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Simulation of a Container Terminal and It's Reflect on Port Economy

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ABSTRACT

The combination between the design and project of container terminals and the reflect on port's economy may be carried out through two main approaches: optimization or simulation. Although the approaches based on optimization models allow a more elegant and compact formulation of the problem, simulation models are mainly based on *discrete event simulation* (DES) models and help to achieve several aims: then measure this impact on port economy before and after implemented this updating overcome mathematical limitations of optimization approaches, support and make computer-generated strategies/policies more understandable, and support decision makers in daily decision processes through a "what if" approach. Several applications of DES models have been proposed and simulation results confirm that such an approach is quite effective at simulating container terminal operations. Most of the contributions in the literature develop object oriented simulation models and pursue a macroscopic approach which gathers elementary handling activities (e.g. using cranes, reach stackers, shuttles) into a few macro-activities (e.g. unloading vessels: crane-dock-reach stacker-shuttle-yard), simulate the movement of an "aggregation" of containers and therefore do not take into account the effects of container types (e.g. 20' vs 40', full vs empty), the incidence of different handling activities that may seem similar but show different time duration and variability/dispersion (e.g. crane unloading a container to dock or to a shuttle) and the differences within the same handling activity (e.g. stacking/loading/unloading time with respect to the tier number). Such contributions primarily focus on modeling architecture, on software implementation issues and on simulating design/real scenarios. Activity duration is often assumed to be deterministic, and those few authors that estimate specific stochastic handling equipment models do not clearly state how they were calibrated, what data were used and what the parameter Values are. Finally, no one investigates the effects of different modeling

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hypotheses on the simulation of container terminal performances. The focus of this paper is on the effects that different hypotheses on handling equipment models calibration may have on the simulation (discrete event) of container terminal performances. Such effects could not be negligible and should be investigated with respect to different planning horizons, such as strategic or tactical. The aim is to propose to analysts, modelers and practitioners a sort of a guideline useful to point out the strengths or weaknesses of different approaches. Drawing on the model architecture which will be affected on port economics.

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1 Introduction

Container terminal performance is linked to the mechanism used in the organization of processes within the container terminal ill are among the ship and the pier or download the inmates operations Om then monitoring operations in the squares and the extent of mastery of those operations and availability of time to wait for the ship and then reduce operating costs of the vessel and also limit the consumption increasing cranes and subsequent spare parts and maintenance operations that the use of any organization.

The Design and project of container terminals may be carried out through two main approaches: optimization or simulation. Although the approaches based on optimization models allow a more elegant and compact formulation of the problem, simulation models are mainly based on discrete event simulation models and help to achieve several aims: overcome mathematical limitations of optimization approaches, support and make computer-generated strategies/policies more understandable, and support decision makers in daily decision processes through a "what if" approach. Several applications of models have been proposed and simulation results confirm that such an approach is quite effective at simulating container terminal operations. Most of the contributions in the literature develop object-oriented simulation models and pursue a macroscopic approach which gathers elementary handling activities (e.g. using cranes, reach stackers, shuttles) into a few macro-activities (e.g. unloading vessels: crane-dock-reach stacker-shuttle-yard), simulate the movement of an "aggregation" of containers and therefore do not take into account the effects of container types (e.g. 20' vs 40', full vs empty), the incidence of different handling activities that may seem similar but show different time duration and variability/dispersion (e.g. crane unloading a container to dock or to a shuttle) and the differences within the same handling activity (e.g. stacking/loading/unloading time with respect to the tier number). Such contributions primarily focus on modeling architecture, on software implementation issues and on simulating design/real scenarios. Activity duration is often assumed to be deterministic, and those few authors that estimate specific stochastic handling equipment models do not clearly state how they were calibrated, what data were used and what the parameter values are. Finally, no one investigates the effects of different modeling hypotheses on the simulation of container terminal performances. The focus of this paper is on the effects that different hypotheses on handling equipment models calibration may have on the simulation (discreet event) of container terminal performances. Such effects could not be negligible and should be investigated with respect to different planning horizons, such as strategic or tactical. The aim is to propose to analysts, modelers and practitioners a sort of a guideline useful to point out the strengths or weaknesses of different approaches.

