STOCHASTIC PREDICTION OF MARITIME ACCIDENTS IN THE STRAIT OF ISTANBUL

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ABSTRACT

A physics based mathematical model is developed to simulate the random transit maritime traffic through the Strait of Istanbul. Based on the geographical characteristics of the Strait and random distributions of surface currents, arrival of transit vessels, vessel sizes and pilotage error in the Strait, the model computes probability distributions of northbound and southbound vessel positions within the Strait. When the pilotage error is zero, the perception of the surface currents and the handling of the ship is perfect. Deviating from this condition, the autopilot fails to handle the ship and perceive the surface currents perfectly. Hence, the deflection of ships from their original routes cause a distribution of vessel positions along established checklines. The results indicate that the effect of pilotage on the casualty risk depends on the vessel size and the position in the waterway. Using the geographical characteristics of the Strait, the model estimated the probability distribution of vessel casualties. Risk maps showing the expected number of accidents in different sections of the Strait are generated for different vessel sizes and casualty types including collion, ramming and grounding.

INTRODUCTION

The transportation cost of one barrel oil from Baku to Ceyhan through pipelines range from \$ 1.00 to \$ 2.00. Whereas, the same piece of work is accomplished by oil tankers for a cost of less than 20 cents per barrel (Brito, 2000). The Turkish Straits, which cover the geographical region comprising the Strait of Istanbul (hereafter referred to as *the Strait*) the Sea of Marmara and the Strait of Çanakkale (the Dardanelles), appears to be a "*cheaper pipeline*". At current rates, annually 50,000 vessels transit the Strait of which 4,500 are tankers that carry hazardous and/or explosive material. Merchant tankers are shipped with various types of oil at the ports in the Black Sea, and the valuable merchandise is transported to world markets over the Mediterranean Sea.

The Strait has experienced over 200 vessel casualties due to collision, grounding and stranding and fire. The reasons of these accidents are identified by Oğuzülgen (1995) as follows.

- insufficient pilotage skills
- natural structure of the Strait
- surface currents
- restricted visibility
- local conditions
- breakdowns and technical insufficiencies

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These parameters affect the casualty risks differently in different regions of the Strait. Since these parameters cannot be exactly estimated at a specific time and location, they are considered as random variables with a specific probability distribution (Tan and Otay, 1999). The objective of the present work is to model, analyze, and predict the grounding and collision risks in the Strait incorporating the surface currents, vessel overall length (LOA), maneuverability characteristics, and the pilotage skills of the captain.

EXISTING TRAFFIC LOAD AND CASUALTY STATISTICS

The existing traffic load in the Strait is analyzed by Gören (2002) in terms yearly number of vessels between 1990-1999 (Figure 1) and the probability distribution of vessel lengths in years 1996–1999 (Figure 2). It is noted that after 1994 there has been a rapid increase in number of transits.

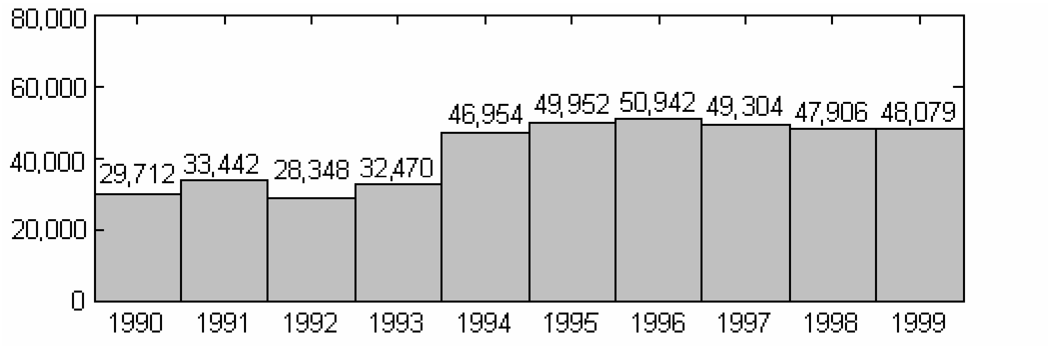

Figure 1. Total number of transiting vessels in 1990-1999 (Gören, 2002)

