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METODOLOŠKI PRISTUP ISTRAŽIVANJU PROCESA OPSLUŽIVANJA – STUDIJA SLUČAJA KONTEJNERSKOG TERMINALA RIJEČKE LUKE[1]

METHODOLOGICAL APPROACH TO THE SERVICE PROCESS RESEARCH CASE STUDY – CONTAINER TERMINAL AT THE PORT OF RIJEKA[1]

SAŽETAK

Za optimalno funkcioniranje kontejnerskog terminala od posebne je važnosti definirati kapacitet terminala koji će omogućiti ostvarenje definiranog plana proizvodnje, a time i plana realizacije lučkih usluga. U praksi je vrlo teško odrediti i dimenzionirati optimalan kapacitet lučkoga kontejnerskog terminala zbog oscilacija lučkog prekrcaja uvjetovanih neravnomjernim pristizanjem kontejnerskih brodova na terminal te neujednačenim trajanjem operacija s kontejnerima. Cilj ovoga rada je prikazati metodološki pristup, odnosno metode primjenom kojih je moguće odrediti značajke i pokazatelje funkcioniranja lučkoga kontejnerskog terminala, a koji su temelj za donošenje odgovarajućih poslovnih odluka za promatrani terminal. Prikazana metodologija je testirana na primjeru kontejnerskog terminala riječke luke Brajdica.

Ključne riječi: *korelacija, razdiobe vjerojatnosti, neparametarski testovi, teorija redova čekanja, kontejnerski terminal riječke luke Brajdica*

SUMMARY

For an optimal functioning of the container terminal, it is especially important to define the capacity of the terminal that affects the possibility of achieving the production plan, and also the realization plan for port services. In practice, it is very difficult to determine and submit an optimal capacity of a port container terminal because of the port reload fluctuation conditioned by the uneven arrival of container ships to the terminal and uneven duration of operations with containers. The goal of this paper is to present the methodological approach, that is, methods that enable to define the features and indicators of a port container terminal operation, which are fundamental for making relevant business decisions for a given terminal. The presented methodology was actually tested on the example of the container terminal "Brajdica" at the Port of Rijeka.

Key words: *correlation, probability distributions, non-parametric tests, queuing theory, container terminal "Brajdica" at the Port of Rijeka*

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1. UVOD

Lučki diskontinuitet[2] je pojam kojim je profesor Ante Turina [16] označio kolebanja u procesu proizvodnje lučke usluge kad u određeno vrijeme u luci nema brodova pa se ne iskrcava, odnosno ukrcava teret s/na brod ili pak kad u danima ili satima istog razdoblja brodovi moraju čekati na obavljanje određenih lučkih usluga. Posljedica je takvih kolebanja neravnomjernost lučkog prometa, tj. neujednačena količina tereta, broja putnika ili brodova tijekom promatranog razdoblja.

Ta se činjenica odnosi na sve vrste luka pa tako i na lučke kontejnerske terminale, tijekom godine, mjeseci i dana, ponavlja u određenim vremenskim ciklusima i prisutna je u svim lukama bez obzira na geografski položaj i državne granice, a rezultat je utjecaja različitih čimbenika (sezonska uvjetovanost, nepravilnost "proizvodnje" lučke usluge zbog tehničkih, tehnoloških i organizacijskih razloga, elementarni poremećaji, ...).

Oscilacije prometa u lukama, koje se ne mogu izbjeći ni predvidjeti količinski u sadašnjosti i budućnosti, utječu na problem dimenzioniranja svih elemenata koji sudjeluju u procesu proizvodnje lučke usluge, posebno na utvrđivanje potrebnog broja pristana. Naime, luka bi trebala raspolagati rezervnim kapacitetima za slučajeve dnevnog ili mjesečnog maksimalnog prometa (tzv. "špica") da bi se u svakom trenutku mogao obaviti lučki prekrcaj, ali takve bi rezerve kapaciteta smanjile stupanj njihova iskorištenja. Neravnomjernost prometa ne utječe samo na veličinu prekrcajnih i skladišnih kapaciteta u luci, već i na broj zaposlenih koji bi trebao biti usklađen s promjenama kapaciteta, a sve se to negativno odražava na poslovanje luke.

Problem dimenzioniranja optimalnog kapaciteta kontejnerskog terminala moguće je riješiti primjenom odgovarajućih kvantitativnih metoda. Cilj je ovoga rada prikazati metodološki pristup, odnosno metode kojima se određuju značajke i pokazatelji funkcioniranja lučkoga kontejnerskog terminala, a koji su temelj za do-

[2] Termin "diskontinuitet" nije najadekvatniji, jer taj pojam u lučkom prekrcaju ne znači prekid procesa proizvodnje lučke usluge, što bi se moglo zaključiti prema terminu, iako ponekad u luci može doći do takvog prekida. Zbog navedenih razloga predlažu se termini: "neravnomjernost", "neujednačenost" ili "oscilacije" lučkog prekrcaja, odnosno lučkog prometa koji će biti korišteni u ovome radu.

1. INTRODUCTION

Port discontinuity[2] is the term introduced by professor Ante Turina [16] referring to fluctuations in the manufacturing process of port services where at times there are no ships in the port and consequently there is no discharging or loading from/onto ships, or where, on days or hours within the same period, ships must wait for particular port services. Such fluctuations result in irregular port traffic, i.e., ununiform quantity of cargo, number of passengers or ships over a given period.

This fact applies to all ports including the port container terminals, throughout the year, months and days, repeated at regular cycles and is present in all ports regardless of geographical location and national boundaries, and it is the result of the influence of various factors (seasonal conditioning, irregularity "production" of port services for technical, technological and organizational reasons, elemental disturbances ...).

Traffic oscillations in ports, which cannot be avoided or foreseen in terms of quantity, both in present time or future, influence the issue of dimensioning all elements involved in a port service process, particularly defining the required number of berths. Specifically, the container terminal should handle with the reserve capacity for cases of daily and monthly maximal traffic ("peak traffic"), so the containers, at any moment, could be reloaded, but such capacity reserves would reduce the usage degree of the terminal. The ununiform traffic does not influence only the volume of transshipment and warehouse capacities in a port, but the number of employees as well, which should be well coordinated with the changes in the capacity, and all these facts have a negative impact on the port operations.

The issue of dimensioning optimal capacity of container terminals may be solved by implementing certain quantitative methods. The objective of this paper is to present the methodological approach, that is, the methods used to determine features and indicators of a port container terminal operation, which are fundamental for making relevant business decisions for the given terminal. For this purpose the sta-

[2] Term "discontinuity" may not be the proper one, since, in port transshipment, it does not mean the ceasing of port service process, as it may suggest, although such a cease may occasionally occur. Therefore, the following terms are suggested: "irregularity", "non uniformity" or "oscillations" in port transshipment or port traffic, which terms will be used hereinafter.

nošenje odgovarajućih poslovnih odluka za promatrani terminal. U tu svrhu su korištene statističke metode (deskriptivna statistika, metoda korelacije, testiranje hipoteze, neparametarski testovi) i metode operacijskih istraživanja (teorija redova čekanja).

U znanstvenoj i stručnoj literaturi je dosad objavljen niz radova vezanih uz primjenu teorije redova čekanja (vidjeti popis literature), međutim, nije prikazan redoslijed metoda koje je neophodno primijeniti da bi se došlo do rezultata potrebnih za optimalno poslovno odlučivanje, što je učinjeno u ovome radu.

Prikazana metodologija ilustrirana je na primjeru kontejnerskog terminala Brajdica luke Rijeka.

2. STATISTIČKA ANALIZA DOLAZAKA KONTEJNERSKIH BRODOVA I VREMENA NJIHOVOG OPSLUŽIVANJA

Analiza toka dolazaka kontejnerskih brodova i vremena njihovog opsluživanja se provodi na način da se najprije ispita postojanje veze između pristiglih brodova i vremena kada su ti brodovi stigli na terminal, a nakon dobivenog zaključka odrede odgovarajuće razdiobe vjerojatnosti koje slijede navedene varijable.

2.1. Međuzavisnost broja brodova i dana pristizanja na kontejnerski terminal

S obzirom na oscilacije dolazaka brodova za pretpostaviti je da ne postoji nikakva veza između broja kontejnerskih brodova i dana kada su ti brodovi pristigli na terminal. Da bi se ispitala postavljena pretpostavka primijenjena je metoda korelacije za grupirane elemente [15, str. 119].

Preduvjet za primjenu ove metode je prikupljanje podataka o broju pristiglih brodova po danima za odabrane godine. U sljedećem koraku podaci se sređuju na način da je broj brodova grupiran prema broju brodova idućeg dana i broju brodova prethodnog dana. U tu svrhu se sastavlja korelacijska tablica u kojoj pojavu X predstavlja broj brodova idućeg dana, a pojavu Y broj brodova prethodnog dana. Podaci u tablici dobivaju se zbrajanjem svih slučajeva gdje je za određeni broj brodova, broj brodova pret-

tistical methods (descriptive statistics, correlation method, hypothesis testing, nonparametric tests) and the operations research methods (queuing theory) are used.

Till nowadays, numerous papers addressing the implementation of the queuing theory (please refer to References) have been published in scientific and technical literature, but none of them has presented the sequence of methods to be applied in order to learn the results necessary for an optimal business decision making. It is this aspect of the problem that this paper addresses.

The presented methodology is illustrated by using the example of a container terminal at “Brajdica”, the Port of Rijeka container terminal.

2. STATISTICAL ANALYSIS OF THE CONTAINER SHIP ARRIVALS AND THE TIME OF THEIR SERVING

The analysis of the flow of arrivals of container ships and their serving time is carried out in the way of first investigating the relationship between the arriving ships and the time when these ships arrived at the terminal, and after the conclusion has been reached, it is necessary to determine the appropriate probability distributions that follow these variables.

2.1. Interdependence between the number of ships and days of arrival at the container terminal

Considering the oscillations in the arrival of container ships, it is fair to assume that there is no relation between the number of container ships and the day the ships arrived at the terminal. In order to verify this hypothesis, the correlation method for grouped elements was applied [15, pg.119].

A prerequisite for the application of this method is to collect the data on the number of ships arriving in the days of the year selected. In the next step the data are going to be arranged in a way that the number of ships is grouped according to the number of ships the next day and the number of ships the previous day. For this purpose a correlation table is compiled in which the occurrence of X is the number of ships the next day, and the occurrence of Y is the number of ships the previous hodnog dana iznosio Y, a istodobno broj brodova idućeg dana X.

Jakost veze između broja brodova idućeg i prethodnog dana pokazuje koeficijent korelacije koji se izračunava prema formuli [15, str. 124]

$$r = \frac{\sum f_{x_i y_j} \cdot X_i Y_j - N\overline{X}\overline{Y}}{N\sigma_x \sigma_y}, \qquad (1)$$

gdje je:

f – frekvencija (broj dana)

N – ukupan broj dana

σ_x – standardna devijacija za pojavu X (broj brodova idućeg dana)

σ_y – standardna devijacija za pojavu Y (broj brodova prethodnog dana)

$\overline{X}$ – aritmetička sredina za pojavu X

$\overline{Y}$ – aritmetička sredina za pojavu Y.

Koeficijent korelacije[3] poprima vrijednosti u intervalu [-1, 1]. Kada se koeficijent korelacije približava ±1, veza među pojavama je jaka, kada je jednak ±1 pojave su linearno zavisne, a kada je koeficijent korelacije blizu nuli veza je slaba. Predznak koeficijenta korelacije pokazuje je li veza prema smjeru pozitivna ili negativna.