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Drawing on the model architecture proposed in a previous contribution by the same authors (,de Luca, 2005), a discrete event simulation model is developed and applied to the Red sea Container Terminal in order to deal with the following issues:

- Analysis of the effects of different estimation approaches (sample mean and random variable estimations) on estimating whole terminal performance, hence on container terminal planning strategies. In particular, analyses were made for different time horizons: long-term planning interventions/investments, medium/short period, short-term or real-time applications.
- Analysis of the effects of different hypotheses on the level of aggregation of elementary activities (undifferentiated vs. container type model).

The paper is divided into four sections. In the first section (section 2) an in depth literature survey is proposed. The aim is to go back over about thirty year of container terminal simulation models, to highlight weaknesses points of the existing approaches to handling equipment activities simulation, and to propose a synthetic but complete outline of the models calibrated and of their parameters. In section 3 a brief description of the discrete event simulation model is reported. In section 4 results from model application are proposed while the main conclusions are drawn in section 5.

2 Literature review

The existing literature reports approaches to either managing a container terminal as a system and trying to simulate all elements or managing a subset of activities (simultaneously or sequentially following a predefined hierarchy). The main contributions seek to maximize overall terminal efficiency or the efficiency of a specific sub-area (or activity) inside the terminal. The most widely followed approaches are based on deterministic optimization methods, although recently a stochastic optimization model was proposed (Murty .2005). Such approaches schematize container terminal activities through single queue models or through a network of queues. Following a stochastic approach, both modeling solutions may lead to analytical problems and/or unsatisfactory results if the probability distribution of activities involved does not belong to the Erlangen family (Nilse, 1977; Ramani,1996). Moreover, the resulting network could be very complicated and theoretical solution might not be easy to obtain. In such a context, an effective and challenging alternative approach for container terminal system analysis may be represented by discrete simulation.

Simulation can help to achieve various aims: overcome mathematical limitations of optimization approaches, allow a more detailed and realistic representation of terminal characteristics, support decision makers in daily decision processes through assessment of "what if" scenarios and make computer-generated strategies/policies more understandable. Simulation is not a new methodology in port operations. Several works have been presented since the 1980s, most of them concerning port operations management. Many of the proposed models do not focus on the details regarding the model set-up, its calibration and its validation; but on the application and/or the simulation of design scenarios. Moreover, although the estimation of handling activity models should be one of the main issues of all container terminal applications, this problem does not seem to be treated in depth in most applications. While many contributions do not present any information on handling activity models used, the remaining contributions carry out very simple approaches (deterministic) and/or give scant information on the estimation approach adopted, the experimental data used, the parameters estimated and on parameter values.

The aim of our analysis is twofold to propose an extensive review of the main contributions in the literature, to focus on the approaches, models and parameters used to model handling activities.

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Starting from the pioneering work of Collier (1980) investigating the role of simulation as an aid to the study of a port as a system, the 1980s saw several works implementing the first simulation-based models. In Agerschou et al.(1983), Tugcu (1983) proposed a simulation model for the port of Istanbul, dealing with berth assignment and unloading operations. Vessel arrival is simulated through Poisson distribution, whereas empirical distributions are used for the remaining activities. El Sheikh et al. (1987) developed a simulation model for the ship-to-berth allocation problem; the phenomenon is modelled as a sequence of queues, and vessel interarrival and service time are modelled through exponential distribution functions. In the same year, Park and Noh (1987) used a Monte Carlo type simulation approach to plan port capacity, Comer and Taborga (1987) developed one of the first port simulation softwares (**PORTSIM**), and Chung et al. (1988) proposed a methodology based on a graphic simulation system to simulate the use of buffer space to increase the use of handling equipment and reduce total container loading time.

