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ASSESSING THE TRANSIT CAPACITY OF PORT SHUNTING YARDS THROUGH DISCRETE SIMULATION

Summary. The port shunting yards are developed inside the area of the ports. The main activities are to receive the freight trains from the hinterland, to shunt the freight wagons according to their final destinations from the area of the port, to receive the wagons from maritime terminals, to accumulate wagons according to their destination, and to depart the freight train to the hinterland. So, it is important for port administration to have good methods to evaluate the transit capacity of port shunting yards. A feasible method is to use the discrete simulation model. In our paper, we develop one of this taking into consideration the input flow characteristics of freight trains from land network, the input flow characteristics of freight wagons from maritime terminals, the number of tracks in a port railway station, the technology used for separation of freight wagons on destinations (inside the port or from hinterland), and the duration of technological processes. From the results, we extract the values of trains and wagon sets that transit through the main areas of the railway station (Receiving Tracks, Hump(s) and Departure Tracks).

1. INTRODUCTION

Shunting yards located in the port area allow transit between the land transport network and maritime vessels. Freight flows from/to the hinterland are characterized by large variations as quantity over time induced by the moment of maritime vessels' arrival and their capacity. Also, the traffic on the railway network is made according to some rules and schedules. In these conditions, the port shunting yard works like a buffer between the land railway network and maritime terminals. The theoretical models used to evaluate the sorting process inside the shunting yard are not close to reality, focusing very less on the required departure times of freight trains [5]. This is an important aspect in the case of main shunting yards from the railway network. The departure and receiving times have some influence over the shunting and accumulation process. In the case of port shunting yards developed in the port area, the slots used by freight trains to circulate on the railway network are not important. The shunting yard works like a buffer between circulation on the railway network and activities inside the maritime port terminals. So, is more important the value of transit capacity to evaluate of port shunting yard to the ability to retrieve the traffic from the network and to forward it to the terminals, respectively the reverse process.

To evaluate the transit capacity of freight wagons through the port shunting yard, it is necessary to know the topology of the railway station, the main activities carried out inside the station, the interdependences between technological processes, their duration, and of course the resources available (engines, humps, etc.) [5].

Another problem is the dynamicity of input flows and the lack of information about the moments when it is necessary to receive/to depart trains for/from a specifically maritime terminal. Using a discrete simulation model, all these kinds of indetermination can be introduced into the calculation process. The railway station is considered a queuing system with different serving stations connected to each other [5, 13, 15]. The results obtained have an error probability, and so for this reason, different scenarios must be applied, and every simulation must be repeated several times.

The main advantage when a discrete simulation model is used is the adaptability to different scenarios and situations. This technique is a feasible solution to assess the transit capacity when are evaluated some improvement projects of the activity of existent port shunting yards, but also for new railway stations that must be built in the area of maritime ports.

2. LITERATURE REVIEW

The activities in the shunting yard raise some specific problems studied in the literature. Some of these are studies carried out at the network level and some are carried out on activities in the railway station. In the first category algorithms and solutions are presented for the best path of the freight wagon through the railway network according to the number of shunting stages [1, 3, 4, 9, 10].

In second category research reports are included about the optimization of activities inside the shunting yards. Some of these split the shunting yards into three categories according to the technology used for shunting. These can be hump yards, flat yards, and gravity yards [5]. The first of them are the most complex using a hump(s) and gravitational pull between Receiving and Classification Tracks. The second type have in general the same configuration as hump yards, but without a hump. So is not used the gravitational split of the freight wagons, requiring a maneuver locomotive. In case of gravity yards, the whole railway station have a slight decline used for shunting process [5].

The simulation model for shunting yards considers the railway station a queuing system. Random aspects of input flows are considered to introduce the real character in the simulation [13]. Using a simulation model, comparisons between different shunting yard typologies can be made to hierarchize the investment in the short or long term [12].

The activities inside the shunting yards can be split on time periods when is used the simulated annealing algorithm. The main entities used in this kind of algorithms are loaded and empty rail cars. For these are studied the movement inside the railway station [11].

The discrete simulation models use dedicated software like SIMUL'8 or ARENA to describe the main process in the terminals. Some of these models are used to simulate the activity in the maritime terminals [7, 14], some are used for the assessment of the capacity of terminals [6, 8], and some are used to evaluate the impact of new technology in the shunting process in the port shunting yards [12, 13, 15].

