A DISCRETE EVENT SIMULATION MODEL FOR THE ANALYSIS OF CRITICAL FACTORS IN THE EXPANSION PLAN OF A MARINE CONTAINER TERMINAL[1]

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Discrete Event Simulation; Marine Container Terminal; Performance analysis.

ABSTRACT

In this paper we present a discrete event simulation model to approach the decision problems arising from an expansion plan of a marine container terminal. In particular the preliminary study herein presented starts from a collaboration with the Southern European Container Hub (SECH) sited in the Port of Genoa, Italy. The planned expansion will take place from 2010, the terminal area will enlarge, thus being capable of doubling the present TEU handling capacity. Due to the foreseen increase in the traffic volume, there is the need of defining new management policies, mainly related to the organization of the yard and quay sides of the terminal. The proposed simulation model, that has been implemented by the Witness software environment, can be used to analyse different scenarios, pertaining to possible changes of the import/export flows, handling techniques, different equipments and investment options as well as different operative rules for the berthing and storage area.

INTRODUCTION AND PROBLEM DEFINITION

The steady increasing number of container shipments is causing higher demands at the seaport container terminals, and, consequently, the competition among seaports is increasing too, especially among geographically close ones. The competitiveness of a marine container terminal is based on different factors, such as ship turnaround time, number of TEUs moved per unit of time, combined with low rates for loading and discharging and fast turnover of containers.
In general terms, an import/export container terminal can be described as an open system with two external interfaces: the quayside, or marine side interface, with loading and unloading of ships, and the land side interface where containers are moved from/to trucks and trains. A container vessel, after its arrival at the terminal, is assigned to a berth equipped with quay cranes for loading/unloading operations. The *import flow* starts with unloading operations from the ship; the unloaded containers are transferred by internal transportation equipment, i.e. vehicles, multi-trailers, fork lifts (FL), straddle carriers (SC) or Reach stackers (RS), to the storage area (yard) for their later departure via trucks or trains. In the yard they are stored in stacks using rail mounted gantry cranes (RMG) or rubbed-tired gantry cranes (RTG). Different storage strategies can be used by the terminal yard management i.e. the pre-marshalling strategy and the sort and store strategy (see e.g. Ambrosino and Sciomachen (2003)). The *export flow* concerns containers that reach the terminal via trains or trucks, are stored in the yard by using dedicated equipment (see e.g. Vis and Harika (2004) for an overview of vehicle types at a container terminal) and finally are loaded on board for their departure by ship.
In general, a marine terminal must be managed in such a way to optimise the collective flows of containers that arrive and leave it via trucks, trains and vessels. An expansion plan can affect the efficiency and the "optimal" management of the whole terminal, thus requiring to analyse the emerging critical factors in the terminal system.
In the following we will deal with the issues arising from an expansion plan of a import/export container terminal sited in the Port of Genoa, Italy that is the Southern European Container Hub, SECH. Following the planned expansion, that will take place from 2010, the terminal area will enlarge from 207.000 to 480.000 sqm, thus making the terminal able of doubling the present TEUs handling capacity.

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In Figure 1 is depicted the planned change of the terminal layout. Interested readers can refer to the web site http://www.sech.it for getting more information about the terminal SECH and its expansion plan.
Terminal design problems, related to the multi-modal interfaces and the equipment type selection, have been approached by facility planners in the first stage of the terminal expansion (see the input data analysis section). The organization of the yard and the quay operations should be revised to be able to meet the new foreseen increased traffic of containers. Terminal managers need to test and compare different new management policies. Their goal is both improving the terminal productivity by a better synchronization among the handling facilities and achieving cost savings related to a better usage of handling and human resources.
For this purpose, using the Witness software environment, we have developed a discrete event simulation model. This model can be used for different "what-if" analysis pertaining to possible changes of the import/export flows, handling techniques and equipment, as well as different operative rules for the quay side and yard area.

