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AN INVESTIGATION OF NAVAL ACCIDENT PROBABILITIES AND CAUSES IN THE ISTANBUL CHANNEL

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Abstract. Ships are prone to accidents in the Istanbul Channel, which is one of the most difficult-to-navigate waterways in the world. Such accidents impose risks on nearby populations, property, and environments. Naturally, the increase in the volume of traffic and adverse meteorological conditions increase these risks. The goal of this study has been to quantify transport risks through statistical regression techniques. Accordingly, regression models have been developed to investigate the relationship between naval accidents in the Channel and suspected accident-causing factors and conditions, such as strong currents and winds, local traffic, channel width and bends, and visibility. The results obtained from such regression models are reported and some important policy suggestions are generated based on these results.

Key words: Naval Accidents, Regression Analysis, The Istanbul Channel

1. INTRODUCTION

Although the sea is not a particularly risky mode of transport, accidents do happen in waterways. Furthermore, the transport of hazardous or dangerous substances by sea creates risks that are quite different from those created by other modes of transport (Spouge, 1993). A tanker can carry 100,000 tons of flammable liquid or 20,000 tons of liquefied natural gas, which implies that the impact zone in the case of a spill can be very large, and the undesirable consequences can be far-reaching.

Ships spend most of their time at sea, where the population at risk is limited to the crew of the ship, and where the risk of collision with another ship is almost zero. However, when a ship is near land (and encounters heavy sea traffic), either for loading or unloading activities or due to travel in a narrow waterway (such as the Istanbul Channel), the risks imposed on the population on land and the environment may become significant. For example, the United States Coast Guard's Casualty Maintenance Database contains about 36,000 accident records for a set of 23 zones encompassing 82 deep draft ports in the United States over a 10-year period (Liu, 1993). The majority of the accidents are minor. However, major accidents, such as the oil spill caused by *Exxon Valdez* (which cost the company over $3,500,000,000 in cleanup and compensation (Anonymous, 1993)), or the *Independenta* and *Nassia* accidents in the Istanbul Channel, occur too frequently to ignore the risks associated with this mode of transport.

Therefore, national and international sea transport traffic within the Istanbul Channel, which is one of the most difficult-to-navigate waterways in the world, naturally poses some very serious risks for the city of Istanbul and the environment. There were 157 collisions in the Istanbul and Dardanelles Channels during 1988-1992 (Knott, 1994), and the United States Energy Information Administration (EIA) rates the possibility of accidental oil supply disruptions the greatest for supplies moving through the Istanbul Channel (Anonymous, 1994). These risks have the potential to cause loss of human life, environmental pollution, damage to historical and cultural heritage, and property damage in huge numbers and dimension. It is possible that accidents such as collision of vessels with each other or with the land mass on either side of the Channel could lead to fires, explosions, the release of poisonous gas, and sinkings. Parallel to increases in the Channel traffic and the growth of the city, the quantity and characteristics of those vessels involved in the traffic, which means that accident risks are increasing over time. On the other hand, because of the free passage conditions of the Montreux Treaty, Turkey does not have full control over the traffic through the Istanbul Channel, and this fact complicates the implementation of many risk-mitigation measures.

Accordingly, assessment of the underlying accident probabilities and estimation of the number of potential accidents, with regard to:

(i) types and characteristics of sea transport vehicles and sea traffic density,

(ii) meteorological and environmental conditions, including rain, wind, fog, currents,

(iii) availability of on-board pilot captains,

(iv) various traffic rules and risk-mitigating measures,

are preconditions in order to determine and implement appropriate risk-mitigating measures and are of great importance for the citizens and city of Istanbul.

Statistical regression is quite a useful quantitative tool in the analysis of these potential accidents (Liu, 1993). Within the study discussed in this paper, regression models were developed to investigate, prioritize, and quantify the relationship between naval accidents in the Channel and suspected accident-causing factors and conditions (such as strong currents and winds, local traffic, channel width and bends, visibility).

2. THE REGRESSION MODELS

2.1 Data Compilation

Past data about accidents in the Istanbul Channel in the period 1982-1994 provided a starting point for the regression study, and the amount of traffic through and across the Channel and the physical and technical characteristics of the Channel and of the sea transport vehicles involved in past accidents were investigated and compiled to be included in the regression models. Most of the data was obtained from related national and international organizations. Furthermore, expert opinions, obtained through various interviews, provided valuable insight into the parameters of the models developed; information on traffic type and density, and environmental and meteorological conditions are some of the data supported by expert opinion.

