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Capacity utilization of the container terminal as multiphase service system

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Abstract

A container terminal can be defined as a mass service system in which a multiphase service processes takes place. The terminal consists of three subsystems: quayside, yard and gate. In this paper, queuing theory as one of the operational research method is been used, to determine indicators of functioning the service system on the example of the container terminal of the port of Rijeka. Applying the queueing theory, the service phases that represent a bottleneck can be determined, as well as the phases in which the largest capacity surpluses are located. Finally, based on the current capacities the optimal turnover of the terminal was provided, without congestions and with the highest degree of terminal utilization. The basic conclusion is that the capacity of the system is limited by the capacity of the subsystem that has the smallest capacity, and in this case it is gate/truck and train operation area.

Keywords: container terminal, operating processes, queuing theory, bottleneck, optimal turnover

1. Introduction

In general terms, a container terminal can be described as an open system of material flow with two external interfaces: the quayside with loading and unloading of ships and the landside where containers are loaded and unloaded on/off trucks and trains. The quayside and landside operations are decoupled by stacks for storing containers. After arrival at the port, a container vessel is assigned to a berth equipped with cranes to load and unload containers. Unloaded import containers are transported to yard positions near to the place where they are expected to be transshipped next. Export containers arrive by trucks on road or by railway at the terminal. They are handled within dedicated operation areas. They are picked up by the internal equipment and distributed to the respective stocks in the yard (Stahlbock, R., Voss, S., 2008).

The basic subsystems of each terminal are the quayside, the yard and the gate. When designing a terminal and determining its capacity, it is important to apply a systematic approach and consider all subsystems to ensure smooth and continuous operational processes at the terminal. Given the amount of terminal transshipment, there are situations where one subsystem is a bottleneck while the other subsystem has excess capacity.

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Therefore, efforts should be made to design the capacities of all subsystems in such a way that they are optimally usable given the expected amount of cargo at the terminal.

The aim of the research is to carry out the case study on the real example of the container terminal at the port of Rijeka. The conclusions will strive to answer the following questions: which service phase(s) represents a bottleneck, where the largest capacity surpluses are and what is the optimal amount of cargo that the terminal can handle in order to avoid congestions with the highest usability of terminal capacities.

So far, in the scientific and professional literature several papers have been published from the field of queuing theory application on the examples of container terminals. A cost model is presented, which determines the combination of the number of berth and cranes on the berth with the least costs for the given traffic of the Rijeka container terminal in Zenzerović, Z. et al. (2011). Zenzerović, Z. et al. (2012) state that the issue of dimensioning the optimal capacity of container terminals can be solved by applying appropriate quantitative methods. The aim of this paper is to present the methodological approach, that is, the methods that determine features and indicators of a port container terminal operation which are fundamental for making appropriate business decisions for the observed terminal. For that purpose, the statistical methods (descriptive statistics, correlation method, hypothesis testing, nonparametric tests) and operations research methods (queuing theory) were used.

The aim of the research by Qianwen L. (2010) was to evaluate the efficiency of container ports and terminals and to study how to improve the scale efficiency of any particular port/terminal. In particular they studied how certain factors influenced the efficiency of container ports and terminals.

Zeng, M. et al. (2014) investigated the queue length and the average waiting time of the railway container terminal gate system, as well as the optimal number of service channels during the different time period. Experimental results indicated that the model could provide the accurate reflection to the operation situation of the railway container terminal gate system, and the approach could yield the optimal number of service channels.

The container terminals of the ports of Rijeka, Ploče and Koper, with special emphasis on the analysis and assessment of the current state of transshipment capacities of these terminals is analyzed in Kolanović, I., et al. (2015). A comparative analysis of the current state of transshipment capacities and the development trends of these terminals are presented

Finally, authors of this paper also seek to point out the importance of the queuing theory in making optimal decisions. The aim of this paper is to explore the capacity utilization of each terminal subsystem. If the terminal is defined as a queuing system, the subject of research is the calculation of capacity utilization of each phase of the queue. The task is to see how useful the terminal is in each phase of container handling given the current amount of annual traffic, and note which of the phases has the lowest usability and whether investment projects for future capacity expansion are necessary and justified (elaborated in the last part of the paper). Furthermore, given the (un)usability of the existing capacities of the terminal, next tasks is to determine the amount of traffic the terminal could handle with the optimal percentage of capacity utilization of each phase of the service at about 95%. The application of the queuing theory on the example of the container terminal operations is extremely useful. Based on the obtained results, that provide insight into the current state of capacity and the existence of excess and bottlenecks, better economic effects can be achieved. In this paper the research of the container terminal is conducted from the aspect of the multiphase process of container service, with the final objective of determining the bottlenecks in the particular phase.

Furthermore, this paper projects the amount of traffic that could be optimal for the technological processes going without delay by a high percentage of capacity utilization at each stage of service.

