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Capacity Analysis of Ro-Ro Terminals by Using Simulation Modeling Method

Emin Deniz ÖZKAN[a], Selçuk NAS[b], Nil GÜLER[c]

[a] *Research Assistant, Dokuz Eylul University, Turkey, E-mail:deniz.ozkan@deu.edu.tr (Corresponding Author)*
[b] *Associate Professor, Dokuz Eylul University, Turkey, E-mail:snas@deu.edu.tr*
[c] *Professor, Istanbul Technical University, Turkey, E-mail:gulern@itu.edu.tr*

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A B S T R A C T

In Ro-Ro terminals, terminal capacity is more needed than other types of marine terminals since Ro-Ro cargoes cannot be stacked. In this sense, the variables affecting capacity of a Ro-Ro terminal can be listed as follows; number of vehicles arrived to a terminal, distance between terminals, ship capacity, terminal gates, customs control units, terminal traffic and local traffic, security check, bunkering services etc. In this study, a model generated intended for making capacity analysis in Ro-Ro terminals by using simulation modeling method. Effect of three variables to terminal capacity was investigated while generating the scenarios; 'number of trucks arriving to terminals', 'distance between terminals' and 'Ro-Ro ship capacity'. The results show that the variable which affect terminal capacity mostly is 'number of trucks arriving to terminals'. As a consequence of this situation, it is thought that a Ro-Ro terminal operator must prioritize the demand factor and make an effective demand forecasting in determination of the terminal area.

1. Introduction

Ro-Ro transport enables loading of cargoes to ships through ramps instead of hatches and also it is a more flexible alternative to containerization for carrying a mix of containerized and wheeled cargo. Ro-Ro vessels are particularly used for transportation of wheeled cargoes such as cars, trucks, tractors and any cargoes that can easily be handled by a fork-lift truck such as pallets, bales, containers, packaged timber, etc. (Stopford, 2009).

After global economic crisis between 2008 and 2009, global maritime transport which is at an increasing trend every passing year has showed an increase of 4.3 % in 2013 (UNCTAD, 2013). Ro-Ro market has also taken its share from this increase. Ro-Ro transport has a significant potential, especially in Europe with the concepts of "Short Sea Shipping (SSS)" and "Motorways of the Sea". Short Sea Shipping is intended for easing overloaded highway routes and in this direction offering maritime transport as an alternative option. "Motorways of the Sea" project was created by the European Commission for the purpose of supporting Short Sea Shipping. With this project, maritime traffic including inland water transport is taken into account as a key element of intermodal transport in the face of increasing problems such as highway and railway congestion and air pollution (Jugovic et al., 2011). In particular, truck and trailer

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transport are performed intensively in the Mediterranean Sea and on the northern shores of Europe (Eurostat). Transport of manufactured automobiles which is a type of Ro-Ro transport and uses trade routes between America, Europe and Japan dominate the Ro-Ro market (Leach, 2007).

Due to the increasing demand, port managers should make analysis with a systematic approach in relation to port capacity to determine whether a terminal area can meet the demand. Here, the demand can be defined as frequency of cargoes arriving to a terminal. In the present study, frequency of trucks arriving to a terminal constitutes the demand. For an existing port, optimization or terminal area expansion studies can be done in order to increase the efficiency. Terminal capacity is an important factor to be considered especially in Ro-Ro terminals since goods cannot being stacked (Armbruster, 2007). Some variables such as inadequate number of terminal gates and customs control units, number of vehicles arrived to a terminal, ship capacity, distance between terminals, bunkering, local traffic in relation to terminal connection can affect a Ro-Ro terminal capacity and insufficient capacity may occur (Günay, 2009; Yaran, 2009; Aksoy, 2011). Besides, Akar and Esmer (2015) emphasizes the importance of demand forecasting such as number of trucks arriving to terminals in a year, for port capacity calculations.

2. Literature Review

In the literature, it was observed that authors mostly studied on container terminals in relation to approaches of capacity analysis in marine terminals (John and Wout, 2014; Zenzerovic et al., 2011; Guan and Liu, 2009; Shabayek and Young, 2002; Kia et al., 2002; Yun and Choi, 1999). Guan and Liu (2009) developed a multi-server queuing model to analyze congestion of a container terminal gate and determine waiting cost of trucks at the terminal gate. In the aforesaid study, three variables were associated with each other; arrival rate of trucks, service rate of terminal gate and number of terminal gates. The aim of their study is minimization of gate operation cost related to terminal operators and gate waiting time related to trucks. Zenzerovic et al. (2011) conducted a study by using queuing theory method to detect optimum capacity of a container terminal and number of berths and cranes per berth with the minimum costs for the given traffic. Shabayek and Young (2002) used “Witness” simulation software to simulate container terminals in Hong Kong. They studied to what extent a simulation model could predict about existing container terminal operations with a high level of accuracy. Yun and Choi (1999) used “Simple ++” simulation software for operation analysis of a container terminal in Korea and developed a simulation model with an object – oriented approach. Their study aimed to determine whether the existing container terminal is efficient enough to meet more demand and also determine whether transfer crane and gantry crane should be more efficient. Kia et al. (2002) examined the role of the computer simulation to evaluate the performance of a container terminal in relation to handling techniques and their effects on terminal capacity. The study compares two different container terminal system (existing and proposed) by using simulation modeling method. Also in this study, some issues are discussed such as performance criteria and model parameters to generate an operational method that increases terminal capacity and reduces the terminal congestion. John and Wout (2014) used queuing models to calculate the capacity utilization of an existing port. They have benefited from the historical data related to the performance of the port’s container and general cargo terminal to ensure the validity of the model.

