Application of queuing theory to tankers and other ships that pass through the Istanbul Strait

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Abstract

For the scientific research of ship arrivals and passage through a strait, the queuing theory can be used. The length of waiting in line (queue) depends on the number of customers (the proportion of arrival), the period of service, the number of service channels serving, and the service discipline.

Istanbul Strait is one of the most crowded and potentially dangerous waterways in the world. Its narrow and winding shape, along with strong surface and counter deep water sea currents hinders navigation. In this paper, a queuing model of maritime traffic in the Istanbul Strait is presented. For this purpose the passing of tankers and other ships are used as examples for the mono service channel. For the data taken between the years 1996-2000, calculations are made according to the criteria that a tanker is not allowed to enter the strait while another one is passing through. Also by using the same method, the traffic density is analyzed for ships other than tankers.

1 Introduction

The Strait of Istanbul, connecting the Black Sea to the Aegean Sea, is one of the major trade arteries in the world with an average of 136 transits a day, second to the Straits of Malacca.

The Montreux Convention of 1936 as it relates to the regime of the Turkish Straits, establishes freedom of passage and navigation with certain formalities for merchant vessels of any flag and with any kind of cargo, by day and by night, and the Strait is kept open for shipping traffic. Hence the Istanbul Strait (Bosphorus) serves as an international seaway of economic and strategic importance.

Due to angular windings, transit shopping either way requires at least twelve major course alterations as much as 80^0, with severely limited vision around these bends.

Geographical and oceanographic conditions as well as navigational constraints are the main parameters making the navigation through difficult and risky. Additionally, since passage through the Strait entails a run by about 17 nautical

miles all the way and takes almost two hours, utmost vigilance is necessary in order to maintain safe standards of navigation and to conduct vessels (Akten, 2006).

Increased shipping traffic through the narrow Istanbul Strait (Bosphorus) has heightened fears of a major accident that could have serious environmental consequences and endanger the health of the 12 million residents of Istanbul that live on either side of the Straits. The Straits have witnessed an increase in shipping traffic since the end of the Cold War to the point that around 50,000 vessels per year (nearly one every 10 minutes) now pass through them. Around one-tenth of these are crude oil or liquefied natural gas tankers (Oguzulgen , S. 1994). This increased congestion has led to a growing number of accidents; between 1988 and 1992, there were 155 collisions in the Straits (Guler N. and Poyraz O., 1997)

In March 1994, the tanker *Nassia*,collided with the dry bulk carrier Shipbroker in the Strait of Istanbul. Burning and spilling its cargo of crude oil, the Nassia drifted perilously close to the European side before the Turkish authorities managed to tow the flaming wreck into the Black Sea .

Thirty seamen were killed in the accident, shipping through the Istanbul Strait was interrupted for seven days and over 500 vessels had to wait for passage. In May of the same year, the Turkish government issued a declaration that, beginning 1 July, Turkey would exercise certain supervisory powers over shipping in the Straits (Istanbul Strait Maritime Traffic Regulations, 1994). Turkey's case here is not that it is exercising powers it did not have previously, but merely tailoring international standards and norms to the Turkish Straits (Güclü, Y. ,2001).

Briefly, the new rules were to be as follows:

1. Ships with dangerous cargoes should inform the Turkish authorities of their intention to pass through the Straits twenty-four hours in advance, and while they were in passage, no other ship would be allowed to pass through the Straits.
2. Ships using the Straits should abide by the report systems, traffic control measures and traffic separation schemes put in place by the Turkish authorities.
3. Speed would be limited to 10 knots, overtaking would be forbidden and vessel height would be sensibly limited to 190 feet because of the two suspension bridges north of Istanbul.
4. Turkey reserved the right to close the Straits temporarily while fire fighting, sounding, sports and scientific activities, rescue operations or anti-pollution projects were going on.

2 The modeling of Istanbul Strait for a single server, single queue

The subject of queuing theory can be described as follows: consider a *service center* and a *population* of *customers*, which at some times enter the service center in order to obtain service. It is often the case that the service

center can only serve a limited number of customers. If a new customer arrives and the service is exhausted, he enters a *waiting line* and waits until the service facility becomes available (Willig, 1999).

The maximum number of tankers that can cross the Istanbul Strait (the capacity of the Bosphorus) can be found by using a First in First Out (FIFO) queuing model, with a single server, single queue and infinite a arrivals(Lee, 1966) (Gross and Harris 1974).

