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PRODUCTIVITY SIMULATION MODEL FOR OPTIMIZATION OF MARITIME CONTAINER TERMINALS

Summary. This article describes a proposed productivity simulation model enabling container terminal operators to find optimization possibilities. A research of more than forty terminals has been done, in order to provide a helping tool for maritime container terminals. By applying an adequate simulation model, it is possible to measure and increase the productivity in all subsystem of the maritime container terminal. Management of a maritime container terminal includes a vast number of different financial and operational decisions. Financial decisions are often in a direct connection with investments in infrastructure and handling equipment. Such investments are very expensive. Therefore, they must give back the invested money as soon as possible. On the other hand, some terminals are limited by the physical extension and are forced to increase annual throughput only with sophisticated equipment on the berth side and on the yard as well. Considering all these important facts in container and shipping industry, the proposed simulation model gives a helping tool for checking the productivity and its time variation and monitoring competitiveness of a certain maritime terminal with terminals from the same group.

MODEL SYMULACJI PRODUKTYWNOŚCI DO OPTYMALIZACJI MORSKICH PRZEWOZÓW KONTENEROWYCH

Streszczenie. W artykule przedstawiono propozycję modelu symulacyjnego umożliwiającego operatorom terminali kontenerowych optymalizuję swoich działań. Badania modelowe obejmowały ponad 40 terminali morskich w celu wyznaczenia odpowiednich narzędzi wspomagających zarządzanie nimi. Wykorzystanie odpowiedniego modelu symulacyjnego pozwala mierzyć i zwiększać produktywność we wszystkich podsystemach morskiego terminalu kontenerowego. Zarządzanie takim terminalem opiera się o szereg różnych wskaźników finansowych i decyzji. Decyzje finansowe są często ściśle powiązane z inwestycjami w infrastrukturę i sprzęt transportowy. Niektóre inwestycje są bardzo kosztowne, w związku z tym muszą się zwrócić możliwie najszybciej. Z drugiej strony istnieją ograniczone możliwości rozwoju obszarowego i terminale są zmuszone do zwiększenia rocznego wykorzystania kei i innych stanowisk. Rozważając wszystkie te istotne fakty dotyczące transportu morskiego i intermodalnego z wykorzystaniem kontenerów, proponowane eksperymenty symulacyjne pomagają w monitorowaniu produktywności, jej zmienności w czasie i konkurencyjności określonego terminala kontenerowego wśród terminali z tej samej grupy.

1. INTRODUCTION

Containerisation realized an extreme growth during the last twenty years. In addition, containers are very complex to manage as clients expect timely door-to-door delivery. Consequently, all major container terminals experienced huge pressure in order to satisfy increased expectations from shipping sector as well as from local economy. Container terminal management is therefore constrained to model an adequate strategy for the increasing container traffic and to facilitate decisions of different time limited actions.

A container terminal provides the interface between different transport means, therefore handling equipment is very important. The number of handling equipment on the sea and landside, and their exploitation productivity is very important element for carriers and global enterprises to choose the sea intermodal point. At the same time, it has an important impact on competitiveness between neighbouring ports or terminals in the region. For this reason, the container terminal management must constantly measure productivity on all subsystems, on berth, yard and in acceptance-delivery zone. The management must establish appropriate strategies for checking the productivity and its rise. Consequently, the typical hierarchical structure of operational decisions described by Zhang can be modified and adapted, in order to achieve a higher performance of the system.

Different simulation models have already been developed to support operational supervisors in every day measurement. IT developed tools are already massively used in different container terminals all over the globe. Such program facilitates productivity measurement and analysis, but cannot give a picture in comparison with other ports or terminals, which are potential or direct competitors.

With a proposed simulation model and research, we would like to give an overview on the situation of production and capacity optimization on maritime container terminals. It is important to know with which container terminal a certain maritime container terminal can be compared and what operational data should be used for a dynamic comparison.

2. SETTING UP A PRODUCTIVITY SIMULATION MODEL

A productivity simulation model must consist of real data and detailed research of infrastructure and handling equipment. Basic data were collected for forty different container terminals from different regions. With such an approach, a wider and general simulation model can be developed enabling the use of it on every container terminal.