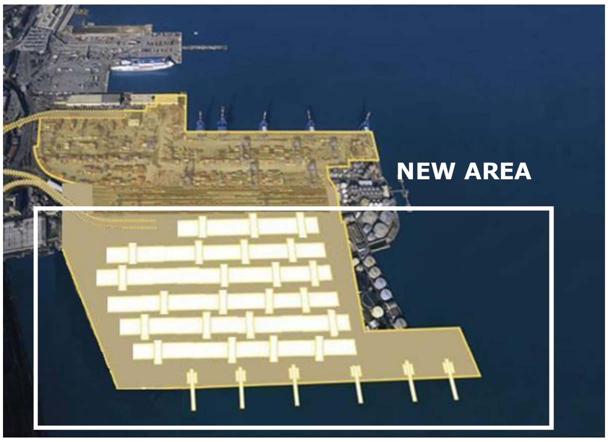

Figure 1. Layout of the SECH: old and new area

A container terminal includes a multitude of interacting factors (e.g. ship, truck and train arrival patterns, various kinds of cargo-handling equipment and human resources) and the randomness and complexity of the problem under consideration make the analysis of a marine terminal an interesting ground for applying simulation models.
We evaluate the terminal performance by analysing some indices of interest, such as the so-called net terminal performance index, the average yard and quay utilization rate and rotation index (Petering and Murty 2009). Moreover, we focus our attention to a "gang utilisation rate", that we use for defining the shifts of the personnel closely related to the container handling operations from the sea side to the land one, and vice-versa.
The paper is organized as follows. A literature review about the use of simulation for optimising the logistic operations at container terminals is reported in next section. Afterwards we focus on the modelling approach and the development of the simulation model, with particular attention to the data analysis and estimation. Finally, conclusions and further work are discussed.

LITERATURE REVIEW

Due to the continuous growth of the container flow over the world, container terminal operations are becoming more and more important in the search for terminal competitiveness. Therefore, there is an ever-increasing number of publications on container terminals showing the need for an optimal management of their logistic activities.
Vis and De Koster (2003) and Steenken et al. (2004) give a classification of the decision problems at marine container terminal in accordance with the following logistic processes: *i)* arrival of the ship, *ii)* discharging and loading of the ship, *iii)* transport of containers from ship to stack and vice versa, *iv)* stacking of containers, and *v)* inter-terminal transport and other modes of transportation.
Moreover, Gunther and Kim (2006) propose a classification of these problems in accordance with the planning level they are related to. In particular, the strategic level refers to long-term decisions pertaining layout, connections, equipment, berthing and yard capacity, the tactical level regarding mid-term decisions pertaining berth and yard planning and policies, while the operational level pertains to short-term decisions related to the quay side and land side operations.
By using an integrated classification, a quite complete list of decision problems to be solved at marine container terminals (MCT) is summarized in Figure 2.

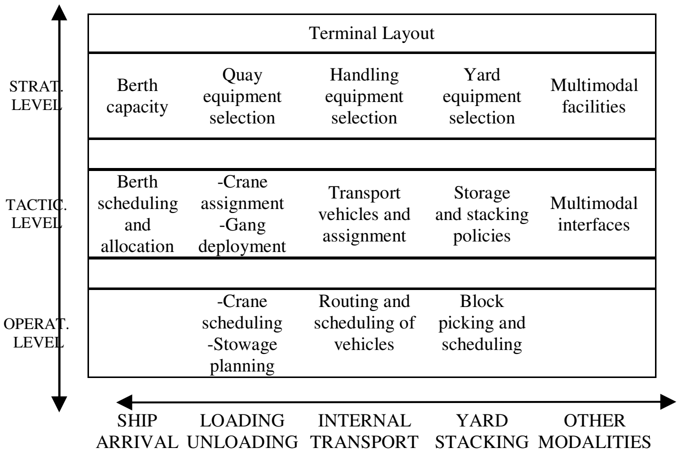

Figure 2. Problems and decisions at MCT: An integrated classification

Most researchers deal with these problems decomposing the complex system into sub-systems and approaching single decision problems separately, i.e. berth allocation problem (Imai et al. 2002, Cordeau et al. 2005), quay

