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Estimation of Vessel Passage through Bosphorus

Alp Küçükosmanoğlu [a], Özen Arlı Küçükosmanoğlu [b]*

[a,b] Burdur Mehmet Akif Ersoy University, Faculty of Engineering and Architecture, Department of Civil Engineering, Burdur 15030, Turkey
E-mail address: akucukosmanoglu@mehmetakif.edu.tr [a], okucukosmanoglu@mehmetakif.edu.tr [b*]

ORCID numbers of authors:
0000-0002-7551-1513[a], 0000-0002-2119-8074[b]

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Abstract

The Bosphorus is a heritage from the past to the present with its natural, historical and cultural features. Vessels passing through the Bosphorus, which is a narrow waterway, create a risk in Istanbul Strait. Thousands of vessels carrying dangerous cargoes pass through the Bosphorus every year. In this study, the changes in the cargos carried by these vessels and number of vessels over years are examined. It is seen that approximately 44000 vessels per year have passed through considering the last decade. The data of Ministry of Transport and Infrastructure, General Directorate of Marine between the years 1995 and 2020 has been used to estimate the change of the number of the vessels for five years period. Although the estimation show that the vessels numbers will decrease with an estimation of ~32,250 vessels for the year 2025, the total gross tonnage will increase in the future years. The results show that, while the number of bulk carrier vessels, livestock carriers, passenger ships and refrigerated cargo carriers will increase, the number of general cargo vessels will decrease in the future years.

Keywords: Bosphorus, Istanbul Strait, Estimation, Vessels Number, Maritime Traffic.

1. Introduction

Istanbul, where Asia and Europe continents meet, has an intense maritime traffic in the Bosphorus, which is a narrow waterway between the Black Sea and the Marmara open through Mediterranean and international waters. Approximately 48,000 vessels/year passed through the Bosphorus according to the data of Ministry of Transport and Infrastructure, General Directorate of Marine between the years 1995 and 2020 as shown in Table 1 [1, 2], besides the local maritime traffic of the region. There are around 2000 scheduled ship traffic daily only in the southern part of the Istanbul Strait [3]. As can be seen from numbers, Bosphorus has a busy maritime traffic. Especially in the last decade many researchers study maritime safety and risk assessment for the region. The main subject is accident statistics and risk assessment over all the studies [4-8]. There are passage schedule and navigation management researches for reducing the maritime risk of this busy region [9-11]. Uğurlu et al. [12] studied economic loss of marine accidents of the region. Therefore, in order to reduce the maritime accidents and enhance the navigation safety, General Directorate of Coastal Safety and related institutions do research and give couple of services in the region.

Table 1. Number of vessels passing through Bosphorus

Years	Number of Vessels	Years	Number of Vessels	Total Gross Tonnage	Years	Number of Vessels	Total Gross Tonnage
1995	46,954	2004	54,564	-	2013	46,532	551,771,780
1996	49,952	2005	54,794	-	2014	45,529	582,468,334
1997	50,942	2006	54,880	475,796,880	2015	43,544	565,216,784
1998	49,304	2007	56,606	484,867,696	2016	42,553	565,282,287
1999	47,906	2008	54,396	513,639,614	2017	42,978	599,324,748
2000	48,079	2009	51,422	514,656,446	2018	41,103	613,088,166
2001	42,637	2010	50,871	505,615,881	2019	41,112	638,892,062
2002	47,283	2011	49,798	523,543,509	2020	38,404	619,758,776
2003	46,939	2012	48,329	550,526,579			

Vessels can request pilot (through Bosphorus) to increase the safety of passage. Average ~53.5% of the passed vessels have requested pilot between the years 2006 and 2020 according to the data of Ministry of Transport and Infrastructure, General Directorate of Marine. Number of passed vessels have been archived on 6 categories in the data. The categories are according to vessel lengths, as shorter than 100 m, between 100-150 m, between 150-200 m, between 200-250 m, between 250-300 m, longer than 300 m as shown in Table 2 [2].

Table 2. Number of vessels passing through Bosphorus according to their length

Years	Number of Vessels								
	Longer than 300 m	Btw. 250-300 m	Btw. 200-250 m	Btw. 150-200 m	Btw. 100-150 m	Shorter than 100 m	**Total**	**Total With Pilot**	Percentage of Vessels with Pilot
2006	0	957	2,696	7,216	22,427	21,584	54,880	26,589	48.45%
2007	25	1,114	2,514	6,840	23,889	22,224	56,606	26,685	47.14%
2008	25	1,256	2,630	7,931	22,050	20,504	54,396	27,001	49.64%
2009	8	1,051	2,812	8,256	20,683	18,612	51,422	24,977	48.57%
2010	6	1,216	2,401	7,881	20,990	18,377	50,871	26,035	51.18%
2011	6	1,283	2,511	8,419	20,176	17,403	49,798	26,011	52.23%
2012	14	1,285	2,567	9,278	18,976	16,209	48,329	24,812	51.34%
2013	14	1,268	2,519	9,307	18,341	15,083	46,532	24,023	51.63%
2014	2	1,364	2,929	10,154	16,734	14,346	45,529	24,508	53.83%
2015	0	1,283	2,647	10,235	16,178	13,201	43,544	23,349	53.62%
2016	0	1,143	2,730	10,363	16,077	12,240	42,553	22,356	52.54%
2017	5	1,318	2,682	10,965	16,101	11,907	42,978	24,059	55.98%
2018	3	1,377	2,726	11,640	14,466	10,891	41,103	23,565	57.33%
2019	0	1,324	3,076	11,873	15,497	9,342	41,112	26,632	64.78%
2020	2	1,299	3,651	10,592	14,441	8,419	38,404	24,754	64.46%

Almost all the passed vessels longer than 150 m length have requested pilot after the year 2019. However, before the year 2018 almost all the passed vessels longer than 200 m length have requested pilot. Average ~85.38% of passed vessels between 150-200 m length, average ~44.91% of passed vessels between 100-150 m length and average ~30.43% of passed vessels shorter than 100 m length have requested pilot between the years 2006 and 2020. Where almost half of the passed vessels between 100-150 m length request pilot, only one third of the passed vessels shorter than 100 m requested pilot for that period (Fig. 1, Table 3).

