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FLORIN RUSCA, Ph.D.[1]
E-mail: florin.rusca@upb.ro
EUGEN ROSCA, Ph.D.[1]
E-mail:eugen.rosca@gmail.com
MUHAMMAD AZMAT, Ph.D., MSc.[2]
E-mail: mazmat@wu.ac.at
HERIBERTO PEREZ-ACEBO, Ph.D.[3]
E-mail: heriberto.perez@ehu.eus
AURA RUSCA, Ph.D.[1]
E-mail:aura.rusca@upb.ro
SERGIU OLTEANU, Ph.D.[1]
E-mail:sergiu.olteanu@upb.ro
[1] University Politehnica from Bucharest, Faculty of Transport
Spl. Independentei, No 313, District 6, Bucharest Romania
[2] Institute for Transport and Logistics, Vienna University of Economics and Business
Welthandelspl. 1, 1020 Wien, Austria
[3] University of the Basque Country, Faculty of Engineering Bilbao
P[0] Rafael Moreno "Pitxitxi", 2 48013 Bilbao Spain

MODELING THE TRANSIT OF CONTAINERS THROUGH QUAY BUFFER STORAGE ZONE IN MARITIME TERMINALS

ABSTRACT

The maritime container terminal allows the transfer of container flows from maritime vessels to the land transport network and vice versa. The transit capacity through the terminal is affected by the handling capacity of the equipment at the terminal, by the size of the storage areas and least by the technologies used in handling and storing the containers in the terminal. In this paper, the influence of these last two technologies on the duration of the process of unloading/loading of sea vessels within the terminal is analyzed. A discrete simulation model is used to evaluate the sizing method for short-term storage area located on the dock. The manner of allocating the flows of containers on it, as well as the working technology of the handling equipment, have an influence on the number of containers taken over, respectively loaded on the maritime vessels. The simulation model topology is developed following the existing physical structure of a container terminal from Constanta Port, in Romania. The obtained results can help the administration of the container terminal in optimizing the activity of handling, storing, and transferring the flows of containers from the maritime environment to the mainland and vice versa.

KEYWORDS

maritime terminal; productivity; simulation model; container terminal

1. INTRODUCTION

The connection between the mainland transport networks and the maritime vessels for the flows of containers is conducted in the container terminals located inside the seaports. The qualitative parameters of the level of service inside the terminal, such as the duration of the process of unloading/loading of maritime vessels, may influence the entire logistics chain, which is transiting the maritime container terminal. Therefore, it is necessary to analyse its influence on the process: the organization of the terminal in the area of action of quay cranes, the number of handling equipment, and not in the last case of the technology used within the process. If the productivity of the quay cranes is not following the productivity of the handling equipment within the terminal, the accumulation of containers in the storage area on the docks can lead to blocking the unloading/loading process of the ship. This storage area acts as a buffer between the operations carried out by the quay cranes, and the rest of the operations carried out inside the terminal. The spatial limitation of this area, for constructive reasons, due, for example, to the existence of an active area of the quay cranes, does not allow an over-dimensioning of it, which could take over the lack of existing coordination in the productivity of the handling equipment within the terminal.

The main flow through the container terminal is from the mainland transport networks to the maritime vessels, respectively, from these last ones to the port hinterland (Figure 1). The discontinuity of the transport process leads to the necessity of storing the containers inside the maritime terminals while waiting for the maritime vessels or the means of terrestrial transport (trains or trucks).

