MARITIME ACCIDENTS FORECAST MODEL FOR BOSPHORUS

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ABSTRACT

MARITIME ACCIDENTS FORECAST MODEL FOR BOSPHORUS

Küçükosmanoğlu, Alp
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A risk assessment model (MAcRisk) have been developed to forecast the probability and the risk of maritime accidents on Bosphorus. Accident archives of Undersecretariat Maritime Affairs Search and Rescue Department, weather conditions data of Turkish State Meteorological Service and bathymetry and current maps of Office of Navigation, Hydrography and Oceanography have been used to prepare the model input and to forecast the accident probability. Accident data has been compiled according to stated sub-regions on Bosphorus and event type of accidents such as collision, grounding, capsizing, fire and other. All data that could be obtained are used to clarify the relationship on accident reasons. An artificial neural network model has been developed to forecast the maritime accidents in Bosphorus.

Keywords: Bosphorus, Maritime Accidents, Artificial Neural Network, Maritime Accidents Forecast

ÖZ

İSTANBUL BOĞAZINDA DENİZ KAZALARI TAHMİN MODELİ

Küçükosmanoğlu, Alp
Doktora, İnşaat Mühendisliği Bölümü
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İstanbul Boğazı'ndaki deniz kazalarının olasılığını ve riskini belirlemek için bir risk değerlendirme modeli (MAcRisk) geliştirilmiştir. Model girdilerini hazırlamak ve kaza olasılığını tahmin edebilmek için T.C. Denizcilik Müsteşarlığı Ana Arama Kurtarma Koordinasyon Merkezi kaza verileri, Devlet Meteoroloji İşleri Genel Müdürlüğü hava durumu verileri ve Seyir Hidrografi ve Oşinaografi Dairesi Başkanlığı batimetri ve akıntı haritaları kullanılmıştır. Kaza verileri İstanbul Boğazı'nda tanımlanan alt bölgelere ve çatma/çatışma, oturma, alabora, yangın ve diğer olmak üzere kaza tiplerine göre derlenmiştir. Elde edilebilen tüm veriler kaza nedenlerinin ilişkisini açıklamak için kullanılmıştır. İstanbul Boğazı'ndaki deniz kazalarını tahmin edebilmek için bir yapay sinir ağları modeli geliştirilmiştir.

Anahtar Kelimeler: İstanbul Boğazı, Deniz Kazaları, Yapay Sinir Ağları, Deniz Kazaları Tahmini

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TABLE OF CONTENTS

Page

CHAPTERS

APPENDICES

LIST OF TABLES

TABLES Page

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

AF	annual frequency of bridge element collapse,
N	annual number of vessels,
PA	probability of vessel aberrancy,
PG	geometric probability between an aberrant vessel and a bridge,
σ	standard deviation
PC	probability of bridge collapse,
PF	adjustment factor to account the potential protection from vessel collision.
BR	aberrancy base rate,
R_B	correction factor for turning angle,
R_C	correction factor for current acting parallel to vessel path,
R_{XC}	correction factor for current acting perpendicular to vessel path,
R_D	correction factor for vessel traffic density.
V_C	current component parallel to vessel path (knots)
V_{XC}	current component perpendicular to vessel path (knots)
H	ultimate bridge element resistance,
P	vessel impact force.
FP	forecasted probability (accident/passage),
CV	current velocity (cm/s),
LOA	length overall ship (m),
AT	average turn of vessel (degree),
HWS	hourly wind speed (m/s),
DWS	daily maximum wind speed (m/s),
RPA	Ratio of Passage Area to Zone Area.
X_{1-11}	Coefficients
R^2	The coefficient of determination
SS_{res}	The residual sum of squares
SS_{tot}	The total sum of squares
y_i	The observed/obtained data

f_i	The estimated data
$\bar{y}$	The mean of the observed/obtained data
ANN	Artificial Neural Network
NN	Neural Network
w	weight matrix of the neural network model
Δw:	the increment of weight matrix
J:	the Jacobian matrix that contains first derivatives of the network errors with respect to the weights and biases
μ:	the learning rate
I:	unit matrix
e:	vector of network errors
R	number of elements in input vector of artificial neuron
n	input of the transfer function of artificial neuron
b	bias of the artificial neuron
S	number of neurons in layer
UMA	Undersecretariat Maritime Affairs
GRT	Gross Tonnage of the Vessel
R_c	Correlation Coefficient
A_z	Zone Area
A_2	Passage Area
W_p	Average Passage Width
$\rho_{X,Y}$	The correlation coefficient of variables X and Y
$\mathrm{cov}(X,Y)$	The covariance of variables X and Y
B_1, B_2	fuzzy sets
C_1, C_2	fuzzy sets
a_i, b_i, c_i	the coefficients of the first-order polynomial linear functions
L_m	Midline length, division line length between the opposite traffic directions

CHAPTER 1

INTRODUCTION

A risk assessment model (MAcRisk) have been developed to forecast the probability and the risk of maritime accidents in Bosphorus. The driving force behind such a study was the concern for the cultural, historical and natural heritage of Istanbul which are both irreplaceable sources of life and inspiration. Istanbul is a city that creates its own history at the meeting point of the two continents of Europe and Asia. This makes Istanbul, the fascinating gateway between the East and the West.

Istanbul’s history is richly layered and it is the only city in the world that spans two continents. Humans have lived in the area now known as Istanbul since at least the Neolithic. The earliest known settlement dates from 6700 BC, discovered in 2008, during the construction works of the Yenikapi subway station and the Marmaray tunnel at the historic peninsula on the European side. What is now called Asian Istanbul was probably inhabited by people as early as 3000 BC.

In the early 100's BC, it became part of the Roman Empire and in 306 AD, Emperor Constantine the Great made Byzantium capital of the Eastern Roman Empire. From that point on, the city was known as Constantinople.

Finally, in 1453, Turks led by Sultan Mehmet II conquered the city. Renamed Istanbul, it became the third and last capital of the Ottoman Empire. It was the nerve center for military campaigns that were to enlarge the Ottoman Empire dramatically. By the mid 1500's, Istanbul, with a population of almost half a million, was a major cultural, political, and commercial center. During its long history, Istanbul has served as the capital of the Roman Empire (330–395), the Eastern Roman (Byzantine)

Empire (395–1204 and 1261–1453), the Latin Empire (1204–1261), and the Ottoman Empire (1453–1922). When the Republic of Turkey was proclaimed on 29 October 1923, the capital was moved from Istanbul to Ankara.

The international name Constantinople also remained in use until the Turkish Postal Services Law of March 28, 1930, according to which all foreign countries were asked to solely use the name Istanbul also in their languages and their postal service networks.

After the establishment of Turkish Republic, the city of Istanbul has continued to expand dramatically and today its population increases at an estimated 700,000 immigrants per year. Industry has expanded as tourism has grown. Today, Istanbul is the largest city of Turkey. Istanbul metropolitan province (municipality) had 13.26 million people living in it as of December, 2010, which is 18% of Turkey's population and the 3rd largest metropolitan area in Europe (including the Asian side of the city) after London and Moscow. Istanbul is a mega city, as well as the cultural, economic, and financial centre of Turkey. It is located on the Bosphorus Strait and encompasses the natural harbour known as the Golden Horn. It extends both on the European and on the Asian sides of the Bosphorus, and is one of the metropolis in the world that is situated on two continents. The other one is Canakkale, again in Turkey.

Istanbul conforms the definition of a great city, not only with its population and the area covered but also with the variety of cultures and ways of living. This cultural structure which enables a good number of elements that contradict with each other and yet exist together even one in another, is the produce of an accumulation of about one thousand years. Istanbul has been the most desired and the most multicultural city for centuries. The city was, from the beginning, a centre of commerce. And it governed one of the most important waterways in the world; the Bosphorus Strait.

Byzantium and Ottoman periods are the most significant stages in the history of Istanbul. In both of these periods, Istanbul has preserved its features of being a political and religious center and has become the religious center of both, the Christianity and the Islam. Therefore, it was ornamented with many great monuments with different functions belonging to these two religions. During the most powerful times of the Ottoman Empire, Sinan, the Master Architect" whom was the 'Chief Engineer' for nearly 50 years Istanbul owes so much to him for its famous skyline which is mostly the creation of his work.

Maritime accidents in Bosphorus is a potential risk to demolish the all these historical and cultural heritages therefore strict measures against to minimize the risk has to be taken based on scientific studies.

Maritime accidents take different names depending of the types of accidents. Collision is a maritime accident type which occurs between two or more vessels. Stroke is an accident that occurs between a vessel and anything except vessel. Capsizing is the event of a vessel accidentally turning over in the water. Grounding is the event that the vessel can not move because it has hit solid ground. Damages to Ship or Equipment is an event where damages occurs on the vessel or equipment of the vessel. Machinery damage is a fault or damage on the machinery of the vessel. Drift is the event that vessel can not move and course uncontrolled. Contact is an event that vessel has not taken a damage to navigate. Listing is the event before the capsizing that the vessel is instable and shift from its normal situation. Hazardous incident is the event that nearly resulting in or having the potential for being an accident. Other than these accident types, fire (vessel is on fire) and others accident types has been seen.

Maritime accident could be occurred from several reasons. The resources of the maritime accidents can be grouped as; geomorphologic resources such that water depth, aberrancy of the formal route of the vessel, current velocity; weather resources such that wind speed, rain, fog; vessel resources such that length, draft and width of the vessel, maneuvering features of the vessel, type of the vessel, cargo condition, fault of the vessel and human-related errors of the captain and crew working on the vessel.

In the study Kucukosmanoglu (2008) the resources of the maritime accidents considering human resources, weather resources and other resources have been studied and probability distributions of accidents for Turkey has been presented.

In order to manage accidents and protect the nature, search and rescue departments have been established in some countries. A search and rescue department has also established in Undersecretariat Maritime Affairs of Ministry of Transportation, Maritime Affairs and Communication of Turkish Republic.

The Undersecretariat Maritime Affairs (UMA) Search and Rescue Department is the management and administration center of the search and rescue service. Furthermore the maritime accidents have also been archived in the Search and Rescue Department.

Accident records of Undersecretariat Maritime Affairs Search and Rescue Department consist of date and time, region, name, Gross tonnage, type, flag, location of the accident, reason, type of the accident, casualties and comments. Furthermore accidents data type has been sub-grouped as capsizing, collision, hazardous incident, machinery damage, grounding, contact, listing fire and other, accident types.

The maritime accidents have been archived on eight regions as Antalya, Canakkale, Istanbul, Izmir, Mersin, Samsun, Trabzon and outside of these regions. According to data between the years 2001 and 2009, average 133 ship accidents have been recorded annually. Table 1.1 and Table 1.2 were prepared based on the data of UMA. The main percentage (~80%) of the accidents has been recorded on the Canakkale, Istanbul and Izmir regions (UMA, 2011). This situation can be explained by the traffic load on these regions, arise from the passage route between Mediterranean and the Black Sea. A cargo ship departure from Black Sea should follow the Bosphorus, Dardanelle and eventually Aegean Sea route to reach to the Mediterranean Sea.

