PERFORMANCE EVALUATION OF CONTAINER TERMINAL OPERATIONS

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ABSTRACT

Due to the recent increase in global trade of finished consumer goods the worldwide container traffic has grown dramatically. As a result, new terminals opened and existing terminals face a much higher container turnover than before. In order to meet these challenges, one of the biggest container terminals in Turkey seeks to reconsider its terminal operations and to improve its overall logistics performance. This paper presents an Arena-based simulation model to analyze the terminal operations and to highlight directions for the future development of the terminal configuration and the operational management of the terminal. The simulation model allows analyzing some pre-defined performance criteria such as average productivity, average resource utilization and average waiting time of the resources to identify potential bottlenecks of the operational areas, namely the quay cranes, the storage yard and the transportation system. Preliminary simulation results are presented in the final section of the paper.

Key Words: Simulation, performance evaluation, container terminal

1. INTRODUCTION

Among all freight transportation systems container transportation has shown by far the highest growth rate in turnover during the last 40 years. The use of standardized containers to store goods of all kind has tremendously improved the efficiency with which shipments are handled. The business environments and challenges of ports, railroads, and trucking companies have dramatically changed as a result of this "container revolution."

Containerized cargo movements have not only changed the way in which transportation modes operate, it has also changed the manner in which transportation modes interact with each other. The new demand with containerization is how to develop more efficient concepts for the interaction of transportation modes, i.e. combine ship, rail, and road haulage to forward freight form the origin to the final destination of a transportation order. This need for combined freight transportation systems has brought about innovative transportation facilities, equipment, and management practices dedicated to intermodal freight movement.

Specifically, issues of logistics control in seaport container terminals have brought about a wealth of publications in the scientific literature [1]. Among the logistics control problems investigated, the overall performance analysis of container terminals, the evaluation of alternate configurations, berth allocation, stowage planning, scheduling of the handling equipment, storage and stacking logistics, quayside and landside transportation planning have been areas of primary interest.

In practice, numerous studies have been undertaken on the design and re-design of facilities and equipment and the development of logistics control software and information systems. Computer-based tools such as simulation offer the possibility to mimic the terminal operations and to evaluate the system performance under different operating conditions and to systematically vary these experimental parameters in order to study the entire system behavior. Recent advances in simulation modeling, enhanced software with increased ease-of-use, and more powerful micro-computers suggest that computerized simulation of container terminals can become more powerful for supporting decisions, e.g. on the facility layout and equipment selection. In addition, changes to existing traffic loads may be examined to assess throughput, adequacy of resources, and the need for additional space requirements.

This paper proposes an Arena-based simulation model as an efficient tool for evaluating the performance of a container terminal. The model allows analyzing some pre-defined performance criteria such as average productivity, average resource utilization and average waiting time (e.g. of quay cranes waiting for a carrier) to identify potential bottlenecks in the operational areas (quay cranes, storage yard, or transportation) in container terminals. This model may also be used to evaluate different scenarios reflecting future traffic conditions and to provide a realistic experimental setting under which selected optimization problems such as quay crane scheduling can be evaluated.

The Haydarpasa Container Terminal in Istanbul has been selected as a sample terminal for our research. The related project has been fully supported by the Turkish Government and the terminal operator.

2. CONTAINER TERMINAL OPERATIONS

In a terminal, containers enter and leave by different means of transport, such as trucks, trains, and ships. Container terminals provide the interface between rail roads, ocean-going ships, and trucks and thus represent the critical link in the intermodal transportation chain. Containers arrive at the terminal by train, ship or truck and are stored in the terminal yard. Then they leave the terminal by the same means to reach their final destinations. The interaction between the main equipment units of a seaport container terminal is illustrated in Figure 1.

