Assessing the impact of traffic regulations on the waiting queues of maritime straits; the Bosporus example

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Abstract: Straits consist a key component of international maritime traffic while, the combination of limited capacity and heavy traffic load poses a challenge for combining safe and efficient navigation. In this article, a general and fully parameterizable queueing model is proposed in order to evaluate the impact of physical characteristics, queueing schemes, applied regulations and transit traffic attributes to the efficiency of the straits system. Bosporus (Istanbul, Turkey) demonstrates a unique combination of, on one hand, navigation difficulties and heavy traffic load and, on the other hand, comprehensive and detailed regulations that govern its operations, thus, comprising a suitable testbench for the proposed model. Variations of five applied regulations and traffic scheduling policies are modelled and their impact on the average waiting time and the average queue length is assessed and discussed.

Keywords: Simulation; Traffic regulations; Maritime straits;

1. Introduction

Chokepoints are a common concept in transport geography and they refer to locations that limit the capacity of traffic and cannot be easily bypassed. Considering the characteristics of maritime transportation, chokepoints (straits, canals, channels, etc) are particularly prevalent. Many of them are the result of the constraints of physical geography while others, are artificial creations. Three concepts define a chokepoint as a resource:

- *Physical characteristics*: A chokepoint is a location forcing the convergence of traffic and limiting its capacity through its physical characteristics (whether by depth, width or overall navigability).
- *Usage*: The value of a chokepoint is proportional to its usage level, with regard to its physical limit of service, and the availability of alternatives.
- *Access*: A level of control must be established to insure safe and efficient access to the chokepoint. This involves agreements regulating its usage, tolls or other means of compensation for the usage and the needed access infrastructures [Rodrigue, 2004].

Although the physical characteristics of most chokepoints are very stable, implying a fixed capacity, their use and value is subject to significant variations. With the growth of maritime traffic and world trade, many have become extremely valuable resources accounting for the most important strategic locations in the world. However, like all fixed supply resources, there is a limit to which they can be used. The closer they are to being "exhausted", the more unstable their usage is and the more efforts to be spend on securing their access.

Regarding straits used for international navigation, their special status was recognized, for the first time in a codified international instrument, in the Third United Nations Law of the Sea Convention 1982 (UNCLOS III). Part III of the Convention sets out the defining criteria, the right of transit passage and the rights and obligations of users and coastal states [UN].

UNCLOS, COLREG (Collision Regulations) and International Maritime Organization (IMO) traffic separation schemes (TSS), in conjunction with long-standing international agreements comprise a set of regulations that apply in navigation through most straits.

2. Objective of the article

Whether due to international agreements or UN and IMO recommendations, applied regulations for navigation in straits imply an effort to compromise the rights and demands of the:

- Coastal states and their economical, social and environmental concerns and
- Clients of international maritime trade and the shipping industry.

On initiating a set of regulations, practical rules and scientific results are evaluated in order to formulate a set that will allow for *efficient* and *safe* navigation. In cases of highly utilized straits there is a trade-off between the two since, stricter safety rules result in an unavoidable degradation of the straits throughput. However, since safe navigation is a priority, rules that have been proved to be sufficient when applied alone, are assembled in a set of joint regulations, whose effect on the throughput of maritime traffic cannot be assessed.

For the same reason, altering or improvement of these rules, in terms of efficiency, needs a considerable amount of time and effort in cases of:

- Time-evolving traffic patterns;
- Special traffic events;
- Changes in the straits' physical characteristics.

The objective of this article is to propose a universal simulation model for the vessels traffic in maritime straits. The proposed approach can offer valuable insight in determining how applied measures and regulations interact with each other as well as with the physical characteristics of the straits in the definition and utilization of the straits' throughput.

Following, a case study on the Bosporus will exhibit the impact of a changeable regulations and traffic environment to the Straits waiting queues. An approach that has produced many interesting results related to maritime traffic in the Bosporus Straits and its consequences and can be used in determining safety rules is the analytical solution of a set of differential equations [K. Sariöz et al., 1999, H. Ors et al., 2003, E. Otay et al., 2003, B. Tan et al., 1999]. In [E. Kose et al., 2003], a discrete-event model of the Straits has been developed that relates the average waiting time in the Straits entrances to the mean arrival rate of vessels. Finally, in [Ozbas et al., 2007], a detailed functional simulation model of the Bosporus has been presented in which factors that affect maritime traffic are being identified.

3. A universal model of maritime straits

A queueing model of maritime straits can help at the assessment of the traffic bottlenecks that develop due to random (e.g. weather conditions) or systematic (e.g. applied regulations or traffic patterns) components of the system. Parameterized modeling of this system can serve as a testbench for benchmarking different regulation sets or varying traffic distributions that can emerge in the future. The proposed methodology focuses at the efficiency of the system and its traffic flow variables, namely:

$$\hat{q}(n) = \frac{\int_0^{T(n)} Q(t)dt}{T(n)}$$

1. the average queue length , where *T(n)* the time required to observe *n* waiting vessels in the system

2. *Q(t)* the number of vessels in queue at time *t*, for $0 \leq t \leq T(n)$ and the average waiting time,

$$\hat{d}(n) = \frac{\sum_{i=1}^{n} D_i}{n}$$

where *n* transiting vessels wait for D_1, D_2, …, D_n time until they enter the straits

To this end, vessels are considered as moving points, with no dimensions, navigating with constant speed, without deviations and in a predefined route. Moreover, the set of maritime traffic regulations is considered as being well-defined and applicable, with no exceptions and invariably to all arriving and transiting vessels.