3. ACTIVITY IN THE PORT SHUNTING YARD

The main role of port shunting yards is to act as a buffer between the rail transport network and the maritime vessels. The main activities of the land-based railway station for the land–water freight flows are to receive trains from the territory, to group freight wagons according to the maritime terminal those have to reach and to accumulate wagons before the arrival of the maritime vessel so that its stationary time to berth can be reduced as much as possible.

For the opposite water–land freight flows, receiving operations for wagons from the maritime terminals are carried out, the shunting process in relation to the hinterland destinations, respectively the accumulation process of wagons necessary for the formation of land-based trains and the waiting of a free slot on the railway network (Fig. 1).

Of course, besides these main activities, other activities such as preparation of customs documents, border police controls, technical check of wagons, etc., can be carried out within the shunting yard.

The route of the wagons through the shunting yard is dependent on the station topology. The lines inside the station are grouped according to the main activities. Therefore, the lines in the shunting yard are organized into Receiving Tracks, Classification Tracks, and Departure Tracks. The transfer of wagons between Receiving Tracks and Classification Tracks is performed by crossing over the shunting installation (hump) of the marshalling yard (Fig. 2). The trains from land (called the inbound trains) are waited in Receiving Tracks. The trains' engines are removed and another engine (belonging to the station) for maneuvers is attached. The technical and the commercial activities are made, and the train stops to exist as an entity. Wagons are separated according to the destination (in this case, maritime terminals) using the shunting installation. This one is composed of one or two humps, a braking system, and an inclined plane.

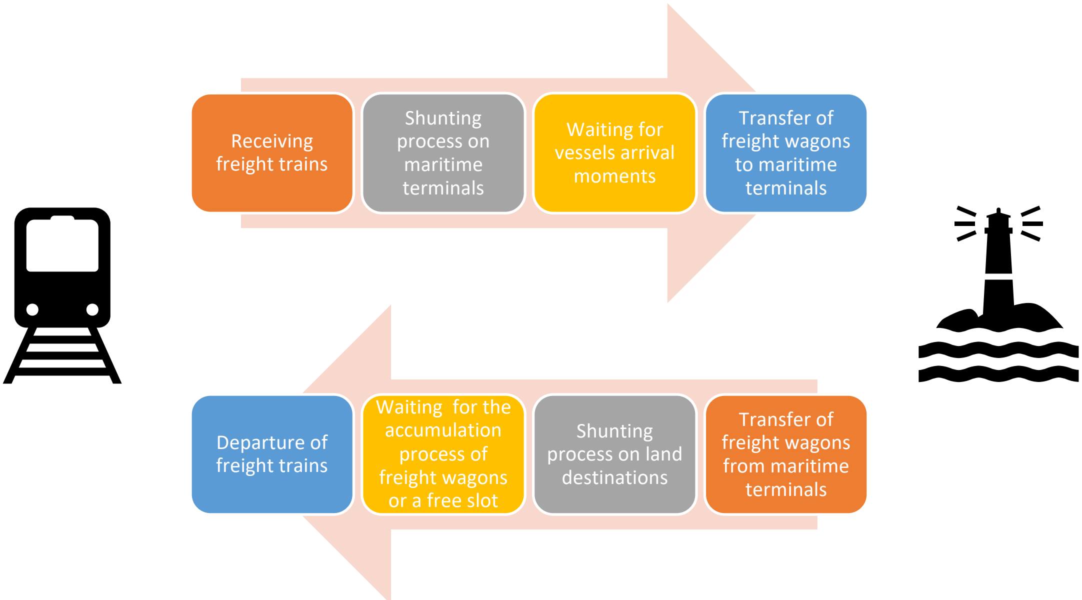

Fig. 1. The main activities inside the maritime shunting yard [authors]