crane assignment problem (Zhang et al. 2002), ground crew planning problem (Legato and Monaco 2004), optimal sizing of storage space and handling facilities (Kim and Kim 2002), stacking strategies (Kang et al. 2006), etc. Other authors propose decision support system, simulation model and queuing models, to study the terminal as a complex system consisting of several integrated and correlated sub-systems (Gambardella et al. 1998; Bingham et al. 2003; Legato et al. 2008; Canonaco et al. 2008). Recently, simulation approaches have been quite often used for testing design and structural parameters affecting the performance and productivity of real marine terminals. Parola and Sciomachen (2005) study the whole logistic inter-modal network among ports and consider marine terminals as single nodes in the given simulation model aimed at evaluating possible growths of the rail connections, while Parola and Sciomachen (2008) approach the modal split evaluation at terminal VTE in Genova (Italy). Nam et al. (2002) examine the optimal number of berths and quay cranes for a terminal in Busan (Korea), while Legato and Mazza (2001) develop a simulation model for the arrival-departure process of vessel at the container terminal of Gioia Tauro (Italy) that is used for optimisation scenario analysis of the berth planning problem. Shabayek and Yeung (2002) describe a simulation model to analyse the Kwai Chung container terminals in Hong Kong, that has been proved to predict the actual container terminal operations with a high order of accuracy. Kia et al. (2002) describe the role of simulation for evaluating the performance of a terminal's equipment and capacity in Melbourne by using interesting performance criteria and model parameters.
In the following we focus our analysis on strategic and tactical decision problems pertaining to a terminal expansion. In particular, we deal with the problem of organizing the berthing and storage area.
We present preliminary results of a collaboration project aimed at developing a discrete event simulation model to support the terminal management during a planned terminal expansion.

MODEL DEVELOPMENT

Data collection and analysis

The terminal SECH is a medium sized import export container terminal based upon the "Indirect Transfer System" (ITS) in which a fleet of shuttle vehicles transports the containers from a vessel to the stack area and vice versa, whilst dedicated cranes (i.e. rail mounted gantry cranes (RMG) or rubbed-tired gantry cranes (RTG)) stack or pick up containers in the yard slots. Export containers arriving by road or railway at the terminal are handled within the truck and train operation areas, picked up by the internal transportation equipment and distributed to the respective stacks in the yard by using dedicated equipment. The terminal is situated within the Port of Genoa. Its total area is 206.000 sqm, the yard area is 13.000 sqm and the quay length is 526 m, corresponding to an handling capacity of 450.000 TEUs (Twenty Equivalent Units) per year. Note that the strategic decisions (layout, connections, equipments, berthing and yard capacity) have been modelled following the facility planners' decisions pertaining to the enlargement plan that will take place from 2010.
Table 1 and Table 2 gives the current (Year 2008) and planned (Year 2010) terminal capacity (yard, quay, rail and gate connections) and equipments, their number, and movements / hour, respectively.

Table 1. SECH facilities (2008- 2010)

	Year 2008	Year 2010
Total surface	206.000 sqm	480.000 sqm
Yard capacity	13.000 teu	24.500 teu
Quay length	526 m	526 m + 760 m
Rail	3 tracks	9 tracks
Gate	5 reversible lines	10 reversible lines

Table2. SECH handling equipments (2008-2010)

	Year 2008		Year 2010	
Equipment	Q.ty	Speed (mov/h)	Q.ty	Speed (mov/h)
Portainer	5	18/19	11	18/19
RMG	6	18	6	18
RMG*	-	-	20	20
RTG	8	16	8	16
Reach stacker	16	14	16	14
Fork lift	8	14	8	14
Internal truck	27	60 Km/h	37	60 Km/h