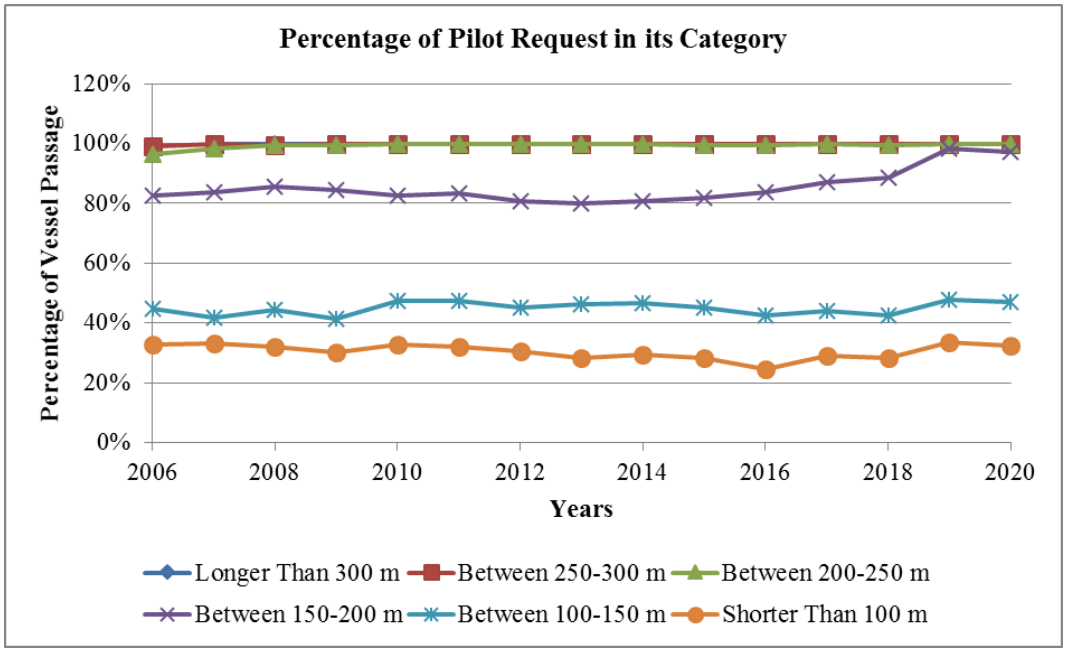

Fig. 1. Percentage of vessels passing through Bosphorus according to vessels length

Table 3. Percentage of vessels passing through Bosphorus with Pilot on vessels category

Years	Percentage of Vessels with Pilot					
	Longer than 300 m	Btw. 250-300 m	Btw. 200-250 m	Btw. 150-200 m	Btw. 100-150 m	Shorter than 100 m
2006		99.06%	96.48%	82.44%	44.70%	32.74%
2007	100.00%	99.64%	98.49%	83.76%	41.84%	33.07%
2008	100.00%	99.60%	99.28%	85.74%	44.39%	31.82%
2009	100.00%	99.90%	99.40%	84.50%	41.45%	29.95%
2010	100.00%	100.00%	100.00%	82.60%	47.17%	32.65%
2011	100.00%	100.00%	100.00%	83.45%	47.51%	32.18%
2012	100.00%	100.00%	99.65%	80.63%	45.03%	30.42%
2013	100.00%	100.00%	99.84%	80.05%	46.38%	28.31%
2014	100.00%	100.00%	99.86%	80.83%	46.49%	29.49%
2015		100.00%	99.32%	81.92%	45.16%	28.38%
2016		100.00%	99.45%	83.56%	42.47%	24.60%
2017	100.00%	99.92%	99.96%	87.23%	43.80%	28.87%
2018	100.00%	99.85%	99.34%	88.43%	42.36%	28.08%
2019		100.00%	99.97%	98.25%	47.92%	33.63%
2020	100.00%	100.00%	100.00%	97.26%	46.95%	32.31%

When the percentage of passed vessel have been calculated according to the length categories for the year 2006; 39.33% of passed vessels are in the shorter than 100 m length category, 40.87 % of passed vessels are between 100-150 m, 13.15% of passed vessels are between 150-200 m, 4.91% of passed vessels are between 200-250 m, 1.74% of passed vessels are between 250-300 m. However, for the year 2020, 21.92% of passed vessels are in the category of shorter than 100 m length, 37.60 % of passed vessels are between 100-150 m, 27.58% of passed vessels are between 150-200 m, 9.51% of passed vessels are between 200-250 m, 3.38% of passed vessels are between 250-300 m, 0.01% of passed vessels are longer than 300 m (Fig. 2). It can be seen from the graph comparing the years 2006 and 2020; that there is no considerable change for

longer than 300m length vessels and a slight decrease for the 100-150 m length vessels. However, the percentage of passed vessel doubled for 150-200 m length and 250-300 m length vessels. The percentage of passed vessel also doubled for the 200-250 m length vessels in the last few years comparing year 2006. Furthermore, the percentage of the passed vessels shorter than 100 m dropped to almost half. If the dominant percentage of the passed vessels generally evaluated, the vessels between 150-200 m length doubled, however the vessels shorter than 100 m dropped to almost half.