2. Basic features of the Rijeka container terminal

Adriatic Gate j.s.c. was founded in 2001 as a subsidiary company of Luka Rijeka dd. International Container Terminal Services Inc. (ICTSI) entered the ownership structure in 2011 as a strategic partner with a concession for 30 years, i.e. until the year 2041. Thereafter the brand name Adriatic Gate Container Terminal (AGCT) is in usage. Currently Luka Rijeka dd holds 49% of the shares of the Adriatic Gate while ICTSI holds 51% of the shares. ICTSI's largest investment is aimed at implementing modern technologies into the IT system that enable automatic tracking of the discharge, storage and shipping of containers. In addition to investing in the IT system, in recent years the container terminal of the port of Rijeka has undergone a period of significant investments in transshipment capacities. A significant part of the outdated transshipment equipment that did not meet the conditions of modern transshipment has been replaced by a new transshipment equipment in whose purchase the concessionaire has invested under the concluded concession contract.

The terminal has two berths, the length of the old one is 300 m and the length of the new berth is 328 m. The old berth has two Panamax cranes with reach 38m and 14 rows in width, and the new one has two Post-Panamax cranes and the possibility of operating one Panamax crane from the first berth. The reach of the post-Panamax crane is 50 m and in width 18 m (AGCT, 2020).

Behind the first berth, stacking area 1 is located with an area of 61,000 m^2, planned for the storage of empty containers and special cargoes (IMO, oversize and Break Bulk (BBK) and Out of Gauge (OOG) cargo). All operations are carried out with the reach stackers. Stacking area 2 is located behind the new berth and it is slightly smaller with an area of 50,000 m^2, and is intended for storage the full containers. All operations are carried out by the RMG (Rail-mounted gantry) cranes.

Next to the stacking area, the gate/rail and truck operation area is located where the containers are shipping mainly with trains to the final destination. Significant funds have been invested at this part of the terminal for the last three to four years, in purchasing the two rail mounted gantry cranes (RMG) and into infrastructure upgrades. Before buying the cranes for this part of the terminal (railway), reach stackers were used for manipulation with the annual capacity of maximum 73,000 TEU. RMG cranes are very important for the terminal because using two cranes, serving four railway tracks, theoretical capacity on the railway amounts 360,000 TEU per year. Currently four railway tracks are used, with the length of 250 meters each. Railway station serves the needs of the container terminal and has an additional eight tracks.

The equipment of the container terminal consists of four quay cranes (two Panamax and two Post Panamax), six rubber tired gantry cranes (RTG), two rail mounted gantry cranes (RMG), six reach stackers, nine tractors, 17 trailers and three forklifts (AGCT, 2020).

The NAVIS system has been implemented at more than 320 container terminals worldwide, helping them improve efficiency and productivity with their optimization

tools, and in 2012 the NAVIS system was implemented at the Rijeka container terminal. NAVIS SPARCS N4 is the main operating system for managing the operations of the Rijeka container terminal with which the various ICT systems for business support are fully connected, and these are (AGCT, 2020):
- Full B2B EDI. support – provides several types of EDI messages and simplifies communication in shipping lines, freight forwarders, customs and all parties involved; B2B (Business-to-Business) EDI is simply the use of Electronic Data Interchange for the purposes of exchanging documents between trading companies;
- System Applications Products, SAP – a program that connects finance, control, and management with materials, human resources and modules for sales and distribution;
AGCT billing – a highly efficient and adjustable payment method that works directly with SAP, Navis N4 and other operating systems;
- ICAM – maintenance management system;
- ZPMC Remote Crane Management System – gives real-time insight into the status, alarms and fault details for STS (ship to shore), RTG and RMG cranes;
- Intermodal Community System – an application developed as a single platform covering the entire documentation and flow of information between all partners in the intermodal logistics chain (railway operators, railway agents, freight forwarders and AGTC).

No other terminal operating system (TOS) can match NAVIS's unique capabilities to coordinate and optimize the planning and management of containers and equipment in complex business environment. NAVIS is the only terminal operating system that enables:
- increase of scalability – optimizes business using ICT infrastructure while eliminating unnecessary operational costs;
- seamless integration – with its open architecture allows easy integration to existing systems and addition of new applications;
- simplified and accelerated implementation – flexible configuration enables rapid development and reduction of implementation costs;
- costly adaptation to be avoided – creating highly adjustable solutions;
- reducing administration and costs – centralizes software and hardware infrastructure,
simplification of terminal operations – monitors the progress and development of technology.

3. Container terminal as a queuing system

Queuing theory studies the processes of servicing randomly arrived units or requests for a service using mathematical models by which the interdependence between unit arrivals, waiting time and service is found, in order to achieve optimal functioning of the observed system.

