SIMULATION OF MARITIME TRANSIT TRAFFIC IN THE ISTANBUL CHANNEL

Alper O. Almaz, İlhan Or, Birnur Özbaş
Department of Industrial Engineering
Boğaziçi University
34342, Bebek, Istanbul, Turkey
E-Mail: alper.almaz@boun.edu.tr, or@boun.edu.tr, birnur@ozbas.com.tr

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ABSTRACT

This study aims to develop a functional simulation model for the maritime transit traffic in the Istanbul Channel and to perform scenario analysis to investigate the effects of type and frequency of transit demand, as well as various natural factors, resources and decision / policy rules, on the system. In this regard, the Channel traffic rules and regulations, transit vessel profiles, pilotage and tugboat services, meteorological and geographical conditions are considered in the model to provide a platform to analyze the effectiveness of various policies and decisions related to the transit traffic in the Istanbul Channel. The statistics tracked and collected in the analysis are the number and types of vessels passed, transit times of vessels, vessel densities throughout the Channel, waiting times of vessels, pilot and tugboat utilizations. In the first phase of the study, scenario analyses have been designed to investigate the effects of the factors of vessel profiles, vessel arrival rates, vessel priorities, pilot and tugboat availabilities and visibility conditions. In the second phase, the analyses are extended by integrating probabilistic current and visibility submodels, comprehensive overtaking rules, parameterization of pursuit distances and other administrative controls (regarding vessels in transit in the Channel). A scenario analysis is being run to reveal the effects of these factors and preliminary results are reported.

INTRODUCTION

The Turkish Straits (the Istanbul Channel and the Dardanelles), which have narrow and winding shapes that give them the semblance of a river, are actually one of the most strategically important waterway systems in the world. Their hard to navigate geographical properties, cross continental bridges and energy transfer lines, meteorological conditions, dense and increasing transit and local traffic, vessel and cargo characteristics, make the Channels' traffic conditions quite complex and risky.

Geographically, the Istanbul Channel (Figure 1) is one of the narrowest waterways in the world. Its length is 31 kilometers, and its average depth is 45 meters. Its average width is 1.5 km, with this width decreasing to 700 meters at its narrowest point (Anadoluhisarı - Rumelihisarı).

Figure 1: The Istanbul Channel

The natural and non-natural factors affecting the safety of transportation in the Channel, as well as the accidents realized in the past, have necessitated some stringent rules and procedures for transit vessels (called the Turkish Straits' Maritime Traffic Regulations) and a sophisticated Vessel Traffic Control and Monitoring System (VTS). The vessels arriving at the north or south entrance of the Istanbul Channel enter the Channel according to the directions of VTS, which uses strict and well defined regulations, rules and all other data that are received by radars, sensors and stations. The primary mission of the regulations and the VTS is to reduce the maritime transportation risks in the Channel.

The objective of this study is to create a functional simulation model (based on the mentioned Rules and Regulations) for the transit vessel traffic in the Istanbul Channel, in order to provide a realistic and practical environment, in which to speedily analyze and evaluate the effects of policies, resource availabilities, possible

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transit vessel profiles and environmental conditions, relying on the rules, procedures and also on past transit vessel and environmental conditions data. In other words, a platform is tried to be obtained for analyzing all rules, procedures and natural conditions affecting the status of Maritime Traffic in the Istanbul Channel. This platform should also be deployable as a tool to support real time decision making at the Traffic Control Authority.

MODEL FORMATION AND OBJECTIVES

The maritime traffic model developed includes the following major components:

- Randomized vessel arrivals at the north and south entrance of the Channel,
- Randomized vessel types and characteristics,
- The Channel Traffic Rules and Regulations,
- The pilotage and tugboat services (with predetermined and parameterized capacities),
- Randomized meteorological conditions of visibility and current,
- Two main traffic lanes, one overtaking lane and integrated overtaking rules.

In line with the study objectives, the simulation model developed realistically reflects the conditions influencing the behavior of transit vessels in the Channel, and thereby correctly mimics the flow of transit traffic itself. Scenario analysis has been another intended objective. The levels of various input factors are collectively arranged into 'scenarios' and it is possible to study and compare the results of different scenarios.