Na temelju dobivene vrijednosti koeficijenta korelacije zaključuje se postoji li značajna ili slučajna zavisnost u redoslijedu dnevnih dolazaka brodova.

Budući da su vrijednosti koeficijenta korelacije, prema dosadašnjim iskustvima autora [20, str. 47–52] vrlo blizu nule, izlazi da nema značajne zavisnosti u redoslijedu dnevnih dolazaka brodova na kontejnerski terminal, što znači da se dolasci brodova mogu promatrati kao nezavisni, u statističkom smislu slučajni i da se može uzeti da je broj brodova koji pristižu na kontejnerski terminal slučajna (stohastička) varijabla.

Analogno se provodi ispitivanje i za varijablu duljina vremena opsluživanja brodova, odnosno broj opsluženih brodova.

Da bi se pokazalo da nema bitne razlike između koeficijenata korelacije za pojedine godine (razdoblja) primjenjuje se postupak testiranja hipoteze, odnosno ispitivanje pretpostavke

[3] Vrijednost koeficijenta korelacije moguće je dobiti primjenom računalnih programa dostupnih na internetu [11], [12].

day. The data in the table are obtained by summing up all cases where, for a certain number of ships, the number of ships of the previous day is presented by Y, while the number of ships of the next day is presented by X.

The strength of relationship between the number of ships the next and the previous day shows the correlation coefficient which is calculated by the formula [15, pg.124]

$$r = \frac{\sum f_{x_i y_j} \cdot X_i Y_j - N\overline{X}\overline{Y}}{N\sigma_x \sigma_y}, \qquad (1)$$

where:

f – frequency (number of days)

N – total number of days

σ_x – standard deviation for the occurence of X (number of ships the next day)

σ_y – standard deviation for the occurence of Y (number of ships the previous day)

$\overline{X}$ – arithmetic mean for the occurence of X

$\overline{Y}$ – arithmetic mean for the occurence of Y.

The correlation coefficient[3] takes values in the interval [-1, 1]. When the correlation coefficient approaches ±1, the connection between the phenomena is strong; when it is equal to ±1, the phenomena are linearly dependent, and when a correlation coefficient is close to zero, the connection is weak. The prefix of the correlation coefficient indicates whether the connection has a positive or negative direction.

On the basis of the correlation coefficient values, a conclusion can be made as to whether dependency is significant or random in the sequence of the ships' daily arrivals.

Since the value of the correlation coefficient, according to previous experiences of the authors [20, pg. 47-52], is very close to zero, it follows that there is no significant dependence of the order of the daily arrivals of ships at the container terminal, which means that the arrivals of the ships can be seen as independent, random in the statistical sense, and that the number of ships arriving at the container terminal can be taken as a random (stochastic) variable.

The duration of service and the number of serviced ships variables are tested in an analogous way.

[3] The value of the correlation coefficient can be obtained by using computer programs available on the Internet [11], [12].

o nepostojanju značajne razlike između njihovih vrijednosti [15, str. 333–334].

Postupak testiranja se odvija na sljedeći način

$H_0: r_1 - r_2 = 0$ i $H_1: r_1 - r_2 \neq 0$.

Empirijske vrijednosti koeficijenata korelacije se transformiraju pomoću odgovarajuće tablice u z_1 i z_2. Standardna pogreška razlike između dviju vrijednosti z iznosi

$$se(z_1 - z_2) = \sqrt{\frac{1}{n_1 - 3} + \frac{1}{n_2 - 3}}\ , \qquad (2)$$

gdje su n_1 i n_2 ukupan broj dana. Hipoteza o jednakosti koeficijenata korelacije se prihvaća kada se razlika $\left|\hat{z}_1 - \hat{z}_2\right|$, koja se dobiva primjenom tablice za preračunavanje r u vrijednost $\hat{z}$, nalazi u intervalu

$$0 \pm t \cdot se\left(z_1 - z_2\right), \qquad (3)$$

gdje je t koeficijent pouzdanosti (t = 1,96 za razinu značajnosti od 5%). Ako je izračunata razlika u intervalu prihvaćanja nul-hipoteze, tada nema dovoljno argumenata da se ta hipoteza odbaci, a to dalje znači prihvaćanje da se koeficijenti korelacije za navedene godine međusobno ne razlikuju bitno. Drugim riječima, na temelju prethodnog zaključka slijedi da nije potrebno ispitivanje međuzavisnosti provoditi za svaku godinu pojedinačno, već je dovoljno uzeti samo jednu godinu ili razdoblje od više godina kao reprezentanta promatrane pojave.

2.2. Određivanje razdiobe vjerojatnosti za pristigle kontejnerske brodove i duljinu vremena njihovog opsluživanja

Dosadašnja istraživanja [20], [22] su pokazala da su broj pristiglih brodova i duljina vremena opsluživanja broda slučajne varijable; zbog toga nije moguće unaprijed odrediti vrijednosti tih varijabli, ali je moguće odrediti njihove razdiobe vjerojatnosti.

Da bi se mogle izračunati vjerojatnosti realizacije slučajnih varijabli koje predstavljaju broj dolazaka brodova i broj opsluženih brodova na kontejnerskom terminalu potrebno je raspolagati podacima o broju dolazaka brodova po danima, zatim provesti statističku analizu tih podataka te usporediti empirijsku razdiobu s odabranim teorijskim razdiobama, odnosno

To show that there is no significant difference between the correlation coefficients for each year (period), the procedure to test the hypothesis, i.e. testing the hypothesis that there is no significant difference between their values, is applied [15, pg.333-334].

The testing procedure is done as follows

$H_0: r_1 - r_2 = 0$ i $H_1: r_1 - r_2 \neq 0$.

The empirical values of the correlation coefficients are transformed by using the appropriate tables in the z_1 and z_2.The standard error of the difference between the two values of z is

$$se(z_1 - z_2) = \sqrt{\frac{1}{n_1 - 3} + \frac{1}{n_2 - 3}}\ , \qquad (2)$$

where n_1 and n_2 are the total number of days. The hypothesis of equality of the correlation coefficients is accepted when the difference $\left|\hat{z}_1 - \hat{z}_2\right|$, which is obtained by applying a Table for converting the value of r in the value of $\hat{z}$, is in the interval

$$0 \pm t \cdot se\left(z_1 - z_2\right), \qquad (3)$$

where t is the confidence coefficient (t = 1.96 for the level of significance of 5%). If the calculated difference is in the interval of accepting the null hypothesis, then there are no sufficient arguments to reject this hypothesis, but it still means the acceptance of the hypothesis that the correlation coefficients for these years do not differ significantly. In other words, based on the previous conclusion, it follows that it is not necessary to test interdependencies performed for each year individually, but it is sufficient to take only one year or a period of several years as the representative of the observed phenomena.

2.2. Determination of the probability distribution for the container ships arrivals and the length of their serving time

The previous studies [20], [22] have shown that the number of arriving ships and the length of the ship serving time are the random variable; therefore, it is not possible to predetermine the values of these variables, but it is possible to determine their probability distribution.

To be able to calculate the probability of the realization of the random variables representing the number of the ships' arrivals and the number of the ship serving time at the container terminal, it is necessary to get the data on odrediti teorijsku razdiobu s kojom se može aproksimirati empirijska razdioba.

Pretpostavka da je empirijska razdioba raspoređena prema nekoj teorijskoj razdiobi ispituje se testovima za verifikaciju statističkih hipoteza, tzv. neparametarskim testovima, od kojih se u praksi najčešće koriste χ^2-test (hi-kvadrat test) i Kolmogorov-Smirnovljev test[4]. Testiranjem se donosi odluka o prihvaćanju ili nul-hipoteze H_0: empirijska razdioba se ponaša prema odabranoj teorijskoj razdiobi ili alternativne hipoteze H_1: empirijska razdioba se ne ponaša prema odabranoj teorijskoj razdiobi.

Ako se nakon primjene testa dobije zaključak da se empirijska razdioba ponaša prema nekoj teorijskoj razdiobi tada se ta razdioba može prihvatiti kao razdioba na temelju koje se donose zaključci o promatranoj empirijskoj razdiobi.

Primjena χ^2-testa se temelji na vrijednosti χ^2 koja se dobiva pomoću formule

$$\chi^2 = \frac{\sum_{i=1}^{n}\left(f_i - f_{ti}\right)^2}{f_{ti}}, \tag{4}$$

gdje je:

f_i – originalna (empirijska) frekvencija i-te vrijednosti slučajne varijable u uzorku

f_{ti} – odgovarajuća teorijska (očekivana) frekvencija

n – broj klasa, odnosno broj parova vrijednosti f_i i f_{ti}

$N = \sum f_i$.

Teorijske frekvencije se izračunavaju po formuli

$$f_{ti} = N \cdot P(x_i), \tag{5}$$

gdje je N ukupan broj jedinica, a $P(x_i)$ su odgovarajuće vjerojatnosti.

Odluka o prihvaćanju ili odbacivanju postavljene hipoteze temelji se na usporedbi izračunate vrijednosti χ^2 i tablične vrijednosti χ_0^2 koja se očitava iz Tablica kritičnih vrijednosti χ^2-razdiobe zavisno od broja stupnjeva slobode (k) i stupnja značajnosti (α), odnosno na temelju vjerojatnosti p_i koja pripada izračunatoj vrijednosti χ^2.

[4] Detaljnije o uporabi ovih testova vidjeti u literaturi iz statistike u poglavlju o neparametarskim testovima [6], [14], [18], [19]. Također se čitateljima preporučuju računalni programi koji se mogu naći na internetu [4], [11], [12].

the number of the ships' arrivals per day, then carry out a statistical analysis of these data and compare the empirical distribution with the selected theoretical distribution, or determine the theoretical distribution with which the empirical distribution can be approximated.

The hypothesis, that the empirical distribution is arranged on the basis of some theoretical distribution, is subject to the statistical hypothesis tests, so called nonparametric tests, of which the most commonly used are χ^2–test (chi–squared test) and Kolmogorov–Smirnov test[4]. The test is the basis for the decision making as to whether accept or reject the null hypothesis H_0: empirical distribution behaves in line with the selected theoretical distribution or the alternative hypothesis H_1: empirical distribution does not follow the theoretical distribution.

If the test asserts that the empirical distribution behaves in line with some theoretical, then such a distribution may be accepted as a distribution that represents the basis for making a conclusion in the given empirical distribution.

The implementation of the χ^2- test is based on the value χ^2 obtained from the formula

$$\chi^2 = \frac{\sum_{i=1}^{n}\left(f_i - f_{ti}\right)^2}{f_{ti}}, \tag{4}$$

where:

f_i – original (empirical) frequency of the i-th value of the random variable in the sample,

f_{ti} – corresponding theoretical (expected) frequency,

n – number of classes or the number of pairs of values f_i and f_{ti}

$N = \sum f_i$.

The theoretical frequencies are calculated by the formula

$$f_{ti} = N \cdot P(x_i), \tag{5}$$

where N is the total number of units, and P (x) are the corresponding probabilities.

The decision on the acceptance or rejection of the hypotheses is based on the comparison of the calculated values χ^2 and the values from

[4] More details on using these tests may be found in References under nonparametric tests [6], [14], [18], [19]. Computer programs, available on Internet, are also suggested [4], [11], [12].

