WCTR 2013 RIO

SELECTED PROCEEDINGS

AN OPTIMIZATION MODEL FOR PLANNING THE RAIL PORT CYCLE IN SEAPORT CONTAINER TERMINALS

CLAUDIA CABALLINI,C. PASQUALE, S. SACONE, UNIVERSITY OF GENOVA, EMAIL FOR CORRESPONDENCE: CLAUDIA.CABALLINI@UNIGE.IT

This is an abridged version of the paper presented at the conference. The full version is being submitted elsewhere. Details on the full paper can be obtained from the author.

ISBN: 978-85-285-0232-9

13th World Conference on Transport Research

www.wctr2013rio.com

15-18 JULY 2013

Rio de Janeiro, Brazil

unicast

AN OPTIMIZATION MODEL FOR PLANNING THE RAIL PORT CYCLE IN SEAPORT CONTAINER TERMINALS

Claudia Caballini[1]
C. Pasquale[1]
S. Sacone[1]

[1] DIBRIS – Department of Computer Science, Bioengineering, Robotics and Systems Engineering - University of Genova, Via all'Opera Pia 13, 16145, Genova, Italy
Email for correspondence: claudia.caballini@unige.it

ABSTRACT

In the last decades, the volumes of goods to be transported by ship have been increasing, making seaports the crucial nodes of the transportation networks. Due to the limited space available in the port areas (especially in Italy), it is necessary to optimize the use of resources in terminal containers. At the same time, it must consider that nowadays there is a strong imbalance in favor of the road transport with respect to the rail one. However, it would be desirable to rebalance the modal shift in favor of the rail mode, both for environmental reasons and for reducing congestion. This research focuses on the rail port cycle in seaport container terminals with the main objective of proposing a planning approach to size port railway terminals, also by evaluating different scenario performances. The final goal is to increase the volume of goods moved by rail transport, in order to allow a greater throughput especially for ports that cannot enlarge their areas because of physical limitations.

INTRODUCTION

The lengthening of supply chains determined by the macro-economic changes that have affected the world context in recent decades (globalization and production delocalization) have led to a continuous increase in the volume of goods moved at a global level, reinforcing the importance of sea transport, as the transport mode best suited to cover long distances. Consequently, the role of ports, as pivot points of transportation networks, has assumed increasingly greater prominence.

Although the port node represents a driving force for the economic development of a country, the high organizational complexity, together with its infrastructural bottlenecks, makes it a weak link in the freight supply chain. This is particular important for what concerns the forwarding of goods towards and from the inland territory. In fact, the current organizational and infrastructural situation of the land transportation network – which is particularly true for the Italian framework – sets limits to the volumes of goods passing through the port node. This aspect is worsened by the fact that the road transport currently represents the most used transportation mode, despite its low sustainability – both in terms of environment and social congestion – compared to the rail one. However, the increasing rate of goods to be handled and transported worldwide imposes to dramatically change the modal split in favor of the rail transport, so allowing to move higher volumes of goods in a more sustainable way.

However, the possibility of winning the role of most used transport in the inland territory is bound to overcome difficulties inherent the system itself, such as the organization of the rail service, the costs required for its production, the adequacy of the fleet and the bottlenecks of the current rail infrastructure, together with the liberalization of the railway market and the tariffs policies.

On the other hand, in addition to environmental advantages, there are other benefits that an effective rail transport can bring. Firstly, it can be properly planned and programmed on a time basis, allowing the achievement of high performance of the system, but above all it offers the possibility of sending large quantities of goods towards the territory (roughly a train can carry up to 60 TEUs in Italy and up to 100-120 TEUs in Northern European ports).

The management of traffic flows in a port represents an optimization problem in which the optimal usage of resources must be defined with different objective functions and under specific constraints. Objectives relate to compliance with a certain level of performance and productivity, while constraints are dictated by the territorial and economic context, as well as the regulatory limits and the financial budget. In particular, the main goals to be pursued refer to the improvement of system performance and the reduction of the goods lead time in the port area.

The present paper is devoted to model and analyze the performance of a rail port system by analyzing different scenarios. More specifically, the terminal equipment productivity, the number of resources and rail schedules are varied with the objective of understanding which is the most suitable configuration in order to manage and to send higher volumes of goods by rail from a port.

In the literature, many works can be found in relation to container terminals [Steenken et al.], [Stahlbock and Voss], intermodal terminals [Crainic] and rail transportation operations [Ferreira]-[Bostel], but few of them analyze the rail transport cycles in seaports and, in the majority of cases, they are focused on specific issues, such as in [Ambrosino], [Caballini], instead of analyzing the whole cycle, as proposed in the present work.