Table 1.1 Number of Accidents According to Regions

Years	**Regions**							**Total Accidents**
	Antalya	**Canakkale**	**Istanbul**	**Izmir**	**Mersin**	**Samsun**	**Trabzon**	
2001	11	20	41	28	8	11	8	**127**
2002	7	13	48	16	4	5	0	**93**
2003	8	22	44	30	4	4	1	**113**
2004	11	24	66	29	8	3	1	**142**
2005	7	24	71	27	3	5	5	**142**
2006	4	16	71	17	5	4	0	**117**
2007	8	27	54	17	6	2	3	**117**
2008	13	55	96	19	7	7	1	**198**
2009	11	22	64	31	6	8	2	**144**
Average	**8.89**	**24.78**	**61.67**	**23.78**	**5.67**	**5.44**	**2.33**	**132.56**

Table 1.2 Percentage of Accidents According to Regions

Years	**Regions**							**Total Accidents**
	Antalya	**Canakkale**	**Istanbul**	**Izmir**	**Mersin**	**Samsun**	**Trabzon**	
2001	%8.7	%15.7	%32.3	%22.0	%6.3	%8.7	%6.3	**%100.0**
2002	%7.5	%14.0	%51.6	%17.2	%4.3	%5.4	%0.0	**%100.0**
2003	%7.1	%19.5	%38.9	%26.5	%3.5	%3.5	%0.9	**%100.0**
2004	%7.7	%16.9	%46.5	%20.4	%5.6	%2.1	%0.7	**%100.0**
2005	%4.9	%16.9	%50.0	%19.0	%2.1	%3.5	%3.5	**%100.0**
2006	%3.4	%13.7	%60.7	%14.5	%4.3	%3.4	%0.0	**%100.0**
2007	%6.8	%23.1	%46.2	%14.5	%5.1	%1.7	%2.6	**%100.0**
2008	%6.6	%27.8	%48.5	%9.6	%3.5	%3.5	%0.5	**%100.0**
2009	%7.6	%15.3	%44.4	%21.5	%4.2	%5.6	%1.4	**%100.0**
Average	**%6.7**	**%18.1**	**%46.6**	**%18.4**	**%4.3**	**%4.2**	**%1.8**	**%100.0**

Bosphorus connecting the Black Sea and the Marmara Sea has a highly dense transportation load and is the only connection of the Black Sea to the warm waters. All goods of Black Sea countries and hinterland linked to world ports via marine transport through the Bosphorus.

Approximately 50,000 vessels pass through the Bosphorus annually. The vessel load between 1995 and 2010 is shown in Table 1.3 which is prepared using UMA maritime accident data. Between 1995 and 2010, traffic load of the strait does not show a significant increase (UMA, 2011) which indicates the saturation level of vessel load for the Bosphorus.

Table 1.3 Number of Vessels Passing Through Bosphorus

Years	**Number of Vessels**	**Years**	**Number of Vessels**
1995	46954	2004	54564
1996	49952	2005	54794
1997	50942	2006	54880
1998	49304	2007	56606
1999	47906	2008	54396
2000	48079	2009	51422
2001	42637	2010	50871
2002	47283	2011	49798
2003	46939		
Average		**~50431**	

Traffic statistics of Bosphorus for 2006 indicates that a total gross tonnage of 475 million tons of ship carrying up to 143 million tons of dangerous cargo navigate in the strait in 2006 (UMA, 2011).

Such intense marine traffic brings about high risks for such a waterway. Approximately half percentage (~47%) of the maritime accidents has been occurred in Istanbul Region as shown in Table 1.2. Therefore this study is focused on Bosphorus maritime accidents probability.

According to the accident data of Undersecretariat Maritime Affairs Search and Rescue Department between 01.01.2001 and 13.05.2010, 169 ship accidents have occurred in Bosphorus region where annual average accident approximates 17. Table 1.4 is prepared based on UMA accident records.

Table 1.4 Number of Accidents through Bosphorus UMA, (2001-2011)

Years	**Number of Accidents**	**Years**	**Number of Accidents**
2001	14	2007	11
2002	22	2008	22
2003	15	2009	7
2004	20	2010	7
2005	28	2011	8
2006	23		
Total		**177**	
Average		**~16**	

The coordinates of accidents have not been included on the data of Undersecretariat of Maritime Affairs. However the site of the accidents has been located on the map using the specific location descriptions for each data. Prepared data is given in Appendix A-1. The mean, variance and standard deviation of the data to be used are calculated and presented in Appendix A-2. Homogenity test for the data used were carried out using Principal Component Analysis to determine the input parameters and the homogenity of the data. The data used was found homogenous (Appendix A-3).

As it is seen from Table 1.4, number of accidents between years 2007-2011 (except 2008) is decreased well below the average number of accidents given as 16. This could be due to

- the effect of control and navigation management efforts of one way passage which was adopted during the constructions of Marmaray Project since the year 2005,
- the protection of the small vessels in Bosphorus under severe weather conditions to control maritime accidents,
- providing more safely passage to the big vessels because of one way passage (Personal Contact, Nurullah Yücel, UMA).

There are few studies about forecast of marine accidents and consequences in the literature. These studies are presented in Chapter 2.

The aim of the study is to forecast the maritime accident probability on Bosphorus via modelling the maritime accidents while considering the available input parameters. A Marine Accident Risk Model (MAcRisk) was developed using Artificial Neural Network where the parameters selected by focusing on the Bosphorus such as geomorphology of the strait, climate condition (wind, rain, fog,...), hydrodynamic structure (currents) data of maritime traffic and ship characteristics. Model used to forecast the accident probabilities in Bosphorus by several scenarios.

CHAPTER 2

LITERATURE

The literature considering maritime safety and risk assessment can be grouped into three main headings. First group look at the risks of ship collision to bridges which provide transportation over water bodies, or examine the probable forces that can be applied to bridges by the colliding vessels. In this group of studies, the probability of maritime accidents and their consequences and preventing measures are determined (AASHTO, 2009). The second and more common group is a collection of fleet management studies considering accident risks of shipping sector. In this kind of studies, the load and design of ships are examined in order to prevent losses. These studies also cover the determination of international design criteria for classification societies. The third group regards the casualties and other accident consequences and examines the probable causes of accidents. In this kind of research, setting up of security and safety tools and determining management needs are the main objectives. Other than these three main groups, there are a couple of regional researches determining probability of accidents. These researches examine and cluster the types and causes of accidents for specific regions or harbours.

Coastal structures, especially those on navigable waters like bridges are susceptible to vessel collision. Bridges are important transportation links between separate coasts of human settlements. Assessment of probability of accident and failure is an essential field of research and there are many studies in the literature (Larsen, 1993; Kristiansen, 2005; Shao et al., 2007). Moreover, there are special standards such as AASHTO (American Association of State Highway and Transportation Officials) that combines those safety evaluation studies of bridge collision.

The second field of research is shipping sector oriented fleet management studies. Accidents are indicator of marine safety, especially the safety of vessels, crews, and cargoes. Maritime accidents have great economic importance. Therefore classification of accidents and prevent losses are important for the sector. A classification tree method is applied by Kokotos and Smirlis (2005), in order to predict the total ship loss cases. The resulting classification tree can be used for risk analysis studies. Causes of accidents include ships running aground; touching the sea bottom; striking wharves, drilling rigs, platforms, or other external substances; colliding with other ships; catching on fire; or suffering an explosion or other serious hull or machinery damage. Kokotos and Smirlis (2005) state that Exhaustive CHAID (Chi-Squared Automatic Interaction Detection) algorithm gives the best classification results for their accident dataset. The classification tree methodology is a data mining technique. Lloyd's accident reports (Lloyd's Casualty Week 1992–1999) were used in classification study. The factors chosen include the type, size, age, and condition of the vessel at the time of the accident; its previous record of accidents; the weather and sea conditions; and the place and location of the ship when the accident occurred. This database contains 4619 records of shipping accidents worldwide between 1992 and 1999. 352 of the records where total ship loss reported were used in the study. Factors related with ship are: age, gross tonnage, type, number of previous owners and accidents and registration society of the ship. The relationship was given by a graph showing the close relationship between ship and accident type. The collision; fire/explosion and grounding accident types are related with tankers, containers and general cargo/ bulk carriers ship types accordingly. Most of the accidents causing total ship loss occurred during typhoon, storm and poor visibility conditions. Area where accident occurred was ranked by Kokotos and Smirlis (2005) as 47.4% for ports, 33.5% for overseas and 19.1% for controlled seaways.

Artana et.al. (2005) developed a hardware and software that are essential for evaluation of marine hazard risk assessment. The system uses human resources and expert view during simulation. Fleet detection and management studies are also important for this group of research. Since 1990, remote sensing based traffic control techniques developed with advanced mathematical methods. Neural Networks has been widely used in image processing and pattern recognition. This promising Neural Networks technique was first started to use in land applications of traffic control systems (Bullock et.al., 1993).

The international safety-related marine regulations have been driven by the serious marine accidents. Lessons were first learnt from serious accidents; therefore safety at sea has been highly emphasized since the end of 1980s when ‘Herald of Free Enterprise’ and ‘Exxon Valdez’ accidents occurred (IMO, 2011). The third group of research generally covers those studies. Wang (2006) reviews the major maritime (transport and offshore engineering structures) accidents in the paper. The evolution of maritime safety regulations in U.K. in 90s are given in the paper in accordance with accidents chronologically. Wang states that decisions made during the design and operation of maritime activities is important for risk assessment.

Kristiansen (1983, 1995, 1997) is one of the researchers in the field where there are many marine safety and security studies of Kristiansen with colleagues. The occurrences of maritime accidents often involve a series of critical events and a multitude of causal factors. There are many scientific studies and perspectives that define those causes and do analysis (Kristiansen, 1995). Kristiansen & Olofsson (1997) established a correlation between accident rate and safety standard expressed in terms of deficiency rate and detention rate. According to Kristiansen (1983) probability of accident due to loss of navigational control is product of two probabilities, namely the probability of loss of navigational control and the conditional probability of being on a critical course.

$$P(C) = P(K) \times P(S/K) \tag{2.1}$$

where,

$P(C)$: Probability of accident due to loss of navigational control,

$P(K)$: Probability of loss of navigational control,

$P(S/K)$: Conditional probability of colliding, grounding of stranding if navigational control is lost,

Vanem and Skjong (2004) have studied the casualty risk of passenger ship. In this study the collision and grounding risks of passenger ships were estimated by the method of Olufsen for passenger ships over 4000 GRT in order to calculate the risk of flooding and loss of life. The frequency of collision was estimated, based on the data between 1990 and 2000 as $P_{collision} \approx 5.16 \times 10^{-3}$. The probability of grounding was obtained from the LMIS database as $P_{Grounding} \approx 1.03 \times 10^{-2}$. Vanem and Skjong (2004) also states that fire probabilities of Ro-Ro type ships and cruise liners passenger ships were found to be significantly different. They found fire accident probability of Ro-Ro type as 1.9×10^{-3} and cruise type as 1.2×10^{-2}.

Beside these three groups of researches, there are also regional works. Those analyses were carried on inland seas, straits or channels that are important for maritime transport. The risk of marine accidents in those regions may bring about more severe consequences.

One of the most important and intensely trafficked shipping areas in the world is Mississippi River. There are two studies carried out in this region. First one is a clustering study. Accident data have been used for marine safety and safety of maritime transport in this study. Hashemi et al (1995) applied NN analysis in order to classify the accidents beside two different methods namely multiple discriminant analysis and logistic regression on the lower Mississippi River data according to vessel type. Prediction of time, location, topographical constrains and traffic could enhance the region/port management and reduce the casualties. Port of New Orleans and the lower Mississippi River region are ranked first among the US ports and waterways in deaths and injuries and second in dollar loss resulting from vessel accidents (Hashemi et al., 1995).

In this study, data sets were chosen carefully in order to prevent poor or misleading findings which are the results of exclusion of important variables. It is also important for method comparison. For this lower Mississippi River region study, recognized experts in maritime safety of the region determined the most critical variables to use in this comparative analysis. Primary data source was vessel monitoring system data of the region and consisted of Accident type (collision, ramming & grounding), Participation (1/0; communication with control center), River stage (elevation[instead of river current data, m/s]), Traffic level (vessel/day), Utilization (%, daily vessel #/ total vessel#), Location (divided into four geographically different region), Weather (divided into seasons according to weather condition patterns), Time (6 hour periods). 279 cases divided into accident types and 10% testing sets, as 234 for training + 45 testing (Hashemi et al., 1995).