Basic working parameters used for productivity measurement of a terminal always contain the already standardised indicators, as annual throughput, berth loading and unloading manipulations per crane or per hour, yard loading and unloading operations, berth and yard occupancy, number of vehicles at the entrance in the terminal by truck or by rail. These are dynamic variables and they change continuously. Thus, it is of high importance to check and adjust them frequently. The main goals of simulation model are:

- Evaluation of productivity on berth with direct connection to total annual throughput,
- Evaluation of container terminal equipment availability and exploitation,
- Evaluation of yard productivity in connection to annual throughput,
- Evaluation of productivity per different groups of terminals and a possibility to have a general overview of applicable results.

2.1. Four groups of maritime container terminals

A simulation model was developed using four main groups of maritime container terminals. Container terminals were classified in one of the groups according to their annual throughput, measured with manipulations on the seaside, which result in number of manipulation for loading and unloading of containers from and on container vessels.

The first group contains container terminals with annual throughput up to 500,000 TEU (twenty equivalent units - equal to one 20' container) and represents smaller maritime container terminals, with regional transport function. In the second group are container terminals with annual throughput between 500,000 and one million TEU. These are medium size maritime container terminals with an important regional traffic role. In the third group are counted container terminals with annual throughput between one and three million TEU, while the fourth group contains container terminals with annual throughput over three million TEU. Maritime container terminals from the third group are big and important terminals, acting on the market as important regional and global shifting points. The biggest maritime container terminals are grouped in the fourth group. Their annual throughput of over three million TEU clearly shows that they play an important hub role on the main trans-national routes around the globe.

Proposed model deals with only four groups, but the model can analyse container terminals even more in details. Consequently, described model can be upgraded with a higher number of groups, with smaller gap in annual throughput between them.

2.2. Defining productivity perimeters

Different productivity indicators can be used for simulation. They indicate the productivity in each subsystem and how adopted infrastructure and handling equipment is exploited. Developed and described simulation model uses four main productivity perimeters in order to cover the main infrastructural exploitation. Thus berth and yard production were processed with production perimeters as below:

- Number of TEU per berth length,
- Number of TEU per berth container crane,
- Number of TEU per hour of each berth container crane,
- Number of TEU per 1,000 square meter of container yard

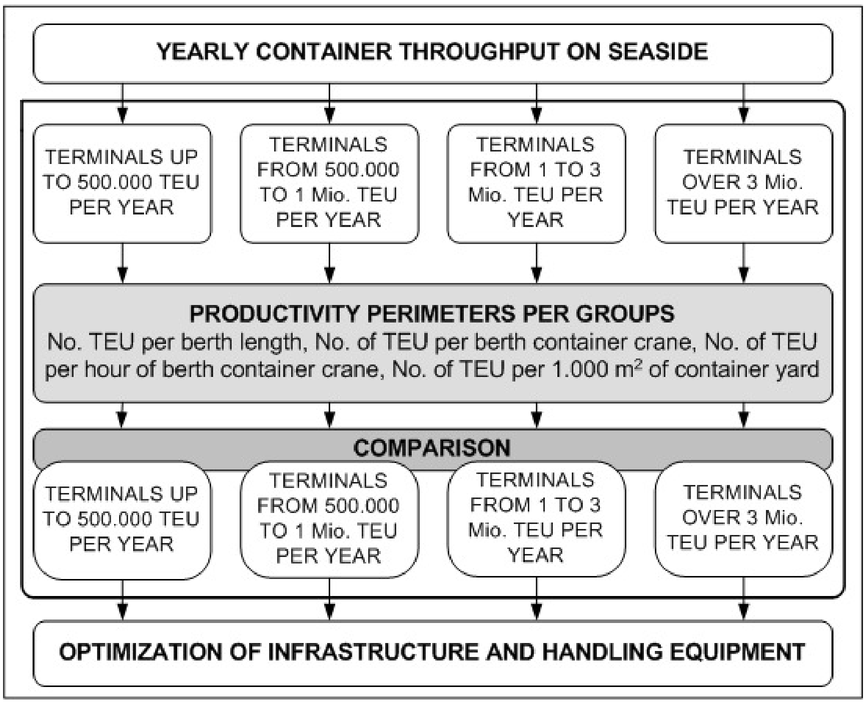

Fig. 1. Productivity simulation model for maritime container terminals
Rys. 1. Model symulacji produktywności morskich terminali kontenerowych

A simulation model therefore consists of four groups which are analysed with four productivity perimeters. Comparison of production data between the four groups can give a general overview of productivity which can be achieved by a certain terminal. Moreover, simulation model can show optimization possibilities and ways to compare different maritime container terminals.

