A TOOL TO SUPPORT HARBOR TERMINALS DESIGN

Agostino Bruzzone[(a)], Francesco Longo[(b)], Alessandro Chiurco[(c)], Felice Crupi[(d)], Marco Lanuzza[(e)], Alessio Luigi Emanuele[(f)], Maria Chiara Curinga[(g)], Jessica Molinaro[(h)]

[(a)]agostino@itim.unige.it, [(b)]f.longo@unical.it, [(c)]a.chiurco@unical.it, [(d)]felice.crupi@unical.it, [(e)]marco.lanuzza@unical.it, [(f)]lemanuele.alessio@msc-les.org , [(g)]mariachiara.curinga@msc-les.org, [(h)]jessica.molinaro@msc-les.org

[(a)]DIME, University of Genoa, Italy
[(b), (c), (f), (g), (h)]DIMEG, University of Calabria, Italy
[(d), (e)]DIMES, University of Calabria, Italy

ABSTRACT

Flows management is a crucial aspect in harbor terminals and entails several issues such as high flows of containers to be handled during loading, unloading and housekeeping operations. It requires implementing proper allocation strategies in terms of resources so as well as to maximize productivity and ensure good performances. To this end, the proposed research work is meant to assess the potentials of Modeling & Simulation to support container terminal design and to come up with an easy to use tool able to support terminal managers in decision-making at various levels. Based on design requirements for a new container terminal scenario, the paper shows how the proposed simulation tool can be used to explore design possibilities including low and high operational levels and to detect terminal behavior during and after its start-up period.

Keywords: container terminal design, decision support system, scenarios analysis, simulation

1. INTRODUCTION

A container terminal is part of a complex transportation network. Usually it is a cross-platform hub linking multi-modal transportation systems up and in most cases it is required to coordinate and synchronize heterogeneous equipment and means such as containerships, feeders, trains, trucks, etc. ensuring high operational efficiency. Because of the many variables involved and the high flows containers, terminal design is quite a difficult task especially when management strategies pursue different and conflicting objectives such as cost efficiency, productivity, etc. Examples of problems in container terminals include scheduling of loading/unloading operations, berth position assignment, cranes and container handling equipment assignment, etc. For instance, relevant efforts have been made to come up with even more automated systems (Kemme, 2012) such as automated rail-mounted-gantry-cranes. To this end, simulation-based optimization approaches have been widely used for problem solving such as berth planning and crane scheduling (Hartmann, 2004; Jimenez and De La Parte, 2003). This is the case, for example, of Beskovink and Twrdy (2010) where simulation is used for operations optimization in a maritime container terminal as well as of Bruzzone et al. (2011) and Bruzzone and Longo (2013) where advanced 3D interoperable simulators are used to support operators training and to improve terminal efficiency. Simulation models are also used to investigate the performances of already existing container terminals Yun and Choi (1999) or to understand to what extent a simulation model could predict the actual container terminal operations with a high order of accuracy (Shabayek and Yeung 2002; Kia et al. 2002). Simulation based optimization is then used to investigate resources allocation and scheduling problems (Gambardella, 2001; Lau and Zhao 2008; Lee et al. 2007; Bruzzone et al. 2012). Additional references in this area can be found in Moorthy and Teo (2006), Bielli et al. (2006), Alattar et al. (2006). Additional simulation approaches to investigate security issues in container terminals (Longo 2010; and Longo 2013).

The great deal of research works in this area allows ascertaining the advantages that simulation based design can bring but not only. Indeed, recreating a terminal container in a simulation model entails a huge amount of modeling and coding work due to the need of setting up a clear and comprehensive picture of processes, entities and relations involved in here and turn such a representation in an executable as well as parametric computerized model (Banks, 1998). This is the reason why simulation development is usually underpinned by strong methodological approaches that are meant to drive the research activities and pave the way for reliable and fully deployable outcomes.

Needless to say that capturing the inherent complexity of a container terminal in a simulation project raises significant research challenges both in terms of modeling capabilities and in terms of ability to find out practical solutions to implement. In other words simulation practices involve many different aspects featured by multisided and multidisciplinary facets.