The paper is organized as follows. After an introduction representing the context of reference and the goals of the proposed research, the description of the system under investigation and its related model are depicted. The following chapter provides the characterization of the numerous scenarios which have been implemented, together with the analysis of the results obtained. Finally, the last chapter presents some conclusion and provides some reflections for further research.

DESCRIPTION OF THE SYSTEM

The above considerations support the necessity of better planning and organizing the port rail cycle in a container terminal, with the goal of increasing the volume of goods moved by train to/from the ports.

In order to plan and organize the rail port cycle, an optimization approach is proposed [Alessandri]. A dynamic model for this system has been defined. The proposed model is a discrete-time queue-based one in which each queue represents the presence of containers in a specific area of the terminal and the system dynamics is basically given by conservation equations. Then, taking into account some physical and real conditions on the operations of handling systems and trains, the other necessary constraints are defined. The resulting optimization problem is a mixed-integer linear mathematical programming problem whose

objective is to find the optimal values of the handling resources and the timing of trains in order to minimize the number of containers waiting in the different terminal areas and allowing a higher quantity of goods to be moved by rail.
The proposed model focuses on the container import cycle. Moreover, seaside operations (or rather the process regarding ships unloading and container transferring from the quay to the yard) are neglected. This means that, once entering the system, containers are immediately stored in the container yard(s), as depicted in Figure 1. From here, they are subject to a certain number of passages up to the moment when they are loaded on rail wagons in the container terminal internal rail park, which is composed of a certain number of tracks. Once the train is composed, a certain amount of time must be waited in order to allow the performing of some documentary operations and the attachment to the train of the diesel locomotive, which shunts the train to an external rail park. Here, after verifying the correctness of the containers loading on rail cars (technical check) and after checking the functioning of the braking system, the train can leave towards its destination at the time imposed by its assigned rail slot. Figure 1 provides a description of such a model.

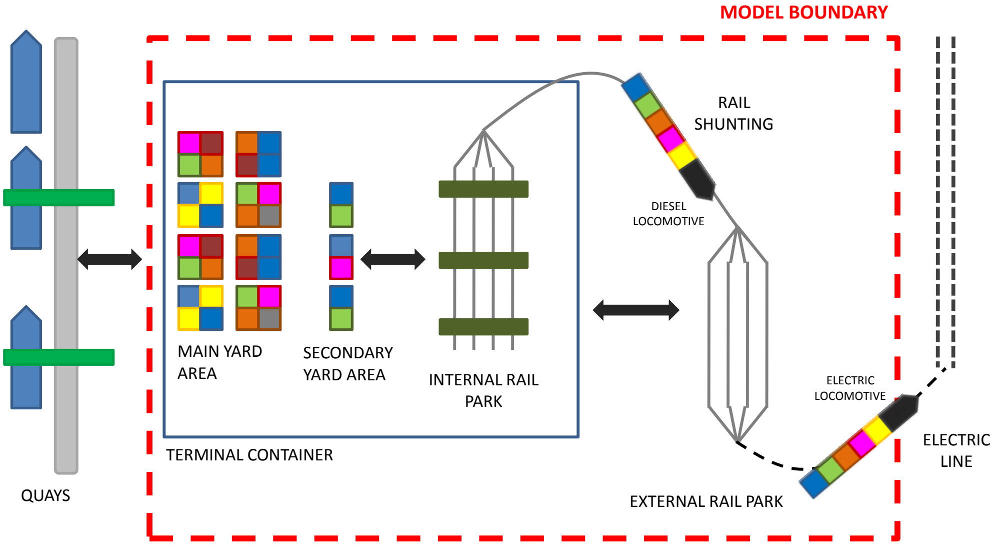

Fig.1 – Framework and boundary of the model

While these processes are common for the majority of the container terminals around the world, what differentiates them is the typology and the number of the equipment means, in addition to the specific terminal layout, hence corresponding to different procedures and operative cycles. In fact, depending on the particular container terminal considered, a specific layout and management must be taken into account.
The objective of this work is to define an optimization approach in order to determine the optimal system configuration in relation to the import railway cycle in terms of number of handling resources and timing of handling operations. The final goal is to decrease the total time spent to compute the whole cycle, which corresponds to the maximization of the number of trains leaving the terminal. Even if the problem could appear not so hard, many complexities arise in reality. First of all, this system is very rigid, starting from the fact that railway tracks represent a resource difficult to be varied; besides, the railway transportation implies a strict and well defined planning that cannot be easily changed. Finally, a problem of resources sharing, in terms of rail tracks and handling equipment, occurs.