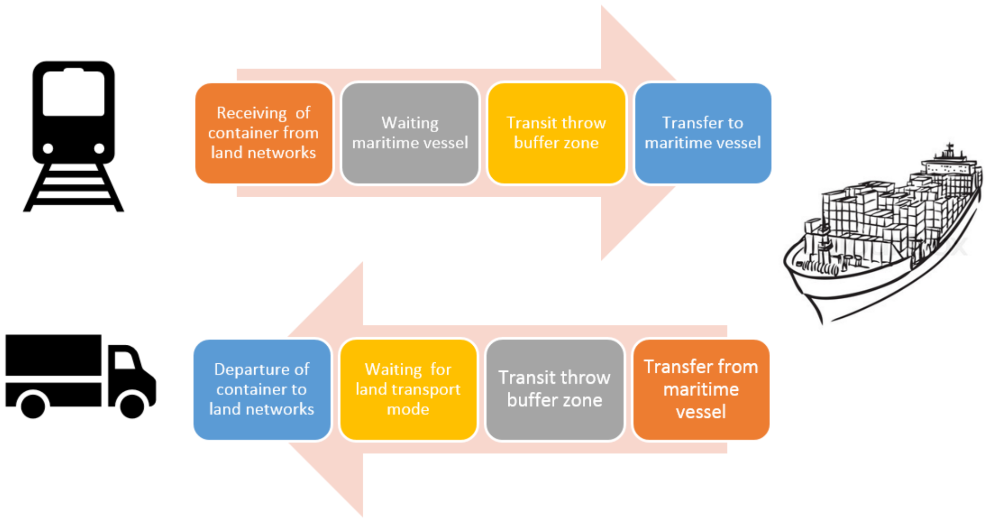

Figure 1 – The main activities inside the maritime container terminals

The transfer from/to the storage area of the container terminal to the maritime berth is conducted with the help of the handling equipment. If the productivity of quay cranes is higher than the total productivity of the handling equipment inside the terminal, the buffer storage area located on the maritime berth should be able to take over the containers that are to be loaded or which have been unloaded. In the case the storage capacity of the buffer area is reached, the duration of the process of unloading/loading of the vessels is increased. This fact can lead to negative economic issues for container terminal administration. For this reason, it is necessary to model the process of unloading/loading of maritime vessels, additionally, to model the process of transferring the containers from/to the buffer zone in order to choose the best working variant of the equipment from the terminal.

In case this modeling becomes difficult due to the stochastic character of the arrival of the ships in the port, in addition to the variation of the handling intervals of the containers, it is recommended to use the discrete simulation models developed with the help of dedicated software packages.

2. LITERATURE REVIEW

Research on the topic of maritime terminals is essential to specialists in the field. The decisional-making process inside of terminals is conducted on three decision levels [1]:

- design level (when is developed the structure of terminal, is decided the dimension of storage area, is calculated the required number of handling equipment, etc.)
- operative planning stage (when is decided quay crane and handling equipment assignment, rules for handling dangerous goods and terminal policies)

- operative stage (daily activities inside the terminal which include handling and storage activities, transfer from land network to maritime transport and reverse operation, etc.)

For all three decision levels in the modeling process of activities it is important to imply improving the quality parameters of the serving process. Some research is made to resolve scheduling problems inside the maritime terminal for handling equipment [2],[3]. For the optimization process of activity, an algorithm for path search, evolutionary algorithm, or discrete simulation is used [4]. The discrete models are an important option in this process for research carried out [5], [6]. The activity inside the maritime terminal is associated with a complex queuing system with serving stations and priority rules [7], [8], [9], [10]. The software used to develop this models can be dedicated to study maritime terminals like in case of Microport [11] or can be used software like Arena or Planimate® adapted for case of container maritime terminals [12], [13]. The developed simulation models are used to evaluate the required capacity for storage area [14], [15], [16], the influence of safety rules for the handling of dangerous goods [17], or to estimate the delay in activity induced by the reliability of handling equipment [18].

3. MODELING THE ACTIVITY

The transfer of the containers inside the terminal to and from the maritime vessels is carried out using the area located on the berth in the action area of the quay cranes. If this area is used for the temporary storage of containers unloaded from sea vessels before their transfer to the central storage area using the handling equipment of the maritime terminal (reach stackers, forklifts, etc.), it is called the buffer zone. At the same time, it is necessary to analyse how this area can influence the functional parameters of the terminal, such as the waiting time at the berth for maritime vessels, the length of the queue of the vessels waiting to enter the terminal, and so forth. In the case of the period of stationing at the berth required for carrying out the operations of unloading/loading of the container ships, there are important aspects such as the storage capacity of the buffer zone, the type of handling operations, the productivity of the handling equipment, the technology used, etc. The operations performed at the berth are the unloading process of the containers from the maritime ship, the loading process of the ships with containers, the operations of rearrangement of the containers on the maritime ship. From these, the last operation takes place only at the express request of the commander of the ship, having a supplementary tariff. For this reason, this operation will not be followed in the modeling process.