In the 1990s much effort was spent on simulating terminal containers: the number of applications based on simulation increased, terminals were modeled more realistically through disaggregation of the main operations in several elementary activities, and much more attention was laid on real case studies. The focus of most contributions was on developing practical tools to simulate terminal operations, on software issues and/or on model validation. Less attention was focused on modelling handling activities and/or model details. Kondratowicz (1990), within a general method for modelling seaport and inland terminals in intermodal freight transportation systems, proposed an object-oriented model, **TRANSNODE,** to simulate different application scenarios. Silberholz et al. (1991) described a simulation program that models the transfer of containerized cargo to and from ships, Mosca et al. (1992) used simulation to ascertain the efficiency of an automatic flatar system servicing a rail-mounted crane, and Hassan (1993) gave an overview of a computer simulation program used as a decision support tool to evaluate and improve port activities. Lai and Lam (1994) examined strategies for allocation of yard equipment for a large container yard in Hong-Kong. In the same year, Hayuth et al. (1994) used a discrete event simulation to build a port simulator, but the main emphasis was on software and on hardware problems. Key issues of the application of modelling and simulation were discussed in Tolujev et al. (1996) and Merkutyev et al. (1998), both contributions proposing an application to the Riga Harbour Container Terminal. Gambardella et al. (1998) proposed a discrete event simulation model (based on process oriented paradigm) to simulate vessel loading/unloading. The model was applied to the Italian container terminal of La Spezia (Italy), with scant information on the data used and on the characteristics of the equipment used in the application. The same case study was analyzed by Mastrolilli et al (1998), using a model similar to that proposed in Gambardella et al. (1998) and proposing a calibration and a validation procedure of simulator parameters. Means and standard deviations are estimated for quay crane, yard crane and straddle carrier service time, whereas speed of cranes and travel time of shuttle trailers are assumed deterministic, as well as vessel arrival and truck arrival. Nevins et al. (1998) developed **PORTSIM**, a seaport simulation model able to animate and visualize seaport processes and in the same year Signorile (1998) developed a software tool to support terminal operators in making strategic decisions. The main emphasis was on optimizing container placement in a terminal; a genetic algorithm approach was adopted, a simple application proposed, yet no details can be found on the performance functions used. The same authors (Bruzzone et al.1999) investigated the effectiveness and benefits of a simulation approach as a decision support system for complex container terminals. Interesting modeling details were

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proposed by Koh et al. (1994), Walton (1996) and Ramani (1996). Koh et al. (1994) developed an object-oriented approach using **MODSIM** simulation software. The proposed model relies on experimental data, average values are used for handling equipment, whereas Weibull distribution seems to fit crane cycle time better. Holguìn-Vera and Walton proposed a simulation model based on the next event approach. The model is calibrated on experimental data and two approaches are carried out: a deterministic one based on empirical distribution and a stochastic one. Gantry crane, yard crane and crane movements are simulated through a random variable made up by systematic and a random component. While the systematic components are estimated using multiple regression, the corresponding random parts are not clearly introduced. Ramani (1996) designed and developed an interactive computer simulation model to support the logistics planning of container operations. The model provides estimates for port performance indicators.

Since the end of the 1990s, the most important ports in the world have been modeled through discrete event simulation models, and greater interest is shown in the calibration of handling activities models. Choi (1999) develop an object-oriented simulation model using **SIMPLE** language and apply it to analyze the container terminal system used in Pusan. The system is analyzed as a whole (gates, yards and berths), deterministic and stochastic distribution functions are considered: deterministic for trailer speed and for inter arrival time of trailers and tractors; uniform for service time at the gates; exponential for inter arrival time of trailers, vessels and service time of cranes.

The same case study proposed by Yun (2000) follows an object oriented approach, developing a model to simulate two different terminals located in Pusan. The simulation tool is generic and transferable to any other terminal; it is based on Visual C++ and gives accurate results once validated on historical data. As regards equipment characteristics, averages are used for cranes and trailer speed, whereas distribution functions are used for crane operation time (Normal distribution). It is not clear whether performance characteristics were estimated. Hussain (2000) deal with berth operation and crane allocation problems. Their discrete event simulation model is based on data collected at the port of Kelang and specific analyses are carried out to identify the distribution functions for inter-arrival time of ships (Weibull distribution) and for service time at berths (distribution not mentioned). The model is implemented in **ARENA s**oftware and is validated on historical data. Mazza (2001) examine the vessel arrival-departure process, developing a queuing network model through an object-oriented approach implemented in VISUAL **SLAM** language. Since no detailed disaggregate data are available, a first order Erlangen distribution is applied for those services with the supposed larger variance, a higher order is adopted for more regular services and, finally, a triangular distribution is used to assign the number of containers to cranes.