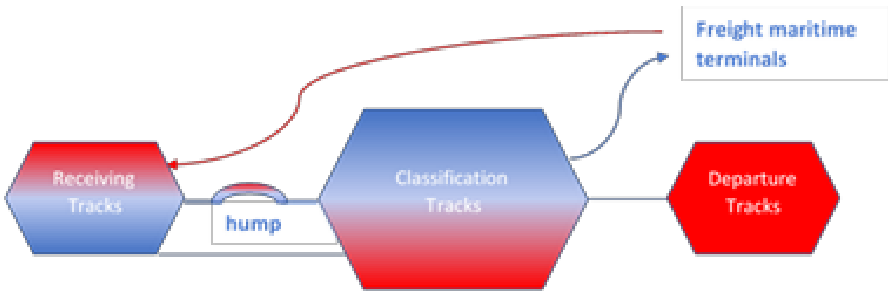

Fig. 2. The transit through port shunting yard (red is water-land flow and blue is land-water flow) [15]

From Classification Tracks, using another engine for maneuvers, the freight wagons are moved to maritime terminals when the vessels arrive in the port or when there is space inside the terminals.

In case of water-land flows, the freight wagons are moved from maritime terminals to the shunting yard to be sent to their destination using the outbound trains. Like in the first case, these are separated using the shunting installation according to the railway destination station on the Classification Tracks. After the accumulating process, the freight wagons are moved using an engine for maneuvers in the Departure Tracks. After finishing the technological process for departure, when it is a free slot on rail transport network, the freight train leaves the port shunting yard.

When the traffic volume of freight wagons is big, the topological structure of the shunting yard can be doubled. The flows coming from land and from water are completely separated from one another (Fig. 3). It is represented by a so-called double shunting yard with two separated zones for Receiving Tracks, two Classification Tracks, and one Departure Track for outbound trains.

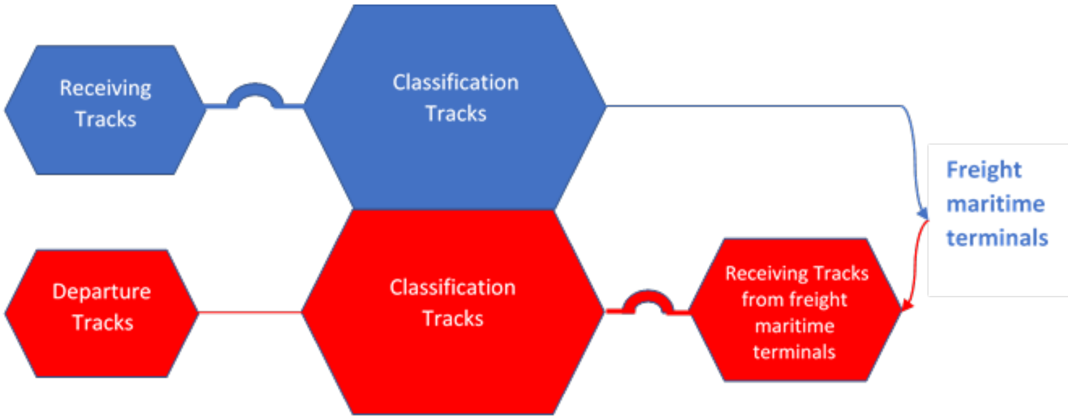

Fig. 3. The double-port shunting yard (red is water-land flow and blue is land-water flow) [15]

The transit capacity of freight wagons through shunting yards located inside the port area with activities dedicated for maritime terminals depends on the particularities of the specific activities carried out in each area of the railway station. To assess the transit capacity, it is important to know the duration of technological processes, the number of tracks for every compartment of the station, and other information about activities developed inside the station.

4. DISCRETE SIMULATION MODEL

The main problem in the assessment of transit capacity is the dynamicity of traffic on the railway network and the lack of information about vessels and trains' arrival. In this case, the use of a discrete simulation model of activities inside the port shunting yard represents a feasible solution. The model developed must take into consideration the input flow characteristics of freight trains from the land network, the input flow characteristics of freight wagons from maritime terminals, the number of tracks in the port railway station, the technology used for separation of freight wagons on destinations (inside the port or from the hinterland), and the duration of technological processes. Using a dedicated discrete simulation software, ARENA 12 from Rockwell, we develop a model considering the topology of a port shunting yard. This is built separate for the case of a simple shunting yard and for the case of a double shunting yard.

For the first case, the inbound trains, which arrive from the railway network, are received in the Receiving Tracks area together with freight wagons from maritime terminals. The outbound trains have technological process for preparing to travel in Departure Tracks, while the technological process for flow of wagons going to maritime terminals are made in Classification Tracks (Fig. 4). For the second case, the port shunting yard has two areas with Receiving Tracks: one for inbound trains and one for freight wagons from maritime terminals (Fig. 5). Also, the railway station can have two areas for Classification Tracks, but sometimes, it is better to have a common area for the case when freight wagons from one maritime terminal must be moved to another terminal through a port shunting yard.