If only the containers unloading operation is considered, the model is developed in relation to the following assumptions [7]:

- The total productivity of handling equipments (Q_1) is lower than quay crane productivity (Q_2), meaning $Q_1 < Q_2$
- The average number of containers arrived per ship N_{cont} exceeds the buffer zone capacity C_{bzone}, meaning $N_{cont} > C_{bzone}$

Three methods for correlating the activity of container handling equipment within the terminal for unloading containers from sea vessels can be identified. In the first method (Figure 2), the productivity of the quay crane is reduced to an equal value with the productivity of the handling equipment when the capacity of the buffer zone is reached.

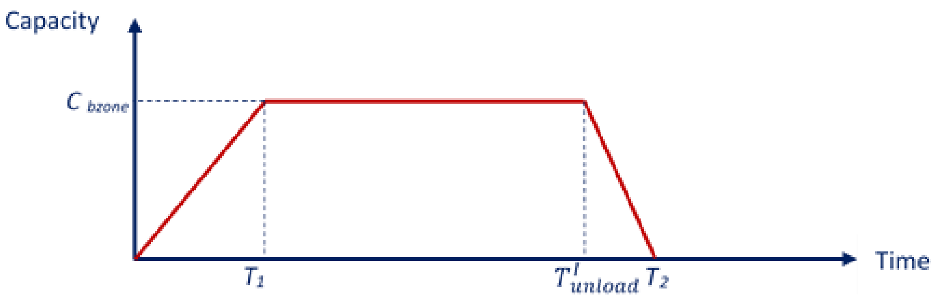

Figure 2 – The first correlation method for the unloading process

The productivity of the handling equipment and the productivity of the quay crane is shown in Figure 3:

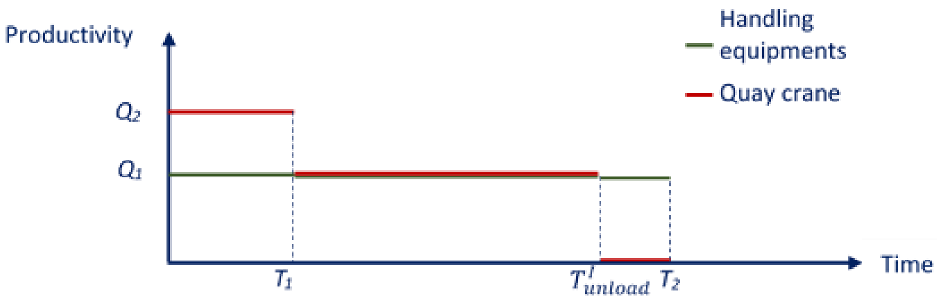

Figure 3 – The productivities of handling equipments

The time required for the transfer of the containers to the storage area of the terminal is determined by equation 1:

$$T_2 = \frac{N_{cont}}{Q_1} \tag{1}$$

The specified time interval for the unloading process of the maritime vessel is determined with the equation (2):

$$T_{unload}^{I} = T_2 - \frac{C_{bzone}}{Q_1} = \frac{N_{cont}}{Q_1} - \frac{C_{bzone}}{Q_1} = \frac{N_{cont} - C_{bzone}}{Q_1} \tag{2}$$

The second method for correlating the activity of the container handling equipment implies a reduction of the productivity of the quay crane to an intermediate value Q_3, $Q_1 < Q_3 < Q_2$, so that the capacity of the buffer zone is not exceeded (*Figure 4,5*).