Via scenario analysis,

- The effects of increasing transit traffic demand (collectively or by vessel type and characteristics), adverse meteorological conditions, changes in the level of services provided (such as tugboats and pilot captains), and vessel class priorities can be better predicted,
- The effects of various interpretations and changes in the application of Traffic Rules and Regulations can be investigated through the model,
- By experimenting with different vessel prioritization schemes, the waiting times of vessels (or certain types of vessels), dangerous pile ups (of waiting vessels), undesirable transit vessel densities (especially in critical parts of the Channel) can be tried to be reduced. The causes of unusual delays can be determined and suggested solution proposals can be experimented on by the simulation model,
- The pilot and tugboat issues can be further elaborated as follows. The number of pilot captains and tugboats available is one of the main factors that cause delay for those vessels that need them. So, determining their availability target levels and expected utilizations at those levels for a given level of transit traffic demand is quite important. Equally important is the capability to track the required change in pilot and tugboat target levels, as a function of changing transit traffic demand.

The simulation model is specifically designed to handle these issues.

MODEL STRUCTURE

The simulation software Arena 9.0 is used in the development of the simulation model of Maritime Transit Traffic in the Istanbul Channel (Figure 2).

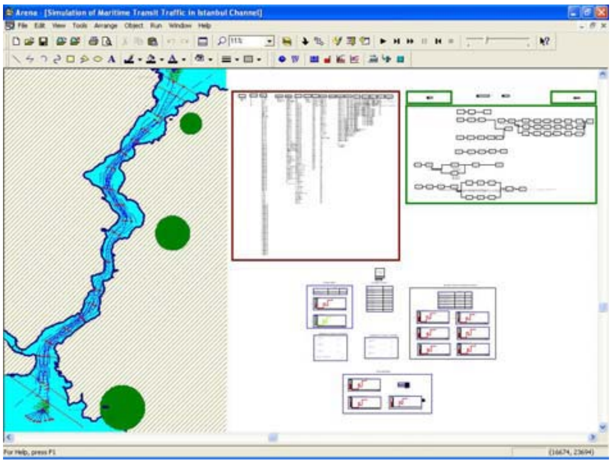

Figure 2: Simulation Model in Arena 9.0

The input data of the system can be listed as: transit vessels' types, lengths, draughts, speeds, anchoring durations, pilot and tugboat demands, visibility and current conditions. The simulation model is designed and developed such that all input factors mentioned can be randomly generated based on probability distributions obtained from historical data or the input data can be read from the text files. The reason for this flexibility is that internally generated input data allows better control of parameters in scenario analysis and independent replication runs helps to analyze the effects of randomness, while external inputting of input data allows the deployment of the model as a real time decision support tool for the Traffic Control Authority.

Three classes of control parameters (which are: external and internal parameters, traffic rules/regulations) are used in order to clarify the logic of the model and to simplify scenario analysis. External parameters (those parameters which can not be controlled by the Channel Authority) can be summarized as meteorological conditions, transit vessel profile, arrival rate, speed capability and pilot captain/tugboat requests. Available number of pilot captains and tugboats, transit vessel priorities and overtaking rules, are the internal parameters of the model (these are the parameters which can be controlled by the Channel Authority). The third class is the Turkish Straits' Maritime Traffic Rules and Regulations (which are regarded as unchangeable throughout this study).

MODEL LOGIC AND FLOW

Vessel Types

The vessel types considered in the model are Passenger Vessels, LNG-LPG Carrying Vessels, Hazardous Material (HazMat) Carrying Vessels, Tankers and General Cargo Carrying Vessels. On the other hand, the Channel Authority Regulations have classified all vessels into 11 "treatment classes", based on their types, lengths and drafts (in a way reflecting the vessels' sensitivity, potential risk and special needs). These classes which are displayed in Table 1 are also deployed in the simulation model.