When studying a marine terminal system, one of the major problems is the difficulty in getting the large amount of data necessary to build a representative model and record the data in a format usable for the statistical parameters estimation. Moreover, in our study an additional problem pertains to the unavailability of the data regarding a "future" situation. For our analysis we decided to start with the real data collected during the time period January 2007-December 2007, and to adjust them following the terminal managers' forecasting.
In particular, the main data are related to: a) the ship inter-arrival time and turnaround time; b) the quay crane service time; c) the truck and train inter-arrival times and d) internal transport and yard stacking equipment service times.
Note that the ship turnaround time includes the ship arrival, the waiting time before using the terminal facilities and the berthing time (service time). The number of available berths is an obvious factor in determining possible queues. The available statistics related to the arrival-departure process of the ships served by SECH gives for each month the number of ship entered, the average time of berthing and

unberthing, the total number of full and empty containers discharged and loaded and the number of restowages which occurred, respectively, during the loading and unloading operations. These reports have been used for obtaining the distributions of the ship inter-arrival time belonging to four shipping services denoted AME, EMA, MIX and NEW. For each service we suppose a negative exponential distribution of the ship inter-arrival times, as it is commonly used (Kia et al., 2002). Finally, using the data provided by the SECH about the handling moves for each vessel, i.e. min, max and mode, we defined a triangular distribution for generating samples of discharging, i.e. import container moves, and loading activities, and a T-normal distribution with a lower and an upper bound, related to the minimum and maximum number of cranes assigned to each ship. The export containers arrive both via trains and trucks. Since the rail modality has a great importance in the model, in our analysis we decided to focus our attention on both block trains, which represent a large part of the volumes transported via rail, and normal singular trains.

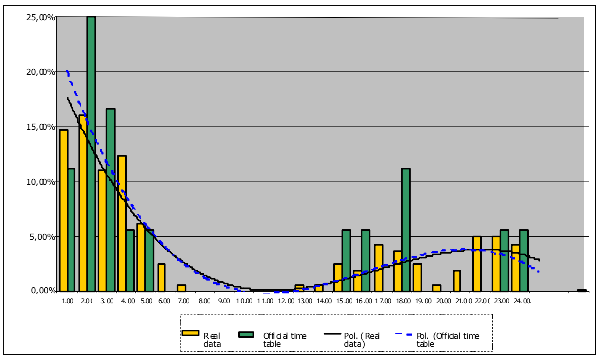

Figure 3. Relative frequency of train inter-arrival times: official timeline versus real data

For studying the arrival process of containers by trains we used the official timeline of the Railways national company and computed the corresponding inter-arrival times split into time slots of 30 minutes each. Note that the official timeline differs from the real trains arrival (real data) profiles observed in the study period (see Figure 3), but in both cases, by using a Chi square test at 90% confidence level, polynomial distributions appear acceptable for modelling the trains' arrival process.

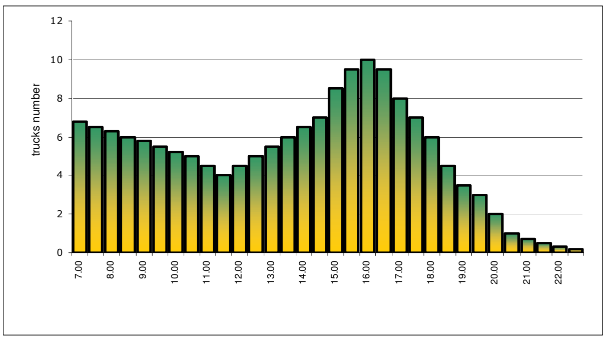

Figure 4. Average distribution of daily trucks' arrivals

Lastly, the time that each truck spends at gate is defined by a triangular distribution that is extrapolated by information of the stevedores, as well as the data concerning the truck arrivals during the day split into 48 time period of 30 minutes each (Figure 4).

Modelling approach and implementation

The discrete event simulation model herein proposed is made up of three modules: the ship flow module, the import container flow module and the export container flow module. These modules manage the action sequence of model objects (ship, import and export containers) through a given series of logistic processes (Figure 5).