For every type of accident, equal quantity of cases included into analysis. If this bias had not been removed, the neural network would have probably been trained in favor of groundings, which were most numerous. The neural network (NN) correctly classified the accident type 80%, whereas discriminant analysis and logistic regression have the accuracy 53 % and 56 % respectively (Hashemi et al., 1995).

The second study carried out with Mississippi River accident data is a cluster methodology comparison. More than 900 vessel accident occurred in lower Mississippi River were examined and compared with two different techniques. The first method is statistical and the other is based on neural network. Blanc et al. (2001) states that for each accident types it is impossible to determine true incidence because of the nature of the data sets. Therefore records are clustered into four groups with quick cluster and self-organizing map algorithms, respectively. Correct classification percentages are 95.7 and 94.3 for statistical and neural network techniques, respectively. The results showed that in addition to VTS participation, weather, current and traffic conditions are also important for safe navigation (Blanc et al., 2001).

Another important marine transport region is Baltic Sea. Helsinki Commission (HELCOM) figure out marine transport and its effects in the region in their thematic assessment study. Accidents, especially oil tanker accidents are threatening this inland ecologically important area. The analysis and outcomes of the effort are owed to develop marine safety and management strategies for the Baltic Sea region. Report introduced that 8% of the marine accidents end up with environmental pollution. According to 2004 year data, main factors of accidents were human factor (39%) and technical failures (20%). Human factor percentage of the pollution occurring accidents is 50% (HELCOM, 2006).

A risk assessment model (MaRisk) using Monte Carlo method has been developed by Kucukosmanoglu in 2008 to define the probability and the risk of maritime accidents on Turkey. Accident archives of Undersecretariat Maritime Affairs Search and Rescue Department have been used. Accident probability distribution has been determined according to event type on all zones (determined by Undersecretariat Maritime Affairs Search and Rescue Department) of Turkey (Kucukosmanoglu, 2008).

The accident probability distributions of Istanbul region of the study according to event type have been presented by Monte Carlo method. The probability distribution of the accident types can be assumed as normal distribution. According to normal distribution assumption the average value and the standard deviation of the probability distributions can be seen in Table 2.1 (Kucukosmanoglu, 2008).

Table 2.1 Accident Probability Distribution in Istanbul Region (Kucukosmanoglu, 2008)

Event Type	Average of the Probability Distribution	Standard deviation of the Probability Distribution
Capsizing	1.51E-02	5.23E-03
Stroke	6.55E-03	6.51E-04
Collision	1.35E-02	7.91E-03
Others	2.46E-03	1.03E-03
Damages to Ship or Equipment	1.31E-04	9.74E-05
Machinery Damage	1.70E-04	1.78E-05
Grounding	3.76E-02	5.60E-03
Drift	5.23E-05	3.26E-05
Contact	5.97E-03	4.44E-03
Fire	4.30E-02	2.09E-02

The presented risk distribution of the study using Monte Carlo method includes the probable accident distributions and risks according to event type of an establishment, zone or Turkey (Kucukosmanoglu, 2008).

In addition to international research, there are studies carried out in Turkey especially for Istanbul region. Istanbul (Bosporus) Strait links Mediterranean (via Marmara Sea) and Black Sea. All Black Sea countries shipping lanes can only be connected with other seas via this natural waterway. Hence, the Bosporus is under intense ship traffic throughout the year. Severe marine accidents were occurred in this strategic waterway. For example, M/V Gotia, having 163 tons fuel oil in her fuel tanks, has collided to Emirgan Pier on 6 October 2002 (Otay and Yenigün, 2003). The environmental consequences of the accident were drastic (Otay, 2003).

In the study of Otay and Özkan (2005), vessel traffic in Bosphorus have been modeled by considering the random structure, and physical factors that control the maritime accident event. Collision, stroke and grounding probabilities of the vessel navigating in both directions in Bosphorus have been calculated by considering geographical structure of the Bosphorus, random distribution of currents, the passage statistics of the vessels, vessels size, and pilotage errors (Otay and Özkan, 2005).

Jale Nur Ece examined the accident parameters and their interactions in Istanbul (Bosphorus) Strait. ECE aimed to explain the relations between those parameters by using accident data occurred in 2005 in Bosporus Strait. All parameters of accidents were analyzed with statistical methods and relations were stated for each parameter in this study (Ece, 2005).

Çanakkale strait is another strategically important strait in the region. Ilgar compile Çanakkale traffic data and examines the accidents types in his study. Every year about to 50000 ships uses Dardanelles Strait where about 150 million tones of oil carried by tankers between Marmara Sea and Aegean Sea. 50 % of the ships are cargo type, whereas 18 % is oil tanker and 10 % is bulk carriers. In Çanakkale Strait, only about 30 % of the ships use pilot. More than 90 % of the ships are longer than 150 m. Grounding and crash are the two most important marine accident types (Ilgar, 2010).

The studies that examines the problem of predicting ship accidents and possible casualties and total ship loss use various datasets and data analysis techniques. The primary data sources are International Maritime Organization (IMO) and Lloyd’s databases with Automatic Identification System (AIS) that is an automatic tracking system used on ships and by Vessel Traffic Services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships and stations. The use of these data sources are challenging that they actually not intended to use for estimation of accident probabilities and maritime traffic risks and difficulties are stated in the literature (Dougherty, 1995; Hashemi et al., 1995; Blanc et al., 2001; IAEA, 2001). The main data source in Turkey is UMA (Undersecretariat Maritime Affairs). The detailed dataset description is provided in relevant chapters.

Wang (2006) states that decisions made during the design and operation of maritime activities is important for risk assessment. There can be significant uncertainties in information and factors that are used in the decision making processes. Another important proactive approach in maritime safety is to reduce the likelihood of malfunctions where human effect in accidents involved into the process. There are decision making studies where 'people friendly' approaches included into risk assessment, especially for offshore maritime activities.

For shipping activities, mainly International Maritime Organization (IMO) and classification societies are leading the maritime and ship safety context. A formal safety assessment framework has been first proposed by the U.K. Maritime and Coastguard Agency in 1993 after serious marine accidents. This kind of analysis requires highly technical and complex systematic methodology and should consist of identification of hazards, risk analysis, risk control options, cost benefit assessment and recommendations for decision-making steps. Human reliability analysis is also an important approach to incorporate human element into quantitative risk assessment studies where more detailed datasets are needed (Wang, 2006; IMO, 2011).

SKEMA is a project funded by European Commision under Seventh Framework Programme aiming to establish a sustainable knowledge platform in the maritime transport that has analyzed the models used in maritime accident risk analysis (SKEMA, 2009). Seven collision and grounding risk analysis models were reviewed by SKEMA. These models are used in Formal Safety Assessment process and some of them were designed to utilize the AIS-data. In this study, the reliability of AIS data was also discussed. Most of them can be applied to all sea areas with variable traffic. But one of the methods can be applicable to heavy traffic areas and one for the ports and harbors. GRACAT, BaSSy, MARCS, SHIPCOF, SAMSON, MARTRAM, DYMITRI are the methods investigated in the SKEMA project and brief explanations of them has been given below.

GRACAT (Grounding and Collision Analysis Toolbox) estimates the probability and damage besides consequences of the damage. GRACAT is based on the Fujii´s and Macduff˝s models (SKEMA, 2009) and the conditional causation probability has been calculated by using the Bayesian networks.

The BaSSy tool developed by DTU and Gatehouse is also based on the Fujii´s and Macduff˝s models. The BaSSy tool takes into account different characteristics of ships such as length, width, speed etc. and analyses historical AIS data, gives a route network and can use electronic charts.

MARCS (Marine Accident Risk Calculation System) is based upon an analysis of the historical causes of serious marine incidents and considers ship size, category, traffic and environmental conditions for calculating accident frequencies.

SHIPCOF software developed by Rambøll is aimed to be used in estimation of grounding and collision candidates. The software considers human error, critical encounter situation, propulsion or steering system failures. Model seemed to underestimate the accident frequency outside fairway.

SAMSON (Safety Assessment Models for Shipping and Offshore in the North Sea) performs various risk assessment calculations regarding maritime safety. This model considers other marine accident types such as foundering, explosion and machine failure besides collision of multiple vessel and grounding (stranding?). During accident frequency (casualty) determination model uses traffic, environmental, historical and physical information.

Posford Haskoning's Marine Traffic Risk Assessment Model (MARTRAM) is a modelling tool which is optimized for high volume marine navigation areas. The range of marine risk events covers capsizing, fire, sinking, foundering, stranding besides collision and grounding.

DYMITRI model is developed for vessel interactions. Fuzzy logic was used for simulating human responses. Model requires physical/environmental data, traffic network and density, historical data and causality rate for the study area and has an ArcGIS interface.

The methods used in the literature are mainly statistical methods, discriminant analysis, logistic regression, stochastic models, and neural networks (Le Blanc and Rucks, 1996; Otay and Özkan, 2005; Le Blanc et al., 2001; Psaraftis et al. 1998). In this study, in addition to statistical and neural network methods, ANFIS method has been used. In fact, few studies on this field of research determined probability of accidents beside classification efforts.

International or regional agencies mostly carried out marine safety and risk assessment studies. The International Atomic Energy Agency (IAEA) gleans all probability assessment studies into one report to assess the probability and expected consequences of fire and explosion events of the maritime radioactive materials transport for all over the World. The risk assessment study is carried out between 1995 and 1999. The purpose of data collection for maritime transport is not studying accident scenarios. Hence, the relevance of datasets is low and data need to be sorted and evaluated carefully. In this study, ship accidents, fire and collision probability are studied with consequences of the events. Accident statistics was taken from the Lloyd’s database and the Marine Accident Investigation Branch (MAIB) of the UK. All accidents types are included into the study whereas military ships, general cargo and fishing ships were excluded (IAEA, 2001).

The marine accident probabilities compiled by IAEA according to different database and societies are given in Table 2.2:

Table 2.2 Ship collisions and collision frequency for 21 ocean regions (IAEA, 2001)

Region	**Collisions 1979–1993**	**Collision frequency (per nautical mile sailed)**
Irish Sea	7	1.70E-07
English Channel	33	1.00E-07
North Sea	134	1.90E-07
Baltic Sea	76	1.80E-07
Western Mediterranean	29	1.50E-07
Tyrrhenian Sea	8	1.10E-07
Adriatic Sea	11	8.10E-08
Aegean Sea, Bosporus	59	5.40E-07
Eastern Mediterranean	21	1.30E-07
Suez Canal, Red Sea, Gulf of Aden	17	3.70E-08
Persian Gulf, Gulf of Oman	17	1.50E-07
Approaches to Singapore	41	7.40E-08
South China Sea, Taiwan Strait	42	1.40E-07
East China Sea	34	8.00E-08
Yellow Sea	13	9.60E-08
Sea of Japan, Korean Strait	35	3.30E-07
Inland Sea of Japan	193	9.70E-07
East Coast of Japan	120	1.90E-06
Western Gulf of Mexico	24	1.20E-07
Coastal waters	252	1.90E-07
Open ocean	70	6.80E-09

The studies in the literature are focused to the site specific studies and can be grouped into three main headings, as:

- the risks of ship collision to bridges,
- fleet management studies and casualties,
- other accident consequences and probable causes of accidents.

The studies can not define a specific method focusing on forecasting the maritime accident probabilities. As it is stated "The use of the existing data sources are challenging that they actually are not intended to use for estimation of accident probabilities and maritime traffic risks and difficulties" by Dougherty (1995), Hashemi et al. (1995), Blanc et al. (2001), IAEA (2001), SKEMA (2009).