Angelides (2002) develop a discrete event model to simulate the inbound container handling problem. The model is implemented in an **EXTEND** software package and applied to the port of Thessaloniki. Truck inter-arrival times follow an Erlangen distribution, whereas maximum, minimum or most probable values are estimated for speed and activity time of equipment involved. Developing a microscopic simulation model, Chin et al. (2002) evaluate the effectiveness of automated guidance vehicles. The focus is on the application and no details are given either on the models or data used.

Yeung (2002) propose a discrete event simulation model employing the Witness program to analyze the performance of Hong Kong's Kwai Chung container. Although the model encompasses all the operations that may occur in a terminal, the focus is on vessel arrivals and their distribution among the existing buffers and operators. While arrivals are simulated through a distribution function (k-stage Erlangen), the remaining

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operations are analyzed in a very aggregate way and average values are considered (average handling capacity).

Kia et al. (2002) use a port simulator developed in **TAYLOR II** software to investigate the effectiveness of two different operational systems applied to the terminal of Melbourne. With the emphasis on terminal capacity, all the activities that occur inside the terminal are not explicitly simulated but aggregated in one variable represented by the vessel's service time. Although no details are reported on the model structure, interesting statistical analyses are presented on vessel arrival patterns (exponential distribution for inter arrival times) and on vessel service time (k-stage Erlang distribution).

Parola and Sciomachen (2005) present a discrete event model to simulate the logistic chain of a system made by two ports, three possible destinations and connections between them (by road and/or by rail). The simulation is undertaken through **WITNESS** simulation software and the main emphasis is on vessel berthing, vessel loading/unloading and gate operations. Vessel inter arrival is represented by an exponential distribution function (estimated), crane working time and truck waiting time by a truncated normal distribution. It is not clear whether the probability distributions were estimated or simply taken from the literature. Bielli et al. (2006) develop a simulation tool in **JAVA** programming language to simulate the port of Casablanca. The focus is on the architecture and on software issues; handling activities are hypothesized as deterministic.

Petrovic (2007) simulate unloading services of bulk cargo vessels. They stress the relevance of a stochastic approach and schematize the system as a three-phase queuing system with different numbers of servers in each phase. A simulation tool is created in PASCAL programming language, and all variables are generated using the Monte-Carlo method according to distribution functions obtained from an existing river terminal: normal for anchorage operations and for crane unloading times, exponential for inter-arrival of vessels.

Cortès et al. (2007) set out to simulate the whole freight transport process in the Guadalquivir river estuary. Despite a detailed description of operations and the software modules implemented, little information on equipment characteristics and time duration is reported. Deterministic functions appear to have been used for gantry cranes, exponential for the transfer time in dock assignment while for vessel arrival time an empirical distribution function is used.

Cho (2007) propose a model to simulate the effectiveness of a dynamic planning system for yard tractors utilizing real-time location systems technology. Auto Mod 11.1 software is used and statistical models are proposed. Of the contributions introduced so far, as already pointed out, only ten papers give information on the handling equipment models used. Half of them adopt a stochastic approach and show estimated parameter values. Most of the contributions deal with vessel loading/unloading operations. There is substantial heterogeneity regarding the level of aggregation of activities involved and how such activities are aggregated in a single macro-activity: El Sheikh (1987), Choi (2000), Kia et al. (2002) and Yeung (2002) analyse the entire time to load (unload) a vessel (vessel cycle time); Koh et al. (1994) and Bugavic and Petrovic (2007) investigate the crane cycle time (time needed to: lock onto the container, hoist and traverse, lower and locate, unlock and return); crane loading time to/from a vessel is analysed by Tugcu (1983), Thiers (1998), Yun and Choi (1999), Merkuryeva et al. (2000), KMI (2000), Sciomachen (2005), Bielli et al. (2006), and Cho (2007). As regards vessel cycle time, a stochastic approach is unanimously proposed.In particular, El Sheikh (1987), Kia et al. (2002) and Yeung (2002) suggest using Erlang random variables whereas Choi (2000) proposes normal random variables for two crane types (quay, yard). As regards crane cycle time, Koh et al. (1994) advise the use of a Weibull random variable;

