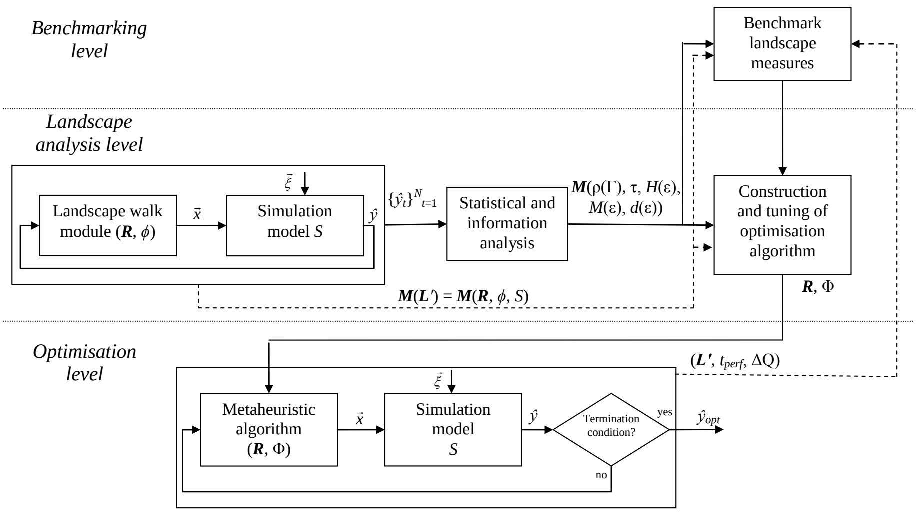

Figure 1: Simulation-based Optimisation with Fitness Landscape Analysis

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At the *optimisation level*, the **metaheuristic algorithm** uses the representation method and a set Φ of suggested operators to optimise the problem. The **termination condition** determines whether the suitable solution is found. When the optimisation cycle is terminated, the best found solution $\hat{y}_{opt} = \langle \vec{x}, \hat{y} \rangle$ is selected.

3. BENCHMARK FITNESS LANDSCAPE EXPERIMENTAL ANALYSIS

3.1. Experimental Analysis of Benchmark Landscapes

The following four fitness functions are widely used for benchmarking of genetic algorithms and were selected for estimating and analysing statistical and information measures of benchmark fitness landscapes. They are Sphere and Rosenbrock functions (De Jong 1975), Rastrigin function (Rastrigin 1974) and Ackley function (Ackley 1987). Experiments with the benchmark landscapes were performed with same number of variables and within a same search domain. Eight different fitness landscapes as a combination of four different benchmark functions and two types of representations are analysed. For a detailed analysis of benchmark fitness landscapes, a software prototype in Java was developed and applied. To estimate structural measures of these landscapes, three series of landscape analysis experiments were performed (Merkuryeva and Bolshakovs 2011).

In the first series of experiments it was found that while correlation measures show dependence on the length of the path generated by a random walk, the behaviour of information content measures does not demonstrate this effect.

In the second series of experiments, the autocorrelation for different benchmark landscapes and lags was defined for two types of solution representation. Correlograms obtained for real-value and binary coded benchmark landscapes show the higher autocorrelation for real-value coded fitness landscapes that make search processes easier in practice.

In the third series of experiments, different information measures for all benchmark landscapes and different ε values were estimated. At ε = 0 information measures become almost identical and essentially do not provide a new information about structures of specific fitness landscapes. At the same time, smaller values of the information content for the Rosenbrock function compared to the Sphere indicate the higher degree of flatness with respect to rugged areas of the landscape (Merkuryeva and Bolshakovs 2011).

3.2. GA Optimisation Experiments with Benchmark Fitness Functions

To find the correlation between the results of fitness landscape analysis and hardness of a real problem for an evolutionary algorithm, a series of optimisation experiments were performed with benchmark landscapes (Merkuryeva and Bolshakovs 2011). GA with one point crossover and corresponding mutation operator was used to estimate a cumulative probability of success for different benchmark landscapes. The results of optimisation experiments show that in most cases, except for the Rosenbrock function, GA found solutions on real-value coded benchmark landscapes are better than on the binary ones that was predicted within the statistical analysis. As the autocorrelation between neighbourhood fitness points is high, it is easier for the genetic algorithm to move to a point with better fitness.

4. SIMULATION-BASED FITNESS LANDSCAPE ANALYSIS

4.1. Fitness Landscape Analysis Tool

A procedure for the simulation-based fitness landscape analysis in a prototype of an analysis tool contains three following stages (see Fig. 2):

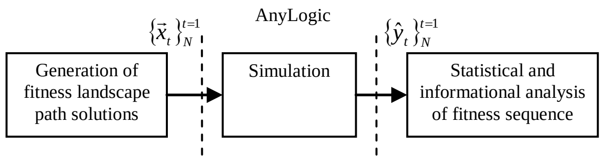

Figure 2: Main Stages of Fitness Landscape Analysis

The procedure is as follows. A developed Java application performs a random walk on the problem fitness landscape with application of mutation operator and produces a sequence $\{\vec{x}_t\}_N^{t=1}$ of landscape path candidate solutions. The solutions are evaluated by simulation model of the analysed system in AnyLogic *parameter variation* experiment with different vectors of input parameters, which are defined in the obtained trajectory. As a result, the model generates an array of fitness values $\{\hat{y}_t\}_N^{t=1}$. Finally, calculation of statistical and information fitness landscape measures is performed on a sequence of obtained fitness values.

In statistical analysis, correlation length and values of autocorrelation function for different lags are calculated. In the information analysis at first a value of information stability ε^* is determined. Then iterative calculations of information content, partial information content and density-basin information are performed for different values of ε within interval [0, ε^*).

Experimental data from several random walks is collected during analysis. As all random walks are started at different random positions, fitness landscape measures are obtained for a large part of the landscape.

4.2. Case Study

A case study of the vehicle scheduling problem with time windows (VSPTW) is considered in the research. Vehicles with various parameters deliver different types of goods from one distribution centre to various stores. A sequence of stores in a route, moving, loading and unloading times are defined for each trip. Delivery time windows and average demand are defined for each store. Vehicle capacities are limited and known. The problem is aimed at assigning vehicles to trips in order to minimise the total idle time of all vehicles, which is defined as a sum of time periods when a vehicle is waiting for the next trip. Vehicle scheduling problem (VSP) is frequently reviewed in the studies (Eiiyi et al. 2008, Nagamochi and Ohnishi 2008). In practice, VSP can also be complicated by stochastic processes, and this is a reason to apply simulation optimisation to solve such problems.

The following two sets of decision variables are introduced: v_i and t_i, where v_i is a vehicle assigned and t_i is a start time of the trip *i*. The problem constraints are vehicle capacity constraints and delivery time windows of stores.

The objective function *f* is specified as follows:

$$f = \sum_{i=1}^{N} T_{idle}^{i} + k_1 T_c + k_2 T_m + k_3 T_0 + k_4 N_{ol} + k_5 N_{ot} \to \min, \quad (5)$$

where T_{idle}^{i} is the total idle time for vehicle *i*; *N* is a number of vehicles; T_c defines the total duration of overlapping trips for one vehicle; T_m defines the total time of window mismatches; T_o and N_{ol} determine the total time and a number of vehicles that have overdone 24 working hours; and N_{ot} is a number of vehicles that are overloaded. All indexes for unsatisfied constraints are multiplied with penalty coefficients k_i.

To determine the fitness of potential vehicle schedule solutions, discrete event simulation model in AnyLogic is developed (Merkuryeva and Bolshakovs 2010). The simulation model evaluates the efficiency of a potential vehicle schedule by estimating the total idle time of all vehicles. To validate the model the existing schedule of a case study was simulated. In the experimental analysis, when the vehicle moving time between two route points was defined as a random variable with normal distribution it was determined that stochastic nature of the vehicle moving time has an impact on the vehicle idle time which grows with the growth of variance. At same time, a sum of all moving intervals for a vehicle is not affected by variance of moving times.

To solve the vehicle scheduling problem with time windows, three optimisation scenarios are defined in the research:

1. Optimisation in OptQuest optimisation tool.
2. Simulation-based fitness landscape analysis and optimisation of the problem in the developed prototype.
3. Fitness landscape analysis and optimisation of the problem in the HeuristicLab framework.

As the simulation model of the vehicle schedule is developed in the AnyLogic software, optimisation tool OptQuest was applied. But, in experiments OptQuest was not able to obtain good solutions of the VSPTW, thus this scenario is not described in the paper.

4.3. Problem Research with Developed Simulation-based Tools

In this scenario, the VSPTW is sequentially analysed by the simulation-based fitness landscape analysis tool prototype and optimised in simulation-based optimisation by tuned genetic algorithm.

Here, solution of the VSP is encoded as an integer vector chromosome, which length is twice the number of trips. Genes with even numbers represent start times of corresponding trips, and odd genes define the assigned vehicle for this trip. To perform the random walk on the fitness landscape, a mutation operator is introduced that changes one randomly selected trip in the solution candidate. For the selected trip a new randomly chosen vehicle is assigned, and start time is shifted by a certain constant value.

Information and statistical measures of the VSPTW fitness landscapes with stochastic and deterministic input data received in experiments are given in Table 1.

Information measures demonstrate that the landscape of problem with stochastic data has higher entropy and should have higher modality. According to the landscape measures, problem with stochastic data should be more complex for the optimisation algorithm as values of autocorrelation function between neighbour solutions ρ(1) are lower.

In both cases the information content is relatively high, and fitness landscape of the optimisation problem is relatively rugged. The partial information content is low, and as a result, the modality of fitness landscape is low. The results of the fitness landscape analysis lead to a conclusion that the case study problem is not hard for evolutionary algorithms. Comparative analysis shows that landscape of VSPTW is less rugged than landscapes of benchmark fitness functions whose solutions are coded in binary chromosomes. Thus the analysed problem could be solved with the GA no worse, than mentioned benchmark problems.

Table 1: Information and Statistical Measures

Model input data	*H*(0.1)	*M*(0.1)	*h*(0.1)	ε*	ρ(1)	ρ(10)	τ
Stochastic	0.66	0.20	0.49	0.40	0.84	0.21	7.24
Deterministic	0.62	0.17	0.37	0.35	0.89	0.32	8.75

In the simulation optimisation, the GA is applied. The optimisation tool is implemented as a Java class, which interacts with the simulation model via ‘Parameter variation’ experiment in AnyLogic. In experiments with population size 200, one point crossover operator for data encoded in real numbers and a described mutation operator the best found solution allowed decreasing the total idle time comparing with the original schedule.

In series of optimisation experiments, simulation model with deterministic data is used and termination condition is set to occur when a large number of generations are generated without improvement of the best solution in the population. Genetic operators are customized for operating with the proposed structure of the chromosome: one point crossover operator for real vectors and above described mutation operator are applied. As fitness evaluation with simulation is time consuming, caching of fitness values is applied. If the solution was already evaluated its fitness value can be returned without simulation from an array of stored fitness values. Optimisation results show that a solution which satisfies all constraints can be found. Acceptable results are obtained with the population size higher than 1000 chromosomes (Merkuryeva and Bolshakov 2012a). But the optimisation algorithm needs improvements, as many found solutions of large dimension instances do not satisfy part of soft constraints

4.4. Fitness Landscape Analysis and Optimisation in HeuristicLab

To perform a faster and more comprehensive analysis, the simulation model was reimplemented as a plug-in of HeuristicLab (Wagner 2009) maintaining all its logic. To enhance the quality of optimisation results, permutation encoding for the VSP solutions is introduced. A chromosome contains $m + n$ genes, where n is a number of vehicles and m is a number of trips. The genes that have values less or equal to m encode the trip number and values greater than m encode delimiters or vehicle designators, and define, that the next sequence of trips should be performed by the corresponding vehicle (Bolshakov et al. 2011).