3. SIMULATION ANALAYSIS

3.1. Group of terminals up to 500.000 TEU

First group of terminals consists of ten maritime container terminals with annual throughput up to half a million TEU. In the model, infrastructure data and actual handling equipment on berth and yard subsystems are used with an average of 5 cranes per each port, 1,115 meters of berth length and 23 ha of yard space. With calculations of production efficiency, using defined production perimeters, we came to the results showed in the Tab. 1.

Table 1

Production perimeters for group of terminals with yearly throughput up to 500.000 TEU

Terminal	Yearly throughput	TEU per berth crane	TEU per berth length	TEU per h/crane	TEU per 1.000 m2
Ravenna	207.000	51.750	323	7	1.380
Buenos Aires	395.000	79.000	446	11	1.975
Varna	155.300	51.767	187	7	1.242
Thessalonica	238.950	59.738	434	8	1.707
Salerno	330.370	66.074	295	9	2.065
Trieste	335.900	47.986	168	7	884
Cagliari	256.500	32.063	169	4	916
Helsinki	428.000	61.143	219	8	1.070
Hamina	178.800	59.600	275	8	941
Aden	496.400	82.733	496	11	1.839
Average	***302.222***	***59.185***	***301***	***8***	***1.402***

The average annual throughput of all ten ports is 302,222 TEU, with the average 59,185 TEU of movements per berth crane. The average performance of a single crane is 8 TEU per hour, and the highest performance was reached by Buenos Aires with 11 moves per hour. On the other hand, Cagliari performed only 4 movements per hour. The performance per berth length varies from 168 TEU to 496 TEU per 1 metre of berth length, with group average of 301 TEU per berth length. Average yard utilization is 1,402 TEU per 1,000 m^2.

3.2. Group of terminals from 500.000 up to 1 million TEU

In the second group of terminals, we analysed 10 terminals with annual throughput between half a million and 1 million TEU. This group has on the average 7 berth cranes per terminal and 1,187 meters of berth. The average berth length is just 72 metres longer in comparison with data from the first group. Exactly the same perimeter of yard space was calculated as the average yard area of the second group is at the same level of 23 ha.

Table 2
Production perimeters for group of terminals from 500.000 to 1 million TEU

Terminal	Yearly throughput	TEU per berth crane	TEU per berth length	TEU per h/crane	TEU per 1.000 m^2
Livorno	589.000	73.625	378	10	2.677
Aqaba	587.500	117.500	1.088	16	1.865
Lisabon	555.000	79.286	411	11	3.083
Gdynia	610.700	76.338	449	11	3.592
Kotka	650.000	92.857	455	13	2.955
Cape Town	767.501	95.938	492	13	3.838
Ilychevsk	539.928	107.986	1.080	15	3.176
Valparaiso	927.000	154.500	941	21	4.635
Miami	828.350	92.039	460	13	3.068
Xiamen HPH	968.000	107.556	1.241	15	2.933
Average	***702.298***	***99.762***	***699***	***14***	***3.182***

The performance results of second group are collected in Tab. 2 where the same productivity perimeters were calculated. The average annual throughput of all ten ports stands at 702,298 TEU. An average data for all performance perimeters is significantly higher in comparison with the data from the first group. An average performance on annual basis per a single berth crane is 99,762 TEU, where the highest annual throughput of 154,500 TEU per berth crane was achieved by Valparaiso port. Consequently, the highest performance per crane hour belongs to Valparaiso port, with 21 movements per hour. Meanwhile, the average performance of a single crane in the group is 14 TEU per hour. The highest performance of containers per berth length was reached by Xiamen port (1,241 TEU). The average performance of the group stands at 699 TEU per 1 meter of berth length. Average yard utilization is nearly three times higher in comparison with data from the first group, as all terminals from the second group reached 3,182 TEU per 1,000 m^2 on average.