On the subject of capacity analysis of Ro-Ro terminals, Fusco et al. (2010) conducted a theoretical study about capacity calculation and determination of some quality indicators, then they used the developed model on an existing terminal. Maksimavicius (2004) conducted a theoretical study aimed to reduce the cargo processing time in Ro-Ro terminals providing required number of terminal gate, customs control units and parking areas. Concerning the studies about Ro-Ro transport in Turkey, Aksoy (2011) studied and modeled an existing Ro-Ro terminal under four processes as import process/export process of trucks and import/export process of trailers. Aksoy calculated occupancy rates of cargoes for four processes at the terminal gate, gamma-ray station, import/export truck scale, fuel station, waiting areas and on the ramp. In the study, “Arena 11.0” simulation program was used. Yaran (2009) used analytic network process method for selection of port location related to a Ro-Ro line that enables especially heavy vehicles to transit between Thrace and Anatolia without joining Istanbul urban traffic. Yaran referred adequate vehicle parking area in one of the criteria that was determined in this study. In addition, Yaran emphasised that it should be evaluated whether there was need an extra-large area in case of the probability of the expansion of the port. Similarly to the aim of Yaran’s study, Yıldırım (2006) used analytic hierarchy process method differently from Yaran’s method for the selection of the location of a Ro-Ro line that was planned to establish around Istanbul.

In the literature, the variables that affect a container terminal capacity are mostly related to cargo handling equipments such as number of berths, number of cranes (Zenzerovic et al., 2011), productivity of cranes (Yun and Choi, 1999). In Ro-Ro terminals, the variables that affect terminal capacity are different since there is not required to cargo handling equipments and Ro-Ro cargoes cannot be stacked. Maksimavicius (2004) referred to required number of terminal gates, customs control units and parking areas in Ro-Ro terminals. According to our field survey and literature review, it can be said that the variables affect terminal capacity in Ro-Ro lines can be frequency of vehicles arrived to a terminal, number of terminal gates, ship capacity, distance between terminals, road connection of the terminal, local traffic, customs control units etc. This study focuses on three of these variables: ‘number of trucks arriving to terminals’, ‘distance between terminals’ and ‘Ro-Ro ship capacity’.

In the literature, there are few studies about capacity analysis of Ro-Ro terminals. In general, these studies focus on the following issues; capacity calculation and determination of some quality indicators, calculation of the capacities of terminal gateways, customs and border control facilities, calculation of occupancy rates of cargoes at the terminal facilities. Unlike other studies (Fusco et al., 2010; Maksimavicius, 2004; Aksoy, 2011), this article focuses on the issue of required terminal area for vehicles. Ro-Ro terminals need more terminal capacity than other types of marine terminals since Ro-Ro cargoes (vehicles) can not be stacked. This study comprises the calculation of “maximum number of trucks accumulated in a Ro-Ro terminal” with different scenarios. “Maximum number of trucks accumulated in a Ro-Ro terminal” gives us required terminal area for vehicles. It is expected that this study will contribute to make up for the deficiency in the literature and could present a theoretical model for Ro-Ro terminal operators and port planners.

3. Methodology

In the literature review, it was observed that queuing theory and simulation modeling methods are mainly used in the analysis of marine terminal systems. It is known that simulation modeling technique is one of the most effective methods in capacity analysis of terminal systems that consist of stochastic processes (Esmer and Tuna, 2007). From this point of view, the main goal of this study is to perform capacity analysis of Ro-Ro terminals by using simulation modeling method and to present a theoretical model for Ro-Ro terminal operators and port planners with the generated model and analysis. In this study, terminal capacity is defined as maximum number of trucks accumulated in terminals. Accumulated maximum number of trucks will allow us to estimate terminal capacity in other words required terminal area for vehicles. In this study, the combination of semi-trailer and towing unit has been defined as truck.