Table 1: Vessel Classes

Length (m.)	Draft (m.)	Type: Tanker	LNG-LPG	HAZMAT	Gen Cargo	Passenger Vessels
< 50	< 15	T1	L2		G2	PA
50 - 100	< 15					
100 - 150	< 15	T2				
150 - 200	< 15	T3	L3		G3	
200 - 250	< 15	T4				
250 - 300	> 15	T5				
> 300	> 15	T6				

The Channel Entrance

The (randomly) arrived vessels first enter the anchoring area according to their request and stays there through their anchoring durations. Those who do not anchor or leave anchoring area are ready to enter the Channel. At that point 'Ready Time' and 'Threshold' attributes are assigned to those vessels. Ready Time is the vessel attribute which is used to determine its place (ordering) in the waiting queue, while Threshold is the attribute that determines the vessel's priority (in the sense that the Traffic Control Authority puts a 'Barrier' to the opposite Channel entrance, once a vessel has waited an amount of time defined by its threshold value). Such a barrier stops the entrance to the Channel from the opposite side, of any vessel whose presence in the Channel would hinder the entrance of the vessel waiting for the appropriate conditions. Note that, it is still possible for a vessel to enter the Channel without putting up a barrier, if it is at the queue head (with respect to Ready Times) and there are no vessels in transit, whose presence hinder its entrance.

All vessels wait in 'Common Queue' and check if the Channel is available and safe for the passage. Entrance to the Channel is first checked against the rules and regulations. The ranking order of this queue is according to the least value of 'Ready Time' attribute.

Each vessel in the 'Common Queue' checks for the satisfaction of Channel Traffic Rules with respect to the existing traffic in the Channel. When there is no restriction due to the Rules, other factors such as pilot and tugboat needs, visibility, current level and daylight restrictions (according to the Regulations, certain types of vessels may sail the Channel only in daylight) are checked with respect to vessels type, length and draught needs and requirements. If all factors are suitable and services are available then the vessel enters the Channel. This process is sequentially followed for all vessels in the 'Common Queue'.

The Channel

In the Channel, a vessel passes through eight different zones. Each zone is divided into a sequence of 'substations' which are set at a distance of 8 cables (0.8 nautical miles ≈ 1.482 km.) from one another. This is to satisfy the regulation that vessels in transit in the Channel shall maintain a pursuit distance of at least 8 cables between each other. This distance is actually a control parameter of the Traffic Control Authority and is also deployed as such in the model.

Overtaking

As mentioned, the simulation model provides three traffic lanes for transit vessels along the Channel (one northbound lane, one southbound lane and an additional lane for overtaking, wherever it is allowed). Since the regulations do not allow overtaking in Kandilli sector (i.e. at the narrowest section of the Channel, between Vaniköy and Kanlıca points), in the model the overtaking lane is removed at this section.

The overtaking rules implemented in the model are as follows: Whenever a vessel is faster than the one ahead, it checks three conditions,

i) there will be no vessels in the overtaking lane from the opposite direction, until the expected completion of its overtake,

ii) the closest vessel in the overtaking lane traveling in the same direction is at least "the pursuit distance" away,

iii) it is fast enough to complete the attempted overtake before it reaches the Kandilli sector.

Pilotage and Tugboat Services

The pilot captain and tugboat needs and requirements of the vessels about to enter the Channel are also taken into consideration. In the model, if a vessel prefers (or is required by regulations) to use any of these services, it seizes them at the designated boarding and disembarking areas at the north and south entrances of the Channel (the associated vessel's transit through the Channel is delayed by a certain amount of time to cover the vessel's slowing down and speeding up during the onboarding/disembarkation activity). When a pilot is seized, a service boat is also seized, since service boats are used to disembark or board pilots. When two vessels demand a service boat at the same time interval, model gives priority to the disembarking vessel.

