

# The influence of storage area design on maritime container terminal capacity

**F Rusca, E Rosca, D Costescu, A Rusca, M Rosca and S Olteanu**

University Politehnica of Bucharest, Department of Transport, traffic and logistics,  
Spl. Independentei no. 313, district 6, 060042, Bucharest, ROMANIA

E-mail: florin.rusca@upb.ro

**Abstract.** The storage areas from maritime container terminals have the role to allow the transfer of containers from maritime ships to inland transport and vice versa or from a maritime ship to another. The number of slots in storage area must be higher enough to not restrict the activity in terminal. In the case of containers loaded with dangerous goods, specifically rules must be applied in accordance with international maritime laws. Applying the security policies will enforce special conditions for storage of containers along with other containers or in a dedicated area for containers loaded with dangerous goods. All these measures lead to a limitation of the storage capacity inside the terminal. In the paper, the authors studying the influence of storage area design, in accordance with handling and storage restrictions of containers loaded with dangerous goods, on container terminal capacity. Taking into consideration the multi-flows interaction and the non-uniform arrivals of vessels and inland vehicles, discrete event simulation stands as a feasible technique for investigate terminal capacity for different organizational schemes of the storage area. The activities conducted inside of container terminal are represented using a logical model and implemented in ARENA software. A simulation model is developed and used to evaluate the variation of terminal activity's parameters. A set of input scenarios are developed to analyse and identify how to organize the activity in the terminal, namely how to segregate the containers within the storage area. The estimation of the general parameters of activity performance obtained through computer simulation helps the container terminal administration to choose an optimal use of storage area.

## 1. Introduction

The maritime container terminal it is part of the logistic chain. This allows the connection between maritime vessels and inland network (road or rail). Inside the terminal, the transit capacity is influenced by berths length, number of cranes and handling equipment's technological process duration, the dimension of storage area. The last of these has an important role in the activity of container terminal allowing the transfer of containers between maritime vessel and inland transport network and vice versa. Also, the process of re-arranging containers on seagoing vessels involves the use of several cells from the storage area.

A special attention must be given to the transportation of container loaded with dangerous goods. For this, specifically rules must be applied in accordance with international maritime laws. In the case of logistic chain with a special component for dangerous goods one of the most frustrating problems when dealing with risks it's that these appear in so many different forms. The transport of dangerous goods, as flammable gases, toxic gases, flammable liquids or flammable solids, etc., involves some



risks and can lead to potential incidents which may result to environmental pollution, property damage, or the worst-case scenario in death or injury to people [1]. Risks can range on a scale from small delay to a natural disaster, from short term to a permanent damage, with effects localized on a part of a logistic chain or affecting the whole chain activity [2], [3]. Situating the transported products in the category of dangerous goods supposes the compliance by the actors of supply chain of a series of specific regulations separately for each mode of transport [4], [5]. However, a series of risks can occur both at the transportation of dangerous goods as well as at handling of them inside the intermodal terminals. Intermodal terminals are obliged according to the regulations, to have a risks management plan which can allow their identification, the prevention of risk appearance, respectively the limitation of external effects in the case of hazard appearance.

The maritime intermodal terminal, component of the logistic chains for the transport of containerized dangerous goods involves several operational risks. The handling operations of the loaded containers with dangerous goods must consider the risks induced by the specifics of these goods. Special operating conditions are required (e.g. specialized staff in handling dangerous goods, special vehicles for loading-unloading operations for maritime, fluvial, rail or road transportation, special storage areas specifically designated for dangerous goods, segregation of dangerous goods according to IMO regulations, containers' storage solutions which may allow direct access to them, marking the areas in which they can be stored, etc.) [3].

For that, the storage area for containers loaded with dangerous goods in the maritime ports should take into consideration a set of regulations. One of this is represented by rules of segregation for containers loaded with dangerous goods. However, are situations when the terminal operator cannot respect these rules, generating an increasing level of risk. Applying the security policies enforce special conditions for containers' storage process along with other containers or in a dedicated area for containers loaded with dangerous goods. All these measures lead to a limitation of the storage capacity inside the terminal.

In case of storage area design with a dedicated area, the transit capacity of maritime container terminals is influenced by the number of slots from each storage area (for containers loaded with non-dangerous goods and for containers loaded with dangerous goods). The influence of design for storage area in the maritime container terminal is analysed using theory of queuing system. For known repartition of input flows, a mathematical model can be developed to calculate the capacity of terminal. But, if it is necessary to take into consideration the multi-flows interaction and the non-uniform arrivals of vessels and inland vehicles, discrete event simulation stands as a feasible technique for investigating the capacity of terminal for different organizational schemes of the storage area. The developed simulation model can be adapted to all kinds of container terminals and transportation network attributes.