A grid of the landscape analysis experiments is created to compare values between different landscapes:

1. Comparison of different mutation operators.
2. Impact measurements of stochastic variables during simulation.
3. Comparison between existing and proposed encodings.

Full results of comprehensive analysis experiments are presented in Bolshakov et al. (2011). For the integer vector representation, fitness landscapes of two operators are analysed. The single position replacement manipulator (*VSPManipulator*) changes the start time of the trip to a new uniformly distributed random number, but the single position shift manipulator (*VSPShiftManipulator*) shifts the start time with a uniformly distributed random number. In random walk, values of autocorrelation function are slightly lower for the replacement operator. In up-down walk the situation is the opposite: replacement mutation has higher correlation than shift mutation, but the three artificial problems are different to the others (see Fig. 3; black dots are for *replacement* and green for *shift* mutator). It can be concluded that for VSPs that the main impact on the local landscape structures has a number and variety of trips.

The plug-in was supplemented with additional logic to estimate the affect of simulation model's stochastic variables on the landscape measures. In following series of experiments vehicle movement times between customers are shifted by a random number that has symmetric triangle distribution in the interval [-20, +20] minutes. The autocorrelation value $\rho(1)$ is lower for landscapes of noisy problems in these experiments. The addition of similar noise has different impact on different instances, which can be measured by $H(0)$ or $M(0)$ in random walks, which values are higher for landscapes with noise. It is determined in experiments, that higher number of replication reduces the impact of the noise on the information measures, although no significant difference of correlation length and autocorrelation values between different numbers of replications was found. The information content's $H(0)$ value is higher for the problem instances with additional noise, especially when only one replication is used.

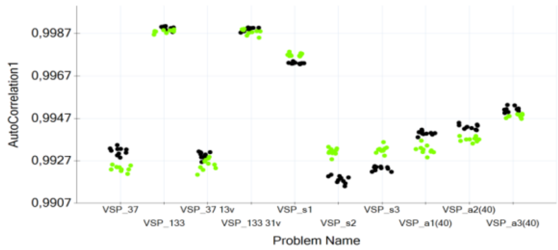

Figure 3: Autocorrelation in Up-Down Walks

To compare the fitness landscape analysis measures between different VSP representations, experiments for each encoding are performed. The value of the autocorrelation function in random and up-down walks is lower for the permutation encoding, which means that landscapes of this encoding should be more rugged.

Evolution Strategy (ES), Simulated Annealing (SA) and Genetic Algorithm were applied in the comparison of VSP optimisation results. For integer encoding, both ES and SA algorithms are fast and highly successful, and it is possible to find solutions with better quality with ES (Fig. 4). GA finds even better solutions, but requires a higher number of evaluations. The permutation encoding is found to be more effective in optimisation of the VSP, as it reduces the search space, even though the fitness landscape for the permutation encoding has to be more rugged. Although it is also found, that for large dimension instances factor of landscape ruggedness dominates the reduction of the size of search space.

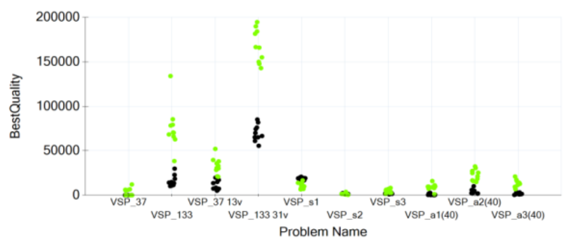

Figure 4: Quality of Best Found Solutions with ES

It is experimentally found that the statistical analysis can predict the performance of these operators. For the GA instances, where the shift operator is better, the autocorrelation for this operator also is higher (Fig. 3 and 4; black dots are for *replacement* and green for *shift* mutator). The same dependency was also found for the ES algorithm.

It is concluded, that optimisation using the ES is the best choice for the solution of the vehicle scheduling problem with time windows. If the GA is selected as the optimisation algorithm, permutation encoding has to be chosen unless the problem contains more than 100 trips. In the integer vector encoding, selection of the appropriate mutation operator is based on the landscape analysis measures: an operator, which has the highest autocorrelation value in the up-down walk, should be selected.

5. APPLICATION IN PRODUCT DELIVERY PLANNING

Two combined optimisation tasks of the integrated delivery planning proposed in Merkuryeva and Bolshakov (2012b) are solved in this section. General task is the determination of the best routes and schedule for the vehicles to deliver goods from a distribution centre to the stores. Optimal distribution of routes and vehicles should minimise a number of used vehicles, total delivery distances, with minimisation of vehicle idle times. The route and schedule plan must fulfil the constraints, such as capacities of vehicles, time windows and warehouse capabilities. For the solution of this task, two optimisation problems are solved sequentially. First task is solved as a vehicle routing problem with time windows. For the second task a route scheduling problem statement is defined that aims optimisation of a schedule of predefined routes.

5.1. Vehicle Routing Experiments

The classical flow-based vehicle routing problem’s with time windows (VRTPW) statement (Cordeau et al. 2001) was applied in the research. All optimisation experiments were performed with application of the Island Offspring Selection Genetic Algorithm (Affenzeller et al. 2009), which is a special type of genetic algorithm that combines features of coarse-grained parallel GA and GA with offspring selection. Experiments were performed with HeuristicLab optimisation framework (Wagner 2009). A GVR crossover was selected as best for the VRPTWs of the case study, as it works with an unlimited number of vehicles, but provides best results in terms of keeping routes not overloaded.

It was found for the considered case, that in best found solutions many routes are 1 to 3 customers long. A number of stores is limited due to the small capacity of the vehicles, and not because of short time windows.

5.2. Vehicle Route Scheduling Problem Statement

It is assumed in the definition of the classical VRPTW, that any vehicle may perform only one route in the planning horizon. In the investigated business case, all routes are shortened by the capacity of vehicles, which leads to the ineffective solutions of the vehicle routing problem. To overcome these obstacles, the route scheduling problem is introduced. It can be formulated on a basis of the VSPTW. In the formulated problem, the routes correspond to the trips in the VSPTW and vehicles may perform any fair number of routes during the day. As far as the final solution of the VRPTW task should be feasible for the capacity and time window constraints, it can be optimised by combining and compacting routes to increase a vehicle utilisation. Application of the vehicle scheduling for the solution of vehicle routing problem allows reducing a number of required vehicles.

A full formal statement of the route scheduling problem is described in (Merkuryeva and Bolshakov 2012b). The decision variables are ones introduced in the routing model (Cordeau et al. 2001), i.e., sets x and s, except that $x_{ijk} = 1$ states that for vehicle k route j will be the next after route i. Two types of soft constraints are introduced: 1) time window constraints; 2) overtime constraints. A fitness function f of the route scheduling problem summarizes all idle times and a number of constraint violations multiplied by penalty values:

$$f = \sum_{k \in V} l_k + p_{ad} N_{ad} + p_{ot} N_{ot} \rightarrow \min, \qquad (6)$$

where l_k is the total idle time of a vehicle k; V is a set of available vehicles; N_{ad} is a number of vehicles, which leave customer after due time; N_{ot} is a number of vehicles, which are scheduled to work with overtime; p_{ad} and p_{ot} are the penalty values for late deliveries and vehicle overtimes, correspondingly.

5.3. Vehicle Route Scheduling Experiments

To resolve the vehicle route scheduling problem, a plug-in in HeuristicLab optimisation framework is developed. In the plug-in, fitness function (6) evaluator simulates a schedule of a solution candidate. A permutation encoding of the VSPTW is applied for the route scheduling, but the trips here are represented by the routes.

Several series of optimisation experiments were performed to determine a suitable algorithm for the route scheduling and numbers of solution evaluations to obtain candidate solutions of the equal fitness are compared. Following algorithms were examined: ES, GA, Island GA with 5 islands and Offspring Selection GA (Affenzeller et al. 2009). The ES was chosen as most suitable, for its ability to provide the best found optimal results of the route scheduling with fewer evaluations (Merkuryeva and Bolshakov 2012b).

A sample experiment based on one day plan and specific demand data for 53 stores is described. The best found solution obtained by the IOSGA for the VRPTW defines 34 routes (Fig. 5). Here, it is possible to combine these routes due to the long time windows. The ES (20+100) algorithm was applied for the route scheduling problem which input data is based on the considered VRPTW solution. As a result, the optimal scheduling solutions were found with all constraints satisfied if at least 6 vehicles are available (see Fig. 5).

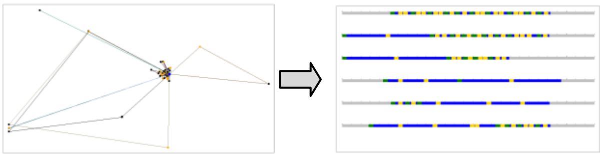

Figure 5: VRPTW and Scheduling Solution of Sample Instance

The proposed vehicle scheduling method that complements vehicle routing can be applied in the vehicle routing and scheduling, when routes are short in comparison with a planning horizon.

6. RESULTS AND CONCLUSIONS

Review of formal definitions of fitness landscape and its structures, with the review of fitness landscape analysis methods allowed development of the formal scheme for the simulation-based optimisation, enhanced with the fitness landscape analysis. Experimental fitness landscape analysis of benchmark landscapes allowed finding the relations and dependencies between structural features of benchmark fitness landscapes, their measures and behaviour of optimisation algorithm on these landscapes.

The developed simulation-based fitness landscape analysis procedure allowed implementation of a software tool prototype for fitness landscape analysis. Application of this tool provided analysis of the vehicle scheduling problem with time windows in simulation-based optimisation. The comprehensive experimental fitness landscape analysis of this problem allowed determination of problem specific properties and internal characteristics of problem’s fitness landscape, which, provided development of recommendations for optimisation scenarios of the vehicle scheduling problem with time windows. Experimental results show that it is possible to use fitness landscape analysis for enhanced optimization of applied problems, but with notice to the stochastic data of simulation optimisation.

The developed methods were applied in the solution of delivery planning operational level optimisation tasks, which allowed improving the overall solutions of vehicle routing and scheduling problem with time windows.

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PASSENGER SLOT ASSIGNMENT FOR AIRPORT'S SECURITY SCREENING

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ABSTRACT

Passenger security screening checkpoints (SSC) keep the area beyond the checkpoint sterile of prohibited items. Despite recent developments in screening device technology has increased the ability to detect these threats; the average amount of time it takes to screen a passenger still remains a concern. Due to the impact of the security screening process on the quality service to passenger and its impact on the scheduled departure time, airports have been analyzing different alternatives to improve the ability of screening devices to detect threats and to speed up the flow of passenger through the airport security screening checkpoint. This paper describes a work in progress proposal 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 investments on extra airport SSC facilities or staff.

Keywords: security screening, passenger slot assignment, queuing, capacity demand balance

1. INTRODUCTION

The purpose of screening checkpoints is to keep the area beyond the checkpoint sterile of prohibited items and it therefore marks the division between landside and airside. A secured area should only be accessible to those individuals that are "cleared" by means of screening.

Despite recent developments in screening device technology has increased the ability to detect these threats; the average amount of time it takes to screen a passenger still remains a concern. Practical experience warns that the process is drastically affected by the increment on the amount of passengers, with longer queuing periods, increased screening device operational costs, and a large task force of security personnel. Moreover, these effects are magnified as the number of travelers per year increases, along with their impatience and dissatisfaction with ever-changing airport security procedures.

Criteria, guidelines, and standards are provided in the Security Manual of IATA. International standards related to aviation security and passenger screening are contained in the Annex 17—Security: Safeguarding International Civil Aviation against Acts of Unlawful Interference; to the Convention on International Civil Aviation.