CHAPTER 3

MARITIME ACCIDENT FORECAST METHODS

In order to develop a model to forecast maritime accident probability in Bosphorus, several approaches were used to estimate the maritime accident probabilities. Firstly, "Guide Specifications and Commentary Vessel Collision Design of Highway Bridges" method of American Association of State Highway and Transportation Officials (AASHTO) has been taken into consideration in the studies. Multiple Linear Regression, Adaptive Neuro Fuzzy Inference System (ANFIS) are used as mathematical tools used in this study will be presented briefly. Since Artificial Neural Network (ANN) which was found to be appropriate in the development of the "Marine Accident Risk" (MAcRisk) model will be discussed in depth.

3.1 Method by American Association of State Highway and Transportation Officials (AASHTO)

Since the present study will be based on probabilistic approach, it is found appropriate to start with ASSHTO methodology which is based on probabilistic estimates for accidents occurring due to collision of vessels to the bridge structures.

In navigable waterways, maritime accident probability increase, because of the maritime transport intensity. Therefore, bridge structures constructed on such waterways should be designed to prevent collapse of the structure. To satisfy the requirements a formula considering the size and type of the vessel, available water depth, vessel speed and structure response has been presented with 3 different analysis methods which can be used to assess the probabilities of different design conditions (AASHTO, 2009).

Method I is a semi-deterministic procedure, Method II is a risk analysis procedure and Method III is a cost-effectiveness analysis procedure. The guide requires the use of Method II unless special circumstances exist.

Method I presents a coarse vessel size for the impact on the bridge element and defines two criteria, as critical/essential bridge and typical bridge.

Method III is similar cost/benefit analysis, where the cost of protection is compared against the benefits of risk reduction. Method III can be used to determine the design vessel, resistance of the bridge member or the protection of the bridge.

The probability of a vessel aberrancy and annual frequency of bridge element collapse can be estimated by Method II.

3.1.1 Method II

In the present study accidents due to vessel aberrancy and several reasons will be a basic consideration in formulation of the model. Therefore Method II is presented focusing on probability of vessel aberrancy.

The probability of aberrancy (*PA*) is a value, because of the deviation of a vessel from its route. The reason can be a human error, adverse weather conditions or mechanical failure. The most accurate method for determining *PA* is based on historical accident data and the number of vessels transiting the waterway (AASHTO, 2009). Method II uses the historical accident data by assuming that there is a relation between the probability of vessel aberrancy and historical accident data.

PA can be estimated for the waterway location by the Equation (3.1):

$$PA = BR\,(R_B)\,(R_C)\,(R_{XC})\,(R_D) \tag{3.1}$$

where;

PA: probability of aberrancy,

BR: aberrancy base rate,

R_B: correction factor for turning angle,

R_C: correction factor for current acting parallel to vessel path,

R_{XC}: correction factor for current acting perpendicular to vessel path,

R_D: correction factor for vessel traffic density.

Aberrancy base rate (BR) can be estimated as 0.6×10^{-4} for ships and 1.2×10^{-4} for barges based on several historical data from United States waterways:

$BR = 0.6 \times 10^{-4}$	For Ships
$BR = 1.2 \times 10^{-4}$	For Barges

The correction factor for turning angle (R_B) can be estimated for 3 regions:

i. Straight Region: For a straight region:

$$R_B = 1.0 \tag{3.2}$$

ii. Transition Region: For a transition region:

$$R_B = \left(1 + \frac{\theta}{90^o}\right) \tag{3.3}$$

iii. Turn/Bend Region: For a turn or bend region:

$$R_B = \left(1 + \frac{\theta}{45^o}\right) \tag{3.4}$$

The correction factor for current acting parallel to vessel path (R_C) can be computed by:

$$R_C = \left(1 + \frac{V_C}{10}\right) \tag{3.5}$$

where;

V_C: current component parallel to vessel path (knots)

The correction factor for current acting perpendicular to vessel path (R_{XC}) can be calculated as:

$$R_{XC} = \left(1 + V_{XC}\right) \tag{3.6}$$

where;

V_{XC}: current component perpendicular to vessel path (knots)

The correction factor for vessel traffic density (R_D) has been defined by low, medium and high density traffic:

- Low Density, $R_D = 1.0$, where vessels rarely meet, pass or overtake each other on the bridge location.
- Medium Density, $R_D = 1.3$, where vessels occasionally meet, pass or overtake each other on the bridge location.

- High Density, R_D = 1.6, where vessels routinely meet, pass or overtake each other on the bridge location.

3.2 Mathematical Tools

Mathematical tools giving the relationship between variables to develop the model will be explained in this section. Multiple Linear Regression, Adaptive Neuro Fuzzy Inference System and Artificial Neural Network have been used to define the relationship of the variables of the model.

3.2.1 Multiple Linear Regression

Multiple Linear Regression analysis is like simple linear regression. However the Multiple Linear Regression has two or more variable for the dependent value.

Multiple Linear Regression is a methodology based on the relationship between variables. The dependent variable M_i can be predicted based on the value of independent variables L_{ij}. For general equation of Multiple Linear Regression model is given below:

$$M_i = \beta_0 + \beta_1 L_{i1} + \beta_2 L_{i2} + \ldots + \beta_j L_{ij} + \varepsilon_i \tag{3.7}$$

where,

β_0 is the coefficient of regression model,

β_1 is the coefficient of ith regression slope acting on L_{i1},

β_2 is the coefficient of ith regression slope acting on L_{i2},

β_j is the coefficient of ith regression slope acting on L_{ij},

ε_i is the error value of ith regression slope,

L_{i1} is the first independent variable of ith regression slope,

L_{i2} is the second independent variable of ith regression slope,

L_{ij} is the jth independent variable of ith regression slope,

M_i is the first dependent variable of ith regression slope.

The matrix form of the variables can be shown in Equation (3.8):

$$M = L\beta + \varepsilon \tag{3.8}$$

Where, M is a vector of the dependent variable, β is a vector of regression coefficients, ε is a vector of error terms and L is matrix of the independent variables:

$$M = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ \vdots \\ M_i \end{bmatrix}, \quad L = \begin{bmatrix} 1 & L_{11} & L_{12} & \cdots & L_{1j} \\ 1 & L_{21} & L_{22} & \cdots & L_{2j} \\ 1 & L_{31} & L_{32} & \cdots & L_{3j} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & L_{i1} & L_{i2} & \cdots & L_{ij} \end{bmatrix} \tag{3.9}$$

$$\beta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \vdots \\ \beta_i \end{bmatrix}, \quad \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \vdots \\ \varepsilon_i \end{bmatrix} \tag{3.10}$$

The least squares calculation procedure will be used to determine the vector of regression coefficients. The general least squares equation is given below:

$$L'L\beta = L'M \tag{3.11}$$

Where, L' is the transpose of L. To solve the regression coefficient after rearrangement of the equation (3.11), equation (3.12) can be obtained:

$$\beta = (L'L)^{-1} L'M \tag{3.12}$$

3.2.2 Artificial Neural Network (ANN)

Artificial Neural Network (ANN), commonly called as Neural Networks (NN), imitates the working mechanism of biological neural networks. The integral part of the biological neural network system is neuron. There are just about 10^{11} neurons that linked each other with 1000 to 10000 connections in the human brain cortex. The axon, dendrites and cell body are constituent parts of the neurons (Figure 3.1). Signals coming from a neuron to the cell body through dendrites are transmitted by the axon. The cell body stability is changed by the coming signal and these stimulations cause chemical reactions in the cell body. Transmission of signal from neuron to neuron takes place in the neurons synapse. The synaptic gap is located between axon and dendrites. Learning process is a consequence of the change or the renewal of the synaptic connections.

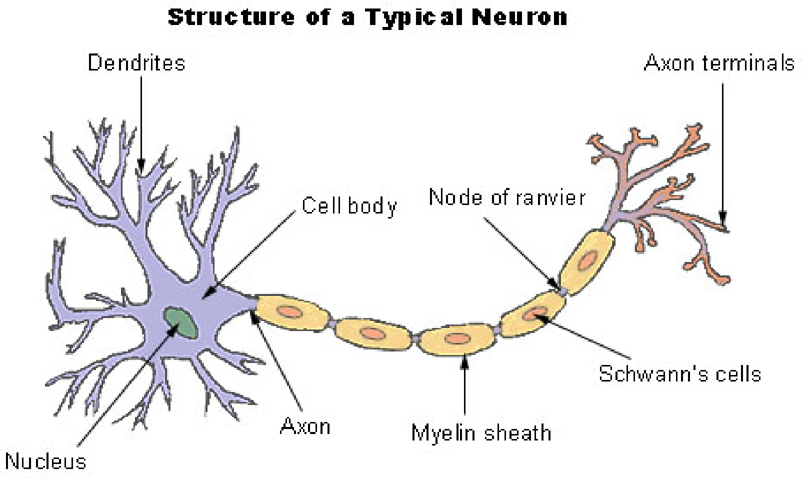


Figure 3.1 A typical neuron structure (E-Library, Medicine, 2010)

ANN are based on the simplified mathematical representation of biological neurons:

- Axon and dendrites express connections (signals from/to cells)
- Synapse expresses weight factor
- Chemical reactions express limit values

Signals coming to the cell depend on the weight factor. These coming signals are transformed to the output signals by means of a nonlinear function considering the body cell balance and limit values. The change of the weight factor through the model simulates the learning process of the biological neuron (Figure 3.2).

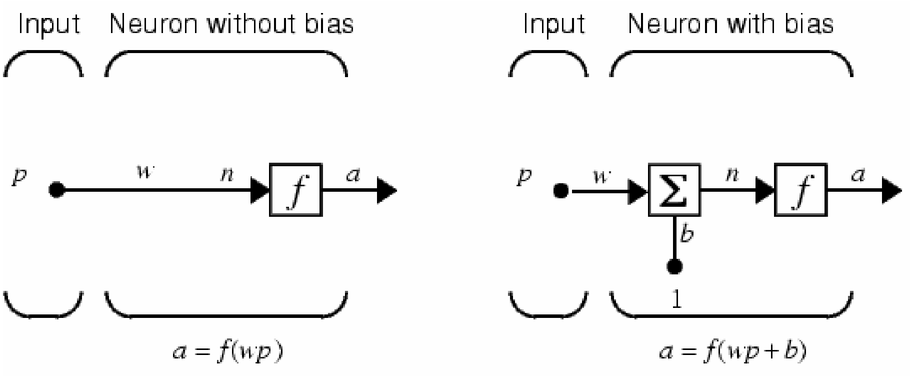


Figure 3.2 Structure of an artificial neuron (Hagan et al., 1996)

The earlier studies on NN began in 1940s with the work of McCulloch and Pitts (1943), who proved that ANN could compute any arithmetic or logical function. They also indicate that any arbitrary logical function could be configured by a NN. Rosenblatt presented the first practical application of ANN in the late 1950s and published a book called “Principles of Neurodynamics” in 1962 (McCulloch and Pitts, 1943). He presented a learning algorithm by which the weights can be changed, and introduced the ability to perform pattern recognition in a perceptron network.

Widrow and Hoff (1960) demonstrated a new learning algorithm in 1960. They used it to train adaptive linear Neural Networks, which were similar to the Rosenblatt’s perceptron in structure and capability. Unfortunately, there had been some same inherent limitations in both Rosenblatt’s and Widrow’s networks. These single-layer systems were not efficient and have limitations as compared to the multilayer systems.

In the early 1980s, Neural Networks became popular again when Parker (1985) and McClelland & Rumelhart (1988) developed the new method that has the ability to train a multilayer neural network, known as the backpropagation algorithm.

Backpropagation, also called back error propagation, is an effective supervised learning method for training multilayer perceptrons (Rumelhart, Hinton & Williams, 1986). The process consists of two steps: a forward propagating step and a backward propagating step.

The input data of training is used in the input layer through the forward step. The data propagates on through the hidden layers, until it reaches the output layer, where it displays the output pattern. In the backward step, the error term is calculated. Then it propagates back to change the assigned weight factors of the inputs. The magnitude of the error value indicates the adjustment size, and the sign of the error value determines the direction of the change.