In the model here proposed, all the considered system is represented with a set of queues, modeling the presence of containers in specific areas of the terminals. Figure 2 provides a logic representation of the queues considered in this system, whose dynamics is represented with discrete-time equations with sample time equal to ΔT. At a generic time step t, the arrival rates of containers (that will be forwarded by rail) in the M different import areas of the terminal are given by the quantities $a_M(t)$ and $a_S(t)$ (expressed in containers per hour). Analogously, $d(t)$ models the demand of containers in import (again expressed in containers per hour), i.e. the pattern of railway slots scheduled from the terminal towards the inland territory.

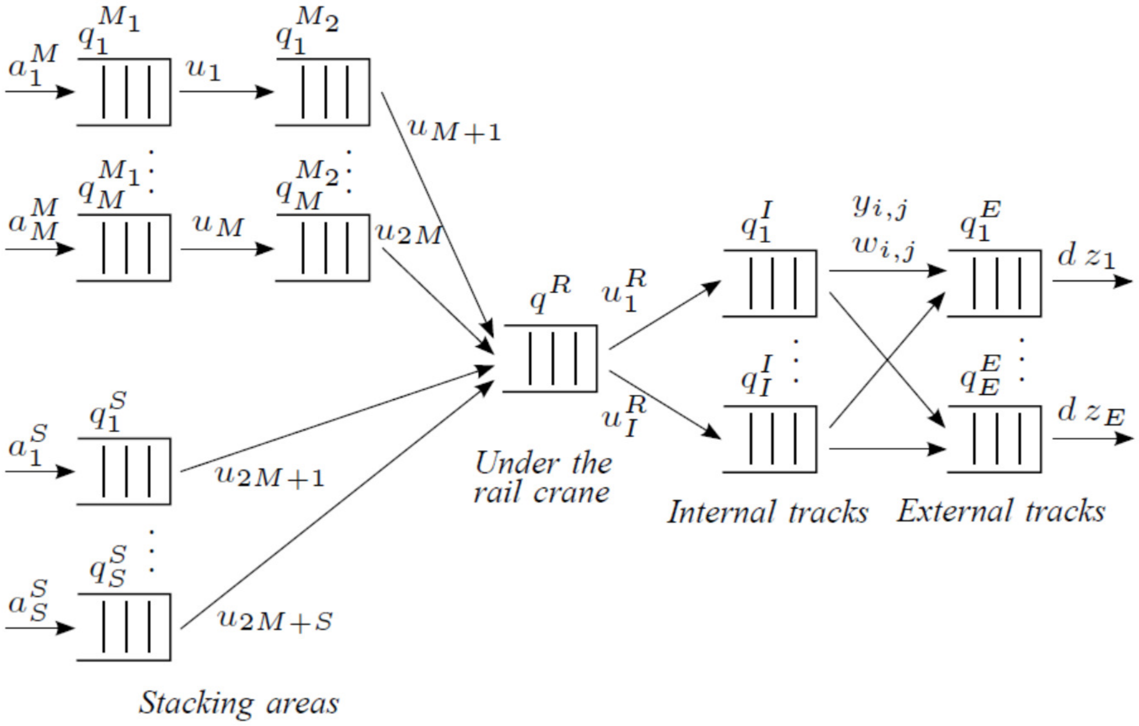

Fig. 2 – Queue model of a generic import rail cycle in a container terminal

Such processes can equivalently be modeled either as deterministic sequences or as random sequences, but in this paper they are assumed to be deterministic. Containers entering the yard are stored in the import yard areas: at each time t, the queue lengths corresponding to these areas are denoted as $q_{M1}(t)$ and $q_S(t)$ (the queue lengths are expressed in terms of number of containers). Before being loaded on the train, containers stored in the main import yard areas $q_{M1}(t)$ are firstly brought to an intermediate buffer (whose length at time t is denoted with $q_{M2}(t)$) before being transported close to the internal rail park (queue $q_R(t)$ at time t). The intermediate buffers represent a further step of container storage and this, consequently, implies the utilization of another type of handling means; for instance, in the specific case here analyzed, we assume that containers are picked up from the main yard by a RTG (Rubber Tired Gantry) crane and then loaded with a reach stacker on a trailer which transports them under the rail crane. On the contrary, containers stored in the secondary import yard area have a different handling cycle and they are directly brought by a reach stacker under the RMG (Rail Mounted Gantry) crane in the rail park.