2.2 Model Development and Analysis

Two basic models were developed to prioritize and quantify the relationship between naval accidents in the Channel and suspected accident-causing factors and conditions. In the first model, the Channel was divided into eight regions and suspected accident-causing factors and conditions with different characteristics and levels in different regions were then taken as candidates for the dependent variables, with number of accidents in each region (**A**) taken as the independent variable. Investigation of the compiled data and interviews with experts, such as pilot captains and Istanbul port administrators, helped in identifying the following factors as the main candidates for such dependent variables in each of the eight Channel regions.

Current Speed (**C**):	The yearly average value of the surface current in the region.
Min. Width (**WD**):	The minimum navigable Channel width in the region (i.e., excluding shallow or ship anchoring areas, port facilities, and wave breakers).
Number of Bends (**B**):	The total number of turns in the region that a typical transit vessel has to go through in order to stay in the sea lane allocated for its passage.
Total Degree (**TD**):	The total number of turning degrees in the region a typical transit vessel has to execute in order to stay in the sea land allocated for its passage.
Max. Degree (**MD**):	The maximum turning degree in the region a typical transit vessel has to execute in order to stay in the sea land allocated for its passage.
Length (**L**):	The length of the region.
Cross Traffic (**CT**):	The scheduled local ferry traffic density in the region. This density is estimated by first determining the total daily ferry traffic load across the Channel and then estimating the percentage load in the region. The weighted average was computed through the summation of (% of a ferry line falling into region) ∞ (number of daily trips on that line), which formed the basis of the region's percentage load. This regional traffic load is then divided by the region's length to estimate the regional traffic density.

A linear regression model was developed between the dependent variable **A** (the total number of accidents in a region in the period 1982-1994) and the independent variables listed above. This initial model could not be expected to have any statistical significance, since there were only eight observations (the eight regions), while the regression equation had seven independent variables (leading to zero degrees of freedom). Nevertheless, the signs of independent variables' parameters in this initial model were employed to eliminate some independent variables from further analysis (and thereby increase the degrees of freedom in succeeding versions of this model). The independent variables, whose parameter signs in the initial model turned out to be the opposite of what was expected, were assumed to be "less important" and were excluded from further analysis.

Various combinations of the remaining independent variables were then tested to identify the most meaningful and statistically significant regression model. This effort led to the identification of the following relationship:

$$\mathbf{A} = 13.307 + 0.23 * \mathbf{TD} + 0.593 * \mathbf{CT}.$$

"Total Degree" and "Cross Traffic" were identified as the two critical factors, having significant effects on the number of naval accidents in the Istanbul Channel. The statistical significance of these two independent variables is displayed in Table 1, while the overall statistical evaluation of the selected model is displayed in Table 2. The hypothesis that these independent variables are not significant (the null hypothesis that coefficients of all variables are zero) was rejected with a maximum error level of p=0.5%; on the other hand, the ratio of explained error to total error was quite satisfactory at R^2=0.88. According to this equation, a unit increase in Channel traffic density (whose current range is between 0-40 vessels per Channel mile) is expected to lead to 0.6 naval accidents over a period of 13 years. Similarly, efforts to negotiate each degree of turning is expected to lead to 0.2 naval accidents over a period of 13 years. The normalization of the above equation leads to

$$\mathbf{A} = 0.000 + 0.471 * \mathbf{TD} + 1.043 * \mathbf{CT}$$

The normalized equation suggested that "Cross Traffic has 2.21 times more effect on naval accidents than "Total Degree."

Table 1. The Statistical Evaluation of the Regional Model

Independent Variables	Coefficient	p Value
Constant	13.307	0.064
Total Degree	0.230	0.040
Cross Traffic	0.593	0.002

Table 2. The Statistical Evaluation of the Regional Model

Source	Degree of Freedom	Sum Squares	Mean Squares	F Value	p Value	R^2
Regression	2	2086.8	1043.4	18.55	0.005	0.881
Error	5	381.2	56.2			
Total	7	2368.0				

In the second regression model, the whole Channel was considered as a single region, and the number of accidents in each season (three months) over the past 5 years (**A**) was taken as the dependent variable. In this model, suspected accident-causing factors and conditions, having different characteristics and levels in different time periods, were taken as candidates for the dependent variables. Investigation of the compiled data and interviews with experts helped to identify the following factors as the main candidates for such independent variables in each of the considered time periods:

Visibility (**V**): The periodic (three monthly) percentages of foggy days (0-0.5 miles visibility) in the Channel.

Wind Speed (**WN**): The periodic average values of the wind speed in the Channel.

Transit Traffic (**TT**): The periodic number of transit vessel passages through the Channel.

Pilotage Service (**P**): The periodic percentages of transit ships accepting the pilotage service offered by the Channel Authority. The original monthly values included some figures such that the number of pilots employed were larger than the number of passages for some months; accordingly, all ratios were normalized.

