SIMULATION OF MARITIME TRANSIT TRAFFIC IN THE ISTANBUL STRAIT – II: INCORPORATING THE TRAFFIC REGIME, ARRIVAL PROCESSES, METEOROLOGICAL CONDITIONS

Ilhan Or, Birnur Ozbas, Tuba Yilmaz
Department of Industrial Engineering
Bogazici University
Bebek, Istanbul, 34342, Turkey
E-Mail: or@boun.edu.tr, birnur@ozbas.com.tr, tuba.yilmaz@boun.edu.tr

KEYWORDS
Discrete Event Modeling and Simulation in Logistics, Transport and Supply Chains, Maritime Traffic, Arena®

ABSTRACT

This study aims to significantly augment and extend an earlier simulation model on the maritime transit traffic in the Istanbul Strait. The new model reflects the new traffic regime, which is in effect since the middle of 2005. This model also incorporates the probabilistic behavior of vessel arrivals and other characteristics, current & visibility conditions, based on extensive past data. Model inputs are parameters associated with the Traffic Control Center decisions, as well as randomized vessel arrival rates / profiles and current/visibility conditions. The model outputs, such as, numbers and waiting times of vessel types in queues, vessel densities and pilot/tugboat utilizations, are designed to facilitate a better understanding of the effects of inputs (individually or in an aggregate manner) through comparisons of a series of scenarios. An additional accomplishment will be the comparison of the new traffic regime with the earlier one, based on the collation of model outputs with those of the previous model (which reflects the earlier regime).

INTRODUCTION

The Turkish Straits (the Straits of Istanbul & Canakkale) are considered as one of the most strategically important waterway systems in the world. However, their difficult geographical properties (such as sharp bends and narrowness), physical obstructions (such as, cross continental bridges and energy transfer lines), meteorological conditions, dense and increasing transit and local traffic, vessel and cargo characteristics, make navigation through these Straits quite complex and risky.

The Strait of Istanbul is approximately 16.74 n. miles long, with an average width of 0.81 n. miles (Figure 1). It is only 0.378 n. miles wide at its narrowest. The ships are bound to alter course at least 12 times at the various bends, with some alterations approaching 80 degrees. The annual transit traffic has long exceeded 50,000 vessels, many of whom are large supertankers and some carrying hazardous and dangerous material. The local traffic includes more than 2000 daily ferry crossings, transporting more than 250,000 people between the Strait's European and Asian shores (Marine Law Research Center).

In order to control and mitigate maritime accident risks and improve the safety of navigation in the described dire environment, The Bureau of Turkish Strait's Maritime Traffic Services (BMTS) has set up a sophisticated Vessel Traffic Control & Monitoring System (VTS) (covering not only the Channel, but also 20 miles into the Black Sea and the Sea of Marmara) and has established and effected a set of stringent Maritime Traffic Rules and Regulations (which will be denoted by R&R). The vessels arriving at the northern and southern entrances of the Strait of Istanbul enter and then navigate through the Channel according to the directions of the BMTS, which are based on the VTS inputs and the R&R.

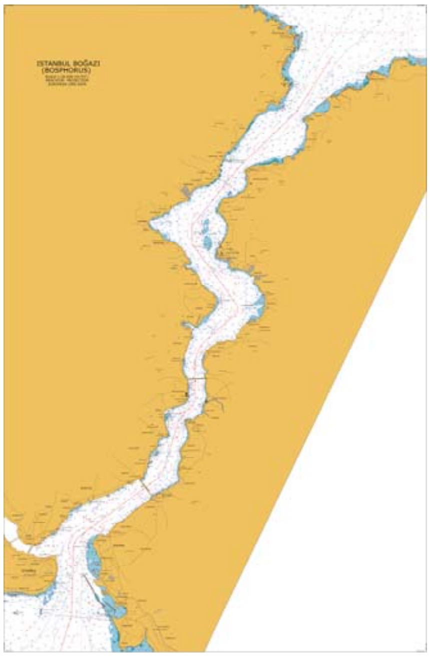


Figure 1: The Strait of Istanbul

The objective in this study is to design a simulation model reflecting the maritime transit traffic in the Strait of Istanbul as it actually happens. Being able to reflect the actual traffic flow, the model will make it possible

Proceedings 21st European Conference on Modelling and Simulation
Ivan Zelinka, Zuzana Oplatková, Alessandra Orsoni ©ECMS 2007
ISBN 978-0-9553018-2-7 / ISBN 978-0-9553018-3-4 (CD)

to observe the effects of different policies, resource availabilities, transit vessel profiles and environmental conditions. This model should also be executable as a tool to support real time decision making at the BMTS, and enable them to analyze effects of rules, procedures and natural conditions on the Strait's maritime traffic.