The productivity - expressed in containers per hour - of the handling resources dedicated to work in the import terminal yard, at time t, is denoted as $u_i(t)$. Containers wait in queue $q_R(t)$, i.e. in the area close to the internal rail park, till they are loaded on the rail cars available in the internal tracks. The internal rail yard is composed of I tracks represented by queues $q_I(t)$. It is here assumed that rail cars are always available in the internal rail park. $u_{R,i}(t)$ represents the productivity at time t of the RMG rail cranes used to load containers on trains in the

related track. Once loaded with C container, a train is ready to be brought from the internal to the external rail park, which is made up of E tracks represented by the queues $q_E(t)$.
It is assumed that one or two siding tracks connect the internal rail park with the external one. Of course, in order to execute the transit, it is necessary that one of the siding track is free for the train passage.
The departures of trains from the internal yard towards the external park are represented by means of a set of binary variables in the optimization problem. The time required to cross the siding track is supposed to be a multiple τ of the sample time ΔT; therefore, the external rail track will receive the train that departed τ time instants before from the internal park.
The train can leave from the external rail park when there is the availability of the corresponding rail slot and this is represented by a positive value of $d(t)$ (to correctly model the train departures from a given external rail track, another set of binary variables is introduced).
The dynamics of the overall transfer activities in the terminal is described with conservation equations that, at each time step $t + 1$, update the queue lengths according to their length at the previous time step t and the number of entering and exiting containers in the time interval $[t, t + 1)$, with length Δt. Then, a certain number of constraints must be respected, among which there are the following ones: only when a train is fully loaded with C containers, it can leave the internal rail park; only one external track can be available to satisfy the external demand; only one train at a time can be transiting on each siding track; the quantity exiting each queue must be lower than or equal to the queue length at the same time step; the handling rates cannot exceed the maximum values of the capacity of the terminal resources.

SCENARIOS EVALUATION AND RESULTS OBTAINED

The proposed optimization model has been applied to a maritime terminal, taking inspiration from an important container terminal located in Northern Italy.
More specifically, it is assumed that there are two import yard areas where import containers to be forwarded by rail are stored. The main one hosts all the containers that will be transported indifferently by road or rail but for which there is no information in advance about their final land transport mode, while the second one, which is closer to the internal rail park, stores only containers that are known in advance to continue by rail. For what concerns the handling means utilized, it is assumed that the import area is served with RTGs that pick up containers from stacks and stock them near the blocks; hence containers are lifted up by reach stackers and posed on trailers that bring them to the internal rail park, where RMG cranes load them on trains. On the other side, containers located in the rail yard area are directly loaded by reach stackers on trailers and transported close to the domestic rail park.
Moreover, it is assumed that the internal rail park is composed of 8 tracks while the external one of 3 tracks; only one siding track is connecting the two parks.

In order to test the goodness of the proposed model, a certain number of scenarios have been implemented and optimized (Table 1). For each scenario, three cases have been further evaluated: rail demands of 30%, 50% and 70% on the total demand have been considered. It is worth underlining that the demand is deterministic being the goal of the paper focused on sizing the number of terminal resources (and consequently the number of trains executed). However, this does not represent a strong assumption because rail transport constitutes a rather rigid system (compared for instance to road transport) both in terms of number of rail slots scheduled per day and number of containers loaded per train.

Besides, the number of handling equipment (RTGs, RMGs, reach stackers and trailers) are varied, as well as the number of tracks in the rail parks. Finally, a situation in which freight rail slots are uniformly distributed along the day is considered, in opposition to the one in which they are concentrated from the evening hours up to the early morning in order to give precedence and priority to the passenger rail transportation (as it currently happens). A scenario in which the capacity of the buffer area (q_R) along the internal rail tracks is increased from 5 to 10 containers is also considered.

Table 1: scenarios implemented

Variables	SCENARIOS														
	1			2			3			4			5		
	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	5b	5c
Rail transport demand	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%
Number of RTG in the main rail yard	2	2	2							2	2	2	2	2	2
number of RMG				2	2	2							2	2	2
number of trailer/reachstacker couples in total							2	2	2	2	2	2	2	2	2
number of queus in the main rail yard															
number of queus in the secondary rail yard															
number of internal rail tracks															
number of external rail tracks															
rail slots distribution along the day															
capacity of q_R queue															

Variables	SCENARIOS											
	6			7			8			9		
	6a	6b	6c	7a	7b	7c	8a	8b	8c	9a	9b	9c
Rail transport demand	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%
Number of RTG in the main rail yard												
number of RMG												
number of trailer/reachstacker couples in total												
number of queus in the main rail yard	2	2	2	1	1	1						
number of queus in the secondary rail yard				1	1	1						
internal rail tracks							4	4	4			
external rail tracks										6	6	6
rail slots distribution along the day												
capacity of q_R queue												

Variables	SCENARIOS											
	10			11			12			13		
	10a	10b	10c	11a	11b	11c	12a	12b	12c	13a	13b	13c
Rail transport demand	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%
Number of RTG in the main rail yard												
number of RMG												
number of trailer/reachstacker couples in total										2	2	2
number of queus in the main rail yard												
number of queus in the secondary rail yard												
internal rail tracks	3	3	3									
external rail tracks	8	8	8									
rail slots distribution along the day				YES	YES	YES						
capacity of q_R queue							10	10	10	10	10	10