The port container terminal can be defined as a service system with the following structure: input units (container ships or TEUs), queue and service places (channels). The features of a container terminal as a mass queuing system are (Zenzerović, 2003):
- open system,
- stochastic system, in which the time of arrival and service are random variables that behave according to certain theoretical distributions
- single-channel or multi-channel depending on the number of service places, and
- single-phase or multi-phase problem depending on whether only one phase of the terminal or several phases are observed (quayside, yard, gate).

There are several basic structures of the queuing system, where the terms channels and phases should be distinguished. Channels represent parallel servers that serve units simultaneously while phases represent sequentially placed servers, where units must pass through all phases. Depending on the number of channels and phases, it can be:
- single channel/single phase,
- multichannel/single phase,
- single channel/multiphase, and
- multichannel/multiphase system.

The structure of the service processes at the container terminal consists of:
- arrival of units (ships or containers in TEU) at the terminal,
- technological processes of servicing containers in phases: on the quayside/berth with available equipment - cranes, at the yard/stacking area and at the gate/truck and train operation area,
- departure of containers.

The basic parameters of the container terminal as a mass queuing system are:

λ – arrival rate, the average number of containers/ships arriving in a unit of time or the reciprocal value of the interarrival time consecutive ship arrivals $\lambda = 1/t_{arr}$,

μ – service rate, the average number of containers/ships that can be served per unit of time at the berth or the reciprocal value of the average time of the ship serving $\mu = 1/t_{serv}$,

S – representing the number of berths (service places).

The traffic intensity (ρ) is the ratio between the arrival and service rate (λ/μ). The condition that should be fulfilled in order to achieve the stability of the service system is $\rho<1$. If the stated condition is not met, it is necessary to increase the number of service places or the capacity of service place. From the above mentioned follows that the arrival rate must always be less than the service rate.

4. The case study of the port of Rijeka container terminal

By the type of system, the container terminal of the port of Rijeka can be defined as a single channel multiphase queuing problem with an unlimited queue. It is multiphase problem because it consists of three subsystems (quayside, yard and gate), see Figure 1. The output from one phase is the input for the next phase. However it should be emphasized that this input can be the same as in the previous phase, but can also be smaller.

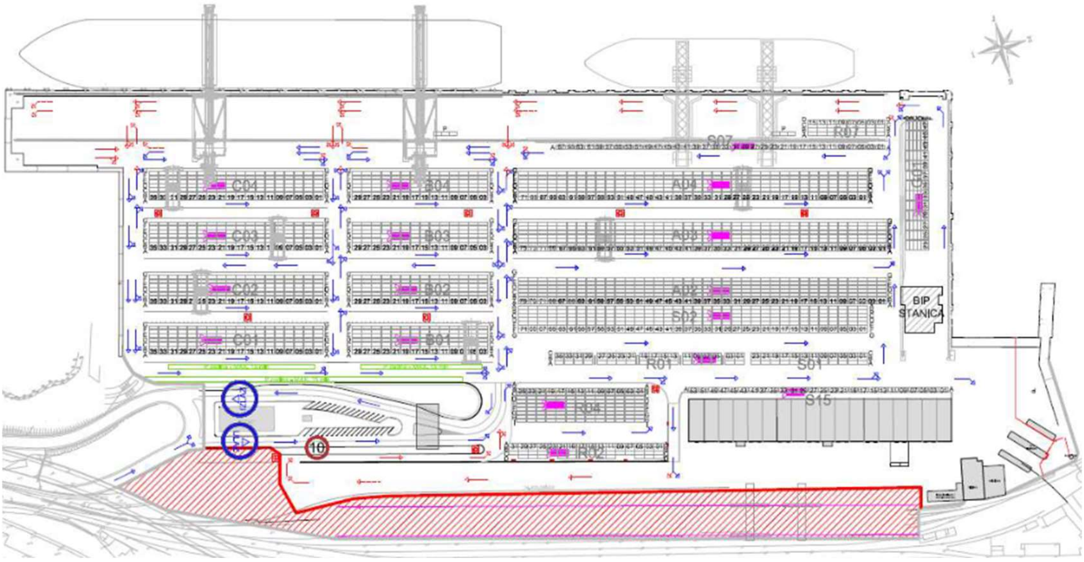

Figure 1: Operation areas of the Rijeka container terminal
Source: AGCT, 2020

The input data (basic parameters) for the calculation of indicators in the queue theory are the arrival rate and service rate in the three basic phases of container service at the terminal. The following are some remarks regarding the input parameters.

In the first phase, the arrival rate is taken as the number of ships arriving at the terminal due to real data on arrivals and departure of ships at the terminal in 2020 based on sailing lists, while in the second and third phases arrival rate is expressed in number of containers being served in the first phase so, as output units from the first phase, represents input units in the second and afterwards in the third phase of service.