A linear regression model was developed between the dependent variable (the total number of accidents in every three-month period between 1990-1994 (A) and the independent variables listed above. This initial model had a low statistical significance and reliability level, and furthermore, the coefficients of some of the independent variables were quite counterintuitive; for example, wind speed, which is expected to have a positive correlation with number of accidents, turned out to have a negative coefficient. So various combinations of independent variables were tested to identify the most meaningful and statistically significant regression model. Unfortunately, none of them led to an acceptable regression equation with a statistically significant set of independent variables.

At this point, discussions with pilot captains uncovered an important characteristic of transit vessels that was being ignored in the available set of independent variables (and who absence from the model could explain the current stand-off): most of the experts interviewed insisted that the age and physical condition of transit vessels very much influenced accident probabilities. Unfortunately, this conjecture could not be verified directly, since past data on age and physical condition of transit vessels (even for the ones that had been involved in accidents) was not available. However, a proxy measure was suggested and used: pilot captains claimed that ships carrying certain flags were, on average, much older and in poorer physical condition. Accordingly, four such flags were selected to represent "transit vessels of higher age and poorer physical condition." In other words, the following additional independent variable was defined and included in the model:

Physical Condition (PC): The number of transit vessels in each time period carrying the selected four flags.

Further experimentation with the expanded set of candidate independent variables led to the identification of the following relationship:

$$\mathbf{A} = 3.0 + 0.63 * \mathbf{V} - 6.59 * \mathbf{P} + 0.02 * \mathbf{PC},$$

which identified "Visibility," Pilotage Service," and "Physical Condition" as the three critical factors having significant effects on the number of naval accidents in the Istanbul Channel. The statistical significance of these three independent variables is displayed in Table 3, while the overall statistical evaluation of the selected model is displayed in Table 4. The hypothesis that these independent variables are not significant (the null hypothesis that coefficients of all variables are zero) was rejected with a maximum error level of p=0.9%; unfortunately, the ratio of explained error to total error was not satisfactory in this case (R2=0.28).

According to the above equation, a percentage point decrease in visibility (whose current range is between 10-30% poor visibility or foggy days in a season) is expected to lead to 0.006 naval accidents in a three-month period. Similarly, a percentage point increase in pilotage usage (whose current range is between 35-55% of transit ships employing this service) is expected to lead to 0.06 fewer naval accidents in a three-month period. On the other hand, a unit increase in the number of "poor physical condition" ships is expected to lead to 0.02 additional naval accidents in each three-month period.

Table 3. The Statistical Evaluation of the Seasonal Model

Independent Variables	Coefficient	p Value
Constant	3.00	0.210
Visibility	0.63	0.002
Pilotage Service	-6.59	0.091
Physical Condition	0.02	0.320

Table 4. The Statistical Evaluation of the Seasonal Model

Source	Degree of Freedom	Sum Squares	Mean Squares	F Value	p Value	R^2
Regression	3	101.19	33.73	4.497	0.009	0.278
Error	35	262.52	7.50			
Total	38	363.69				

2.3 Model Critique

The most unintuitive aspect of the regional regression model was the absence of "Current Speed" as an independent variable in the resulting equation. During the interviews and discussions, the pilot captains emphasized this factor as one of the most important causes of naval accidents. Two conjectures are proposed for this omission:

(i) The Current speed values employed in the model are yearly and regional averages, while the actual current speed values realized during accidents, which may be quite different from these averages, are obviously far more important. Unfortunately, these actual values have not been recorded, and therefore are unavailable for statistical analysis.

(ii) There may be a statistical relationship (correlation) between "Local Traffic" and "Current Speed" data, shadowing the relationship between "Accidents" and "Current Speed." Such a correlation was investigated and the computed correlation coefficient of 0.494 was verified as suspicious. On the other hand, regressing "Current Speed" alone with "Accidents" led to a relationship significant at the 90% level and having an R^2 value of 0.415.

The most unintuitive aspect of the seasonal regression model is the absence of "Transit Traffic" and "Wind Speed" as independent variables in the resulting equation. During the interviews and discussions, the pilot captains emphasized these factors as some of the most important causes of naval accidents. Two conjectures are proposed for the omission:

(i) The wind speed values employed in the model are seasonal averages, while the actual wind speed values realized during accidents, which may be quite different from these averages, are obviously far more important. Unfortunately, these actual values have not been recorded and therefore are unavailable for statistical analysis.