The input data of computer simulation are presented in Tab. 1.

The discrete simulation models are developed using the logical blocks to describe the activities inside the port shunting yard. The connection between these blocks shows the route of the flow from land (railway network) to water (maritime terminals) and the opposite flow from the maritime terminal to the land railway network.

In the case of a double-port shunting yard simulation model to separate the freight wagons according to destinations from the hinterland or maritime terminals two humps can be used: one for every direction (to water or to land), thus increasing the transit capacity through the port shunting yard.

Table 1

Values of input data of simulation

Input data	Simple port shunting yard	Double-port shunting yard
Topological parameters		
Number of lines in Receiving Tracks	6 lines (3 lines dedicated to arrival trains and 3 lines dedicated to freight wagons from maritime terminals)	3 lines in every group of lines from Receiving Tracks
Number of lines in Classification Tracks	16 lines	16 lines for both directions of port shunting yard
Number of lines in Departure Tracks	6 lines	
Number of humps	2 humps (but it is used only once each time)	1 hump for every direction
Duration of technological process		
Technological process in Receiving Tracks	60 minutes for arrival trains and 40 minutes for freight wagons from maritime terminals	
Shunting process	25 minutes	
Technological process in Classification Tracks	50 minutes	
Technological process in Departure Tracks	60 minutes	
Input flows		
Land-water flows	We use the intervals between the arrival of the trains as follows: Exponential (λ=0.8 hours, 1 hour, 1.2 hours), Normal (λ=0.8 hour and σ=0.2 hours, λ=1 hour and σ=0.1 hours)	
Water-land flows	We use the intervals between the arrival of freight wagons set from maritime terminals as follows: Exponential (λ=0.6 hours, 0.7 hours, 0.8 hours), Normal (λ=0.5 hours and σ=0.1 hours, λ=0.7 hours and σ=0.1 hours)	
Number of wagons from a train	60 wagons	
Number of freight wagons set moved in a single maneuver to and from maritime terminals	40 wagons	

The steps of calibration and validation in the development process of simulation models were created for the duration of the technological process in Receiving Tracks, Departure Tracks, and the shunting process. For this, we use the normative from Romanian shunting yards and a survey conducted in different situations. We observe a connection between the duration of technological process and number of freight wagons in trains or in wagons set. So, we chose for our simulation the number of wagons in trains, respectively 60 wagons (which is a common value for this category of trains) and 40 wagons in wagons set from maritime terminal, which is a little smaller taking in consideration the common length of industrial lines inside the maritime terminals.