In the first phase, service rate is expressed in the number of ships based on the ship's stay at the terminal, while in the second phase service rate is the number of containers that can be served at the warehouse, i.e. the number of containers that can be shipped from the terminal in the third phase, depending on the land transport possibilities of trucks and railways

The relation between ships and containers, as input units, is taken as follows: 1 ship is 984 TEU, what is obtained from the annual turnover of the terminal of 305,049 TEU that is realized with the arrival of 310 ships. The same ships always come to the terminal in weekly services from which approximately the same number of containers is unloaded, in average 984 TEU/ship so the traffic is uniform without peak loads.

4.1 The first phase of service (quayside)

At the quayside it could be theoretically accepted two ships at once, but in practice this happens rarely and here is therefore taken a single channel problem with two Post panamax cranes operating at the left berth (Figure 1). The containers are transshipped from the ship to the shore using quay cranes. After disembarkation, the containers are disposed at the yard with reach stackers and RTG cranes. From the yard, the containers are transported by rail or road to their final destinations.

Table 1: Descriptive statistics of the ship' service time and for the time of ships' arrivals (in hours) in 2020

Indicator	service time	*Indicator*	interarrival time

Number of ships	310
Smallest to largest time	1.9 - 51.5
Average service time	15.725
Standard deviation	9.193
Sample variance	84.513
Mode	16.5
Skewness	1.045
Kurtosis	0.874

Number of ships	310
Smallest to largest time	0 - 103.2
Average interarrival time	27.27
Standard deviation	18.88
Sample variance	356.393
Mode	32
Skewness	1.023
Kurtosis	1.153

Based on a sample of 310 ships arrived at the terminal in 2020 and the exact time of arrival and departure of each ship, data on the time between two consecutive arrivals and service time of each ship were obtained. According to these data for 2020 (Sailing list of AGCT, 2020), the average time between two ship arrivals was 27.27 hours, which means the ship's arrival rate (λ) was 0.88 ships/day, i.e. 310 ships/year. The turnover of the terminal in 2020 was 305,049 TEU (AGCT, 2020), so it follows that the average number of TEUs per ship was 984 TEU. From the above sample, the average service time was 15.725 hours, giving the service rate (μ) of 1.526 ships per day, i.e. 557 ships/year and approximately 548,104 TEU/year.

Variables ships' service time and ships' interarrival time can be approximated with the corresponding theoretical distribution so the hypothesis of fitting was tested. Testing was performed using three types of tests: Kolmogorov-Smirnov (K-S), Chi-Squared test and Anderson-Darling (A-D) test with the EasyFit 5.5 software. Results of goodness of fit for ships' interarrival time is Gen. Gamma distribution, according to K-S (0,04286), A-D test (6,2757) and Chi-Squared test (8,4834). For the ships' service time Gamma distribution is the best fit, with K-S test 0,06531 and A-D test 1,9662 (Figure 2).

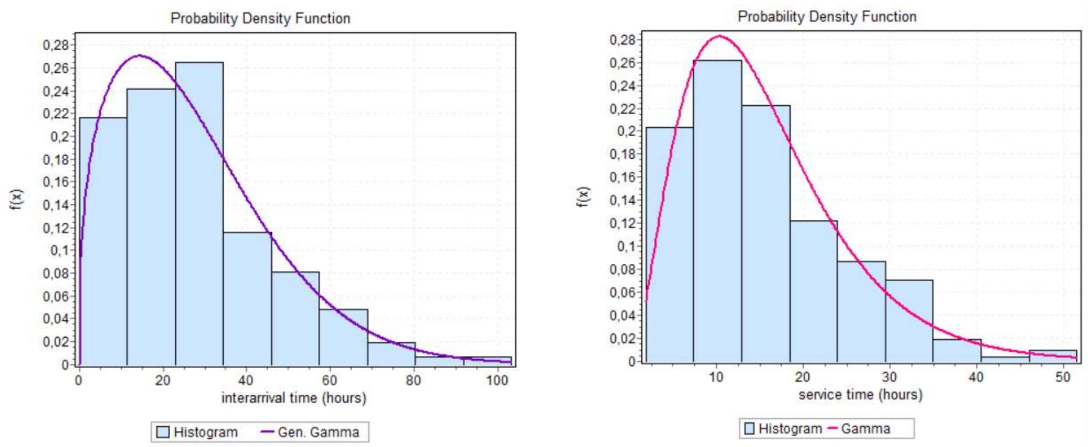

Figure 2: Goodness of fit for ship' interarrival time and service time
Source: authors using EasyFit 5.5

Based on the above data for year 2020, the traffic intensity (ρ) for the terminal, calculated as λ/μ, was 0.56 and the probability of no operations at the berth (P_0): $P_0 = 1 - \rho = 0.44$.

Therefore, the traffic intensity of the berth with the available equipment in 2020 was 56% while the probability that there are no operations on the berth was 44%.