Additionally, two control mechanisms added to the model for increasing the utilizations of pilots and tugboats. At any entrance, while the pilot or tugboat is released, if the number of idle pilots or tugboats is higher than or equal to predefined limits, the excess pilot or tugboat is transferred to the opposite side in 30 minutes and 90 minutes respectively (time allowed for deadheading). Also, when a pilot or tugboat is seized, number of remaining resources is checked. If the value is zero and the other side has more than two idle of that resource, they are sent to the side in need of. During the transfer of excess pilot and tugboat, number of transferring resources is also checked by a control mechanism in order to avoid simultaneous transfers. When a vessel completes its transit of the Channel, it releases the pilot or tugboat at the disembarking area. When the seized pilot or tugboat is released, it is designated to be an additional available resource at the release entrance.

The Visibility

Regulations obligate that when visibility drops to 1 mile or less in any area within the Channel, vessel traffic shall be permitted in one direction only, and when visibility drops to less then 0.5 mile, vessel traffic shall be suspended in both directions.

As mentioned before, in the model, daily visibility values can be either externally inputted or internally generated (with respect to a probability distribution based on historical data). The statistical analysis of past visibility data has shown a strong seasonal pattern (low visibility levels are far more frequent in the winter season). Accordingly, three probability distributions (corresponding to three distinct seasons) are developed to govern the random generation of daily visibility conditions throughout the Channel. The summer (June, July, August and September) and transition seasons (May and October) are based on empirical distributions. The winter season is based on an on/off process and is modeled through a phase type distribution. In this on/off process the system state alternates between on state and off state successively. The on state signifies good visibility conditions, whereas off state signifies bad visibility conditions. The lengths of these on/off periods are better approximated by mixtures of generalized Erlang (MGE) distributions.

The Current

The Channel features a north to south surface current almost at all times. This current attains its peak value at the narrowest point of the Channel, while tapering off to around 90% of the peak value at the two entrances. The peak current value varies probabilistically between 0 to 6 knots with a mean about 2.7 knots. Naturally, this current affects the realized speed of transit vessels (speeding up the southbound vessels and slowing down the northbound ones). Additionally, vessels which may experience navigation problems at higher current levels are either assigned tugboats to aid them or are not allowed in the Channel until conditions improve. These factors are incorporated to the model through vessel speed alterations (due to current), tugboat assignments and/or vessel entrance denials.

Current values throughout the Channel are determined through the random generation of a daily peak value, which is then reflected to the whole Channel via appropriate predetermined percentage factors for each substation in the model. Both the probability distribution of the peak value (which is based on an autoregressive forecasting model) and the percentage factors are determined based on historic current data.

VERIFICATION AND VALIDATION

For verification purposes, the modeling is accomplished in stages where each additional stage is individually debugged and tested. Next, additional subprograms and levels of detail are added and debugged successively until a model is developed that satisfactorily represents the system under study. Within this context, the powerful "tracing" technique of discrete-event simulation is deployed. In a trace, the state of the simulated system, i.e., the contents of the event list, the state variables, certain statistical counters, etc., are displayed just after each event occurs and compared with hand calculations to see if the program is operating as intended (Law and Kelton 2000). In the Channel simulation model, after each added block or principle, the model is debugged by the trace. Furthermore, the developed animation of the simulation output can also be used to observe the events and thus support the verification process. The observation of the vessel behavior in entering, proceeding in and exiting the primary and overtake lanes are especially supportive for the verification of the model logic through animation.

For validation purposes, the model structure and output should be plausible for any extreme and unlikely combination of levels of factors in the system. Therefore, extreme condition validations, which involve assigning extreme values to selected parameters and comparing the model-generated behavior to the anticipated behavior of the real system under the same extreme condition, are applied.

The most definitive test of a simulation model's validity is to establish that its output data closely resemble the output data that would be expected from the actual system. Therefore, the results of 10 replications (each covering a four month period) for the base model, whose Channel vessel traffic and meteorological condition data is based on year 1999 information and statistics (obtained from the Channel Authorities' reports), are compared for validation of the system. According to these reports, on average 3930 monthly vessel passage is observed in 1999. In the model outputs, the 99% confidence interval (based on the simulation runs) for this response variable is [3864.49, 3929.11]. Although the reports do not give specific information about the average number of vessels waiting in the queues and average waiting times of vessels, according to the experimental runs of the simulation model, the 99% confidence interval of average number of vessels waiting in the queues is [28.77, 32.99] and the 99% confidence interval of average waiting times of all vessels is [177.09, 195.87] (in minutes), where these values are reasonable and close to the conjectural values of the real system.

