A SIMULATION MODEL FOR A CONTAINER TERMINAL[*]

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ABSTRACT

Today the efficiency of container terminals (CT) plays a relevant role in freight transportation. Most existing contributions to the simulation of terminal operations follow a microscopic approach that allows for detailed analysis. But, such an approach may lead to computational problems and is rather computer demanding, especially when resulting models are to be used to support optimization. Hence main applications focus on specific operations, aimed at supporting operational management. On the other hand, decisions about the container terminal configuration regard types and number of handling means, berth and yard layout, etc. In this case a macroscopic approach, based on container flows rather than single container movement, could be more effective to simulate all the activities that occur in a container terminal.

This paper is part of a more general research project aimed at container terminal analysis, say simulation and optimization. Several main modelling approaches will be followed: *macroscopic models* based on continuous flow networks, *microscopic models* based on discrete event models, or on coloured Petri networks (say logical and/or time and/or multi-type discrete flow networks). All of them will be applied for supporting performance analysis of a container terminal through performance indicators. The whole methodology will be applied to analyze the performances of Salerno Container Terminal.

In particular, this paper proposes a discrete event simulation model, which can be rather easily calibrated against real data, and applied to analyze the current configuration and to simulate and evaluate alternative design configurations.

1 INTRODUCTION

Today, more than 90% of international cargo moves through seaports and the 80% of total goods shipped moves on containerized vessels. In such a context the efficiency of container terminals assumes a relevant role in the transport chain economy. A container terminal should manage in the most efficient way container vessel berths on the docks, unload inbound (import) containers (empty or filled with cargo), load outbound (export) containers and storage yards. Such a goal can be obtained by coordinating the berthing time of vessels, the resources needed for handling the workload, the waiting time of

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[*] Due to unforeseeable and unavoidable commitments what follows is only a first version of this paper, the final one will be available at the conference and included in the final version of the electronic proceedings.

customer trucks and, at the same time, by reducing the congestion on the roads, at the storage blocks and docks inside the terminal as well as to make the best use of the storage space.

Each of these activities significantly influence a port efficiency with consequences on the local and global economy of the freight transport system. It is not worthless to say that the management of container terminal operations has thus become crucial in order to meet the demand for container traffic both effectively and efficiently.

A container terminal can be considered as a transportation system and can be split, as usual, into two main components: demand and supply. The supply system is the set of facilities, services and regulations which allows to move the containers inside the terminal, the demand system is represented by origin-destination of freight, demand flows by in-bound and out-bound containers.

The design and appraisal of a project for a container terminal can be carried out through macroscopic or microscopic simulation tools, depending on the main goal of the analysis, such as : *macroscopic models* based on continuous flow networks, *microscopic models* based on discrete event models, or on coloured Petri networks (say logical and/or time and/or multi-type discrete flow networks).

Main advantage of the microscopic approach is that it allows for a detailed analysis in which each single activity is explicitly. Of course this approach may lead to computational problems and is rather computer demanding, especially when resulting models are to be used to support optimization. Hence it is better suited for operative planning or operations management. On the other hand, decisions about the container terminal configuration regard types and number of handling means, berth and yard layout, etc. and are better considered within strategic planning. In this case a macroscopic approach, based on container flows rather than single container movement, could be more effective to simulate all the activities that occur in a container terminal.

The existent literature faces the problem either managing a container terminal as a system and trying to simulate all elements or managing a sub-set of activities (simultaneously or sequentially following a predefined hierarchy). The main contributions try to maximize the whole terminal efficiency or the efficiency of a specific sub-area (or activity) inside the terminal. The most followed approaches are based on deterministic or stochastic optimization methods, and each activity is usually analyzed using queuing models. Examples in literature are focused on specific activities, and regard container storage and retrieval in the yard operations, space requirement problems, space requirement and crane capacity, re-marshalling strategy, storage space allocation and stowage of vessels or berth allocation.

Since queuing models may lead to analytical problems and/or unsatisfactory results, an effective and stimulating alternative approach for container terminal system analysis may be represented by simulation. The approach provides good results in predicting the actual operation system of the container terminals.

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The most followed approaches are based on deterministic optimization methods. Recently a stochastic optimization model have been proposed for maximize terminal efficiency (Murty et al., 2005). The proposed models estimate the total workload for a time period and minimize, for example, the average time terminal takes to unload and load a docked vessel. Usually each activity is analyzed using queuing models. Such an approach may lead to analytical problems and/or unsatisfactory results if the probability distribution of the arrival times and service times of the ships does not belong to the Erlang family. Moreover, the operation of container terminals is better schematized by a network of queues, rather than a single queue, the resulting network is usually very complicated and theoretical solution might not be easy to obtain.

An effective and stimulating alternative approach for container terminal system analysis may be represented by simulation. (Yun and Choi (1999) propose a simulation model of the container terminal system of the Pusan east container terminal. The model is developed using an object-oriented approach and estimates container terminal performances. Shabayek and Yeung (2002) propose a simulation model employing the Witness program to analyze the performance of Hong Kong’s Kwai Chung container. The approach provides good results in predicting the actual operation system of the container terminals.

This paper is part of a more general research project aimed at container terminal analysis, say simulation and optimization. For several main modelling approaches will be followed: *macroscopic models* based on continuous flow networks, *microscopic models* based on discrete event models, or on coloured Petri networks (say logical and/or time and/or multi-type discrete flow networks). All of them will be applied for supporting performance analysis of a container terminal through performance indicators.

This research project can be broken down into three main steps (figure 1):

1. *methodological issues*

  - different approaches identification
  - models architecture identification (for each approach);
  - models specification (for each approach);
  - decision variables definition (for each approach);
  - performance indicators specification;

2. *applications*
   - test-site choice (object of this paper);
   - survey for the calibration of the model parameters (object of this paper);
   - actual scenario simulations (for each approach);
   - hypothetic scenario simulations (for each approach);
3. *conclusions*
   - comparisons;
   - guidelines for applications: strengths, weaknesses, fields of application for each approach, most effective indicators…

The whole methodology will be applied to analyze the performances of Salerno Container Terminal:

- estimate the performances of SCT;
- find out its main inadequacies and critical points;
- simulate hypothetic scenarios in order to improve the system efficiency.