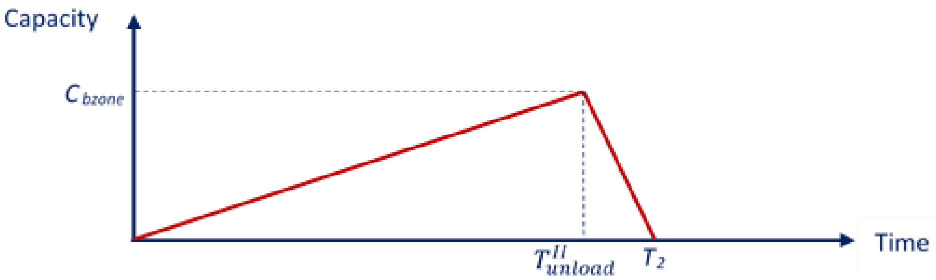

Figure 4 – The second correlation method for the unloading process

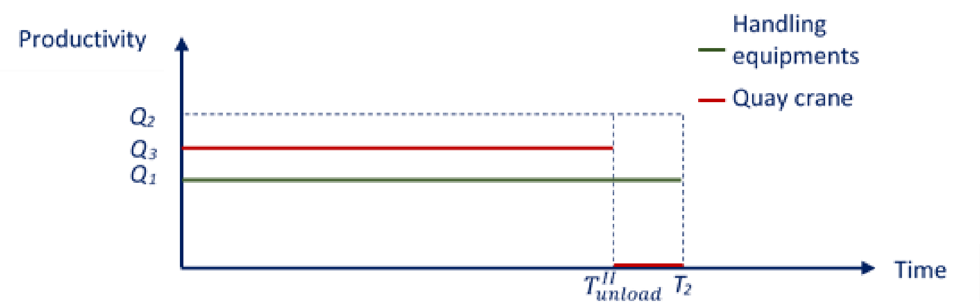

Figure 5 – The productivities of handling equipments

Also, for this method, the time interval required for the transfer of the containers in the storage area of the terminal is determined by equation 1. Additionally, the specified time interval required for the unloading process of the maritime vessel is calculated by with equation 2. The value of the average productivity of the quay crane is obtained by menos of equation 4:

$$T^{II}_{unload} = T^{I}_{unload} = \frac{N_{cont} - C_{bzone}}{Q_1} \tag{3}$$

$$Q_3 = \frac{N_{cont}}{T_{unload}} = \frac{N_{cont}}{\frac{N_{cont} - C_{bzone}}{Q_1}} = \frac{Q_1 N_{cont}}{N_{cont} - C_{bzone}} \tag{4}$$

The last method of correlating the activity of container handling equipment involves stopping the process of unloading containers from maritime vessels when the capacity of the buffer zone is consumed. (*Figure 6,7).*

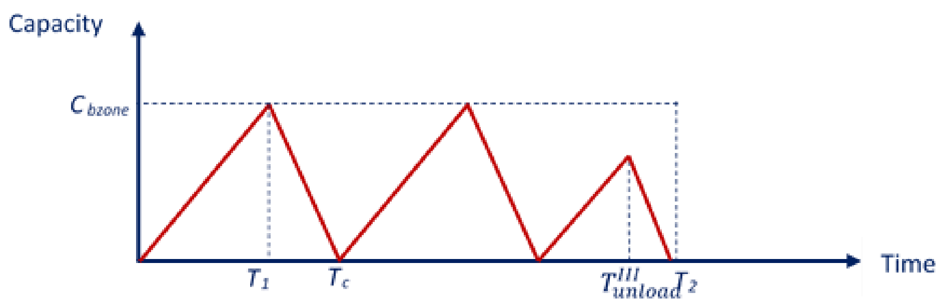

Figure 6 – The third correlation method for the unloading process

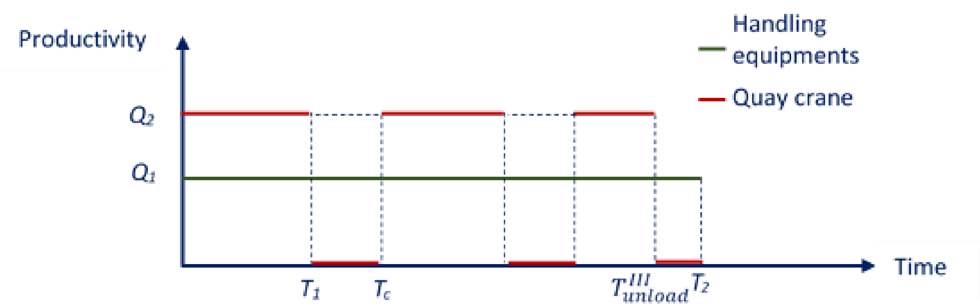

Figure 7 – The productivities of handling equipments

In order to be able to calculate the time interval required for the unloading process of the maritime vessel, it is necessary to determine the duration of an unloading cycle (*Equation 5*), and their number (*Equation 6*).