Kolmogorov-Smirnovljev test (*K-S* test) uspoređuje empirijsku $F_n(x)$ s teorijskom $F(x)$ funkcijom razdiobe. Apsolutna vrijednost maksimalne razlike empirijske funkcije razdiobe i pretpostavljene teorijske

$$D_n = \max|F_n(x) - F(x)|, \qquad (6)$$

(gdje je n broj elemenata u uzorku) je slučajna varijabla koja ima svoju razdiobu vjerojatnosti. Kolmogorovom razdiobom konstruira se kritična oblast testa, na način ako je maksimalna razlika u jednoj točki (tj. za određenu vrijednost ispitivanog obilježja) prevelika i nađe se u kritičnoj oblasti, tada treba odbaciti hipotezu H_0 da obilježje X u osnovnoj populaciji ima pretpostavljenu razdiobu.

Značajno ograničenje primjene *KS*-testa je da pretpostavljena teorijska funkcija razdiobe mora biti neprekidna, za razliku od χ^2-testa koji je izvorno kreiran za diskretne razdiobe vjerojatnosti, ali se može prilagoditi i za kontinuirane razdiobe [6, str. 261].

Pored navedenih testova spominje se i Anderson-Darling test[5].

Prema iskustvima autora kao i objavljenim stručnim i znanstvenim radovima [2, str. 78], [5], [8, str. 356], [22, str. 54], broj brodova često slijedi Poissonovu razdiobu, a taj se zaključak odnosi i na vrijeme opsluživanja broda[6].

Kada rezultati testa pokažu da se navedene varijable ne prilagođavaju dovoljno dobro niti jednoj od odabranih teorijskih razdioba, tada statistika ne daje pravo prihvaćanja nul-hipoteze, odnosno primjenu zakonitosti teorijske razdiobe na zaključivanje o empirijskoj razdiobi. Međutim, pojedini statističari predlažu ili metodu simulacije [8, str. 358] ili prihvaćanje pretpostavljene razdiobe kao aproksimaciju realnog problema [17], [3], s obrazloženjem [6, str. 265] da realne razdiobe vjerojatnosti koje opisuju statističke zakonitosti realnih slučajnih pojava su samo približno normalne, približno eksponencijalne, te da je testiranje "donekle objektivan način" za utvrđivanje odgovarajućeg modela. Računalni program WinQSB [1] također koristi aproksimaciju i metodu simulacije za probleme reda čekanja tipa $G/G/S$ i za redove čekanja kojima je stupanj opterećenja kanala $\rho \geq 1$.

[5] Detalji se mogu naći u uputama računalnih programa Easy Fit [4] i Statgraphics [11].

[6] Međutim, moguće je da se uz iste podatke, primjenom jednog testa ili više testova dobiva zaključak o prihvaćanju različitih razdioba vjerojatnosti [6, str. 245].

Table χ_0^2 which is read from the Table of the critical values χ^2- distribution depending on the number of degrees of freedom (k) and on the level of significance (α), or based on the probability p_i that belongs to the calculated values χ^2.

The Kolmogorov-Smirnov test (*KS*-test) compares the empirical $F_n(x)$ with the theoretical $F(x)$ distribution function. The absolute value of the maximum difference of the empirical distribution function and the assumed theoretical

$$D_n = \max|F_n(x) - F(x)|, \qquad (6)$$

(where n is the number of elements in sample) is a random variable having its probability distribution. The Kolmogorov distribution constructs the test critical area so that if the maximum difference in one point (i.e., for a particular value of the given property) it too large and falls in a critical area, the H_0 hypothesis, stating that the property X in the basic population does have the assumed distribution, should be rejected.

A significant limit put on the application of the *KS*-test assumes that the theoretical distribution function must be continuous, as opposed to χ^2- test, which was originally designed for discrete probability distributions, but can be adapted for continuous distributions too [6, pg. 261].

Besides the above mentioned tests is the Anderson–Darling test[5].

According to the experiences of the authors and published professional and scientific literature [2, pg. 78], [5], [8, pg. 356], [22, pg. 54], the number of ships often follows the Poisson distribution, and this conclusion applies also to the serving time of a ship[6].

When test results show that these variables do not adapt well enough to any of the selected theoretical distributions, then the statistics does not give the right to accept the null hypothesis, i.e., the application of the theoretical distribution patterns to the conclusions made in respect to the empirical distribution. However, some statisticians suggest a method of simulation [8, pg. 358] or the acceptance of the supposed distribution as an approximation of the real problems [17], [3], with an explanation [6, pg. 265] that the real probability distribution describing the statistical rules of real random phenomena

[5] Details can be found in the instructions of computer programs EasyFit [4] and Statgraphics [11].

[6] However, it is possible that the same data, using one or more tests, get a decision on the acceptance of various probability distributions [6, pg. 245].

3. DEFINIRANJE LUČKOGA KONTEJNERSKOG TERMINALA KAO SUSTAVA OPSLUŽIVANJA

Da bi se lučki kontejnerski terminal mogao definirati kao sustav opsluživanja najprije se, primjenom teorije redova čekanja, određuju osnovni parametri: prosječan broj kontejnerskih brodova (odnosno kontejnera) koji pristižu na terminal u promatranoj jedinici vremena i prosječan broj kontejnerskih brodova (odnosno kontejnera) koji se mogu opslužiti u jedinici vremena na terminalu. Zatim se na temelju tih parametara izračunavaju odgovarajući pokazatelji funkcioniranja lučkoga kontejnerskog terminala, kako bi se na kraju, zavisno od postavljenog kriterija optimalnosti, donijela odluka o optimalnom kapacitetu lučkoga kontejnerskog terminala.

3.1. Sustavni pristup istraživanju kontejnerskog terminala

Lučki kontejnerski terminal je dio lučkog sustava namijenjen prekrcaju kontejnera izravnim ili posrednim rukovanjem između kontejnerskih brodova i kopnenih prijevoznih sredstava, i obrnuto te ostalim djelatnostima vezanim za promet kontejnera. Zbog neravnomjernosti dolazaka brodova i kopnenih vozila te organizacije tehnološkog procesa na kontejnerskom terminalu, u praksi prevladava posredno rukovanje kontejnerima preko slagališta [21, str. 36].

Lučki kontejnerski terminal je otvoreni sustav koji neprekidno i vrlo intenzivno komunicira s okolinom i usko je vezan sa sustavom pomorskog prometa, sustavom kopnenog prekrcaja i ostalim sustavima koji su nositelji uslužnih aktivnosti neophodnih u prometu kontejnera.

Lučki kontejnerski terminal je složen sustav sa sljedećim podsustavima kao svojim elementima [21, str. 36–37]:

- *podsustav brod* predstavlja element na koji je usmjerena aktivnost, a obuhvaća brodove, odnosno kontejnere prema vrsti i količini;
- *podsustav operativna obala* uključuje pristane, obalne kontejnerske dizalice i krcalište (operativna površina namijenjena operacijama s kontejnerima);

are only approximately normal, approximately exponential, and that testing is a "somewhat objective way" to determine the appropriate model. A computer program WinQSB [1] also uses the approximation and simulation methods for the queuing problems of the $G/G/S$ type and for the queues with the channel load degree (traffic intensity) $\rho \geq 1$.

3. DEFINING THE PORT CONTAINER TERMINAL AS A SERVING SYSTEM

In order to define a port container terminal as a serving system, basic parameters should be defined by using the queuing theory: the average number of container ships (or containers) arriving in a given unit of time and the average number of container ships (or containers) that can be served on the terminal in a unit of time. Then, on the basis of these parameters, relevant indicators of a port container terminal operation are calculated, and finally, depending on the optimality criterion, the decision is made on the optimal capacity of the port container terminal.

3.1. System approach to the study of a port container terminal

The port container terminal is a part of the port system whose purpose is the transshipment of containers by direct or indirect handling between container ships and shore transportation and vice versa as well as other activities connected with the container traffic. Due to the random arrivals of ships and road vehicles and the organization of the technological processes in the port container terminal, handling through the stacking area predominates in practice (21, pg. 36).

The port container terminal is an open system which constantly and very intensively communicates with the environment and is closely linked to the maritime transportation system, shore transportation system and other systems which carry out serving activities indispensable in the container traffic.

The port container terminal is a complex system with the following subsystems as its elements [21, pg. 36-37]:

- *the ship subsystem* is an element which the activity is aimed at and which covers ships or containers according to the amount and type,

- *podsustav slagalište* je otvoreni prostor uređen za smještaj i čuvanje različitih vrsta kontejnera do njihovog ukrcaja na brod ili utovara na kopneno vozilo;
- *podsustav prometnica za unutarnji prijevoz* čine željeznički kolosijeci, željeznička postrojenja te cestovne prometnice;
- *podsustav rukovanja kontejnerima* obuhvaća operacije s kontejnerima na sidrištu, pristanu i slagalištu;
- *podsustav organizacije* je element terminala sa zadatkom planiranja, koordinacije, nadzora i kontrole prekrcajnog procesa, administrativnog praćenja kontejnera, fakturiranja usluga lučkoga kontejnerskog terminala.

Elementi lučkoga kontejnerskog terminala su tehničke, tehnološke, ekonomske, pravne i organizacijske prirode i nalaze se u odnosima međusobne funkcionalne povezanosti.

Projektiranje svakog podsustava zasebno onemogućuje definiranje lučkoga kontejnerskog terminala kao cjeline, odnosno određivanje veza između navedenih podsustava. Stoga sustavni pristup nalaže da se svi elementi lučkoga kontejnerskog terminala trebaju razmatrati zajedno kao podsustavi u međusobnoj interakciji da bi se moglo pratiti poslovanje lučkoga kontejnerskog terminala i postići njegovo optimalno funkcioniranje.

Budući da kapacitet pristana determinira potreban kapacitet ostalih podsustava lučkoga kontejnerskog terminala, a time i propusnu moć kontejnerskog terminala kao cjeline, problem određivanja optimalnog kapaciteta lučkoga kontejnerskog terminala svodi se na izračunavanje optimalnog broja pristana, što će biti prikazano u ovome radu.

3.2. Pokazatelji funkcioniranja lučkoga kontejnerskog terminala

Iz prethodnih zaključaka slijedi da se broj dolazaka brodova i duljina vremena njihovog opsluživanja mogu uzeti kao slučajne varijable, a zatim empirijske razdiobe tih varijabli aproksimirati s odgovarajućim teorijskim razdiobama. U tome se slučaju za izračunavanje pokazatelja funkcioniranja lučkoga kontejnerskog terminala može primijeniti analitički pristup pomoću teorije redova čekanja.

- *the quay subsystem* is made up of berths, wharf container cranes and loading spots (operational surface area for carrying out operations with containers),
- *the stacking area subsystem* is an open area organized for the stacking and protection of various types of containers until they are dispatched from the terminal,
- *the internal traffic network subsystem* is made up of railway tracks, rail installations and road networks,
- *the container handling subsystem* covers supervision of containers at anchorage, at the berth and on the stacking area,
- *the organization subsystem* is an element of the terminal aimed at planning, coordinating, supervising and controlling the transshipment processes, administrative monitoring of containers, invoicing port container terminal services, etc.

The elements of the port container terminal have a technical, technological, economic and organizational nature and are all in mutual functional interaction links.

Designing a particular subsystem separately is in collision with defining a port container terminal as a whole, as well as with determining the relationships between the subsystems. Therefore, a system approach claims that all elements of a port container terminal must be taken into consideration together as subsystems in mutual interaction with the aim of monitoring a port container terminal work and achieving its optimal functioning.