This study is actually an integral part of an ongoing simulation and risk analysis study on the maritime transit traffic in the Strait of Istanbul. The model developed and presented is an extension of a previous model (Almaz 2006; Ozbas 2005); however, it involves some major changes and enhancements, as explained below.

MODEL FORMATION AND OBJECTIVES

As mentioned above, a simulation model of the transit traffic through the Strait of Istanbul has already been developed (Almaz 2006; Ozbas 2005). However, since middle of 2005, the BMTS has been implementing a new traffic regime in the Strait: allowing only uni-directional traffic flow through the Strait in by day and reverting back to bi-directional flow by night. The BMTS has preferred this new policy since it avoids the daytime meeting of any northbound and southbound vessel, thereby categorically eliminating undesirable meetings (i.e. meetings of vessel types/classes that are to be avoided in the whole or some parts of the Istanbul Strait due to the R&R). Because of this new regime, the previous simulation model, which allows bi-directional traffic flows at all times (just delaying those vessels whose entrance to the Strait would have violated the R&R, because of the presence of another specific vessel in the Strait at that time) has become unusable and a new model (implementing the new regime) inevitable. On the other hand, the new model will also facilitate the comparison of the new regime with the old one on a multitude of performance indicators.

Major components included in the new maritime traffic model are as follows:

- Random transit vessel arrivals at the northern and southern entrances of the Strait;
- Randomized vessel types and attributes;
- Maritime Traffic Rules & Regulations (R&R);
- Pilotage, tugboat conditions and availability;
- Randomized visibility and current conditions;
- Uni-directional traffic flow of all vessel types (in predetermined time windows) by day, bi-directional flow of certain vessel types by night;
- One main traffic lane, one overtaking lane and one restricted purpose counter lane (i.e. serving the opposite direction) by day; two main lanes and one overtaking lane by night;
- Integrated time window determination, scheduling (of vessel entrances to the Strait) and overtaking rules.

The simulation model is designed to provide support on the following issues:

- The effects of meteorological conditions, such as visibility, current and storm;
- The effects of changing the pursuit distance between vessels;
- The effects of assigning different priorities (in terms of waiting times) to direct and indirect vessels and to different vessel classes;
- The effects of changing the durations of uni-directional northbound / southbound and bi-directional time-windows;
- The effects of pilot and tugboat availabilities, as well as transit vessel profiles and arrival rates.

The simulation model of the Maritime Transit Traffic in the Strait of Istanbul is developed using Arena 10.0.

In parallel with the R&R terminology, the vessel type specifications presented in Table 1, are used throughout this study.

Table 1: Transit vessel types

<table>
<tr><th></th><th colspan="5">Type</th></tr>
<tr><th>Length</th><th>Tanker</th><th>LNG -LPG</th><th>Hazardous Cargo</th><th>Dry Cargo</th><th>Passenger vessels</th></tr>
<tr><td>< 50</td><td rowspan="2">E</td><td rowspan="3" colspan="2">C</td><td rowspan="3">D</td><td rowspan="6">P</td></tr>
<tr><td>50- 100</td></tr>
<tr><td>100-150</td><td>C</td></tr>
<tr><td>150-200</td><td colspan="3">B</td><td rowspan="3">C</td></tr>
<tr><td>200-250</td><td rowspan="2" colspan="3">A</td></tr>
<tr><td>250-300</td></tr>
<tr><td>> 300</td><td colspan="5">A</td></tr>
</table>

Some significant rules and regulations of the R&R are exemplified below:

- Southbound Class A or B vessels should not enter the Strait until the preceding one has passed the Bogazici Bridge (which is about 13 n. miles from the northern entrance), while northbound Class A or B vessels should not enter the Strait until the preceding one has passed Filburnu (which is about 14 n. miles from the southern entrance).
- Class A vessels should make their transit only by day and no vessels should be traveling from the opposite direction during their passage.
- There should be no Class A, B or C vessels approaching from the opposite direction, during the transit of Class B vessels.
- Vessels longer than 200 meters are required to get pilot captains.