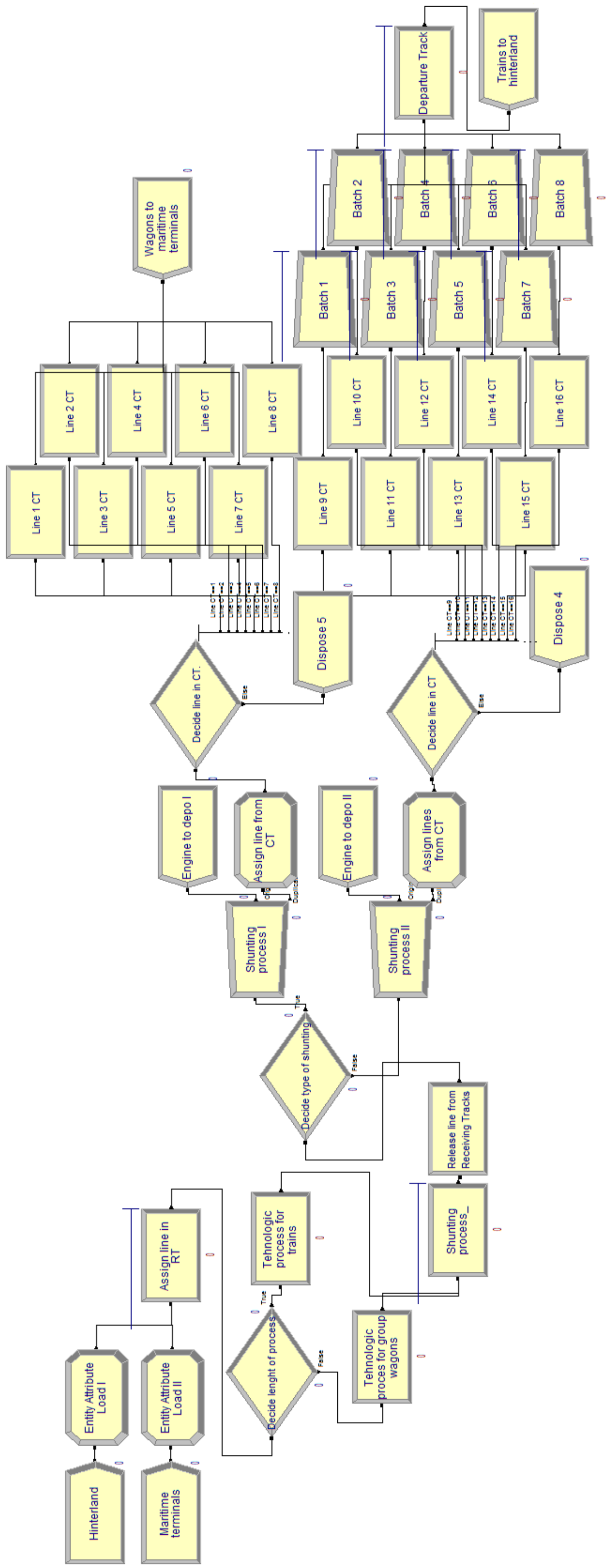

Fig. 4. Simple port shunting yard simulation model [16]