Variables	SCENARIOS											
	14			15			16			17		
	14a	14b	14c	15a	15b	15c	16a	16b	16c	17a	17b	17c
Rail transport demand	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%	+30%	+50%	+70%
Number of RTG in the main rail yard	2	2	2							2	2	2
number of RMG	2	2	2							2	2	2
number of trailer/reachstacker couples in total	2	2	2				1	1	1	1	1	1
number of queus in the main rail yard												
number of queus in the secondary rail yard												
internal rail tracks												
external rail tracks												
rail slots distribution along the day				YES	YES	YES	YES	YES	YES	YES	YES	YES
capacity of q_R queue	10	10	10	10	10	10	10	10	10	10	10	10

Each scenario has been performed over a time interval equal to two days with a time step Δt equal to 15 minutes. The capacity C of each train has been set to 40 containers, while the number of time steps τ needed to cross the siding track has been fixed to 3 (45 minutes).

Table 2 provides the results obtained for each scenario. As it can be seen in the graphs in Figures 3 and 4, all the scenario configurations allow to perform the 30% of rail demand. However, in case of 50% of rail demand, this is fulfilled only if, on one side, the capacity of queue q_R (representing the buffer available to store containers along the rail crane or, alternatively, the number of trailers per each reach stacker) is increased up to 10 and, on the other side, the couple reach stacker/trailer is increased to 2 units (scenarios 13 and 14), or when rail slots are uniformly distributed during the day (scenarios 16 and 17). This means that a more proper distribution of the rail slots along the day avoids to increase the number of the terminal handling equipment (or, alternatively, the same number of handling means but with a higher productivity).

A rail demand transportation equal to 70% of the total volume of goods to be send in the inland is fully satisfied only when a mix of factors occurs: the number of RTG and RMG is doubled, rail slots are uniformly distributed and the capacity of q_R queue is raised up to 10 units (scenario 17).

Table 2: Scenario's results - KPIs

KPIs	SCENARIOS' RESULTS														
	1			2			3			4			5		
	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	5b	5c
# of performed trains	7	9	10	7	9	10	7	10	10	7	10	10	7	10	10
# of performed trains/number of available slots (%)	100,00	81,82	62,50	100,00	81,82	62,50	100,00	90,91	62,50	100,00	91	62,50	100,00	91	62,50
average # of containers in the main yard	1.142,28	1.123,75	1.141,27	1.148,25	1.122,33	1.139,48	1.141,23	1.100,09	1.138,16	1.141,82	1.105,04	1.143,03	1.141,82	1.105,04	1.143,03
average # of containers in the secondary yard	164,05	118,15	106,77	400,23	118,30	107,38	170,61	118,52	121,76	170,36	116,18	119,65	170,36	116,18	119,65
RTG average productivity	1,33	4,94	6,03	0,00	4,94	6,03	1,29	5,80	6,04	1,29	5,80	6,04	1,29	5,80	6,04
trailer/reach stacker average productivity	10,50	14,67	16,33	5,50	14,67	16,33	10,50	15,50	16,33	10,50	15,50	16,33	10,50	15,50	16,33
RMG stacker average productivity	10,52	14,69	16,35	5,52	14,69	16,35	10,52	15,52	16,35	10,52	15,52	16,35	10,52	15,52	16,35

KPIs	SCENARIOS' RESULTS											
	6			7			8			9		
	6a	6b	6c	7a	7b	7c	8a	8b	8c	9a	9b	9c
# of performed trains	7	9	10	7	9	10	7	9	10	7	9	10
# of performed trains/number of available slots (%)	100,00	81,82	62,50	100,00	81,82	62,50	100,00	81,82	62,50	100,00	81,82	62,50
average # of containers in the main yard	1.142,18	1.122,33	1.139,00	1.142,18	1.122,75	1.139,96	1.142,18	1.122,33	1.139,48	1.142,18	1.122,33	1.139,48
average # of containers in the secondary yard	164,73	118,86	108,05	164,84	118,88	108,50	165,04	118,69	107,48	164,64	118,35	107,65
RTG average productivity	1,29	4,94	6,03	1,29	4,93	6,03	1,29	4,94	6,03	1,29	4,94	6,03
trailer/reach stacker average productivity	10,50	14,67	16,33	10,50	14,67	16,33	10,50	14,67	16,33	10,50	14,67	16,33
RMG stacker average productivity	10,52	14,69	16,35	10,52	14,69	16,35	10,52	14,69	16,35	10,52	14,69	16,35