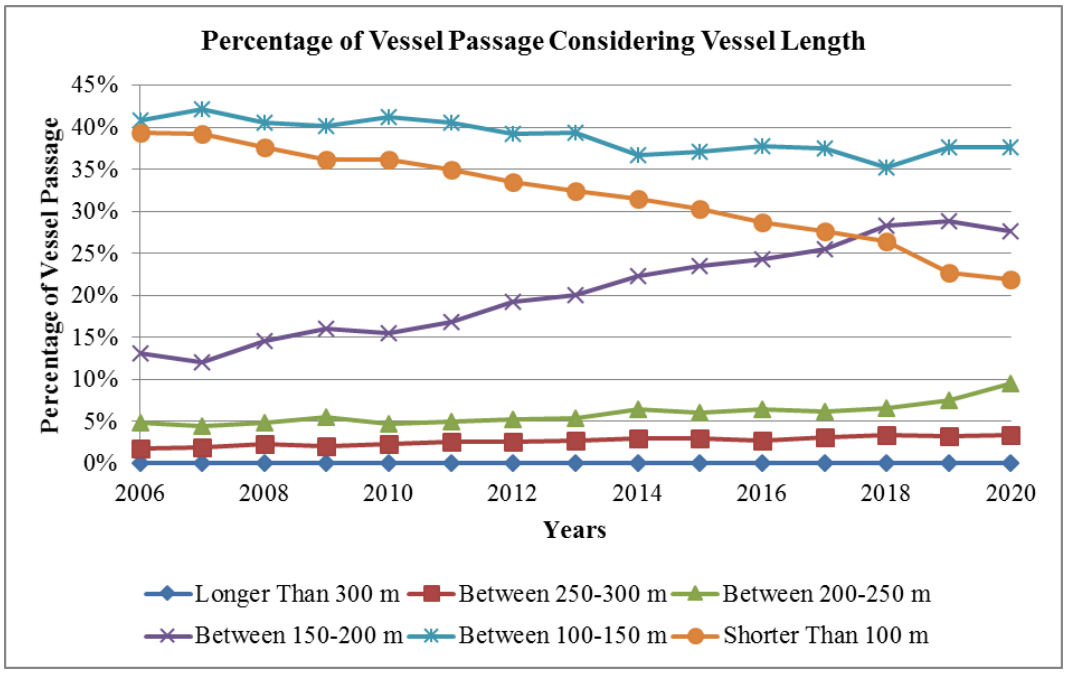

Fig. 2. Percentage of vessels passing through Bosphorus according to vessels length

Passed vessels through Bosphorus have been also archived between the years 2006 and 2020 according to their types. The data consists of 17 types of vessels: Barge / Barge Carrier; Bulk Carrier; Cement Carrier; Container Ship; Ferry; General Cargo Ship; Livestock Carrier; Naval; Passenger Ship; Refrigerated Cargo Carrier; Roll on Roll of Vessel; Other Tanker, TTA; Chemical Tanker, TCH; Liquefied Petroleum Gas/Natural Gas Tanker, LPG/LNG; Tug; Vehicle Carrier and Other (Table 4).

Table 4. Number of vessels passing through Bosphorus according to vessels types

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Barge / Barge Carrier	63	47	52	53	28	17	2	19	12	17	6	18	3	9	15
Bulk Carrier	5,419	5,145	5,978	6,635	5,863	6,341	7,163	6,898	7,263	7,485	7,664	8,206	8,501	8,811	8,592
Cement Carrier	13	6			3	4	2	1	4	8	4	6	12	9	18
Container Ship	2,401	2,727	2,773	2,014	2,292	2,718	2,707	2,868	3,073	2,664	2,734	2,659	2,561	2,642	2,633
Ferry	4	1	1		1	3	1	1	4	2	1	1	1	2	1
General Cargo Ship	33,082	34,822	32,735	30,840	30,876	29,288	27,126	25,521	24,107	22,412	21,344	21,163	19,269	18,637	16,864
Livestock Carrier	141	136	70	147	243	238	390	432	391	434	585	544	508	530	555
Naval	168	166	200	180	114	94	129	196	237	318	342	237	176	178	205
Passenger Ship	1,658	1,702	1,147	786	631	481	583	474	649	444	291	336	367	250	74
Refrigerated Cargo Carrier	908	819	805	623	602	441	248	204	65	24	40	46	34	59	52
Roll on Roll of Vessel	436	441	713	350	457	599	492	406	431	377	352	396	245	266	222
Other Tanker, TTA	7,659	7,204	6,564	6,557	6,464	6,216	5,912	5,685	5,587	5,825	6,033	6,212	6,014	5,934	5,252
Chemical Tanker, TCH	1,680	2,050	1,975	1,876	1,711	1,660	1,779	1,561	1,618	1,576	1,681	1,878	1,950	2,462	2,653
Liquefied Petroleum Gas/Natural Gas Tanker, LPG/LNG	814	800	764	866	1,099	1,227	1,336	1,760	1,540	1,232	989	742	623	561	530
Tug	294	253	313	304	293	245	274	241	231	282	237	262	384	270	175
Vehicle Carrier	14	92	189	78	42	47	37	47	93	17	16	45	88	113	87
Other	126	195	117	113	152	179	148	218	224	427	234	227	367	379	476
Total	54,880	56,606	54,396	51,422	50,871	49,798	48,329	46,532	45,529	43,544	42,553	42,978	41,103	41,112	38,404

2. Methodology

Data can be examined via statistical methods. Regression analysis can be used to see the data change [13]. Generally, linear regression analysis is used to see the trend of the data. It is also possible to use other regression analysis to obtain more suitable regression lines. However, to see the trend and estimate the vessel passage roughly, linear regression analysis has been preferred in the study. Although polynomial regression analysis has been performed in the study, the results are not given for all trials.

2.1. Linear regression analysis

Linear regression is the simplest regression analysis can be applied to the data (x_i, y_i). Mathematical expression of the regression line is shown in Eq. (1).

$$y = a_0 + a_1 x \tag{1}$$

To calculate slope (a_1) Eq. (2) and to calculate constant (a_0) Eq. (3) can be used, where n is the number of the data, $\overline{y}$ mean value of the data y, $\overline{x}$ mean value of the data x.

$$a_1 = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{2}$$

$$a_0 = \overline{y} - a_1 \overline{x} \tag{3}$$

Coefficient of determination (R^2) in Eq. (4) is used to quantify the error of the regression line where S_t is the total sum of the squares around the mean as shown in Eq. (5) and S_r is the total sum of the squares of the residuals as shown in Eq. (6).

$$R^2 = \frac{S_t - S_r}{S_t} \tag{4}$$

$$S_t = \sum_{i=1}^{n} (y_i - \overline{y})^2 \tag{5}$$

$$S_r = \sum_{i=1}^{n} (y_i - a_0 - a_1 x_i)^2 \tag{6}$$

Coefficient of determination of the model is the explanation percentage of the original uncertainty.