3.3. Group of terminals from 1 to 3 million TEU

According to the established simulation model, the third group contains 10 terminals with annual throughput between 1 and 3 million TEU. Such terminals are huge intermodal systems with sophisticated handling equipment. Logically these terminals should achieve higher performance, but the main question is whether the degree of utilization is at the same level when comparing the first and the second group or not. The 10 terminals analysed have an average annual throughput of 1.95 TEU achieved with 18 berth cranes. These systems have longer berth, as it measures 2,445 metres on average, and wider container yards (54 ha).

The Tab. 3 shows that relative level of container handling and storage productivity is on a higher level, but the difference is not as evident as between the first and the second group. Terminals are performing higher number of TEU per crane on the annual basis and per hour. The modern terminal at Khor Fakkan is ahead of the group. On the opposite side is Tacoma port, because port’s performance is even lower in comparison with average values of the second group. Average results are approximately 20% higher that results from the second group, therefore even the group's annual average is two times higher the general performance is not increasing with the same degree.

3.4. Group of terminals over 3 million TEU

In the last group, mega container terminals with annual throughput of over 3 million TEU at seaside are classified. The so-called mega terminals are in function of pure hub terminals, serving container industry with special role to connect different mega mother vessels with smaller ones acting in feeding services. Consequently, these terminals have efficient handling equipment in the yard and berth as well, in order to shorten vessel's lay-time in the port. On average, an analysed group has 27 berth cranes placed on 3,233 meters of berth. Yard subsystems are using on average more than 80 ha.

Table 3

Production perimeters for group of terminals from 1 to 3 million TEU

Terminal	Yearly throughput	TEU per berth crane	TEU per berth length	TEU per h/crane	TEU per 1.000 m^2
La Spezia	1.246.100	113.282	889	16	5.418
Jakarta HPH	2.701.000	128.619	982	18	3.751
Tacoma port	1.861.300	77.554	760	11	2.091
Barcelona	2.569.500	151.147	857	21	3.671
Marsaxlokk	2.300.000	115.000	1.150	16	3.770
Haifa	1.395.000	139.500	1.026	19	2.790
Khor Fakkan	2.112.400	150.886	1.457	21	5.281
Keelung	2.055.200	70.869	555	10	4.780
Kwangyang	1.810.000	113.125	385	16	3.620
Manzanilo	1.409.782	108.445	860	15	3.524
Average	**1.946.028**	**116.843**	**892**	**16**	**3.870**

Table 4

Production perimeters for group of terminals from over 3 million TEU

Terminal	Yearly throughput	TEU per berth crane	TEU per berth length	TEU per h/crane	TEU per 1.000 m^2
Gioia Tauro	3.467.700	138.708	1.020	19	3.853
Valencia	3.602.112	156.614	1.029	22	5.003
Port Klang N.	3.005.920	111.330	1.002	15	2.505
Tanjung Pelepas	5.594.341	155.398	1.554	22	7.459
Tokyo	4.270.800	137.768	953	19	4.745
Colombo	3.687.465	141.826	1.163	20	6.250
Salalah	3.068.000	180.471	1.364	25	4.037
Algeciras	3.324.310	151.105	1.119	21	5.541
Felixstowe	3.200.000	110.345	907	15	4.000
Mod. Ter. HKG	5.720.000	190.667	2.352	26	7.150
Average	**3.894.065**	**147.423**	**1.246**	**20**	**5.054**

Production perimeters for the last ten terminals are unequivocally on a very high level. The performance on the seaside is very close to 150,000 TEU per berth crane. Furthermore, the performance per crane hour is over 20 movements. The yard utilization is on average over 5,000 TEU per 1,000 m^2. Such production can be achieved only with sophisticated infrastructure and suprastructure. Consequently, all processes must be correctly organized and aligned in a unique well-known production strategy.

4. SIMULATION ANALYSIS

Analysed data inside each group serve to obtain a comparison among four groups of maritime container terminals. Obtained data are collected in Tab. 5 and clearly demonstrate the fact that smaller maritime container terminals achieve lower production on berth and yard subsystems. This is directly related to the sophisticated handling equipment used by bigger terminals, enabling them to perform higher density of container storage on the yard and higher production per berth container crane.