MODEL OUTPUTS

Each simulation runs generates two monthly output files with respect to north and south entrances, total entrances, all vessels and each vessel type. The statistical values in the first output file are comprised of maximum, minimum, average values, standard deviations and 95 percent confidence intervals of the following responses;

- Number of vessels in queue (still waiting for transit) at end of each month;
- Number of vessels that have completed their transit;
- Waiting time of vessels that have completed their Channel transit (aggregate of all vessels and by vessel type at each direction);
- Waiting time of vessels in queue at end of each month (by queue type);
- Transit time of vessels that have completed their Channel transit (aggregate of all vessels and by vessel type at each direction);
- Pilot captain and tugboat utilization (ratio of total busy time and total available time);
- Vessel densities (number of transit vessels per mile) in each zone and for the entire Channel (aggregate of all vessels and by vessel type).

Another output file is associated with the effects of meteorological conditions. It includes the number of vessels in each queue just before and after the fog occurrences in the simulation runs. Accordingly, the effect of the visibility level on the vessel traffic can be better observed.

RESULTS OF THE BASIC MODEL

Various experimental simulation runs have been accomplished for the basic model (i.e. the one in which the stochastic current and visibility submodels, comprehensive overtaking rules and parameterized pursuit distances have not yet been deployed).

The analysis regarding the basic model simulation runs is focused on six factors. These factors and their levels deployed in different scenarios are displayed in Table 2.

Table 2: Factors and Levels

Factor	*Name*	*Low*	*Average*	*High*
A	Vessel Profile	Normal		HazMat High
B	Arrival Rate	Normal		High
C	Threshold	None	All Same	Different
D	Pilot/Tugboat	10/4	15/6	20/9
E	Visibility	Normal		Low
F	Season	Winter		Summer

These six factors and their different levels are chosen to form 144 distinct scenarios (including the base scenario). In the settings of the base scenario vessel profile and arrival rate is normal, no threshold (or priority) is applied to any vessel, pilot and tugboat availabilities are 15/6 respectively, the visibility is normal (106 hours according to 1999 statistics) and the season is winter.

In this regard, 10 replications of the base scenario are run for four months (between January and April for the winter season, between April and July for the summer season). Additionally, one replication has been run for the other scenarios. In order to analyze the effects of these factors, the response variables are used from the output files. The significant factors affecting the response variables are determined by analyzing ANOVA tables through the Design Expert 6.0 software. The important factors, interactions of these factors and their effects on responses are also investigated.

According to the results of the basic model, the most significant factor seems to be the number of pilots and tugboats in service, while the second effective factor is the arrival rate of vessels. Table 3 summarizes some of the key results of obtained. In this table, some selected scenarios are given to compare the effects of vessel profile, arrival rate and pilot/tugboat availability on the outputs, when threshold, visibility and season factors are fixed at their base scenario settings. Further results and discussions regarding the basic model simulation runs can be found in (Özbaş 2005).

Table 3: Comparison of selected scenarios w.r.t. base scenario

Vessel Profile	**Arrival Rate**	**Pilot / Tugboat**	*Number of vessels passed*	*Avg transit times of vessels*	*Vessel density in the Channel*	*Avg waiting times of vessels*	*Max waiting times of vessels*	*Number of vessels in queues*	*Pilot utilizations*	*Tugboat utilizations*
Normal	***Normal***	***15 / 6***	1	1	1	1	1	1	1	1
High	***Normal***	***15 / 6***	0.990	1	1	1.656	1.425	1.561	1.036	1.003
Normal	***High***	***15 / 6***	1.142	1.007	1.155	1.653	1.489	1.879	1.151	1.151
High	***High***	***15 / 6***	1.152	1.008	1.138	5.957	3.216	6.305	1.187	1.131
Normal	***Normal***	***10 / 4***	0.975	0.995	0.966	10.566	5.718	9.757	1.456	1.381
High	***Normal***	***10 / 4***	0.951	0.992	0.948	19.393	12.311	19.043	1.463	1.262
Normal	***High***	***10 / 4***	1.076	1	1.069	24.239	14.363	29.338	1.604	1.380
High	***High***	***10 / 4***	1.052	0.997	1.052	31.514	19.685	40.174	1.622	1.265