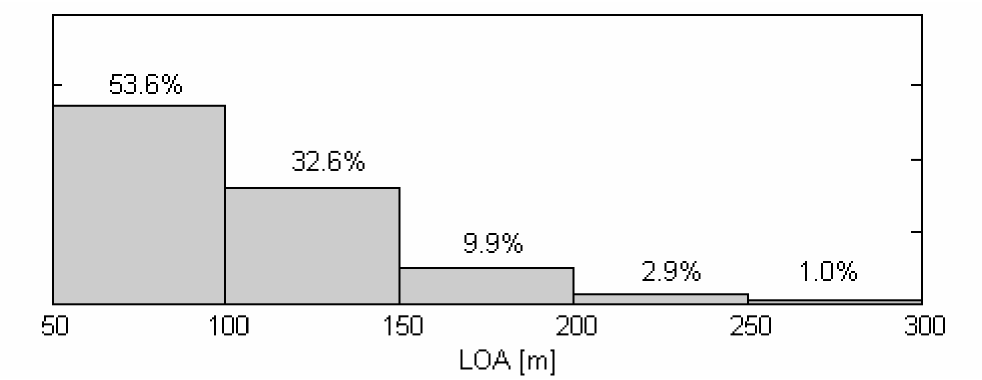

Figure 2. Probability distribution of transiting vessel lengths in 1996–1999 (Gören, 2002)

In nautical terms, the word *casualty* refers to any incident which disrupts a vessel's normal movement. Common examples of vessel casualties include *collision (C)*, *grounding (G)*, *ramming (R)*, *fire* and *mechanical malfunction*. Collision is defined as any contact between two vessels, which are underway or anchored or in the process of docking or undocking. Ramming is the collision of a vessel with a fixed object such as a dock, pier, bridge, shore, seaside road or residences. Grounding represents the contact of vessel hull with the sea bottom. The statistical distribution of CRG (collision, ramming and groundings) casualties with respect to vessel overall lengths (only those between 50 m and 200 m) are given in Figure 1.

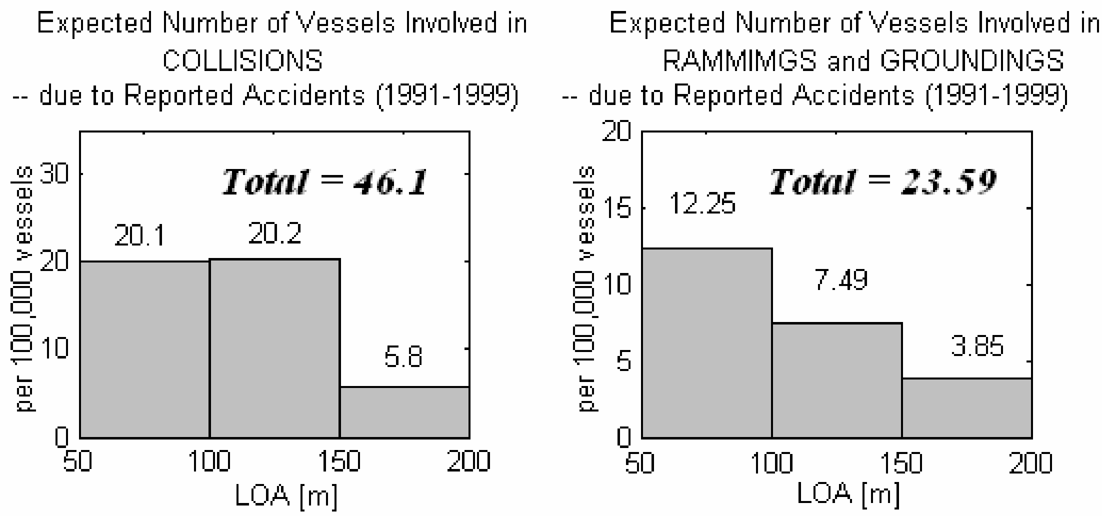

Figure 1. Length distribution of CRG casualties in 1991 – 1999 (Gören, 2002)