Terminals from the first group utilize shorter berth length and berth cranes with theoretical handling capability of up to 18 manipulations per hour. Such infrastructure and suprastructure can accommodate smaller and middle-sized container vessels. These terminals also need a wider storage platform, as they mainly use manipulators and forklifts for container handlings, and they are, in most cases, in function of regional entering and outgoing points.

Table 5

Average production perimeters per group of terminals

	Yearly Throughput	TEU per berth crane	TEU per berth length	TEU per h/crane	TEU per 1.000 m^2
I. Group	302.222	59.185	301	8	1.402
II. Group	702.298	99.762	699	14	3.182
III. Group	1.946.028	116.843	892	16	3.870
IV. Group	3.894.065	147.423	1.246	20	5.054

Terminals from the second and the third group use more sophisticated technology; therefore, their cranes can handle up to 25 TEU per hour. At the same time, handling equipment can handle containers until the sixth row in height and does not need additional transport paths. The fourth group with mega terminals achieves very high medium system's productivity. Number of TEU per berth crane is almost tripled in comparison with terminals up to half a million TEU (Fig. 2). Number of TEU per berth length is even four times higher in comparison with medium perimeter from the first group and doubled in comparison with the second group.

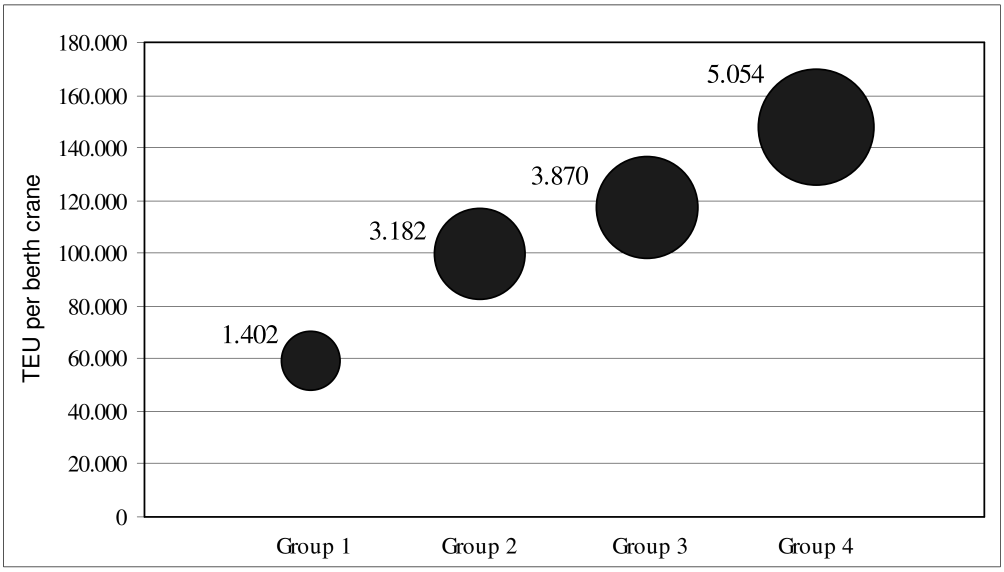

Fig. 2. Group comparison of productivity perimeters per berth cranes and on the yard
Rys. 2. Porównanie grupowe produkcyjności strefy wokół żurawi portowych i powierzchni magazynowej

The differences between groups are enormous. Thus, it is clear that terminals use completely different infrastructure and suprastructure. Consequently, it is impossible and meaningless to compare different maritime container terminals between them without an appropriate previous ranking. In addition, maritime container terminals can compete only in a certain group; even they are placed in a different region on the other side of the globe. This thesis has been analysed and tested by using described simulation model.

4.1. The case of Adriatic ports

Ports and terminals in the Adriatic Sea very often declare that they want to compete directly with Northern European ports. They would like to offer their strategic position as an alternative transport or logistics choice compared with North-European transport route, covering the area of central and South East Europe. Their marketing and commercial strategy is focused on the shortest inland connections up to final economy basins. New road infrastructure with highway connections on V. and X. Paneuropean corridors attracts new cargo flows on the South-European transport route, using the northern Adriatic ports as the EU entrance points. New market situations with decreasing inland transport costs all over Europe are helping them in this continuous battle.