2.2. Polynomial regression analysis

A second order polynomial regression analysis can be also applied to the data (x_i, y_i). Mathematical expression of the regression line is shown in Eq. (7).

$$y = a_0 + a_1 x + a_2 x^2 \tag{7}$$

The terms (a_0, a_1, a_2) as shown in Eq. (8) can be solved with any method. To determine coefficient of determination (R^2) Eq. (4) and Eq. (5) can be used. However S_r the total sum of the squares of the residuals should be calculated using Eq. (9).

$$\begin{aligned} (n)a_0 + (\sum_{i=1}^{n} x_i)a_1 + (\sum_{i=1}^{n} x_i^2)a_2 &= \sum_{i=1}^{n} y_i \\ (\sum_{i=1}^{n} x_i)a_0 + (\sum_{i=1}^{n} x_i^2)a_1 + (\sum_{i=1}^{n} x_i^3)a_2 &= \sum_{i=1}^{n} x_i y_i \\ (\sum_{i=1}^{n} x_i^2)a_0 + (\sum_{i=1}^{n} x_i^3)a_1 + (\sum_{i=1}^{n} x_i^4)a_2 &= \sum_{i=1}^{n} x_i^2 y_i \end{aligned} \quad (8)$$

$$S_r = \sum_{i=1}^{n} (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2 \quad (9)$$

3. Application and Results

The number of vessels passed through Bosphorus data (Table 1) have been analyzed by linear regression between the years 1995 and 2020 (Fig. 3). However the coefficient of determination (R^2) the explanation of data is calculated an inadequate value as 24.85%.

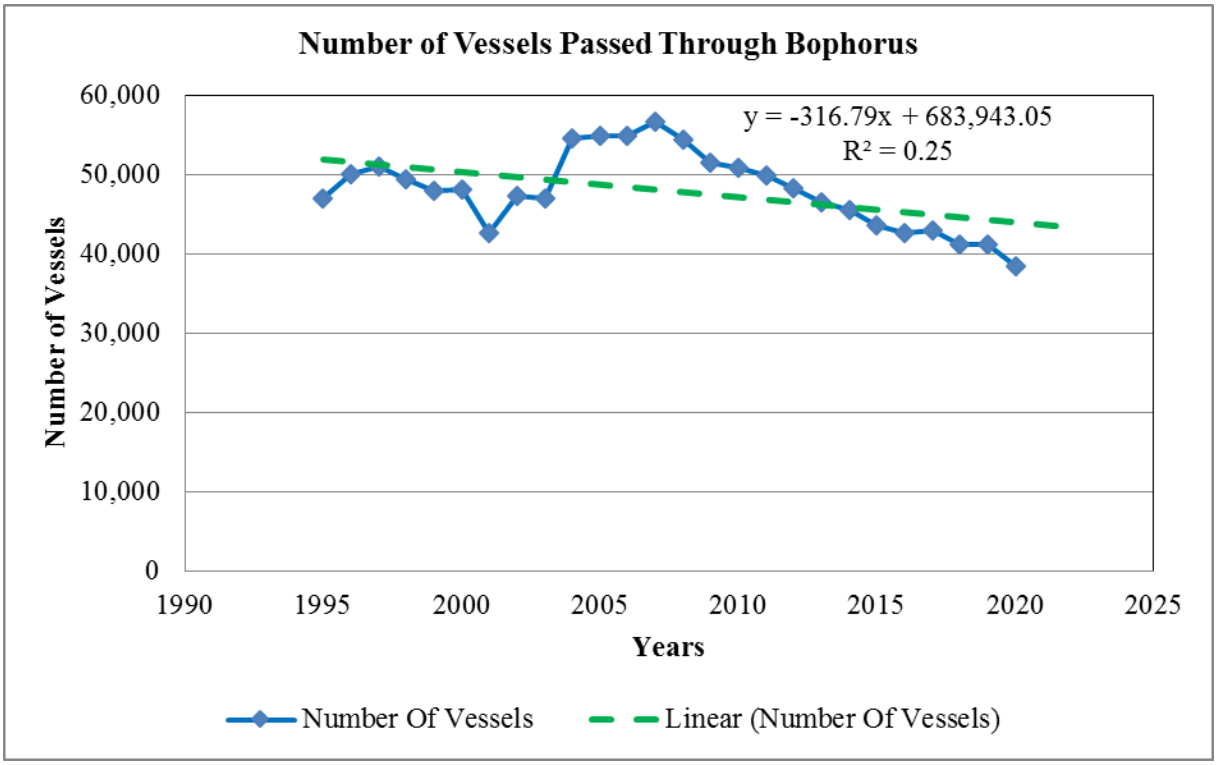

Fig. 3. Number of vessels passing through Bosphorus

Therefore, the data of number of vessels passed through Bosphorus have been reanalyzed by linear regression between the years 2006 and 2020 (Fig. 4). The coefficient of determination value is calculated as 97.38%. Thus the linear regression line can be used to estimate forward 5 years period. The projected estimation gives 32,255 vessels will pass through Bosphorus in 2025 (Table 5).

Table 5. Estimation of forward 5 years period of number of vessels passing through Bosphorus

Years	Number of Vessels
2021	37,238
2022	35,992
2023	34,747
2024	33,501
2025	32,255