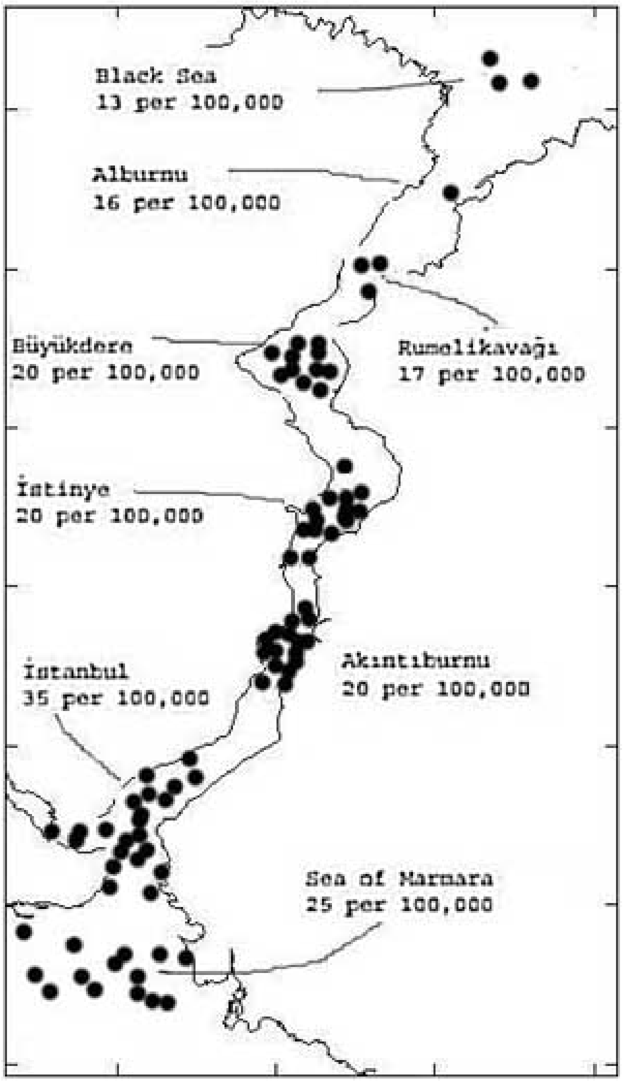

Figure 4. Past casualties in the Strait (courtesy of Kornhauser and Clark, 1995)

HYDRODYNAMIC MODEL OF SHIPS NAVIGATING AT SLOW SPEEDS

A vessel exposed to surface currents while navigating through a narrow waterway at slow speeds is considered as a rigid body in space, and therefore it holds 6 degrees of freedom (DOF) in space as shown in Figure 5.