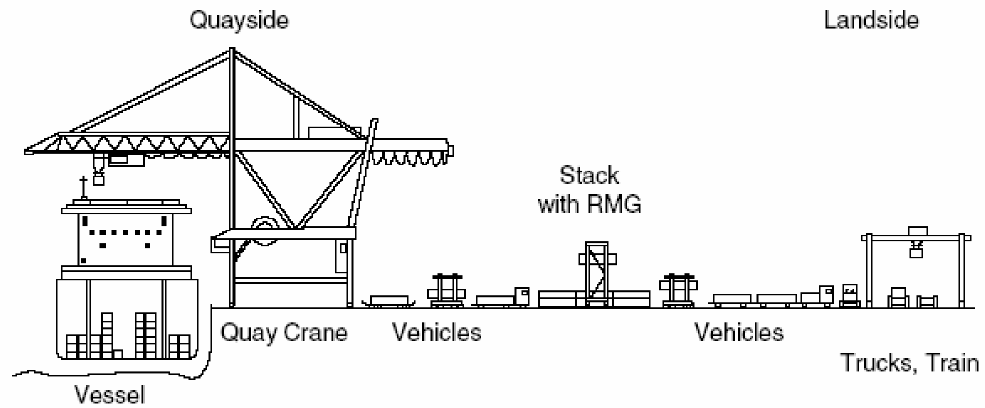

Figure 1. Transportation and handling chain of a container [1]

2.1 Quay Crane Operations

A quay crane is used to load and unload containers to and from a ship. To unload a ship, the quay crane picks up containers from the ship and puts them on shuttle trucks that move the containers to the storage yard in the terminal. To load a ship the quay crane unloads a container from a shuttle truck and puts it on the ship.

2.2 Storage Yard Operations

Operations in the storage yard are more flexible than quay crane operations. This is due to the numerous ways in which containers can be moved and stored within the area. In the storage yard, yard cranes, top-pick loader, or straddle carriers are used to stack containers. In container ports, stacking is the most common container storage mode. For instance, containers can be stacked four-high by use of a yard crane that unloads trucks and trains. Stacking requires close attention to be paid to the location of the container within the storage block to prevent multiple reshuffles or misplaced containers.

2.3 Internal Truck Operations

The third key element of port operations is the movement of containers between quay cranes and the storage yard. Quay cranes unload ships and place containers on shuttle trucks which move them to the storage locations in the yard. Containers, which are stored in the storage yard, leave the terminal by trucks to reach their final destinations. In addition, many European container terminals have railway links which are not so common in most Asian countries. The productivity of a container ship's journey depends on the berthing time at the terminal which is primarily affected by the coordination of the transport and handling equipment. For example, too many trucks in the system cause long queues at the cranes and long waiting times for service. Conversely, few trucks in the system will result in idle times of the stacking equipment.

3. HAYDARPASA CONTAINER TERMINAL

The Haydarpasa Port was established in Istanbul Bosporus in 1903 by the Ottoman Empire Railway Management. In 1979, Turkish State Railways modernized the port for a container terminal and this frame of terminal is still in use. The Haydarpasa container terminal includes three berths totaling 3,215 feet of quay length with four rail-mounted quay cranes and one rubber-tired quay crane, and nine rubber-tired yard cranes in the storage area. Inside the terminal transport operations are carried out manually by 31 internal trucks. With these specifications, the Haydarpasa container terminal can be classified as a modern port facility, but it cannot be considered as an ACT (Automated Container Terminal).

Per year, 1700 Container vessels with a total loading capacity of 750,000 TEUs can be serviced in the Haydapasa container terminal. Because the terminal is located in the town center, it doesn't have enough storage space and possibilities for expansion are very limited. Haydarpasa has a total storage capacity of 15,000 TEUs – 290 acres of container storage yard divided into nine storage blocks, each with a capacity of over 1650 TEUs and four-high stacking capacity. The Haydarpasa container terminal layout shown in Figure 2 is unique, as the orientation of the storage yards are both vertical and parallel to the berths. The terminal is operated around the week with three eight-hour shifts a day.