## 2. Mathematical model

The activity of maritime container terminals is influenced by the number of free slots in the storage area. If this is incorrectly sized, the transit capacity of maritime container terminals is reduced. The maritime container terminals are modelled as a queuing system. The mathematical models are different, depending on both characteristics of the entering traffic flows and of the serving stations. Synthetically, the Kendall-Lee classification [6] mentions the code A/B/n: (m/D) facilitating the mathematical model's identification. The letter "A" represents the characteristics of the vessel(containers) arrival flow, the second letter "B" represents the characteristic of the serving process "n" is the number of the cranes or handling equipment, "m" is the maximum number of vessels waiting for a free berth and "D" is serving discipline or rule.

The Little equations describe the qualitative parameters for queuing system used to model the maritime container terminal:

$$\begin{aligned} \bar{n}_a &= \lambda \bar{t}_a; \quad \bar{n}_s = \lambda \bar{t}_s; \quad \bar{t}_s = \bar{t}_a + \frac{1}{\mu}; \\ \bar{n}_s &= \bar{n} + \rho; \quad \rho = \frac{\lambda}{\mu} < 1 \end{aligned} \tag{1}$$

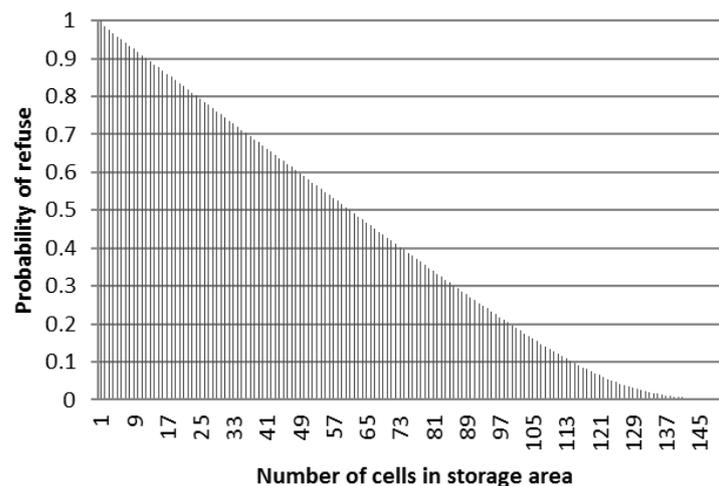
where  $\bar{n}_a$ , the average number of units in system,  $\lambda$ = average arrival rate for container,  $\bar{t}_a$  is the average time of serving for a vessel (container),  $\bar{t}_s$ , the average number of vessels (containers) in waiting queue,  $\bar{n}_s$  is the average number of units in system,  $\mu$  is the average intensity of serving and  $\rho$  is the solicitation of the serving system .

The probability to not find a free cell in storage area is calculated, when this is analysed as queuing system, as the probability of refuse. In particular case of queuing system M/M/n:(n/FIFO), with arrival according to a Poisson distribution and storage time according to exponential distribution, the probability of refuse is:

$$p_n = \frac{\frac{1}{n!} \left(\frac{\lambda}{\mu}\right)^n}{\sum_{k=0}^n \frac{1}{k!} \left(\frac{\lambda}{\mu}\right)^k} \tag{2}$$

where  $p_n$ = the probability of refuse to receive a new container in the storage area, which must wait a free cell,  $\lambda$ = average arrival rate for containers,  $\mu$ =average service rate, and n- the number of cells in the storage area.

For a hypothetical case with average arrival rate for containers  $\lambda=60$  containers/day and a waiting time in storage area  $t_{st}=2$  days, we obtain, taking in consideration a variable number of storage cells n, a set of values for probability  $p_n$  depicted in figure 1.



**Figure 1.** The variation of probability of refuse.

In this case, for a capacity of 60 slots in storage area, the probability of refuse is 0.50. If the storage area is divided in two zones, one for containers loaded with dangerous goods and one for other kind of containers, with arrival rates  $\lambda_{DG}$  containers loaded with dangerous goods /per day and  $\lambda_{nonDG}$  for other kind of containers, the probability of refuse is calculated as in table 1.

**Table 1.** The probability of refuse when the arrival rate varies.

No	$\lambda_{nonDG}$	$\lambda_{DG}$	$n_{nonDG}$	$n_{DG}$	$p_n^{nonDG}$	$p_n^{DG}$
1.	40	20	40	20	0.51	0.52
2.	40	20	50	10	0.39	0.75
3.	40	20	30	30	0.63	0.29
4.	50	10	40	20	0.60	0.15
5.	50	10	50	10	0.50	0.53
6.	50	10	30	30	0.70	0

From the obtained results, it is observed the influence of arrival rate, number of allocated slots in the storage area and probability of refuse. The management authority of the maritime container terminal must take a decision: if it allocates for containers loaded with dangerous goods a big number of slots, the probability of refuse decreases to the detriment of the other types of containers. In other conditions, adapting the number of slots for arrival rates of container loaded or non-loaded with dangerous goods, we obtain for probability of refuse almost similar results, but with containers loaded with dangerous goods waiting for a free slot in inappropriate conditions.