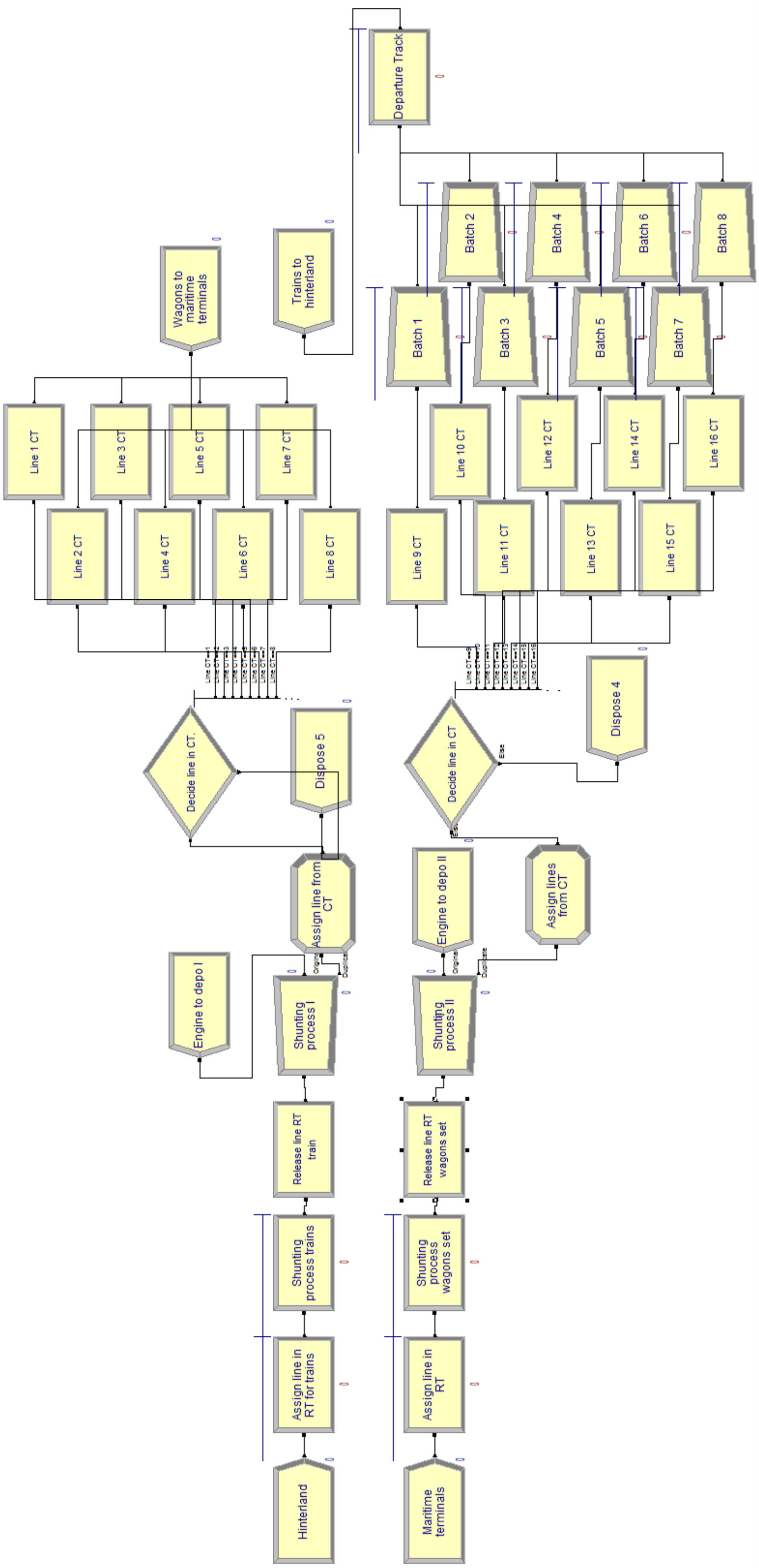

Fig. 5. Double-port shunting yard simulation model [16]

The simulation setup parameters are presented in Tab. 2.

Table 2

Simulation setup parameters

Parameters	Input value
Number of replications	10 replications
Warm Period	30 days
Replication Length	180 days
Rule to assign a line in Classification Tracks	Uniform
Rule to assign a line in Receiving Tracks	Cyclical (no priority)
Rule to assign hump	In queue (no priority)

The results obtained using five different parameters for input flow from land, as we describe in Tab. 1, for every type of port shunting yard, simple or double, are presented in Tab. 3a and Tab. 3b:

Table 3a

The simulation results for simple port shunting yard (average values)

Scenario / Attribute	I	II	III	IV	V
Land-water flow	Expo(0.8)	Expo (1)	Expo (1.2)	Norm (0.8,0.2)	Norm (1,0.1)
Water-land flow	Expo (0.6)	Expo(0.7)	Expo(0.8)	Norm (0.5,0.1)	Norm (0.7,0.1)
Usage (average ratio)					
Line 1 to 6 in Receiving Tracks [%]	1	0.98	0.69	1	0.99
Hump [%]	1	0.99	0.88	1	1
Departure Tracks [%]	0.15	0.15	0.14	0.16	0.15
Usage (average number)					
Line 1 to 6 in Receiving Tracks [wagons]	10080	10080	8934	10128	10080
Hump [wagons]	10080	10059	8948	10080	10080
Waiting time to enter in Departure Tracks [hour]	373	33	0.77	579	16

In the previous tables, we showed the transit capacity for different areas of a railway station, like Receiving Tracks, Shunting Area, and Departure Tracks, respectively, for the usage of the lines from these areas. As we expected, the transit capacity takes higher values for the case when the topology of railway station is in accordance with a double-port shunting yard. But this is not always true. As we can see in Fig. 6 when the interval between the arrival moments is smaller (like in Scenarios I and IV), the transit capacity, indeed, is bigger for a double-port shunting yard with 20-35% versus a simple port shunting yard, but when this interval is increased, the transit capacity takes on almost similar values.

However, the use of a railway station with a double shunting yard allows to obtain some acceptable values of waiting time for a free line in Receiving Tracks. From the simulation model, we obtain some high values of waiting time that can be reduced by drawing up a rigorous schedule of train arrivals at the port shunting yard [2].