In particular, container terminal simulation models can be very different from one another depending on their scope, applicability, functionalities, level of detail and underlying paradigms. With this in mind, the proposed research work, seeks to bring about a comprehensive as well as flexible tool that can be used for design testing, dynamic analysis, decision support but also for performances monitoring and control. To this end the simulation model capabilities include the ability to simulate operational processes such as arrivals (vessels, feeder-ships, trains and trucks) and loading/unloading operations occurring quayside and landside in a typical container terminal (expressly conceived for being as general as possible in such a way that it can enclose all the typical features of a container terminal). Moreover, the simulation model input parameters have been accurately selected to allow evaluating different design possibilities based on real and potential resources availability and structural changes to investigate a wide variety of scenarios. It goes with a careful evaluation of constraints on loading and unloading critical times, yard capacity, equipment capacity, etc. given that waiting times and delays are cost to be avoided.

The paper is organized as follows: section 2 describes the requirements for the design of a new container terminal, section 3 deals with data collection while section 4 briefly presents the simulation model. Section 5 and 6 reports simulation results and summarizes the conclusions.

2. REQUIREMENTS FOR THE DESIGN OF A NEW CONTAINER TERMINAL

As already mentioned in the Introduction section, Container terminal design is quite a complicated issue because of the different entities and flows interacting each other. This section summarizes the requirements for the design of a new container terminal.

It is assumed that the container terminal must work h24, d365. The terminal lay-out is characterized by:

- a 1200 meters quay;
- a 900 meters wide yard with up to 30000 available containers slots;
- a rail terminal with 8 tracks;
- an entrance gate with up to 30 lanes.

At this stage of the design, it is supposed that the container terminal life cycle will be subdivided in three phases:

- low operational efficiency (start-up period), up to 12 months (Lo-O);
- regular operational efficiency, at least 12 months (R-O) after the Lo-O period;
- high operational efficiency, during the remaining part of the terminal life cycle (Hi-O).

Table 1 reports the duration of each single operational efficiency level, the total number of TEUs expected as well as the expected division between 20” and 40” containers. Additionally, table 2 reports information about the Import/Export flows during the three operational efficiency levels and expected percentage of TEUs moved by feeder ships, trucks and trains.

The import flow will come from international shipping companies through containerships (mother vessels) with capacity up to 12500 TEUs. Such containers will be then redirected within the region through feeder ships, trucks and trains. The export flow (arriving through feeder ships, trucks and trains) may leave the port through international shipping companies (mother vessels). Imported and exported containers are stored in the yard before leaving the terminal with very limited transshipment operations. In addition, it is required that the average waiting time of containers in the yard area is 10 days with a 48 hours variance.

Berth unloading and loading operations will be executed by using quay cranes while yard connections will be assured by Straddle Carriers; the rail terminal will make use of Rail Mounted Transtainer (RMT). In particular cases it will be also required the use of Reach Stackers to move containers to and from the yard as well as for housekeeping operations (e.g. in case of Straddle Carriers maintenance operations, containers flow peaks, etc.).

Table 1 – Duration of the different operational efficiency levels and containers flow division

Operational Efficiency Level		**Duration [Months]**	**Containers Flow [TEUs/year]**	**Total Flow Division**	
				40”	**20”**
Lo-O	Low Operational Efficiency	12	250000	87500	75000
R-O	Regular Operational Efficiency	12	700000	245000	210000
Hi-O	High Operational Efficiency	TBD	1000000	350000	300000

Table 2 – Average containers import/export flow division

Operational Efficiency Level		**Average Import/Export Flow**	**Average Import/Export Flow Division**		
			to/from Train	**to/from Truck**	**to/from Feeder Ship**
Lo-O	Low Operational Efficiency	50%	70%	20%	10%
R-O	Regular Operational Efficiency	50%	70%	20%	10%
Hi-O	High Operational Efficiency	50%	70%	20%	10%

According to the information reported above and in tables 1 and 2, the design requires to check if the yard capability is enough to handle the TEUs flow hypothesized in the three operational efficiency levels. It is also hypothesized that the weight of containers handled in the terminal does not exceed 45 tons.

To this end, it is required a risk lower than 10% to saturate more than 75% of the available yard capability. It is also required to design the three operational efficiency levels scenarios by evaluating the total number of Straddle Carriers, Quay cranes, Reach Stacked and Rail Mounted Transtainers.