2. PROCESS AND PROBLEM DESCRIPTION

The screening process basically consists of two stages, primary screening and secondary screening. Secondary screening of passenger or baggage item will follow if the passenger cannot be cleared in the first stage, if the passenger is identified by risk assessment for increased measurements, or if the passenger is randomly selected as a requirement.

Screening personnel is required to randomly select passengers for additional screening throughout the day, but those random selections may not be concentrated during off-peak hours.

2.1 Description of the screening stages

Before entering the queue to the security screening checkpoint passengers are checked for a valid document/ticket and in some States photo identification is required.

Next, the passenger enters the queue. Posted instructions tell passengers what to do and explain the screening steps.

At some airports transparent sealable plastic bags are provided to passengers, in which all "loose" items the passenger carries with him/her should be placed.

Bins are provided for placement of carry-on baggage, electronic devices (laptop computers, phones, etc.), as well as for shoes, jackets and hats, and the plastic bag. The presence of tables before the screening area improves passenger flow and allows for an easier and quicker divesting of items. The carry-on allowance is usually restricted to two items, whereof each item is restricted in size and weight. The amount each passenger is allowed to carry is limited to one carry-on bag and one personal bag (e.g., purse or briefcase).

All bins are placed onto the conveyor belt of the x-ray machine. Only after placement the passenger will walk through the Walk Through Metal Detector (WTMD). If the passenger sets off the alarm the searcher will ask the passenger if all items were removed. Provided that the flow will not be interrupted the passenger can proceed through the same WTMD again, or use a WTMD offset from the main path.

Otherwise, a second screening with a Hand Held Metal Detector (HHMD) will be necessary. Passengers that need to undergo a second screening should have their belongings removed from the conveyor belt by checkpoint staff and left behind the conveyor belt.

Following the second screening, the passenger may redeem the belongings. The secondary screening consists of "frisking" by a HHMD. If the metal detector keeps on being triggered, a hand search will be necessary. With consent the passenger is hand searched by security staff of the same gender. Refusing a secondary search automatically means that the passenger will be denied access to the airside. The passenger may request that the search is conducted in private starting 2005. Also the pat-down procedure will be changed, besides patting-down the entire back and front of the torso around the abdomen the pat-down search will include the arms and legs.

Carry-on baggage should be hand searched when the content appears suspicious or cannot be readily identified. The time limit for each bag is 5 s. If the bag cannot be cleared within these 5 s, it will be hand searched. If a bag is identified as a potential threat, the conveyor belt should be stopped. This is done to prevent other bags passing the screening without the full attention of the screener. Consent by the passenger should be granted before a manual search, and can only be performed in presence of the passenger. Hand searches should be complemented with Explosives Trace Detector (ETD) inspection. Likewise, continuous random checks by ETD of cleared bags should be performed at each screening station. If restricted or prohibited items are found they should be identified and confiscated. Once passengers and carry-on baggage are cleared, they may enter the sterile area.

Despite existing several configurations for the distribution of the screening facilities (concourse, holding area, and boarding gate), the most extended layout of the security screening checkpoint (SSC) is a central location within the terminal's perimeter, prior to a concourse, and thereby being able to serve various gates (IATA 2005).

2.2 Problem description

Due to the impact of the security screening process on the quality service to passenger, managing and maintenance costs and the impact on the scheduled departure time, airports have been analyzing different alternatives to improve both:

- The ability of new screening device to detect threats
- The flow of passenger through the airport security screening checkpoint.

This paper describes a proposal 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 investments on extra airport screening capacity.

3. STATE OF THE ART

There are several papers published in the literature that could be considered with some relationship with the slot screening assignment process, such as papers tackling better queue management in the airport, delay analysis generated in the flow of passengers through the screening processes, virtual queues, capacity/demand algorithms and pricing algorithms among others.

However it has not yet been reported a work with the scope of the present proposal in the slot screening assignment to avoid idleness and capacity deficit of screening resources in the airport side, and a service to change queuing by waiting in the passenger side. Thus, in this section, instead of a deep analysis of scientific publications related to the mentioned area, it will be presented tree prototypes and innovative approaches which somehow have some similarities with the new slot assignment approach proposed.

3.1 SecurXpress at Montreal's Airport

SecurXpress, is the brand new mobile solution for *Aéroports de Montréal*. The mobile solution consists of a text messaging service (SMS) to ensure travelers receive priority treatment at security screening checkpoint "A" at the Montreal airport. Available to passengers departing on domestic and international (except U.S.-bound) flights, SecurXpress sends a text message to their mobile device indicating the specific time they must show up at checkpoint "A." The service, offered in both French and English, is the first of its kind in Canada.

The new service means that passengers can now reserve, free of charge, a priority time for going through security. To confirm the time, passengers reply with a text message. The reservation is valid for a maximum of 5 people. The travelers must then show up at the appointed time at a checkpoint in the SecurXpress line.

To sign up for SecurXpress or SMS alerts, passengers only have to fill out a form on the *Aéroports de Montréal* website, up to 24 hours before their flight.

Time window intervals have been established to ensure that the passenger won't have to wait very long for his flight, but will have plenty of time to get to the boarding gate. The first person to reserve priority passage is assigned the priority-passage slot closest to the flight departure time; the second is assigned a slot 5 minutes earlier, and so on.

The system has been designed to accommodate groups of no more than 5 people. If there are more than 5 people in a group, different passage time reservations (each for maximum 5 people) will have to be made using different mobile phone numbers.

Passengers that arrive earlier to the airport than the slot time assigned are allowed to go through the general screening facilities. On the other way around, in case the passenger miss his slot, and there are not extra slots available, the passenger will have to line up in the non-priority corridors and be subject to the normal wait times.

SecurXpress service is a simple way that tries to avoid lineups at the security screening checkpoints during peak periods. Passage times are spread out for priority users in a dedicated checkpoint corridor, preventing unnecessarily long waiting times. The service sends an SMS with a reminder alert 15 minutes before the scheduled passage time. The access to the SecurXpress checkpoint corridor is managed by the passage-time confirmation message displayed in the mobile phone.

This innovative solution was entirely designed and developed in-house at TC Media. This new mobile solution joins the other services already offered by TC Media to *Aéroports de Montréal*, such as the SMS service for flight status updates which is also hosted and maintained by TC Media. For the past several years, passengers have been able to receive real-time updates and alerts via text message (SMS) on their cell phones for flight schedule changes of over 10 minutes. Thus, when a flight is delayed or cancelled, passengers subscribed to the service receive an alert.

3.2 Virtual queuing at airport security lanes (De Lange 2013)

A virtual queue (VQ) can be interpreted as an invisible line of passengers waiting to enter a physical queue. In this scenario, the concept is based on the allocation of time windows (TWs) to passengers that allow them to enter a priority lane during a specific time interval. It is a process that offers the opportunity to redistribute the passenger arrivals by shifting the demand out of peak periods into idle periods.

VQ principles turned out to be very successful for call centers (see e.g., Camulli 2007) and amusement parks (see e.g., Lutz 2008), which took advantage of people's flexible schedules.

However, the situation at airports is more complex from a queuing perspective due to passenger time constraints related to the flight schedules (Narens 2004). Still, virtual queues at airports could potentially lead to shorter queues with the same number of security agents, or similar waiting times with fewer security agents.

Since passengers would know exactly how long they have to wait, they could choose to occupy themselves by shopping or dining. The parameters of a security lane operation for a queuing analysis are: the passenger service rate, the number of available security lanes, and the passenger arrival rate. The passenger service rate and the number of available security lanes are straightforward. However, verifying the passenger arrival rate is more difficult.

In order to incorporate the VQ principles it is necessary to acknowledge several additional parameters. In Narens 2004, it is showed that for simulating a virtual queue it is necessary to determine a VQ protocol: it is necessary to define who the eligible passengers are and how and when these passengers can arrive at the security checkpoint without waiting in the general line.

It is worthwhile to note that the VQ process does not require a separate security lane (see Figure 1); instead some barriers and enabler accessing mechanisms could be deployed to allow passengers in the VQ to have a straight access to the screening service.

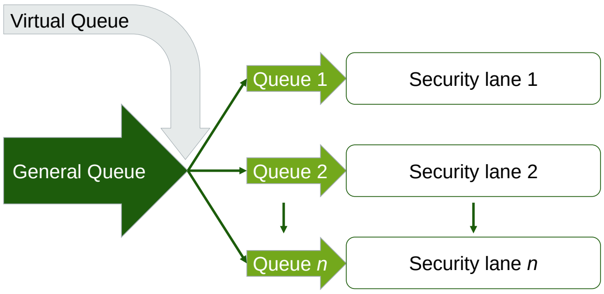

Figure 1. Coexistence of the VQ with the classical security lane queues

In Figure 1 the virtual queue and the general queue are joined together at the point where the passengers are spread across the smaller queues for the security lanes. At this point, passengers in the virtual queue receive priority over passengers in the general queue to proceed to a security lane, similar to how business class travelers receive priority at check-in over the economy passengers.

In this scenario the concept of VQ allocates Time windows (TWs) to passengers. A TW could be interpreted as a time interval during which passengers are allowed to bypass the general queue. The TWs could be provided in a ticket format at the check-in desks. If the passenger decides to come outside the TW, he or she would not be admitted to the priority queue.

Only those passengers who are eligible would receive a TW, which is determined by the passenger arrival time at the checking lanes (Narens 2004), from where it is assumed that they would directly head to the security lanes if no TW is offered. A passenger thus needs to arrive at the check-in lanes just prior to or during a peak interval.

When the number of security lanes is decreased, the average passenger waiting time in general increases. However, by applying the principles of virtual queuing (VQ) this effect could be limited to acceptable levels. In many occasions the average waiting time could even be reduced. The success of VQ depends on the reliability of the forecast model, the passenger arrival pattern, and the number of eligible participating passengers and the length of the time windows (TWs).

3.3 Fast track security lane or express security lane

This service provides passengers with the ability to avoid waiting in the standard queue to the security area that can be developed at peak times. Passengers holding a certain airline ticket type have granted access to this service. Additionally, the Fast Track Lane service can be pre-booked online and inside the airport facilities (i.e. electronic kiosk) several days before the travel date or even 4 hours ahead of departure.

This premium pre-book service provides all departing passengers with swift access to the airport's security area. All passengers departing are subject to the same rigorous security checks regardless of using the Fast Lane or the standard queue lane. The same criteria in relation to prohibited items i.e. limited quantities of liquids and restrictions on sharps still apply.

Having purchased a pre-book ticket for each person travelling, passengers should make their way to the security area. On entry to the security area the passenger will be required to provide the booking reference number or confirmation email and boarding card to the security staff.

If the passenger has made a booking for more than one person then the people on that booking must use the Fast Track lane together. If passengers travelling together want to use Fast Track at different times each one then they need to book the Fast Track on an individual basis. The booking for this service is non-transferable.

The Fast track ticket is valid only on the day of travel between the times specified within the booking. The passengers will not receive a refund if they do not use the Fast Track facility. Passengers must allow sufficient time to arrive at their departure gate at the published boarding time as stated by their airline.

4. SOLUTION APPROACH

The main idea behind the solution approach proposed in this paper is to deal with the 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 in a better management of the actual screening facilities by lessen the peak demands through a reward mechanism that will allow to avoid idle capacities.

A new paradigm of balancing screening capacity with passenger queuing time will be described for different operational contexts considering:

- A stochastic model for passenger preferences: each type of customer arrives according to a different general distribution
- Scaling the airport capacity considering the demand
- Queue dynamics of the passengers as they proceed through the security checkpoint
- Screening performance: provide a reward mechanism that improves the predictability of the screening service time

As a result it is expected to provide an optimal strategy to smooth the peak congestion of passenger queuing for the screening checkpoint while minimizing also the idle capacity (and in consequence the operational costs).