Since the model aims in studying traffic flow characteristics, accidents can be represented as time-delaying events that do not affect the quality of service of the operating straits. Thus, the probability of an accident for a transiting vessel is considered to be zero and the historical average accident delays are added in the average delays due to maintenances or bad weather conditions.

A universal and fully parameterizable model of maritime straits has been developed in ANSI C [Law et al., 2000] and is presented in Figure 1 [Mavrakis et al., 2007]. The model consists of four main components: the physical description of the waterway, the waiting queues at its entrances, the applied transit regulations and the description of the traffic that uses the waterway.

Physical description of the waterway includes:

- Definition of the traffic routes that it permits;
- Existence and description of any internal ports, since they function as additional entrance or exit traffic points;
- Definition of any special characteristics like water locks or narrowings that affect navigation;
- Description and quantitative evaluation of factors that limit the waterway's availability, partially or as a whole, e.g. weather conditions, accident probability or maintenance periods.

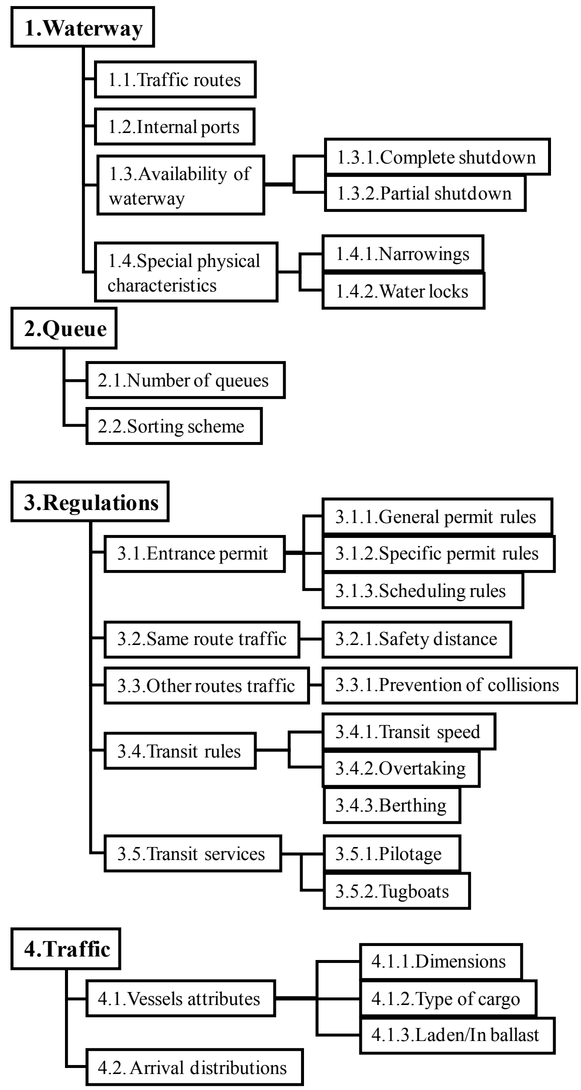


Figure 1: Parameterized straits model

The queues' component reflects the number and type of queues used in each entrance of the waterway, where first come - first serve or sorted queues can be implemented.

Applied transit regulations include, apart from rules regarding the conduct of transit (transit speed and overtaking), the necessary conditions to permit entrance to a vessel, transit rules that ensure safe navigation and are dependent on the same or different route traffic and description of the transit services that can affect aspects of transit maritime traffic like the provision of pilots and availability of tugboats.

Finally, the model is parameterized with regard to the transiting vessels attributes (namely, size, type of vessel and whether it transits laden or in ballast) as well as the time distribution of vessels arrivals, in terms of their attributes and direction of transit.

4. Typical model flow

A typical model configuration regards a waterway with two opposite, identical routes. Arriving vessels are placed in the respective waiting queue, which is then sorted. In the first occasion, the first vessel in the queue enters the straits. After a predefined amount of time (determined by its speed), the vessel exits the straits and, thus, the simulation system (Figure 2). A sequencer module determines, whether a vessel in the waiting queue can enter in the desired direction.

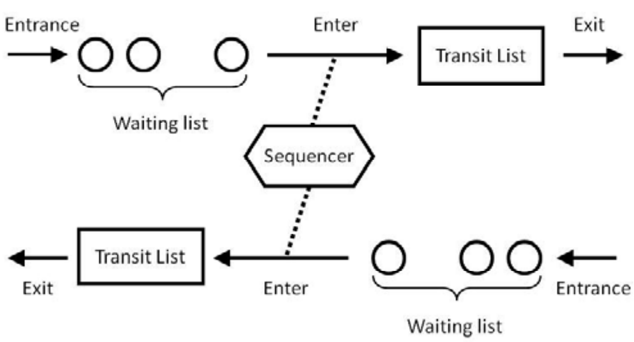


Figure 2: Bosporus model

Upon a vessel's arrival, the sequencer checks the waterway conditions with regard to the traffic regulations and if every constraint is met, the vessel enters the waterway. Otherwise, the vessel is added to its waiting queue and entrance is postponed for a time instance that is calculated with respect to the current conditions. Upon a vessel's entrance, the sequencer variables are updated and new potential entrance times for both directions are calculated. A transit list that maintains all currently transiting vessels is updated. A separate event for closing of the waterway due to severe weather conditions is provided. This event is also used to model delays due to accidents, mechanical problems of the transiting vessels or other occurrences (e.g. maintenance works). A second separate event is provided to demark the daytime and nighttime periods of every simulation day based on a set of sunrise/sunset data.