KPIs	SCENARIOS' RESULTS											
	10			11			12			13		
	10a	10b	10c	11a	11b	11c	12a	12b	12c	13a	13b	13c
# of performed trains	7	9	10	7	10	10	7	10	10	7	11	13
# of performed trains/number of available slots (%)	100,00	81,82	62,50	100,00	90,91	62,50	100,00	90,90909	62,50	100,00	100	81,25
average # of containers in the main yard	1.142,18	1.122,33	1.139,48	1.142,56	1.101,41	1.145,58	1.142,18	1100,885	1139,482	1.135,11	1048,64	999,64
average # of containers in the secondary yard	164,66	118,54	107,53	189,11	121,55	118,83	165,48	104,1167	107,4948	176,14	133,28	134,65
RTG average productivity	1,29	4,94	6,03	1,28	6,60	6,03	1,29	5,799792	6,03125	2,11	7,47	10,23
trailer/reach stacker average productivity	10,50	14,67	16,33	10,50	16,33	16,33	10,50	15,5	16,33333	11,33	17,17	20,50
RMG stacker average productivity	10,52	14,69	16,35	10,52	16,35	16,35	10,52	15,52083	16,35417	11,35	17,19	20,52

KPIs	SCENARIOS' RESULTS											
	14			15			16			17		
	14a	14b	14c	15a	15b	15c	16a	16b	16c	17a	17b	17c
# of performed trains	7	11	14	100,00	90,91	62,50	100,00	100,00	93,75	100,00	100,00	100,00
# of performed trains/number of available slots (%)	100,00	100	87,5	7	10	10	7	11	15	7	11	16
average # of containers in the main yard	1.137,86	1056,45	959,50	1.142,56	1101,41	1101,41	1.173,14	1059,10	864,81	1.140,22	1077,58	922,11
average # of containers in the secondary yard	174,17	129,82	126,43	189,87	115,32	114,26	202,59	125,65	199,38	191,72	108,68	104,20
RTG average productivity	2,11	8,27	12,69	1,28	6,60	6,60	1,60	8,26	14,35	2,11	8,27	15,21
trailer/reach stacker average productivity	11,33	18,00	23,00	10,50	16,33	16,33	11,33	18,00	24,67	11,33	18,00	25,50
RMG stacker average productivity	11,35	18,02	23,02	10,52	16,35	16,35	11,35	18,02	24,69	11,35	18,02	25,52

It is worth underlined that the exchange in the number of tracks between the internal and external rail park (scenario 10) does not bring any improvement to the system performance.