The key contribution of the screening slot assignment should be the efficient and effective use of available screening resources.

The goal is to revamp the flow of passengers through the screening system paradigm to provide a solution that balances the trade-off between maximizing security and minimizing the expected amount of time it takes to screen passengers and baggage through security checkpoints. In Marin 2007, queue theory is used to address the effect of queue length on service rates, and its consequences on the security screening process.

The allocation of passengers to a queuing system with multiple servers (screening facilities) to minimize the number of passenger in the queue or the amount of time the passenger spends in the queue, has been studied extensively in literature, through either static flow models (Jain 2005, Winston 1977, Filipiak 1984) or dynamic flow models (Kumar 1985, Lin 1984, Kelly 1983, Meyn 2001). However, these models lacks of a trade-off approach to maximize some form of reward.

The problem of assigning passengers to a specific time window (i.e. Slot) is performed under a static passenger assignment policy in which the time window is assigned independent of the queue behavior of prior passenger assignments and requires the proper modeling of the following aspects:

4.1 Passenger arrival Process: Peak smooth policies

The demand for screening capacity fluctuates according to the programmed amount of flights for the immediate future departure flights, the passenger arrival pattern, and its behavior during the screening process.

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 random behavior which corresponds to the occupancy of the aircraft and the other 2 factors already mentioned (arrival pattern and behavior).

This fluctuating demand leads to idle capacity during the time periods between the peaks and to the generation of queues during the peak periods as sometimes the arrival of passengers exceeds the screening capacity. In Figure 2 it can be seen the idle capacity of screening resources (screening capacity above the demand) and the queue generation when demand is above capacity. In order to balance the capacity with the demand, one solution could be to shift the arriving passengers at the security lanes out of the peak periods to idle capacity between the peak periods.

Figure 2: Unbalanced screening Capacity/Demand

The most obvious solution for this would be to develop a reward mechanism that would compensate the effort of earliness or the risk of tardiness in the preferences of the arrival process of passengers.

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The reward mechanism to be designed will be based on a win-to-win approach in which the airport will save money by avoiding idle screening resource periods and the passenger will benefit by avoiding the queuing times.

4.2 Time window range

One of the critical aspects in implementing a slot assignment policy for security screening is the right discretization of continuous time in constant or variable time intervals. Long time interval discretization has the advantage of performing more passenger assignments to the same interval, in such a way that the probability of a non-shown passenger is reduced, however it can generate unbalanced situations inside the time window period.

On the other hand, a time discretization on too short time periods can contribute to a uniform distribution of the arrival process but it can generate also several inefficiencies due to non-shown passengers.

Thus, an algorithm to determine the evaluation of a fixed or a variable time window period should be designed and validated.

4.3 Time window assignment policy

There are several factors that affect passenger pattern behavior regarding the earliness time period to get to the screening security checkpoint before the flight departure.

Among these factors, it should be considered from one side the reliability of the public transport systems that connect the hinterland with the airport, the frequency and diversity of transport means and the facilities for private transport, which somehow could be quantified in a deterministic model.

However there are some other factors which should be described from a stochastic approach due to the inherent uncertainty of the process, such as the user preferences about to be in the safe side by arriving with extra time before the departure to avoid potential queues, or frequent flyer behavior which tends to arrive with very short clearance gap.

When assigning a TW to a passenger it could lead to a situation in which extra earliness time has been assigned to a frequent flyer while a very short clearance gap could be assigned to a passenger with a safe side preference. To avoid this kind of penalties that will affect the reward mechanism, a methodology that could match passenger preferences with available capacity must be in place.

In order to provide a good quality on the TW assignment for those passengers that looks for a short clearance gap, it is important to have a better prediction of the screening process time of precedent passengers.

There is some empirical evidence that frequent fliers with short clearance gaps use to cross the security screening area with minimum time compared to tourists which have a considerable extra time before the departure time.

A mechanism to determine the potential sample of passengers that could use the slot security screening service should be properly designed according to legal regulations. Thus, for example, a potential idea to be explored could rely with an airport and/or airline Data Base in which it keeps record of the alarms fired during the lasts flights by each particular candidate. Thus, every time a passenger fires an alarm in the Rx machine because he forgot to remove liquids or computer elements from the hand baggage or it fires an alarm in the metal arc detector, it will be recorded (using the boarding pass or any other IT identification mechanism) in the airport database and/or in the airline database and it will be excluded from the candidate list for the slot security screening service during a certain amount of consecutive flights without firing any alarm.

The TW assignment model should also consider that by improving the screening process time towards a deterministic and predictable model, passenger behavior will be affected by a better confidence on the performance of the screening security checkpoint which probably will contribute to shorter clearance gaps. Thus, the algorithm should consider the changes of arrival pattern behavior due to a better confidence on the screening processes.

Finally, the slot assignment algorithm should consider some equity and fairness criteria to avoid extra earliness penalization to some passengers which flight departure is concentrated in peak periods.

Thus, the design and implementation of the TW assignment algorithm should consider not only the scheduled flights but also some reward mechanism to preserve equity and fairness criteria.

4.4 Screening dynamic reconfiguration

To avoid the idle capacity or the capacity deficit illustrated in Figure 2 the slot assignment service should consider new efficient mechanisms and layout redesign to allow the use of screening resources by the normal passengers when there are non-shown 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.

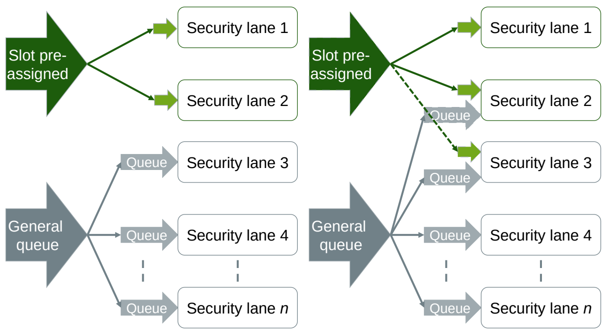

Figure 3: Priority policies for screening checkpoints

Left hand side picture (in figure 3) illustrates a rigid system in which screening facilities are distributed between slot assignment service and general passengers.

This approach is known to generate idle and deficit capacities. At the right hand side it is represented the same architecture but with some policies that allows the dynamic assignment of screening resources according to slot arrival passengers.

It should be said that the implementation of such a dynamic policy would require extra human resources to constantly re-assign resources to slot requirements in order to avoid idleness or deficit capacities.

In Figure 4, it has been represented a different approach based on a layout redesign 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.

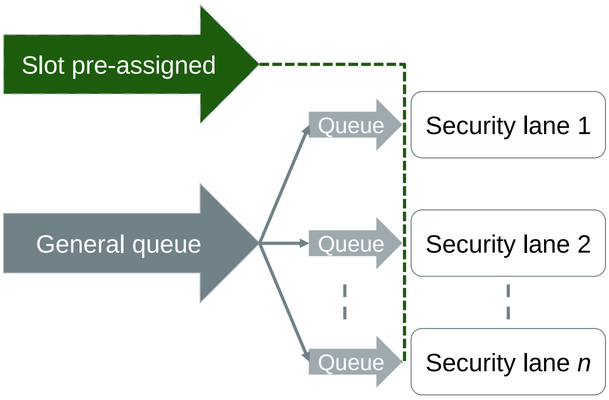

Figure 4: Layout redesign

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.

5. DISCUSSION AND FUTHER WORK

This paper describes a work in process concept towards a better balanced demand capacity in security screening process in the context of the European FP7 funded project, INTERACTION.

This solution solves different inefficiencies and points for improvement detected for the Turnaround process. The main ones solved are the need to shorten and better manage the queues at the security control and the inability to locate passengers after their way through check-in counter (if traditional check-in is done).

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

The assignment of slots to the passengers introduces additional steps to the passenger process, such as the request and reception of the security slot, which makes the passenger process more complex. This negatively impacts the passenger buy-in. But on the other hand, the passenger can have more control over the process as it will be able to better manage its time, which positively impacts the passenger buy-in.

Modeling of demand is critical to the development of this solution. The demand modeling may be done particularly for each airport wanting to implement this solution.

The passenger preferences may depend on different aspects such as cultural characteristics, type of travel, and ground access to the airport, among others. In order to have a realistic prediction of the demand, real data related to each airport and its main users must be carried out. Not only the airport accessibility and its passengers must be studied but the layout and characteristics of the airport itself, which may also influence passenger behavior and preferences.

ACKNOWLEDGMENTS

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TRAINING IN CAR TERMINALS: A MODULAR ARCHITECTURE BASED ON DISTRIBUTED AND INTEROPERABLE SIMULATION

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ABSTRACT

The paper presents a research work focused on simulating car terminal operations. Particular attention is paid on procedures and protocols currently applied when car terminal operations are carried out and a special emphasis is given on learning processes implemented to let car terminal operators learn these procedures. In such a framework, the proposed research relies on a modeling and simulation based approach devoted to improve operator's efficiency and enhance the effectiveness of training activities. As a matter of facts, operators can experience various working conditions and learn the protocols and procedures that have to be applied while interacting with a 3D virtual environment that recreates the car terminal, its processes and its actors.

1. INTRODUCTION

Car terminals are quite complex systems where many operations involving complex coordination problems usually take place. Indeed, operations in car terminals are regulated by security, reliability, optimization and synchronization protocols that each worker has to know and apply when performing his tasks.

In such a context, one of the main problems is to reduce the time taken for training new workers while keeping the risk of accidents, errors and of low performances at work as low as possible.

In the current practice, training activities avail from "traditional" tools and procedures, for instance slides and oral lessons in classroom where protocols, best practices, the terminal environment, the cars that are involved at work and the driving rules are introduced and explained to the training audience. Although this teaching approach is traditionally accepted and well known by workers, today advanced solutions and technologies can be used to make training sessions more engaging and reduce the amount of abstract information and theoretical concepts to be memorized. Furthermore, such solutions allow trainees to experience a number of different situations (e.g. different traffic conditions and weather conditions while driving, different yard and ship layout, etc.) giving evidence of the security issues they may incur. In addition, it is worth noticing that while traditional training approaches may improve the performance of workers, they involve longer times and require direct training on the real system.

Under these premises, ICO-BLG, the car terminal operator working in the port of Gioia Tauro, and the MSC-LES lab at the University of Calabria, are collaborating (under the umbrella of the Calabrian Pole for Logistics, Transport and Transformation) on a joint research project (CTSIM, Car Terminal SIMulator) which aims at innovating teaching and training approaches by using advanced tools based on Modeling and Simulation.

As far as the state of the art in the field of port operations training by using simulation approaches is concerned, it is worth saying that while many research works can be found for container terminals, there are really few works for car terminals. Indeed, in the area of container terminals, simulation is used not only for training by using 3D Virtual Simulation (Ballis and Abacoumkin, 1996; Bruzzone et al. 2010, Bruzzone et al. 2011; Bruzzone and Longo, 2013; Bruzzone et al. 2013; Massei et al. 2013; Longo et al. 2013) but also for decision making (Merkuryev et al., 1998; Henesey et al. 2006; Hadjiconstantinou et al. 2009; Macías and De La Parte, 2004; Latorre-Biel et al., 2014). As for serious games and 3D virtual simulation, many works can be cited, i.e. a meaningful example can be found in Bijl and Boer, 2011. However, a survey of the state of the art clearly shows that there is a lack of research in the field of training in car terminals by using 3D virtual, distributed and interoperable simulation (Longo et al. 2013). To this end, the proposed research work seeks to fill the gap thanks to a simulation architecture, CTSIM indented to support training activities in car terminals.