A macroscopic models has been already developed by the same authors and first results have been presented elsewhere (de Luca S., Cantarella G.E. and Cartenì A., 2005). First results of a microscopic models based on discrete event simulation are reported in this paper. the coloured Petri networks will be addressed in future papers.

In this paper we develop a (microscopic) discrete event simulation model for a performance analysis of a container terminal. The basic structure of a discrete event simulation model consists of different elements representing the different activities of a container terminal, each with own specific input variables, constraints and system (performance) indicators. The whole system can be interpreted as an oriented graph, where nodes correspond to significant activities, links represent the physical and/or functional relationships between the elements and paths are, in our case study, a sequence of activities followed by containers. A cost function is assigned to each activity in order to relate the variables, the constraints and the work system indicators. The time instant which each activity occurs is explicitly taken into account.

The proposed model allows to measure terminal performances, and two main applications may be carried out: (i) *cost analysis* in order to identify terminal critical points, and (ii) *scenario analysis* in order to simulate the feasibility, effectiveness and efficiency of hypothetic scenarios due to supply system modifications.

The paper is divided into three sections: in the first the model architecture is described; in the second some preliminary results of data analysis about the test-sit are given; in the third conclusions of the study are reported.

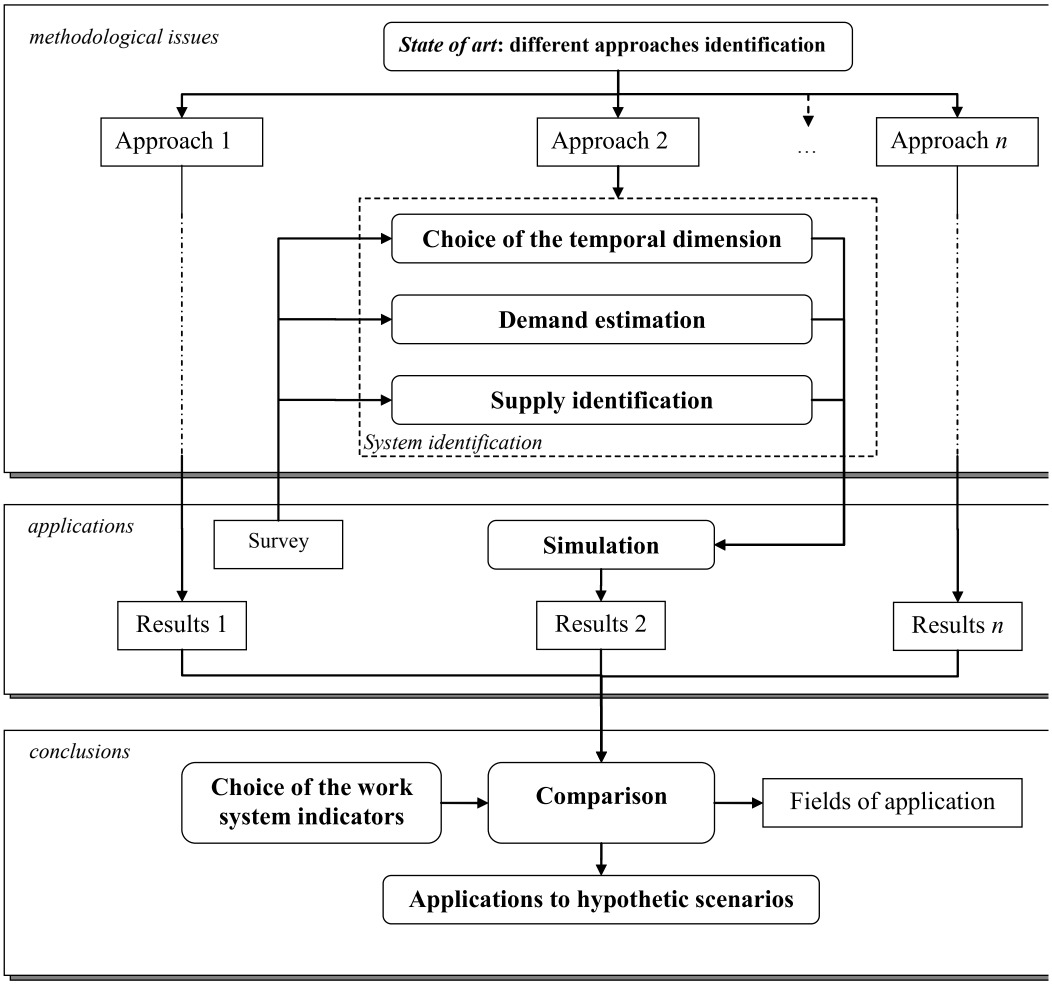


Figure 1 –Methodological architecture

2 MODEL ARCHITECTURE

A Container Terminal (CT) can be divided into: gate, yard, and berth subsystems. Container handling equipments are storage (yard) cranes, loading/unloading (berth) cranes, yard tractors, trailers, reach stackers, … .
The management of a CT consists of *berth planning*, *yard planning*, *storage planning* and *logistics planning*. Berth planning refers to the plan/control of the load/unload activity. Yard planning refers to the optimal container allocation into the storage areas (import, export and transhipment). Storage planning refers to the storage location in the bay of the ship. Logistics planning refers to the operations of the container handling in between the vessel's bay and the yard.
After a preliminary identification of all system elements (cited above), each activity has been exploded by identifying input variables, constraints and relationships. The resulting time-space graphs have been characterized by estimating the relevant cost functions. The cost functions have been estimated by combining the container monitoring data available for the terminal and an "ad hoc" survey made in the terminal; finally, they have been validated on data not used in calibration stage.