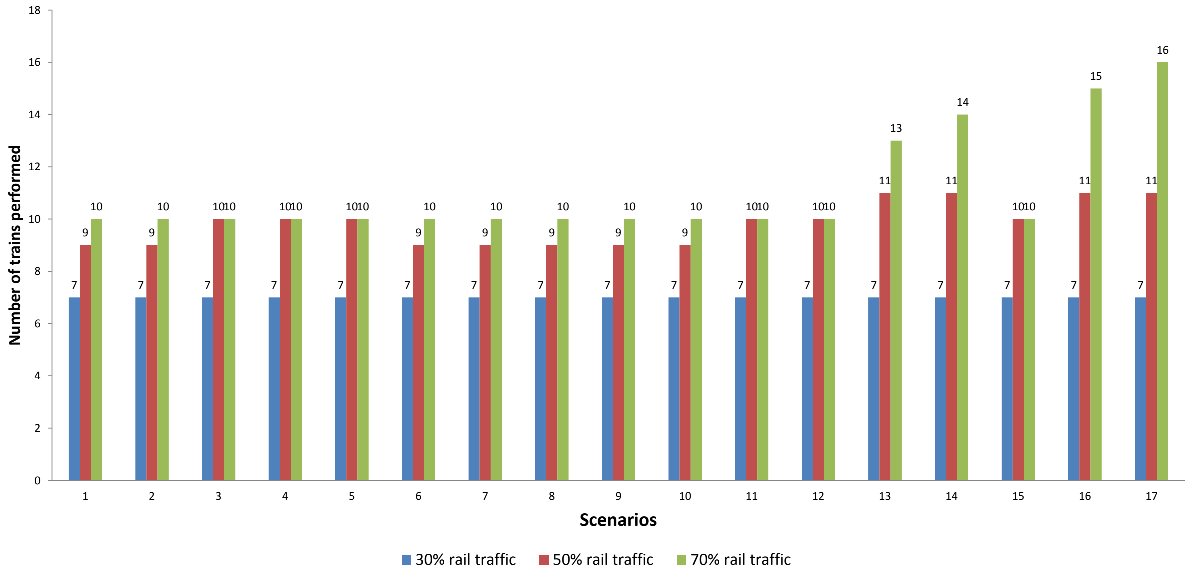

Fig.3 – Number of performed trains in two days

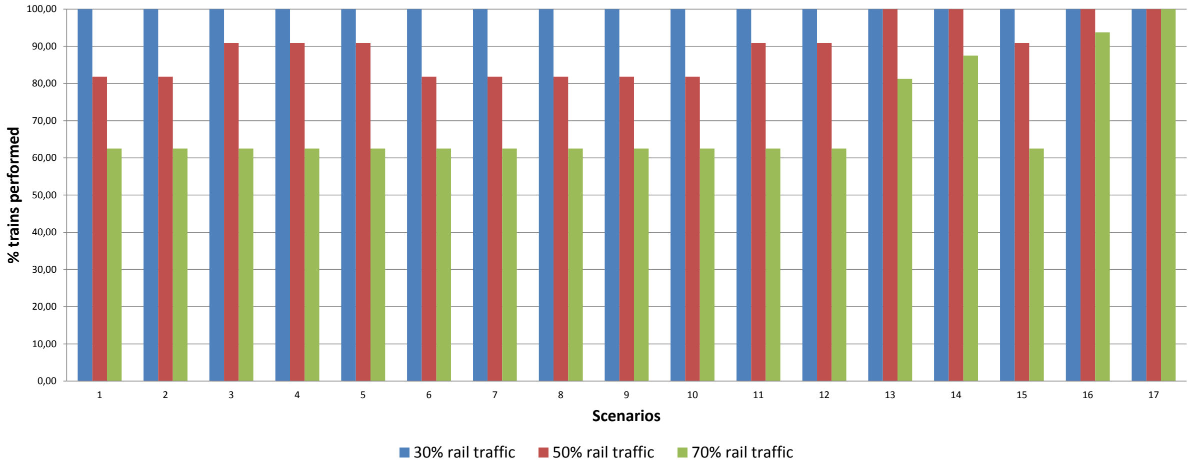

Fig. 4 – Percentage of performed trains over the number of available rail slots

Moreover it must be highlighted that a better spreading of rail slots over the day allows not to modify the infrastructure equipment, so saving costs for the terminal container operator. In fact, the system performances obtained in scenario 11 (slots uniformly distributed) are as good as the ones provided by scenarios 3, 4 and 5 in which the number of handling means is increased (or, alternatively, their productivity is raised up).

Finally, it can be said that a bottleneck of such a terminal layout is represented by the queue buffer q_R of containers along the internal rail park. This is confirmed by the fact that in case q_R is not increased, the RMG works at 20 movements/hour (Figure 5), while in case of q_R capacity is set to 10, the rail crane performs at its maximum productivity, which is 30 movements/hour (Figure 6).