CTSIM is a 3D Virtual and Interoperable System composed by different simulators among others the parker and the driver simulator this paper focuses on. Within a car terminal, the parker is the worker in charge of giving all the indications the drivers need to park correctly the handled vehicles (e.g. cars). In turn, the driver is the worker in charge of moving vehicles from the yard to the ship and vice-versa (performing also parking operations). This paper introduces both the parker and the driver simulator that can work in a standalone mode (to allow single operator training), but they can even work in a multiplayer mode and interoperate each other sharing the same virtual 3D environment (for cooperative training). For instance, the CTSIM system can host 4 drivers (e.g. for cars) and 1 parker and they can "play" all together in the same scenario sharing the same 3D virtual environment. They can see each other and they can collaborate as it happens in a real car terminal.

Each simulator will be presented in the next paragraphs; however it is worth mentioning that, as far as the technologies involved are concerned, the CTSIM project makes use of the most innovative technologies such as Microsoft Kinect®, tracking gloves, wheel and pedals, etc., that are integrated by using dedicated software and hardware (developed at the MSC-LES lab at the University of Calabria) with the aim of simulating as faithfully as possible car terminal operations.

2. MAIN PROCESSES AND ACTIVITIES IN A CAR TERMINAL

As described in Longo at al. (2013), the main activities in a car terminal involve vehicles unloading from ships and parking in the yard area, and vehicles loading and parking on board of ships. Loading and unloading operations involve different actors with different roles.
The main actors are:

- Driver: the driver is in charge of vehicles handling. He is responsible for conducting vehicles from the ship to the yard during unloading operations and from the yard into the ship during loading operations; he is also in charge of vehicles handling inside the yard area during shifting operations. During special manoeuvres he collaborates with the quality checker and with the parker to reduce the possibility of errors.
- Taxi Driver: the taxi driver brings the drivers from the yard onto the ship during unloading operations and from the ship to the yard during loading operations. In addition, the taxi driver also carries out coordination activities, communicating with the Quality Checker and Parker, to ensure the correct loading / unloading sequence.
- Quality Checker: the quality checker has inspection and coordination functions. Inspection functions consist of verifying that: the operations are carried out according to work instructions, the dangerous points are suitably warned and the cars inspected. Coordination functions refer to those activities that are undertaken together with taxi drivers and parkers and are aimed at choosing and communicating the position (in the yard or in the ship) where vehicles should be placed ensuring that the fixed loading/unloading sequence is respected.
- Service Person: the service person is the figure responsible for the viability definition on board of ships and on the ramps; he is also in charge of first intervention and barcode insertion activities.
- Tally Man: the tally man is the figure in charge of scanning the bar code for VIN acquisition (Vehicle Identification Number) and assigning vehicles with a suitable destination (rows/parks) avoiding scanning vehicles (wrongly placed) with a different destination compared to the one assigned to the same row.
- Marshall (Parker): the marshall (parker) will ensure that vehicles are parked according to the work instructions (distances, parking on the line, check handbrake / first gear, etc.).

The activities of drivers and taxi drivers are cyclic; for this reason it becomes important for a driver to be always focused on his job to avoid any loss of efficiency that would negatively affect the overall system performances. It is worth noticing that, as depicted in figure 1, there are some "waste of time" activities like *Waiting to park, Take Taxi, Leave Taxi, Waiting to leave.*

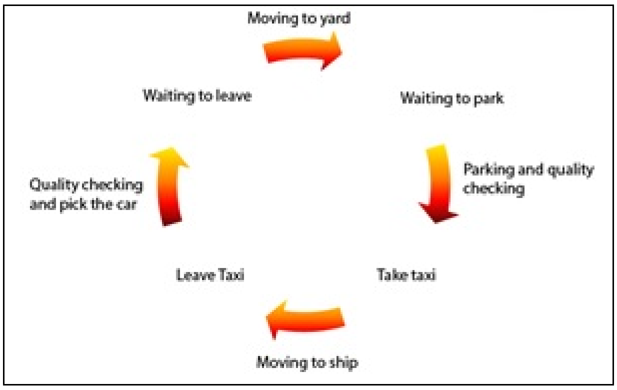

Figure 1: cyclic activities of a driver

Needless to say that all these activities must be carried out as quickly as possible to keep safeguard the terminal productivity.
Furthermore during these activities, drivers and taxi drivers behaviour has to be compliant with security protocols such as:

- they cannot accelerate to much the car;
- they cannot overheat the engine of the car;
- the cannot depart drifting;
- they cannot overpass another car;
- they cannot drive slower than what is expected;
- they cannot drive with flat tires;
- they have to respect the stops signals;
- the taxi has to stay far from the cars, at least 5 meters and maximum 10 meters;
- they have to respect speed limits;
- during the driving, cars have to be 15 meters far each other.

The departing procedure has to follow a specific order to avoid accidents and to reduce traffic problems.

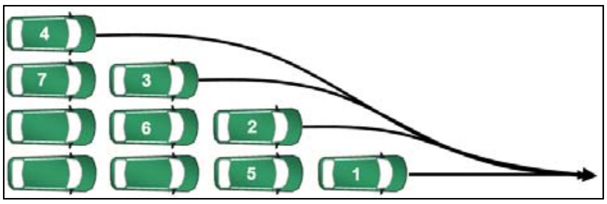

Figure 2: Departing order of cars

Drivers have to pay attention also on the near cars, especially in the break out activity. The steering angle during the departure does not exceed 30° until the car is completely exited from the park position.

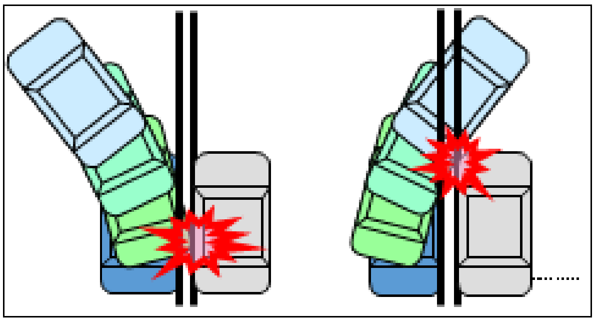

Figure 3: Departing steering angle error

During the movement towards the parking area, cars have to be 15 meters far from each other to avoid any kind of collision.

When the driver arrives to the parking area, he must follow all the instructions given by the parker, who coordinates all the parking operations. When the parking operation is complete, before leaving the car, the driver has to:

- insert 1st gear;
- pull the handbreak;
- backward the seat;
- turn off the lights;
- close the windows.

After completing these operations, the driver takes again the taxi and returns on board the ship to pick another car.

Parkers give the instructions to park the cars and coordinate the traffic. Parker and drivers communicate by gestures as shown in the following pictures.

Figure 4: straight wheels gesture

Figure 5: steer 1/3 to the right gesture

Figure 6: steer completely to the left gesture

Figure 7: stop gesture

Figure 8: put into reverse gesture

3. THE CTSIM ARCHITECTURE

The main idea behind CTSIM is to develop a system based on virtual simulation to train all the actors involved in car terminal operations. Currently there is an ongoing research project (also named CTSIM) carried out by the car terminal operator of the port of Gioia Tauro, Italy (ICO-BLG) and the MSC-LES lab (Modeling & Simulation Center – Laboratory of Enterprise Solutions) at University of Calabria. At this stage the main goal of the research project is to develop the parker simulator (for parkers training) and the car simulator (for drivers training) that will be used to teach parkers and drivers all the protocols, best-practices and procedures.

The car simulator simulates the vehicles physics (a medium size car is considered) including the physics of the engine, the gear, and the wheels friction with asphalt. The car simulator also implements a collision engine that reproduces all the collisions and the related damages (see figure 9). The car simulator includes not only a medium car, but also a truck simulator (with tractor and trailer). In this case, of course all the differences like weight, steering angle, engine behaviour, brakes, velocity, acceleration, etc. are considered.

Figure 9: car simulator – outside view after a collision

Figure 10: car simulator – inside view after a collision

The Parker Simulator is an avatar driven simulator that can be controlled by the parker to perform training operations. The simulator implements gesture recognition and tracks the parker movements by using the Kinect for the body, and a tracking glove for fingers gestures. The tracking glove is needed because the tracking precision of the Kinect is not enough for fingers movements recognition. It is worth saying that the tracking glove has been completely developed at MSC-LES lab in order to reduce costs and come up with a low-cost solution to be integrated as part of the CTSIM architecture (the description of the tracking glove is out of the scope of this paper).

The movement of the avatar is controlled by using a joystick therefore the parker can move in the parking area (on the yard or on board the ship), to provide the drivers with the right indications for supporting cars parking operations.

Figure 11: Parker Simulator, example of hand gestures

The configuration of the environment is another important aspect of CTSIM. Usually, a car terminal can host different types of ships, with different layouts and ramps. Operations may take place with different weather conditions and also with different positions of the cars in the parking area and on board of the ship. As far as the ship configuration is concerned, these features (configuration of the ship) have been included in another CTSIM module called ship simulator. An additional module is currently under development to allow the user to set up different yard configurations and training scenarios.

3.1. Network communications in the CTSIM distributed and interoperable simulation

Interoperable and distributed simulation is a mandatory approach when dealing with cooperative training (Bruzzone et al. 2008). As already mentioned the CTSIM system includes multiple simulators (the car simulator, the parker simulator, the ship simulator, etc.) able to run on different computers (distributed simulation) and to interact each other (interoperable simulation) by sharing the same virtual environment as well as different objects, attributes, interactions and parameters. Therefore each simulator is able to run standalone or combined with other simulators. In addition, multiple instances of the same simulator can run and interact each other, e.g. four car simulators and one parker simulator; this configuration can be used to train (at the same time) four drivers and one parker (figure 12 depicts a double view of the car simulator and the parker simulator).

The CTSIM network architecture is modular, as was explained before. It uses a TCP/UDP connection between all the simulators, with Unity 3D communication protocols and messages and share only the 3D models that each player is using, by sending all the information (e.g., positions, rotations and other useful information) to recreate the same 3D visualization in all the simulators sharing the same 3D scene. The network must be characterized by a low communication latency even considering the high number of entities within each simulator and the complexity of the 3D models. For this reason, the 3D models of the environment (ship, parking area, static objects) are pre-loaded in each client; what the network shares during the simulation are only the 3d models of the cars and parkers, and all the dynamic objects.

Figure 12: Double view: the car simulator and the parker simulator

4. THE CAR SIMULATOR

The Car Simulator recreates the standard operations of various types of vehicles to be loaded/unloaded onto/from ships. All the movements of the vehicle are recorded, and it is possible, at runtime during the simulation, to evaluate the accuracy of each operation.

As described in Longo at al. (2013), the Car Simulator can be controlled by specific hardware interfaces (eg. Steering wheel, pedals, dashboard, etc.). Currently a real car cockpit including steering wheel, pedals, gear and all the other commands that can be usually seen in a real car, is under preparation. The integration of the real car cockpit with the Car Simulator will be done by using Arduino platform, stepper motors as well as other low-cost dedicated hardware. The main goal is to have (at the end of the CTSIM project) a real car cockpit fully integrated with the Car Simulator and multiple secondary workstations equipped with game controls (steering wheel, pedals, joysticks, etc.) and integrated with the Car Simulator. Therefore it will be possible to carry out cooperative training of drivers (one driver using the real car cockpit simulators and the others using the secondary workstations. Each workstation (as well as the real car cockpit) will be equipped with a sound system in order to provide the user with the feeling of driving a real car within a real car terminal environment. The Car Simulator is also equipped with multiple views that allow the visualization of the vehicle from multiple perspectives when moving within the port area.

As far as the collisions engine is concerned, each vehicle has a mesh that is sensible to any kind of collision. Depending on the strength of the collision, the collisions engine calculates the damage and modifies the 3d aspect of the vehicle. This engine is also used to evaluate the level of cars damages, so it is possible to understand the real consequences of a behaviour (currently the collision engine is under modification to include a cost function able to evaluate direct and indirect cost related to vehicles collisions and accidents).