The port performance is not exposed even though this element is of crucial importance for container carriers in decision when and how they will call different ports in the specific region. This can be done easily and transparently by using such a simulation model. Obtained data can be used as promotion element, or in case the productivity is deviating drastically, as an element to re-define goals of system's performance.

Table 6

Production perimeters comparison for Port of Koper and Port of Rijeka

	Yearly Throughput	TEU per berth crane	TEU per berth length	TEU per h/crane	TEU per 1.000 m2
Port of Koper	353.880	88470	594	12	1.966
Port of Rijeka	168.777	42.194	328	6	1.383

With the developed simulation model, we analysed container terminals at Koper and Rijeka. Their performance on the berth and yard subsystems was analysed using the same production criteria as in the simulation model described. The obtained data are presented in Tab. 6 and they clearly show that Port of Koper is achieving higher performance on both subsystems, even though both terminals have almost the same infrastructure and suprastructure. The port of Koper has 4 berth cranes, 596 meters of berth and 18 ha of yard space, while the port of Rijeka has 4 berth cranes, 514 meters of berth and 12 ha of yard space.

4.2. Conclusions for Koper and Rijeka terminals

The port of Koper has a higher productivity results in comparison with the results from the first group. At the same time, the results are lower when compared with those from the second group. Consequently, we conducted that the port of Koper must invest in both subsystems in order to obtain throughput grow. Additional berth cranes are necessary, as well as the investment in berth prolongation. The performance on the yard is also very high; therefore, the subsystem is working on its upper limit. Investments in yard extension are also necessary to obtain a throughput of over half a million containers per year.

Port of Rijeka is working with evidently lower intensity. The main emphasis must be done to the yard subsystem. The yard performance is very close to medium performance result of the first group. Meanwhile the berth subsystem is working exceedingly below the group's medium result. Consequently, the port of Rijeka must extend yard area and thus will loosen the berth subsystem, allowing it to obtain a higher performance. Moreover, investments on the berth side are not necessary, even if the terminal has a plan to reach a throughput of 250,000 TEU in the next years. Of course, such decisions are in direct relation if carriers have an intention to call the port of Rijeka with their mother vessels, as in case of the port of Koper, which serve also vessels with capacity over 6,500 TEU.

5. CONCLUSIONS

Many different simulation programs are used in different port systems around the world. Programs are constantly measuring production in subsystems of port and per single handling or transport unit. In most cases, these are IT tools which do not give a general and clear picture to terminal management. Terminal and port managers in medium and small systems are searching for simple statistics comparison in order to position themselves properly. This is very important even in direct comparison with neighbouring systems, as they are very often acting on the market as direct competition.

For this reason, we developed productivity simulation model, which calculates and measures performance per subsystems, using data, which are very often clearly and easily accessible. Consequently, model data is easy to build and use for comparison. A research of more than forty terminals has been done in order to provide a helping tool for maritime container terminals. The model can be extended with analyses of greater number of terminals and with greater number of production perimeters, measuring also handling on the yard, throughput on the gates, handling on the rail side, etc. With the correct application, it is possible to measure and increase the productivity on all subsystem of the maritime container terminal.

With the described model, we conducted that terminals cannot be directly compared. Firstly, they must be sorted by throughput or by other perimeters, as number of berth cranes or by berth length, etc. The comparison can be done only when they are sorted and grouped. Therefore, Adriatic ports and terminals cannot directly compete with Northern European ports, as those ports are big subsystems, mostly ranged in the third or fourth group of our model. Adriatic ports must be compared with terminals from the same range, but it is recommended to extend the simulation and comparison model to a wider global area.

Analyses of the two Adriatic ports and their container terminals gave us a picture that the port of Koper is working on very high productivity levels and very close to system's upper level. On the opposite side is the port of Rijeka, especially its berth subsystem. Yard subsystem is a critical element of the system and must be subject to additional investments and development. All these analyses were based on the increasing trend of containerisation in the world and in the region. Even the latest intermediate results for 2009 shows a decrease in the container throughput. In spite of this negative trend, containerisation will grow in the next period, therefore the port of Rijeka and the port of Koper must constantly check and compare their productivity, and where and how to expand infrastructure and suprastructure of the system.

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