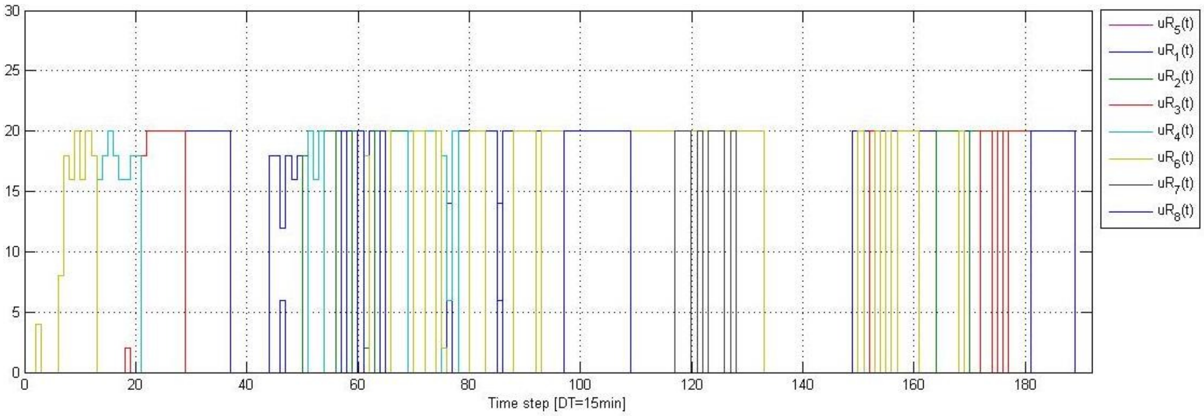

Fig. 5 – RMG productivity in case of q_R equal to 5 units

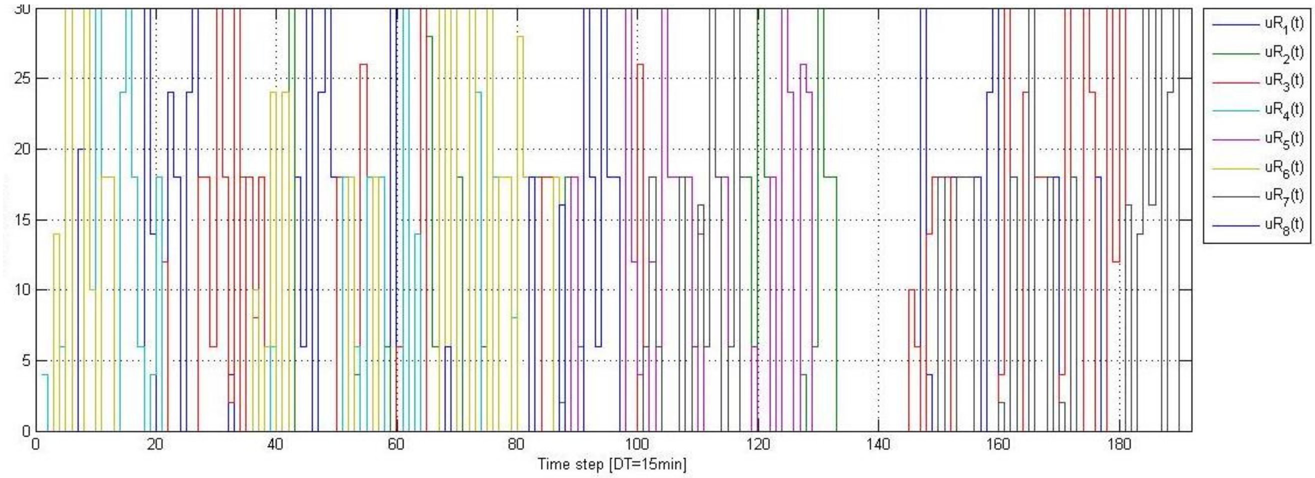

Fig. 6 – RMG productivity in case of q_R equal to10 units

CONCLUSION

The goal of the present work is to model and analyze, under different scenario configurations, the performance of the rail import cycle in a seaport container terminal.

The main results show that, by properly optimizing the distribution of rail slots and the number of resources utilized in the whole cycle, it is possible to maximize the number of trains leaving/arriving in the terminal. More specifically, in the case here examined, the rail slots distribution and the "reach stacker-trailer" system represent the terminal bottleneck. In fact, on one side, the concentration of slots in particular portions of the day does not allow the terminal to have the necessary time for loading trains in time for their departure and, on the other side, the low productivity of the "reach stacker-trailer" system limits the ones of the RTG and RMG cranes which all work in series. A uniform distribution of rail slots along the day and doubling of the "reach stacker-trailer" resource allow to raise terminal performance in terms of trains executed.

Moreover, it appears evident that the layout of the terminal, in terms of storage areas and handling equipment utilized, definitely influences the rail performance of the terminal.

The work presents some important application consequences since it aims at increasing the rail traffic, at reducing the congestion in ports (i.e. increasing the throughput) and at minimizing the costs for the terminals by optimizing the use of their resources. Moreover, this research may provide some suggestions to terminal operators about the number and the productivity of their equipment systems in order to satisfy their current and future rail traffic demand from/to their container terminal.

Further research will be devoted to integrate and synchronize the import rail cycle with the export rail one and to test other container terminals with different layouts and operative procedures so to be able to perform a comparative analysis.

REFERENCES

Alessandri, A., Sacone, S. and Siri, S. (2007). Modelling and optimal receding-horizon control of maritime container terminals. Journal of Mathematical Modelling and Algorithms, 6, 109-133.

Ambrosino, D., Bramardi, A., Pucciano, M., Sacone, S. and S. Siri (2011). Modeling and solving the train load planning problem in seaport container terminals. Proceedings of the 7th annual IEEE Conference on Automation Science and Engineering.

Bostel N. and Dejax P. (1998). Models and algorithms for container allocation problems on trains in a rapid transshipment shunting yard. Transportation Science, 32, 370-379.

Caballini, C., Pasquale, C., Sacone, S. and Siri, S. (2012). A discrete-time model for optimizing the rail port cycle. Proceedings of CTS 2012, 13-TH IFAC Symposium On Control In Transportation Systems, September 12-14.

Crainic, T.G. (2009). Service Design models for Rail Intermodal Transportation. L.Bertazzi et al. (Eds.), Innovations in Distribution Logistics, Lecture Notes in Economics and Mathematical Systems 619, Springer Verlag.

Ferreira, L. (1997). Planning Australian Freight Rail Operations: An Overview. Transportation Research. Part A: Policy and practice, 31, 335-348, (1997).

Stahlbock, R. and Voss, S. (2008). Operations research at container terminals: a literature update. OR Spectrum, 30, 1-52.

Steenken, D., Voss S. and Stahlbock, R. (2004). Container terminal operation and operations research - a classification and literature review. OR Spectrum, 26, 3-49.