Salerno Container Terminal (SCT) has been the case study of the work. It is located into Salerno harbour, and is a major private container terminal in the South of Italy. This container terminal is, at the same time, small and very efficient; in fact it operates close to 0,5 millions of TEUs per year (say 50.000 TEUs/ha). In addition the location of Salerno harbour does not allow to enlarge area for terminal, hence SCT should greatly rely on intensive approach to operation rather than an extensive one in order to keep pace with increasing demand.

Simulation seems to be one of the most effective approaches to analyze complex systems, and it seems to be the most recommendable methodology to analyze a container terminal system.

In this work we develop a (microscopic) discrete event simulation model for a performance analysis of a container terminal. A discrete event system is a dynamic system, whose states (possibly described by logical variables too), may change each time an event (in a preliminary defined set) occurs. The sequence of events describes the evolution over time of the system (clearly in discrete a-periodic time).

The basic structure of a discrete event simulation model consists of different elements each of them representing one type of activity of a container terminal. The connections of whole system can be represented as an oriented graph (see the example in figure 2), where **nodes** correspond to significant *event*, **links** represent *activities* and **paths** are a *sequence* of activities; in our case study, containers moves along a path.

Table 1 reports the main container terminal activities regarding container flows, without explicitly showing info flows also. A cost function is assigned to each activity in order to relate the variables, the constraints, the system indicators. The time instant at which each activity occurs is explicitly taken into account.

The model architecture proposed is represented in figure 2. As we can observe all the container paths across the terminal could be refer to three macro-activities: *import*, *export* and *transhipment*. Through the proposed architecture it is possible to jointly simulate these macro-activities that influence each other, since they compete for common resources. The simulation of this mutual influence allows to explicitly simulate the sharing of the infrastructures (handling units, yards, terminal roads …).

The disaggregate structure of a discrete event simulation model allow to easily compute several performance indicators (function of the model variables). These indicators could be *global* or *local*; The former are referred to the container terminal as a whole (e.g. average number of movements per day; average number of unproductive movements per day); the second ones are referred to specific sequences of activities (e.g. vessel average load/unload time; containers average transfer and/or storage time).

Both the typologies of indicators could be expressed in different measure units, most used being time (e.g. vessel unload time) or number of operations per time period (for instance number of movements per day), other units may be used such as money per time period.

For each indicator a specific sub model should be specified w.r.t. model variables, and possibly some constraints.

ID.	**ACTIVITY DESCRIPTION**
c.t. T-RS	container transfer from Truck to Reach Stacker
c.t. RS-S	container transfer from Reach Stacker to Shuttle
c.t. S-C	container transfer from Shuttle to Crane
c.t. RS-B	container transfer from Reach Stacker to Berth
c.t. RS-C	container transfer from Reach Stacker to Crane
c.t. B-C	container transfer from Berth to Crane
c.t. C-V	container transfer from Crane to Vessel
c.t. V-C	container transfer from Vessel to Crane
c.t. C-B	container transfer from Crane to Berth
c.t. B-RS	container transfer from Berth to Reach Stacker
c.t. B-S	container transfer from Berth to Shuttle
c.t. S-FL	container transfer from Shuttle to Fork Lift
c.t. FL-T	container transfer from Fork Lift to Truck
c.t. C-R	container transfer from Crane to Rail
c.t. C-T	container transfer from Crane to Truck
c.m.j	j container movement ($j \in [1 \ldots 16]$)
Br. Ac.	bureaucratic activities
Stor.	storage
Wait	container waiting time
Cust. Ac.	customer activities
Rail Br. Ac.	rail bureaucratic activities
Truck Br. Ac.	truck bureaucratic activities

Table 1 – Container terminal physical flow activities

An indicator associated to a sequence of activities (e.g vessel average unload time) is function of:

- the number of containers per type: {20', 40'} × {full, empty} × {reefer, non reefer};
- the number of handling units available per type: e.g. {reach stacker, fork lift, front loader, straddle carrier ….};
- the starting system configuration, say at initial time (all the terminal activity in the initial time could influence the value of the system indicators; e.g. traffic congestion, gate queue).

Furthermore, the number of handling units available per type is function of the starting system configuration (e.g. the average number of handling units per vessel is function of the number of vessel loading/unloading).

For a time performance indicator (e.g vessel average unload time), its value is represented by the difference between the ending time of the operations and the starting one. For a performance indicators measured in number of operations for temporal interval (e.g. average number of unproductive movements per day), defined the time period (included or coincident with the simulation time period), the value of the indicator is given by the number of operations developed in the defined the time period.