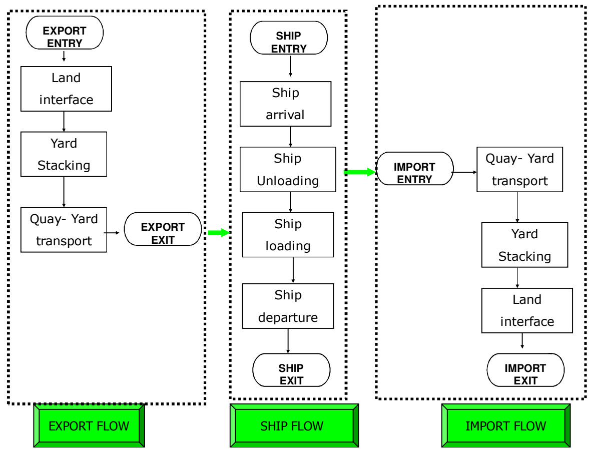

Figure 5. Model hierarchy structure

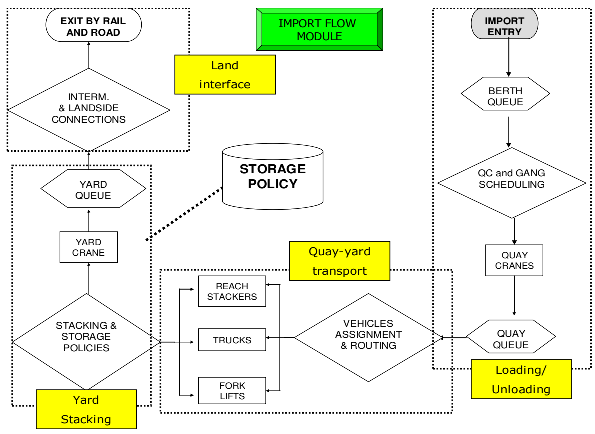

Figure 6. Flow chart of the import flow module

Each module is represented by a flow chart, where activities and events that compose the module are nodes of the graph and edges fixing the logical sequence among nodes. In Figure 6 is reported the hierarchical flow chart referred to the import flow module. Note that for each node, a simulation quasi-language provides the simple activities and events specification as input or output rules.

Those rules can be viewed as the declaration of the solution of the different decision problems to be solved at a marine terminal (Figure 2). As an example, Figure 7 shows the representation of the storage policy followed at SECH to stack import containers that is a pre-marshalling strategy, i.e. containers are stored in different areas in accordance to their weight (W), type, shipping company and size.

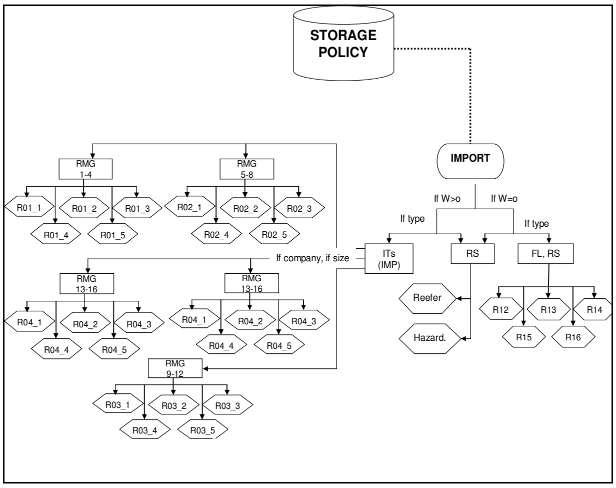

Figure 7. Representation of the storage policy strategy

The model has been implemented using the simulation software package Witness 2008 (Witness, 2008), that is a flexible visual-interactive environment that allows defining an animation along with the model construction.

Model objects, denoted parts, pass through the system according to the module flow charts, from/to queue (i.e. buffers), and are processed by machines that perform some specified activities. Inter-arrival times and service times have been modelled by following the information obtained from the data analysis presented in the previous section. The Witness model implementation is shown in Figure 8, where the basic elements are depicted as they appear on the computer screen. Note that the model implementation results in 7 model objects (4 ship services, trains, import and export containers), 208 buffers, 175 machines, 15 empirical distributions, 75 among variables, attributes and functions for a total number of 489 elements.