Since the capacity of the berth determines the required capacity of other subsystems of port container terminals, and thus the throughput capacity of a container terminal as a whole, the problem of determining the optimum capacity of the port container terminal is reduced to calculate the optimum number of berths, which will be shown in this paper.

3.2. Indicators of a port container terminal functioning

From previous findings, it follows that the number of the ship arrivals and the length of their serving time may be taken as random variables, and after that the empirical distributions of these variables can be approximated with the corresponding theoretical distributions. In this case an analytical approach, using the queuing

Lučki kontejnerski terminal definira se kao sustav opsluživanja sa sljedećom strukturom [21, str.50]: ulazne jedinice su kontejnerski brodovi koji formiraju (ili ne) red čekanja (zavisno od trenutačne situacije) da bi bili opsluženi (iskrcaj kontejnera) na pristanu kontejnerskog terminala, te nakon obavljene usluge izašli iz sustava. Vrijedi i obrnuto, u slučaju ukrcaja kontejnera na brod.

Sa stajališta teorije redova čekanja lučki kontejnerski terminal ima ove značajke [21, str. 52]:

- Kontejnerski terminal je otvoreni sustav budući da izvori ulaznog toka, tj. brodovi nisu sastavni dio sustava.
- Kontejnerski terminal je jednokanalni ili višekanalni sustav (zavisno od broja pristana), s time da se na sidrištima formiraju redovi čekanja brodova za pojedine pristane.
- Broj pristiglih kontejnerskih brodova kao i duljina vremena opsluživanja, odnosno vrijeme boravka broda na pristanu raspoređeni su prema određenim teorijskim razdiobama (najčešće prema Poissonovoj ili Erlangovoj razdiobi reda k, gdje je k prirodan broj). Vrijeme opsluživanja broda zajedno s vremenom provedenim u redu čekanja predstavlja vrijeme boravka broda na terminalu i jedan je od važnijih pokazatelja funkcioniranja lučkoga kontejnerskog terminala.
- S obzirom na disciplinu čekanja kontejnerski je terminal sustav u kojem se opsluživanje najčešće obavlja prema pravilu FIFO (prvi stigao – prvi opslužen), iako je moguće da postoje brodovi s prioritetom u opsluživanju.

Osnovni parametri lučkoga kontejnerskog terminala su intenzitet toka dolazaka brodova λ i intenzitet opsluživanja μ.

Za odabrani sustav kontejnerskog terminala parametar λ predstavlja prosječan broj kontejnerskih brodova, odnosno kontejnera koji pristižu na terminal tijekom promatrane vremenske jedinice (primjerice: tijekom godine, mjeseca ili dana) ili recipročnu vrijednost prosječnog vremenskog intervala između dva uzastopna dolaska broda $\lambda = 1/\bar{t}_{arr}$.

Analogno se objašnjava i intenzitet opsluživanja μ koji predstavlja prosječan broj kontejnerskih brodova, odnosno kontejnera koji se mogu opslužiti u jedinici vremena na pojedinom pristanu ili recipročnu vrijednost prosječnog trajanja usluživanja $\mu = 1/\bar{t}_{serv}$. Parametar μ

theory, can be applied for calculating the functioning indicators of the port container terminal.

A port container terminal is defined as a queuing system with the following structure [21, pg. 50]: the input units are container ships that form (or not) a queue (depending on the momentary situation) to be served (unloading of containers) at the container berths (serving channels), and leave the system when the service has been performed. This could also be reversed, in the case of container loading on board a ship.

From the queuing theory viewpoint, a port container terminal has the following characteristics [21, pg. 52]:

- A port container terminal is an open system as the ships are not a component part of the system.
- A port container terminal is a single or multichannel system (depending on the number of berths) and, in this connection, ships at anchorage form queues for particular berths.
- The number of the ship's arrivals, as well as the duration of the serving time, i.e. duration of the ship's stay at the berth, are allocated according to certain probability distributions (most often according to Poisson's or Erlang's distribution of the k-order, where k is a natural number). The ship's serving time, together with the time spent queuing at the berth, represents the time of the ship's stay at the terminal, and is one of the more significant indicators of the port container terminal operations.
- As regards queuing discipline, a container terminal is a system where the serving is most often carried out according to the FIFO rule (first come-first served), but it is possible that there are certain ships which have priority in serving.

The basic parameters of the port container terminal are the intensity of the arrivals of ships (arrival rate) λ and the intensity of the ship serving (service rate) μ.

For the selected container terminal system, parameter λ represents the average number of container ships (i.e. containers) arriving at the terminal during the observed time unit (for example: during a year, month or day) or the reciprocal value of the average time interval between two consecutive ship arrivals $\lambda = 1/\bar{t}_{arr}$.

The intensity of the ship serving μ, which represents the average number of container predstavlja propusnu moć jednog pristana, a umnožak $S \times \mu$, gdje je S oznaka za broj pristana, propusnu moć, odnosno kapacitet kontejnerskog terminala.

Količnik intenziteta toka dolazaka i intenziteta opsluživanja je stupanj opterećenja pristana ili intenzitet prometa. U praksi se vrijednosti parametara λ i μ određuju na temelju empirijskih podataka ili procjenom zavisno od cilja i predmeta istraživanja.

Na temelju definicije kontejnerskog terminala kao sustava opsluživanja i osnovnih parametara terminala izračunavaju se pokazatelji funkcioniranja lučkoga kontejnerskog terminala: koeficijent iskoristivosti kontejnerskog terminala, vjerojatnost opsluživanja, prosječan broj brodova u redu čekanja, odnosno na terminalu, prosječno vrijeme broda u redu čekanja, odnosno provedeno na terminalu, ...

Prema klasifikaciji problema redova čekanja, kontejnerski terminal je sustav s čekanjem koji dozvoljava beskonačni broj brodova u redu čekanja s oznakom $M/M/S/\infty$ ili $G/G/\infty$, zavisno od teorijske razdiobe za dolaske i vrijeme opsluživanja broda.

Pokazatelji funkcioniranja kontejnerskog terminala izračunavaju se prema odgovarajućim formulama teorije redova čekanja[7] [22, str. 19–26].

Promjena broja pristana utječe na povećanje, odnosno smanjenje vrijednosti pojedinih pokazatelja kontejnerskog terminala: povećanjem broja pristana smanjuje se broj brodova u redu čekanja i na terminalu te vrijeme čekanja i vrijeme boravka broda na terminalu, a povećava neiskorištenost pristana.

Na temelju pokazatelja o funkcioniranju kontejnerskog terminala može se postaviti pitanje kako odrediti broj pristana da se čekanje broda i pristana svede na najmanji mogući iznos.

Odluka o optimalnom broju pristana kontejnerskog terminala zavisi od postavljenog kriterija optimizacije, primjerice: postotka iskorištenja pristana, duljine vremena čekanja broda u redu, broja brodova u redu čekanja ili troškova

[7] Osim navedenog izvora formule za izračunavanje pokazatelja sustava opsluživanja mogu se naći u knjigama iz teorije redova čekanja [3], [7], [8], [17]. Čitateljima se preporuča korištenje odgovarajućih računalnih programa, primjerice WINQSB koji se može naći na http://winqsb.en.softonic.com/download (travanj, 2012).

ships (i.e. containers) that can be served in a unit of time at a certain berth or the reciprocal value of the average time of the ship serving $\mu = 1/\bar{t}_{serv}$ has been analogously explained. The parameter μ represents the throughput of the single berth and the product $S \times \mu$, where S is the berth number, the throughput, or the capacity of the container terminal.

The ratio between the arrival rate and the service rate is the degree of the berth load or the traffic intensity. In practice, the values of the parameters λ and μ are defined on the basis of the empirical data sheet or of the assessment depending on the goal and object of research.

Based on the definition of a container terminal as a queuing system and the basic parameters of the terminal, the indicators of the port container terminal functioning are calculated: the efficiency coefficient of a container terminal, the probability of serving, the average number of ships in the queue or at the terminal, the average time of a ship in the queue or spent at the terminal, ...

According to the classification of queuing problems, the container terminal is a queuing system that allows an infinite number of ships in the queue with the sign $M/M/S/\infty$ or $G/G/\infty$, depending on the theoretical distributions for the arrival rate and the serving time of a ship.

Indicators of a container terminal operation are calculated according to the corresponding formulas of the queuing theory[7] [22, pg. 19–26].

The change in the number of berths affects the increase or decrease of the values of certain indicators of a container terminal: increasing the number of berths reduces the number of the queuing up ships and of the ships at the terminal as well as the waiting time and the stay time at the terminal, while the underutilization of the berth is increased.

On the basis of the container terminal operation indicators, a question may be raised as to how to define the number of berths in order to reduce the waiting time and the number of berths as much as possible.

The decision on the optimal number of berths at a container terminal depends on the established optimization criteria, for example: the percentage utilization of the berth, the

[7] Except from the above sources the formulas for calculating the parameters of the queuing process can be found in books on the theory of queues [3], [7], [8], [17]. Readers are advised to use appropriate computer programs, such WinQSB which can be found at http://winqsb.en.softonic.com/download (April 2012).

čekanja broda i nezauzetosti pristana, odnosno odabire se onaj kriterij koji se smatra najvažnijim za efikasno funkcioniranje kontejnerskog terminala.

Efikasnost kontejnerskog terminala najčešće se u praksi određuje pomoću pokazatelja duljine vremena boravka broda na terminalu (vrijeme broda provedeno u redu čekanja i vrijeme opsluživanja broda) i ona se povećava ili povećanjem broja pristana ili skraćivanjem prosječnog vremena opsluživanja. Međutim, povećanjem broja pristana povećat će se vjerojatnost da su pristani slobodni, a to znači da će se povećati nezauzetost pristana. Isto tako, skraćivanje vremena opsluživanja broda može utjecati na kvalitetu usluge te na smanjenje broja dolazaka brodova. Zato se efikasnost kontejnerskog terminala najbolje može odrediti uvođenjem vrijednosnih pokazatelja, tj. pomoću troškova, budući da se u praksi čekanje broda plaća, a nezauzetost pristana se također može vrijednosno izraziti.

4. STUDIJA SLUČAJA – KONTEJNERSKI TERMINAL RIJEČKE LUKE BRAJDICA

Primjena predloženih metoda proučavanja procesa opsluživanja na lučkim kontejnerskim terminalima prikazana je na primjeru kontejnerskog terminala riječke luke.

4.1. Tehničko-tehnološke značajke kontejnerskog terminala Brajdica

Do 2011. godine vlasnik kontejnerskog terminala Brajdica bila je tvrtka Jadranska vrata d.d. u stopostotnom vlasništvu Luke Rijeka d.d. Novi strateški partner i vlasnik 51% dionica tvrtke Jadranska vrata d.d., koja je njegovim ulaskom preimenovana u Adriatic Gate Container Terminal je međunarodni lučki operater ICTS (International Container Terminal Services).

Kontejnerski terminal Brajdica raspolaže s dva pristana: Kostrensko pristanište-jug te Kostrensko pristanište-zapad. Dužina južnog pristana iznosi 295 metara, a dubina mora uz obalu 12 metara, dok je zapadni pristan dug 164 metara s dubinom mora uz obalu od 11 metara. Na zapadnom pristanu se nalazi obalna kontejnerska dizalica Metalna, koja je preseljena s

length of the queuing up time of a ship, the number of ships queuing up or the waiting costs of a ship and the unoccupancy of the berth, and, finally, or, in other words, the one criterion, that is considered as the most important for an efficient functioning of the container terminal, is selected.