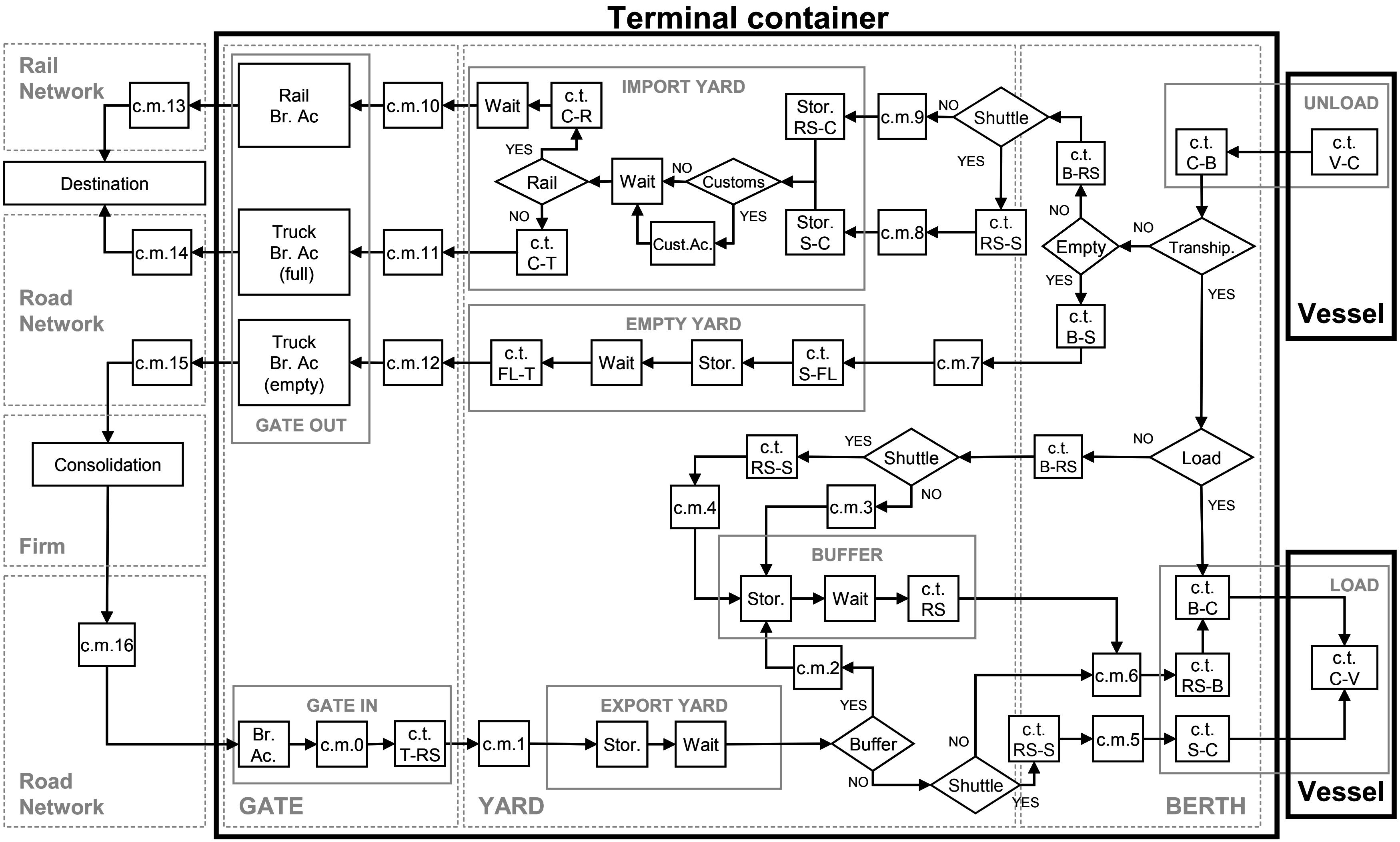


Figure 2 – Model architecture

In the case study at the hand, the phase of calibration has not presented relevant difficulties. In fact the object of the simulation is a very closed and monitored system (the container terminal). Therefore, the amount of input OD demand was exactly known, as corresponding to the arrivals/departure of the vessels/trucks/trains (and so the number of the TEUs is known). The only parameters to be calibrated are the parameters of the cost functions associated to the single activity described above, since no route choice is considered.

The performance measure used for the validation has consisted in the average macro activity (Import, Export and Transshipment) time per vessel. The choice of this parameter has been determined by the type of data measured by the terminal monitoring office.

Since the output of simulation may be considered a realization of a stochastic process (the time associated to each single activity is the realization of a random variable), the values used for the calibration is obtained by determining the average of 25 simulations (see Law and Kelton, 2000 about the "replication/deletion approach" for calculating the number of simulations required to obtain an estimate of the sampling average with a fixed interval of reliability).

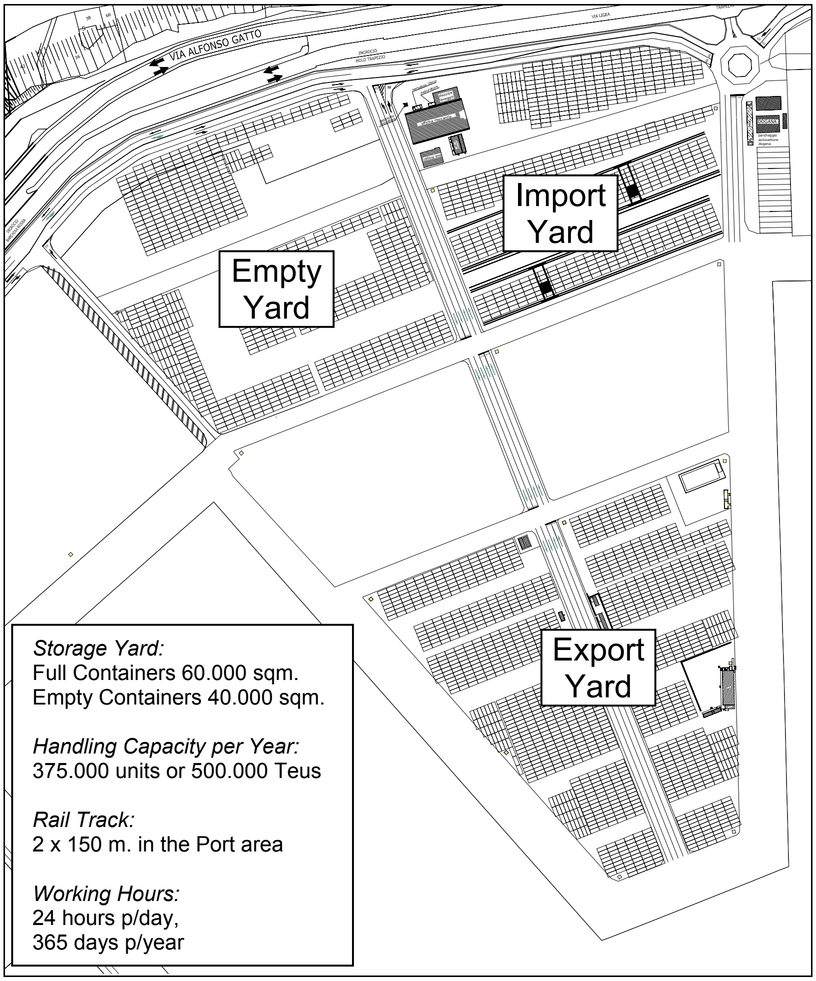
By simulating the flows of container along the terminal, a calibration of the above mentioned parameters is effected by minimizing the differences between the average of the times observed and that of the times simulated, by means of *RMSE* statistics.