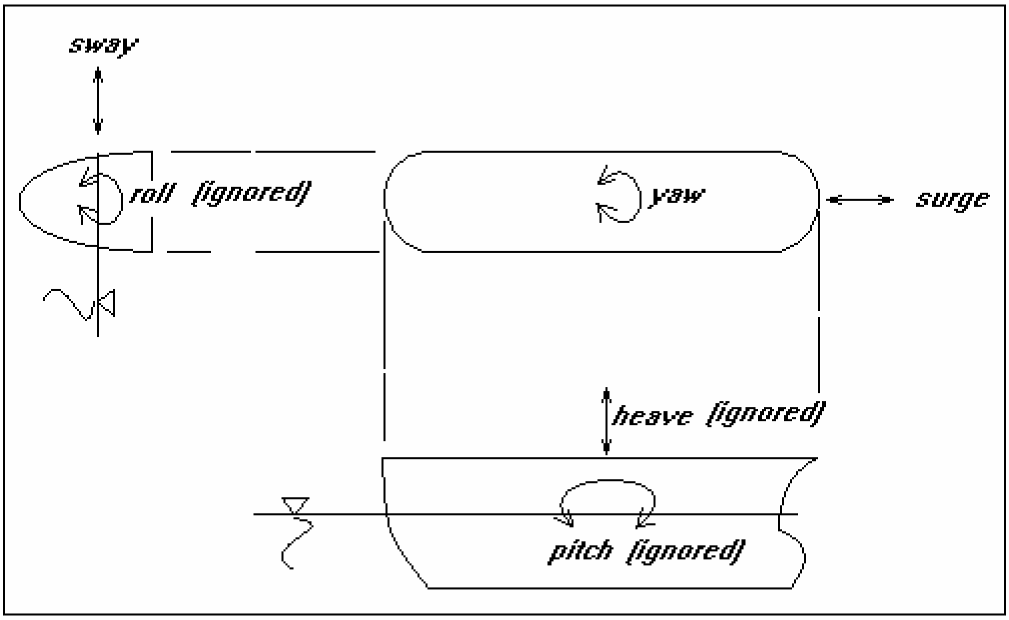

Figure 5. The included and ignored degrees of freedom (DOF)

The *pitch*, *roll* and *heave* DOFs are motions, which are mainly excited by the influence of wave and wind forces. However, within the Strait, these types of forces do not reach large magnitudes, and the vessels navigate at relatively slow speeds. Most of the ship maneuvering models are expressed in terms of surge, sway and yaw only. For faster vessels a fourth term representing the roll motion can be introduced. Since our task is to model and analyze the navigation of ships through the Strait at relatively slow speeds, incorporating only the 3 DOF (surge, sway and yaw) is adequate for the present model.

To compute vessel trajectories, the forces acting on the hull, rudder, and propeller are formulated. Because of high Reynolds number, turbulent eddies may develop around the hull, rudder and propeller complicating the flow. Solution of the complete flow equations for high Reynolds numbers is a highly sophisticated task which is beyond the scope of the present work. Therefore empirical formulae based on theoretical and experimental finding on ship hydrodynamics are used in the present study.

TRAFFIC SIMULATION

The transit maritime traffic in the Strait is regulated within officially established traffic lanes. In the present mathematical model, the predetermined vessel routes are arranged to coincide with the center lines of the official lanes. Among the possible external forces which effect the ship's navigation, only the most important one, the surface current, is included in the simulation as a typical deterministic current field readily taken from a depth averaged finite element model (Örs, 1998).

The position distributions of vessels are discritized at certain locations, where a set of lines, named as stations, are situated. The vessels start their travel at an entrance station and navigate continuously until the next station is reached. In between two successive stations, the position of the vessel is computed by solving a set of simultaneous, nonlinear, differential equations which control the motion of the ship in an hydrodynamic flow field. The intersection of vessel trajectories with another set of lines, named as checklines, are recorded where the checklines and the stations mesh the Strait rather orthogonally. Briefly, the simulation algorithm maps the vessel position distribution from a checkline to the next one (Figure 6).