$$T_c = \frac{C_{bzone}}{Q_2 - Q_1} + \frac{C_{bzone}}{Q_1} \tag{5}$$

$$N_{cycles} = round\left[\frac{N_{cont}}{C_{bzone}}\right] \tag{6}$$

The number of unloading cycles is added to the last cycle in which a lower number of containers are unloaded ($N_{cont}^{last\ cycle}$) than the capacity of the buffer zone (Equation 7). In these conditions, the necessary time interval for the unloading process of the sea vessel is determined with equation 8.

$$N_{cont}^{last\ cycle} = N_{cont} - C_{bzone}N_{cycles} \tag{7}$$

$$T_{unload}^{III} = T_c N_{cycles} + \frac{N_{cont}^{last\ cycle}}{Q_2} \tag{8}$$

If the model represents loading operations for the sea vessel, three methods for correlating the activity of the handling equipment of the terminal with the quay crane are identified. All these methods start from the next assumption:

- The buffer zone is loaded to full capacity, C_{bzone}, before moment T_{load}^{start} when the loading process of N_{cont} starts on the maritime vessel using handling equipments with productivity Q_1

Based on the justifications of the loading process, three methods for correlating the activity of handling equipment are represented in Figures 8, 9, and 10, together with the productivities of the container handling equipment.

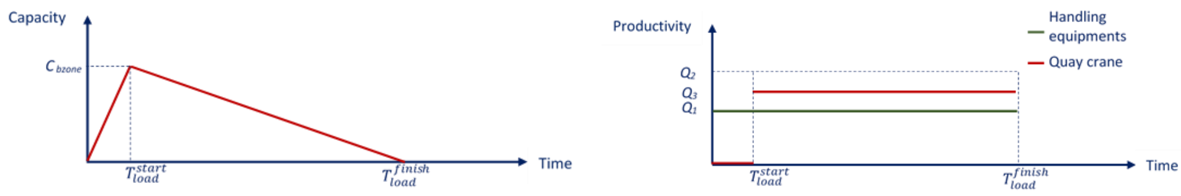

Figure 8 – The first correlation method for the loading process

The required time interval for loading the maritime vessel for the first method for correlating the productivity of the handling equipment is:

$$T_{load}^{I} = T_{load}^{finish} - T_{load}^{start} = \frac{N_{cont}}{Q1} - \frac{C_{bzone}}{Q_1} = \frac{N_{cont} - C_{bzone}}{Q_1} \tag{9}$$

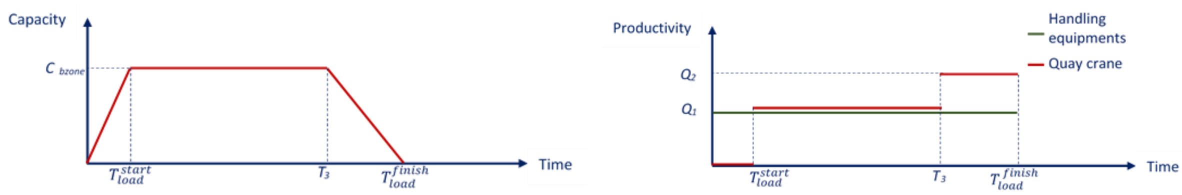

Figure 9– The second correlation method for the loading process

The required time interval for loading the maritime vessel for the second method for correlating the productivity of the handling equipment is:

$$T_{load}^{II} = T_{load}^{finish} - T_3 + T_3 - T_{load}^{start} = \frac{N_{cont}}{Q1} - \frac{C_{bzone}}{Q_1} = \frac{N_{cont} - C_{bzone}}{Q_1} \tag{10}$$