Model validity and credibility

Once a simulation model has been constructed and implemented, it need to be validated to ensure that the simulation outputs adequately represents the real measures under investigation. In our case study the model to be validated represents a system that doesn't currently exist (the terminal SECH in 2010), thus we can't get the real output data to apply statistical tests techniques. Consequently, the effective and strong method of the results validation has to be replaced by the face validation (Law, 2007). In particular, the terminal managers review the simulation model for reasonableness and test if the simulation results are consistent with the perceived system behaviour of the SECH container terminal resulting from the expansion plan.

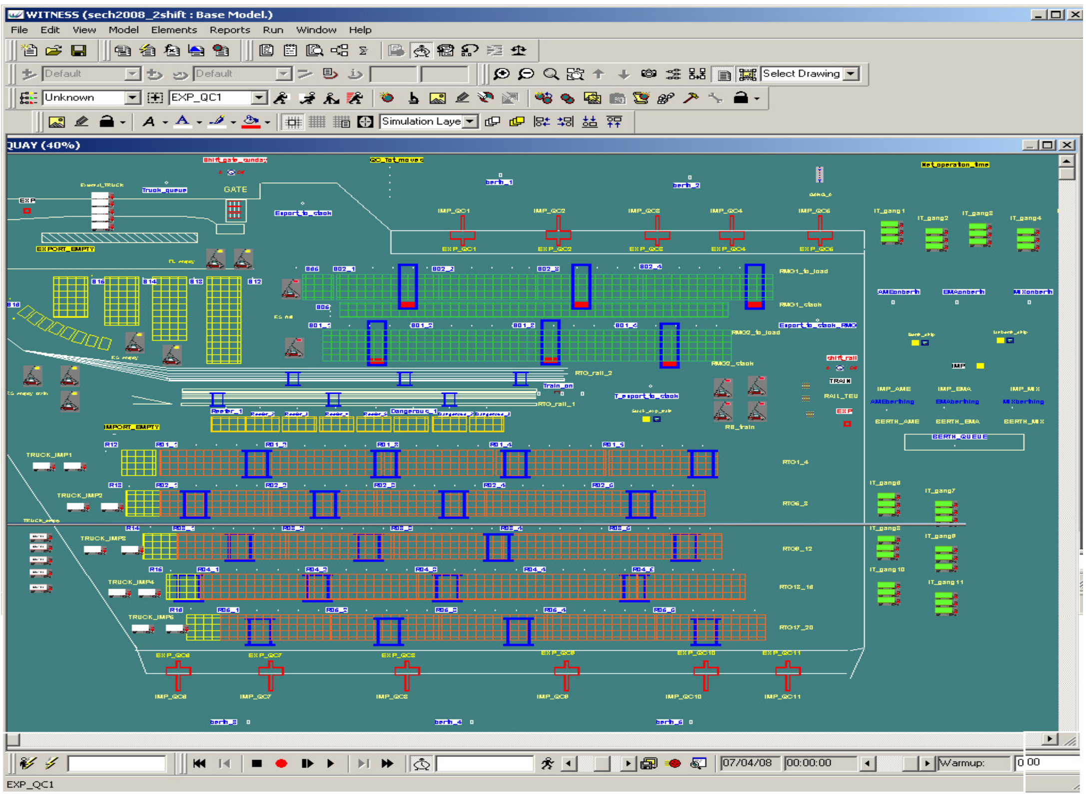

Figure 8. The simulation model Witness representation

Moreover, to improve the model credibility, we decided to validate the model related to the current layout (the “old area” in Figure 1) by using quantitative techniques. In particular, we used a classical statistical test, such as the t-Test, for comparing three monthly output measures, i.e. average estimates of ship arrivals, containers’ arrivals by train and trucks, with the real measures related to the period January-December 2007. We decided to test the null hypothesis H_0 under a probability of rejecting the model fixed to the α=0.05 level, obtaining for all months values inferior to the critical value.