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Bugavic and Petrovic (2007), for a bulk cargo terminal, propose normal random variables and report the estimated parameters.With regard to crane loading/unloading time, Tugcu (1983), Thiers (1998), KMI (2000) and Bielli et al. (2006) follow a deterministic approach, contrasting with the stochastic approach adopted by Yun and Choi (1999), Merkuryeva et al. (2000), Lee and Cho (2007), Parola (2005). Choi (1999) propose the exponential distribution function both for quay crane and yard crane; Merkuryeva et al. (2000) propose the uniform distribution function for quay crane and a triangular distribution function for yard gantry crane;

Cho (2007) suggest the exponential distribution function for quay crane and a triangular distribution function for yard gantry crane operation time.

Parola and Sciomachen (2005) estimated a normal random variable but do not report parameter values.With respect to crane speed, all propose deterministic and aggregate models while only Choi (1999), Choi (2000), KMI (2000) and Legato et al.(2008) report the estimated mean values.

With respect to other handling equipment, not much can be found in the literature: Angelides (2002) use deterministic values for a straddle carrier, whereas Merkuryeva et al. (2000) propose a triangular distribution function for the forklift. As regards shuttle performances (speed, travel time, waiting time …), the few models existing are hard to transfer to different case studies (due to the influence of path length, path winding, traffic vehicle congestion inside the terminal and so on). Hence they are omitted in this survey. For each type of handling equipment and for each activity simulated, probability distribution and corresponding parameters are reported.

3 Model

The proposed approach schematizes a container terminal (CT) as a discrete event system and models its functioning through a simulator. A discrete event system can be defined as an interacting set of entities/objects that evolves through different states as internal or external events happen. Entities/objects may be physical, conceptual (information flows) or mathematical, and can be resident or transient. Resident entities remain part of the system for long intervals of time; transient entities enter into and depart from the system several times. Entities can be characterized by parameters and/or variables. Parameters define static (stationary) characteristics that never change, variables define the state (dynamic characteristics) of each entity and may change over time and can further be classified as deterministic or stochastic. In a CT entities represent the handling equipment, the containers and all those physical locations relevant to CT operations (dock, yard, gates, etc..).

- Handling equipment is a resident and active entity and may be characterized by parameters, variables and an activity.
- Containers are transient and passive entities.
- Physical locations are resident and passive entities. As for containers, they may be characterized by parameters and variables.

  Apart from the above-described entities other entities can be considered. Such entities do not usually move containers but can control/manage entities

  that handle containers and can thus change their attributes. The change in such attributes may be driven by simple heuristic rules (e.g. if there are more than four trucks waiting for a reach stacker, use one more reach stacker) or by sub-models that change entity attributes, trying to optimize overall terminal performance in real time.

In discrete event modelling the model is defined once the case study is defined and three main tasks should be carried out.

a) Identification of the terminal's logical and functional architecture.
b) Demand characterization and estimation.
c) Supply characterization and calibration.

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Case study

In this paper the red sea Container Terminal is analyzed. is a major private container terminal operator in southern Italy, and is both small and very efficient: it handles close to 0.45 MTEUs per year in less than 10ha (100,000 m2), which amounts to 45 TEUs/ha. The red sea Container Terminal can be divided into three subsystems: enter/exit port gates (land-side), container yards, and berths (sea-side). Container handling equipment comprises storage cranes, loading/unloading cranes, yard tractors, trailers and reach stackers. The basic activities occur simultaneously and interactively, and can be grouped into four main operations: receiving (gate – yard), delivery (yard – gate), loading (yard – berth) and unloading (berth – yard).