Table 1. Haydarpasa's and Turkey's container handling numbers and ratios (1998-2007)

Year	Handling in Haydarpasa (TEUs)	Handling in Turkey (TEUs)	Haydarpasa's market share in Turkey (%)	Haydarpasa's increase (%)	Turkey's increase (%)
1998	319,671	776,184	41.18		
1999	298,230	1,011,608	29.48	-0.07	0.23
2000	288,112	833,238	34.58	-0.04	-0.21
2001	224,544	841,653	26.68	-0.28	0.01
2002	224,282	1,999,083	11.21	-0.00	0.58
2003	244,429	2,496,390	9.79	0.08	0.20
2004	316,982	2,937,699	10.79	0.23	0.15
2005	340,629	3,194,960	10.66	0.07	0.08
2006	398,968	3,998,166	9.97	0.15	0.20
2007	396,437	4,699,529	8.43	-0.00	0.15

The volume of containers transported through Istanbul has increased over six times since 1998, with a throughput of over 4.5 million TEUs in 2007. Also Turkey's ports rank on the world market is consequently increased during these years. Despite this increase, Haydarpasa container terminal's market share in Turkey hasn't developed with the same ratio. For the period from 1998 to 2007, total container movements in Turkey and in the Haydarpasa container terminal are shown in Table 1. In 2008, Haydarpasa's market share of container trade in Turkey is estimated to be 10 percent or 450,000 TEUs.