5. Bosporus model

The Bosporus lies between the Black Sea to the North, and the Sea of Marmara to the South. It is approximately 31 km long (Figure 3), with an average width of 1500 meters and only 700 metres at its narrowest point, has many sharp turns, some of them more than 45 degrees and constant surface and deep water currents. Bosporus traverses through the city of Istanbul, an urban area of over 12 million people and an average of 50000 vessels transit it annually, along with hundreds of passenger, fishing, and leisure crafts, which daily cross it from one side to the other [Republic of Turkey, TMFA and TUMPA].

Figure 3: Bosporus straits geography.

Navigation in Bosporus is regulated by the 1936 Montreux Convention which is considered as the most detailed international convention regulating navigation in straits. According to it, all merchant vessels enjoy, in principle, complete freedom of passage and navigation by day and night, without being subject to any 'formalities' except for sanitary controls and optional towage and pilotage services [Jia, 1998; Plant , 1996; Plant, 2000; Republic of Turkey; TMFA and WVTS].

Bosporus, apart from its importance for international maritime trade, has faced a number of changes in the recent years that underpin the need for a modelling approach like the one proposed in the current article; A set of maritime regulations that were introduced in 1994 and amended in 1998 and 2002 that transformed traffic management in Bosporus; a novel Vessel Traffic Service (VTS) system that is gradually coming online and that will eventually offer new capabilities; the increased crude oil production in Russia and NIS countries as well as the economic development of Black Sea littoral states that will alter the traffic patterns; evolution of maritime vessels safety and navigation procedures and subsystems;

6. Constraints and input data description

Following the proposed parameterization, the simulation model is configured according to the actual physical characteristics of the Bosporus, the transit rules, regulations and policies, as applied by the Turkish maritime authorities and the historical traffic data [Brito, 2000, GMCSSA, 2003, Kose et al., 2003, Nitzov, 1998, Ors et al., 2003, Otay et al., 2003; Tan et al. 1999; TUMPA and TSA]. An event graph for this model is shown in Figure 4 [Law et al., 2000]:

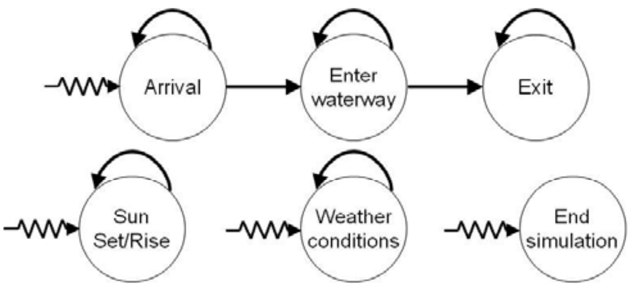


Figure 4: Event graph for the Bosporus model

1. *Waterway*
    a. *Traffic routes*. Two directions of traffic, northbound (Marmara Sea to Black Sea) and southbound (Black Sea to Marmara Sea), each 31 km long.
    b. *Internal ports*. In this paper, internal ports of Bosporus are not modeled.
    c. *Weather conditions*. An independent event for weather conditions is triggered every 4 hours of simulation time. Using a Poisson distribution, a decision is made of whether the Straits are suitable for navigation due to severe weather or not for the next 4 hours. The model is adjusted so that the Straits are closed, on average, for 480 hours every year. Shutdowns due to weather conditions apply to the whole waterway.
    d. *Accident probability*. On average, 30 hours every year are added to the severe weather period to count in for the closing of the Straits due to accidents or mechanical problems of the transiting vessels. Shutdowns due to accidents apply to the whole waterway.
    e. *Special physical characteristics*. A special set of rules apply for the Straits narrowing between Vanikoy and Kanlica. There are no water locks or other physical obstacles in Bosporus.
2. *Queues*
    a. *Number of queues*. One queue per direction for all vessels.
    b. *Sorting scheme*. According to the applied regulations, passenger vessels are scheduled to enter the Straits with top priority over all other vessels. Dangerous cargo vessels are scheduled to enter the Straits with minimum priority over the remaining types of cargo. A first-in-first-serve scheme (FIFS) is implemented; however, the whole queue is scanned in order to find the first vessel that can transit without violating any regulation.
3. *Regulations*. Detailed regulations, as applied by the Turkish authorities, can be found in [GMCSSA, 2003]. In brief:
    a. *Entrance permit*. Vessels longer than 200 m, carrying dangerous cargo can navigate through the Straits only during daytime. During severe weather conditions or accident occurrences, no vessel can enter the Straits. Once every day, during daytime and for a predetermined period of time, two-way traffic is suspended and a batch of large or dangerous cargo vessels is forwarded in one-way traffic mode. Afterwards, traffic is inverted and a batch of large or dangerous cargo vessels is forwarded in the opposite direction.
    b. *Same route traffic*. The minimum safety distance between two consecutive vessels that enter the Straits in the same direction is defined to 8 cables (~1.5 km). The safety distance is considerably longer between two large dangerous cargo vessels; nearly 29 km for northbound vessels and 23 km for southbound vessels.
    c. *Other routes traffic*. Virtually no dangerous cargo vessels can enter on the opposite direction of an already transiting dangerous cargo vessel. Moreover, two-way traffic is suspended, when a large or dangerous cargo vessel transits the Straits. Special attention is paid to schedule transits so as to avoid meetings of almost all types of vessels between Vanikoy and Kanlica.
    d. *Transit rules*. A constant transit speed of 10 knots relative to land is used for all vessels and overtaking is not allowed. Overtaking is not allowed within Bosporus. All vessels transit the whole length of the Straits; a vessel does not depart from or arrive in a port within Bosporus.
4. *Traffic*. The simulation system uses as its input historical data that have been processed to match the conventions of the model. A uniform distribution is used to generate all possible events for the discrete-event model. Interarrival time is defined to be the same at both entrances (~21.45 minutes).