(ii) There is a statistical relationship (correlation) between "Transit Traffic" and "Physical Condition" data, shadowing the relationship between "Transit Traffic" and "Accidents." Such a correlation is investigated and the computed correlation of 0.685 verified suspicions. Unfortunately, the regression of "Transit Traffic" alone with "Accidents" did not lead to a statistically significant relationship.

On the other hand, especially the periodic model falls quite short of explaining the total variation in the number of accidents. The reason for this poor fit may be lack of reliable data and the monthly aggregation of visibility and wind values, as explained above. Another important reason could be better adherence to traffic rules and regulations because of the publicity associated with the development of new Istanbul Channel traffic regulations and guidelines, which went into effect in July 1994. Such a behavioral change would also explain the non-detection of a statistically significant relationship between "Transit Traffic" alone and "Accidents."

3. THE COMPARISON OF MEAN PROPORTION OF TWO SAMPLES

Because of the weak points discussed above, a related but quite independent study was initiated to confirm the significance of one critical factor — the Pilotage Service — on the Channel naval accidents. For this purpose, the pilotage service utilization of two populations —transit vessels involved in naval accidents in the Istanbul Channel, and all transit vessels in the Channel — was statistically compared. In this process, the hypothesis that "the pilotage service utilization of these two populations are equal" was rejected with a maximum error level of p=5%, confirming our suspicions that the proportion of the total (average) vessels utilizing pilotage service is significantly higher than the proportion of vessels involved in Channel naval accidents utilizing pilotage service.

Unfortunately, one critical assumption of such hypothesis tests — that the two populations be independent — was not satisfied in this case: vessels involved in naval accidents were a subset of (therefore dependent to) all vessels, and separate pilot utilization data was not available for the independent subset "vessels not involved in naval accident." On the other hand, the null hypothesis was rejected with such a comfortable safety margin that this handicap was regarded as non-critical in this case: the null hypothesis would still be rejected with the same error level if the mean of the first population (transit vessels involved in naval accidents) were 0.343, instead of the computed value of 0.1351 (the mean of the second population, all transit vessels, was computed to be 0.5).

4. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The two regression models developed in this study have validated, quantified, and prioritized the relationship between the naval accidents in the Istanbul Channel and suspected accident-causing factors and conditions. Most of the "accident causes" are quite intuitive, but the quantitative assessment of their overall and relative importance is new and could prove to be very beneficial in evaluating various risk-mitigating measures. Furthermore, such explicit relationships could be very useful in further quantitative studies on transportation risks in the Istanbul Channel. In this context, the development of a detailed simulation model of the Channel traffic is suggested as an important next step. Such a model, which would be based on relationships such as the ones identified in this study could be a valuable tool for a rigorous risk analysis of the Istanbul Channel naval traffic (Erkut and Verter, 1995; Keeney, Kulkarni and Nair, 1990) and could provide a platform for an objective, quantitative evaluation of various policy alternatives (Calkins, 1994; Curtis, 1986).

Further regression studies, especially on the multi-collinearity issue discussed in Section 2.3, are also suggested. However, the highest priority issue regarding any further quantitative analysis of Istanbul Channel naval traffic and its risks is proper data collection and storage. Within this context, detailed periodic current, visibility, and wind measurements, detailed and reliable recording of transit traffic data and pilotage services accomplished, and precise and full information regarding accidents and near accidents are strongly suggested.

5. POLICY SUGGESTIONS BASED ON REGRESSION RESULTS

The following policy suggestions can be made based on the regression results and related observations:

(i) The regional model has highlighted the critical influence of cross traffic on naval accidents. Accordingly, additional measures to regulate local traffic (such as safety and physical condition inspections, better enforcement of right of ways, and speed limits) are strongly suggested.

(ii) The regional model has also highlighted the accident-prone nature of the many sharp turns along the Istanbul Channel. Accordingly, additional and/or better warning signals and floating and land-based lights are suggested.

(iii) The seasonal model has highlighted the importance of poor visibility on naval accents. Accordingly, additional measures (such as additional speed and frequency limitations on transit and local traffic and a stricter definition of traffic stoppage conditions) are suggested on foggy or poor visibility days.

(iv) The seasonal model has also highlighted the accident-reducing effect of the pilotage service offered by the Channel Authority. Accordingly, transit vessels should be actively encouraged to employ this service (through a more attractive fee structure, insurance premiums sensitized to on-board pilot availability, and better promotion of the service offered, among other measures).

(v) The seasonal model has also highlighted the influence of vessel age and physical condition on naval accidents. Accordingly, enforcement of some minimum standards (or requiring an escort for vessels unable to satisfy those standards) are suggested. Another measure in this regard could be the deployment of emergency and support vessels at strategic locations, ready for immediate action in case of breakdowns related to age or physical condition.

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