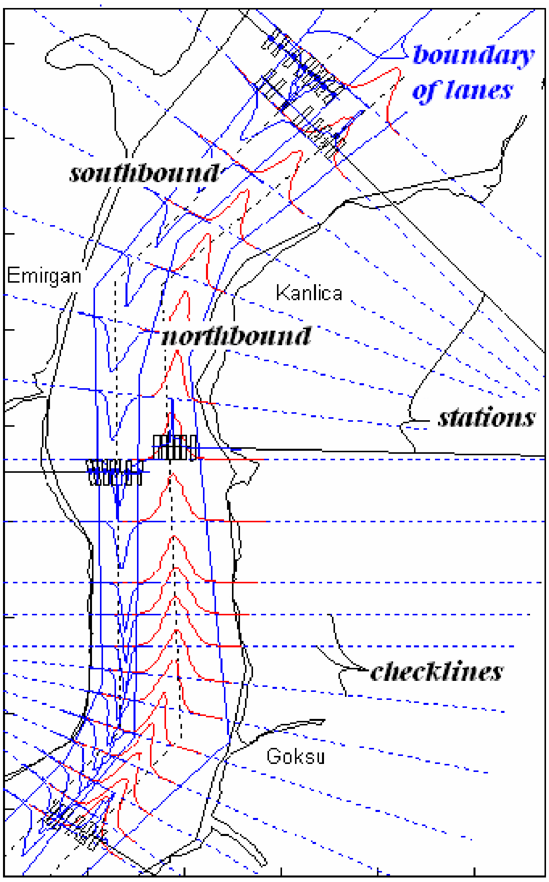

Figure 6. Probability distribution of vessel positions for vessels with LOA = 125 m.

The random parameters incorporated in the model are the pilotage error, the vessel length and the vessel position. When the pilotage error is zero, the perception of the surface currents and the handling of the ship is perfect. Deviating from this condition, the autopilot fails to handle the ship and perceive the surface currents perfectly. Hence, the deflection of ships from their original routes cause a distribution of vessel positions along the checklines.

CASUALTY MODEL

The casualty model operates as a post-processing unit independent of the mathematical simulation program. Following the completion of the mathematical simulation program for a constant vessel length under a constant flow field, the position distributions are analyzed to yield the probability of CRG casualties at each checkline. Afterwards, the CRG probabilities are interpolated along the Strait to give a continuous map of casualty probabilities.

At each checkline the scattered position nodes are compiled into a continuous form separately for north- and south- bound traffic as described. The collision probability at any individual checkline is defined as the probability of two vessels (a northbound and a southbound) being positioned at a distance closer than or equal to a typical collision distance (Figure 7). The grounding probabilities are defined as the probability of vessels being located at a depth shallower than or equal to a typical vessel draft, selected as 10 m.

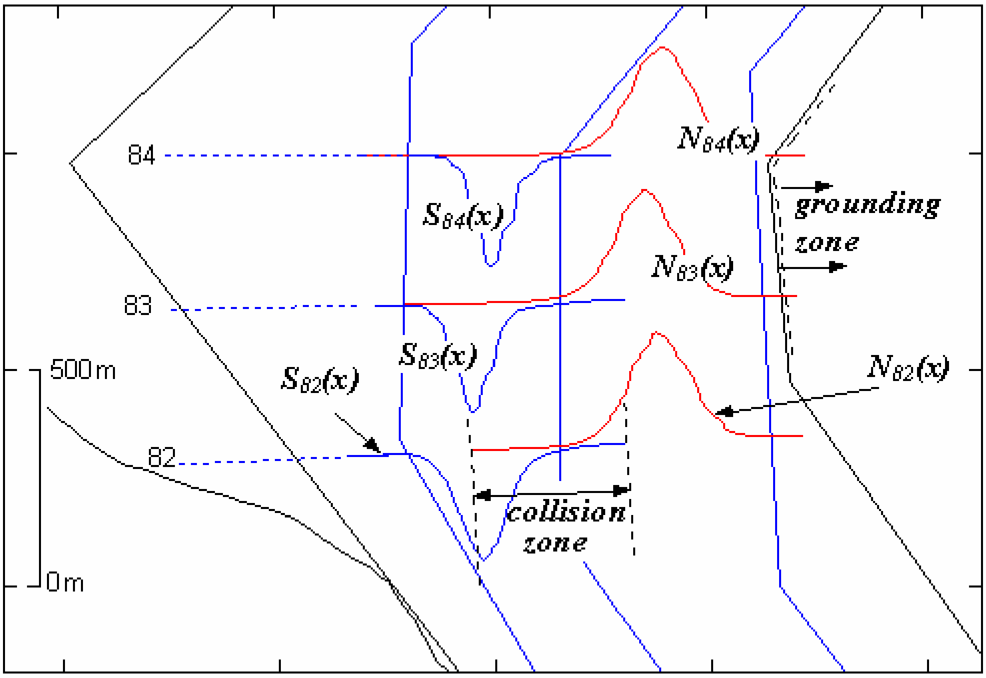

Figure 7. The probability distributions of vessel positions at successive checkpoints

The whole domain of the Strait is meshed with checklines where each checkline represents a finite area. When a vessel navigates within the Strait she is positioned in one of the cells. Therefore, the time duration for the navigation of a single vessel is distributed among the cells. The probability of existence of a vessel in a cell is directly proportional to the time duration spent within the cell. So that at regions where the checklines are closely packed and cells are shorter or the vessel velocities are relatively higher because of the increased water flow velocities, the probability of existence of the vessels at these cells appear to be relatively smaller.