In order to optimize the work of the CPU and GPU, because of the high number of vehicles in a car terminal, the Car Simulator loads only one geometric model for each vehicle and it replicates this model to render all the vehicles displayed in the virtual scene. This approach allows the trainer to set the parking conditions easily and, at the same time, allows the optimization of the GPU workload since only one vehicle is loaded on GPU RAM while the others are rendered as a replication of this one.

Another important part of the Car Simulator, is the performance evaluation module. All the procedures and activities carried out by a driver are evaluated and recorded (real time) during the game. Therefore, it becomes possible to correct mistakes, understand wrong and dangerous behaviours, calculate parking accuracy, keep under control the vehicles velocity and also check if all the security protocols are correctly applied. Data recorded during the training sessions jointly with replay functionalities become an indispensable support for de-briefing sessions in which the trainees have the opportunity to see, in a 3D Virtual Environment, their errors and understand the training gaps that should be filled in.

5. THE PARKER SIMULATOR

The Parker Simulator development is a really complex work that merges different types of technologies to reach a good level of accuracy for tracking correctly all the movements of a real parker and reproducing all these movements in a 3D Virtual Environment by using an avatar. The use of the Microsoft Kinect® in research works is diffused, (especially during the last years and for gestures recognition and training). Examples of works in this area can be found in Guyon et al. (2012), Fothergill et al. (2012).

The tracking of the main bones of the body was performed by using the Microsoft Kinect v2 connected to Unity 3D for visualization. Therefore, the Kinect, by using cameras and IR sensors, understands the position of the bones and sends all these data to Unity 3D, updating the position of each bone in the avatar 3D model. The main problem encountered by using the Kinect is related to the accuracy of fingers and of little parties of the body; such accuracy is pretty low and therefore it is not enough for the purposes of the Parker Simulator (as already shown in figures 4 to 8, the Parker uses the arm, the hand and the fingers to give specific indications to the driver that usually has to perform quite complex parking operations in narrow spaces). For this reasons, in order to track correctly both hands and all the fingers, we decided to use a Tracking Glove created and developed “in-house” at MSC-LES lab. The tracking glove allows recognizing the different gestures of a parker and evaluating the accuracy of these gestures. A literature survey shows that different studies were already made with different types of gloves (e.g. Wang and Popović, 2009) and other technologies to track the movement without gloves (Utsumi et al., 1999). However, the main goal of the Tracking Glove developed as part of the CTSIM project is to create a low-cost solution (less then 500.00 €) to be specifically used for detecting Parkers gestures.

The last thing developed and implemented for the Parker Simulator is the possibility to walk and move in the car terminal. Indeed, for a real parker it becomes critical to move around, look at the distances between vehicles and understand gestures that have to be done for supporting drivers operations. For this reason, by using a joystick the user can walk in the terminal (both in the yard area and on board ship). Therefore 3 different technologies (the Kinect, the tracking glove and the joystick) are jointly used to let the avatar recreating the movements and the gestures of a real parker. These 3 technologies are characterized by low-cost hardware but, at the same time, really suitable for operators training within car terminals.

6. CONCLUSIONS

The paper presents the CTSIM system that is currently under development for operators cooperative training in car terminals. The CTSIM includes multiple simulators but this paper is mostly focused on the car simulator and on the parker simulator. A preliminary study of the state of art was made before proceeding in the design and in the implementation of the simulators; in particular training simulators for port operators were analyzed. The study clearly reveals how Modeling & Simulation can be profitably used for operators training in port environment. Indeed, many simulators have been developed and used to train ships pilots, forklift operators, Reach Stacker operators, Straddle Carrier operators, Gantry Crane operators, Offshore Crane operators, Tower Crane operators, etc. However, there is clearly a lack of research in the field of 3D Virtual Simulators for operators working in car terminals. The analysis of the current procedures used in car terminals has also confirmed the effectiveness and the potential benefits of Modeling & Simulation in such a dynamic and complex environment.

Indeed, the paper illustrates the main activities and processes of a car terminal including security protocols, best-practices for the driver and parker. In such a context, the high number of procedures that each person has to learn and how workers interact each other are relevant. For this reason, the MSC-LES lab at University of Calabria and ICO-BLG decided to carry out a research project to develop a simulation based solution for operators training in a car terminal. In particular, this paper describes the Car Simulator that is able to simulate a medium car, a truck (tractor and trailer) and all the procedures performed by a driver in a car terminal and a Parker Simulator that, by using the Kinect, a tracking glove and a joystick, tracks all the human body and also the fingers gestures, to simulate with a high accuracy all the movements and gestures of the parker.

This two simulators are distributed and interact each other by sharing the same virtual environment; the connection is guaranteed by a TCP/UDP protocol also able to work on separated computers. It is possible also to have more than one Car Simulator and more than one Parker Simulator for cooperative training.

The CTSIM project is still ongoing and the authors are working to complete the whole system by the end of 2014.

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DATA FUSION AND SIMULATION AS DECISION SUPPORT SYSTEM IN NAVAL OPERATIONS

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ABSTRACT

This paper proposes an approach for creating a decision support system in Naval Operation combining statistical approaches with modeling and simulation; it is proposed as case study the problem of maritime piracy; in this context data fusion based on Bayesian Networks and Dempster-Shafer could be applied to develop innovative classification solution to identify suspect behaviors and to support to the Naval Planner; indeed this paper focuses on the use of a discrete event simulator in order to create the evaluation framework to measure the effectiveness of the proposed classification approaches respect a realistic scenario inspired by Aden Gulf piracy**.**

Keywords: *Discrete Event Simulation, Bayesian Networks, Dempster-Shafer theory, Anti-Piracy, Intelligent Agents*

1. INTRODUCTION

Decisions in military operational contexts are complex problems affected by many factors and boundary conditions; in particular in maritime asymmetric warfare the uncertainty on large data set are representing critical elements affecting the planning as well as the decision making capabilities. In contexts similar to this one, wrong decisions could lead to dramatic consequences, so it is evident that human responsibility in decision making can't be substituted, therefore the use of simulation and decision support systems (DSS) could improve reliability, efficiency and effectiveness of the processes. This way, this paper is focusing on creating aids for supporting decision makers instead of addressing automated decision systems driven by computational systems.
From this point of view, it results useful to consider the possibility to combine modeling and simulation (M&S) with Dempster-Shafer methodologies for facing this challenge; indeed these methods represent a generalization of Bayesian models and could support classification problems within complex environments. Moreover the aim of the proposed decision support systems is addressing the necessity to be able to proceed in identifying and classify not cooperative targets within an asymmetric mission environment.
The paper proposes a simulation solutions to be used for testing the tactical aid and classification system used in the context of naval anti-piracy operations; this projects benefits from previous models as proposed in figure 1 (Bruzzone et al. 2011a); this stochastic simulator is able to estimate the effectiveness of the classification algorithms and of the overall naval plan respect the specific boundary conditions, indeed such approach could lead also to develop training aids to introduce naval planner in effective use of the input provided by intelligent classification systems. The paper provides experimental results in this case while in future the authors will finalize details of the classification approach in this case study and related integration with the simulator.

2. PIRACY AS APPLICATION CASE STUDY

The new warfare scenarios are characterized by new unconventional threats (i.e. terrorism, insurgency etc).
In maritime domain, piracy attacks are increasing over, in particular along Somalian Coast and in Arabian Sea.
From 2008 around 1000 piracy attacks are reported by the IMB (International Maritime Bureau) into the annual report and most of episodes are attributed to Somalia pirates. Those attacks generate huge economic and social damages to the entire world due to the great value of goods moved by sea. In fact, in a pirate attack often the interests of many countries are affected: the state of the attacked vessel, hostage's countries, the State of the industrial company owner of the cargo and so on.
The maritime piracy has become a critical issue in specific regions (for instance the Somalia coast) due to local factors such as political and socio-economical

instabilities since 2006. Actually, the maritime piracy is not a new phenomenon, but changes in geographic “hot spots”, the increased frequency of incidents and the severity of attacks are requiring to face the current maritime piracy situation in a more effective and efficient way. For these reasons it could be interesting to develop innovative solutions for classification and simulation.

Fig.1: Discrete Event Simulator based on PANOPEA

Different models were developed to analyze the maritime traffic and to support maritime surveillance systems (Monperrus et al., 2008; Xiao et al. 2010) propose a framework of the Dynamic Data Driven Multi-Agent Simulation system in the maritime traffic domain.
The use of Modeling and Simulation (M&S) to address complex problems is largely used in a wide spectrum of fields such as military (Bruzzone 2010; Longo et al. 2008; Merkuryev et al. 1998), logistics (Merkuryev et al., 2009; Engelhardt-Nowitzki et al. 2013; Longo, 2014, Prado et al. 2014), distribution and transportation (De Felice and Petrillo, 2013), medicine (Diaz et al., 2012), economics ones. Furthermore, simulation is an evolving sector and the continuous improvement of M&S, with special reference to distributed interoperable simulation provides new opportunities for innovative applications where it is necessary to combine different models; in our case the possibility to connect the simulator with real C2 (Command and Control) systems for training or with Data Farms for scenario awareness have a big potential.
Indeed Intelligent agents are a new paradigm for developing software applications (Oren et al. 2000; Piera et al., 2013); more than this, agent-based computing has been hailed as ‘the next significant breakthrough in software development’ (Sargent, 1992), and ‘the new revolution in software’ (Guilfoyle and Warner, 1994).
The advantage to introduce IA (Intelligent Agents) in this sector is based on several aspects; one pretty interesting is their existing, even if limited, capability to self-explain the motivations of their actions and to interact dynamically with users (Bruzzone, Massei 2007; Moraitis, Spanoudakis 2007).

There are several methodologies that could be investigated to be used for creating intelligent agents to direct automatic consensus creation such as AHP or GMCR (Bruzzone, Massei, Tarone, Madeo 2011b; Inohara 2010).
In 1763 Thomas Bayes published his paper titled “An Essay towards solving a Problem in the Doctrine of Chances” as a solution to a problem of inverse probability, but the term “Bayesian networks” was coined by Judea Pearl in 1985 where in his essay “Probabilistic Reasoning in Intelligent Systems” summarized the properties of Bayesian networks and established Bayesian networks as a field of study (Pearl, 1988; Pearl and Russell, 2002).
Dempster-Shafer theory is a generalization of the Bayesian theory of subjective probability; the basis of this theory are included in two papers: Shafer’s “A mathematical theory of evidence” (1976) and Dempster’s “Upper and lower probabilities inducted by a multivalued mapping” (1967). From a quantitative point of view, Dempster-Shafer theory is equivalent to probabilistic argumentation.

3. PIRACY AND CLASSIFICATION

In the proposed piracy scenario, the threats (i.e. pirates) are usually hiding within a large traffic of small medium size boats looking for proper opportunity to attacks. So the decision maker should be able to properly decide about the different alternatives in patrolling an area as well as in the best way to address suspects within this context; often among many different objects it is required to identify the most effective approach to guarantee their classification, their nature, intentions, dangerousness and efficiency of the feasible actions. Therefore this problem need to be solved considering also efficiency aspects that strongly affect the sustainability of the mission; for instance cost reduction and effectiveness improvement could allow protecting large areas for longer times with limited resources, guaranteeing economic feasibility of the mission itself.
The not-linear nature of the problem outlines the strong dependence of the proper solution from the boundary conditions (i.e. patrolling resource capabilities, pirate attack procedures, boarding times, etc); due to this fact the simulation is the best approach to be able to quickly evaluate different alternative Courses of Actions (COAs) as well as different hypotheses on the scenarios.
An interesting issue is due to the fact that the threats are not collaborative and adopt behaviors devoted to guarantee their camouflage within the general traffic; these aspects become pretty challenging for classification because in this case the target detection and proper classification don’t rely on technical features as it happen in traditional cases. In traditional naval classification the threat is usually identified by considering its features such as Radar Frequency collected by ESM (Electromagnetic warfare Support Measure) or length and number of chimney estimated by

the analysis of the ship silhouette captured by an ISAR (Inverse Synthetic Aperture Radar); vice versa in the proposed scenario the pirate boat is often exactly identical to a small medium size boat, just because the pirates are just hiding inside these ones; the capability to identify the type or even the name of the boat don't contribute too much in detecting pirates.