Figure 1 shows the main steps of the methodology. For the purpose of this study, face to face interviews with authorized personnel was conducted in two most important Ro-Ro terminals of Turkey (Pendik Ro-Ro Terminal and Çeşme Port). Besides interviews, field surveys and on-site investigations were carried out in these terminals. In field surveys and on-site investigations, some processes related to trucks were observed such as X-Ray control, weighing on a truck scale, loading to ship, unloading from ship, lashing/unlashing on ship deck. Annual data of "Statement of Facts" were obtained from Pendik Ro-Ro Terminal for ensuring the validity of the system. The distributions of these data were gained and these distributions were used in the simulation program as input data for berthing/unberthing processes of ships and loading/unloading processes of trucks. After building the model, it was performed that whether the model was working in accordance with desired purposes. The simulation model was run in company with various scenarios and then analysis and evaluations were conducted.

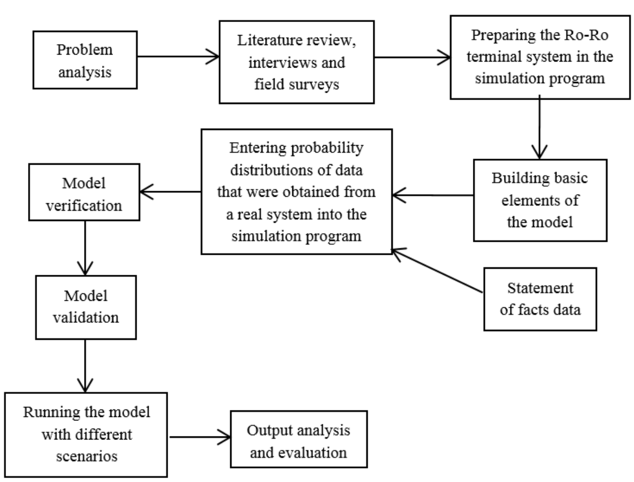

Fig. 1. The main steps of the methodology

In this article, effect of three variables to terminal capacity was investigated while generating the scenarios; 'Number of trucks arriving to terminals', 'Distance between terminals' and 'Ro-Ro ship capacity'. While selecting these variables, operational surveys were performed at Pendik Ro-Ro Terminal and Çeşme Port and studies of Fusco et al. (2010) and Günay (2009) was taken as reference. It will be understood that "distance between terminals" means the distance in nautical mile between two Ro-Ro terminals. Ro-Ro vessels have been taken into account as typical Ro-Ro vessels which carry only trucks and semi-trailers and navigate in international waters. Car carrier and car/truck carrier which are other types of Ro-Ro vessels have not been considered in this study.

For the variable of number of trucks arriving to a terminal in a year, simulation scenarios were produced by changing from 10000 up to 28000 trucks. These numbers were determined by taking as reference the number of vehicles carried per year in overseas Ro-Ro lines of Turkey. For the variable of distance between terminals, simulation scenarios were produced by changing from 80 up to 1120 nautical miles. These numbers were determined by taking as reference distances of Turkish Ro-Ro transportation routes. For the variable of Ro-Ro ship capacity, simulation scenarios were produced by changing from 80 up to 240 trucks. These numbers were determined by taking as reference carrying capacities of today's typical Ro-Ro vessels which carry trucks and semi-trailers.

For the constants in scenarios, it was assumed that the number of trucks arriving to terminals in a year is 20000 trucks and this value was determined by taking as reference the average number of trucks arriving per year to any Ro-Ro terminal in Turkey. It was assumed that the distance between terminals is 160 nautical miles and this value was determined by taking as reference average distance of Turkish national Ro-Ro routes. It was assumed that the Ro-Ro ship capacity is 200 trucks and this value was determined by taking as reference the average capacity that is seen in today's typical Ro-Ro vessel which are operated in The Mediterranean Sea.

According to the literature review, it was observed that various simulation software were used in studies of port operations, port planning and port capacity analysis: Promodel, Arena 11.0, Witness, Simple ++ etc. (Nas, 2013; Aksoy, 2011; Ng and Wong, 2006; Swedish, 1998; Dachyar, 2012; Shabayek and Young, 2002; Yun and Choi, 1999).

In order to create the system model, "Promodel 2011" simulation software was used in this study. Promodel 2011 enables simulation scenarios and has a good ability of animation. Analysts could see the interactions between sub-processes and are able to understand the working of these processes (Harrell et al., 2004).

Various studies were performed using Promodel simulation software in the maritime field. In Turkey, Nas (2013) conducted a study named "Optimization of the Resources with Simulation Modeling Method in Technical Navigation Services: Park Site Selection for Tugs. Ng and Wong (2006) developed a model aimed at determination of effect of the ship traffic in Hong Kong container terminals area on container terminal capacity. Swedish (1998) performed a study related to modeling an inland waterway network allocated fleet of barges tugboats. Dachyar (2012) simulated operations in the largest ferry terminal of Indonesia using Promodel.