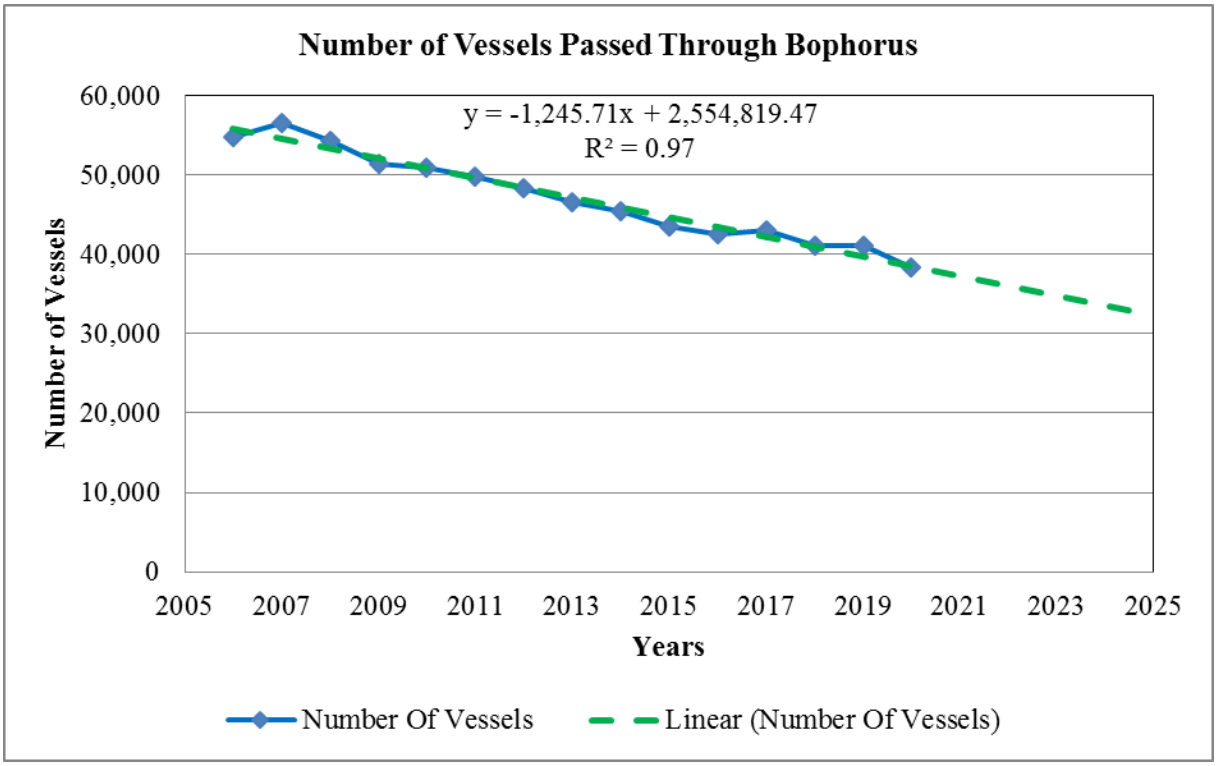

Fig. 4. Number of vessels passing through Bosphorus

The total gross tonnage (GT) data of vessels passed through Bosphorus have been analyzed by linear regression between years 2006 and 2020 (Fig. 5). The coefficient of determination value is calculated as 94.34%. Thus the linear regression line can be used to estimate forward 5 years period. The estimation shows that 684,862,096 total gross tonnage will pass through Bosphorus in year 2025 (Table 6).

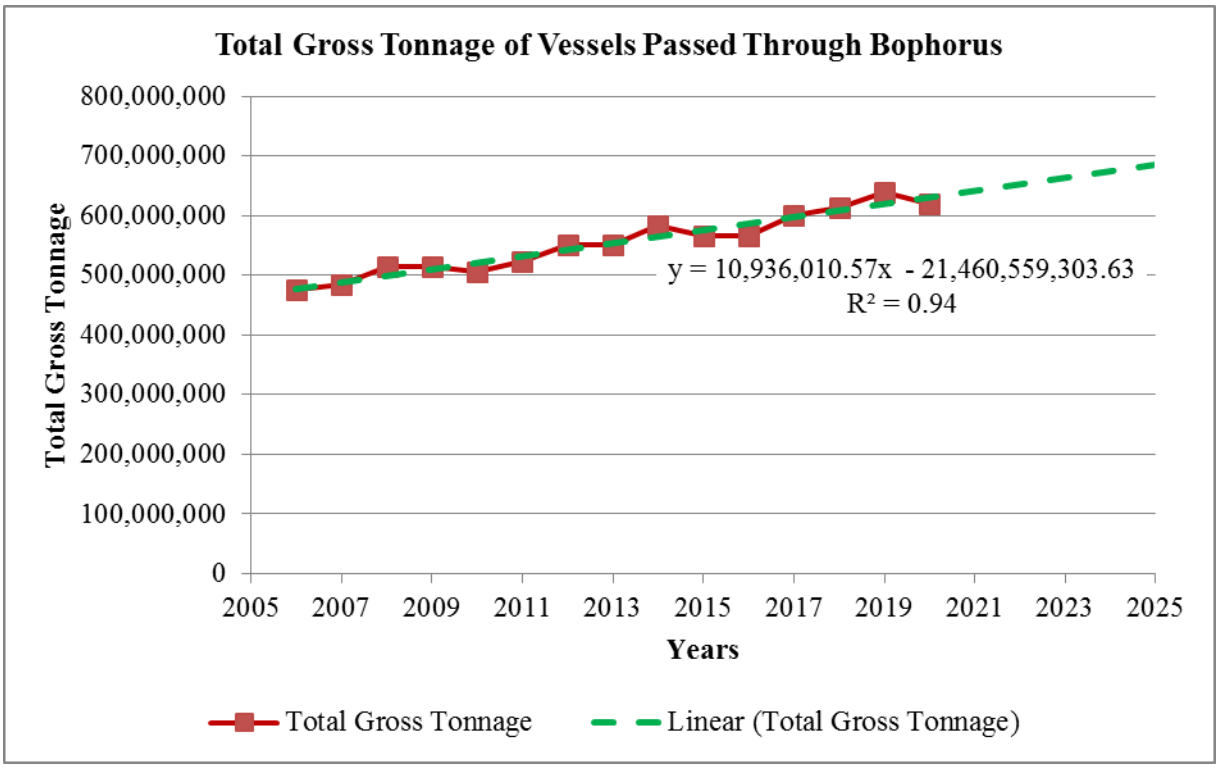

Fig. 5. Total gross tonnage of vessels passing through Bosphorus

Table 6. Estimation of forward 5 years period of total gross tonnage of vessels passing through Bosphorus

Years	Total Gross Tonnage of Vessels
2021	641,118,054
2022	652,054,065
2023	662,990,075
2024	673,926,086
2025	684,862,096

The gross tonnage per vessel has been calculated by dividing total gross tonnage to number of vessels (Fig. 6) and the estimation show that 18,582 gross tonnages per vessel will pass through Bosphorus in year 2025 (Table 7).