RESULTS OF THE INTEGRATED MODEL

In the second phase, the basic model and analysis are extended, by integrating probabilistic current and visibility submodels, comprehensive overtaking and encountering rules and parameterizing pursuit distances of vessels in transit in the Channel. Preliminary experimental simulation runs of the integrated model have focused on four additional factors and their effects on output statistics. Some new scenarios considered and investigated, based the levels of these factors are displayed in Table 4.

Table 4: Additional Factors and Levels

Factor	*Name*	*Low*	*High*
A	Current Profile	Normal	High
B	Kandilli Encounter Rule	Normal	Conservative
C	Vessel Pursuit Distance	4 cables	8 cables
D	Season	Winter	Summer

As mentioned before, the current profile in the Channel depends on a randomly generated peak current value, whose mean is taken as 2.7 knots for the 'Normal' setting, and as 3.5 knots for the 'High' setting.

Kandilli encounter rule reflects an important Channel Regulation. According to this rule, certain types of vessels are not allowed to come across in the Kandilli sector (in order to reduce high risk encounters in this critical sector). However, since the exact speeds of the vessels in the Channel are hard to predict, this rule needs to be applied within a confidence factor. In the 'Normal' setting of the confidence factor, Channel entry time of vessels are regulated, so that potential undesirable encounters (based on expected transit speeds) will not take place within 2 stations in each direction of the Kandilli sector. While in the 'Conservative' setting of the confidence factor, potential undesirable encounters are avoided within 4 stations in each direction of the Kandilli sector.

Vessels in transit in the Channel have to maintain a pursuit distance of at least 8 cables. This distance is designed as a parameter in the integrated model and can vary between 2 cables to 10 cables. In the scenario analysis 4 cables and 8 cables settings are used.

Seasons are effective in the model since the visibility condition is modeled in a seasonal pattern.

For the preliminary scenario analysis of the integrated model, 16 simulation runs (corresponding to the 16 combinations of the considered factors) are taken for four months with one replication. The base scenario setting is determined as normal current profile, conservative setting of the Kandilli rule, 8 cables pursuit distance and summer season. The effects of the factors are observed on 8 response variables, which are selected from the output files and comparisons with the base scenario are reported.

For the base scenario, the average transit time of all vessels is 122 minutes which is about 106 minutes for south bound and 138 minutes for the northbound. A total of 15457 vessels passed though the Channel whose daily average is 129. Pilot utilization is about 29% and tugboat utilization is about 51.5%. There are on average 64 vessels waiting in the queues.

The worst scenario occurs at the settings of high current profile, conservative setting of the Kandilli rule, 8 cables pursuit distance and winter season. The average transit time increases to 125 minutes with total vessels passed being 15282 and average number waiting in the queues being 106. Besides, average waiting time increases by 67%.

On the other hand, the best scenario occurs at the settings of normal current profile, normal setting of the Kandilli rule, 4 cables pursuit distance and summer season. In this scenario average transit time decreases to 119.5 minutes with total vessels passed being 15560. Average number waiting in the queues decreases to 26 while the average waiting time decreases by 58%.

In order to analyze the effects of these factors on the selected response variables, Design Expert 7.0 software is used. The percent contributions of the significant factors to explain the variance of the responses between scenario runs are given in Table 5. Besides, the directions of the effects are given where + denote an increase and – denote a decrease.