MODEL INPUTS

Model inputs can be classified into three groups: arrival processes, visibility/current related parameters, other inputs. The simulation model is designed and developed such that the intended input factors can be randomly generated based on probability distributions obtained from historical data. This approach enables better parameter control during scenario analysis, and easy, independent replication of simulation runs for validation and evaluation purposes.

Vessel Arrival Processes

Vessel arrivals are investigated in detail based on the actual arrival data of around 54,000 transit vessels in 2005, obtained from the BMTS. A pre-analysis revealed that most inter-arrival times have different patterns. So, vessels were first classified as Tanker, LNG-LPG, Hazardous Cargo Carriers, Dry Cargo, and Passenger Vessels, based on the terminology deployed in the R&R. However, in some cases, this classification turned out to be insufficient for the probabilistic representation of inter-arrival times. Thus, other attributes, such as vessel length, transit direction, indirect versus direct passage and time of day have also been considered in classifying inter-arrival times. The Input Analyzer module of Arena is used for analyzing the arrival patterns. This module provides the suggested distributions, histograms and data summaries, including mean square error (MSA) and p-value terms. The recommended distributions are evaluated based on MSA and p-values, as well as a visual comparison of the suggested function with the histogram. As an example, Figure 2 displays the arrival pattern and the suggested probability distribution (Gamma[402,0.955]), for northbound Tankers in length class 50-100 meters. This particular fit resulted in an MSA value of 0.000348 and p-value of 0.416. A total of 56 distinct arrival patterns has been developed in this fashion.

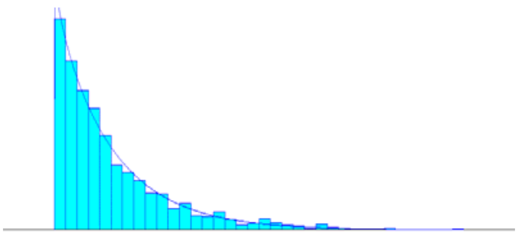


Figure 2: The Histogram for arrivals of 50-100 m Tankers at the southern entrance of the Strait

Another effect on arrival patterns is Black Sea storms. It has been observed that, especially southbound transit demand decreases significantly on days affected by stormy weather conditions at the Black Sea, while transit demand showing significant increases before and after a storm. Interarrival times and durations of possible Black Sea storms are modeled based on past 20 years' meteorological data, and interarrival rates of southbound transit vessels are adjusted accordingly.

The Visibility

The R&R permits only uni-directional vessel traffic when visibility drops to 1 mile or less anywhere within the Strait. Vessel traffic is fully suspended when visibility drops to less than 0.5 mile.

In the model, daily visibility values can be either externally inputted or internally generated (with respect to probability distributions based on historical data). The analysis of past visibility data revealed a significant seasonal pattern, namely low visibility levels being far more frequent in the winter season. Thus, the year is divided into three seasons, regarding potential visibility realizations: summer, winter and transition seasons. The visibility realizations in the summer (June - September) and transition seasons (May - October) are modeled using empirical distributions. The winter season visibility realizations are modeled through a phase type distribution, based on an on/off process (Altiok 1996). In this approach, good visibility conditions are represented by the on state, while bad visibility conditions are represented by the off state. The lengths of these on/off periods are approximated by mixtures of generalized Erlang (MGE) distributions (Almaz 2006).

The Current

The Istanbul Strait features a north-to-south surface current at almost all times. The peak speed of this current is usually attained at the narrowest section, with speed decreasing gradually to around 90% of the peak at the entrances. The peak current speed shows random variations between 0 to 6 knots with a mean about 2.7 knots. The current alters the effective speeds of transit vessels (increasing the speed of southbound vessels, while decreasing that of the northbound ones). Moreover, vessels which may experience navigation problems at higher current levels are either assigned tugboats or are not allowed to enter the Strait until current speed decreases. The effects of current are included in the model via vessel speed alterations due to current, tugboat assignments and/or not allowing vessel entrances.

The surface current is represented in the model by generating daily peak current values, through an autoregressive forecasting model, based on historic realizations. The generated peak values are assumed to remain unchanged throughout a day and they are projected to different regions of the Strait, through pre-determined and constant percentage factors based on historic data (Almaz 2006).