RESULTS

Model results provide the probability of vessel positions along 123 selected checklines distributed over the longitudinal axis of the Strait. The computed position probabilities of north- and south- bound vessels are then used to calculate the casualty probability at each of the checklines. Finally, the distribution of casualty probability is graphically presented as risk maps for different vessel sizes of north- and south- bound traffic.

The risk maps in Figures 8 and 9 show the computed probability distribution of collision and Ramming/Grounding risk for various vessel lengths in north- and south- bound traffic. Note that the graphs appearing to the left of the risk maps are the discrete casualty risk graphs referring to the according cell. Therefore, it shall not be treated as a continuous probability density function where it is integrated to obtain the total casualty risk in the Strait. Instead, one has to sum all the discrete casualty probabilities belonging to according cells to obtain the total casualty risk.

Apart from the peaks of the collision probability at approximately 13th and 17th kilometers of the Strait in Figure 8, the simulation results agree well with the existing accident data. These peaks are situated at the station lines where the incoming vessel position distributions are discretized and recombined according to the shape functions. Since constant shape functions are used in the present model, the artificially imposed shape function error is responsible for these incorrect peaks.

Risk maps in Figures 8 and 9 clearly show that, the vessel length directly correlates with the casualty risk for both north- and south- bound vessels.

When the north- and south- bound traffics are compared, interesting results have been observed. Small northbound vessels are more likely to collide with large southbound vessels. Due to ship hydrodynamics, vessels traveling in the direction of the current (southbound vessels) are more difficult to be controlled and therefore more likely to cause accidents. At the same time, larger vessels have a higher accident risk. Therefore, large vessels traveling in southbound traffic have the highest risk of collision. In this sense, the model results simulate the directional dependence of accident risk at an acceptable level.

Oğuzülgen (1995) identified the following places where accidents intensively occur.

- Southern entrance
- Kandilli area (12km – 13 km from the southern entrance)
- Yeniköy area (16 – 18 km from the southern entrance)
- Büyükdere area (20 km – 25 km from the southern entrance)
- Northern entrance

The simulation results verifies the above observations except for the northern and southern entrances where the pilotage error is usually not the leading cause of accident. Instead, accidents in these areas are due to the densely populated waiting zones situated near the two exit points of the Strait. Apart from this exception, the high risk regions identified by the mathematical simulation results match with the regions of the Strait where the accidents occur extensively.

Expected number of collisions and rammings and groundings are calculated for vessels smaller than 200 m. Simulation results indicate that collision has a higher risk compared to ramming and grounding.

The statistical data reveal that during the years 1995 – 1999, when the traffic density was steady at an approximate rate of 50,000 vessels/year, 47 vessels had been involved in ramming and grounding casualties, compared to the 106 vessels, which had been involved in collisions. The stochastic model, however, overestimates the number of rammings and groundings in comparison to collisions (see Figures 8 and 9). According to the accidents occurred in years 1995 – 1999, the ratio of the number of vessels involved in collisions to the number of vessels involved in rammings and groundings was 2.25. According to the mathematical simulation, this ratio is 1. This is primarily a consequence of the constant shape functions or inadequate discretization.