The statistical validation of the model has been effected in two subsequent steps. First the model outputs have been compared with the data surveyed along the container terminal in order to check how far the model was fit to adequately represent real conditions. Secondly, the model outputs have been compared with the data of a hold-out sample. As a matter of fact the model was checked for its capacity of reproduce hypothetic scenarios (transferability of the model to different scenarios).

3 APPLICATION

In the following some preliminary results of data analysis about the test-site are given. The Salerno terminal – SCT is a major private container terminal in the South of Italy, it operates 24hours/day and 7 days per week and 365 days per years. Vessels take only 20 minutes from the pilot station to the berth. The terminal operates by 5 ship-to-shore cranes, all equipped with twin-lift spreaders, on an area of approximately 100.000 sq. meters (10he), used for the storage of full and empty containers.

Containers moving through the gates are managed by the Gate Allocation System. This system notifies the driver of the location to proceed to and simultaneously updates the Yard Control Computer of the arrival of the container. Radio-frequency is used to update the yard equipment to position the containers at the right stack-location. Salerno Container Terminal has created a quick and simple system for the handling of full import containers stocked under *RTGs* (Rubber Tyred Gantry Crane). After checking the relevant documentation, the Out Gate operator gives the driver an identification plate with a number on it. Meanwhile the plate number is fed into the computer system which automatically converts it into the container number and then transmits it to the *RTG* operator via radio-frequency. In the meantime the identification plate has been placed on the truck window, thus allowing the *RTG* operator to read it. The *RTG* operator is then able to locate the container by the simple operation of entering the number shown on the plate and the container is then loaded on the truck. The terminal operates by 5 ship-to-shore cranes (3 post Panamax with a out reach of 52 m. and able to handle vessels with 16 containers across), all equipped with twin-lift spreaders, on an area of approximately 100.000 sq. meters, used for the storage of full and empty containers. New Copas/Cosmos systems incl. Ships/yard/traffic/viewer (into the cranes), Terminal Operating & monitoring system/Invoice and Management software and Gate security system.



Storage Yard:
Full Containers 60.000 sqm.
Empty Containers 40.000 sqm.

Handling Capacity per Year:
375.000 units or 500.000 Teus

Rail Track:
2 x 150 m. in the Port area

Working Hours:
24 hours p/day,
365 days p/year

Figure 3 – Salerno Container Terminal characteristics

As said before, this container terminal is at the same time a small and very efficient one; in fact it operates close to close to 0.5 millions of TEUs per year (say 50.000 TEUs/ha). These figures should be compared with those terminals such as the HIT and COSCO-HIT terminals in Honk-Kong which operate 6.6 millions TEUs over 122 ha of land, that is 54.000 TEUs/ha, and of Delta Terminal in the Netherlands which operates 2.5 millions of TEUs, that is 9.000 TEUs/ha. In addition the location of Salerno harbour does not allow to enlarge area for terminal, hence it should be cleared that SCT should greatly

rely on intensive approach to operation rather than an extensive one in order to keep pace with increasing demand.
As said before, for the calibration of the model parameters crucial is the planning of the survey. In particular, the main terminal activities have been grouped into four groups:

1. Vessel (arrive/departure of vessels);
2. Gate (arrive/departure of trucks);
3. Yard (dwell time, storage);
4. Berth (load/unload, buffer, transfer to yard…);

Two typology of data are used:

- container monitoring data (available for the terminal);
- “ad hoc” survey made in the terminal.

The first typology refers to all the information that the terminal monitoring office measured every day. In particular the data refers to the January 2003 – July 2005 period are used (more than 1.000 vessels are monitored). These data has been used for the data analysis of the Vessel, Gate and Yard macro-areas, and particularly for the estimation of the berth-side/land-side demand (per type of container and time period) which involve the container terminal.
Jointly with these data, an integrative survey was carried out during the first six months of the 2005. In particular all the Berth macro-area activities referred to more than 3.000 containers were monitored (equal to the 20% of the containers loaded/unloaded per month and equal to the 1% of the containers loaded/unloaded per year).
In the following some preliminary results of data analysis (and some performance indicators) are described.

3.1 Vessel

Aggregate results concerning more than 1.000 vessels are reported in table 2. As we can observe, a vessel waits, on average, 1,2 hours at the dock before the load/unload operations begin; every vessel is worked, on average, for more than 11 hours and waits, on average, 1,5 hours before departurel. The average number of container unloaded/loaded per vessel is 260, and 1,4 crane are used, on average, for a single vessel. In figure 4 the relative frequency distribution of vessel number per day is reported.Through these data, berth-side demand (per type of container and time period) has been estimated.

activity	*min.*	*max.*	*mean*	*st. dev.*
waiting time before load/unload *(hour)*	0,0	11,2	1,2	1,4
load/unload time *(hour)*	0,8	46,1	11,1	6,7
waiting time before sail *(hour)*	0,0	8,0	1,5	1,4
number of cranes used	1,0	3,0	1,4	0,5
number of movements	11,0	1215,0	261,7	188,3