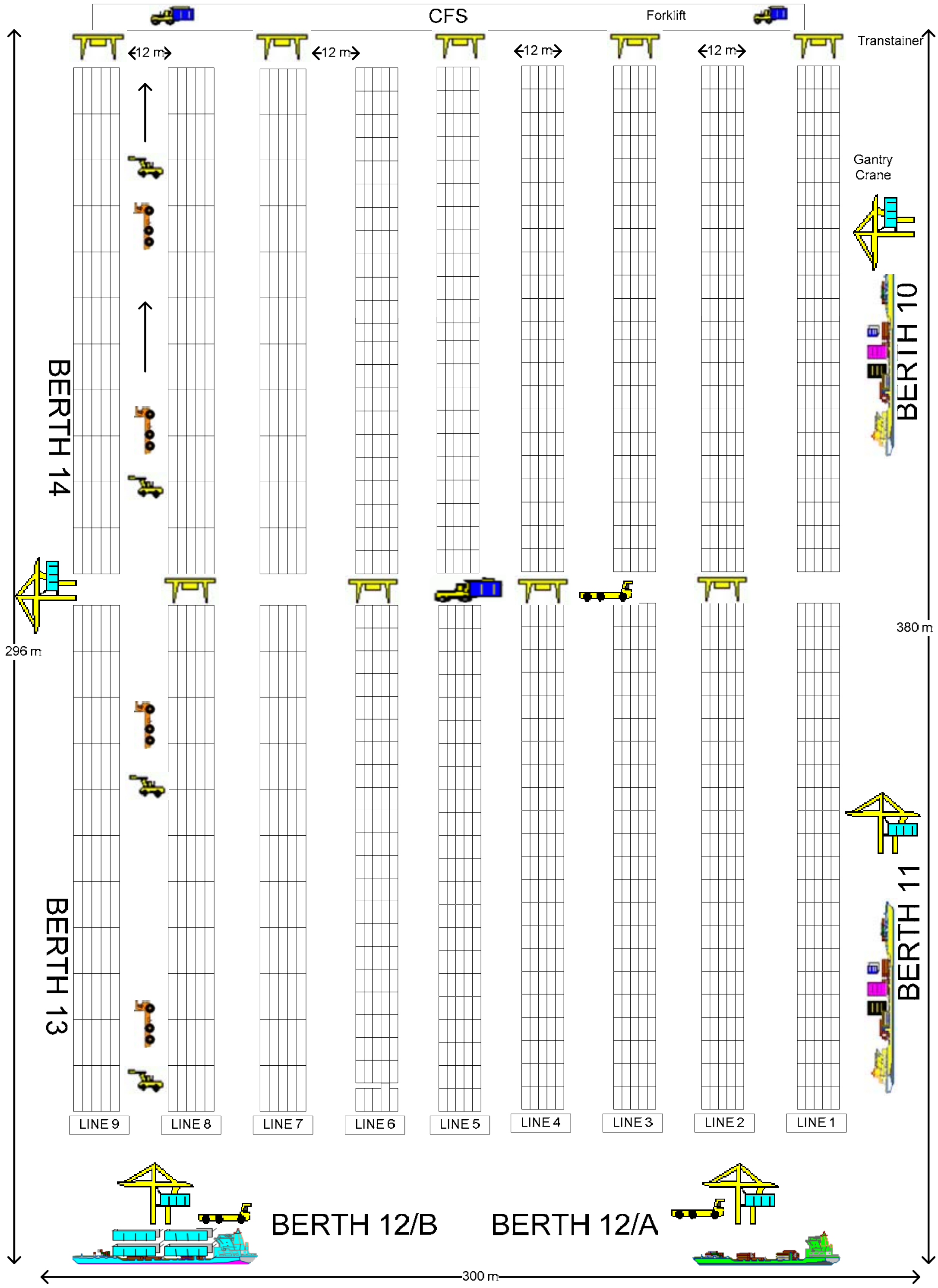

Figure 2. Haydarpasa Terminal Layout

In the early 1990s the world's containerized trade reached a turning point. In the 1990s, China's manufacturing boom created a remarkable demand for container terminals all over the world. However, with the land scarcity in Istanbul Bosporus and the governments' bureaucratic mill in handling administrative matters, the Haydarpasa container terminal could not simply expand its area to meet the growing demand. Instead, it had to revise and restructure its operations to maximize its capacity and to maintain its leading position in industry. However, it couldn't have actualized these restrictions to keep its position with growing competition of private firms in the same region. Private company's labor costs were cheaper than at Haydarpasa which is a public terminal. Also in the course of these years, private companies have modernized their equipment and strive to decrease their internal operation times. As a result, Haydarpasa's market share has decreased continuously, while Turkey's containerized trade was rapidly growing.

4. SIMULATION MODELING OF CONTAINER TERMINALS

4.1 Literature review

Simulation can be defined as creating a computer model of a real or proposed system and conducting experiments with the model to describe the observed behavior and/or predict the future behavior before investing any time or money. Because experimenting with a real system could be costly and/or impractical, simulation has become an extremely important tool for designing and analyzing complex systems. It is a cost-effective way of pre-testing proposed systems, plans, or policies before incurring the expense of prototypes, field tests, or actual implementations.

Steenken et al. [1] describe three types of simulation in container terminals: strategical, operational and tactical simulation. The main purpose of strategical simulation is to decide on the terminal layout and handling equipment which promises high performance and low costs. Operational simulation aims to test alternative optimization methods in a simulation environment before they are implemented in real terminal planning and control systems. On the other hand, tactical simulation means the integration of simulation into the terminal's operation system, i.e. simulation is carried out parallel to the real operation of the terminal.

Hartmann [2] explains simulation models as tools to evaluate the dynamic processes in a container terminal that allow generating and analyzing statistics such as average productivity, average waiting time, average number of re-shuffle moves in the stack. This way, potential bottlenecks can be identified. Depending on the application, detailed simulation models usually cover both physical resources (particularly the equipment such as cranes and vehicles) and components which reflect the control strategy of the terminal. Hence, simulation models also provide a testing environment for optimization algorithms. To enhance the performance of the simulation runs distributed simulation can be applied [3].

Bruzzone et al. [4] demonstrate the effectiveness of simulation for complex container port management. The presented application examples and experimental results show benefits in reusability, flexibility, modeling time and performance estimation. Gehlsen and Page [5] present a framework for simulation projects including heuristic optimization procedures (GA) in a parallel distributed environment. Liu et al. [6] use future demand scenarios to design the characteristics of different terminals in terms of configuration, equipment and operations. A microscopic simulation model is developed and used to investigate a terminal system for the same operational scenario and evaluate its performance. Moreover, a cost model is developed evaluating the cost associated with each terminal concept.