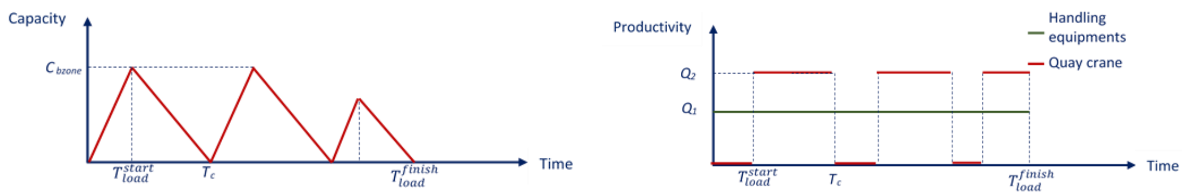

Figure 10– The third correlation method for the loading process

The required time interval for loading the maritime vessel for the third method for correlating the productivity of the handling equipment is:

$$T_{load}^{III} = T_c N_{cycles} + \frac{N_{cont}^{last\ cycle}}{Q_2} + \frac{N_{cont}^{last\ cycle}}{Q_2 - Q_1} - \frac{C_{bzone}}{Q_1} \tag{11}$$

If both unloading and loading operations are conducted for a maritime vessel, any of the methods can be used for correlating the productivity of the container handling equipment with the productivity of the quay crane. Testing the solutions used and identifying the optimal method to correlate the productivity combination can be performed with the help of discrete simulation models both during the download process and during the loading process.

4. DISCRETE SIMULATION MODEL

Using ARENA software, a discrete simulation model is developed to evaluate the correlation procedures between quay crane productivity and handling equipment productivity [19]. The model is developed using structural and technological data of a real container maritime terminal from Romania. The SOCEP terminal is a vital container port operator from the harbor of Constanta, having a capacity of over 500,000 TEU per year. The handling equipment includes shore Panamax cranes on the quay and straddle carriers. Other handling equipments inside the terminal are reach stackers and forklifts, but this are used for loading/unloading containters in relation with land network. The berth depth is 13,5 meters, and the length of the berths is 470 meters. Inside the terminal are two berths, and our simulation model are developed for one of them. The containers are unloaded from maritime vessels to a buffer zone using shore Panamax cranes. This is located on quay and have a limited capacity. From buffer zone the container are moved to main storage area using straddle carriers. The process is reversed for containers shipped to seagoing vessels. The simulation model contains three sub-models for the unloading process and three sub-models for the loading process. This combination allows having nine simulation paths. The structure of simulation paths for unloading and loading processes is represented in Figure 11.

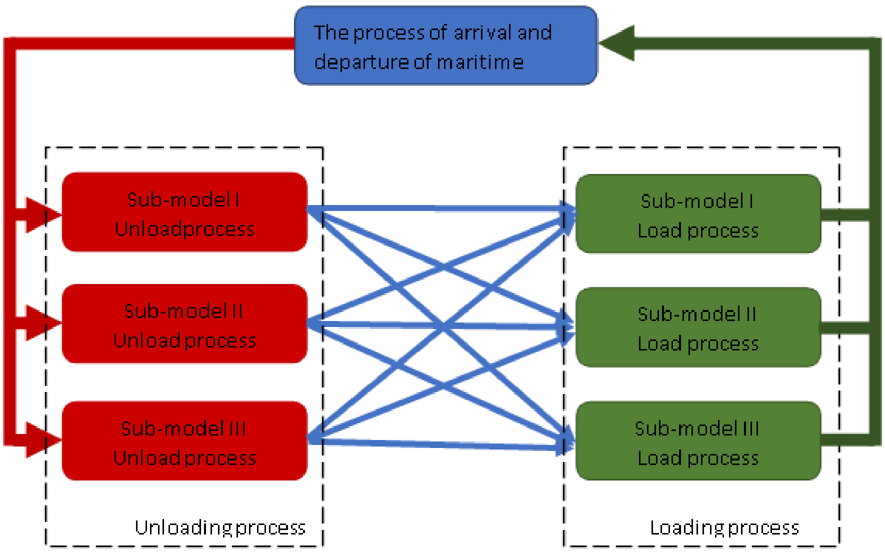

Figure 11 – The model structure for first nine simulation paths

To these paths, another six simulation paths are added, three of them when there are only container loading processes in action and another three when there are only container unloading processes in action (*Table 1*).