The achievements in application of NN provides solutions in a wide range of problems such as image processing, pattern recognition, speech recognition, signal processing, industrial control, aerospace, manufacturing, business, finance, medicine etc. The NN are mostly preferred because of their applicability to complex nonlinear and multivariable systems.

3.2.2.1 Transfer Function

In Figure 3.2, the sum of the weighted input wp and the bias is the input argument of the transfer function; where, w is the weight coefficient and p is the input variable. The bias is able to be added to the product wp or not, as shown in Figure 3.2. The transfer function, typically selected a step function or a sigmoid function, produces the output *a*.

There are many transfer functions. Three of the most commonly used functions are hard-limit, linear and log-sigmoid transfer functions. The hard-limit function (Figure 3.3) can be used to make classification decisions. It limits the output by 0 or 1 according to the input value.

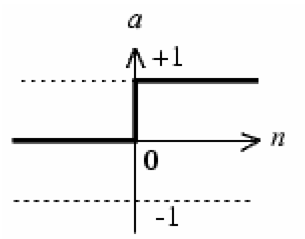


Figure 3.3 Hard-limit transfer function (Hagan et al., 1996)

The linear transfer function can be used to solve linearly separable problems. The illustration of the function can be seen in Figure 3.4.

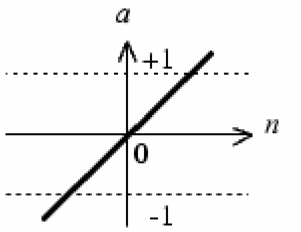


Figure 3.4 Linear transfer function (Hagan et al., 1996)

The sigmoid transfer function (Figure 3.5) gives the output into the range 0 to 1 with the input between minus infinity and plus infinity. It is used commonly in backpropagation networks.

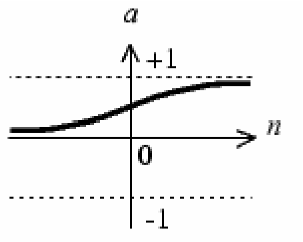


Figure 3.5 Log-sigmoid transfer function (Hagan et al., 1996)

3.2.2.2 Artificial Neuron

A more detailed artificial neuron can be seen in Figure 3.6. Where *R* is the number of elements in input vector, *w* is the weight coefficient and *b* is the bias. Input of the transfer function (*n*) is simply the sum of *wp* and *b*:

$$n = w_{1,1}p_1 + w_{1,2}p_2 + ... + w_{1,R}p_R + b \tag{3.13}$$

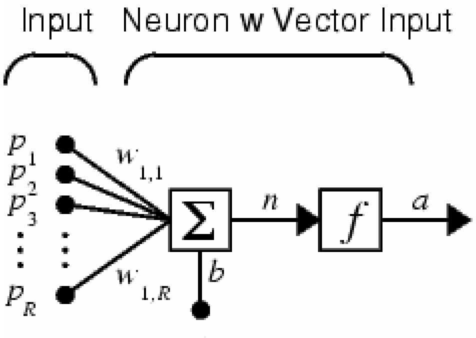


Figure 3.6 Artificial neuron (Hagan et al., 1996)

The Figure 3.6 contains a lot of detail for complex ANN models. Therefore an abbreviated notation can be used to simplify the neuron as shown in Figure 3.7.

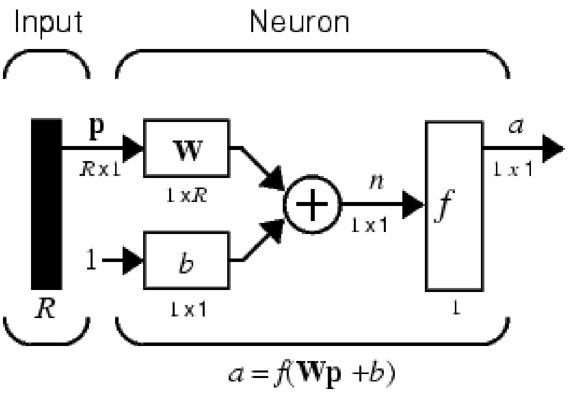


Figure 3.7 Abbreviated artificial neuron (Hagan et al., 1996)

3.2.2.3 Two or More Artificial Neurons in a Layer

It is possible using multiple neurons in a layer. A one layer network with *R* input elements and *S* neurons can be seen in Figure 3.8. In this network, each element of the input vector *p* is connected to each neuron input through the weight matrix *w*.

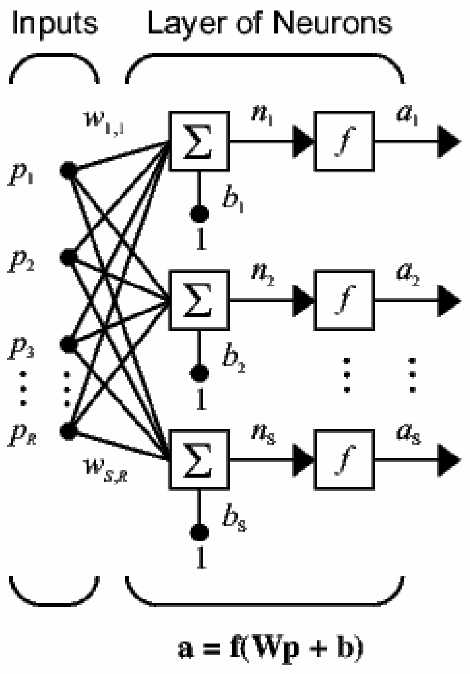


Figure 3.8 More neurons in a layer (Hagan et al., 1996)

Each neuron gives an output *n* for the transfer function and according to transfer function type the output *a* is produced. The abbreviated presentation can be seen in Figure 3.9.

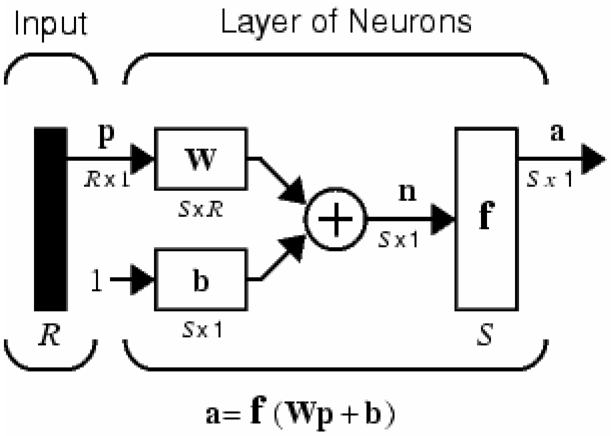


Figure 3.9 Abbreviated neurons in a layer (Hagan et al., 1996)

3.2.2.4 Neural Network with Multiple Layers and Neurons

An artificial neural network can have several layers and neurons. A network with 3 layers, *s* neurons *R* inputs and *s* outputs can be seen in Figure 3.10. It is not necessary using same number of neurons as outputs.

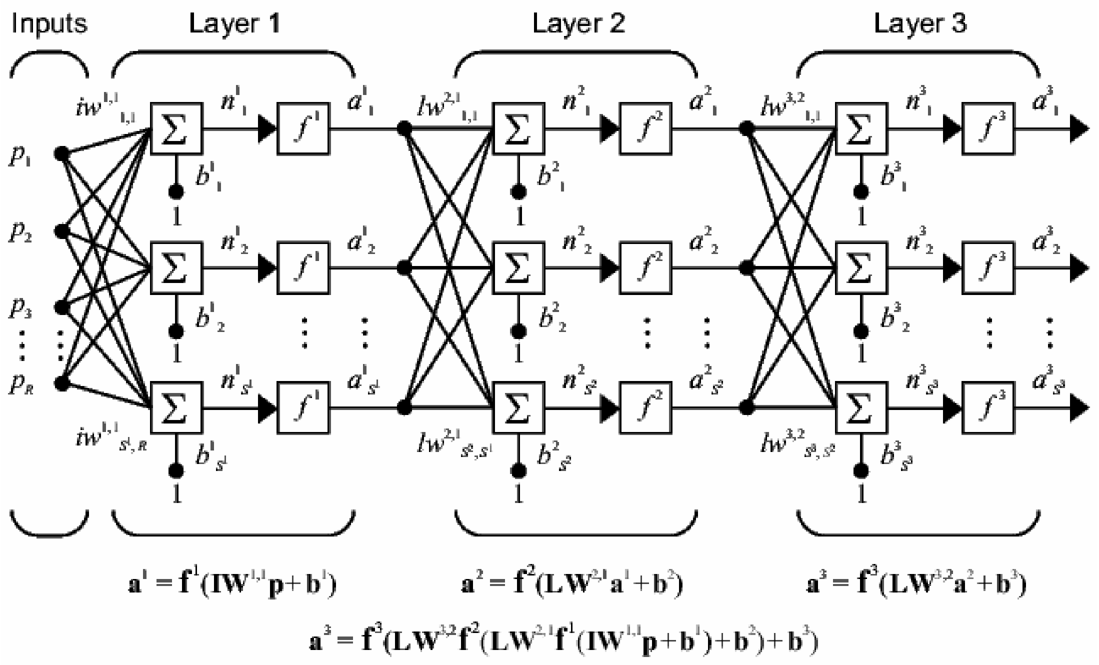


Figure 3.10 Multiple Layers and Neurons (Hagan et al., 1996)

A layer producing the output is called output layer and all other layers are called as hidden layers. In Figure 3.10, the output of the first layer is the input of the second layer and the output of the second layer is the input of the output layer (layer 3). The same three layer network can also be seen by abbreviated notation in Figure 3.11.

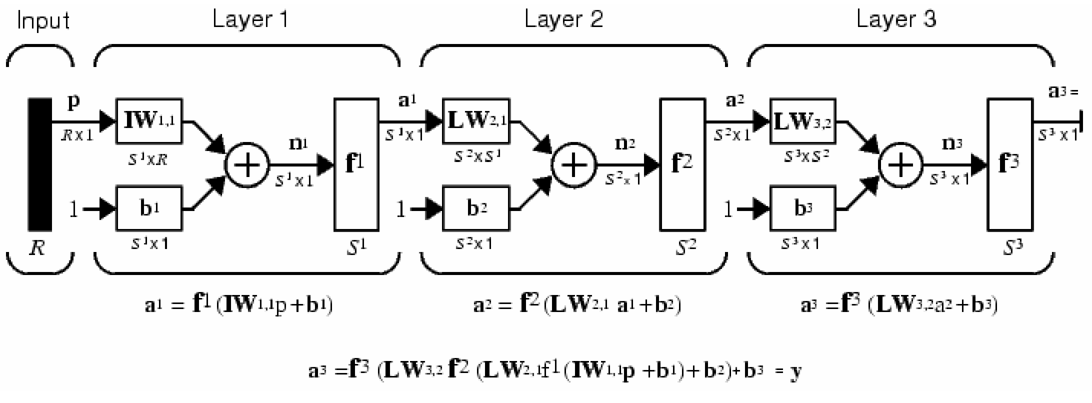


Figure 3.11 Multiple Layers and Neurons by abbreviated notation (Hagan et al., 1996)

3.2.2.5 Training

Determination of the weight matrix (*w*) is a trial and error process. Size of the weight matrix depend to the Artificial Neural Network model. Input and output values train the weight matrix through iteration process. Differences between target and forecast have been used to refine the weight matrix.

The Levenberg-Marquardt algorithm has been used on the network for training. The Levenberg-Marquardt algorithm can be presented as follows:

$$w^{new} = w^{old} + \Delta w \tag{3.14}$$

$$\Delta w = \left[J^T J + \mu I\right]^{-1} J^T e \tag{3.15}$$

where;

w:	is weight matrix,
Δw:	the increment of weight matrix,
J:	is the Jacobian matrix that contains first derivatives of the network errors with respect to the weights and biases.
μ:	is the learning rate,
I:	unit matrix,
e:	is a vector of network errors.