According to obtained fitting distribution this problem is defined as M/G/1 queueing problem and following indicators are then calculated with Pollaczek-Khinchine formulae (Gosavi, 2020).

Mean number of customers in the queue is:

$L_Q = \dfrac{\lambda^2\sigma^2 + \rho^2}{2(1-\rho)} = 0.485$ ship, i.e. 477 TEU in the queue if it is taken that the average number of TEUs per ship is 984 TEU, where σ^2 is variance of service time and λ is 0.03667 ships/hour.

Mean waiting time in the queue is:

$W_Q = \dfrac{L_Q}{\lambda} = 13.23$ h - ship waiting time, which means that 1 TEU is waiting in the queue 0.8 min.

Mean waiting time and mean number of customers in the system are:

$W = W_Q + 1/\mu = 29$ h - ship' time in the system, where $1/\mu$ is 15.725 h for one ship or $1/\mu$ is 0.96 min for 1 TEU which means that 1 TEU is 1.76 min in the system, and

$L = \lambda W = 1.063$ ships, i.e. 1,046 TEU in the system (units waiting and being served).

The values obtained for above indicators are relatively small which was expected considering very low traffic intensity.

Furthermore, the question arises as to what quantity of containers could be served with the existing transshipment equipment installed at the two berths and work in three shifts with the assumption of 95% utilization.

The capacity of the crane is 30 movements per hour, and for conversion into TEU units it was necessary to multiply it by the number 1.55 which represents the ratio between 20' and 40' containers. So, it follows that the crane capacity is 47 TEU per hour. The two cranes are multiplied with the capacity of 47 TEU per hour and then with 365 days since the cranes work all days of the year. After that, it was multiplied by 22.5 hours, as 24 hours should be reduced by the workers half-hour breaks during three shifts. In order to obtain the most precise service parameter the coefficient of interference in operations and the coefficient of accidental downtime or maintenance were also taken into account.

Capacity of the left berth, the maximum number of TEUs that can be served per year is obtained as follows: $\mu = 2\cdot 47\cdot 22.5\cdot 365\cdot 0.9\cdot 0.8 = 555{,}822$ TEU per year. The second berth with two Panamax crane has approximately 60% capacity of the left one and, with this capacity added, the total amount of containers served at the terminal at these two berths could be theoretically nearly 890,000 TEU.

With the annual turnover of 305,049 TEUs and maximum capacity of two berths with four quay cranes of 890,000 TEUs, it can be easily concluded that the terminal could handle much larger amounts of containers, from the aspect of the quayside as the first phase of containers services. The possible turnover, with the 95% equipment utilization is 0.95·890,000=845,500 TEUs, which is 2.8 times higher turnover than in 2020. So, currently the terminal has overcapacity regarding the first service phase at the quayside.

4.2 The second service phase (storage yard)

Since the storage yard capacity is affected by limited space possibilities and not only equipment capacities, the surface of the yard as well as the height to which the containers are stacked should be taken into account, thus obtaining maximum storage capacity.

Considering above mentioned it is necessary to take in the further calculation the capacity that is less than these two:

capacity of the yard according to available equipment capacity,

capacity of the yard according to available space.

Assuming that all containers as output units from the first phase move to the second phase of service, i.e. storage yard, the arrival rate is the same in the amount of 305,049 TEU per year. The storage area has two reach stackers and six RTG cranes. The capacity of reach stackers is 20 movements per hour, while the capacity of RTG cranes is slightly lower and amounts to 16 movements per hour. The number of movements is converted into TEUs by multiplying with the number 1.55 as in the case of cranes at the quay.

The service rate for the storage yard, or the average number of TEUs that can be served in a unit of time at the storage area, is obtained as follows:

$\mu = 2 \cdot 31 \cdot 22.5 \cdot 365 \cdot 0.9 \cdot 0.8 = 366{,}606$ TEU/year (considering the part of the storage area with reach stackers)

$\mu = 6 \cdot 25 \cdot 22.5 \cdot 365 \cdot 0.9 \cdot 0.8 = 886{,}950$ TEU/year (the part of the storage area with RTG cranes)

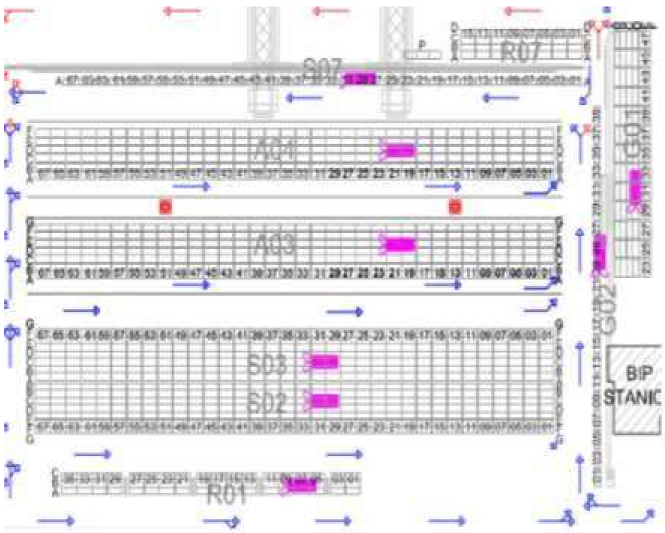

Figure 3: Storage area SA1 with reach stackers

Source: AGCT, 2020.