4. Modeling of Ro-Ro Terminal Operations

4.1. *Modeling Approach*

Some assumptions were made in order to model and analyse a Ro-Ro terminal system. These assumptions were determined based on field surveys and literature review:

- Terminal capacity is maximum number of trucks accumulated in terminals.
- Units of analysis that are processed in the system are only trucks. Semi-trailer transport and roll-trailer transport which is used for heavy project cargoes have not been taken into account.
- There are two terminals in the system. It was considered in this manner since international Ro-Ro transport carried out between two terminals.

– Two Ro-Ro ships are operated between two terminals. Ships leave the terminal after loading of full capacity.
– The loading process begins after the unloading of trucks from the ship.
– The speed of ships has been taken into account as average is 17 knots and standard deviation is 2 knots in accordance with the normal distribution.
– Arrivals of trucks for both terminals have been defined as exponential distributions in simulation program.
– Processes of loading/unloading, ship berthing/ unberthing and voyage have been defined as normal distributions.
– All trucks are same types and have five axles. Taking Ligteringen (2000) as reference it has been assumed that a truck take space an area of 60 m^2 with four meters of width and 15 meters of length.
– Vehicle traffic in front of the terminal and the effect of local traffic and transportation links on terminal capacity have been excluded.
– It has been accepted that berths are continually available for berthing and unberthing of ships.
– Weather conditions have been excluded.
– All procedures that can delay loading and unloading processes related to port formalities have been excluded.

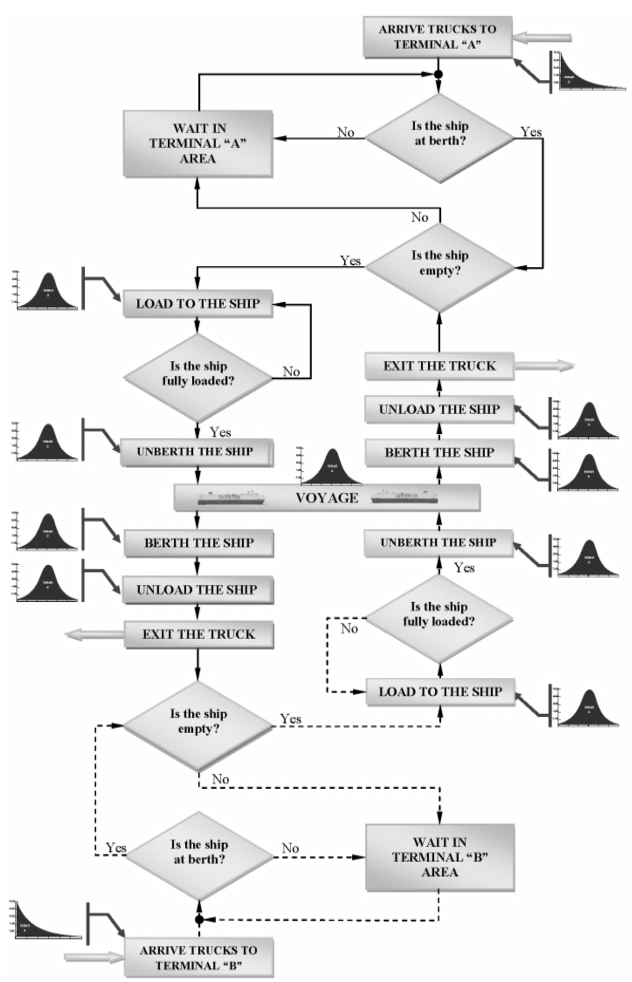

Fig. 2. Algorithm of the system

As shown in Figure 2, the working of the created system is as follows: In both terminals, trucks enter terminals in compliance with the exponential distribution defined to the program as stated above. If the ship is at the berth, trucks are loaded into the ship in accordance with the normal distribution as shown in Figure 3d. Loading process continues until the ship is loaded with full capacity. If the ship is not at the berth, trucks accumulate in the terminal area. When the ship is loaded with full capacity, it moves toward to the other terminal. There are three navigational processes (voyage, berthing and unberthing) in the system. Time distribution of the navigational processes is shaped like a normal distribution as shown in Figure 2, Figure 3a and 3b. The loading process of accumulated trucks in the other terminal begins in accordance with the normal distribution after the ship discharges trucks in accordance with the normal distribution as shown in Figure 3c.

4.2. *Determination of the System Data*

Annual "Statement of Facts" data which was obtained from Pendik Ro-Ro Terminal have been used for the purpose of entering elapsed times at loading, unloading, berthing, unberthing processes to the simulation program as probability distributions. The data was obtained between the dates of 31/12/2012 and 22/12/2013.

The elapsed times at loading, unloading, berthing, unberthing processes were calculated. Kolmogorov – Smirnov tests were performed in SPSS 20 to determine probability distributions of the processes. According to the results, all processes are fitted for the normal probability distribution. Figure 3 shows the descriptive statistics for the distributions of each process.