The following are additional requirements (starting from the beginning of the Regular Operational Efficiency phase):

- mother vessels unloading and loading operations must be completed within 48 hours (even in case of equipment failure and maintenance operations);
- up to 4 trains (with capacity up to 60 containers) must be unloaded and loaded within 6 hours from their arrival.

3. DATA COLLECTION

One of the most important steps in a simulation study is to accurately collect all the data needed to appropriately feed the simulation model. Without containers handling equipment technical data it would be impossible to design the terminal design and meet all the requirements reported in section 2. Table 3 reports an example of technical data collected for container handling equipment including the equipment name, capacity, speed and productivity. The speed is intended as the equipment overall speed while the operational productivity is the number of containers that the equipment can handle per hour. Note that the portainers (quay cranes) outreach is always greater than 44 meters (for each type of container).

Table 3 – Example of technical data for container handling equipment

Equipment		Capacity	Piled Containers	speed	Operational Productivity
		[kg]	-	[m/s]	[TEU/h]
PT-1	Portainer	80000	5	0.75	30
PT-2	Portainer	50000	5	0.75	25
PT-3	Portainer	46000	5	0.50	25
RT-1	Rail Transtainer	50000	5	1.00	25
RT-2	Rail Transtainer	50000	5	1.00	20
RS-1	Reach Stacker	46000	5	7.00	20
CS-1	Straddle carrier	50000	4	10.00	25
CS-2	Straddle carrier	50000	5	10.00	25
CS-3	Straddle carrier	50000	5	10.00	25

Table 4 reports an example of information about purchase costs, operative costs and maintenance costs for the container handling equipment. The operative

Table 4 – Information about Purchase Costs, Operative Costs and Delivery Time for each container handling equipment

Equipment		Purchase cost	Operative Cost	Maintenance Cost
		[kEuro]	[Euro/h]	[kEuro/year]
PT-1	Portainer	8471.11	210.21	20.74
PT-2	Portainer	6763.47	167.19	18.67
PT-3	Portainer	2387.70	73.58	36.60
RT-1	Rail Transtainer	2346.15	44.91	8.80
RT-2	Rail Transtainer	1740.28	48.42	23.98
RS-1	Reach Stacker	348.74	8.26	3.73
CS-1	Straddle carrier	580.40	8.92	3.43
CS-2	Straddle carrier	950.40	9.42	4.50
CS-3	Straddle carrier	780.44	9.64	5.80

costs include personnel costs and all other direct costs (e.g. fuel, energy, etc.) while the maintenance costs are evaluated on a yearly base. Additional information have been collected regarding the inter-arrival times for mother vessels, feeders, trucks and trains.

In addition, according to Longo (2010) and Bruzzone et al. (2007), breakdowns and maintenance operations for quay cranes and yard resources have been taken into account. For container handling equipment, the following parameters have been taken into consideration: the failure rate (Fr-1) during the Infant Mortality Period (IMP), the failure rate (Fr-2) during the Useful Life (UL), the failure rate (Fr-3) in the last part of the equipment lifecycle, Wear Out Period (WOP) and the Life Extension Date (LED). The approach used by author for modelling the equipment failure rate is a graphical representation known as bathtub curve. The approach based on the bathtub curve is reported in many books on reliability theory (Birolini, 2003; Rausand and Hoyland, 2004).

The failure rate during the IMP and during the WOP is calculated using a two-parameter Weibull distribution. The failure rate during the UL makes use of a negative exponential distribution. Equations (1) and (2) are used within the simulation model for evaluating the reliability and the failure probability density function of each container handling equipment.

$$R(t) = e^{-\int_0^t Fr(t)dt} \tag{1}$$

$$f(t) = Fr(t) * e^{-\int_0^t Fr(t)dt} \tag{2}$$

- R(t) reliability function
- Fr(t) failure rate, defined as number of failures per unit of time
- f(t) failure probability density function

Table 5 reports information about non operative service time for each container handling equipment. Non operative service time must be intended as up-times in which the equipment is available but cannot be used due to ongoing operations such as re-fueling, operators shift, etc.

Finally, Table 6 reports information about other costs, including annual operating costs, control room operating costs, gates annual costs, yard annual costs, rail annual cost and quay annual costs.