The efficiency of the container terminal is mostly defined by using the indicator of the duration of the ship stay at the terminal (the duration of the ship in queue and the duration of the ship serving) and is increased either by increasing the number of berths or reducing the average serving time. However, by increasing the number of berths the probability that the berths are free will also increase which means that the unoccupancy of berths will increase. Moreover, reducing the time of a ship serving time can affect the quality of service and reduce the number of the ship arrivals. So the efficiency of the container terminal can be best determined by using the value indicators, in other words the costs, since the waiting of the ship produces payments and the disengagement of the berths also carries a value.

4. CASE STUDY– THE CONTAINER TERMINAL “BRAJDICA” AT THE PORT OF RIJEKA

The implementation of the proposed methods for studying the serving processes at the port container terminals is presented through the example of the container terminal “Brajdica” at the Port of Rijeka.

4.1. Technical-technological aspect of the container terminal “Brajdica”

Since the year 2011, the owner of the container terminal “Brajdica” has been the company Jadranska vrata, the company owned by the Port of Rijeka in 100 percent of stocks. The new strategic partner and the owner of 51 percent of the stocks of the company Jadranska vrata, which, with the entering of this new partner, was renamed into the Adriatic Gate Container Terminal, is now the international port operator ICTS (International Container Terminal Services).

The container terminal “Brajdica” has two berths: the first berth, the Kostrenska quay – SOUTH, and the second berth, the Kostrenska quay – WEST. The southern berth is 295 m long južnog pristana 2009. godine radi povećanja operativnog kapaciteta terminala. Metalna se koristi isključivo za prekrcaj manjih brodova, i to u slučaju zauzetosti južnog veza, budući da je dohvat dizalice ograničen i dozvoljava samo niže dizanje kontejnera. Na južnom pristanu trenutno su u eksploataciji dvije obalne kontejnerske dizalice korejskog proizvođača Samsung koje svojim tehničko-tehnološkim značajkama osiguravaju potrebe prekrcaja kontejnerskog terminala.

Mehanizacija slagališta riječkog kontejnerskog terminala se sastoji od autodizalica s hvatačem, čelnih viličara s dugim nosačima vilica te tegljača s prikolicama i poluprikolicama. Osnovu slagališnih prekrcajno-prijevoznih sredstava čine autodizalice s hvatačem koje se ubrajaju u tzv. horizontalnu mehanizaciju.

Postojeća ukupna površina kontejnerskog terminala riječke luke iznosi približno 140 000 m^2 od čega je površina slagališta kontejnera 56 100 m^2.

Radi povećanja kapaciteta kontejnerskog terminala i mogućnosti servisiranja većih brodova u tijeku je izgradnja nove operativne obale u dužini od 328 metara u produžetku postojećeg Kostrenskog pristaništa-jug s dubinom mora uz pristan od 14,5 metara. Kostrensko pristanište-zapad koristit će se u prijelaznoj fazi do završetka produženja južnog pristaništa te nije predviđeno za daljnju eksploataciju u budućnosti s obzirom na ograničenja u pogledu dubine mora i duljine pristana. Na tom pristanu se danas obavljaju prekrcajne operacije manjih feeder brodova samo u slučaju zauzetosti južne obale.

Nakon dogradnje postojećeg pristana na jugu će biti postavljene još dvije obalne kontejnerske dizalice eksploatacijskih značajki potrebnih za servisiranje kontejnerskih brodova Post-Panamax generacije kapaciteta od 8 000 do 10 000 TEU-a. Na taj će način postojeće dvije kontejnerske dizalice moći prelaziti na novi produženi dio obale i tako omogućiti prekrcaj broda s tri, odnosno četiri mosta, zavisno od veličine broda.

Projekt proširenja terminala predviđa instalaciju dva para portalnih prijenosnika velikog raspona na skladišnom prostoru punih kontejnera kako bi se postigla bolja iskoristivost slagališne površine. Primjenom tih skladišnih mostova postojeća horizontalna tehnologija

and the sea depth is 12 m at the quay, while the western berth is 164 m long with the sea depth of 11 m at the quay. On the western berth, the older port container crane “Metalna” is located. This crane was moved from the south quay in 2009 in order to increase the operating capacity of the terminal. “Metalna” is used only for the handling of smaller container ships, when the south berth is not available, since the crane outreach is limited allowing only the lower lifting of containers. On the southern berth, there are two port container cranes manufactured by Samsung whose technical and technological features ensure the existing needs of the container terminal.

The machinery of the Rijeka container terminal stacking area consist of a reachstackers, of main forklifts with long fork carriers, tugmaster trailers and semi trailers. The bases of the transport-handling equipment operating on the stacking area are reachstackers that are part of the so-called horizontal machinery.

The actual total surface area of the container terminal in the Port of Rijeka is 140,000 m^2 of which the stacking surface is 56,100 m^2.

In order to increase the capacity of the container terminal and to serve larger ships, the new operating quay will be 328 meters long with the sea depth of 14.5 meters and will be constructed as the extension of the south quay. The Kostrenska quay – WEST will be used in the transitional phase till the ending of the extension of the south quay and it is not predicted for further exploitation in the future, considering the limits related to the sea depth and the length of the quay. On this quay, the reload operations of smaller feeder ships are done only when the south quay is not available.

After upgrading the existing quay on the south, two container cranes, with technical features necessary for servicing container ships of the Post-Panamax generation with the capacity of 8,000 to 10,000 TEU, will be placed on the south quay. The two existing container cranes will be able to move onto the new quay and will enable the serving of a ship with three or four cranes, depending on the size of the ship.

The project of the quay extension predicts the installation of two pairs of large range transtainers on the storage surface for full containers, in order to enable a better usage of the stacking surface. By using these shore container cranes, the existing horizontal reload technology would be replaced by the vertical technology.

prekrcaja zamijenila bi se vertikalnom tehnologijom.

Rekonstrukcija i nadogradnja terminala predviđa uređenje približno 167 000 m^2 površine lučkog područja, dok će se po završetku dogradnje površina slagališta kontejnera s postojećih 56 100 m^2 povećati na 103 600 m^2.

Nakon realizacije opisanih projekata kapacitet kontejnerskog terminala Brajdica iznosit će približno 500 000 TEU-a godišnje.

4.2. Statistička analiza prometa kontejnerskog terminala Brajdica

Analiza kretanja kontejnerskog prometa riječke luke [11] pokazuje da, nakon izrazitog pada koji se zbog ratnih događanja već počeo osjećati devedesetih godina te nastavio sve do kraja desetljeća, od 2001. godine kreće porast prometa. Tako je u 2000. godini prekrcano 9 722 TEU-a, da bi se pozitivna tendencija kretanja prometa kontejnera nastavila sve do 2008. godine kada je ostvareno 168 761 TEU-a, odnosno 17 puta veći promet u odnosu na 2000. godinu. U 2009. godini zabilježen je pad kontejnerskog prometa (prekrcano je 130 740 TEU-a) generiran u prvom redu smanjenjem uvoza uslijed gospodarske krize, dok je tijekom 2010. godine ostvaren oporavak prometa rastom od 4% u odnosu na godinu dana ranije.

Uspoređujući broj brodova pristiglih na kontejnerski terminal s ostvarenim prometom uočeno je da broj brodova raste sporije u odnosu na količinu prometa što je u skladu s dolaskom sve većih brodova na terminal, odnosno veće količine prekrcanih kontejnera po pojedinom brodu. Tako je u 2008. godini na terminal privezano 256 brodova ili 33,3% više nego u 2003. godini, dok je u istom razdoblju promet povećan za gotovo 6 puta.

Međutim, za sveobuhvatnu analizu nisu dovoljni samo podaci o godišnjem prometu i ticanju brodova već treba uzeti u obzir promet po mjesecima i danima koji, zbog oscilacija, znatno utječe na dimenzioniranje kapaciteta terminala.

Na temelju metodologije iz dijela 2.1. ovoga rada ispitana je veza između broja brodova i dana pristizanja na terminal Brajdica; sastavljena je korelacijska tablica za broj brodova pristiglih idućeg i prethodnog dana u razdoblju od 2000. do 2010. godine. S obzirom na prethodno objašnjene različite tendencije kretanja godiš-

The reconstruction and extension of the terminal predicts the development of nearly 167,000 m^2 of port surface, while, after upgrading the container stacking surface with the existing 56,100 m^2, will increase to 103,600 m^2.

After achieving the described projects, the capacity of the container terminal Brajdica will be nearly 500,000 TEU per year.

4.2. Statistical analysis of the traffic at the container terminal "Brajdica"

The analysis of container traffic trends in the Port of Rijeka [11] has shown that, after a striking decrease, which due to the war started as early as in the '90s and continued up to the end of the decade, it has been increasing since the year 2001. In 2000, there were 9,722 TEU handled and the positive trend continued up to the year 2008 with 168,761 TEU, or with a 17 times larger transshipment as compared to the year 2000. In 2009, a decrease of the container traffic was noted (130,740 TEU), resulting from the reduced import caused by the economic crisis, while in 2010, the transshipment was slightly recovered, i.e. increased by 4% as compared with the previous year.

The comparison of the number of ships that arrived to the container terminal with the realized traffic shows that the number of ships increases slower as compared to the traffic volume, which corresponds to the arrival of ever larger ships to the terminal, i.e., greater quantity of containers per ship rate. In 2008, 256 ships were berthed, i.e. 33.3% more than in 2003, while the respective traffic increased by almost six times.

However, for a comprehensive analysis the data on the annual container traffic and on the arrivals of ships are not enough, so what should be taken into account are the monthly and daily container traffic data that, due to oscillations, significantly affect the dimensioning of the terminal capacity.

On the basis of the methodology presented in 2.1, the relation between the number of ships and days of their arrivals at the container terminal "Brajdica" has been examined; the correlation table has been compiled for the number of ships that arrived on the next and previous day in the period from 2000 to 2010. Considering the previous explanation in respect to different trends in the annual traffic, the periods from 2000 to 2006 and from 2000 to 2010 njeg prometa uzeto je u razmatranje razdoblje od 2000. do 2006. te od 2000. do 2010. godine. Za prvo razdoblje dobiven je koeficijent korelacije r = – 0,0378641, a za drugo r = – 0,00021421.

S obzirom da su obje vrijednosti koeficijenata korelacije vrlo blizu nule, slijedi zaključak da ne postoji značajna zavisnost u redoslijedu dnevnih dolazaka brodova na terminal Brajdica u navedenim razdobljima, što znači da se dolasci brodova mogu promatrati kao nezavisni, tj. da su dolasci brodova u statističkom smislu slučajni.

Testiranjem koeficijenata korelacije za razdoblje 2000. – 2006. i 2000. – 2010. ispitana je pretpostavka da ne postoji značajna razlika između tih koeficijenata. Prema (2) i (3) interval prihvaćanja hipoteze glasi 0 ± 0,0496; razlika $\left|\hat{z}_1 - \hat{z}_2\right|$ = 0,0379 – 0,0002 = 0,0377 se nalazi u tom intervalu na temelju čega se zaključuje da se na razini 5% značajnosti prihvaća pretpostavka da se koeficijenti korelacije u oba skupa međusobno ne razlikuju.