In technical terms here the classification problem deals with classification of suspect conditions and behaviors, while feature analysis is much less sensitive in this process.

Obviously in order to classify behaviors or boundary conditions that are correlated to high probability of pirate activity requires quantification of these elements in proper way; this approach is pretty challenging considering the high variability that corresponds to the necessity to introduce many parameters.

The authors in order to face this issue decided to introduce fuzzy modeling; indeed this approach gives the opportunity to support efficiently the decision making process, because of its capability in quantify these parameters in semantic terms by acquiring measures of their perception; in this way it could be possible to estimate by a fuzzy allocation matrix the degree of suspect affecting a boat approaching a cargo; at the same time the use of fuzzy membership functions could be used to extract the meaningful of specific boundary conditions respect the threat nature.

Based on this approach it becomes possible to elaborate the information and behaviors of different actors by using data fusion (Fenton and Neil 2007). The proposed approach focuses in the development of a data fusion architecture able to apply these methodologies to the specific case and in particular to the development of a platform supporting decision making and classification for ship commander of both military vessels and commercial cargo.

4. SIMULATION AND CLASSIFICATION AS COMBINED DSS

The Naval Operation requires to deal with uncertainty even in the information age; as anticipated in the proposed case study, it is challenging to obtain clear identification of the asymmetric threats (i.e. piracy) a through traditional technological surveillance: pirates hides among generic small medium size boat traffic and don't are characterized by features that could be easily detected by sensors (e.g. infrared and/or ISAR imaging, EMS etc); in this case it is fundamental to combine classical sensor data with information, behaviors, reports, boundary conditions; therefore specific features could also influence the classification (e.g. high speed); due to these reason, it is interesting to develop an innovative data fusion approach to classify suspect targets in order to estimate their probability to represent non collaborative threats such as a pirate boat while they operate as fishermen waiting for an opportunity to attack.

In this context the use of this innovative classification algorithms represent a significant improvement in planning naval operation by providing to the decision makers an indication where to concentrate their resources in patrolling an area; this approach support the definition of most effective approach for inspecting suspects boats.

Indeed the integration of this approach with simulation allows evaluating the reliability and efficiency of the proposed naval planning; in the proposed case the use of stochastic discrete event simulation allows to estimate the Measure of Merits (e.g. patrolled area, number of effective inspections) in statistical terms by conducting risk analysis and by defining their confidence bands.

Therefore, it becomes possible to estimate the probability to successfully identify the pirates by using resources (e.g. helicopter) for inspecting a specific suspect boat; the proposed solution allows considering also the information provided by reports received by local authorities and intelligence resources.

The simulator estimates costs and times to accomplish specific planning, so it represents a decision support system able to identify most promising alternatives among the necessity to inspect multiple suspect boats with different resources; simulation could be used also for coordinating a vessel task force in patrolling a specific area respect a particular threat.

5. CLASSIFICATION PROBLEMS

In classification problems, unfortunately, complete statistical knowledge regarding the conditional density functions of each class is rarely available, which precludes application of the optimal Bayes classification procedure. In these cases the adoption of the Dempster-Shafer methodologies looks really feasible. When no evidence supports one form of the density functions rather than another, a good solution is often to build up a collection of correctly classified samples, called training set, and to classify each new object using the evidence of nearby sample observation.

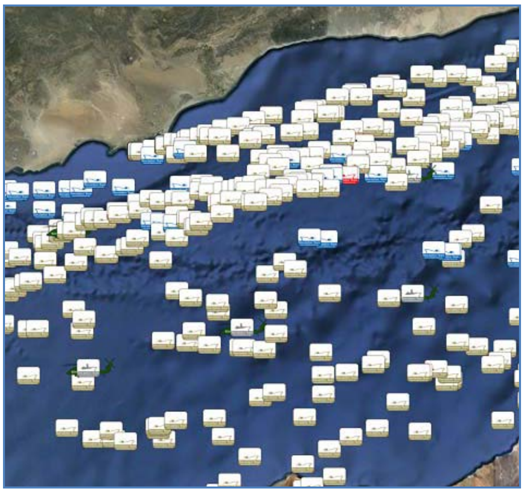

Fig.2: Simulator integrated within GIS Representation

Indeed, a Bayesian network is a graphical model that encodes probabilistic relationships among variables of interest (Castillo 1997). When used in conjunction with statistical techniques, the graphical model has several advantages for data analysis; first of all, the model encodes dependencies among all variables, it readily handles situations where some data entries are missing.

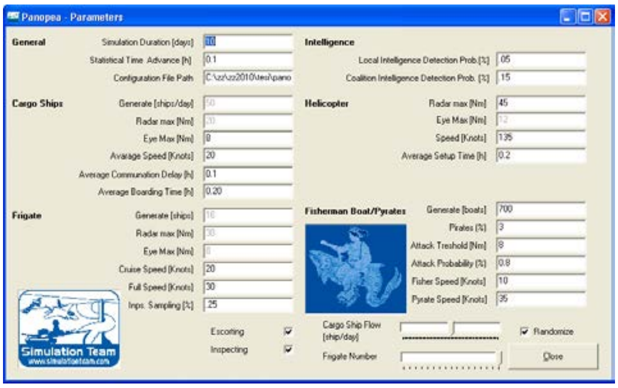

Fig.3: Simulator Main Input Variables

Another important advantage of the proposed approach is related to the fact that the Bayesian networks are useful to learn causal relationships, to gain understanding about a problem domain and to predict the consequences of intervention. In addition to these aspects, the proposed models combine causal and probabilistic semantics, so they are the ideal representation for fusion of a priori knowledge (which often comes in causal form) and current data. Last, but not least, Bayesian statistical methods, in conjunction with Bayesian networks, offer an efficient and principled approach for avoiding the data overfitting (Ben-Gal 2007).

The focus in this paper is on naval operations so the Bayesian network and Dempster-Shafer theories should be applied in this context; as anticipated it is challenging to identify different kind of boats by high level data fusion in order to understand and forecast their intentions and nature based on their behaviors (Darwiche 2009).

Formally, Bayesian networks are Directed Acyclic Graphs whose nodes represent random variables in the Bayesian sense: they address observable quantities, latent variables, unknown parameters or hypotheses. In these networks the Edges represent conditional dependencies, while not connected nodes represent variables that are conditionally independent of each other. Each node is associated with a probability function that takes as input a particular set of values for the node's parent variables and gives the probability of the variable represented by the node. For example, if the parents are *m* Boolean variables then the probability function could be represented by a table of 2^m entries, one entry for each of the 2^m possible combinations of its parents being true or false. Similar ideas may be applied to undirected, and possibly cyclic, graphs; such are called Markov networks (Gelman et al. 2003).

Efficient algorithms exist that perform inference and learning in Bayesian networks; Bayesian networks that model sequences of variables (*e.g.* speech signals or protein sequences) are called dynamic Bayesian networks, while generalizations of Bayesian networks able to represent and to solve decision problems under uncertainty are called influence diagrams (Neil et al. 2005).

The first step of this analysis consists in defining the critical variables to be considered in these algorithms:

- danger distribution areas
- object dimension
- object speed
- object direction respect the potential target
- number of objects proceeding in formation
- distance of object from coast
- intelligence data and information
- weather conditions
- waves periodicity
- historic data

6. SIMULATION MODEL

The proposed model is based on discrete event stochastic simulation and it reproduces a piracy scenario in the Horn of Africa, a very critical area in terms of pirates' attacks against cargo ships especially during 2009-2011. This scenario includes navy vessels and helicopters, intelligence assets, ground bases, cargos as well as other boats (i.e. fisherman and yachts) and pirates hiding in the general traffic. The proposed simulator is derived from PANOPEA simulator (Bruzzone, Tremori, Merkuryev 2011a); in this simulation engine the user is able to set all major simulation features including Simulation Duration, Stochastic Influence and Replications.

The simulator is also integrated with a GIS (Geographic Information System) in order to visualize the whole scenario that include over 1500 small medium size boats, hundreds of commercial cargos plus the patrolling vessels (see figure 2); all these elements operates driven by the IA in the Aden Gulf reacting each other and to the evolution of boundary conditions: for instance small boats sail back to their ports when weather conditions are degenerating, or a vessel moves to a Naval Base in case of severe failures.

The entities are directed by IA-CGF (Intelligent Agents Computer Generated Forces) and apply strategies for succeeding based on their scenario awareness (Bruzzone, Tremori, Massei 2011c).

In addition, the simulator model different C2 (Command and Control) strategies, indeed the Simulation Team implemented different simulators addressing alternative C2 Architectures, including hierarchical and edge solutions corresponding N2C2M2, NATO NEC Command and Control Maturity Model (Bruzzone et al. 2009).

The model reproduces piracy activities for evaluating different strategies in N2C2M2. This simulator is a stochastic discrete event simulator integrated with IA-CGF (Intelligent Agent Simulation Computer Generated Force) in HLA (Bruzzone et al. 2011d).

The following actors are part of the simulation model:

- **Pirates**, different attack modes are considered: Outrunning, Maintaining Innocent Speed, Following a Ship, Hiding between Ships, Swarming. The main characteristics of these units are: agile structure, knowledge of the sea area, support from local population and in some case from political structure.
- **Navy**, including the vessels of different coalition forces patrolling the area. The command and control system. Different C2 (Command and Control) level of maturity are modeled including conflicted, deconflicted and collaboration approaches as well as C2 edge. Patrol modality is based on use of vessels (i.e. frigates and destroyers), helicopters, rigid hull inflatable boats (RHIB), Unmanned Aerial Vehicles (UAV) & special force squads. These platforms includes stochastic variables related to their reliabilities and availabilities.
- **Cargos** correspond to commercial ship travelling on the area in the direction of Suez Channel, Cape of Good Hope and/or Far East.
- **Small Medium Size Boats** represent the general traffic created by fishermen boats, small boats devoted to service and feeders sailing in the area, they could include also pirate support boats.
- **Intelligence Agencies**, that represent critical support for the Navy in order to identify and predict pirates activities by using resources, instruments and techniques such as: field agents, data analysis, special commandos, satellite and communication technologies.
- **Local Authorities**, represent Local Coast Guards and Authorities that could provide additional information and resources for additional control of the area; it evident that some of the coastal countries could represent additional resources, while someone has low credibility being characterized by unstable government, strong presence of gangs, warlords etc. The trustiness of Local Authorities is subjected by dynamic evolution considering the possibility of corruption or sympathy with pirates; due to these reason the adoption of an agile approach in C2 could lead toward the necessity to manage the structure dynamically.

In this context the False Alarms (FA) are defined as suspect boats that don't hide pirates; the FA are requested to be checked and/or inspected due reports originated by intelligence, local authorities or cargos.
The table below is a synthesis of some high level variable defining the scenario.
The use of the discrete event stochastic simulator allows users to carry out experiments over the scenario by changing several parameters related to boundary conditions as proposed in figure 3 (e.g. weather conditions, pirate distribution probabilities, intelligence effectiveness) or vessel characteristics (e.g. Cargo Average Speed, Navy Vessel Cruise Speed and Full Speed, Radar Range and Eye Range of View).