Table 2 - Vessel operations

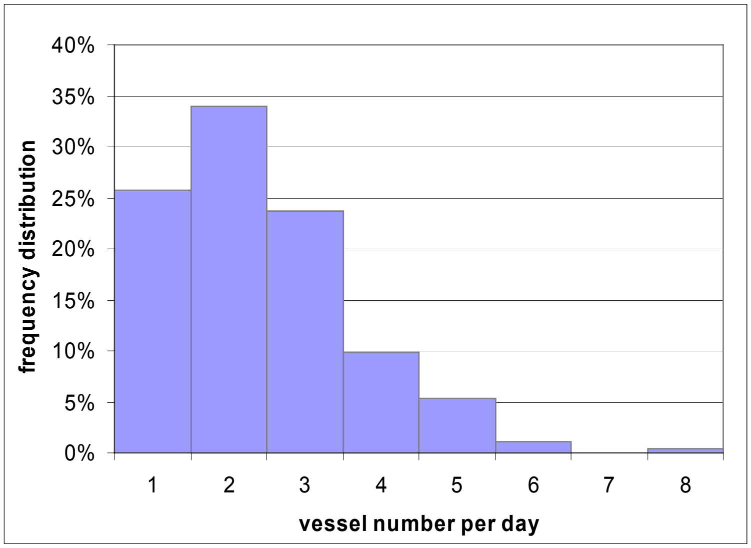


Figure 4 – Relative frequency distribution of vessel number per day

3.2 Gate

The gate is the container land-side entrance. These data are used for the estimation of the land-side demand (per type of container and time period). In figure 5 the average number of arriving TEUs against time (in a day) are reported. As we can observe, the 16:00-17:00 is the daily peak hour while the 07:40-08:40 is the morning peak hour.

In figure 6 relative frequency distribution of gate-in waiting time (equal to the queue waiting time plus the service time) is reported. More than 25% of the trucks wait 4-6 minutes before entering in the terminal; while more than 20% of the trucks wait 6-8 minutes before entering.

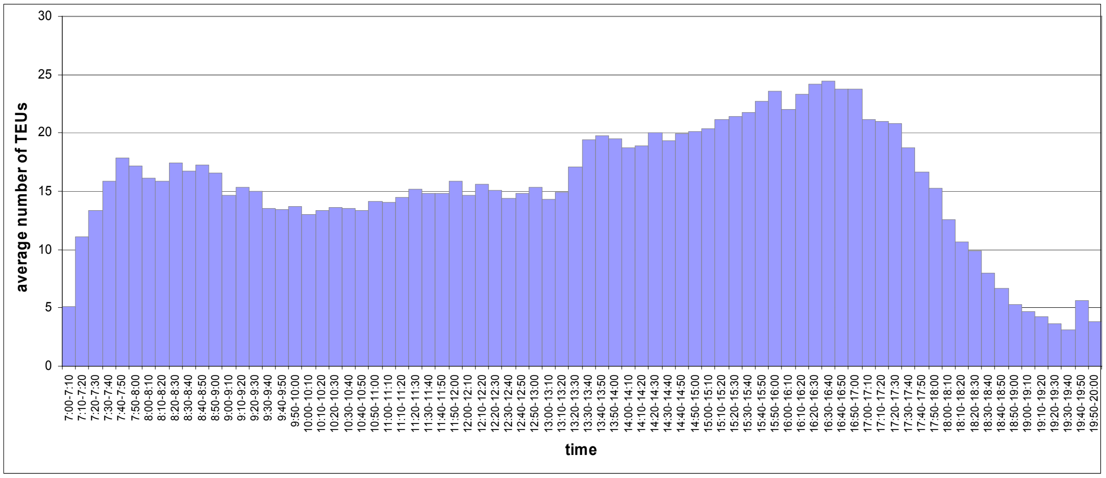


Figure 5 – Average number of arriving TEUs against time (in a day)

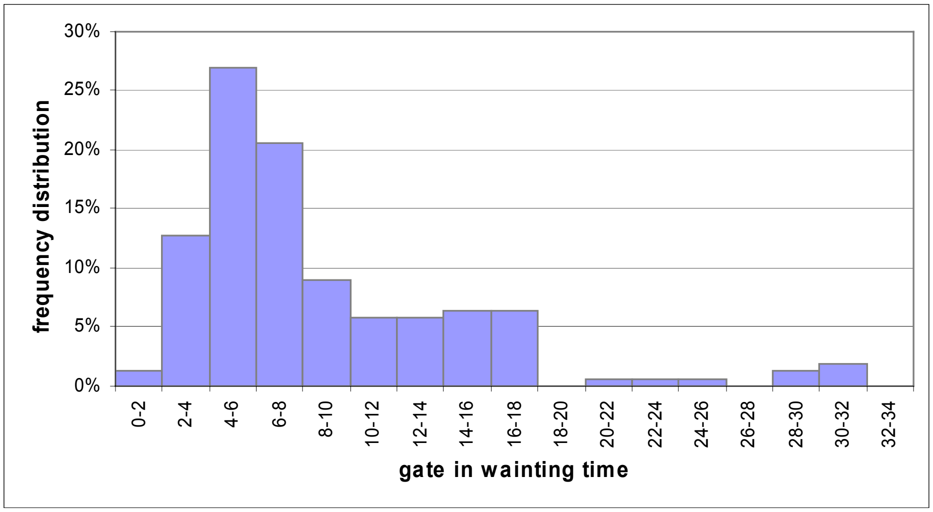


Figure 6 – Relative frequency distribution of gate in waiting time.

3.3 Yard

Yard data have been used for the estimation of the dwelling time, the yard occupancy and the storage time per tier (these results will be available in the final version of the paper). In table 3 the TEU dwelling time per day are reported. The export yard is the most efficient and productive yard (TEU stocked for 5,6 days on average). The import yard is less efficient (TEU stocked for 11,1 days on average) because of the irregularity of the trucks arrival (for container collection). In the empty yard the TEUs are stocked, on average, for 13,6 days because of sometime the shipping companies used this yard as a warehouse.

yard	*mean*	*st. dev.*
Empty	13,6	18,0
Export	5,6	4,4
Import	11,1	11,2

Table 3 – TEU dwelling time (day)

The yard occupancy has been estimated dividing the number of TEUs for the yard capacity. The yard capacity has been estimated through the relation:

$$(\mathit{Yard\ Area} * 0{,}6 / 14{,}7) * 5$$

where:
Yard Area is the area (m^2) of the yard considered;
0,6 is an estimated occupancy coefficient;
5 is the maximum number of tiers used by the SCT;
14,7 is a TEU area (m^2).