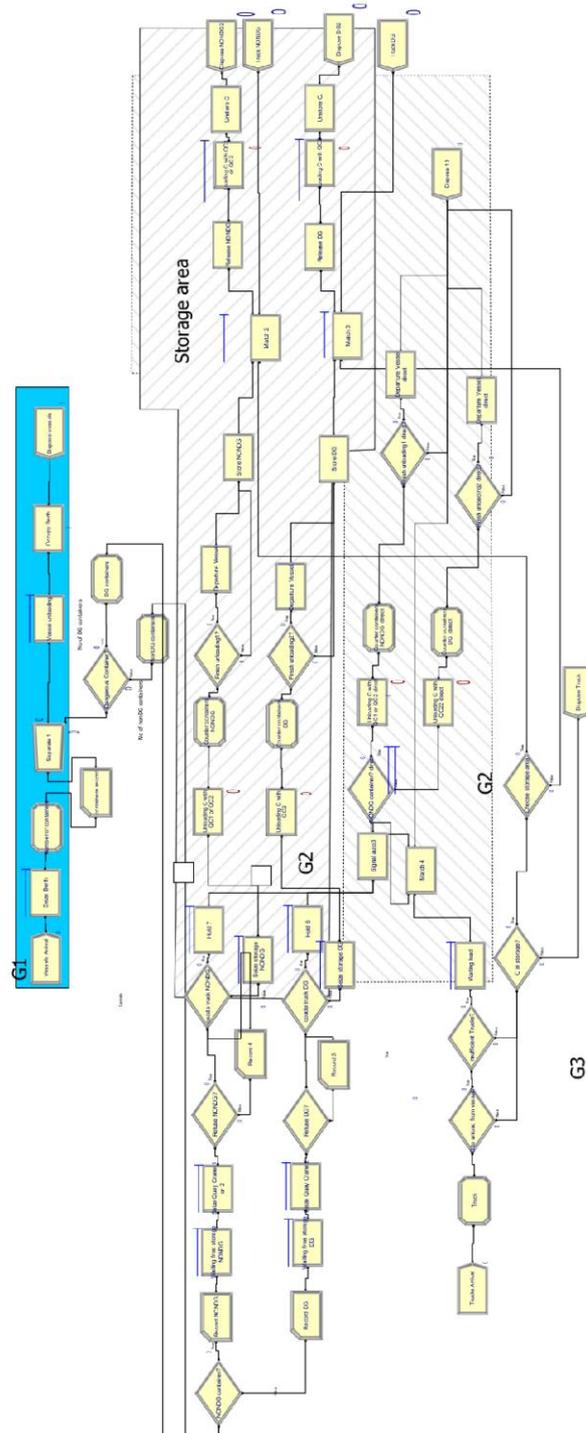
When it is necessary to take in consideration in the developed model for maritime container terminal the multi-flows interaction and the non-uniform arrivals of vessels and inland vehicles, it is required to develop a discrete event simulation [7], [8], [9].

### 3. Simulation model. Study case

The activity inside the terminal is influenced by the storage area design, the handling and storage restrictions, the characteristics of entering flows, etc. For a hypothetical maritime container terminal, in our paper, the activities are represented using a logical model and implemented in ARENA software. A simulation model is developed and used to evaluate the variation of terminal activity's parameters. The input data are grouped in five scenarios to analyse and identify how to organize the activity in the terminal. The results obtained can be used to help the container terminal administration to choose an optimal use of storage area.

The model has three components, the first one simulates the vessels arrival to the berth, in the second part are simulated the handling activities and the last component is used for simulating the arrival of inland vehicle (figure 2).

In the simulation model, after the arriving time, the vessel is allocated to a free berth. If the berth is occupied the vessel waits to be released. The containers are unloaded from the vessel using two cranes. Applying segregation rules for container loaded with dangerous goods (DG) or with common goods (nonDG), one of the crane is used for unloading DG and nonDG containers and the second just nonDG containers. The unloading process of DG/nonDG containers, from vessel to yard terminal may be performed only if one of the two following situations is possible: one truck is available and so the container is unload directly to truck and quits the system, or one cell from storage area (assigned to DG/nonDG container) is free and so the container is unload to storage area. If these minimal conditions are not completed the container is waiting on vessel until one of the two situations occurs.