The neural network fitting tool of Neural Network Toolbox of Matlab© program has been used to develop the model. The neural network fitting tool can solve a data fitting problem with a two-layer feed-forward backpropagation network trained with Levenberg-Marquardt algorithm.

3.2.3 Adaptive Neuro Fuzzy Inference System (ANFIS)

ANFIS is an efficient and transparent Neuro-Fuzzy paradigm first proposed by Jang (1992, 1993, and 1996). It is a combination of neural network analysis and fuzzy logic method. Generally fuzzy modeling requires defuzzification operation. However not using defuzzification operation Sugeno type fuzzy model is widely used in sample-based fuzzy modeling. Sugeno type fuzzy model is used in the ANFIS mathematical tool.

Assume that the fuzzy inference system under consideration has two inputs x_1 and x_2 and one output y. For a first-order Sugeno model, a common rule set with two fuzzy if-then rules is the following:

Rule 1: If x_1 is B_1 and x_2 is C_1, then $f_1 = a_1 x_1+b_1 x_2 + c_1$.
Rule 2: If x_1 is B_2 and x_2 is C_2, then $f_2 = a_2 x_1+b_2 x_2 + c_2$.

where B_1, C_1, B_2, C_2 are fuzzy sets, a_i, b_i and c_i ($i = 1, 2$) are the coefficients of the first-order polynomial linear functions. ANFIS mathematical tool actually solve weight factors (a_1, a_2, b_1, b_2,…etc.) considering rule bases by using neural network structure within the process by the help of optimization method such as backpropagation.

It is possible to assign different weights to each rule based on the structure of the system. Figure 3.12 shows the structure of a two-input first-order Sugeno fuzzy model with two rules, where w_1 and w_2 are weight factors.

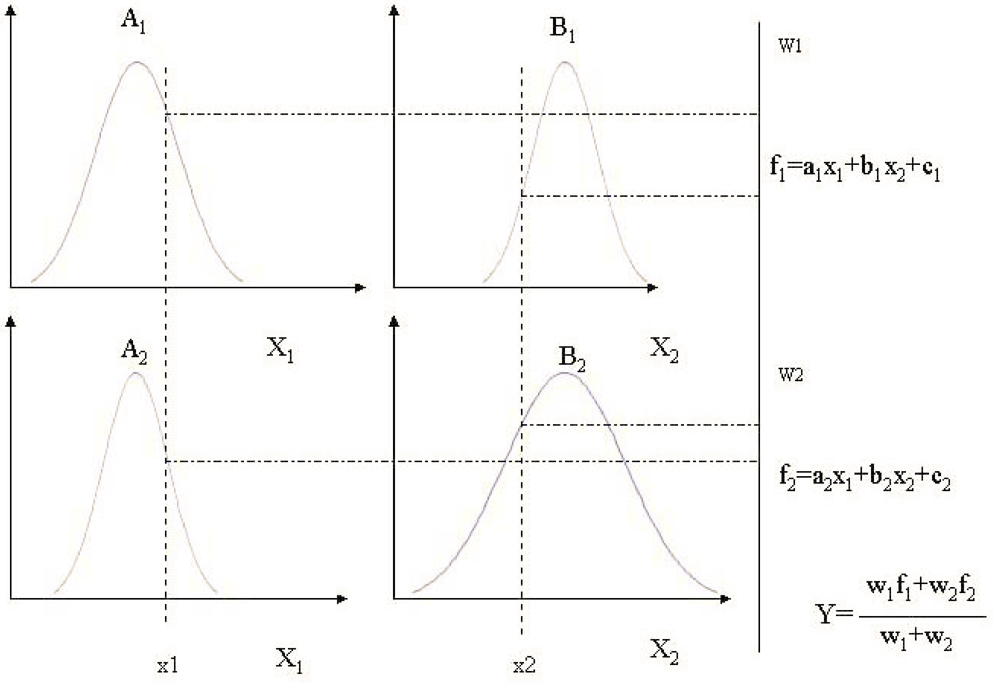


Figure 3.12 A two input first order Sugeno fuzzy model (Deng, 2002)

ANFIS integrates the primary elements and functions of a fuzzy logic interface with neural network (NN) structure. The hybrid system is a multi-layered fuzzy rule-based NN (Li, Ang & Gray, 1999). Input and outputs are defined by membership functions in this hybrid structure. Thus neural nets could have more crisp and meaningful inputs which improve the overall output quality when compared with the standard NN.

The general ANFIS structure has a five-layer fuzzy rule-based neural network as shown in Figure 3.13. Network is consisting of nodes in each layer. Input variables are placed in layer 1. Layer 2 represent the outputs of the membership grade of the corresponding inputs that is membership functions itself. The nodes in layer 3 performs rule bases. Layer 4 is the output membership functions layer. Finally, layer 5 performs the overall output.

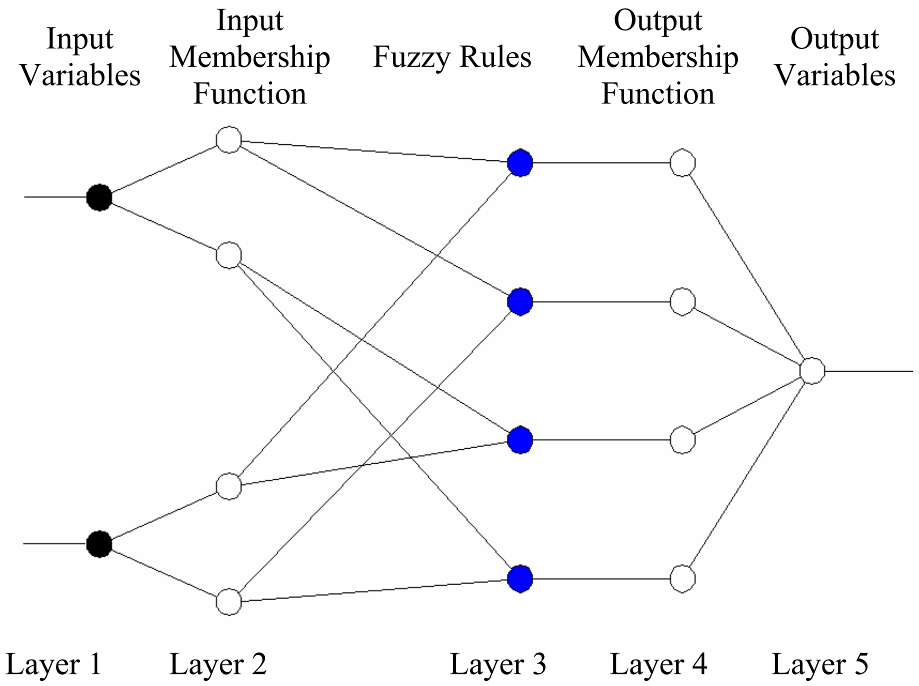
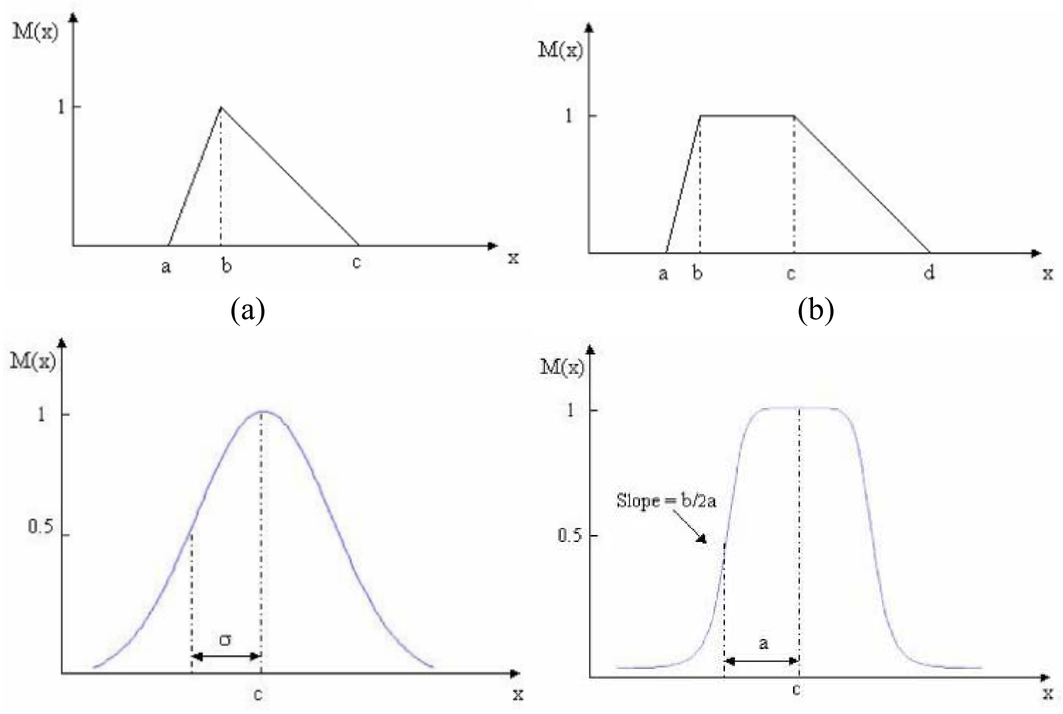


Figure 3.13 General neuro fuzzy architecture

A fuzzy set can be defined mathematically by membership function if it is continuous. Although there exists many types of membership functions, triangular, trapezoidal, Gaussian, and bell curves shaped MFs are the most well known membership functions where triangular and trapezoidal membership functions have been widely used due to their simplicity and computational efficiency (Yen & Langari, 1999). The common MFs explained by Deng (2002) are given in Figure 3.14 briefly.



(a) (b)

(c) (d)

Figure 3.14 Triangular (a), Trapezoidal (b), Gaussian (c) and Generalized bell (d) membership functions (Deng, 2002)

If-then rules are the rule base of the system. The rule base captures and represents the knowledge. Generally, this scheme is achieved by using linguistic variables (Zadeh, 1973; Zadeh, 1975).

A fuzzy if-then rule takes a form as:

IF x is A_n THEN y is B_n (x)

where; A_n and B_n are linguistic values defined by fuzzy sets on universes X and Y, respectively.

There are basically three conceptual components of a fuzzy inference system:

- a rule base, which contains a selection of fuzzy rules,
- a database, which defines the membership functions used in the fuzzy rules,

- a reasoning mechanism, which performs the inference procedure upon the rules and given facts to derive a reasonable output or conclusion.

Most fuzzy inference systems can be classified into three types, as: Mamdani fuzzy model, Sugeno fuzzy model and Tsukamoto fuzzy model depending on the types of fuzzy reasoning and fuzzy if-then rules employed.

Mamdani fuzzy model was first developed by Mamdani & Assillian, (1975) to control a steam engine and boiler combination by a set of linguistic control rules. Sugeno fuzzy model (or TSK model) was proposed to develop a systemic approach to generate fuzzy rules from a given input-output data set (Takagi & Sugeno, 1985; Sugeno & Kang, 1988). Tsukamoto fuzzy model (Tsukamoto, 1979) was proposed as another approach to the fuzzy reasoning method. The fuzzy rules and the forms of this model are described in corresponding literature.

ANFIS tool of Fuzzy Logic Toolbox of Matlab© program has been used to develop the model.

CHAPTER 4

DEVELOPMENT OF THE "MAcRisk" MODEL

Maritime accident could occur from several reasons. The reasons of the maritime accidents can be grouped as; geomorphologic factors such that water depth, aberrancy of the formal route of the vessel, current velocity, weather conditions such that wind speed, rain, fog, vessel specifications such that length, draft and width of the vessel, maneuvering features of the vessel, type of the vessel, cargo condition, fault of the vessel and human-related errors such that captain and crew behaviour on the vessel.