According to the historical data, arriving vessels can be represented by a matrix consisted of all possible length and cargo categories (Table 1). Since, the applied transit regulations discriminate laden from in ballast vessels, a distribution for the cargo state of arriving vessels is needed (Table 2). Following a series of interviews with maritime agents, passenger vessels (passenger, RO-RO, etc) are assumed to be always laden, while general cargo vessels (bulk carriers, container carriers, general cargo ships, etc) are assumed to be 75% laden for both directions. On the other hand, dangerous cargo vessels (which include all oil tankers, chemical tankers, LPG/LNG carriers, etc) are assumed to heavily depend on the direction of transit: for southbound transits 90% of the vessels are considered laden a ratio that for northbound transits falls to only 20%. This bias can be justified by the general pattern of the Black Sea oil industry which mainly exports large amounts of Caspian Sea and Russian oil using the ports of Novorossiysk, Supsa and Tuapse through the Straits and imports smaller quantities of oil for refining in Bulgaria and Romania as well as oil products. Indicatively, for the period 1997-1998, the quantity of oil and oil products that was transited southbound through the Straits was six-fold the quantity that was transited the opposite way.

Table 1: Arriving vessels' attributes distributions (%)

LOA (m) / Type of cargo	50-100	100-150	150-200	200-250	250-300
Passenger Cargo	0.15	0.47	0.24	0.04	0.10
General Cargo	42.56	32.02	12.09	1.83	0.39
Dangerous Cargo	0.84	1.14	4.31	2.40	1.42

Table 2: Vessels laden/in ballast (%)

		Passenger Cargo	General Cargo	Dangerous Cargo
Southbound	Laden	100%	75%	90%
	In Ballast	0%	25%	10%
Northbound	Laden	100%	75%	20%
	In Ballast	0%	25%	80%

Vessels under 50 m are not included in the input data since they transit the Straits essentially unconditionally, while transits for vessels over 300 m are rare incidents. Also, use of tugboats, pilotage services, maneuvering to and from the actual designated waiting vessels areas and the subsequent time spaces are not modeled in this article.

7. Assessing the impact of traffic regulations

Apart from the codified maritime regulations, there are a number of implementation policies that the Turkish maritime authorities exercise in order to service incoming traffic. In this paper, three maritime regulations and two implementation policies have been selected to be studied:

- Length of the Bosporus Straits waterway that is regulated;
- Minimum safety distance between two consecutive transiting vessels;
- Forwarding of the first vessel that can enter the Straits without violating the regulations, regardless of its position in the waiting queue.
- Alternately suspension, during daytime, of two-way traffic, and transit of a batch of large or dangerous cargo vessels in each one-way traffic period;
- Partial suspension of navigation through the Straits during night time;

In all cases, the regulation or policy under consideration is treated as a free variable and the simulation results are compared against those of the base scenario that consists of: i) The actual, currently applied maritime regulations and policies; ii) Vessels' distribution with regard to their length and cargo rates according to the data of Table 1 and Table 2 and iii) A mean annual arrival rate of 55000 vessels for both directions. Each scenario is run for a simulation time of one year and repeated three times.

7.1 Scenario 1

Definition of the total (regulated) length of Bosporus as well as of the minimum safety distance following a laden dangerous cargo vessel is studied in this scenario. The boundaries are defined by the line Turkeli light traffic control station – Yam Burnu in the north and the Ahirkapi traffic control station location in the south (a total navigation length of approximately 31 km). After a southbound dangerous cargo vessel passes the Bosporus bridge (23.5 km distance from the northern boundary) or a northbound dangerous cargo vessel passes the Hamsi Burnu – Fil Burnu line (29 km distance from the southern boundary), another similar vessel may enter Bosporus on the same direction.