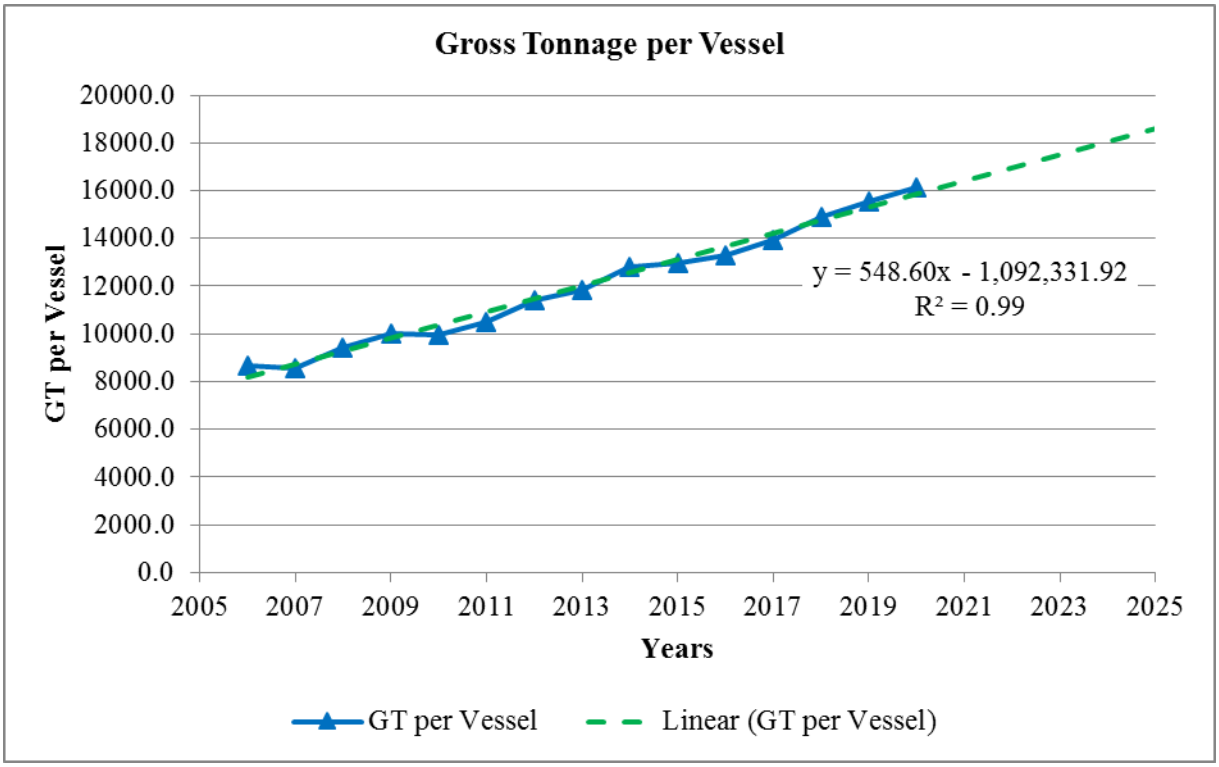

Fig. 6. Total gross tonnage per vessel passing through Bosphorus

Table 7. Estimation of forward 5 years period of total gross tonnage per vessel passing through Bosphorus

Years	Total Gross Tonnage per Vessels
2021	16,388
2022	16,936
2023	17,485
2024	18,034
2025	18,582

The data of number of vessels according to vessel type (Table 4) has been analyzed and selected results of regression analysis considering the coefficient of determination, have been given below. Vessel type of bulk carrier have been analyzed by linear regression between years 2006

and 2020 (Fig. 7). The coefficient of determination value is 94.05%. Thus the linear regression line can be used to project for 5 years. The estimation show that 10,103 bulk carrier type vessels will pass the Istanbul Strait in year 2025 (Table 8).

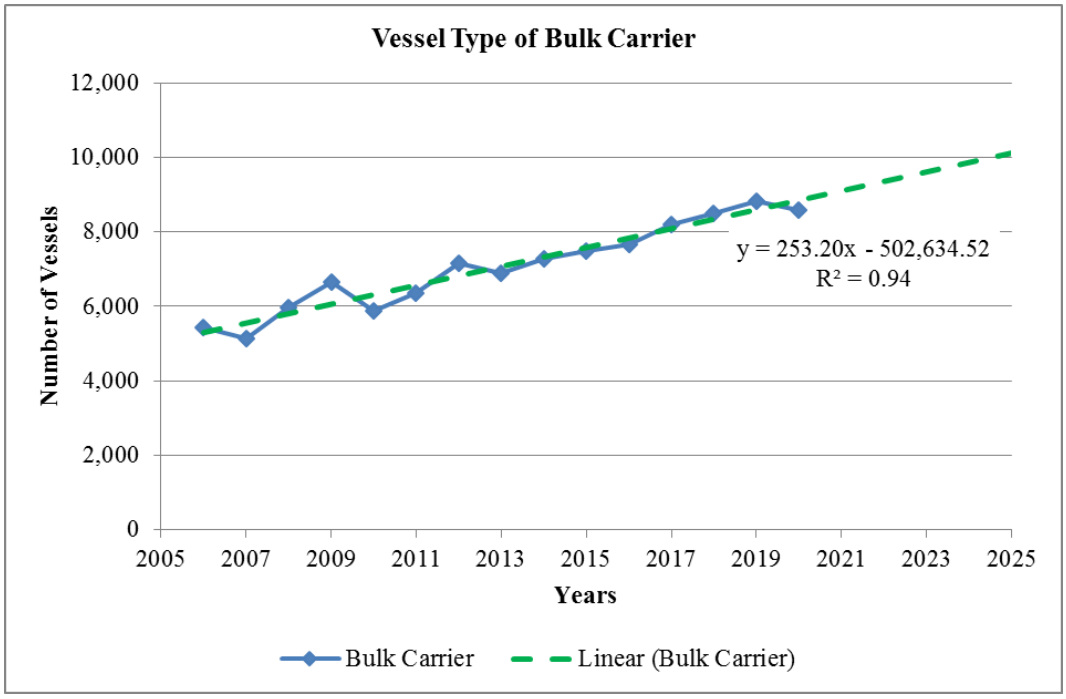

Fig. 7. Number of bulk carrier vessel type passing through Bosphorus

Table 8. Estimation of forward 5 years period of number of bulk carrier vessel type

Years	Bulk Carrier Vessel Type
2021	9,090
2022	9,343
2023	9,596
2024	9,850
2025	10,103

Vessel type of general cargo have been analyzed by linear regression between the years 2006 and 2020 (Fig. 8). The coefficient of determination value is calculated as 98.11%. Thus the linear regression line can be used to estimate forward 5 years period. The estimation show that 10,356 general cargo type vessels will pass through Bosphorus in year 2025 (Table 9).