Table 2: Calculation of static capacity for SA1

	Storage width (TEU)	Storage length (TEU)	Width·Length·Height (height is 3 TEUs)
A04	6	34	612
A03	7	34	714
S03	7	34	714
S02	7	34	714
R01	3	30	270
R07	4	8	1080
S07	1	34	102
G01	6	13	234
G02	1	20	60
Sum			4,500 TEU

Source: AGCT, 2020

To determine the capacity (static and dynamic) of the storage yard by the available space the area is further considered as one surface (SA1 with reach stackers and SA2 with RTG cranes).

The average retention of containers at the storage area for imported containers is 5.9 days, and for export 6.3 days, which is in the average 6.1 days. Based on the obtained data for static capacity and the average retention time of the containers, the total dynamic capacity of the storage area is calculated as follows:

the total static capacity of the storage area is 4,500+4,620 = 9,120 TEU

the total dynamic capacity of the storage area is $9{,}120 \cdot 365/6.1 = 545{,}705$ TEU/year.

In conclusion, for the service rate (parameter μ), in the further calculation the limiting factor should be taken into account and that is the available space:

$\mu = 1{,}253{,}556$ TEU/year (considering the equipment capacity)

$\mu = 545{,}705$ TEU/year (taking the available space into account)

Based on the above data, the traffic intensity of the storage yard in 2020 is 55%:

$$\rho = \frac{305,049}{545,705} = 0.55,$$

while the probability of not usable space ($P_0 = 1 - \rho$) of significant 45%.

It can be concluded that the storage yard as the second phase of servicing containers in terms of capacity could receive much larger quantities of containers than it currently receives and that the optimal amount of cargo for the storage yard due to constraint of available space is approximately 518,000 TEUs annually, with 95% of utilization.

Figure 4: Storage area SA2 with RTG cranes
Source: AGCT, 2020.

Table 3: Calculation of static capacity for SA2

	Storage width (TEU)	*Storage length (TEU)*	*Width·Length·Height (height is 5 TEUs)*
B01	7	15	525
B02	7	15	525
B03	7	15	525
B04	7	15	525
C01	7	18	630
C02	7	18	630
C03	7	18	630
C04	7	18	630
Sum			4,620 TEU

Source: AGCT, 2020.

Indicators L, L_Q, W and W_Q are not calculated for the second and third phases due to the fact that some containers stay at the storage yard for several days waiting for shipment to the final destination. The waiting time of containers in the second and third phases depends not only on the capacity of the equipment but also on other external objective factors, such as the delivery time that causes earlier or later further shipment of containers in the logistics chain.

4.3 The third phase of service (gate)

Only two thirds of the cargo handled at the berth is transported by the rail so in the further calculation for the third phase the arrival rate would be 203,366 TEU per year. The remaining third of the cargo is transported by road with trucks. Of the equipment, the gate has four reach stackers and two RMG cranes with the capacity of 20 movements per hour which is 31 TEU per hour.

The service rate for the third phase is:
$\mu = 4 \cdot 31 \cdot 22.5 \cdot 365 \cdot 0.9 \cdot 0.8 = 733{,}212$ TEU/year (based on the reach stackers)
$\mu = 2 \cdot 31 \cdot 22.5 \cdot 365 \cdot 0.9 \cdot 0.8 = 366{,}606$ TEU/year (based on the RMG cranes).

Figure 5: Gate/train operation area
Source: AGCT, 2020.

In total, the service rate with regard to equipment would be 1,099,818 TEU/year. However, the capacity of the train operation area also does not depend only on the available equipment, according to which the capacity greatly exceeds the current demand. Limiting factor at the gate is the frequency of rail transport of containers, which is the number of weekly container block trains. Hence the theoretical annual capacity of the railway from the official website of the terminal is 360,000 TEU per year. The traffic of containers at the rail operation area in 2020 was 203,366 TEU so the utilization amounts 56%:

$$\rho = \frac{203{,}366}{360{,}000} = 0.56 .$$

From the above, follows that this service phase at the terminal also has surplus of capacity, and could handle larger quantities of containers.