The relative frequency distribution of yard occupancy are reported in figure 7. The empty-container yard is close to saturation (yard occupancy greater than 80%) for more than 60% of the days; while the export and the import yard occupancy values are always lower than 55%.

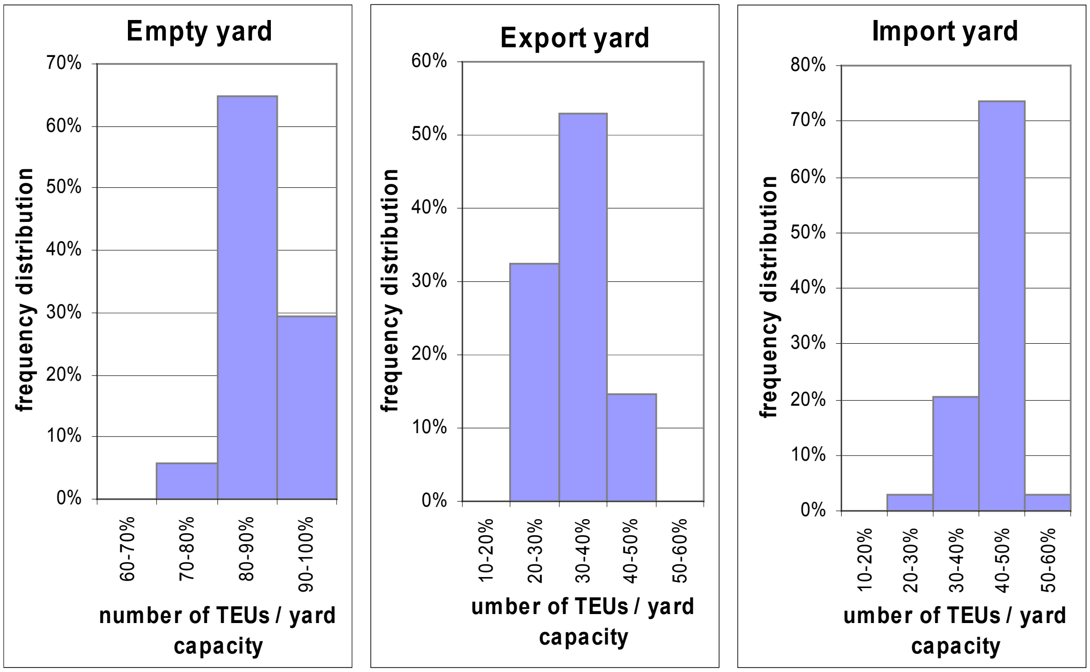


Figure 7 – Relative frequency distribution of yard occupancy

3.4 Berth

As said before, more than 3.000 containers were monitored. Six typologies of containers were considered: {20', 40', 2x20'} x {empty, full} (2x20' meaning that two 20' containers are loaded/unloaded at the same time).
In tables 4 and 5 the performance indicators relative to all the berth activities (e.g. shuttle lag time, loading time, unloading time transfer time) are reported.

Id.	*activity*	*cont. type*		*min*	*max*	*mean*	*st. dev.*
E.4.1	Shuttle lag time	Tugmaster		0,15	11,88	3,49	2,19
		Reach Stacker		0,28	4,05	1,99	0,81
E.4.1	Shuttle waiting time			0,25	8,28	2,21	1,80
E.4.3	Loading time (from shuttle to vessel)	20’	Full	0,58	2,62	1,56	0,52
		20’	Empty				
		40’	Full	0,68	2,77	1,52	0,48
		40’	Empty	0,83	3,00	1,56	0,64
		2x20’	Full	1,02	3,72	2,03	0,62
		2x20’	Empty				
E.4.4	Loading time (from berth to vessel)	20’	Full	0,58	3,33	1,40	0,60
		20’	Empty				
		40’	Full	0,83	2,68	1,61	0,48
		40’	Empty	0,87	6,43	3,04	2,67
		2x20’	Full	1,17	2,67	1,62	0,56
		2x20’	Empty				

Table 4 – Import activities per type of container (in minutes)

Id	activity	cont. type		min	max	mean	st. dev.
I.2.1	Shuttle lag time	Tugmaster		0,15	8,00	3,46	2,16
I.4.1	Shuttle waiting time	Tugmaster		0,15	4,97	1,84	1,17
I.2.3	Unloading time (from vessel to shuttle)	20’	Full				
		20’	Empty				
		40’	Full				
		40’	Empty	0,52	1,95	0,99	0,42
		2x20’	Full				
		2x20’	Empty	0,62	1,87	1,07	0,23
I.2.4	Unloading time (from vessel to berth)	20’	Full	0,47	1,17	0,85	0,16
		20’	Empty	0,42	1,97	0,77	0,32
		40’	Full	0,42	1,90	0,90	0,27
		40’	Empty	0,53	1,23	0,74	0,22
		2x20’	Full	0,28	2,40	0,95	0,37
		2x20’	Empty	0,67	2,13	0,89	0,40
I.2.5	Loading time (from berth to shuttle)	20’	Full	0,47	1,88	1,14	0,50
		20’	Empty	0,28	1,83	0,83	0,36
		40’	Full	0,37	2,55	1,24	0,59
		40’	Empty	0,78	3,15	1,59	1,00
I.2.6	Transfer time from berth to yard			0,99	3,38	1,47	0,92

Table 5 – Export activities per type of container (in minutes)

In figure 8 an example of a relative frequency distribution of unloading/loading time is reported.