The maritime accident data recorded on the UMA archive includes the types of the accidents such that collision, stroke, capsizing, grounding, damages to ship or equipment, machinery damage, drift, contact, listing, hazardous incident, fire and others.

In this study causes of the maritime accidents geomorphologic factors such that current velocity, average width and average turn, weather conditions (monthly total precipitation, daily maximum wind, daily average wind, daily total precipitation, hourly wind speed, monthly foggy days and monthly average wind speed), vessel related factors (gross tonnage (GRT) of the vessel and length overall (LOA) of the vessel) have been processed to forecast the accident probability. However all the prepared data have not been used in the forecasting procedure.

In the forecasting procedure of maritime accident probability on Bosphorus, the input parameters that will be used in forecasting have been determined by correlation matrix and ANFIS tool. The selection of the input parameters has also been done considering the easiness of obtaining the data.

After the input parameters have been determined, Method II the "Guide Specifications and Commentary Vessel Collision Design of Highway Bridges" of AASHTO has been used and Formula 1 (Formula based on Method II of AASHTO), Formula 2 (Multiple Linear Regression), Model 1 (Adaptive Neuro Fuzzy Inference System (ANFIS)) and Model 2 (Artificial Neural Network (ANN)) have been developed to forecast the accident probability.

4.1 Bosphorus Strait

Bosphorus is an important waterway connecting two regional seas, Marmara and Black Sea. Anatolian and European continents lie on both sides of the Bosphorus. (Figure 4.1).

The length of the Bosphorus is approximately 32 km. But, when considering coast line, the length extends to 55 km (from Rumeli Lighthouse to Ahırkapi Lighthouse) on the West side and 40 km (from Anadolu Lighthouse to Lighthouse of İnic Point) on the East side. The maximum width of the Bosphorus is 3600 m between Anadolu and Rumeli Lighthouse. The narrowest place of the Bosphorus strait is between Anadolu and Rumeli fort, with 760 m. The deepest point is 120 m, and in between Bebek and Kandilli districts (Ece et al., 2011).

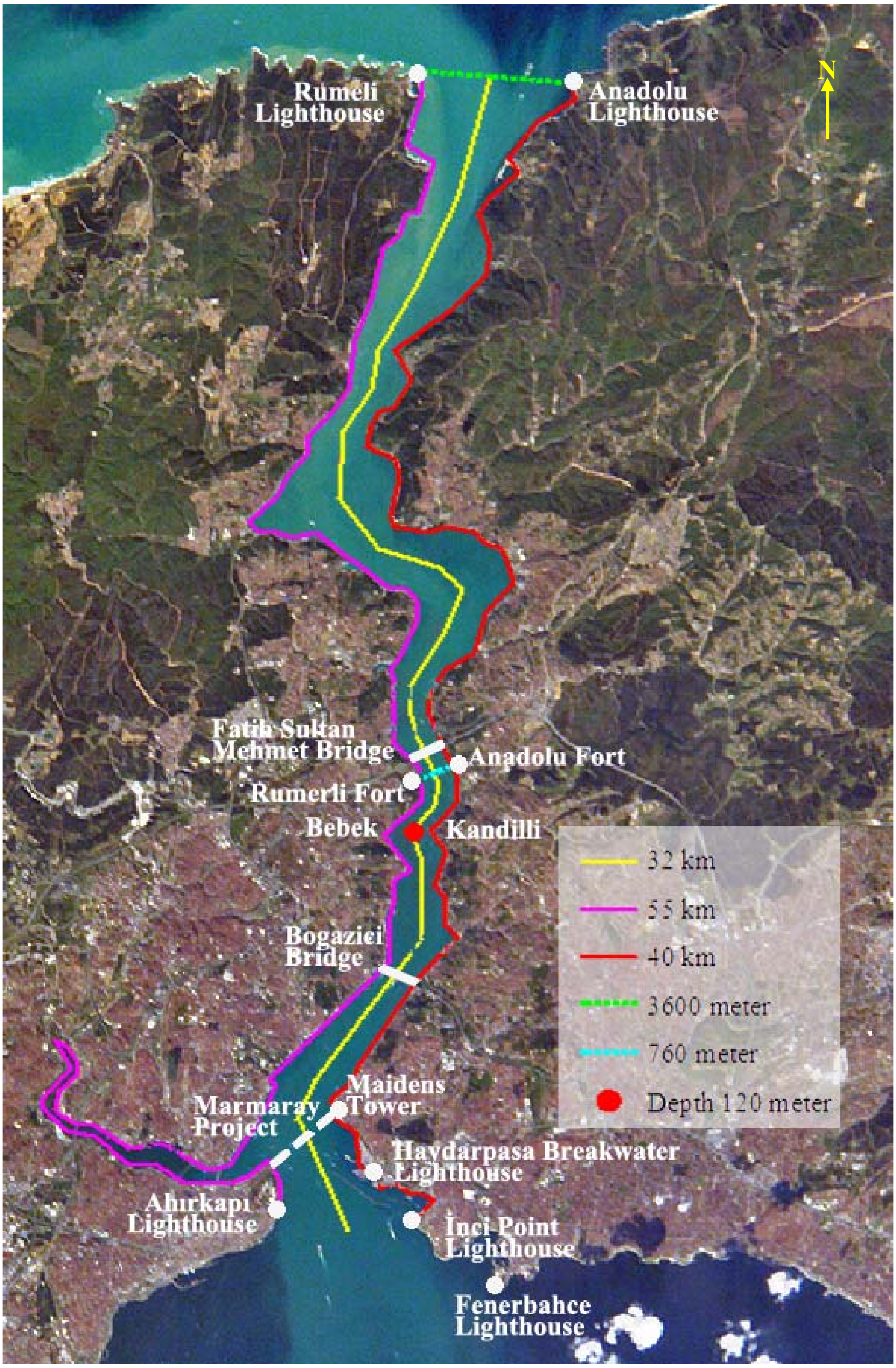


Figure 4.1 Physical Properties of Bosphorus Strait

Bogazici Bridge opened in year 1973 and Fatih Sultan Mehmet Bridge opened in year 1986 connects the two continents. Marmaray project connects two sides via underwater tunnel will be completed in 2013 (Ece et al., 2011).

Almost every place of Istanbul has historical and touristic features. Counting historical beauties of the Bosphorus is not literally possible. The most important places amoung numerous will be introduced briefly in Figure 4.2.

Figure 4.2 Location of Palaces and Forts along the Bosphorus

There is a two layered current patern in Boshorus. The current from Black Sea to Marmara Sea flows on surface and mediterranean water flows from Marmara Sea to Black Sea at the bottom of the Bosphorus. Sometimes, the reverse currents can also be seen on the surface.

4.2 Model Parameters

The model parameters have been compiled to forecast maritime accident probability on Bosphorus. Accident archives of Undersecretariat Maritime Affairs Search and Rescue Department, weather conditions data of Turkish State Meteorological Service and bathymetry and current maps of Office of Navigation, Hydrography and Oceanography have been used to prepare the model input data and to forecast the accident probability. Prepared data has been presented in Appendix A in detail.

4.2.1 Maritime Accident Data

Maritime accident data has been taken from the accident archives of Undersecretariat Maritime Affairs Search and Rescue Department. The accident archives between 01.01.2001 and 13.05.2010 has been compiled by considering the accident location (Figure 4.3).

Admiralty Maps of Office of Navigation, Hydrography and Oceanography (ONHO) 2921A and 2921B have been registered and presented in Figure 4.3. The left boundary, midline and right boundary of the passage have been digitized. Accident locations have been plotted on the map (Figure 4.3). Based on the distribution and accumulation of accidents, 17 zones were defined along the Bosphorus as shown in Figure 4.3.

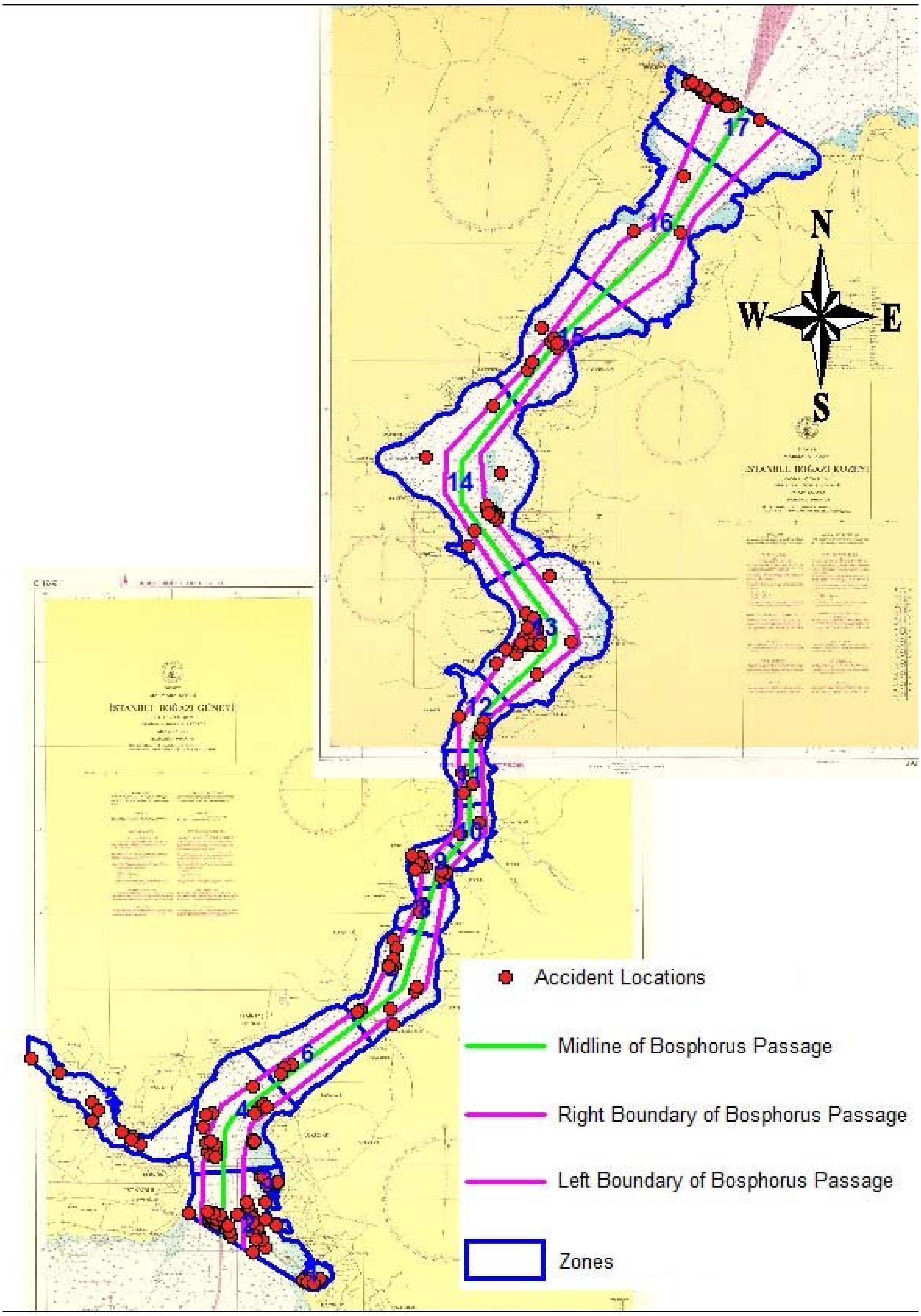


Figure 4.3 Accident Locations

The accident data can be gathered together by its location and judgment because very few data include coordinates of the maritime accidents. 210 maritime accident records have been archived between 01.01.2001 and 13.05.2010 according to data of Undersecretariat Maritime Affairs (UMA) Search and Rescue Department and presented in Table 4.1.