4.4 Analysis of results

All the obtained results indicate that, according to the current turnover, there is no congestion at any stage of service at the terminal. The capacities of the quayside, storage yard and gate are not fully utilized. Container traffic in all of three phases was significantly less than the available capacities. The terminal has possibilities to handle larger quantities of cargo, having capacity surpluses in all three phases.

Peak traffic affects the need for reserve capacity, not only infrastructure but also human labor. It is desirable to have reserve capacities but this greatly reduces the coefficient of their utilization.

From the calculation of the traffic intensity of each service phase on the example of the Rijeka container terminal, it follows that there are significant capacity reserves due to the fact that currently available capacities in all three phases are not fully utilized. The degree of capacity utilization in all three phases are only 56%, 55% and 56%, respectively.

The fact is that at the time of ship arrival and mass unloading of containers there is a peak load of all capacities at the terminal which in the first phase of the service lasts until all planned containers are unloaded from the ship. In the second and third phase, the process of container stacking may take several days depending on the delivery time of the container to the final destination.

However, considering the existing and planned traffic of the terminal, at this moment it is not necessary to purchase and install additional capacities at any stage of service, and during peak loads at the terminal, it is possible to work in three shifts so that working hours are twenty-four-seven, 24/7.

Based on the calculated data, it can be concluded that the third phase (train operation area) represents possible bottleneck because it has the smallest capacity. Taking that into account it is calculated that the optimal turnover at the terminal would be 342,000 TEU per year, by degree of usability of 95%.

In 2020, the container terminal of the port of Rijeka had a turnover of 305,049 TEU per year, which means that there are still capacities of receiving the larger quantities of cargo. The highest capacity surpluses are located at the quayside service phase but, when planning the possible turnover, the service phase with the less capacities (the railway) should always be taken as limiting factor.

5. Current plans and projects for further capacity development

The new project of the intermodal railway terminal, currently in the implementation phase, "Port of Rijeka multimodal platform development and interconnection to Adriatic Gate container terminal (POR2CORE-AGCT)" – Reconstruction of the railway station Rijeka and Rijeka container terminal is a joint project of the Port of Rijeka Authority and HŽ Infrastruktura d.o.o., for which the Grant Agreement was signed in 2015. The Agreement was signed between the Innovation and Networks Executive Agency (INEA), based on the authorizations provided by the European Commission, the Port of Rijeka Authority (Coordinator) and HŽ Infrastruktura (Beneficiary) (HŽ infrastrukutra, 2020).

This is the railway from Rijeka to the Hungarian border and is the largest and most expensive project in the Transport Development Strategy of the Republic of Croatia and the National Railway Infrastructure Program 2016/2020. The aim of the project is to build transport railway line (RH2 transport corridor) that connects Port of Rijeka with the trans-European transport network (TEN-T network), which would improve the transport connection between Croatia and the EU. Also, the project would facilitate the transport of goods by rail from/to ships in accordance with the requirements of interoperability and intermodality, and at the same time eliminate the existing bottleneck of the terminal.

This is in line with the results of the research of this paper, which determined the gate of the terminal, as the third phase of servicing containers, as a bottleneck. The total value of the project is € 35.6 million, and the HŽ share amounts to € 26 million. The maximum co-financing rate from the CEF amounts to 85% of the total value of the project, i.e. € 30.26 million (Port of Rijeka Authority, 2020).

The reconstruction of the railway station and the construction of a new container terminal will have a considerable impact on the existing capacity of the station and will provide technical requirements for interoperability in accordance with Directive 2008/57/EC and Technical Specifications for Interoperability (TSI) for the trans-European conventional rail network. The action consists of the following activities:

- project management,
- construction of an intermodal terminal for loading/unloading of containers,

- reconstruction of the railway station Rijeka (Brajdica) and
- the construction of a new track in the connecting tunnel.

The reconstruction of Brajdica station includes a total of eight tracks in the railway area and the construction of four new tracks in the port area. So far, the first four tracks have been reconstructed adjacent to the station building and the remaining four tracks are being built. The overhead contact line and station lighting were reconstructed, and along the first four tracks, cable ducting was built and new turnouts were installed. A facility for interlocking and signaling and telecommunication devices was built next to the station building, as well as an auxiliary power supply facility. In the port area, 400 m long tracks were constructed on a concrete base, lighting pillars and portals of overhead contact line support, and cable ducting is being built.

The most complicated works are those on the construction or extension of a 400 m long turnout track tunnel. In addition to the existing tracks, the tunnel has been expanded to include another track, so, alongside regular train operation it will be possible to handle trains at the same time. The portal structure, or 70 m of excavated artificial tunnel, is connected at the entrance to the tunnel and now forms a unique structure with a turnout track. So, the upgraded rail yard will feature two new rail mounted gantries over four rail lines and on-dock rail terminal could offer an annual capacity of 360,000 TEU per year (HŽ infrastruktura, 2020).