Iz navedenog slijedi da se broj dolazaka brodova na kontejnerski terminal Brajdica može uzeti kao slučajna varijabla, a zatim empirijske razdiobe te varijable aproksimirati s odgovarajućim teorijskim razdiobama. Isti se zaključak dobiva i za varijablu – vrijeme boravka broda na kontejnerskom terminalu.

4.3. Usporedba empirijskih s teorijskim razdiobama

Ispitivanje o slaganju empirijske razdiobe s nekom od teorijskih razdioba provedeno je primjenom neparametarskih testova (vidjeti 2.2. ovoga rada).

4.3.1. Dolasci brodova

S obzirom na različite tendencije kretanja prometa, empirijska razdioba za broj brodova pristiglih na terminal Brajdica je prema ocjeni autora sastavljena za tri razdoblja, i to: 2000.–2006., 2007.–2010. i 2000.–2010., a izračunati pokazatelji prikazani u tablici 1.

were considered. The obtained correlation coefficients were r = – 0.037864 and r = – 0.00021421 for the first and second period respectively.

Given that both the values of the correlation coefficients very close to zero, it follows that there is no significant dependence on the order of the daily arrivals of ships at the container terminal “Brajdica” in those periods, which means that the arrivals of ships can be seen as independent, i.e. that the arrivals of ships are random in the statistical sense.

The correlation coefficients for the 2000 to 2006 and 2000 to 2010 periods were tested aiming to examine the hypothesis that there is no significant difference among the coefficients. According to (2) and (3), the hypothesis acceptance interval is 0 ± 0.0496; the difference $\left|\hat{z}_1 - \hat{z}_2\right|$ = 0.0379 – 0.0002 = 0.0377 is within the interval, thus leading to the conclusion that the hypothesis, stating that the correlation coefficients of both the sets do not differ, is accepted at a 5% significance level.

In view of all this, the number of the ship arrivals at the container terminal “Brajdica” can be taken as a random variable, and then the empirical distribution of these variables can be approximated with the corresponding theoretical distributions. The same conclusion has been reached for the variable during the ship’s stay at the container terminal.

4.3. Comparison of the empirical and theoretical distributions

The examination of the empirical distribution agreement with some of the theoretical distributions was performed by using the nonparametric tests (see 2.2. of this paper).

4.3.1. Arrivals of ships

Considering the various tendencies in the movement of ships, the empirical distribution for the number of ships arrived at the container terminal “Brajdica” has been compiled at the author’s discretion for the three following periods: 2000 to 2006, 2007 to 2010 and 2000 to 2010. The calculated indicators are shown in Table 1.

Tablica 1. Deskriptivna statistika za dolaske brodova na terminal Brajdica u razdoblju 2000.– 2010.
Table 1 *Descriptive statistics for the ships' arrivals at the container terminal "Brajdica" in the 2000 to 2010 period*

Pokazatelj *Indicator*	2000 – 2006	2007 – 2010	2000 – 2010
1. Broj brodova dnevno (x) *1. Number of ships – daily* (x)	0 – 4	0 – 4	0 – 4
2. Broj dana (f) *2. Number of days – total* (f)	2 557	1 461	4 018
3. Prosj. broj brodova dnevno ($\overline{X}$) *3. Average number of ships per day* ($\overline{X}$)	0.45483	0.67967	0.53659
4. Standardna devijacija (σ) *4. Standard deviation* (σ)	0.65782	0.69543	0.68030
5. Mod (M_0) *5. Mode* (M_0)	0	1	0
6. Koef. asimetrije (α_3) *6. Coefficient of skewness* (α_3)	1.32	0.80871	1.10154
7. Koef. zaobljenosti (α_4) *7. Coefficient of kurtosis* (α_4)	1.29	0.63425	0.87884

Rezultati iz prethodne tablice pokazuju da je prosječan broj pristiglih brodova dnevno iznosio manje od jednog broda, te da je najviše dana bilo bez ijednog broda, odnosno s jednim brodom (razdoblje 2007.– 2010.), a s obzirom da se broj brodova kretao dnevno od 0 do 4 broda, slijedi da empirijske razdiobe nisu simetrične, već desnostrano asimetrične i manje zaobljene u odnosu na normalnu razdiobu.

Ovi rezultati već ukazuju na "ponašanje" razdiobe dana prema broju brodova. Međutim, s odgovarajućim neparametarskim testovima moguće je izračunati "veličinu" slaganja empirijske razdiobe s odabranim teorijskim razdiobama.

U tu svrhu su korišteni računalni programi EasyFit 5.5 [4], Statistica 6 [12], Statgraphics 9.3. − 9.4. [11] i dobiveni rezultati navedeni u tablicama 2. – 4.

Na temelju rezultata iz tablice 2 slijedi da bi se mogla prihvatiti pretpostavka da se razdioba pristiglih brodova ponaša prema Poissonovoj razdiobi. Međutim, prema ulaznim podacima neprihvatljiv je rang 1 za diskretnu uniformnu razdiobu po *K-S* testu, tim više što se na osnovi rednog broja ranga ne može zaključiti prihvaća li se H_0; daljnjim istraživanjem ustanovljeno je da su kritične vrijednosti izvan intervala prihva-

The results presented in the previous table show that the daily average number of arrived ships was less than one ship, that on most days there were no ships or there was one single ship (period 2007 to 2010). Considering the fact that the number of ships per day was 0 – 4, it follows that the empirical distributions were not symmetric, but right biased asymmetric and less rounded as compared with a normal distribution.

These results indicate the "behavior" of the day distribution as related to the number of ships. However, adequate nonparametric tests enable us to calculate the "magnitude" of the empirical distribution matching with the selected theoretical distributions.

For this purpose, the following software has been used: EasyFit 5.5 [4], Statistica 6 [12] and Statgraphics 9.3.–9.4. [11] and the obtained results have been pointed out in Tables 2– 4.

On the basis of the results from the table 2, it follows that the hypothesis, stating that the distribution of the ships' arrivals behaves in line with the Poisson distribution, may be accepted. However, according to the input data, rank 1 is not acceptable for a discrete uniform distribution per *K–S* test, particularly since it cannot be concluded whether H_0 is accepted or not on the basis of rank ordinal number; further investigation revealed that critical values are outside the null hypothesis acceptance interval. It must also ćanja nul-hipoteze. K tome treba dodati da ovaj program ne uključuje ostale testove kao što je-primjerice, χ^2–test koji se u statističkoj literaturi preporuča i za prekidne i kontinuirane empirijske razdiobe [6, str. 261].

Zbog toga je bilo potrebno koristiti i ostale računalne programe (Tablice 3. i 4.).

be said that the software does not include other tests, for example, χ^2–test, which statistics literature recommends for both the discontinuous and the continuous empirical distributions [6, pg. 261].

It was therefore necessary to use other computer programs (Tables 3 and 4).

Tablica 2. Rangiranje razdiobe brodova pristiglih na terminal Brajdica prema vrsti testa, vrsti teorijske razdiobe i razdoblju na koje se odnose podaci (EasyFit 5.5)
Table 2 *Ranking the distribution of the ships' arrivals at the container terminal "Brajdica" according to the type of test, type of theoretical distribution and the period to which the data relate (EasyFit 5.5)*

Teorijska razdioba *Theoretical distribution*	2000 – 2006		2007 – 2010		2000 – 2010	
	Test / *Test*					
	K-S	*A-D*	*K-S*	*A-D*	*K-S*	A-D
1. Binomna / *Binomial*	3	2	1	4	3	3
2. D. uniformna / *D. uniform*	1	4	3	3	1	4
3. Geometrijska / *Geometric*	4	3	4	2	4	2
4. Poissonova / *Poisson*	2	1	2	1	2	1

Opaska: *K-S* (Kolmogorov-Smirnovljev test), *A-D* (Anderson-Darling test)
Note: K–S Kolmogorov–Smirnov test, A–D Anderson–Darling test

Tablica 3. χ^2–test za razdiobu pristiglih brodova na terminal Brajdica u razdoblju 2000. – 2010. (Statistica 6)
Table 3 *χ^2–test for the distribution of the ships' arrivals at the container terminal "Brajdica" in the 2000 to 2010 period (Statistica 6)*

Teorijska razdioba *Theoretical distribution*	Razdoblje / *Period*		
	2000 – 2006	2007 – 2010	2000 – 2010
1. Binomna / *Binomial*	9.2008 (0.010)	31.5063 (0.000)	0.7975 (0.671)
2. Poissonova / *Poisson*	4.0513 (0.132)	91.4273 (0.000)	42.533 (0.000)
3. Normalna / *Normal*	2 680.5 (0.000)	1 525.34 (0.000)	4 225.2 (0.000)

Tablica 4. Rangiranje broja pristiglih brodova na terminal Brajdica prema vrsti testa, vrsti teorijske razdiobe i razdoblju na koje se odnose podaci (Statgraphics 9.3. – 9.4.)
Table 4 *Ranking the number of the ships' arrivals at the terminal "Brajdica" according to the type of test, type of theoretical distribution and the period which the data are related to (Statgraphics 9.3.– 9.4.)*

Teorijska razdioba *Theoretical distribution*	2000– 2006			2007– 2010			2000– 2010		
	Test / *Test*								
	K-S	*A-D*	χ^2	*K-S*	*A-D*	χ^2	*K-S*	*A-D*	χ^2
1. Binomna / *Binomial*	–	–	4.469 (0.215)	–	–	91.240 (0.00)	–	–	42.468 (0.00)
2. Poissonova / *Poisson*	–	–	4.487 (0.213)	–	–	91.427 (0.00)	–	–	42.533 (0.00)
3. Normalna / *Normal*	0.385 (0.00)	362.5 (<0.01)	575.4 (0.00)	0.275 (0.00)	140.8 (<0.01)	120.83 (0.00)	0.345 (0.00)	477.92 (<0.01)	635.25 (0.00)

Opaska: *K-S*(Kolmogorov-Smirnovljev test), *A-D*(Anderson-Darling test), χ^2-test; vrijednosti u zagradama su vjerojatnosti p_i
Note: K–S Kolmogorov–Smirnov test, A–D Anderson–Darling test, χ^2 – test; values in the parentheses are the probabilities p_i

Program Statistica za diskontinuirane slučajne varijable (broj brodova) koristi samo χ^2-test. Prema dobivenim rezultatima najbolje je slaganje broja pristiglih brodova s Poissonovom razdiobom u razdoblju od 2000. do 2006. te s binomnom razdiobom u razdoblju od 2000. do 2010. godine.

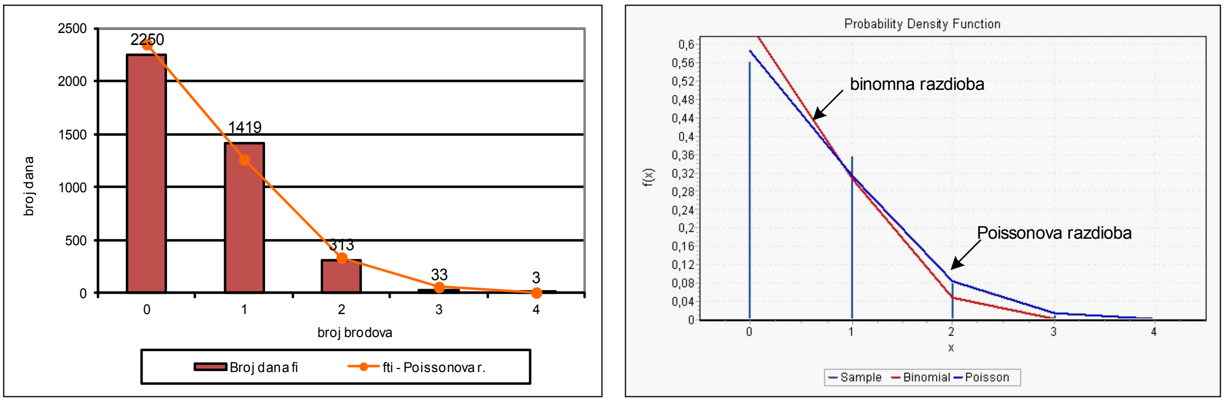
Primjenom računalnog programa Statgraphics dobiveni rezultati za različite testove dovode do zaključka da je razdiobu brodova pristiglih na kontejnerski terminal riječke luke najbolje aproksimirati binomnom, odnosno Poissonovom razdiobom.