Sub-models for loading and unloading processes correspond to the following situation:

- Sub-model I unload process– the gantry crane works until the buffer zone is full and then its productivity is reduced to total productivity of straddle carriers (*Figure 3*);

- Sub-model II unload process –the gantry crane works at adjusted productivity, so in the situation when the buffer zone is full, all the containers can be unloaded from the maritime vessel (*Figure 5*);
- Sub-model III unload process – the gantry crane works until the buffer zone is full and then stops until straddle carriers transfer all the container to the main storage area (*Figure 7*);
- Sub-model I load process– the gantry crane waits for transfer of containers in the buffer zone at full capacity, and then its productivity is adjusted in such manner to have always at least one container to move on the maritime vessel (*Figure 8*);
- Sub-model II load process – the gantry crane, waits for transfer of containers in the buffer zone at full capacity and then its productivity is reduced to total productivity of straddle carriers until the last part of the process when the productivity is increased to its maximum value (*Figure 9*);
- Sub-model III load process – the gantry crane, works with productivity at maximum value but alternating working periods with periods of stagnation of the activity (*Figure 10*);

Table 1 – The simulation paths

Path	**Unload process**	**Load process**	**Path**	**Unload process**	**Load process**
I	Sub-model I	Sub-model I	**X**	Sub-model I	None
II	Sub-model I	Sub-model II	**XI**	Sub-model II	None
III	Sub-model I	Sub-model III	**XII**	Sub-model III	None
IV	Sub-model II	Sub-model I	**XIII**	None	Sub-model I
V	Sub-model II	Sub-model II	**XIV**	None	Sub-model II
VI	Sub-model II	Sub-model III	**XV**	None	Sub-model III
VII	Sub-model III	Sub-model I			
VIII	Sub-model III	Sub-model II			
IX	Sub-model III	Sub-model III			

The simulation run parameters are presented in Table 2:

Table 2 – Run parameters

No	*Parameter*	*Value*
1	*Simulation period*	*180 days*
2	*Warm period (to pass transient state)*	*30 days*
3	*Number of replications*	*10*
4	*Hours per day*	*24 hours*
5	*Number of vessels*	*infinite*

5. RESULTS AND CONCLUSIONS

The input variables for simulation are represented in Table 3. These data are introduced in the simulation model following the real data collected from the maritime container terminal. Some of them can record some variations depending on factors as human intervention, environment, commercial restrictions, etc.

Table 3 – Simulation input variables

No	*Parameter*	*Value*
1	*Number of quay cranes*	*1*
2	*Time interval for container manipulation with quay cranes*	*2.4 minutes*
3	*Number of straddle carriers*	*3*
4	*Time interval for container manipulation with straddle carrier*	*8 minutes*
5	*Time between maritime vessels arrivals*	*Exponential with λ=12,16,20,24*
6	*Buffer zone capacity (we consider the case of 40 ft containers) – number of containers*	*20, 40 containers*
7	*Mooring time*	*2 hours*
8	*Number of containers to unload*	*Uniform (20,100)*
9	*Number of containers to load*	*Uniform (20,100)*

From the simulation model, data about the queue of maritime vessels to enter at berth (Figure 12), the vessels' mean unloading time (Figure 13) and vessels' mean loading time (Figure 14) are collected.