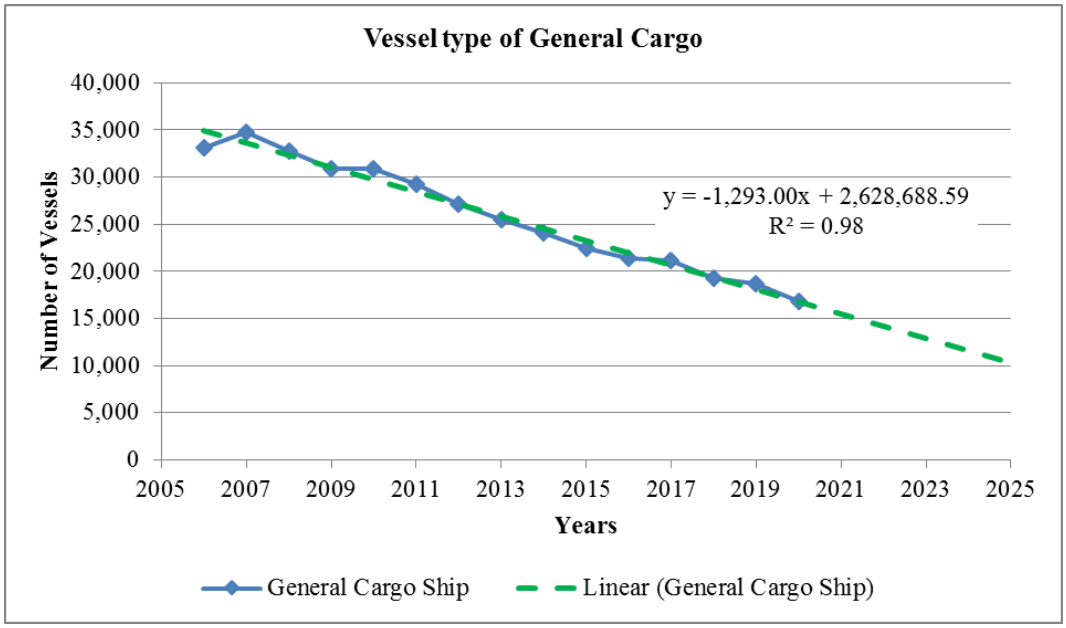

Fig. 8. Number of general cargo vessel type passing through Bosphorus

Table 9. Estimation of forward 5 years period of number of general cargo vessel type

Years	General Cargo Vessel Type
2021	15,528
2022	14,235
2023	12,942
2024	11,649
2025	10,356

Number of vessel type of livestock carrier passed through Bosphorus have been analyzed by linear regression between the years 2006 and 2020 (Fig. 9).

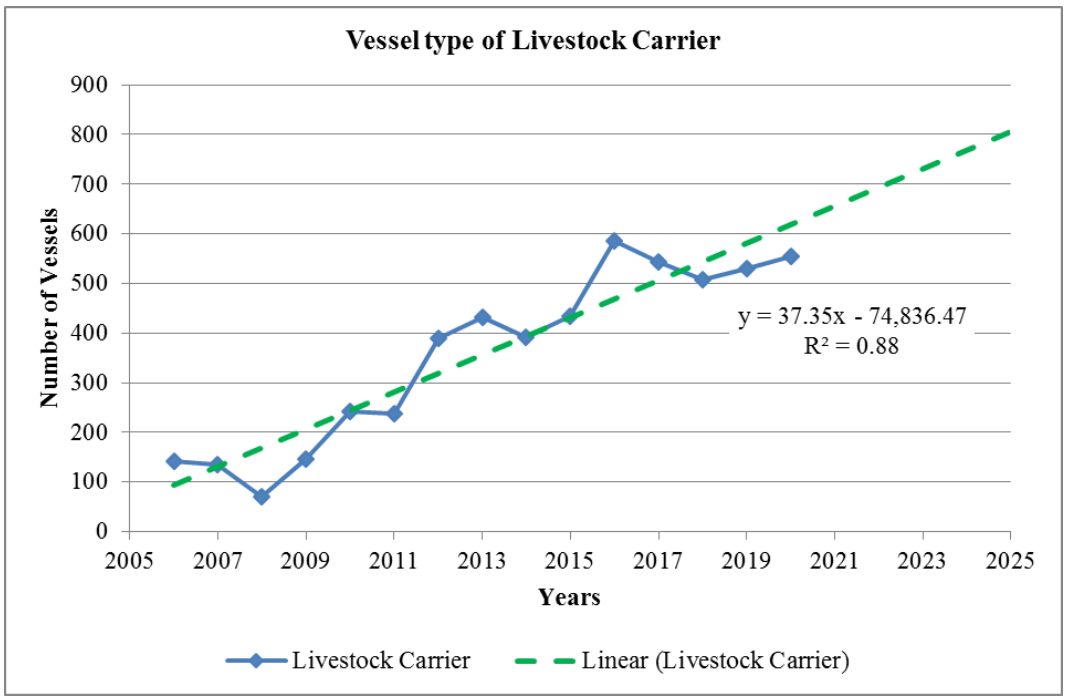

Fig. 9. Number of livestock carrier vessel type passing through Bosphorus

The coefficient of determination value is 88.43%. Thus the regression line can be used to estimate forward 5 years period. The estimation show that 805 livestock carrier ship type vessels will pass in the year 2025 (Table 10).

Table 10. Estimation of forward 5 years period of number of livestock carrier vessel type

Years	Livestock Carrier Vessel Type
2021	655
2022	692
2023	730
2024	767
2025	805

Number of passenger ship vessels have been analyzed by second order polynomial regression between the years 2006 and 2020 (Fig. 10). The coefficient of determination value is calculated as 88.02%. Thus the polynomial regression line can be used to estimate forward 5 years period. The estimation show that 733 passenger ship type vessels will pass through Bosphorus in 2025 (Table 11).