Cargo ship	
Number of Cargo Ships	Ships/day
Radar Max	Nm
Eye Max	Nm
Average Speed	Knots
Average Communication Delay	Minutes
Average Boarding Time	Minutes
Frigate	
Number of Navy Vessels	Ships
Radar Max	Nm
Eye Max	Nm
Cruise Speed	Knots
Full Speed	Knots
Inspection Time	Minutes
Intelligence	
Local Intelligence Detection Prob.	%
Coalition Int. Detection Prob.	%
Helicopter	
Radar Max	Nm
Eye Max	Nm
Speed	knots
Average Setup Time	Minutes
Small Medium Size Boats and Local Traffic	
Number of Boats	
Pirates	%
Threshold Distance for a Pirate to Attack a Cargo	Nm
Attack Probability	%
Small Medium Size Average Speed	knots
Pirates Maximum Speed	knots

Table 1. Parameters to be set in the Simulator

In addition to these aspects, the users are able to enable Escorting and Inspecting modes in order to activate strategies about escorting ships with same as well as inspections on suspect boats carried out by frigates and helicopters.

6. EXPERIMENTAL ANALYSIS

The stochastic simulator has been validated dynamically by using ANOVA (Montgomery 2000).
Through the analysis of Mean Square pure Error (MSpE) it is possible to determine the optimal duration of simulation run by identify the point of stabilization of the experimental error on the controlled variables.

$$\bar{Y}_i(t) = \frac{\sum_{j=1}^{r} Y_{ji}(t)}{r}$$

$$MSpE_i(t) = \frac{\sum_{j=1}^{r}\left(Y_{ji}(t) - \bar{Y}_i(t)\right)^2}{r-1}$$

$$ACFp_i(t) = \frac{2\lambda}{\bar{Y}_i(t)}\sqrt{\frac{\sum_{j=1}^{r}\left(Y_{ji}(t) - \bar{Y}_i(t)\right)^2}{r-1}}$$

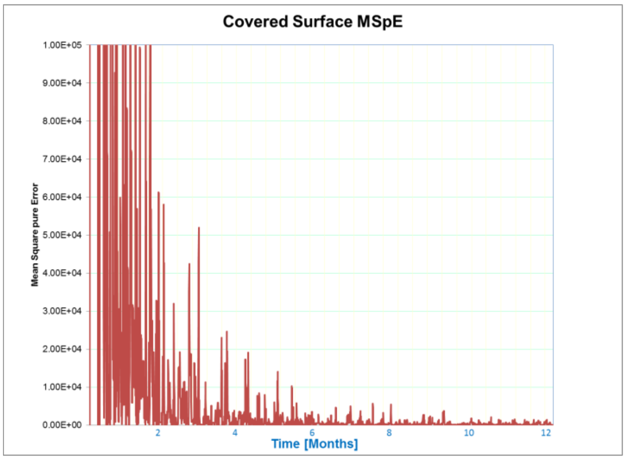

Fig.4: Total Covered surface MSpE

$\bar{Y}_i(t)$ Mean of the i-th controlled variable at t time over r replications obtained by changing random seeds of statistical distributions

r number of replications obtained by running the simulator just changing random seed and keeping same values for boundary conditions and independent variables

$Y_{ji}(t)$ Value of the i-th controlled variable at t time On the j-th replication

t simulation time

$MSpE_i(t)$ Mean Square pure Error at t time on the i-th controlled variable

$ACFp_i(t)$ Amplitude in percentage of the confidence Band of the i-th controlled variable at t time

λ percentile of the desired confidence band normally estimated based on a t of student distribution

The analysis has been carried out over several target functions including among the others:

- Total Detections
- Total Correct Classifications
- Total Correct Engagements
- Total Pirates in the Area
- Detected Pirates in the Area
- Properly Classified Pirates in the Area
- Successfully Engaged Pirates in the Area
- Total False Alarms in the Area
- Detected False Alarms in the Area
- Properly Classified False Alarms in the Area
- Improperly Engaged False Alarms in the Area
- Recently Covered Area
- Total Covered Area
- Total Costs
- Total Number of Escorts
- Total Number of Inspections by Helicopters
- Total Number of Inspections by RHIB
- Total Number of Inspections by UAV

In the following graph it is presented the convergence of the MSpE respect a subset of these variables; for instance in figure 4 it results evident that the Covered Area stabilize its variance within 4 simulation months.
Similar analysis in terms of MSpE time evolution is proposed in figures 5, 6 and 7 addressing costs, total FA detections and comparative analysis on successful classification ratio on pirates and FA.
The FA and Pirate Detection Effectiveness are presented as ration among number of entities successfully checked respect their total number.

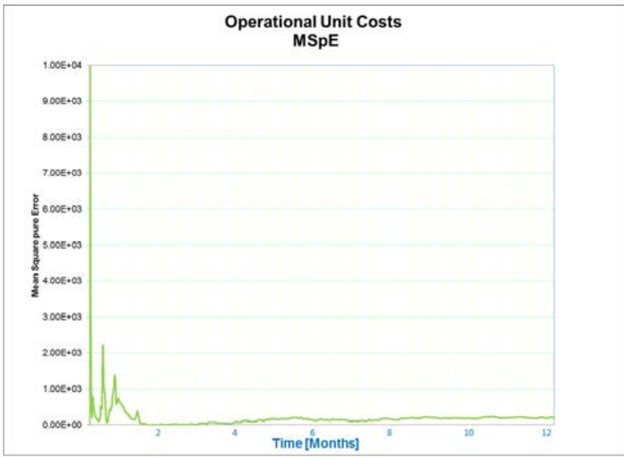

Fig.5: Operational Unit Costs MSpE

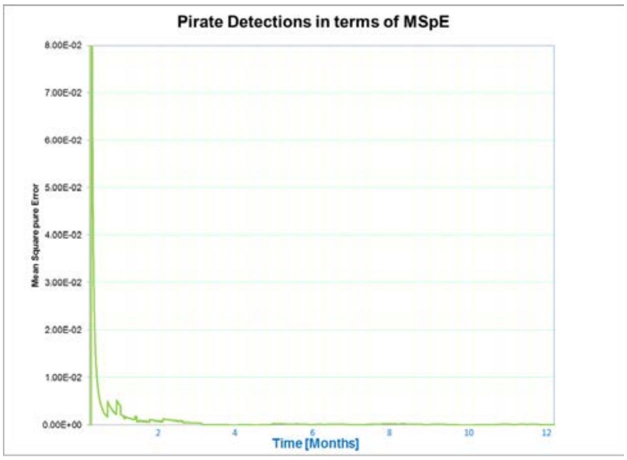

Fig.6: Pirate Detections MSpE

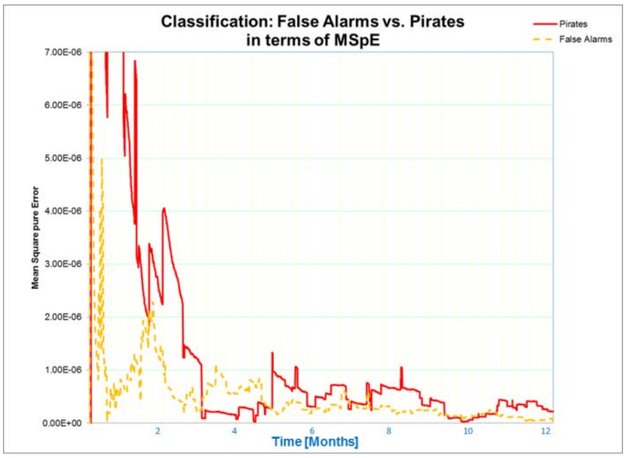

Fig.7: Classification False Alarms vs. Pirates MSpE

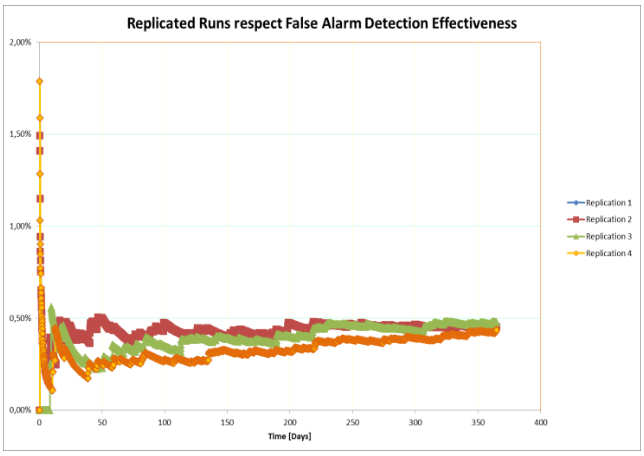

Fig.8: Replicated runs: FA Detection Effectiveness

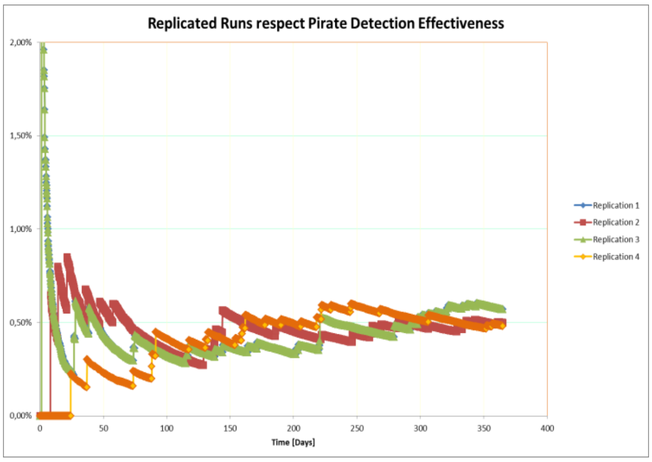

Fig.9: Replicated runs: Pirate Detection Effectiveness

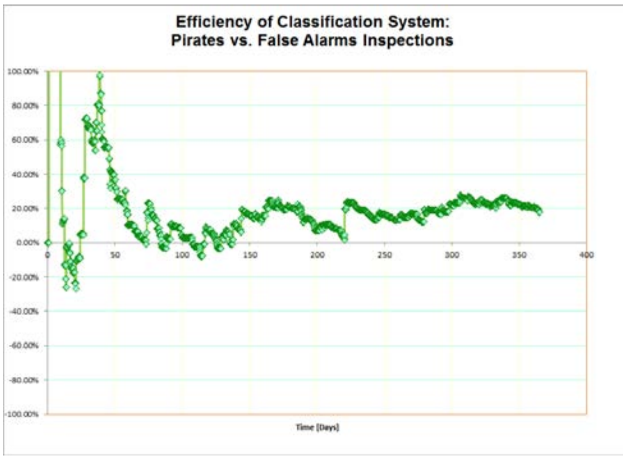

Fig.10: Benefits of the Classification System

The Figure 10 proposes the ratio of Inspections on real Pirates hiding in general traffic respect suspect contacts resulting in innocent boats (FA):

$$IE(t) = \frac{IFA(t) \cdot TPy(t) - IPy(t) \cdot TFA(t)}{IPy(t) \cdot TFA(t)}$$

IE(t) Inspection Efficiency Metrics at t time
IFA(t) Total Completed Inspections resulting in FA at t time
TFA(t) Total FA in the area at t time
IPy(t) Total Completed Inspections resulting in Pirates at t time
TPy(t) Total Pirates in the area at t time

It is evident that the number of targeted pirates is 20% higher than FA confirming that the classification algorithms directs the resources of the Navy to inspect most effective targets.

7. CONCLUSION

The simulator proposed was successfully used to carry out preliminary experimental analysis for validating the new classification modes proposed; currently the authors are working on tuning the data fusion algorithms as well as the fuzzy models in order to improve the efficiency of the algorithms, while the simulator is under further development in order to include additional details.
This research will be extended to conduct additional experimental campaigns in other geopolitical areas as well as to cover other operational needs such as maritime interdiction and/or sea border protection.

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