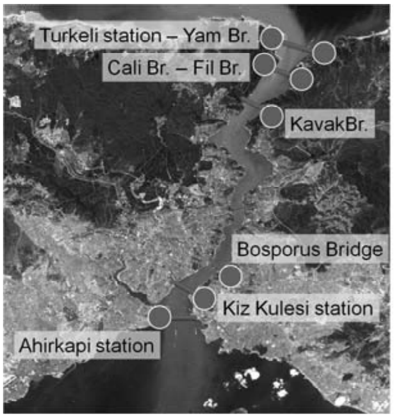


Figure 5: Bosporus Straits waypoints

Scenario 1 examines the possibility of reducing the regulated length of the Straits or the minimum safety distance between two consecutive dangerous cargo vessels. For this purpose, waypoints (Figure 5) are combined to generate 5 new combinations of distances (Table 3). Combination #1 corresponds to the base scenario (SB stands for southbound traffic and NB for northbound traffic).

Table 3: Distances combinations

Combination / Distance (km)	1	2	3	4	5	6
Total Bosporus length	31.0	29.0	29.0	27.0	25.0	23.0
Northbound safety distance	29.0	29.0	27.0	27.0	25.0	23.0
Southbound safety distance	23.5	21.5	23.5	21.5	19.5	19.5

Average waiting time and queue length (Figure 6 and Figure 7) for all vessels, and specifically for dangerous cargo vessels, decrease as the total length and minimum safety distance following dangerous cargo vessels decrease. However, simulation shows that reducing the regulated length of the Straits or the minimum safety distance between two consecutive dangerous cargo vessels would not result in significant benefits, while, in the meantime, substantially increase the exposure of inhabited areas of Bosporus near its entrances to unregulated traffic.

Results are slightly different for each direction of travel (SB and NB) due to the different rules that apply on laden or in ballast large and dangerous cargo vessels. Specifically, southbound dangerous cargo vessels are more often laden (Table 2), thus, more strict regulations apply to them and any following vessel [GMCSSA, 2003].

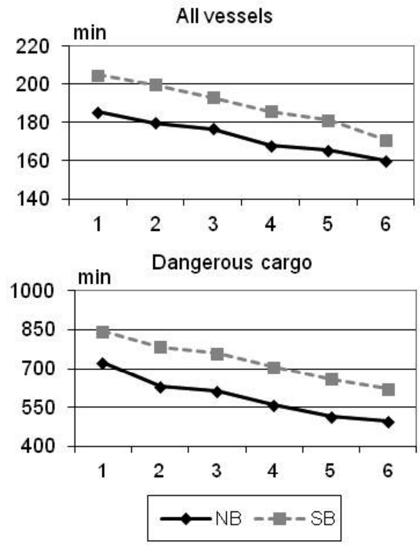


Figure 6: Scenario 1 - Average waiting time

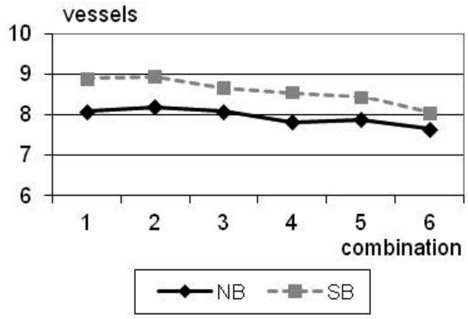


Figure 7: Scenario 1 - Average queue length

7.2 Scenario 2

The minimum safety distance between two consecutive vessels transiting the Straits is studied in this scenario which, according to the applied maritime regulations, is defined to 8 cables (1482 m). Scenario 2 studies the span from 5 to 11 cables.

As minimum safety distance moves from 5 to 11 cables, dangerous cargo vessels suffer from a two-fold increase in their average waiting time, which also affects the average waiting time for all categories of vessels (Figure 8). Dangerous cargo vessels contribute most in the increase of the average queue length (Figure 9). In the area of 8 cables, changes in average waiting time and queue length can be considered as linearly proportional to changes in the minimum safety distance. Again, results are slightly different for each direction of travel (SB and NB) due to the different rules that apply on laden or in ballast large and dangerous cargo vessels.

Simulation results for the first two scenarios show that a tradeoff between safety distances and level of navigation safety is anticipated, although, in the presence of a modern VTS system like the one currently implemented, less strict regulation could be studied.

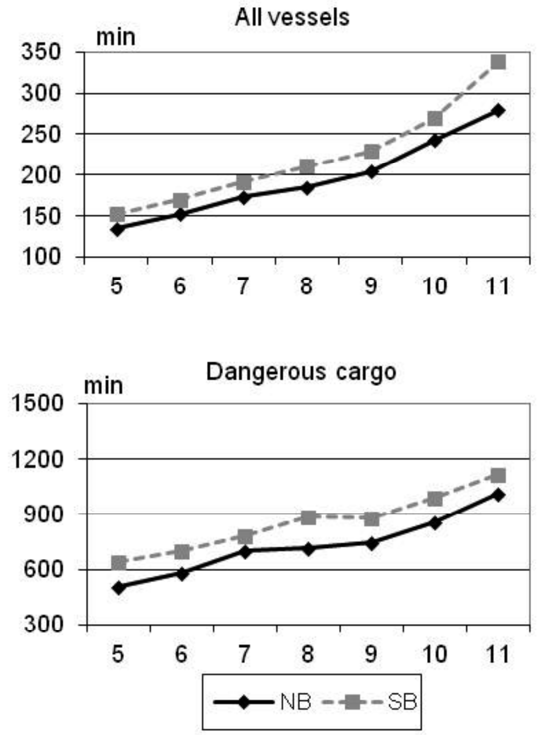


Figure 8: Scenario 2 - Average waiting time.