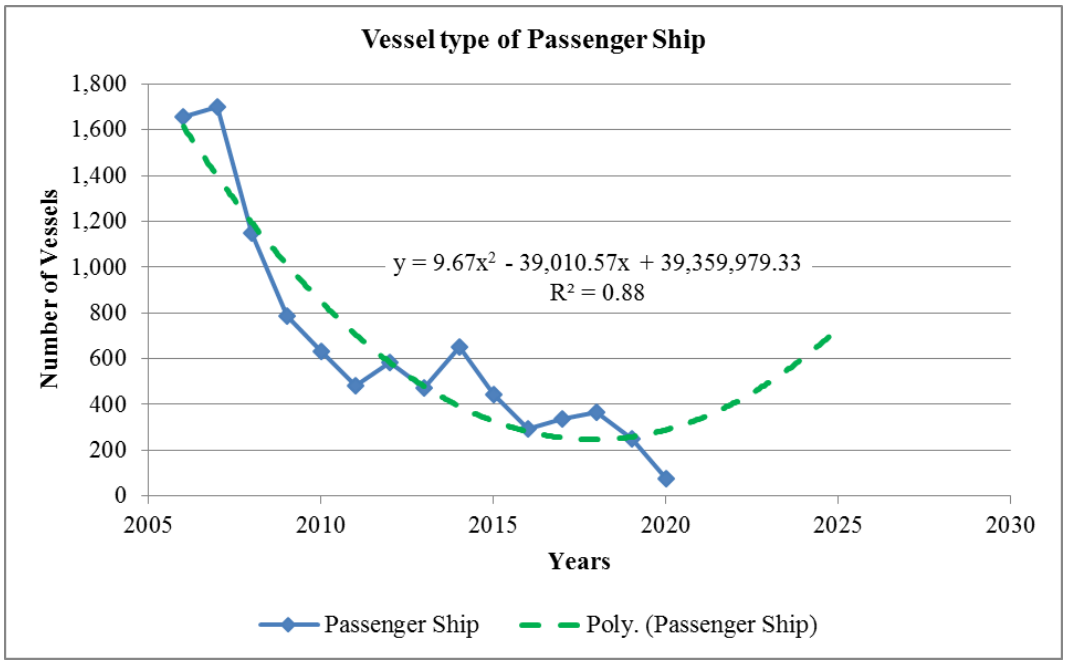

Fig. 10. Number of passenger ship vessel type passing through Bosphorus

Table 11. Estimation of forward 5 years period of number of passenger ship vessel type

Years	Passenger Ship Vessel Type
2021	338
2022	408
2023	497
2024	605
2025	733

Number of refrigerated cargo carrier vessel type have been analyzed by second order polynomial regression between the years 2006 and 2020 (Fig. 11). The coefficient of determination value is calculated as 96.40%. Thus the polynomial regression line can be used to estimate forward 5 years period. The estimation show that 274 refrigerated cargo carrier vessels will pass through Bosphorus for the year 2025 (Table 12).

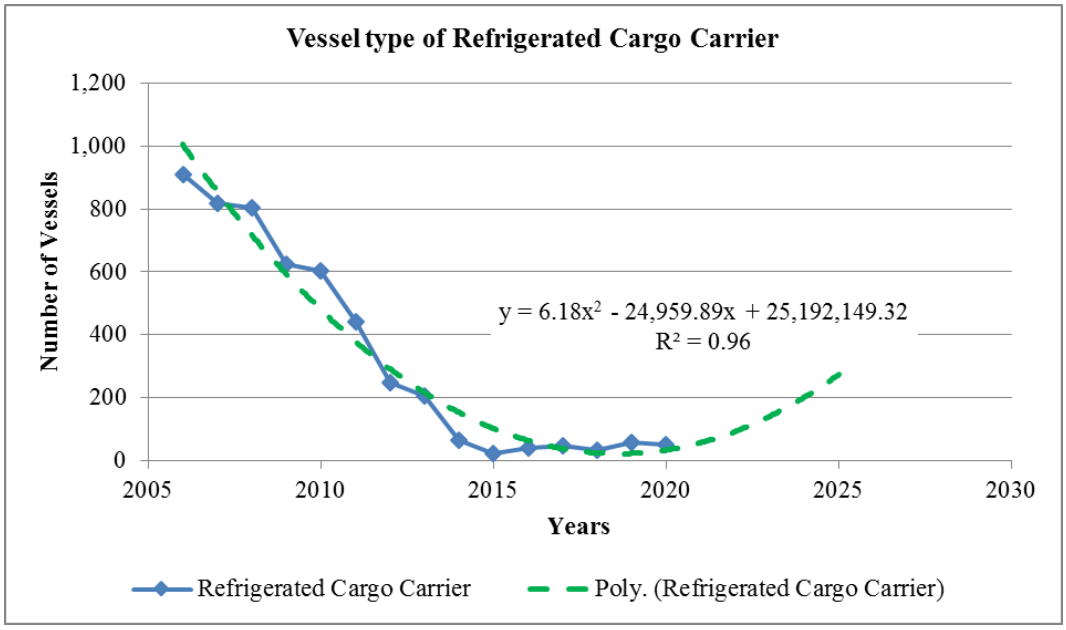

Fig. 11. Number of refrigerated cargo carrier vessel type passing through Bosphorus

Table 12. Estimation of forward 5 years period of number of refrigerated cargo carrier vessel type

Years	Refrigerated Cargo Carrier Vessel Type
2021	57
2022	93
2023	141
2024	201
2025	274

4. Conclusions

The data of Ministry of Transport and Infrastructure, General Directorate of Marine between the years 1995 and 2020 has been used to estimate the change of the number of vessels in the future years. Although the estimation show that the number of vessels passed through Bosphorus will decrease in the future years (Fig. 4, Table 5), the total gross tonnage will increase (Fig. 5, Table 6). Furthermore, the gross tonnage per vessel will also increase in the future (Fig. 6, Table 7).

The data of number of vessels according to vessel type (Table 4) has been analyzed and selected projectable results of regression analysis have been given in this study. The estimation results show that the number of bulk carrier vessel type (Fig. 7, Table 8), the number of livestock carrier vessel type (Fig. 9, Table 10), the number of passenger ship vessel type (Fig. 10, Table 11) and the number of refrigerated cargo carrier vessel type (Fig. 11, Table 12) will increase in

the future. However, the number of general cargo vessel type (Fig. 8, Table 9) will decrease in the future years.

It is expected that these estimations will be apply with a high degree of accuracy if present conditions in the region will continue. These conditions may include international trade, economy, maritime transport, local regulations...etc. In order to improve the estimations all influencing variables should be study. More precise estimations can be made with statistical models.

Notations

m	Meter
Btw.	Between
y	Dependent variable of the data
x	Independent variable of the data
a_1	Slope
a_0	Constant
$\overline{y}$	Mean value of the data y
$\overline{x}$	Mean value of the data x
R^2	Coefficient of determination
GT	Gross Tonnage

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