The maximum number of tankers that can pass should be calculated according to regulations. According to the regulations, the maximum speed of the tankers is 10.0 nm (18.5 km/h), and if a large ship with dangerous load (length is greater than 150 m) enter the Istanbul Strait, (Bosphorus) another ship with the same specifications cannot enter the Istanbul Strait. Since the data for ship length is not available and taking into consideration the heavy tanker traffic, all tankers are considered to be a large ship. Additionally, the ferry and boat traffic on the Istanbul Strait is not taken into consideration: (Şimşek, 2003)

1 day: 1440 minutes
Length of Istanbul Strait : 16 miles = 160 gomina
Speed of Ship: 10 mph = 100 gomina/hr
The time it takes for a tanker to leave the Istanbul Strait: t
t=160/100 = 1.6 hours = 96 minutes

The number of tankers that cross the Istanbul Strait are given in the tables 1 and 2.

Table 1. Number of tankers and other ships that crossed the Istanbul Strait in 1996- 1998 (source: Turkish pilots organization)

	1996			1997			1998		
	Tankers	Others	Total	Tankers	Others	Total	Tankers	Others	Total
January	336	3255	3591	337	3214	3551	397	3550	3947
February	324	2834	3158	329	3062	3391	345	3302	3647
March	380	3534	3914	357	3850	4207	378	3567	3945
April	300	3794	4094	351	3428	3779	364	3553	3917
May	377	4344	4721	381	4432	4813	440	4019	4459
June	347	3813	4160	365	4325	4690	456	3837	4293

	1996			1997			1998		
	Tankers	Others	Total	Tankers	Others	Total	Tankers	Others	Total
July	382	3933	4315	363	4375	4738	469	3969	4438
August	355	4340	4695	408	4003	4411	449	3778	4227
September	357	4007	4364	362	3910	4272	433	3736	4169
October	368	4159	4527	386	3792	4178	526	3910	4436
November	402	4046	4448	343	4381	4724	438	3453	3891
December	320	3645	3965	321	3867	4188	447	3488	3935
Total	4248	45704	49952	4303	46639	50942	5142	44162	49304
Month. Aver.	354	3808	4162	359	3886	4245	429	3680	4109
Daily Aver.	12	125	137	12	130	142	14	123	137

Table 2. Number of tankers and other ships that crossed the Istanbul Strait in 1999, 2000 (source: Turkish pilots organization)

	1999			2000		
	tankers	other	Total	tankers	other	total
January	318	3256	3574	384	2900	3284
February	299	3193	3492	345	3052	3397
March	381	3715	4096	368	3540	3908
April	360	3842	4202	425	3794	4219
May	455	4073	4528	435	3692	4127
June	401	3955	4356	460	3731	4191
July	382	3798	4180	482	3767	4249
August	374	3648	4022	448	3820	4268
September	376	3540	3916	403	3652	4055
October	407	3670	4077	383	3660	4043
November	331	3367	3698	425	3924	4349
December	368	3397	3765	379	3610	3989

	1999			2000		
	tankers	other	Total	tankers	other	total
Total	4452	43454	47906	4937	43142	48079
Monthly average	371	3621	3992	411	3596	4007
Daily average	12	121	133	14	120	134

Calculating the average number of arrivals for tankers in 1996:

$$\mu = \frac{1440}{96} = 15 \text{ tanker /day; } \lambda = 12 \text{ tanker/day}$$

The expected number of tankers in the system: L
The expected number of tanker in queue: Lq
Average time spent per tanker in the system (Istanbul Strait): W
Average time spent per tanker in queue: Wq
The probability of there being no tankers in the system (Istanbul Strait): P0

At any given moment, there can be 1 or 0 tankers in the Istanbul Strait since according to regulations when a ship carrying dangerous loads enters the Istanbul Strait there cannot be another ship of the same characteristics. Therefore there can be a maximum of 1 tanker on the Istanbul Strait . This probability can be found to be P_1 = % 80.

The expected number of tankers to cross the Istanbul Strait : Lb

Using the formulas above, calculations have been made for years 1996, 1997, 1998, 1999 and 2000 and the results can be found in Table 3. As can be seen in the table, the percent capacity used of the Istanbul Strait for tanker crossing is 80-93%, and the ratio of the Istanbul Strait being unused is 7-20%. The number of tankers in queue is between 3.2 - 13, and the time that tankers wait in queue is between 8 - 24 hours. In 1996 4248, and in 2000 4937 tankers crossed the Istanbul Strait .