Other Inputs

The other inputs used in the model are transit vessel attributes and implementation-oriented interpretations of the R&R by the BMTS.

Vessel attributes are type, length, transit direction, anchoring duration, direct or indirect transit intention, speed, pilot and tugboat demands. The type, transit direction and length of each transit vessel are determined during vessel generation in the arrival process. Then, based on these attributes, anchoring duration, speed, direct or indirect transit intention, pilot and tugboat demands of vessels are randomly determined, through empirical probability distributions obtained from 2005 historical data.

Model inputs regarding the interpretations of the R&R are as follows:

- Class A Vessel Pursuit Distances: As indicated above, the R&R actually require that a Class A vessel should not enter the Strait until the preceding one is at least 13-14 n. miles ahead. In practice, this distance based rule, is implemented as the following time based pursuit intervals: 75 min. between two consecutive southbound Class A vessels and 90 min. between two consecutive northbound Class A vessels. However, the BMTS has some flexibility to somewhat alter these two time based specifications, thus changing pursuit distances. Accordingly, northbound and southbound pursuit distances between two consecutive Class A vessels have been taken as model inputs.
- Other Vessel Type Pursuit Distances: The R&R also requires specific minimal pursuit distances between other vessel types. Yet, in practice, these minimal pursuit distances are again enforced through time based pursuit intervals, such as, 30 min. between two consecutive Class C vessels, 10 min. between two consecutive Class D, E and P vessels, 90 min. between two consecutive northbound Class B vessels and 75 min. between two consecutive southbound Class B vessels. Since, the BMTS has some flexibility to somewhat alter these pursuit interval, they have also have been taken as model inputs.
- Indirect Transit Encouragement Coefficient: This coefficient indicates the direct transit vessel waiting time equivalent of a unit of waiting time of an indirect transit vessel. The realized waiting times of indirect vessels are multiplied by this coefficient and the modified values are used in the FIFO (first come-first serve) implementation to determine the order of entrance to the Strait. This way, indirect vessels appear in queue as if they arrived earlier. This coefficient represents the prioritization policy of the BMTS for indirect transit vessels.
- Class A Priority Coefficient: This coefficient assigns a relative priority (or dis-priority) to the waiting times of Class A vessels. Waiting times realized by Class A vessels are multiplied by this coefficient, while comparing different scheduling alternatives.
- Daytime specifications: These are the parameters used to define the start and length of daytime during the year.

THE TRAFFIC FLOW

The backbone of the model has two key components: i) the determination of daytime time-window lengths for northbound and southbound traffic, ii) the scheduling of vessels within these time windows. These and other model logic related issues are discussed below.

Vessel Arrivals

In the model, all vessels are generated at their SP2 times (also known as the contact time), which is the time approximately 2 hours before arrival at the Strait. Then, anchoring vessels enter anchoring area and remain there throughout their anchoring duration (an attribute of the vessel). Arriving vessels with no anchoring needs and those who have completed their anchoring durations are registered to the relevant northbound or southbound entrance queue together with their arrival times. These queues are ordered according to modified waiting time (waiting time adjusted by indirect transit encouragement coefficient) of vessels.

Time-Window Size Determination

Since Class A vessels have the most restrictions on Strait entrance and transit, number of northbound and southbound Class A vessels waiting are the primary factors considered in determining the two daytime uni-directional window sizes. So, every morning both the absolute and relative lengths of the northbound and southbound Class A vessel queues are considered in tentatively dividing the available daytime into the two uni-directional time windows. This tentative split is then compared against the two neighboring alternatives of increasing either window to allow for one additional Class A vessel (and decreasing the other window accordingly). The following factors are taken into consideration in the comparison of the mentioned three alternatives:

- Total waiting time of Class A vessels;
- Total waiting time of other vessels;
- Sufficiency of Class C, D, E vessels which are to be scheduled in between Class A vessels;
- Sufficiency of pilot captains for vessels to be scheduled.

A score for each alternative is calculated (based on pre-set weights for the mentioned factors), and the alternative with best score is chosen.

Next, starting direction of the daytime traffic must be decided (i.e. which uni-directional window to initiate first). This decision is based on:

- The total number of vessels waiting vessels in the northbound and southbound queues;
- The total waiting time of vessels designated to be in the northbound and southbound windows;
- The total number of indirect transit vessels designated to be in the northbound and southbound windows.