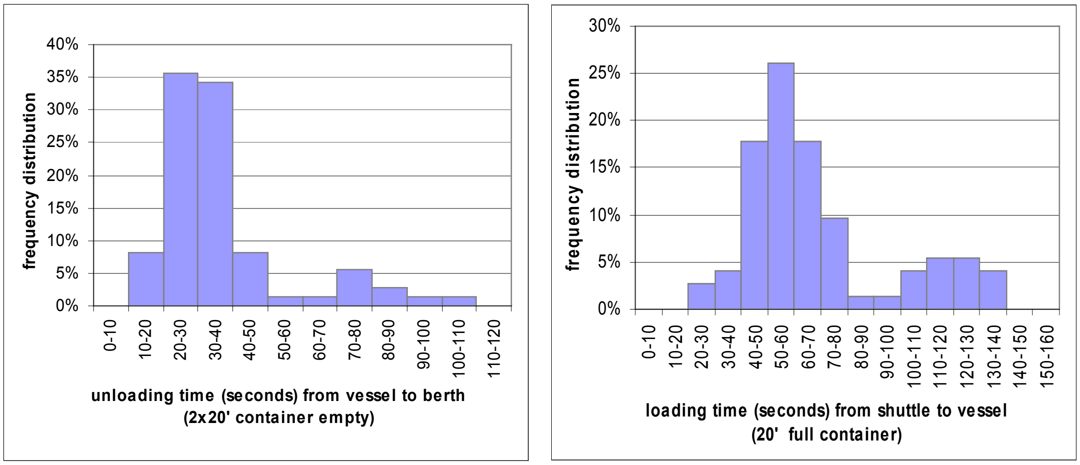


Figure 8 – An example of a relative frequency distribution of unloading/loading time (seconds).

4 CONCLUSIONS

In this paper the structure of a microscopic discrete event model for container terminal simulation has been presented together with preliminary results of a real scale application. The contents of the paper will be further developed in the final version of the paper.

Theoretical research perspectives have been highlighted within a more general research project framework. The application will be further developed to support a comparison among different approaches and an analysis of design scenarios.

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BIBLIOGRAPHY

1. Avriel M.,; Penn M.,; Shpirer N., Witteboon S. (1998); Stowage planning for container ships to reduce the number of shifts; *Annals of Operations Research* Volume: 76, pp. 55-71.
2. Chen C.-Y., Hsieh T.-W. (2002), A time–space network model for the berth allocation problem, *19th IFIP TC7 Conference on System Modeling and Optimization*, July, Cambridge, UK, 1999.
3. Cheung R.K., Li C.-L., Lin W. (2002), Interblock crane deployment in container terminals, *Transportation Science* 36 (1), 79–83.
4. de Luca S., Cantarella G.E. and Cartenì A. (2005); A macroscopic model of a container terminal based on diachronic networks, presented at the *Second workshop on the schedule-based approach in dynamic transit modelling;* 29-30 may 2005 – Ischia, Naples, Italy). To be published in the forthcoming Proceedings
5. Law A.M. and Kelton W.D. (2000) *Simulation Modeling and Analysis*, 3rd Edition, McGraw-Hill, New-York.
6. Imai A., Nagaiwa K., Tat C.W. (1997), Efficient planning of berth allocation for container terminals in Asia, *Journal of Advanced Transportation* 31 (1), 75–94.
7. Imai A., Nishimurra E. (2001), Papadimitriou S., The dynamic berth allocation problem for a container port, *Transportation Research. Part B: Methodological* 35, 401– 417.
8. Kozan E. (1997), Comparison of analytical and simulation planning models of seaport container terminals, *Transportation Planning and Technology* 20 (3), pp. 235–248.
9. Kim K.H., Bae J.W. (1998), Re-marshaling export containers in port container terminals, Computers & Industrial Engineering 35 (3–4), 655–658.
10. Kim K.H., Kim H.B. (1998), The optimal determination of the space requirement and the number of transfer cranes for import containers, *Computers & Industrial Engineering* 35 (3– 4), 427–430.
11. Kozan E., Preston P. (2000), Genetic algorithms to schedule container Gulf Conference on Decision Support Systems, *Council of Ministers General Secretariat*, State of Kuwait, (6 – 8 November), pp. 189– 208.
12. Lai K.K., Shih K. (1992); A study of container berth allocation; *Journal of Advanced Transportation* 26 (1); pp. 45– 60.
13. Murty K. G., Liu J., Wan Y. and Linn R. (2005); A decision support system for operations in a container terminal***;*** *Decision Support Systems* Volume: 39, Issue: 3, pp. 309-332.

14. Nishimura E., Imai A., Papadimitriou S. (2001), Berth allocation in the public berth system by genetic algorithms*, European Journal of Operational Research* 131, 282– 292.
15. Radmilovic Z., Colic V., Zlatkohrle (1996), Some aspects of storage and bulk queuing systems in transport operations, *Transportation Planning and Technology* 20; pp. 67–81.
16. Shabayek A.A., Yeung W.W. (2002), A simulation model for the Kwai Chung container terminals in Hong Kong; *European Journal of Operational Research* 140, pp. 1–11.
17. Taleb-Ibrahimi M., Castilho B.D., Daganzo C.F. (1993), Storage space vs. handling work in container terminals, *Transportation Research. Part: B Methodological* 27 (1), 13– 32.
18. Van Hee K.M., Wijbrands R.J. (1988), Decision support system for container terminal planning, *European Journal of Operational Research* 34, 262–272.
19. Wilson I.D., Roach P.A., Ware J.A. (2001), Container stowage preplanning: using search to generate solution, a case study, *Knowledge-Based Systems* 14 137– 145.
20. Yun W.Y., Choi Y.S. (1999), A simulation model for container-terminal operation analysis using an object-oriented approach; *Int. J. Production Economics* 59; pp. 221-230.
21. Zhang C. (2000), Resource Planning in Container Storage Yard, *PhD thesis*, Dept. of IEEM, Hong Kong University of Science and Technology.
22. Zhang C., Wan Y.-W., Liu J., Linn R. (2002), Dynamic crane deployment in container storage yards, *Transportation Research. Part B: Methodological* 36 (6), 537–555.
23. Zhang C., Liu J., Wan Y.-W., Murty K.G., Linn R.J. (2003), Storage space allocation in container terminals, *Transportation Research Part B: Methodological* Vol.: 37, pp. 883-903.