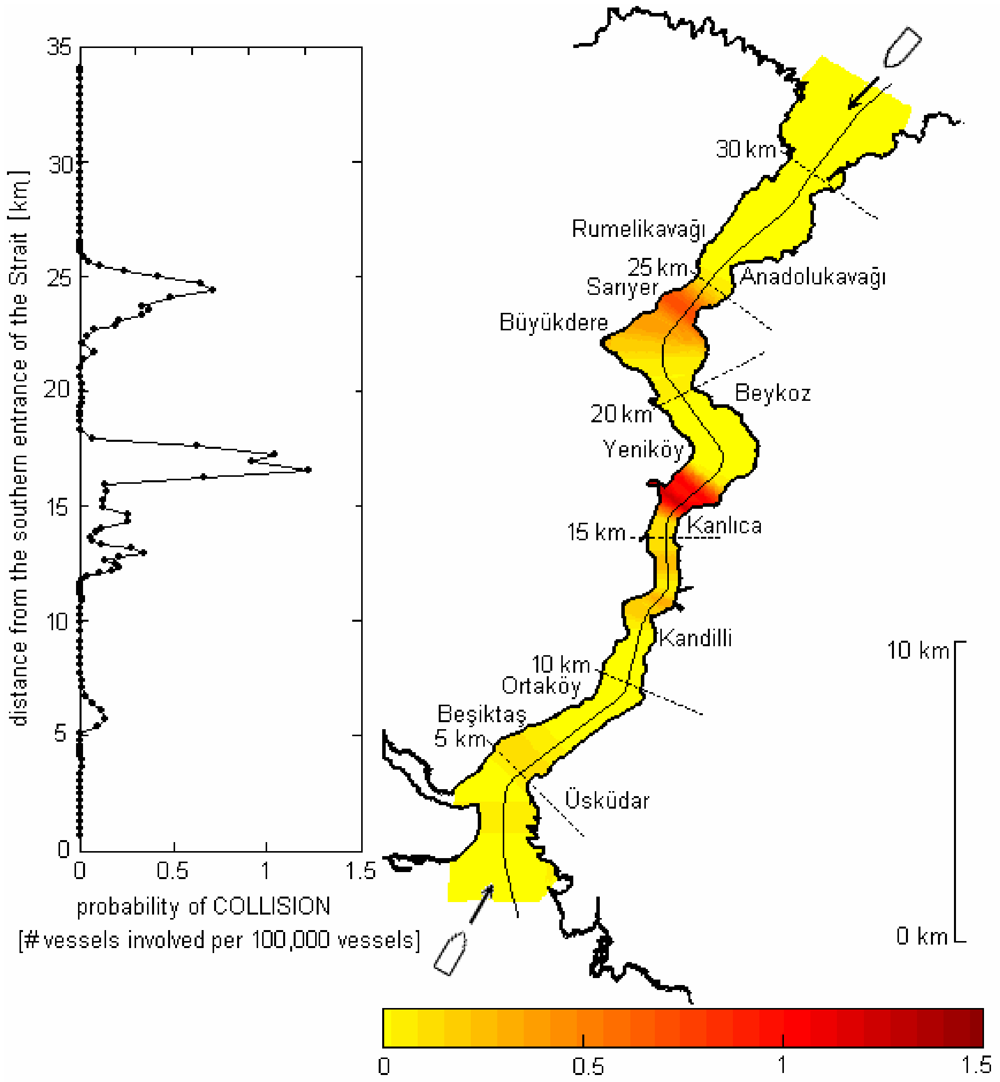

Figure 8. Risk map for collision (per 100,000 vessels)