Nam et al. [7] examine the optimal number of berths and quay cranes for a terminal in Busan, Korea. Different operational patterns are represented in four scenarios for performance evaluation by use of simulation experiments. Results reveal that sharing quay cranes with adjacent berths can increase the productivity. Moreover, terminal development and operation policy implications are considered. Shabayek and Yeung [8] develop and describe the application of a simulation model of the Kwai Chung container terminal. Their objective is to investigate to what extent a simulation model could predict the actual container terminal operations with a higher order of accuracy. Similarly, Kia et al. [9] describe the role of simulation for evaluating the performance of a terminal's equipment and capacity. Performance criteria and related model parameters are discussed.

Hartmann [2] develops an approach for generating realistic scenario data of port container terminals as input for simulation models and for the test of optimization algorithms. A scenario consists of data concerning the arrival of ships, trains and trucks within a time horizon and information about containers being delivered or picked up. Users can control various typical parameters. Yun and Choi [10, 11] propose an object-oriented simulation model for the analysis of container terminals consisting of gate, container yard, berth and equipment like transfer cranes, gantry cranes, trailers, and yard tractors. Output of resource statistics can be used to analyze the capacity and operational efficiency of an existing container terminal.

Analytical approaches that use queuing techniques instead of discrete event simulation in order to evaluate terminal allocation and layout planning problems can be found in, e.g., [12, 13]. Lagana et al. [14] use a computational grid to solve a major seaport logistic problem by a simulation optimization approach centered on a queuing network model of the logistic process. Parola et al. [15] analyze potential use of the system by giving particular attention to the land transport and the modal split re-equilibrium with the aim of evaluating a possible future growth of the container flows. Some simulation models are applied to highlight both features and problems of the logistic activities of the intermodal network.

Ottjes et al. [16] propose a generic simulation model structure for the design and evaluation of multi-terminal systems for container handling. Roop et al. [17] develop three sample simulation models. The first model evaluates the performance of the container terminal that was designed. The second model compares different sizes of equipment groups. It is used for determining the optimal number of cranes and trucks. The last model carries our sensitivity analyzes to determine terminal performance levels for different parameter settings.

Novitsky et al. [18] discuss customization of a simulation model of container terminal operations as well as of maritime information systems. They present the use of a special technology for the development and customization of maritime information systems that are based on info-logical models of data processing operations. Canonaco et al. [19] focus on the optimal management of container discharge/loading at any given berthing point within a real maritime terminal. They propose a queuing network model. To get a systematic representation of real constraints and policies of resource allocation and activity scheduling, an event graph (EG) based methodology has been used.

In our research, Arena Enterprise Edition 10.0 is used to simulate the Haydarpasa container terminal. Arena combines event and process modeling approaches. It comprises both the Siman simulation language and animation systems, thus, allowing an easy integration of animation elements with simulation constructs. Each Siman diagram represents a flow diagram of the real process simulated. Arena Based models are animated models that are very convenient for communication with the customer and for validating the model.

4.2 Application

The Haydarpasa terminal does not have an efficient data collection system. Data collected from the terminal operations are manually entered into a data collection program at the end of each shift. Data from 2000 to 2007 include all necessary information for use in the simulation study of the terminal operations.

In addition, the following assumptions are used to make model more realistic.

- The Haydarpasa container terminal has five different berths, which are shown in Figure 2. Actually, berths 10 and 11 as well as berths 12/A and 12/B service the same vessel. Accordingly, berths 10 and 11 are considered as a combined berth called No. 1 with two quay cranes. Similarly berths 12/A and 12/B are combined into No. 2 with two quay cranes. Berths 13 and berth 14 are using the same rubber-tired crane. Also they cannot service two vessels simultaneously so that these berths are combined into berth No. 3 equipped with one rubber tired crane.
- Vessels are divided into three different categories according to their tonnages. Vessels whose tonnages are lower than 10,000 GRT are called as small vessels. Vessels with tonnages between 10,000 GRT and 15,000 GRT are called medium, and vessels with more than 15,000 GRT are called big vessels for the purpose of this simulation study.
- Although the terminal operates various trucks which are different in size, velocity and model, we assume that all trucks are of the same type.
- We assume that operating conditions of the terminal are not affected by weather conditions and do not differ between the working shifts. Also we assume that vessel arrivals to berths are unscheduled.
- One of the major problems in the Haydarpasa terminal is the condition of the ground in the stacking area because rubber tired yard cranes often damage the surface of the transportation paths and the storage area. Thus, these cranes sometimes do not work properly. We considered this problem as a equipment failure. Because the terminal hasn't got any data about failure ratios, all necessary failure ratios of yard cranes were obtained from interviews with various expert workers.