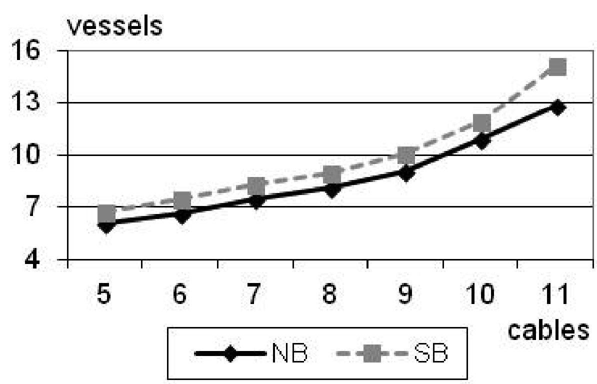


Figure 9: Scenario 2 - Average queue length.

7.3 Scenario 3

An implementation policy is studied in this scenario, namely the forwarding of the first vessel that can enter the Straits without violating the regulations, regardless of its position in the waiting queue. After taking into account that passenger vessels are scheduled on top of the waiting queue, and large or dangerous cargo vessels on the bottom, applied regulations imply a FIFS scheme for the scheduling of each cargo category [GMCSSA, 2003]. This practice would downgrade the service capacity of the Straits since, e.g. a 75-meter tanker could wait for days behind a 200-meter tanker that arrived earlier. To ease the problem, we assume that every time a vessel can enter Bosporus, the traffic supervisor scans the whole waiting queue (passenger then general cargo then dangerous cargo vessels in a FIFS fashion) to locate a vessel that can enter without violating any regulation.

Scenario 3 studies the benefit of such a policy. For this purpose, 3 variations have been created: i) The FIFS scheme is strictly followed and vessels must wait for their turn to enter the Straits (policy #1), ii) FIFS scheme is strictly followed for passenger and general cargo vessels while dangerous cargo waiting queue is scanned each time so that small vessels can get past and enter on first occasion (policy #2) and iii) The base scenario policy where all three waiting queues are scanned (policy #3).

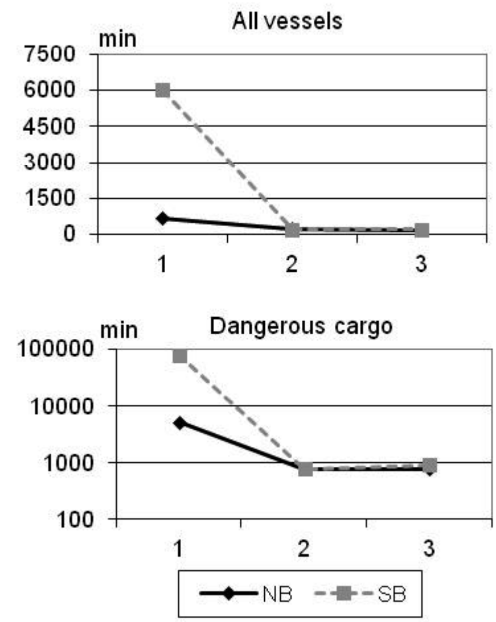


Figure 10: Scenario 3 - Average waiting time.

Average waiting time is reduced to even the 1/30 of the original time (southbound traffic) after applying the studied policy (Figure 10). The improvement must be wholly attributed to the dangerous cargo vessels category, where, especially for the southbound traffic, average waiting time is reduced two orders of magnitude. This is due to the better optimization of the time slots that are available for this kind of traffic; short and medium length, in ballast, dangerous cargo vessels can transit mixed with general traffic all day long leaving the regulated, one-way traffic periods to large and laden dangerous cargo vessels.

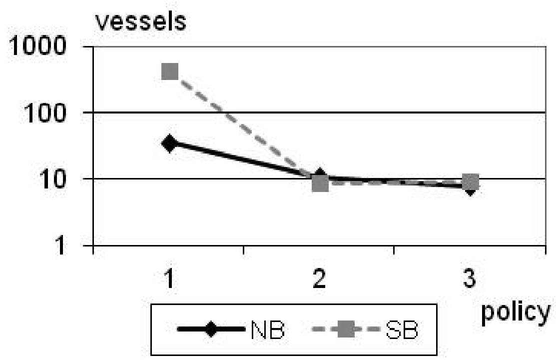


Figure 11: Scenario 3 - Average queue length.

Average queue length (Figure 11) follows the trend of average waiting time due to the better scheduling of large and dangerous cargo vessels.

7.4 Scenario 4

An implementation policy is studied in this scenario, namely the alternate suspension of two-way traffic, during daytime. Usually, large or dangerous cargo vessels suffer from large delays due to the longer safety distance that their transit requires as well as the fact that they cannot transit Bosporus during nighttime. To ease the problem, maritime authorities suspend traffic for a predefined amount of time during daytime, e.g. first to southbound traffic, allow the transit of a batch of northbound, large or dangerous cargo vessels and then apply the same policy to the opposite direction.