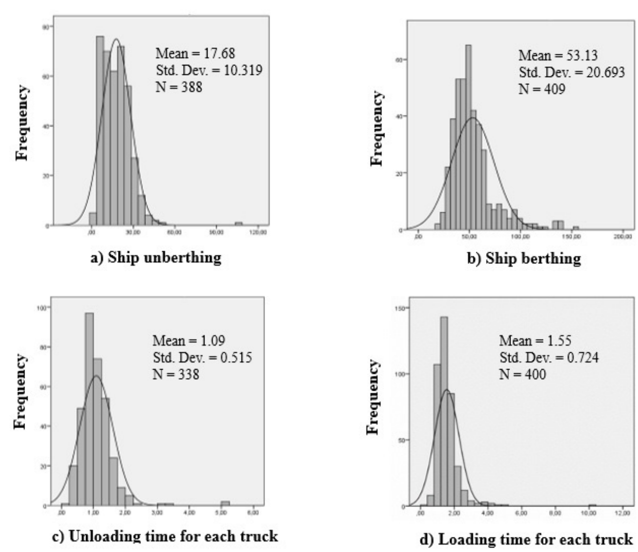

Fig. 3. The distribution of elapsed times at each process (minute)

5. Running the Simulation Model and Output Analysis

After building of the model, it was checked that whether the model was working in accordance with desired purposes. By running of the simulation model, the animation was slowed down at a speed that movements could be seen clearly and each step of the model was monitored. Counters were placed on required locations in the model as an indicator of desired results and necessary corrections were done. After each correction, the model was repeatedly monitored by running and this process was performed several times. Thus, it was ensured that the system was working in the direction of desired purposes and in accordance with the real system.

In this section, terminal capacity in other words maximum number of trucks accumulated in terminals was examined in company with various scenarios. It was defined that warm-up time of the model is 720 hours (i.e. period of one month) and running time of the model is 8760 hours (i.e. period of one year) in the simulation program. 20 times repetition of each scenario was found suitable for both terminals.

5.1. *Scenario 1: Analysis of the Effect of 'Arriving Trucks' on Terminal Capacity*

In this part, the effect of the variable of "number of trucks arriving to terminals in a year" on terminal capacity was examined while the variables of 'distance between terminals' and 'Ro-Ro ship capacity' are constants. It was assumed that the Ro-Ro ship capacity is 200 trucks and the distance between terminals is 160 nautical miles. As shown in Table 1, the number of trucks arriving was changed in various numbers from 10000 up to 28000 in the simulation program and scenarios were produced. Each scenario was run 20 times. In this 20 repetitions of each scenario, totally 40 outputs belonging to the number of accumulated trucks in two opposing terminals were obtained.

For determining terminal capacity i.e. maximum number of trucks accumulated in terminals, averaging of maximum values of 40 outputs that are consisted of repetitions will not constitute a statistically significant result. The average of the maximum values in specific estimation range of different results obtained from simulation repetitions will give us the significant results. Therefore, the confidence interval of maximum values of 40 outputs was examined. The maximum value that consisted in the confidence interval was accepted as the maximum number of trucks accumulated in the terminals. This accepted maximum value was used to determine terminal capacity. According to Easton and McColl (1997), confidence intervals are generally calculated with confidence levels of 95 %, 90 % or 99 %. In addition, according to Bowen and Starr (1982), if the distribution is the normal distribution and number of sample is greater than 30, the following formula is used for calculating the confidence interval:

$$\overline{X} - Z_{\alpha/2}\left(\frac{\sigma_x}{\sqrt{n}}\right) < \mu_x < \overline{X} + Z_{\alpha/2}\left(\frac{\sigma_x}{\sqrt{n}}\right)$$

$\bar{x}$ = Sample mean
σ_x = Sample standard deviation
n = Number of sample
$Z_{\alpha/2}$ = Value of the z-table

$$\alpha = 1 - \left(\frac{confidence\ level}{100}\right)$$

μ_x = Unknown population mean

SPSS 20 was used in the confidence interval analysis. As shown in Table 1, confidence intervals were determined in each repetition by calculating the average of the maximum number of trucks in confidence level of 95 %.

Table 1
Confidence interval values in confidence level of 95 % of maximum numbers of trucks accumulated in the terminals depending on arriving trucks

	Maximum number of trucks accumulated in the terminal	
Arriving trucks/year	Lower value of confidence interval	Upper value of confidence interval
10000	116.23	178.76
12000	144.98	226.21
14000	160.70	246.74
16000	147.76	242.33
18000	173.21	248.33
20000	160.35	256.39
22000	178.94	288.15
24000	198.09	315.15
26000	208.49	329.00
28000	217.00	313.54

As shown in Table 1, in the case of each ship has capacity of 200 trucks, the distance between the terminals is 160 nautical miles and the number of trucks arriving to the terminals in a year is 10000, the maximum number of trucks accumulated in the terminals is between 116.23 and 178.76 in confidence level of 95 %. These confidence interval values give information about required terminal area i.e. the terminal capacity for each case.