Model architecture

Three different macro-activities were taken into account: import, export and transhipment. Apart from vessel arrival and berthing (not relevant to our case study) and apart from truck arrival, all the typical activities of a container terminal were explicitly simulated.

Demand characterization

Demand is represented by single containers. For each macro-operation (import, export, transhipment), the demand flows were characterized over space, time and type. As regards spatial characterization, container flows were subdivided by origin and destination zone and were arranged in origin destination matrices. In particular, for each operation macro-origin and macro destination zones were identified, usually corresponding to quays, yards, gates. Different matrices were estimated for each container type (20 feet vs. 40 feet, full vs. empty, …), each demand flow was characterized by its distribution over time. (details; de Luca, 2009).

Supply characterization

As introduced in the previous sections, in a container terminal macro operations, operations and handling activities may be distinguished. Macro operations are set up by operations; operations are set up by elementary handling activities. In such a classification the different entities involved must be characterized by their geometrical characteristics (if physical points) and by the corresponding performance supplied (time duration and/or transport capacity). Storage capacity was estimated for quays and yards; averages and probability distribution functions were estimated for handling equipments time duration. In the following tables, results of estimation (sample means and probability function parameters) are reported for each handling equipment and for each activity. Details on the pursued estimation methodologies and/or comments on estimation and calibration results may be found in de Luca, 2009).

Handling equipments involved were: mobile harbour crane (MHC), gantry crane (GC), reach stacker (RS). MHCs operating in the red sea Container Terminal are three Gottwald HMK 260 mounted on rubber-types and are mainly devoted to loading/unloading containers to/from berthed vessels. The results, reported in table 6, concern loading activities from shuttle to vessel or from dock to vessel, and unloading activities from vessel to dock. The following container types were considered: undifferentiated containers, 20’, 40’ and 20’x20’. Since most red sea Container Terminal loading/unloading activities concern full containers, the analysis is mainly focused on full containers. Some results on empty containers are proposed only for activities that systematically involve empty containers. Statistical analysis for undifferentiated containers shows that the distribution function is always statistically significant. The same random variable seems to be the best approximation for loading and unloading activities that involve 20’ and 40’ (full or empty) containers means and standard deviations related to distribution are reported. operating in the Redea Container Terminal are four rubber-tyred gantry cranes used both for ovement/storage of containers and for loading of shuttles/trucks. This

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crane type usually consists of three separate movements for container transportation. The first movement is performed by the hoist, which raises and lowers the container. The second is the trolley gear, which allows the hoist to be positioned directly above the container for placement.

The third is the gantry, which allows the entire crane to be moved along the working area. The analyses carried out concern loading and unloading to the shuttle/truck, and loading and unloading to the stack (sometimes called pile). Each activity was analyzed distinguishing undifferentiated containers from 20' and 40' containers. Moreover, loading time from stack is reported, further distinguishing the tier. The analysis is focused on full containers, since these activities are the most frequent in the red sea Container Terminal. Finally, averages and standard deviations were estimated for trolley speed and crane speed. As regards undifferentiated containers, the Gamma distribution function proved the best solution for all analysed activities. Similar results were achieved on analysing activities for each container type and each tier number. means and standard deviations are reported for each activity.

The RSs operating in the red sea Container Terminal are eleven and are equipped with a twin-lift spreader able to move two full 20' containers. They are used both to transport containers in short distances very quickly and to pile/storage them in various rows.

The analyses carried out concern: loading to shuttle/truck, unloading from shuttle/truck and stacking. Each activity was analyzed distinguishing undifferentiated containers from 20' and 40' containers. Moreover, stacking was analyzed distinguishing the tier number. The analysis is focused on full containers since in red sea Container Terminal the main activities are related to full containers. For the stacking time, the time duration for each tier, up to five, was computed, but it was not possible to distinguish containers typology. For the mentioned activities Gamma random variable fits the data better due to best values of the validation test regards RSs speed, the authors suggest to estimate the time duration of these activities directly.