Table 4: Time periods combinations

Time (hr) \ Combination	1	2	3	4	5	6	7	8
Northbound one-way time period	0.0	1.0	2.0	2.0	2.0	3.0	3.0	3.0
In between two-way time period	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Southbound one-way time period	0.0	2.0	2.0	3.0	4.0	4.0	5.0	5.0
Total one-way time period	0.0	3.0	4.0	5.0	6.0	7.0	8.0	8.0

Scenario 4 examines how different time periods of two-way traffic suspension times affect traffic variables. For this purpose, 8 combinations have been created (Table 4); combination #1 assumes no suspension time while combination #7 assumes that, in total, 8 hours/day are reserved for daytime, one-way, large or dangerous cargo vessels transit. Combination #6 corresponds to the base scenario that is applied in all other scenarios of this article. Finally, combination #8 is an extra experiment that uses the same time windows as combination #7 but allows for two-way, passenger and general cargo traffic (1 hour) in between the one-way, large or dangerous cargo vessels traffic periods.

Average waiting time for all vessels substantially decreases when the studied policy is applied. Though, after combination #3, the average waiting time seems unaffected by the increase in the suspension periods, this is not the case for each cargo category and maritime authorities are called to balance an increase in the passenger and general cargo waiting times for the benefit of large and dangerous cargo vessels and vice versa, depending on the actual day to day demand for transits (Figure 12).

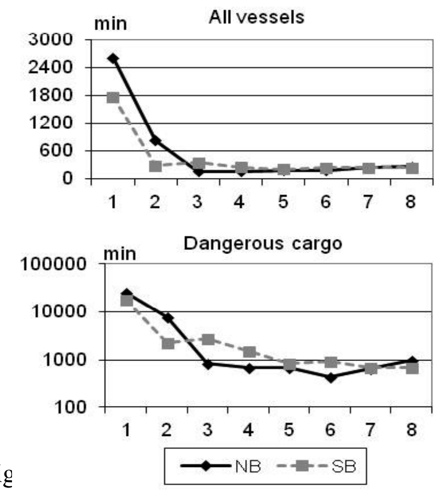
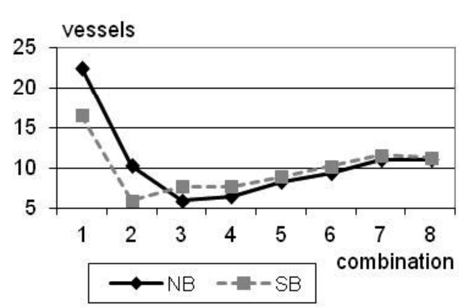


Fig e

The trade-off between these two categories of traffic is well justified, since an increase in the two-way traffic suspension periods (up to 8 hours or one third of the day) reduces the available time slots for passenger and general cargo vessels. Moreover, it is evident that average waiting time for dangerous cargo vessels is reduced only when an increase in the respective two-way suspension time period is implemented (e.g. for northbound traffic in combinations #2, #3 and #6).

Figure 13: Scenario 4 - Average queue length.



Average queue length (Figure 13) is steeply reduced in the first two cases and then slightly increasing in proportion to the total suspension time for both directions which results from the fact that for an ever increasing time (4 to 8 hours from combination #3 to combination #7) Bosporus is closed to passenger and general cargo traffic that account for almost 90% of the total traffic (Table 1).

Combination #8 might propose an alternative that achieves better results. Between the two suspension periods, there a small period of 1 hour that passenger and general cargo traffic (that has been accumulated during the first suspension period) is served, thus resulting in a better performance than in combination #7.

In general, implementation of the studied policy can substantially decrease average waiting times for large or dangerous cargo vessels (in one case, up to 98% or from ~20 days down to ~7.5 hours) in the expense of larger, but tolerable, average waiting times for passenger and general cargo vessels (in one case, six-fold increase or from ~0.5 hour up to ~3 hours)

7.5 Scenario 5

Suspension of large dangerous cargo vessels traffic during nighttime is studied in this scenario. According to the applied regulations [GMCSSA, 2003], laden, dangerous cargo vessels longer than 200 m and laden or in ballast, dangerous cargo vessels longer than 250 m cannot transit Bosporus during nighttime.

Scenario 5 examines three policy variations: i) The base scenario, where current regulations are applied, ii) All vessels can transit during nighttime but with the use of a double minimum safety distance (16 cables), along with the special safety distance that is used after the transit of a dangerous cargo vessel (23 or 29 km depending on the direction of transit); iii) All vessels can transit during nighttime using the 8 cables minimum safety distance.

Average waiting time and average queue length evolve similarly in the three policy variations. They both increase from policy #1 to policy #2 and stay almost unaltered from policy #1 to policy #3. Applying a double minimum safety distance during nighttime effectively cuts in half the respective transit slots, a cut that accounts for 18.4% – 30.6% of all slots during a single day (the exact figure depends on the time of year), offsetting any benefit that might come from allowing large dangerous cargo vessels transit during nighttime and resulting in a significant increase from policy #1 to policy #2 (Figure 14 and Figure 15).