The basic simulation model of the terminal was developed under these assumptions. Arena Input Analyzer 10.0 and SPSS 14.0 are used to analyze 84-months data. Some important distributions are shown in Table 2. Also distributions are cross-checked with results of multi-factorial regression analysis using the F-test. For example, the Haydarpasa terminal hasn't got any data about individual container loading and unloading times of each vessel whose berth docking time and undocking times are registered by the data collection system. However, the terminal's information system provided the required data about the total number of containers loaded and unloaded for each vessel. Given these data, multi-factorial regression analysis is used to check the validity of the assumed operation times of quay cranes.

Table 2. Simulation Model Distributions

Distribution	**Type**	**Expression**	**Units**
Small vessel arrival	Creation time interval	TRIA(25, 29.6, 38)	Hours
Small vessel loading	Total loading	0.999 + EXPO(118)	TEUs
Small vessel unloading	Total unloading	259 * BETA(1.31, 1.43)	TEUs
Berth 1 loading (Small)	Avg. loading time	NORM(4.02, 2.14)	Minutes
Berth 3 unloading (Big)	Avg. unloading time	TRIA(1.2, 3.02, 4.22)	Minutes
Line 1 loading	Avg. storage loading	0.45+EXPO(3.78)	Minutes
Line 5 unloading	Avg. storage unloading	1.02+EXP0(2.98)	Minutes

The simulation model is used as a test bench to provide an efficient performance evaluation tool for the container terminal [3, 20]. This model allows analyzing the current situation using some pre-defined performance criteria such as:

- average resource utilization,
- average queue waiting time,
- average service time for vessels,
- the number of container handled.

These performance criteria are used to identify potential bottlenecks of the operational areas such as quay cranes, yard and transportation equipment in the container terminal.

5. RESULTS

In this paper, a simulation model that allows to evaluate the utilization of resources and to measure selected performance criteria has been presented. Table 3 shows selected results of a simulation run with 10 replications for a 12-month simulation period with a one-month warm-up period.

Table 3. Performance Criteria

Criteria	Average Value	Units
Average quay crane utilization	65.2	%
Average yard crane utilization	51.45	%
Average internal truck utilization	45.6	%
Average truck waiting time	0.12	Hours
Average docking time at berth 1, medium vessel	19.1	Hours
Average docking time at berth, medium vessel	0.87	Day
Average no. of containers handled	377,000	TEUs
Average terminal utilization	50.3 (377,601 / 750,000)	%

The simulation results show that the average resource and terminal utilization are in the order of 50 to 60%. Average quay crane utilization is somewhat higher, but still fairly low. Our results indicate that logistics operations of the terminal must be improved with the possible application of new integrated control systems and possible reorganization of parts of the terminal.

6. CONCLUSION

This paper represents a starting point of our research work which aims at improving the logistics operations of the Haydarpasa container terminal. In this paper we have described a terminal simulation model which allows evaluating the performance of the current configuration of the terminal using pre-defined performance criteria. The proposed model is not exhaustive and additional factors are to be integrated in the future. In the current phase of the project, the results of the simulation are calibrated and validated against actual performance data.

The results of the simulation show that some operational management problems exist in the terminal. With the use of integrated algorithms for the logistics control of the terminal, the capacity utilization of the current terminal configuration can be improved without investment in equipment and land. The simulation model will also be used to evaluate different scenarios and to identify directions of future research.