The correlation analysis was performed in order to reveal the relation between 'the number of trucks arriving to the terminals' and 'the maximum number of trucks accumulated in the terminals'. Results of the correlation analysis are shown in Table 2. According to results, it was determined that significant, positive and a high level of relation exists between 'the number of trucks arriving to the terminals' and 'the maximum number of trucks accumulated in the terminals' (r = 0.959).

Table 2
Correlation analysis performed for determining the relation between 'the number of trucks arriving to the terminals' and 'the maximum number of trucks accumulated in the terminals'

		The maximum number of trucks accumulated in the terminals	The number of trucks arriving to the terminals
The maximum number of trucks accumulated in the terminals	Pearson Correlation	1	0.959
	Sig. (2-tailed)		0.000
	N	10	10
The number of trucks arriving to the terminals	Pearson Correlation	0.959	1
	Sig. (2-tailed)	0.000	
	N	10	10

Figure 4 was generated in order to show the relation between 'lower and upper reliability values of maximum numbers of trucks accumulated in the terminals' and 'arriving trucks'. Equations and R^2 values which were obtained from regression analysis that performed between reliability values are presented below.

The equation of distribution of upper confidence interval values:

$$y = 1.6675x^{0.5153}$$
$$R^2 = 0.9073$$

The equation of distribution of lower confidence interval values:

$$y = 0.9934x^{0.5234}$$
$$R^2 = 0.8936$$

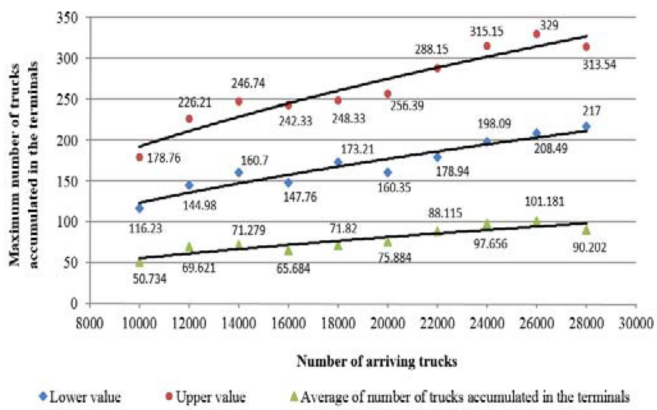

Fig. 4. The scatter graph of confidence interval values of maximum numbers of trucks accumulated in the terminals depending on arriving trucks

The curve estimation analysis of lower and upper confidence interval values of maximum numbers of trucks accumulated in the terminals was performed in SPSS 20. It was determined that confidence interval values of maximum numbers of trucks accumulated in the terminals depending on arriving trucks show an exponential distribution.

As shown in Figure 4, in the case of the capacity of each Ro-Ro ship is 200 trucks, the distance between the terminals is 160 nautical miles and the number of trucks arriving to the terminals in a year is 10000, there is needed a terminal area of at least 10680 m^2 for 178 trucks. With same constants, in the case of the number of trucks arriving to the terminals is 28000, there is needed a terminal area of at least 18780 m^2 for 313 trucks.

5.2. *Scenario 2: Analysis of the Effect of 'Distance Between Terminals' on Terminal Capacity*

In this part, the effect of the variable of distance between terminals on terminal capacity was examined while the variables of 'number of trucks arriving to terminals' and 'Ro-Ro ship capacity' are constants. It was assumed that the number of trucks arriving to the terminals is 20000 and the Ro-Ro ship capacity is 200 trucks. As shown in Table 3, the distance between the terminals was changed in various numbers from 80 up to 1120 nautical miles in the simulation program and scenarios were produced. Each scenario was run 20 times. In this 20 repetitions of each scenario, totally 40 outputs belonging to the number of accumulated trucks in two opposing terminals were obtained.

The confidence interval of maximum values of 40 outputs was examined. SPSS 20 was used in the confidence interval analysis. As shown in Table 3, confidence intervals were determined in each repetition by calculating the average of the maximum number of trucks in confidence level of 95 %.

Table 3
Confidence interval values in confidence level of 95 % of maximum numbers of trucks accumulated in the terminals depending on the distance between the terminals

	Maximum number of trucks accumulated in the terminal	
Arriving trucks/year	Lower value of confidence interval	Upper value of confidence interval
80	174.88	278.66
120	174.06	276.28
160	193.98	276.56
210	180.92	282.17
240	177.91	268.28
320	192.01	293.13
400	195.18	276.56
480	196.82	293.77
560	188.51	264.18
640	195.27	252.42
720	227.84	311.95
800	214.62	282.37
960	252.80	309.89
1000	264.03	338.81
1120	288.83	355.31

As shown in Table 3, in the case of each ship has capacity of 200 trucks, the number of trucks arriving to the terminals is 20000 and the distance between the terminals is 80 nautical miles, the maximum number of trucks accumulated in the terminals is between 174.88 and 278.66 in confidence level of 95 %. These confidence interval values give information about required terminal area i.e. the terminal capacity for each case.