A score for the two alternatives is calculated (based on pre-set weights for the mentioned factors), and the alternative with best score is chosen.

In the case of insufficient Class A vessels for filling the determined uni-directional windows, the night-time bi-directional flow regime is stretched into the remaining day-time.

The Strait Entrance

The model accomplishes the scheduling of vessels to enter the Strait as follows (this way closely mimicking the practices of the BMTS): In a uni-directional time-window, first available Class A vessels are considered on an FIFO basis and scheduled throughout the duration of the window, at time intervals predefined by the user, to form the backbone of the schedule. Then, available Class C, D, E and P vessels are considered in FIFO basis and spread out to the intervals between Class A vessels, while giving consideration to, i) their pair wise time intervals set by the user, ii) their effective speeds (among the set determined with respect to FIFO, faster vessels being scheduled first), iii) pilot and tugboat needs and availabilities. In a bi-directional time-window, Class A vessels are not allowed and available Class B vessels are scheduled as the backbone. Then, available Class C, D, E and P vessels are considered in FIFO basis and spread out to the intervals between Class B vessels. In uni-directional windows only Class P vessels are allowed from the opposite direction, while in bi-directional windows Class P, D, E vessels are allowed from the opposite direction.

This traffic regime automatically avoids the following situations, which are strictly ruled out in the R&R. i) Class A vessels transiting at night; ii) Class A vessels meeting any vessels (except passenger vessels) in the Strait, iii) Pursuit distance requirements of all vessel types, iv) Class B vessels meeting Class A or Class B vessels in the Strait.

The Strait Transit

Vessels pass through eight different zones in the Strait (Or and Kahraman 2002) at speeds determined in the input stage (and adjusted by the current). All vessels follow the assigned single main transit lane (southbound or northbound), unless they need to overtake a slower vessel ahead and they are in a region where overtake is possible (then they temporarily move into the parallel overtaking lane to accomplish the overtake). Each zone is divided into a sequence of 'stations', which are set at a distance of 2 cables (0.2 n. miles ≈ 0.3705 km.) from one another. Hence, each transit lane comprises of 84 stations covering a distance of 16.8 n. miles (since the overtaking lane is discontinued in the region where overtake is not allowed, it contains fewer stations).

Overtaking

In the model, whenever a vessel is faster than the one ahead, the implementation of overtaking is initiated after checking the following conditions:

- There should be no vessels in the overtaking lane from the opposite direction, until the overtake is completed ,
- The closest vessel in the overtaking lane traveling in the same direction should be at least "the pursuit distance" away,
- The overtaking vessel should be fast enough to complete the attempted overtake before reaching the Kandilli region (where overtaking is not allowed and thus no overtaking lane exists).

Once overtake is completed, the vessel returns to the main transit lane.

Pilotage and Tugboat Services

The pilot and tugboat needs of a vessel are identified by its pilot and tugboat demand attributes (determined in the input stage). If a vessel has pilot or tugboat need (or is so required by the R&R), it seizes and releases them at the designated embarking and disembarking areas at the Northern and Southern entrances of the Strait. In order to cover the time spent by a vessel's slowing down and speeding up during pilot embarking / disembarking activity, associated vessel's transit is delayed by a certain amount of time.

Every morning, all pilots and tugboats are sent to the entrance associated with the starting uni-directional window, to embark on the entering vessels, as needed. A vessel exiting the Strait, releases its pilot and/or tugboat at the disembarking area. The released pilot and tugboat is then designated to be an additional available resource at the release station. As uni-directional flow proceeds, pilots and/or tugboats are dead-headed to the active entrance as needed, with the needs being updated whenever a Class A vessel is entered. The general aim is to have no vessels waiting due to pilot/tugboat unavailability.

MODEL OUTPUTS

Each simulation run generates following outputs (for each end of month considered in the run):

- Aggregate and type based, numbers and waiting times of vessels in queues (still waiting for transit);
- Number and transit time of vessels that have completed their transit (aggregate and type based);
- Waiting time of vessels that have completed their transit (aggregate and type based);
- Pilot captain and tugboat utilizations;
- Vessel densities (number of transit vessels per mile) in each zone and for the entire Strait (aggregate and type based).

Another model output highlights the effect of meteorological conditions. It includes the number of vessels in each queue just before and after fog occurrences, so that the effect of visibility level on the vessel traffic can be better observed.