**Figure 2.** The simulation model.

The statistic variables used to evaluate the activity inside the maritime container terminal obtained from discrete simulation model are the length of queue for a free berth  $N_{v,b}$  and the mean of waiting time  $W_{v,b}$ , unloading vessel time  $W_{v,u}$ , number of containers with destination in the maritime container terminal  $N_c$ , storage time and number of nonDG/DG containers in the storage area,  $W_{s,nonDG} / W_{s,DG}$  and  $N_{c,s,nonDG} / N_{c,s,DG}$ , the berth and crane utilization  $\rho_b$  and  $\rho_{oc}$  and also the nonDG/DG container

storage capacity utilization  $\rho_{S,nonDG}$ ,  $\rho_{S,DG}$ . Finally, a probability that an arrival for an DG/nonDG container does not have space in storage area, called probability of refuse  $p^1_n$ ,  $p^2_n$ .

The common input data for all five scenarios are:

- number of containers per vessel,  $N_C$  (normal distribution with  $\lambda=400$  and  $\sigma=80$ );
- trucks inter-arrival times,  $T_T$  (constant, one truck per 3 minutes);
- number of cranes (2 cranes);
- the capacity of storage it is 600 including a separated area for DG containers;

The specific input data for every scenario are presented in table 2.

**Table 2.** The input data for discrete simulation.

Scenario	Scenario I (S.I.)	Scenario II (S.II.)	Scenario III (S.III.)	Scenario IV (S.IV.)	Scenario V (S.V.)
Capacity of storage area for nonDG containers $C_{nonDG}$	500	400	300	500	500
Capacity of storage area for DG containers $C_{DG}$	100	200	300	100	100
Vessels inter-arrival times to berth, $T_V$ ;	exponential distribution with $\lambda =20$ (hours)	exponential distribution with $\lambda =20$ (hours)	exponential distribution with $\lambda =20$ (hours)	exponential distribution with $\lambda =25$ (hours)	normal distribution with $\lambda=20$ and $\sigma= 3$ (hours)
Quay crane unloading/ loading time, $T_Q$	triangular distribution with min=3, mode=4, max=5 (minutes)				

The run setup parameters for simulation process are:

- warm-up period 30 days;
- number of replications 3;
- replication length 60 days;
- working time on day 24 hours.

The output simulation data in case of our scenarios are presented in table 3

**Table 3.** The output data from discrete simulation.

Scenario	$N_{v,b}$	$N_c$	$W_{v,b}$	$W_{v,u}$	$W_{s,nonDG}$	$W_{s,DG}$	$N_{c,snonDG} / N_{c,s DG}$	$\rho_b$	$\rho_{S,nonDG}$	$\rho_{S,DG}$	$\rho_{oc1}, \rho_{oc2}$	$p^1_n$	$p^2_n$
S.I.	5.14	412	95	15.9	77	117	405/ 85	0.92	0.81	0.85	0.89	0.82	0.78
S.II.	4.35	423	78	16.5	104	43	342/ 164	0.94	0.85	0.82	0.90	0.91	0.72
S.III.	4.15	404	78	15.9	278	82	232/ 177	0.89	0.96	0.59	0.88	0.98	0.03
S.IV.	1.18	390	25.5	14.2	62	134	212/ 47	0.65	0.42	0.47	0.67	0.48	0.42
S.V.	1.08	413	21	16.0	112	25	396/ 89	0.93	0.79	0.89	0.92	0.77	0.80

The increasing of area dedicated to containers loaded with dangerous goods (S.I. to S.II. and S.III.) conduce to a reduction of the value of probability that a container loaded with dangerous goods doesn't find a free cell ( $p_{2n}$ ) and waits in queue from 0.78 to 0.03. On the other hand, the probability that a container loaded with non-hazardous goods will not find a free cell ( $p_{1n}^1$ ) increases approximatively with 20% from 0.82 to 0.98. When the vessels arrival flow in terminal is decreased (S.IV. and S.V.) the number of vessels in queue is reduced from 4-5 vessels to only one. Also, the waiting time in queue is only a quarter from time obtained in S.I.

#### 4. Conclusion

In conclusion, the design of storage area has an influence on parameters of handling activities inside of terminals. In case of storage of containers loaded with dangerous goods in a separated zone, the capacity of storage from all maritime container terminals can be reduced if the segregation it is not correctly made. Using the discrete simulation model it can be tested a set of design versions for storage area of a maritime container terminal. The results obtained help the management of the terminal to take correct decisions in the strategic and operational development plans. The decisional process it is organized on three levels: terminal design, operational planning and real-time control [10]. A discrete simulation model are useful in the development and operation of the terminal at any decisional level. The model developed in our paper can be adapted to all kind of maritime container terminals and be tested for different type of arrival flows in terminal, of vessels, containers and inland transport vehicles (train or trucks).

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