The correlation analysis was performed in order to reveal the relation between 'the distance between the terminals' and 'the maximum number of trucks accumulated in the terminals'. Results of the correlation analysis are shown in Table 4. According to results, it was determined that significant, positive and a high level of relation exists between 'the distance between the terminals' and 'the maximum number of trucks accumulated in the terminals' (r = 0.841).

Table 4
Correlation analysis performed for determining the relation between 'the distance between the terminals' and 'the maximum number of trucks accumulated in the terminals'

		The maximum number of trucks accumulated in the terminals	The distance between the terminals
The maximum number of trucks accumulated in the terminals	Pearson Correlation	1	0.841
	Sig. (2-tailed)		0.000
	N	15	15
The distance between the terminals	Pearson Correlation	0.841	1
	Sig. (2-tailed)	0.000	
	N	15	15

Figure 5 was generated in order to show the relation between 'lower and upper reliability values of maximum numbers of trucks accumulated in the terminals' and 'the distance between the terminals'. Equations and R^2 values which were obtained from regression analysis that performed between reliability values are presented below.

The equation of distribution of upper confidence interval values:

$$y = 0.0001x^2 - 0.1073x + 292.5$$
$$R^2 = 0.7192$$

The equation of distribution of lower confidence interval values:

$$y = 0.0001x^2 - 0.0436x + 185.14$$
$$R^2 = 0.9431$$

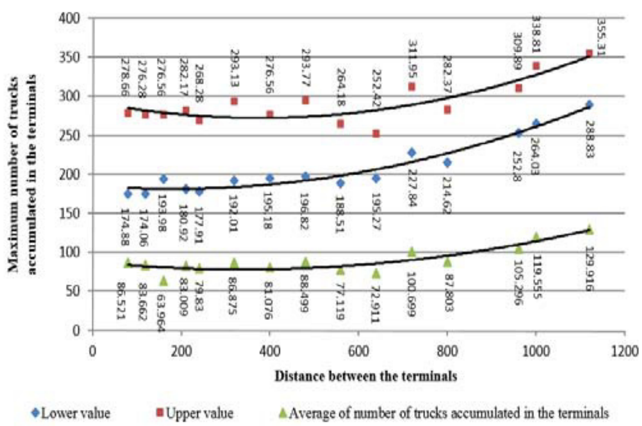

Fig. 5. The scatter graph of confidence interval values of maximum numbers of trucks accumulated in the terminals depending on the distance between the terminals

The curve estimation analysis of lower and upper confidence interval values of maximum numbers of trucks accumulated in the terminals was performed in SPSS 20. It was determined that confidence interval values of maximum numbers of trucks accumulated in the terminals depending on the distance between the terminals show a polynomial distribution.

As shown in Figure 5, in the case of the capacity of each Ro-Ro ship is 200 trucks, the number of trucks arriving to the terminals is 20000 and the distance between the terminals is 80 nautical miles, there is needed a terminal area of at least 16680 m^2 for 278 trucks. With same constants, in the case of the distance between the terminals is 1120 nautical miles, there is needed a terminal area of at least 21300 m^2 for 355 trucks.

5.3. *Scenario 3: Analysis of the Effect of 'Ro-Ro Ship Capacity' on Terminal Capacity*

In this part, the effect of the variable of Ro-Ro ship capacity on terminal capacity was examined while the variables of 'number of trucks arriving to terminals' and 'distance between terminals' are constants. It was assumed that the number of trucks arriving to the terminals is 20000 and the distance between the terminals is 160 nautical miles. As shown in Table 5, the Ro-Ro ship capacity was changed in various numbers from 80 up to 240 trucks in the simulation program and scenarios were produced. Each scenario was run 20 times. In this 20 repetitions of each scenario, totally 40 outputs belonging to the number of accumulated trucks in two opposing terminals were obtained.

The confidence interval of maximum values of 40 outputs was examined. SPSS 20 was used in the confidence interval analysis. As shown in Table 5, confidence intervals were determined in each repetition by calculating the average of the maximum number of trucks in confidence level of 95 %.

Table 5
Confidence interval values in confidence level of 95 % of maximum numbers of trucks accumulated in the terminals depending on the Ro-Ro ship capacity

	Maximum number of trucks accumulated in the terminal	
Distance between the terminals	Lower value of confidence interval	Upper value of confidence interval
80	151.02	245.72
100	165.55	265.09
120	156.27	255.07
140	155.47	254.27
160	169.68	264.86
180	187.20	292.09
200	193.98	276.56
220	172.30	270.09
240	172.40	275.54

As shown in Table 5, in the case of the number of trucks arriving to the terminals is 20000, the distance between the terminals is 160 nautical miles and each ship has capacity of 200 trucks, the maximum number of trucks accumulated in the terminals is between 151.02 and 245.72 in confidence level of 95 %. These confidence interval values give information about required terminal area i.e. the terminal capacity for each case.