Iz tablica 2.–4. slijedi zaključak da se dolasci brodova na kontejnerski terminal Brajdica najbolje slažu s binomnom i Poissonovom razdiobom što potvrđuje grafikon 1.

The program Statistica for discontinuous random variables (number of ships) uses only χ^2-test. The results have shown[8] that the number of the ships' arrivals fits best in with the Poisson distribution ranging from the 2000 to the 2006 period of time, as well as with the binomial distribution ranging from year 2000 to year 2010.

The Statgraphics software has provided results in various tests, leading to the conclusion that the distribution of the ships' arrivals at the Port of Rijeka container terminal may be most appropriately approximated by the binominal and Poisson distribution.

Finally, from tables 2–4, it follows that the arrivals of the ships at the container terminal "Brajdica" most appropriately match the binominal and Poisson distribution, as confirmed in Graph 1.



Grafikon 1. Usporedba dolazaka brodova na kontejnerski terminal Brajdica s binomnom i Poissonovom razdiobom u razdoblju 2000.–2010.

Graph 1 *Comparison of the ships' arrivals at the container terminal "Brajdica" with the binominal and Poisson distribution for the 2000 to 2010 period of time*

4.3.2. Vrijeme opsluživanja

Kao što je navedeno u dijelu 3.2. ovoga rada intenzitet opsluživanja predstavlja broj opsluženih brodova u jedinici vremena, a može se odrediti kao recipročna vrijednost trajanja usluge (vremena opsluživanja).

Za kontejnerski terminal Brajdica autori su raspolagali s podacima o duljini vremena opsluživanja broda za razdoblje od 2007. do 2010. godine na temelju kojih su izračunati pokazatelji prikazani u tablici 5.

Prosječno vrijeme opsluživanja broda iznosilo je 14,1787 sati, međutim, za najveći broj brodova vrijeme opsluživanja je trajalo 6,75 sati; koeficijenti asimetrije i zaobljenosti pokazuju da je razdioba vremena opsluživanja desnostra-

4.3.2. Serving time of a ship

As stated in section 3.2. of this paper, the service rate is the number of ships served in the unit of time, and can be defined as the reciprocal value of the serving time of a ship.

The authors have had data in respect to the ship serving duration for the 2007 to 2010 period, which have been used to calculate the indicators presented in Table 5.

[8] In Tables 3 and 4, in parentheses are the probabilities p_i upon which the decision on the acceptance (or not) of the null hypothesis; the probabilities are not equal to 0, because, in this table, their values with a smaller number of decimal places are entered. Values p_i less than 0.05 indicate the rejection of the null hypothesis that the empirical distributions treats selected the theoretical distribution at the 5% level of significance, and 0.01 at the 1% level of significance.

Tablica 5. Deskriptivna statistika za vrijeme opsluživanja broda na terminalu Brajdica u razdoblju 2007.– 2010.
Table 5 *Descriptive statistics for the serving time of a ship at the container terminal "Brajdica" in the 2007 to 2010 period of time*

Pokazatelj / *Indicator*	2007 – 2010
1. Vrijeme opsluživanja (x) *Time of serving a ship* (x)	1 – 89.5 sati 1 – 89.5 hours
2. Broj brodova (f) *Number of ships – total* (f)	997
3. Prosj. vrijeme opsluživanja ($\overline{X}$) *Average time of serving per ship* ($\overline{X}$)	14.17870 sati 14.17870 *hours*
4. Standardna devijacija (σ) *Standard deviation* (σ)	8.45785 sati 8.45785 *hours*
5. Mod (M_0) *Mode* (M_0)	6.75 sati 6.75 *hours*
6. Koef. asimetrije (α_3) *Coefficient of skewness* (α_3)	1.80
7. Koef. zaobljenosti (α_4) *Coefficient of kurtosis* (α_4)	8.78

no asimetrična i s većom zaobljenosti od normalne razdiobe.

Testiranje razdiobe vremena opsluživanja s obzirom na slaganje s odabranom teorijskom razdiobom provedeno je primjenom neparametarskih testova i računalnih programa Easy Fit 5.5, Statistica 6 i Statgraphics 9.3.– 9.4.

Dobiveni rezultati su prikazani u tablicama 6.–8.

The average time of serving a ship is amounted to 14.1787 hours; however, for the greatest number of ships the serving time lasted 6.75 hours, the coefficients of skewness and kurtosis indicate that the distribution of the serving time is right sided asymmetric with a greater curvature of the normal distribution.

Testing the distribution of the serving time with respect to the fitting in with the selected theoretical distribution has been performed by using nonparametric tests and the computer software EasyFit 5.5, Statistica 6 and Statgraphics 9.3.–9.4. The results are shown in Tables 6–8.

Tablica 6. Rangiranje razdiobe vremena opsluživanja broda na terminalu Brajdica prema vrsti testa i vrsti teorijske razdiobe u razdoblju 2007.–2010. (EasyFit 5.5)
Table 6 *Ranking the distribution of the ship serving time at the container terminal "Brajdica" according to the type of test and the theoretical distribution for the 2007 to 2010 period of time (EasyFit 5.5)*

Teorijska razdioba *Theoretical distribution*	Test / *Test*		
	K-S	A-D	χ^2
1. Gamma	1 (0.2960)	6 (< 0.20)	16 (< 0.01)
2. Gen. Pareto	2 (0.1454)	48 (<0.01)	N/A
3. Beta	3 (0.1295)	1 (≤ 0.20)	8 (< 0.01)
4. Gamma (3P)	5 (0.1273)	2 (≤ 0.20)	3 (<0.01)
5. Gen. Gamma (4P)	8 (0.0925)	3 (<0.20)	7 (<0.01)
6. Log-Pearson 3	7 (0.0962)	4 (<0.20)	2 (< 0.01)
7. Pearson 6 (4P)	15 (0.0391)	8 < 0.20)	1 (< 0.01)

Opaska: *K-S* (Kolmogorov-Smirnovljev test), *A-D* (Anderson-Darling test), χ^2–test, N/A– nedostupno
Note: K – S Kolmogorov–Smirnov test, A – D Anderson–Darling test, χ^2 *– test, N/A – not available*

Tablica 7. *K-Si* χ^2*-test* za razdiobu vremena opsluživanja broda na terminalu Brajdica u razdoblju 2007.– 2010. (Statistica 6)
***Table 7** K-S test and* χ^2*-test for the distribution of the ship serving time at the container terminal "Brajdica" in the 2007 to 2010 period of time (Statistica 6)*

Teorijska razdioba *Theoretical distribution*	K-S	χ^2
1. Eksponencijalna / *Exponential*	0.22596 (<0.01)	220.8099 (0.000)
2. Gamma / *Gamma*	0.04113 (<0.10)	11.5922 (0.003)
3. Normalna / *Normal*	0.09267 (<0.01)	99.8644 (0.000)
4. Lognormal / *Log–normal*	0.04713 (<0.05)	36.4755 (0.000)

Opaska: *K-S* (Kolmogorov-Smirnovljev test), χ^2–test

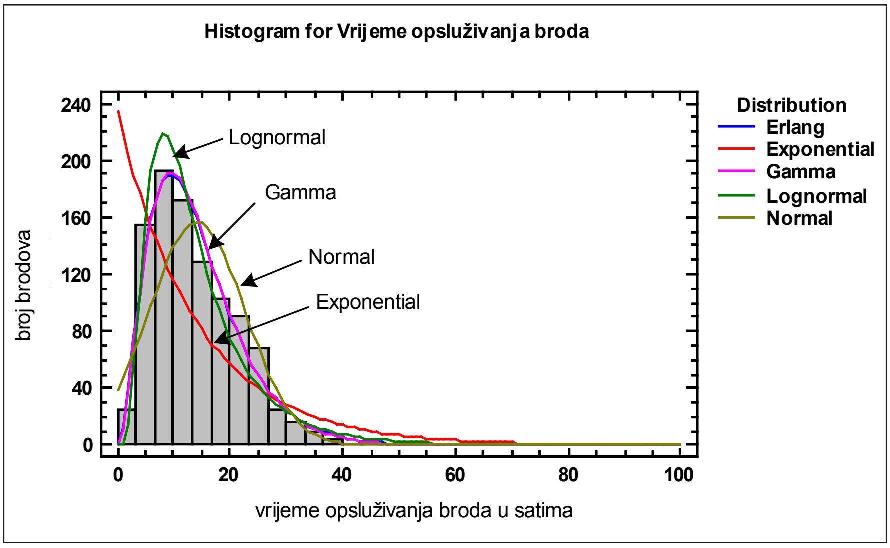
Note: K–S Kolmogorov–Smirnov test, χ^2 *– test*

Tablica 8. Rangiranje razdiobe vremena opsluživanja broda na terminalu Brajdica prema vrsti testa i vrsti teorijske razdiobe u razdoblju 2007.–2010. (Statgraphics 9.3.– 9.4.)
***Table 8** Ranking the distribution of the ship serving time at the terminal "Brajdica" according to the type of test and the theoretical distribution for the 2007 to 2010 period of time (Statgraphics 9.3.– 9.4.)*

Teorijska razdioba *Theoretical distribution*	Test / *Test*		
	K-S	*A-D*	χ^2
1. Erlangova / *Erlang*	0.9923 (0.0000)	–	116.641 (0.0000)
2. Eksponencijalna / *Exponential*	0.2260 (0.0000)	86.9355 (<0.01)	529.359 (0.0000)
3. Gamma / *Gamma*	0.0409 (0.0713)	1.5411 (≥0.10)	123.140 (0.0000)
4. Lognormal / *Log–normal*	0.0471 (0.0239)	3.5001 (<0.05)	141.917 (0.0000)
5. Normalna / *Normal*	0.0927 (0.0000)	–	317.042 (0.0000)

Opaska: *K-S* (Kolmogorov-Smirnovljev test), *A-D* (Anderson-Darling test), χ^2-test

Note: K–S Kolmogorov–Smirnov test, A–D Anderson–Darling test, χ^2*–test*



Grafikon 2. Usporedba vremena opsluživanja broda na kontejnerskom terminalu Brajdica s odabranim teorijskim razdiobama u razdoblju 2007.–2010.
***Graph 2** Comparison of the ship serving time at the container terminal "Brajdica" with the selected theoretical distributions for the 2007 to 2010 period of time*

Iz tablica slijedi da se na temelju podataka za razdoblje od 2007. do 2010. razdioba vremena opsluživanja ponaša prema gamma razdiobi, što potvrđuje grafikon 2.