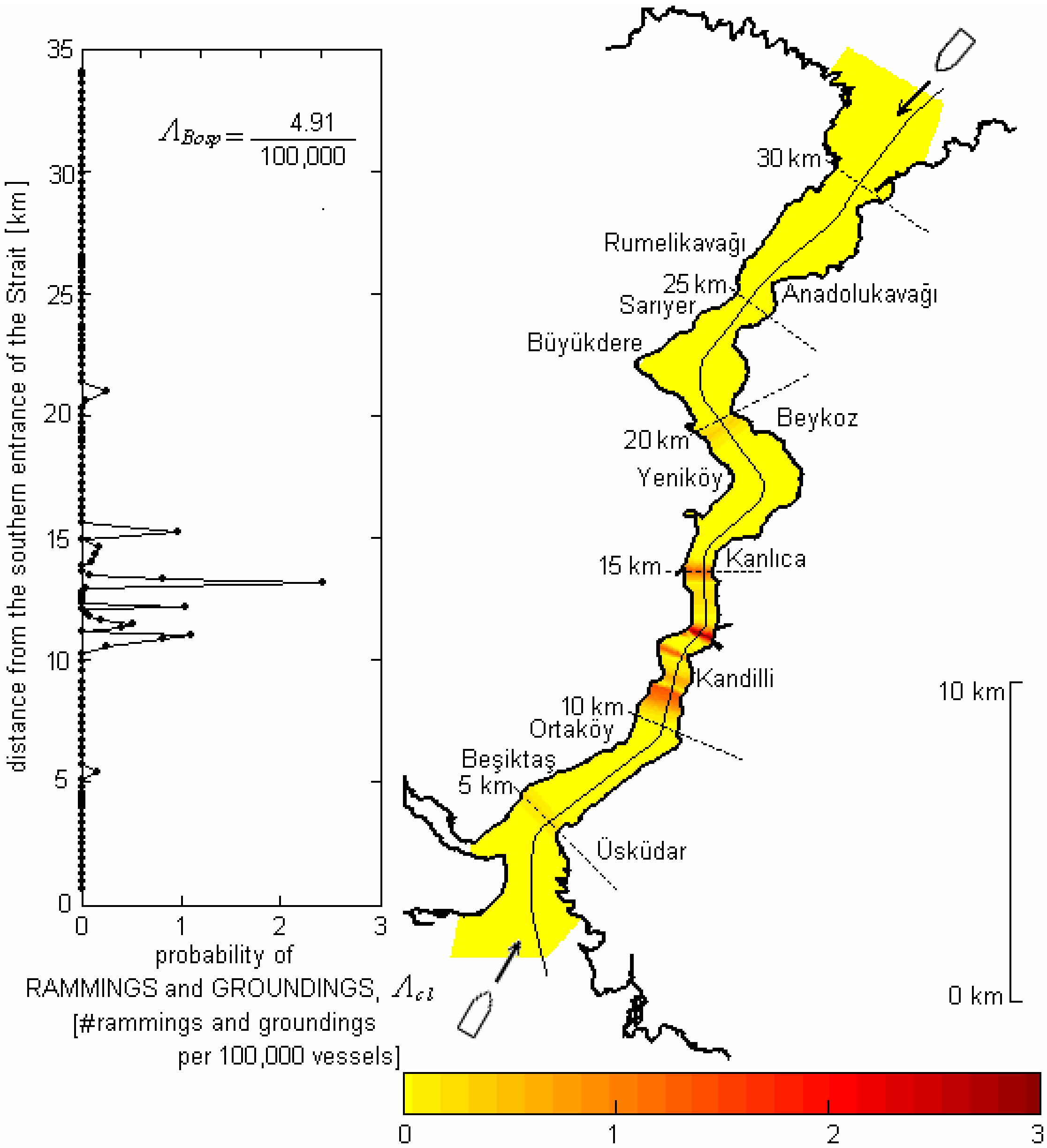

Figure 9. Risk map for ramming and grounding (per 100,000 vessels)

CONCLUSION

A physics based stochastic simulation has been developed to investigate casualty risk in the Strait of Istanbul with regards to the existing vessel traffic condition. The model results indicate certain regions in the Strait as high-risk regions. It is found that when the same pilotage error is incorporated for all vessel types regardless of vessel size or travel direction, the vessel length directly correlates with the casualty risk. It is also verified in the model that the southbound vessels are at a more disadvantageous condition in terms of ship handling due to the south going surface flow. Therefore, larger southbound vessels are found to be the main cause of the collisions in the Strait of Istanbul. The collision and ramming/grounding risks are evaluated separately. According to the model, the collision risk is higher than ramming/grounding risk in the Strait of Istanbul.

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