Table 5 – Information about Non Operative Service Time for each container handling equipment

Equipment		Non Operative Service Time [hours/year]
PT-1	Portainer	286.93
PT-2	Portainer	287.75
PT-3	Portainer	603.28
RT-1	Rail Transtainer	431.98
RT-2	Rail Transtainer	400.59
RS-1	Reach Stacker	899.04
CS-1	Straddle carrier	867.79
CS-2	Straddle carrier	728.50
CS-3	Straddle carrier	984.00

Table 6 – Information about other terminal annual costs

Cost Type	Value [k€/year]
Container Terminal Preparation Costs	120000,00
Annual Operating Costs	9000,00
Control Room Annual Costs	2200,00
Gates Annual Costs	900,00
Yard Annual Costs	500,00
Rail Annual Costs	800,00
Quay Annual Costs	320,00

4. DESIGNING THE CONTAINER TERMINAL THROUGH A SIMULATION MODEL

The simulation model consists of four different parts:

- a flow chart
- an animation
- an input section
- an output section

Within the flow chart part the user can visually assess how the simulation model works in terms of entities, resources, flows and relations. The animation shows the evolution of the container terminal operations over the time (Yazdani et al., 2005); the input section allows the user setting up a number of different input parameters such as number of straddle carriers, number of reach stackers, inter-arrival times for mother vessels, feeders, trains and trucks, etc. Finally, the output section reports the main simulation results, including the total number of containers currently stored in the yard, the risk of yard saturation, the total number of vessels, trucks and trains served from the beginning of the simulation, the vessels turn-around times, the trains turn-around times, the container handling equipment utilization levels.

Figure 1 shows the simulation model animation that includes vessels unloading/loading operations, movements from/to the yard performed by straddle carriers, trains unloading/loading operations executed by rail transtainers and trucks entering to and exiting from the yard area through dedicated gates. It is worth noticing that the user can switch among the three operational levels just by clicking the buttons in the right part of the animation (Low-O, R-O and Hi-O respectively).

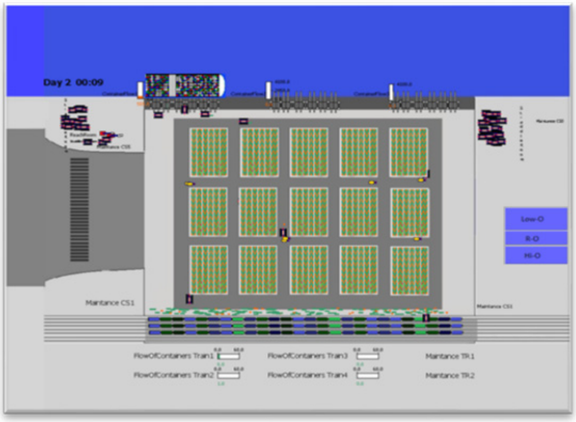

Figure 1 – Simulation Model Animation

The figure 2 shows a view of the Input Section and some of the parameters that can be changed at run-time by the user (additional parameters can be changed by the user before the beginning of the simulation).

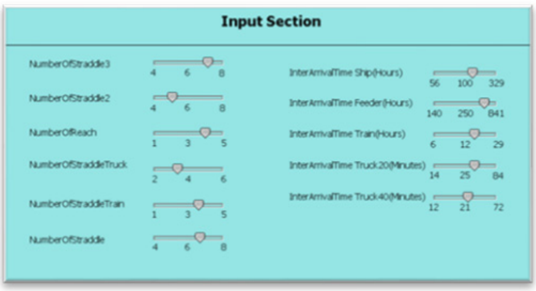

Figure 2 – Simulation model input section

The figure 3 shows the output section reporting the most important simulation results.

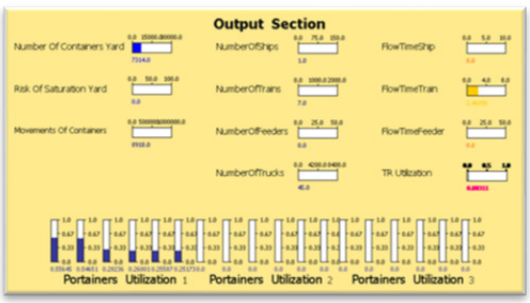

Figure 3 – Simulation model output section

Simulation results are also saved in databases and can be accessed both at run-time and at the end of the simulation as well as they can be exported on .txt or .xls files for additional analysis.