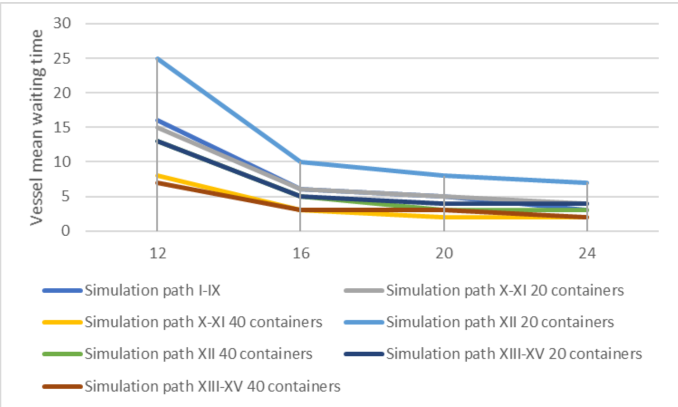

Figure 12– The waiting queue for the maritime vessels entering in terminal

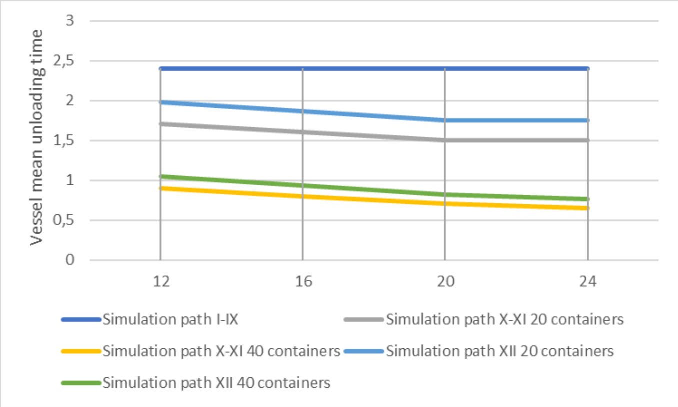

Figure 13– The vessel mean unloading time

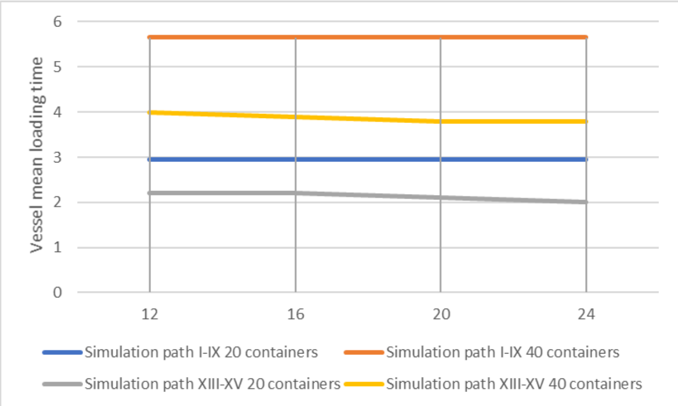

Figure 14– The vessel mean loading time

The size of the waiting queue for the maritime vessels entering the container terminal is influenced by the type of the processes that are performed in the terminal (unloading process for containers, loading process for containers, or both of them). When, within the container terminal, for a vessel, unloading and loading activities are carried out, it is observed that the technology of correlating the productivity of the handling equipment does not influence the size (length) of the waiting queue (simulation path I-IX). The reason is that the buffer capacity cannot be used between the loading and unloading processes. When a single process is performed the buffer zone can be used to perform some container handling operations from the storage zone to the buffer zone before the ship arrives at the terminal. When a maritime vessel performs only the unloading/loading process of containers, the simulation paths X and XI show approximately the same waiting time for entering at berth. In the simulation path XII, a more significant value for waiting time was recorded. The same results for simulation paths XIII-XV were noticed. The arriving time interval between maritime vessels has a direct influence on waiting time for entering at terminal berths for all simulation paths.

For the vessel mean loading time and unloading time obtained in simulation paths I to IX, the correlation between productivities of quay cranes and terminal handling equipment have no influence. However, for the simulation paths X to XII, the usage of the gantry crane until the buffer zone is full and then, stopping its activity (simulation path XII) induces an unloading time bigger in comparison with previous two simulation paths (simulation path X and XI). The capacity of the buffer zone influences overloading/unloading time in simulation paths X-XV. A more significant value for capacity allows obtaining lower values for the duration of the handling process from/to maritime vessel with 40-50% approximatively.

In conclusion, the correlation between productivities of quay crane and maritime terminal handling equipment is important only when it is necessary to unload containers from vessels or to load containers on the vessel. Also, the capacity of the buffer storage zone from quay influences the duration of handling time of the containers from/to maritime vessels. When it is necessary to unload and load containers from/to maritime vessels, the productivity of terminal handling equipment is the determinant factor in assessing the maritime terminal activities parameters, namely: vessel's mean waiting time, mean unloading time or vessel mean loading time.

The obtained results can help the administration of the container terminal in optimizing the activity inside the maritime terminal. Future research is needed to describe the complexity of processes in maritime container terminals. Limitations of the simulation environment may affect the quality of the results obtained but the modeling structure can help to overcome this impediment.

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