The project "Upgrade of the Rijeka Port infrastructure – AGCT dredging (POR2CORE-AGCT dredging)" is a part of a large investment cycle of the Port of Rijeka, one of seven major infrastructure development projects for which co-financing from the Connecting European Facility – CEF) was ensured, and it is realized with partners or independently by the Port of Rijeka Authority. The projects relate to the modernization and construction of railway infrastructure in the port, construction of new intermodal capacities, reconstruction and modernization of port terminals, and they are in progress in almost all port basins and will all be completed by 2023.

In 2020, the construction contract was signed for this project including works on dredging the seabed in the length of 100 m along the quay wall of the southern berth, which will level the depth of the sea along the entire length of the operational Kostrensko Pier South of 428 m at the Adriatic Gate container terminal. The project was approved in 2018, and its total value is estimated at 17,389,436.00 EUR, with a share co-financed by EU grants of 20% in the independent implementation of the Port of Rijeka Authority. When the two-phase dredging scheme of 130 meters of quay over its Berths 1 and 2, be completed, the AGCT will be the first terminal in the northern Adriatic able to be able to berth vessels of up to 20,000 TEU capacity, with a length overall (LOA) of up to 400 meters and beam of 59 meters. Everything will be accompanied by the purchase of new equipment, primarily two new Super post panamax cranes, with an outreach of 24 rows, as part of the berth upgrade, as well as new rubber tyred gantries and prime movers introduced on the landside. Total terminal yard capacity is expected to be increased up to 600,000 TEU per year, in line with demand (Port of Rijeka Authority, 2020).

The Rijeka container terminal is configured to provide optimal connection to the road and rail network, and it is planned to increase the share of rail transport to 60 percent. Railway traffic is mostly directed to Hungary, Serbia, Bosnia and Herzegovina and the interior of Croatia, especially Zagreb. Considering that the railway still has spare capacity, and with the full liberalization of rail transport that allows the operation of private railway operators, AGCT, in cooperation with ship-owners and operators, will continue to increase its market range and increase the share of terminals in the part of the market covered by rail.

Very important project "Rijeka Land Sea Express", a new maritime and intermodal service of the port of Rijeka to the countries of Central Europe, started in March 2019, with the joint work of COSCO Shipping Lines from China and Europe (one of the world's largest container shipping companies), and the companies Dragon Maritime, PEARL, Ocean Rail Logistics (the company responsible for rail transportation within the COSCO Group), Express, HZ Cargo, Rail Cargo Operator – Hungaria, BILK, Transagent and Adriatic Gate. The new intermodal service consists of a regular weekly shipping line connecting the Greek Piraeus, the main hub of COSCO Shipping Lines for the Mediterranean, with Rijeka and the line-coordinated railway services – block trains for container transport on the lines between Rijeka and Budapest, as well as Rijeka and Belgrade. Through "Rijeka's Land Sea Express", COSCO offers its clients 32-day travel requests from East China to Budapest and 28 days from South China to Budapest, connecting overseas and rail services and using Piraeus and Rijeka as transshipment ports (Port of Rijeka Authority, 2020).

Finally, it is important to point out that in 2019 Rijeka was ranked among the top 100 ports in the world according to the LSCI (Liner shipping connectivity index), which has been published by UNCTAD, the United Nations Trade and Development Agency, since 2006. The index refers primarily to container traffic, and is calculated every year, for almost a thousand ports all over the world, based on their connection by shipping lines with other world ports, but also the hinterland, the efficiency of cargo handling and other parameters.

6. Conclusion

To develop port as a strong intermodal center, it is necessary to determine its possibilities, limiting factors and bottlenecks. Queuing theory is an important method of operational research that allows optimal decision making and locating the system bottlenecks.

From this research and calculation it can be identified that the current bottleneck of the Rijeka container terminal is the gate/train operation area, i.e. railway capacities. Considering the turnover from 2020, the capacities of all subsystems: quayside, storage yard and gate have not been fully used. However, in the future if traffic increases, the limiting factor would be the railway capacities, in comparison to the quayside and the storage yard. Afterwards, the yard is recognized as the next bottleneck of the terminal that should be expanded.

In 2020, the terminal had a turnover of 305,049 TEU. The calculation determined that there is still space for receiving larger quantities of cargo, but not more than 342,000 TEU/year, considering the lowest railway capacities with the utilization of 95% with no traffic jams. The basic conclusion is that the capacity of the system is limited by the capacity of the subsystem that has the smallest capacity. The various projects are currently underway to expand the terminal's capabilities and enable the Rijeka container terminal to become an important intermodal hub. The results of the research conducted in this paper are in line with the plans of the current and future projects of the Rijeka container terminal for future capacity expansion. Although this paper is conceived largely as a case study, the conducted research and applied methodology can be used to calculate capacities and their usability for any other case of a particular port/terminal.

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