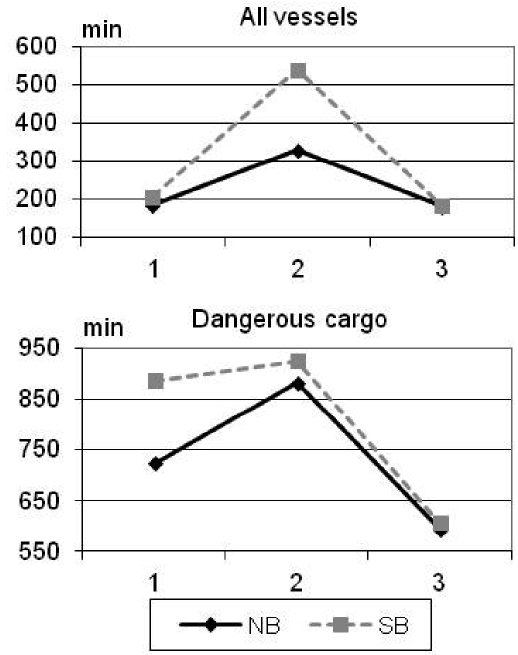


Figure 14: Scenario 5 - Average waiting time.

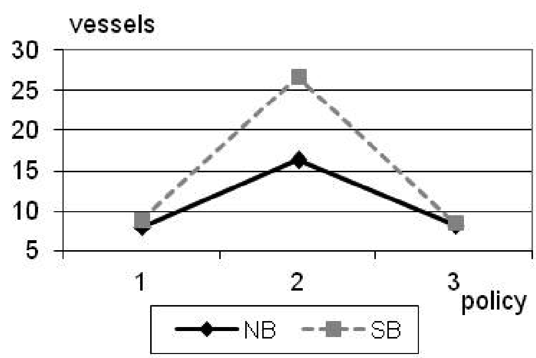


Figure 15: Scenario 5 - Average queue length.

In any case, large dangerous cargo vessels account for less than 4% of the total maritime traffic in Bosporus (Table 1) but require larger safety distances around them and this combination is reflected in the second comparison (policy #1 to policy #3), where although average waiting time for large dangerous cargo vessels traffic has been reduced (18% for northbound and 32% for southbound traffic) passenger and general cargo waiting times and queue lengths corresponding increase offset this improvement.

Moreover, apart from not improving the general traffic characteristics, transit of large dangerous cargo vessels during nighttime would increase the probability of an accident within Bosporus.

8. Conclusions

Bosporus can be considered a finite resource consisting of time slots that are distributed so that arriving maritime traffic is efficiently serviced. Moreover, the marine environment of the straits and the urban environment of Istanbul have to be secured from accidents that can inflict serious damages in case a large dangerous cargo vessel is involved. In this context, applied regulations recognize three types of traffic which contest for the available limited resources: passenger, general cargo and dangerous cargo.

Passenger and general cargo vessels oppose to dangerous cargo vessels and as a general trend increase in the availability of slots for the one group decreases available slots for the other. In all five scenarios, passenger traffic, having top priority over all other traffic was less affected by any modeled regulation variation. On the contrary, dangerous cargo traffic is very sensitive to any change, a trend that is intensified by the fact that dangerous cargo vessels consume more time slots due to increased safety distances during their transit.

The presented model shows that different regulations and policies have a varying effect on the average waiting time and average queue length for the three different cargo categories. In addition, the applied variations have not been proved equally effective: e.g. scenario #1 exhibits an improvement in traffic variables on the expense of leaving large areas of Bosporus (and Istanbul) unregulated and so rather unprotected. Also, some variations may have a result opposite than the desired one: scenario #5 indicates that permitting dangerous cargo vessels transit during night time (a change in regulations that could be discussed since the Turkish authorities have implemented a modern VTS system) would not have the expected result: neither average waiting time nor average queue length are improved (policy #1 - policy #3). Moreover, the Bosporus system safety would be compromised, since, in case of an accident, SAR operations are greatly hindered during night time.

In any case, scenarios #3 and #4 indicate that clever scheduling policies can substantially improve traffic variables in Bosporus, while keeping safety at the desired level. Even more, and provided the suitable tools, experimenting with these policies (e.g. combination #8 in scenario #4) shows that there is room for more improvement. The proposed parameterized model can add to this direction by allowing for the modelling and quantitative analysis of almost any possible combination of straits physical characteristics, traffic regulations and arriving traffic distributions in maritime straits in general and in Bosporus in particular.

Finally, the presented parameterized model can offer similar insights regarding the traffic of vessels in other maritime straits around the world. By the application of simple programming steps, it can offer valuable help in determining how applied measures and regulations interact with each other as well as with the physical characteristics of the straits in the definition and utilization of the straits' throughput.

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Оценка Воздействия Регуляций Движения в Ожидании Очереди на Морских Проливах - Пример Босфора

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Резюме: Проливы являются ключевым компонентом международного морского движения а сочетание ограниченной способности и большой транспортной нагрузки формулирует вызов для объединения безопасной и эффективной навигации. В этой статье предлогается общая и вполне параметрируемая модель очередей, для того, чтобы оценить влияние физических характеристик, схемах очередей, прекладных регуляций и транзитных атрибутов движения на эффективность системы проливов. Босфор (Стамбул, Турция) демонстрирует уникальное сочетание, с одной стороны, трудностей навигации и большой транспортной нагрузки и, с другой стороны, обширные и подробные регуляции, которые управляют свою деятельность, таким образом, включая подходящий испытательный стенд для предлагаемой модели.
Моделируются вариации пяти прекладных регуляций и политики планирования движения и оценивается и обсуждается их влияние на среднее время ожидания и среднюю длину очереди.

Ключевые слова: Симуляция; Регуляции движения; Морские проливы;