5. SIMULATION BASED DESIGN ANALYSIS AND RESULTS

In this section an application example is proposed that shows how the simulation model can be used to support the design of the container terminal. The simulation model briefly presented in section 4 has been used to support the container terminal design and to meet the requirements described in section 2. To this end multiple simulation runs have been executed and the results are summarized below.

As first step the simulation model has been used to check possible combinations of mother vessels, feeders, trucks and trains to respect the yearly flow of import/export containers reported in tables 1 and 2. Table 5 reports the results of the simulation with average number of mother vessels, feeders, trucks and trains in the three different operational efficiency level phases.

Table 5 – Number of mother vessels, feeders, trucks, trains and flow of containers over 1 year in the three operational levels scenarios

	Mother Vessels	Feeders	Trucks	Trains	TOTAL TEUs FLOW
Low-O	32	14	25000	1458	250000
R-O	88	36	70000	4083	700000
Hi-O	126	50	100000	5833	1000000

As far as the risk to saturate more than 75% of the available yard capacity is concerned, according to the data reported in table 5 it never happens that the risk is greater than 10%. Basically, this means that the current yard design (with capacity up to 30000 TEUs) can be accepted and it is able to handle the import/export flow of containers.

The simulation model has been also used to set-up correctly the number of quay cranes, straddle carriers, reach stackers and rail transtainers. To this end, note that from the 12th month (starting of the R-O phase), there is a requirement about the mother vessel unloading and loading operations; such operations must be completed within 48 hours from the vessel arrival (even in case of equipment failure and maintenance operations). In order to meet this requirement, simulation results show that 18 quay cranes are required (PT1-type portainers).

A similar analysis has been carried out regarding the number of straddle carrier needed to meet the requirement in each operational efficiency scenario. It has been found out that in the Hi-O scenario, 4 straddle carriers for each quay crane are needed to move container to/from the yard. As far as the requirement for train unloading and loading operations is concerned (4 trains to be handled within 6 hours from their arrival), the simulation results show that 2 rail transtainer (RT1) are needed each one served by 3 straddle carriers for yard connections.

As far as the number of reach stackers is concerned, the simulation model shows that 10 reach stackers are enough (in the Hi-O scenario) to support yard operations in case of straddle carriers failure and maintenance and in case of flow peaks.

Finally, the simulation model is also able to calculate the main costs both for container handling equipment purchase and for running the terminal container. An example of costs evaluation is reported in tables 7 and 8. Table 7 reports the purchase costs, the operating costs and maintenance costs for the portainers, while table 8 reports the same costs for the rail transtainers.

Table 7 – Purchase, Operating and Maintenance costs for the Portainers

Portainers	**Cost [k€]**
Purchase Costs	152479.98
Operating Costs	22097.28
Maintenance Costs	373.32

Table 8 – Purchase, Operating and Maintenance costs for the Rail Transtainers

Rail Transtainers	**Cost [k€]**
Purchase Costs	4692.30
Operating Costs	786.83
Maintenance Costs	17.600

6. CONCLUSIONS

The main goal of this study was to assess the potential of Modeling & Simulation to support the design of container terminals. To this end, a specific container terminal design scenario has been proposed; the scenario is characterized by three operational efficiency levels (according to the terminal evolution over the time) and, for each level, the expected import/export flows of containers have been hypothesized. Additional information (needed for the design) are also reported: technical data for each container handling equipment and costs (purchase, operative, maintenance and annual general costs).

Based on these data and information, the authors have developed a simulation model that is able to recreate with high-accuracy all the container terminal operations, including vessels arrival and departure, vessels unloading and loading operations, movement to/from the yard by straddle carriers, trains and trucks arrivals and departures and related loading and unloading operations. The simulation model is equipped with a nice animation to show the ongoing operations during the simulation, with an easy to use input section (for parameters variation) and with an output section to show the simulation results.

In the last section of the paper, an application example is provided that shows how the simulation model can be used to support the container terminal design. In order to fulfill the design requirements, the simulation model has been used to evaluate sustainable flows of vessels, feeders, trains and trucks and to calculate the number of portainers, straddle carriers, reach stackers and rail transtainers needed and related costs.

ACKNOWLEDGMENTS
The research presented in this paper is part of the T-ESEDRAS project co-financed by the European Union, the Italian Government and Calabria Region under the program POR/FESR Calabria 2007/2013, Asse I, Ricerca Scientifica, Innovazione Tecnologica e Società dell'informazione.