Table 5: Summary of important factors and their effects

Responses / Factors	Current	Kandilli Rule	Pursuit Dist.	Season
Number of vessels passed	- 1%	- 21%	- 10%	+ 64%
Avg transit times of vessels	+ 63%		+ 34%	
Vessel density in the Channel	+ 70%		+ 25%	+ 4%
Avg waiting times of vessels	+ 8%	+ 61%	+ 11%	- 15%
Max waiting times of vessels	+ 17%	+ 23%	+ 18%	- 23%
Number of vessels in queues	+ 7%	+ 63%	+ 11%	- 13%
Pilot utilizations	+ 64%		+ 28%	+ 6%
Tugboat utilizations	+ 39%	- 11%	+ 13%	+ 34%

Table 5 points out the importance of factors on the increase or decrease of an output statistic. That is, 64% of the variation in the number of vessels passed is caused by the change in the season. Besides, the high setting of the season, which is summer, increases the number of vessels passed.

According to the results of the integrated model, each factor has an importance on different aspects. Current mostly affects the transit time and the density in the Channel and through these pilot and tugboat utilizations as well. Kandilli rule has most influence on waiting times and number of vessels in queues. Pursuit distance is significantly effective on all of the responses while season mostly affects number of vessels passed.

CONCLUSION

In this study a simulation model of the maritime transit traffic in the Istanbul Channel is discussed. The results of the basic model are briefly mentioned. Then, the results of an integrated model are presented via a preliminary scenario analysis.

The results of the scenario analysis on basic model indicate the importance of pilot and tugboat availability, arrival rate of vessels and vessel profiles. On the other hand, the results of the scenario analysis on integrated model depict the important effects of some external conditions (such as current and visibility) on the transit traffic. That is the number of vessels passed is mostly affected by the visibility conditions and the average transit time of the vessels is mostly affected by the current. Additionally, the impacts of some control parameters (such as the Kandilli encounter rule and the pursuit distances) on the system are also quite important. The average waiting time of vessels is mostly affected by the Kandilli rule, while pursuit distance has very significant effects on all of the outputs.

Even through the preliminary results obtained, the study has also shown that adverse meteorological conditions combined with major increases in transit traffic and changes in vessel profile could lead to very undesirable traffic congestions and thus increases in risk in the Channel. On the other hand, the management and control tools available to the Channel Traffic Authority can be very much effective in managing these congestions and risks.

FURTHER STUDIES

The study continues with the inclusion of updated Channel Rules and Regulations, more sensitive and up-to-date vessel profiles and arrival distributions to the integrated model. Then, an extended scenario analysis will be performed on the integrated model, aiming at a comprehensive investigation of all factors affecting the transit traffic system. Moreover, it is expected that this model will provide a platform for a comprehensive risk management and analysis study of the Istanbul Channel.

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AUTHOR BIOGRAFIES

ALPER O. ALMAZ was born in Bursa, 1979. He received his BS (2003) in Industrial Engineering from Marmara University, Istanbul, Turkey. He is currently an MS student at the Department of Industrial Engineering of Boğaziçi University, Istanbul, Turkey. His personal e-mail address is: alperalmaz@hotmail.com

İLHAN OR was born in Istanbul, 1951. He received his BS (1973), MS (1974) and Ph.D. degrees (1976) from Northwestern University, Evanston, Illinois, USA. He has been a faculty member at Department of Industrial Engineering of Boğaziçi University, Istanbul, Turkey since 1976 and currently is the Department Chairperson. He was a visiting faculty member at Syracuse University (1982-1983) and University of Maryland (1983). He served on the "Naval Research Logistics Quarterly" Journal's Editorial Board between 1993-2003. Research areas are environmental and risk management, energy policy and planning, production and maintenance planning. His e-mail address is: or@boun.edu.tr and personal web page is: http://www.ie.boun.edu.tr/~or/

BİRNUR ÖZBAŞ was born in Istanbul, 1980. She received her BS (2003) from Yeditepe University, Istanbul, Turkey and MS (2005) from Boğaziçi University, Istanbul, Turkey. She is currently a PhD student and research assistant at the Department of Industrial Engineering of Boğaziçi University. Her e-mail address is: birnur@ozbas.com.tr