VERIFICATION AND VALIDATION

During model development, each additional stage is individually debugged and tested for verification purposes. Additional subprograms and levels of detail are added and debugged successively until the model accurately represented the real system. "Trace" and "Debugger" of Arena 10.0 are deployed for this task. In a trace, the state of the simulated system (i.e., the contents of the event list, the state variables, certain statistical counters, etc.), is displayed just after each event occurrence and compared, through manual calculations to see if the program is operating as intended (Law and Kelton 2000). Moreover, the animation of the simulation model can be used to visually follow the arrival, entrance and transit activities of vessels in a way supporting the verification process.

Another verification related activity performed is the comparison of the uni-directional time-windows determined by the model (based on the actual 2005 vessel arrivals) with those realized in the 2005 BTMS practice. This way, the computation mechanism deployed is verified to closely mimic the BTMS practices.

For validation purposes, the model structure and output should be acceptable, adequate for any extreme and unlikely combination of levels of factors in the system. Extreme condition validations will be performed by assigning extreme values to selected parameters and model outputs will be compared with what is expected to be.

As mentioned, 2005 Istanbul Strait transit data (i.e vessel arrival and transits times) is already available. It is also planned to acquire 2006 transit data and compare model outputs (based on 2006 data) with the actual 2006 transit realizations, for validation purposes.

SCENARIO ANALYSIS AND RESULTS

Various scenarios will be constituted by considering different inputs, namely vessel arrival rates, visibility, current, BMTS implementations (e.g. pursuit intervals between vessels), pilot/tugboat availabilities. The comparisons of these scenarios, based on the outputs listed previously, will lead to a good understanding of the relative and absolute effects of individual and combined effects of the stated inputs on the outputs, as well as leading to a healthy understanding of the overall effectiveness and desirability of the new traffic regime. An additional interesting accomplishment will be the comparisons of model outputs with those of the previous model (Almaz 2006; Ozbas 2005) on scenario basis. All results obtained, experience gained and conclusions reached will be presented and discussed at the Conference.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of TUBITAK - Turkish Technological and Scientific Research Institute, in this research, through the Research Project 104Y207.

REFERENCES

Almaz, A. Ö. 2006. "Investigation of Transit Maritime Traffic in the Istanbul Straight through Simulation Modeling and Scenario Analysis." M.S. Thesis, Dept. of Industrial Engineering, Bogazici University.

Altiok T. 1996. "Tools of Probability." In Performance Analysis of Manufacturing Systems, Springer, New York. 15-65.

Law, M.L. and Kelton, W.D. 2000. "Simulation Modeling and Analysis". New York, McGraw-Hill.

Or, I. and I. Kahraman. 2002. "A Simulation Study of the Accident Risk in the Istanbul Channel", *International Journal of Emergency Management*, Vol. 1, No. 2, pp. 110-124, Interscience.

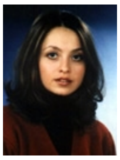
Ozbas B. 2005. "Simulation of Maritime Transit Traffic in the Istanbul Channel." M.S. Thesis, Dept. of Industrial Engineering, Bogazici University.

VTS Users Guide. Turkish Straits Vessel Traffic Service. 2004. General Management of Coastal Safety and Salvage Administrations, May 2004, Istanbul.

Marine Law Research Center, Istanbul Bilgi University "Turk Bogazlarinda Trafik Sistemi Gelismeler ve Sorunlar".http://denizhukuku.bilgi.edu.tr/doc/turk_bogazlarinda_trafik_sistemi_gelismeler_ve_sorunlar.doc (accessed December, 2006).

AUTHOR BIOGRAPHIES

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 Bogazici University, Istanbul, Turkey since 1976. 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 and 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) in Systems Engineering from Yeditepe University, Istanbul, Turkey and MS (2005) in Industrial Engineering from Bogazici University, Istanbul, Turkey. She is currently a PhD student and research/teaching assistant at the Department of Industrial Engineering of Bogazici University. Her e-mail address is: birnur@ozbas.com.tr

TUBA YILMAZ was born in Ankara, 1983. She received her BS (2006) in Industrial Engineering from Bogazici University, Istanbul, Turkey. She is currently a Masters' student and research/teaching assistant at the Department of Industrial Engineering of Bogazici University. Her e-mail address is: tuba.yilmaz@boun.edu.tr