The correlation analysis was performed in order to reveal the relation between 'the Ro-Ro ship capacity and 'the maximum number of trucks accumulated in the terminals'. Results of the correlation analysis are shown in Table 6. According to results, it was determined that significant, positive and a high level of relation exists between 'the Ro-Ro ship capacity' and 'the maximum number of trucks accumulated in the terminals' (r = 0.706).

Table 6
Correlation analysis performed for determining the relation between 'the Ro-Ro ship capacity' and 'the maximum number of trucks accumulated in the terminals'

		The maximum number of trucks accumulated in the terminals	The Ro-Ro ship capacity
The maximum number of trucks accumulated in the terminals	Pearson Correlation	1	0.706
	Sig. (2-tailed)		0.033
	N	9	9
The Ro-Ro ship capacity	Pearson Correlation	0.706	1
	Sig. (2-tailed)	0.033	
	N	9	9

Figure 6 was generated in order to show the relation between 'lower and upper reliability values of maximum numbers of trucks accumulated in the terminals' and 'the Ro-Ro ship capacity'. Equations and R^2 values which were obtained from regression analysis that performed between reliability values are presented below.

The equation of distribution of upper confidence interval values:

$$y = 158.38x^{0.1035}$$
$$R^2 = 0.5404$$

The equation of distribution of lower confidence interval values:

$$y = 75.118x^{0.1613}$$
$$R^2 = 0.5083$$

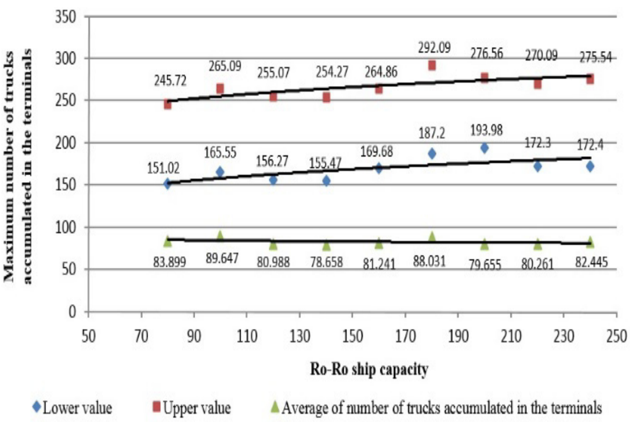

Fig. 6. The scatter graph of confidence interval values of maximum numbers of trucks accumulated in the terminals depending on the Ro-Ro ship capacity

The curve estimation analysis of lower and upper confidence interval values of maximum numbers of trucks accumulated in the terminals was performed in SPSS 20. It was determined that confidence interval values of maximum numbers of trucks accumulated in the terminals depending on the Ro-Ro ship capacity show an exponential distribution.

As shown in Figure 6, in the case of the number of trucks arriving to the terminals in a year is 20000 and the distance between the terminals is 160 nautical miles and the capacity of each Ro-Ro ship is 80 trucks, there is needed a terminal area of at least 14700 m^2 for 245 trucks. With same constants, in the case of the capacity of each Ro-Ro ship is 240 trucks, there is needed a terminal area of at least 16500 m^2 for 275 trucks.

6. Conclusion

Increase in Ro-Ro traffic worldwide, requires a growth in terms of capacity in Ro-Ro terminals. Not being able to stack Ro-Ro cargoes, necessitates ensuring adequate terminal capacity in Ro-Ro terminals. Before planning a new Ro-Ro terminal or enlargement of an existing terminal, it is important that a Ro-Ro terminal operator determine whether performance improvement will be sufficient and how much increase in capacity will be. It is known that simulation modeling technique is one of the most effective methods in capacity analysis of terminal operations that consist of stochastic processes. From this point of view, in this study, a model generated intended for making capacity analysis in Ro-Ro terminals by using simulation modeling method.

Distribution equations for upper confidence interval values in each scenario indicate relations between required terminal capacity and variables. In the first scenario, confidence interval values of "terminal capacity" depending on "arriving trucks" show an exponential distribution. In the second scenario, confidence interval values of "terminal capacity" depending on "distance between terminals" show a polynomial distribution. In the final scenario, confidence interval values of "terminal capacity" depending on "Ro-Ro ship capacity" show an exponential distribution.

Consequently, it was determined that the variable which affect terminal capacity mostly is 'number of trucks arriving to a terminal'. As a consequence of this situation, it is thought that a Ro-Ro terminal operator must prioritize demand factor and make an effective demand forecasting in determination of terminal area.

It is expected that the generated simulation model and performed analysis could be a theoretical model for Ro-Ro terminal operators and port planners. For future studies, it is thought that effect of more variables on terminal capacity could be studied and studies related to optimization of terminal capacity could be conducted.

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