4 Simulation

To plan investments for a container terminal several project scenarios need to be compared through performance indicator estimation. These indicators could be global, if referring to the container terminal as a whole (aggregate indicators), or local if referring to a single container (disaggregate indicators).

Global indicators are generally used to evaluate the benefits of long-term investments; while local indicators are used to evaluate the benefits of medium/short-term investment and for real time applications. To test the applicability of the model architecture proposed for all the cited

kinds of application, the implemented model was validated with respect to performance indicators coherent with those measured by the terminal monitoring office and summarized above: global performance indicators

- Terminal operation time: daily time required to bring all terminal activities to a close;

local performance indicators

- handling equipment indicators;
- vessel loading and/or unloading time;
- quay/yard crane idle time;
- shuttle waiting time;
- shuttle transfer time;
- reach stacker stacking time;
- reach stacker idle time;
- gate in/out waiting time;

Container Indicator;

- container operation time: time required to move a container with handling equipment (e.g., time spent moving a container from quay to vessel or from shuttle to stack). Starting from the model architecture proposed in the previous section, four different models based on four different

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handling equipment models, were implemented:

- **Sample Mean Undifferentiated model.1** Sample mean values are used to estimate handling equipment time duration and there is no distinction between containers type.
- **Sample Mean Container Type models.2** Sample mean values are used to estimate handling equipment time duration and containers type are explicitly taken into account: 20’ full and/or empty; 40’ full and/or empty; 2 x 20’ full.
- **Random Variable Undifferentiated model.3** The time associated to each single activity is the realization of a random variable, handling equipments time duration is modeled as a random variable and there is no distinction between containers type.
- Random Variable Container Type models. Handling equipment time duration is modeled as a random variable and containers type are explicitly taken into account: 20’ full and/or empty;40’ full and/or empty; 2 x 20’ full.

The results in terms of simulation time point out that random variable models require a computational time much greater than sample mean ones. The former require about 20 minutes, the latter are below one minute. Results in terms of global indicators show an average absolute percentage error of more than 10% for the handling model, whereas in using the handling model the percentage estimation error is lower than 5%. Using the Container Type models, results in terms of global indicators show an average absolute percentage error of about 9% for the sample mean model, whereas in using the random variable model the percentage estimation error is about 3%.

The use of sample mean handling models does not produce very good results in terms of local indicators; average percentage estimation errors exceed 13% for handling equipment indicators and are about 30% for container indicators.

Results obtained using random variable handling models are significant:

average absolute percentage errors for handling equipment indicators are more than 6% with the handling model, and about 3% with handling models. With respect to container indicators, when only using the handling models the absolute percentage estimation error is acceptable in all other cases the estimation errors are about 30%.

5 Conclusions

In literature numerous efforts may be found in the field of simulation of a container terminal, most of the existing papers are only focused on the application and/or on the comparison of design scenarios and do not pay great attention on the model set-up, its calibration and its validation. If on the one hand, many contributions do not present any information on equipment handling models used, the remaining contributions carry out very simple approaches (deterministic) and/or give scanty information: on the estimation approach pursued, on experimental data used, on parameters estimated and on parameters value. Moreover, no one investigates the effects that different hypotheses on handling equipment models calibration may have on the simulation of container terminal performances. Such effects could not be negligible and should be investigated with respect to different planning horizons, such as strategic or tactical. In this paper a discrete event simulation model was proposed and applied to the red sea container terminal in order to address some of the open issues introduced above. The aim was to suggest to analysts, modellers and practitioners a sort of a guidelines useful to point out the strengths or weaknesses of different approaches. Guidelines were presented through:

a) a preliminary in depth literature survey;
b) the description of the developed discrete event models, with particular attention to estimation results of handling activity models for three handling equipment

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(mobile harbour cranes, gantry cranes, reach stackers) and for different container type (undifferentiated, 20 feet, 40 feet, empty, full….);

c) the simulation of the effects of different hypotheses regarding the approach to estimate handling activities time duration (sample mean vs random variable estimation), the level of aggregation of handling activities (e.g. vessel loading vs explicit simulation of elementary activities sequence), the segmentation of container type.

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