Table 3b

The simulation results for a double-port shunting yard (average values)

Attribute \ Scenario	I	II	III	IV	V
Land-water flow	Expo(0.8)	Expo (1)	Expo (1.2)	Norm (0.8,0.2)	Norm (1,0.1)
Water-land flow	Expo (0.6)	Expo (0.7)	Expo (0.8)	Norm (0.5,0.1)	Norm (0.7,0.1)
Usage (average ratio)					
Line 1 to 3 in Receiving Tracks [%]	0.60	0.50	0.41	0.58	0.47
Line 4 to 6 in Receiving Tracks [%]	0.68	0.57	0.49	0.73	0.51
Hump I [%]	0.50	0.42	0.34	0.51	0.41
Hump II [%]	0.69	0.59	0.51	0.83	0.59
Departure Tracks [%]	0.18	0.15	0.13	0.22	0.15
Usage (average number)					
Line 1 to 3 in Receiving Tracks [wagons]	5142	4269	3522	5211	4194
Line 4 to 6 in Receiving Tracks [wagons]	7041	6009	5220	8388	6006
Hump I [wagons]	5138	4268	3521	5208	4194
Hump II [wagons]	7039	6010	5224	8387	6008
Waiting time for trains to enter in Departure Tracks [hours]	0.23	0.12	0.07	0.001	0.001
Waiting time for wagons set to enter in Departure Tracks [hours]	0.35	0.19	0.11	0.001	0.001

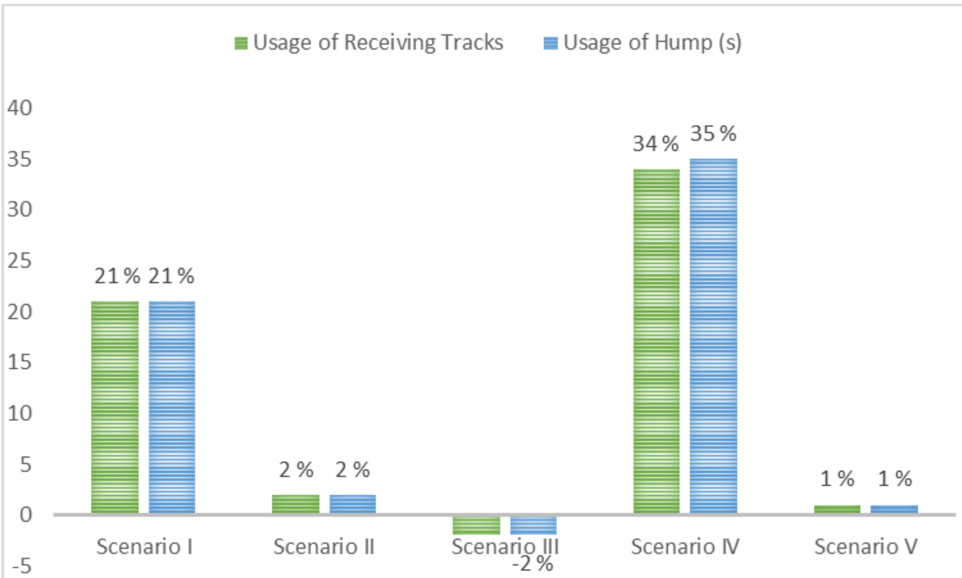

Fig. 6. The variation of usage for Receiving Tracks and Hump(s), comparing the simulation models

5. CONCLUSION

When evaluating a possible project to develop a shunting yard located in a port area, it is extremely important to have the skills to determine the value of its transit capacity. The classical methods of analysis do not take into account the nonuniformity of the traffic flows entering the shunting yard, respectively, the interactions between the processes carried out in different groups of lines. In these conditions, considering the shunting yard as a queueing system allows a better assessment of the transit capacity value. This analysis method is approached using a simulation model built in accordance with the station topology and the existing interactions between the different technological processes carried out in the station.

In our paper, two types of railway stations were analyzed: a simple port shunting yard and a double-port shunting yard. A discrete simulation model was developed using a dedicated software for every type of railway station. We used in the simulation a warm period (one month) and we have collected data from ten repeated simulations. The input data were classified into five different scenarios and were used in the simulation model of the activity in a simple port shunting yard, but also for a simulation model developed for a double-port shunting yard. The results allow us to evaluate the transit capacity through a port shunting yard of freight wagons received from the railway network, but also for freight wagons from maritime terminals with destination to the hinterland.

Our research was applied for the case of a port shunting yard and we take into consideration the possible natural limitation of the specific activities with this area where the land to build a railway station is recovered from the sea. Starting from this, we mention that the developed simulation models can also be adapted for every type of shunting yard from the railway network.

Guidelines of our further research in the domain of this paper include some aspects like the limitation imposed by the different lengths and capacities of the railway tracks, the impact of priority requests, the reliability of rolling stock, etc.

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