4.4. Određivanje optimalnog broja pristana na kontejnerskom terminalu Brajdica

Iz prethodnih rezultata slijedi da je na kontejnerskom terminalu Brajdica na temelju dosadašnjeg prometa, a zbog usporedbe s varijablom vrijeme opsluživanja broda, za razdoblje od 2007. do 2010. prosječan broj pristiglih brodova iznosio λ = 0,6797 brodova dnevno. Uzevši u obzir prosječno vrijeme opsluživanja broda od 14,1787 sati izlazi da je propusna moć, odnosno kapacitet pristana u tom razdoblju procijenjen na μ = 24 sata/14,1787 sati = 1,6927 brodova/dan te da je stupanj opterećenja terminala u razdoblju od 2007. do2010. ($\rho = \lambda/\mu$) iznosio svega 0,40 (40%).

Za izračunavanje pokazatelja funkcioniranja kontejnerskoga terminala primijenjen je računalni program WINQSB [1].

Prema opcijama koje navedeni program nudi ulazni parametri su prosječan vremenski razmak između dva uzastopna dolaska broda ($1/\lambda$) te prosječno vrijeme zadržavanja broda na terminalu ($1/\mu$). To znači da je za daljnje istraživanje potrebno analizirati varijablu vremenski razmak između dva uzastopna dolaska broda prema shemi 4.3. ovoga rada da bi se odredila teorijska razdioba koju slijedi navedena varijabla ili, što je jednostavnije, izračunati recipročnu vrijednost od prosječnog broja pristiglih brodova λ.

Ovim istraživanjem se došlo do zaključka da je proces opsluživanja na kontejnerskom terminalu Brajdica problem reda čekanja tipa *M*/G/S. Primjenom programa WINQSB vrijednosti pokazatelja su unesene u tablicu 9. Radi usporedbe u tablici su dani rezultati za razdoblje 2007.–2010. te posebno za 2010.

Također je razmatrana varijanta procesa opsluživanja s prometom očekivanim u sljedećim godinama od 300 000 TEU-a pa je pretpostavljeno prosječno 529 pristiglih brodova godišnje s približno 500−550 TEU-a po brodu (λ = 1,450 brodova/dan), a na temelju podataka o radu terminala Brajdica u 2010. [23] prosječan broj opsluženih brodova (jedan pristan s dvije dizalice) je iznosio μ = 2,0712 brodova/dan.

It follows from these tables that, on the basis of the data for the 2007 to 2010 period of time, the serving time distribution matches the gamma distribution, as confirmed in Graph 2.

4.4. Determination of the optimum number of berths at the container terminal "Brajdica"

As the results have shown, based on the previous traffic and on the comparison of the ship serving time duration at the container terminal "Brajdica" in the 2007 to 2010 period of time, the average number of the ships' arrivals was λ = 0.6797 per day. Considering the average serving time of 14.1787 hours per ship, it follows that the throughput or berth capacity in that period was estimated to μ = 24 hours/14.1787 hours = 1.6927 ship/day and that the degree of the terminal load ($\rho = \lambda/\mu$) in the period from the year 2007 to the year 2010 equaled to as low as 0.40 (40%).

Software WINQSB [1] has been used for calculating the container operation indicators.

Following the options offered by the software, the input parameters are the average time between two subsequent arrivals of ships ($1/\lambda$) and the average stay at the terminal ($1/\mu$). It means that it is necessary to analyze the average time variable between the two subsequent arrivals of ships according to the instructions shown in 4.3 herein in order to define the theoretical distribution followed by the mentioned variable or, which is a simpler solution, calculate the reciprocal value of the average number of the arrived ships λ.

This research has led to the conclusion that the serving process at the container terminal "Brajdica" is of the *M*/G/S type queuing issue. The software WINQSB has been used for filling up values in Table 9. For the sake of comparison, the presented results refer to the periods from 2007 to 2010 and separately for the year 2010. The alternative serving process, involving 300,000 TEUs traffic as expected in the following years, has been considered as well, assuming an average number of 529 ships' arrivals with approximately 500-550 TEUs per ship (λ = 1.450 ship/day), and, based on the data for the "Brajdica" container terminal operation in 2010 [23], the average number of the served ships (one berth with two cranes) amounted to μ = 2.0712 ship/per day.

Tablica 9. Pokazatelji funkcioniranja kontejnerskog terminala Brajdica u razdoblju 2007.– 2010. te za prognozirani promet od 300 000 TEU-a
Table 9 *Indicators of the "Brajdica" container terminal operation in the 2007 to 2010 period of time and of the forecasted traffic of 300,000 TEUs*

Pokazatelj *Indicator*	Oznaka *Symbol*	Jedinica *Unit*	2007–2010 *M/G/1*	2010 *M/G/1*	Prognoza *Forecast* *M/M/1*
1. Broj pristana *Number of berths*	S	pristan	1	1	1
2. Intenzitet dolazaka *Arrival rate*	λ	brodovi/dan	0.6797	0.7178	1.450
3. Intenzitet opsluživanja *Service rate*	μ	brodovi/dan	1.6927	2.0712	2.071
4. Stupanj opterećenja *Traffic intensity*	ρ	%	40.15	34.66	70.00
5. Brodovi na pristanu *Ships at the berth*	L	brodovi	0.5630	0.4640	2.3349
6. Brodovi u redu čekanja *Ships queuing up*	L_Q	brodovi	0.1614	0.1176	1.6348
7. Vrijeme na terminalu *Time at the terminal*	W	sati	19.8781	15.5135	38.65
8. Vrijeme u redu čekanja *Queuing up time*	W_Q	sati	5.6996	3.9309	27.06
9. Vjerojatnost nezauzetosti pristana *Probability of the berth unoccupancy*	P_0	%	59.85	65.34	28.99

Opaska: *M/G/*1 označava sustav opsluživanja s jednim pristanom, dolascima brodova prema Poissonovoj razdiobi i vremenom opsluživanja prema gamma razdiobi s parametrima za razdoblje 2007.–2010. a=0, b=2,8103 i c=5,0452, a za 2010. s parametrima a=0, b=3,2506 i c=3,5632.

Note: M/G/1 symbolizes a queuing system with a single berth, the ships' arrivals according to the Poisson distribution and the ship serving time according to the gamma distribution with parameters covering the 2007 to 2010 period of time, a = 0, b = 2.8103 and c = 5.0452, and for the year 2010 with parameters a = 0, b = 3.2506 and c = 3.5632.

Rezultati iz prethodne tablice pokazuju da je u 2010. godini, u odnosu na razdoblje 2007.-2010., povećan intenzitet tijeka dolazaka brodova, kao i intenzitet opsluživanja, što je utjecalo na smanjenje broja brodova i duljinu vremena provedenog u redu čekanja i na pristanu.

Međutim, treba naglasiti da ovi rezultati nisu dovoljno usporedivi, jer je za 2010. uzet u obzir samo jedan pristan, budući da se na njemu odvija najveći dio prometa na terminalu.

Povećanje prometa na terminalu će smanjiti nezauzetost pristana, ali će se povećati broj brodova, kao i vrijeme provedeno u redu čekanja i na terminalu. Sve to dokazuje da je, očekujući nove brodove s kontejnerima, opravdana izgradnja novog pristana s odgovarajućim brojem dizalica čija je realizacija u tijeku.

The results from the previous table show that in 2010, as compared to the period from the year 2007 to the year 2010, the intensity of the flow of the ship arrivals (λ) increased, as well as the serving intensity of a ship (μ), which has resulted in reducing the number of ships and the length of the time spent in queuing up and at the berth.

However, it should be emphasized that these results are not sufficiently comparable, since, in 2010, only one berth was taken into consideration, although the greatest part of the throughput at the container terminal is effected at this very one berth.

The increase in the traffic at the container terminal will reduce the berth downtime, but the number of ships will be increased as well as the waiting time in a queue and at the container terminal. Said this, and expecting new ships with containers, building a new berth equipped

Prema 3.2. ovoga rada optimalan broj pristana se određuje na temelju postavljenog kriterija optimizacije koji je izražen u naturalnim ili vrijednosnim jedinicama. S obzirom na složenost sustava opsluživanja na kontejnerskom terminalu autori preporučuju da se optimalno rješenje odredi koristeći model ukupnih troškova koji obuhvaća troškove svih sudionika u procesu opsluživanja (brod, pristan, teret), a koji je detaljno prikazan u radu [23].

5. ZAKLJUČAK

Za optimalno funkcioniranje terminala od posebne je važnosti definirati kapacitet kontejnerskog terminala koji utječe na mogućnost ostvarenja postavljenog plana proizvodnje, a time i plana realizacije lučkih usluga.

Lučki kontejnerski terminal je sustav složen od određenog broja međusobno zavisnih podsustava. Problem određivanja optimalnog kapaciteta lučkoga kontejnerskog terminala svodi se na izračunavanje optimalnog broja pristana, s obzirom da kapacitet pristana determinira potreban kapacitet ostalih podsustava, a time i propusnu moć kontejnerskog terminala u cjelini.

Međutim, zbog oscilacija prekrcaja kontejnera uvjetovanih neravnomjernim pristizanjem brodova na lučki kontejnerski terminal te neujednačenim trajanjem operacija s kontejnerima, u praksi nije jednostavno utvrditi i dimenzionirati optimalan kapacitet terminala.

Jedan od načina određivanja optimalnog kapaciteta lučkoga kontejnerskog terminala je primjena odgovarajućih kvantitativnih metoda. U ovom je radu prikazan metodološki pristup, odnosno metode kojima se određuju značajke i pokazatelji funkcioniranja lučkoga kontejnerskog terminala, a koji su baza za donošenje odgovarajućih odluka vezanih za poslovanje terminala. U tu svrhu su prikazane odgovarajuće statističke metode i metode operacijskih istraživanja.

Prikazana metodologija je primijenjena na kontejnerski terminal riječke luke Brajdica, međutim, ta se metodologija može primijeniti za bilo koji terminal u sadašnjim ili budućim uvjetima poslovanja uz preduvjet raspolaganja odgovarajuće statističke baze podataka.

with an adequate number of cranes is quite justified, and this project has been in progress.

According to section 3.2. of this paper, the optimal number of berths is determined based on a set of optimization criteria, which is expressed in natural units or securities. Given the complexity of the system of the ship serving time at the container terminal, the authors have recommended that the optimal solution is determined by using the total costs model, which includes costs of all of those involved in the service activities (ship, berth, cargo), as described in details in paper [23].

5. CONCLUSION

For the optimal functioning of the container terminal it is especially important to define the capacity of the terminal that affects the possibility of achieving the set plan, and thus the plan of the port services realization.

The port container terminal is a complex system made up of a number of interdependent subsystems. The problem of determining the optimum capacity of the seaport container terminal comes down to calculating the optimal number of berths, since the capacity of the berth is determined by the required capacity of other subsystems, as is the throughput capacity of the container terminal taken as a whole.

However, due to the fluctuation in the container transshipment caused by irregular ships' arrivals at the port container terminal and by varied duration of the container operations, it is not easy to define and dimension the optimal terminal capacity.

One way of determining the optimum capacity of a port container terminal is the application of appropriate quantitative methods. This paper presents a methodological approach, i.e. the methods to determine the characteristics and indicators of the functioning of port container terminals, which are the basis for making appropriate decisions regarding the operation at the terminal. For this purpose, appropriate statistical methods and methods of operational researches are presented.

The presented methodology has been applied to the "Brajdica" container terminal at the Port of Rijeka. However, this methodology can be applied to any container terminal in the current or future operating conditions, but with a set prerequisite to give access to all relevant statistical databases.

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