The number of tankers crossing shows that the tanker traffic on the Istanbul Strait is increasing. Taking into consideration factors like the increase in number of tankers , the traffic of ferries and boats that have been ignored in this research, and also weather conditions which lead to the Istanbul Strait being closed to tanker traffic, the capacity of the Istanbul Strait should be increased.

Table 3. Calculation results for the tankers crossing the Bosporus between the years 1996-2000

	1996	1997	1998	1999	2000
λ	12	12	14	12	14
L	4	4	14	4	14
L_q	3,2	3,2	13	3,2	13
W (hour)	8	8	24	8	24
W_q(hour)	6,5	6,5	24	6,5	24
P_0	20%	20%	7%	20%	7%

3 An example application of the model for Other Ships

The maximum number of ships that can cross the Istanbul Strait (the capacity of the Bosphorus) can be found by using a First in First Out (FIFO) queuing model, with a single server, single queue and infinite arrivals.
According to the regulations, the maximum speed of the tankers is 10.0 nm (18.5 km/h),and the distance between the ships should be kept 8 gomina (1 gomina = 185 meter). The ships cannot pass each other.
The other intercity maritime traffic like boats and ships are neglected.

1 day: 1440 minutes

The length of Istanbul Strait : 16 mil = 160 gomina

Vessel speed : 10 mile /h = 100 gomina/ h

The distance between two ships : 8 gomina

The duration for a vessel to leave Istanbul Strait: (t)

t = 160/100 = 1.6 hour = 96 minutes

The number of maximum vessels that can exist in the Strait at any time: (S)

S = 160/8 = 20 vessels

The number of vessels that can pass the Strait without any restrictions: (N)

$N = (1440/96) \times 20 = 300$ vessels

If the duration of a vessel entering the Strait and leaving the Strait (96 minutes) is taken as a period, than total number of the periods in a day are: (T)

$T = 1440/96 = 15$ period

Without any restrictions 300 ships can pass the strait to the north in a day. The data given in the tables are the total number of ships that pass the strait both in north and south directions. A loaded ship that passes to the north will come back to the south after unloading its cargo. For this reason the number of ships that pass the strait in the north and south directions are agreed to be equal in number.

When the calculations are carried out for the year 1996, since 20 ships can pass every 96 minutes;

$(1440/96) \times 20 = 300$ ships /day can pass.

$\mu = 300$ ships /day

$\lambda = 63$ ships /day

Expected number of ships that exists in the system : L

$$L = \frac{\lambda}{\mu - \lambda}$$

$$L = \frac{63}{300 - 63}$$

L = 0.27 ship

Expected number of ships in the queue (L_q)

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$$

$$L_q = \frac{63^2}{300(300 - 63)} = 0.06 \text{ ship}$$

Average time per ship spent in the system (In the strait): (W)

$$W = \frac{1}{\mu - \lambda} = \frac{1}{300-63} = \text{ 0.004 day = 0.1 hour = 6 minutes}$$

Average time per ship spent in the queue (W_q)

$$W_q = \frac{\lambda}{\mu(\mu-\lambda)} = \frac{63}{300(300-63)} = 0{,}001 \text{ day = 0,02 hour = 1 minute}$$

The probability that no ship exists in the system (In the strait) : P_0

$$P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{63}{300} = 0{,}79 = \% 79$$

The expected number of ships that pass through the Strait: (L_b)

$L_b = (L - L_q)\, T = (0{,}27 - 0{,}06)\, 15 \cong 3$ ships

By using the above formulas the calculations are made for the years 1996, 1997, 1998, 1999, 2000. The results are tabulated in the table 4.

Table 4. The results of the calculations for the ships other than tankers for the years 1996-2000

	1996	1997	1998	1999	2000
λ	63	65	62	67	67
L	0,27	0,27	0,27	0,29	0,29
L_q	0,06	0,06	0,06	0,06	0,06
W(hour)	0,1	0,1	0,1	0,1	0,1
W_q(hour)	0,02	0,02	0,02	0,02	0,02
P_0	0,79	0,78	0,79	0,77	0,77

4 Conclusion

In this paper the passing of tankers and other ships through the Istanbul Strait have been used as examples for the model of single service channel.

In the light of obtained results for the years 1996-2000, it is observed that there is dense traffic in the straight and the number of tankers passing through the straight has been increasing. The calculations related with tables 1 and 2 might indicate that passage of more than one tanker might be possible.

As can be understood from the table 4, the ship passage rate is between 21-23%. The queuing time for the ships is short. The traffic to the north is not very dense.

All the calculations and results are the outcome of the data related with 1996-2000. To give a more actual interpretation, new data and other methods might be used.

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