REFERENCES
Alattar, M. A., Karkare, B., Rajhans, N., 2006. Simulation of container queues for port investment decisions. In: Proceedings of the sixth International Symposium on Operations Research and its Applications.

Banks J., 1998. Handbook of Simulation. J. Wiley & Sons New York.

Beskovink B., Twrdy E. (2010), Transport: Planning organization and productivity simulation tool for maritime container terminals.July 2010, Volume 25, Iusse 3 pp 293-299.

Bielli, M., Boulmakoul, A., Rida, M., 2006. Object oriented model for container terminal distributed simulation. European Journal of Operational Research 175 (3), 1731–1751.

Birolini, A., 2003. Reliability Engineering: Theory and Practice. Springer.

Bruzzone, A.G., Bocca, E., Longo, F., Massei, M., 2007. Logistics Node Design and Control over the Whole Life Cycle based on Web Based Simulation. International Journal of Internet Manufacturing and Services, 1(1), pp. 32-50.

Bruzzone AG, Longo F, Nicoletti L, Bottani E, Montanari R (2012). Simulation, analysis and optimization of container terminals processes. International Journal of Modeling, Simulation, And Scientific Computing, vol. 3, p. 1240006-1-1240006-20, ISSN: 1793-9623, doi: 10.1142/S1793962312400065.

Buzzone A.G., Longo F (2013). 3D simulation as training tool in container terminals: The TRAINPORTS simulator. Journal of Manufacturing Systems, vol. 32, p. 85-98, ISSN: 0278-6125, doi: 10.1016/j.jmsy.2012.07.016

Bruzzone, A., Longo, F., Nicoletti, L., Diaz, R. (2011). Virtual simulation for training in ports environments. Proceedings of the 2011 Summer Computer Simulation Conference, pp 235-242.

Gambardella, L.M., Mastrolilli, M., Rizzoli, A.E., Zaffalon, M., 2001. An optimization methodology for intermodal terminal management. Journal of Intelligent Manufacturing 12 (5–6), 521–534.

Hartmann S. (2004). OR Spectrum: Generating scenarios for simulation and optimization of container terminal logistics. March 2004, Volume 26, Issue 2, pp 171-192.

Jiménez Macias E., Perez De La Parte M., (2003). Simulation and optimization of logistic and production systems using discrete and Continuos PN. Proceedings of the Summer Computer Simulation Conference, SCSC 2003; Montreal; Canada, volume 35, Issue 3, pp. 507-512

Kemme N. (2012) OR Spectrum: Effects of storage block layout and automated yard crane systems on the performance of seaport container terminals. July 2012, Volume 34, Issue 3, pp 563-591

Kia, M., Shayan, E., Ghotb, F., 2002. Investigation of port capacity under a new approach by computer simulation. Computers and Industrial Engineering 42 (2–4), 533–540.

Lau, H.Y.K., Zhao, Y., 2008. Integrated scheduling of handling equipment at automated container terminals. International Journal of Production Economics 112 (2), 665–682.

Lee, D., Cao, Z., Meng, Q., 2007. Scheduling of two-transtainer systems for loading outbound containers in port container terminals with simulated annealing algorithm. International Journal of Production Economics 107 (1), 115–124.

Longo (2010). Design and integration of the containers inspection activities in the container terminal operations. International Journal of Production Economics, 125, pp. 272-283.

Longo F (2012). Supply chain security: an integrated framework for container terminal facilities. International Journal of Simulation & Process Modelling, vol. 7, p. 159-167, ISSN: 1740-2123, doi: 10.1504/IJSPM.2012.049154.

Moorthy, R., Teo, C.-P., 2006. Berth management in container terminal: the template design problem. OR Spectrum 28 (4), 495–518.

Rausand, M., Hoyland, A., 2004. System Reliability Theory: models, statistical methods, and applications. Wiley-IEEE.

Shabayek, A.A., Yeung, W.W., 2002. A simulation model for the Kwai Chung container terminals in Hong Kong. European Journal of Operations Research 140 (1), 1–11.

Yazdani, R., Schmidt, F.A., Merkuryev, Y, Kamperman, F., (2005). The generic animation and simulation tool for ports and terminals. International Journal of Simulation: Systems, Science and Technology, Volume 6, Issue 7-8, Pages 61-69.

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 (1–3), 221–230.