Output analysis: performance indexes and running configuration

For the output analysis, we focus our attention on two series of performance indexes: i) the service-oriented indexes that measure the service levels provided to clients, and ii) the productivity-oriented indexes that measure the container traffic volume internal performance.

In the first group the most important indices are: 1) the average ship berthing time; 2) the so-called net terminal performance index, expressed in terms of the ratio between the total number of containers moved from each ship and the berthing time, and 3) the average container dwell time, i.e. the average time spent in the system, both for import and export containers. When referring to the productivity-oriented indexes we can mention: 1) the import and export container throughput, i.e. number of containers that leave the system during the simulation run; 2) the yard utilization rate, expressed in terms of number of containers in the yard over its operative capacity; 3) the quay utilization level, expressed in terms of percentage of utilization of berthing area; 4) the “gang” utilisation rate expressed in terms of percentage of utilisation, i.e. busy time, of the shifts, 6 hours long, involved in the loading and unloading operations of each ship; and 5) the rotation index given by the ratio between the run period considered, i.e. 30 days, and the average dwell time.

Note that apart from the above mentioned indexes many other performance metrics can be used depending on the specific purpose of the scenario analysis performed.

Table 3. CI and CPU for alternative running configurations

n	90% Confidence Interval				CPU
	Mean (X(n))		*Half Lenght*	*Relative Error*	
5	37332,800	+/-	378,921	1,015%	2' 18''
10	37391,400	+/-	253,800	0,679%	4' 36''
20	37382,550	+/-	131,072	0,351%	9' 09''
30	37398,767	+/-	114,288	0,306%	12' 21''
40	37398,300	+/-	96,593	0,258%	16' 33''

Moreover, one of the aim of our simulation study is to derive performance indices for evaluating the efficiency of the terminal under consideration; for this reason it is important to choose the conditions under which the performance indexes are computed with an acceptable level of errors (Law, 2007). In this case, we calculate the 90% confidence interval (CI) related to the random variable X, defined as the containers monthly throughput of the system, by making 5, 10, 20, 30, 40 IID replications (Table 3). The independence of replications has been obtained by using different random numbers for each replication. Note that the containers monthly throughput for each replication has been calculated by using the Parts Reports Statistics, provided by Witness. In particular, note that the performance measure herein analysed is the sum of the number of import and export containers that have been shipped out during each replication, one month length. Consequently, the column “Mean X(n)” of Table 3 reports the sample mean of the total containers’ throughput calculated in the n=5,10,20,40 replications, respectively. By the comparison of the half length error, we can see that by using 40 replications we are able to reduce its value below the “100 containers” level considered acceptable from the terminal management point of view. Note that to make n=40 IID replications the computational time (CPU) required is about 16 minutes (see Table 3).

CONCLUSIONS AND FURTHER RESEARCH

In this paper, we have presented a discrete event simulation model developed to get some help in the expansion plan of a terminal located in the port of Genoa, Italy. From some preliminary results the proposed model seems to be a useful tool for comparing and analysing different management decisions.

An extensive experimentation is in progress in cooperation with the terminal management. In particular, we are involved in an extensive scenario analysis for evaluating, among others, the growth of the traffic volume, the optimal trade-off between investment required for adding new yard and quay equipments and added value due to larger containers’ movements, different operatives rules and handling techniques for the berthing and stacking area, etc. Moreover, a future direction of our research will be to study the integrated use of optimisation and simulation, with the aim of generating optimal solutions to some critical decision problems which can be used as input data for the simulation model. In particular, following the critical factors underlined by the terminal managers, we will firstly approach the Gang Deployment Problem (GDP), that is the problem of determining the amount of resources (gangs) needed to perform the loading and unloading operations of each ship entering the terminal taking into consideration both the overall gang cost and the ship cost related to the time the ship spends on berth. Secondly, we will attempt to provide solutions to the cranes scheduling problem which could generate the gang work plans for each ship entering and leaving the terminal and manage the work sequences on each crane in the terminal with relevant cost savings.

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