REFERENCES

[1] Stenken, D., Voß, S., Stahlbock R. (2004), Container terminal operation and operations research – a classification and literature review. *OR Spectrum,* 26-2, 3-49.

[2] Hartmann, S. (2004), Generating scenarios for simulation and optimization of container terminal logistics. *OR Spectrum*, 26-2, 171-192.

[3] Biellia, M., Boulmakoulb, A., Ridab, M. (2005), Object oriented model for container terminal distributed simulation. *European Journal of Operational Research*, 175-3, 1731-1751.

[4] Bruzzone, A.G.,Giribone, P.,Revetria, R. (1999), Operative requirements and advances for the new generation simulators in multimodal container terminals. In: Farrington P A, Nemhard, H. B., Sturrock, D. T., Evans, G. W. (eds) *Proceedings of the 31st Conference on Winter Simulation*, 2, 1243–1252. ACM Press, New York.

[5] Gehlsen, B., Page, B. (2001), A framework for distributed simulation optimization. In: *Proceedings of the 33rd Conference on Winter Simulation*, 508–514. IEEE Computer Society, Washington, DC.
[6] Liu, C-I., Jula, H., Ioannou, P. A. (2002), Design, simulation, and evaluation of automated container terminals. *IEEE Transactions on Intelligent Transportation Systems*, 3(1),12–2.
[7] Nam, K.-C., Kwak, K.-S., Yu, M.-S. (2002), Simulation study of container terminal performance. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 128(3): 126–132.
[8] Shabayek, A. A., Yeung, W. W. (2002), A simulation for the Kwai Chung container terminal in Hong Kong. *European Journal of Operational Research*, 40: 1–11
[9] Kia, M., Shayan, E., Ghotb, F. (2002), Investigation of port capacity under a new approach by computer simulation. *Computers & Industrial Engineering* 42: 533–540.
[10] Yun, W.Y., Choi, Y.S. (1999), A simulation model for container-terminal operation analysis using an object-oriented approach. *International Journal of Production Economics,* 59, 221–230.
[11] Yun, W. Y., Choi, Y. S. (2003), Simulator for port container terminal using an object oriented approach. *Working paper,* Pusan National University.
[12] Kozan, E. (1997) Comparison of analytical and simulation planning models of seaport container terminals. *Transportation Planning and Technology*, 20, 235–248.
[13] van Hee, K. M., Wijbrands, R. J. (1988), Decision support system for container terminal Planning. *European Journal of Operational Research*, 34, 262–272.
[14] Lagana D., Legato P., Pisacane O., Vocaturo F., (2006), Solving simulation optimization problems on grid computing systems". *Parallel Computing*, 32-9, 688-700.
[15] Parola, F., Sciomachen, A. (2005), Intermodal container flows in a port system network: Analysis of possible growths via simulation models. *International Journal of Production Economics*, 97-1, 75-88.
[16] Ottjes, J.A., Weeke, H.P.M., Duinkerken, M.B., Rijsenbrij, J.C. , Lodewijks, G. (2006), Simulation of a multiterminal system for container handling. *OR Spectrum*, 28-4, 447-468
[17] Roop, S.S., Koster P. (1998), Optimal design of intermodal transportation facilities: simulation as a tool to model intermodal container movements. Texas A&M University.
[18] Novitsky, L., Ginters, E., Merkuryev, Y., Merkuryeva, G., Ragozin, V., Victorova, E. (2001), Industrial customisation of maritime simulation and information system in the Latvian port areas. *Society for Modelling and Simulation International*, 396-398.
[19] Canonaco, P., Legato, P., Mazza, R. M., Musmanno, R., (2008), A queuing network model for the management of berth crane operations. *Computers and Operations Research*, 35-8, 2432-2446.
[20] Gambardella, L.M., Rizzoli, A.E., Zaffalon, M. (1998), Simulation and planning of an intermodal container terminal. *Special Issue of Simulation Journal in Harbour and Maritime Simulation*, 21-2, 107-116.