Table 4.1 Compiled Accident Data of UMA Search and Rescue Department (01.01.2001-13.05.2010)

Zones	**Capsizing**	**Collision**	**Stroke**	**Hazardous Incident**	**Others**	**Damages to Ship Or Equipment**	**Machinery Damage**	**Stranding/ Grounding**	**Drift**	**Contact**	**listing**	**Fire**	**Total**
1*		2	2					1					**5**
2	3	14	1	2	2			5		3		1	**31**
3*		1						3				1	**5**
4	1	5	2	6	3							1	**18**
5*	2	2	1									4	**9**
6		2			1								**3**
7		3		5	1		2	2				2	**15**
8		1										1	**2**
9	1	1	4	2			1	2	1	1			**13**
10		1						1					**2**
11			2						1				**3**
12		1	1	2					1				**5**
13	3	1	5	2		1	1	9	1	1		1	**25**
14				3	1			14					**18**
15				2	2		1	2	1				**8**
16								1				1	**2**
17	5	5		1	3			2	1	1	1	5	**24**
A*		6	1	3	1		1	4	2	2		2	**22**
Total	**15**	**45**	**19**	**28**	**14**	**1**	**6**	**46**	**8**	**8**	**1**	**19**	**210**

Zone 1, Zone 3 and Zone 5 are not located in the passage way of Bosphorus. Zone 1 and Zone 3 are located within the harbours and Zone 5 is the Golden Horn area.

Those zones are not included in forecast analysis since they are not within the Bosphorus. Zone A includes the accidents of which the locations unknown but registered. Therefore Zone A is also not included into computations by considering the inadequacy of the data.

41 maritime accident data, that does not located Bosphorus passage or has no specific location can not be used in analysis:

- 22 of them having no specific location can not be included on the analysis because the location of the data has been recorded only as Bosphorus Strait (Zone A).
- 5 of them whose locations recorded as Kadıköy pier or Kadıköy breakwater located in Zone 1 has not been included on the analysis.
- 5 of them whose locations recorded as Harem located in Zone 3 has not been included on the analysis.
- 9 of them whose locations recorded as Haliç (Golden Horn) located in zone 5 has not been included on the analysis.

Eventually, 169 maritime accident data remain after the exclusion of 41 maritime accidents. A record of maritime accident data of Undersecretariat Maritime Affairs Search and Rescue Department include date and time, region, vessel name, vessel gross tonnage, vessel type, vessel flag, location of the accident, coordinates of the accident (rarely), reason of the accident, type of the accident, casualties, comments, pilot, load condition and environmental pollution. Furthermore type of the accidents has been sub-grouped as capsizing, collision, stroke, hazardous incident, machinery damage, grounding, drift, contact, listing, fire and other accident types. In the model these accident types grouped into 5 in alignment with worldwide practice: collision, capsizing, grounding, fire and the others.

Accident probability is determined by dividing the number of accidents to the total number of vessels passing through Bosphorus between 01.01.2001 and 13.05.2010

(UMA) where the number of passing vessels is given as 481 872 and presented in Table 4.2.

Table 4.2 Number of vessels passing through Bosphorus

Years	Number of Vessels	Years	Number of Vessels
2001	42637	2006	54880
2002	47283	2007	56606
2003	46939	2008	54396
2004	54564	2009	51422
2005	54794	2010*	18351
Total			**481872**

* From January to middle of the May has been taken

Probability of the maritime accidents considering all groups together has been presented in Table 4.3.

Table 4.3 Number and Probabilities of Maritime Accidents

Zones	Number of Accidents	Probability of Accidents
2	31	6.43E-05
4	18	3.74E-05
6	3	6.23E-06
7	15	3.11E-05
8	2	4.15E-06
9	13	2.70E-05
10	2	4.15E-06
11	3	6.23E-06
12	5	1.04E-05
13	25	5.19E-05
14	18	3.74E-05
15	8	1.66E-05
16	2	4.15E-06
17	24	4.98E-05
Total	169	

Some of the data of the archive can not be considered as maritime accident, hazardous incident, damages to ship or equipment and machinery damage (UMA). Therefore the probability of the accident has been recalculated and presented in

Table 4.4 by disregarding 25 for hazardous incident, 1 for damages to ship or equipment and 5 for machinery damage. Thus the number of accidents records that can be used is 138.

Table 4.4 Number and Probabilities of Maritime Accidents

Zones	Number of Accidents	Probability of Accidents
2	29	6.02E-05
4	12	2.49E-05
6	3	6.23E-06
7	8	1.66E-05
8	2	4.15E-06
9	10	2.08E-05
10	2	4.15E-06
11	3	6.23E-06
12	3	6.23E-06
13	21	4.36E-05
14	15	3.11E-05
15	5	1.04E-05
16	2	4.15E-06
17	23	4.77E-05
Total	138	

Number of accidents and probabilities of the zones were given in Table 4.4 which are obtained by summing up collision accidents (collision + stroke +contact) given in Table 4.5, capsizing accidents (capsizing + listing) given in Table 4.6, grounding accidents (grounding + drift) given in Table 4.7, and fire and other accidents given in Table 4.8.

Table 4.5 Number and Probabilities of Collision Accidents

Zones	**Collision**	**Stroke**	**Contact**	**Number of Accidents**	**Probability of Collision**
2	14	1	3	**18**	3.74E-05
4	5	2	0	**7**	1.45E-05
6	2	0	0	**2**	4.15E-06
7	3	0	0	**3**	6.23E-06
8	1	0	0	**1**	2.08E-06
9	1	4	1	**6**	1.25E-05
10	1	0	0	**1**	2.08E-06
11	0	2	0	**2**	4.15E-06
12	1	1	0	**2**	4.15E-06
13	1	5	1	**7**	1.45E-05
14	0	0	0	**0**	0.00E+00
15	0	0	0	**0**	0.00E+00
16	0	0	0	**0**	0.00E+00
17	5	0	1	**6**	1.25E-05
Total	**34**	**15**	**7**	**55**	

Probability of capsizing accident has been calculated by summing the capsizing and listing on the data archive (Table 4.6).

Table 4.6 Number and Probabilities of Capsizing Accidents

Zones	**Capsizing**	**Listing**	**Total**	**Probability of Capsizing**
2	3	0	3	6.23E-06
4	1	0	1	2.08E-06
6	0	0	0	0.00E+00
7	0	0	0	0.00E+00
8	0	0	0	0.00E+00
9	1	0	1	2.08E-06
10	0	0	0	0.00E+00
11	0	0	0	0.00E+00
12	0	0	0	0.00E+00
13	3	0	3	6.23E-06
14	0	0	0	0.00E+00
15	0	0	0	0.00E+00
16	0	0	0	0.00E+00
17	5	1	6	1.25E-05
Total	**13**	**1**	**14**	

Table 4.7 Number and Probabilities of Grounding Accidents

Zones	**Stranding/ Grounding**	**Drift**	**Total**	**Probability of Grounding**
2	5	0	**5**	1.04E-05
4	0	0	**0**	0.00E+00
6	0	0	**0**	0.00E+00
7	2	0	**2**	4.15E-06
8	0	0	**0**	0.00E+00
9	2	1	**3**	6.23E-06
10	1	0	**1**	2.08E-06
11	0	1	**1**	2.08E-06
12	0	1	**1**	2.08E-06
13	9	1	**10**	2.08E-05
14	14	0	**14**	2.91E-05
15	2	1	**3**	6.23E-06
16	1	0	**1**	2.08E-06
17	2	1	**3**	6.23E-06
Total	**38**	**6**	**44**	9.13E-05

Probability of grounding accident has been calculated by summing the grounding and drift on the data archive (Table 4.7). The probability of fire accident and the probability of other accident have been determined by using the archive data (Table 4.8).

Table 4.8 Number and Probabilities of Fire and Other Accidents

Zones	**Others**	**Probability of Others**	**Fire**	**Probability of Fire**
2	2	4.15E-06	1	2.08E-06
4	3	6.23E-06	1	2.08E-06
6	1	2.08E-06	0	0.00E+00
7	1	2.08E-06	2	4.15E-06
8	0	0.00E+00	1	2.08E-06
9	0	0.00E+00	0	0.00E+00
10	0	0.00E+00	0	0.00E+00
11	0	0.00E+00	0	0.00E+00
12	0	0.00E+00	0	0.00E+00
13	0	0.00E+00	1	2.08E-06
14	1	2.08E-06	0	0.00E+00
15	2	4.15E-06	0	0.00E+00
16	0	0.00E+00	1	2.08E-06
17	3	6.23E-06	5	1.04E-05
Total	**13**	**2.70E-05**	**12**	**2.49E-05**

The archive data include date and time, region, name, Gross tonnage, type, flag, reason, type of the accident, casualties and comments. However, length overall (LOA) of the vessel has been determined by OCDI (2002) standard considering the type and GRT of the ship (Appendix A).

4.2.2 Admiralty Maps of Office of Navigation, Hydrography and Oceanography (ONHO)

For the development of the model, admiralty maps and surface current velocity data were used to define (Figure 4.4 and Figure 4.5):

- Zone area (A_z): total area between the coastal boundaries for each zone.
- Passage area, Area 2, (A_2): zone assigned for each maritime traffic lane.
- Midline: division line between the opposite traffic directions.
- Midline length, (L_m): division line length between the opposite traffic directions.
- Average passage width ($W_p=A_2/L_m$): average width between the passage boundaries.
- Area 1 = A_z - A_2
- *RPA*: ratio of passage area to zone area = $A_2/A_z = W_p * L_m/A_z$
- Average turn (*AT*): change of the direction of the midline alignment.

Admiralty maps 2921A and 2921B (ONHO) has been used to prepare the above given geometrical properties of Bosphorus (vessel passage width, ratio passage area to Zone area (*RPA*) and average turn (*AT*)) for each Zones from 1 to 17 except Zones 1, 3 and 5, since these Zones are not located on the passage like Zone 18.

An example computation is given for Zone 13 (Figure 4.4). To determine the average passage width (791.4 m), the passage area (2 807 393 m^2) has been divided by the midline length (3 547.5 m) in Zone 13. The ratio passage area is calculated by dividing A_2 (2 807 393 m^2) to A_z (6 255 780 m^2). These computations are carried out for each zone and presented in Table 4.9.

In the computations of passage width using the average width found to be appropriate since the range of the widths within the zones are not significant (Appendix D-1).

The measured turning angle has been presented in Table 4.10.

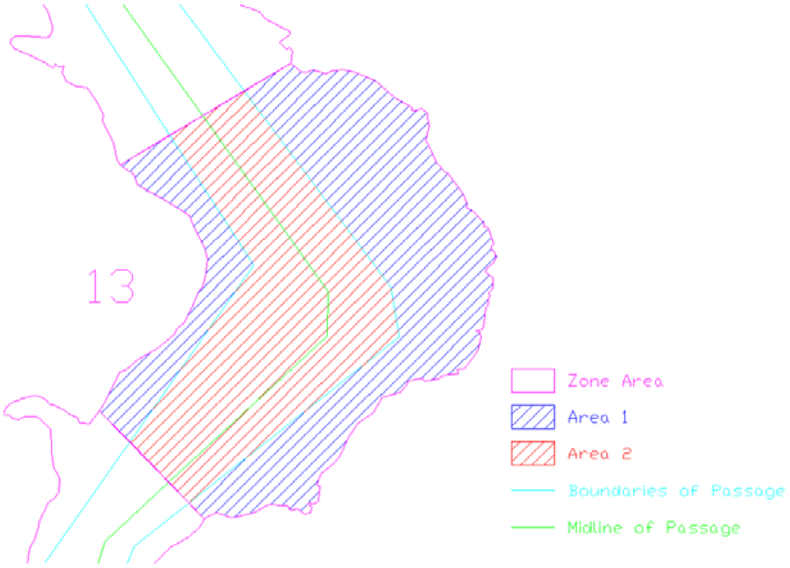


Figure 4.4 Parameters used on calculation of average passage width and *RPA*

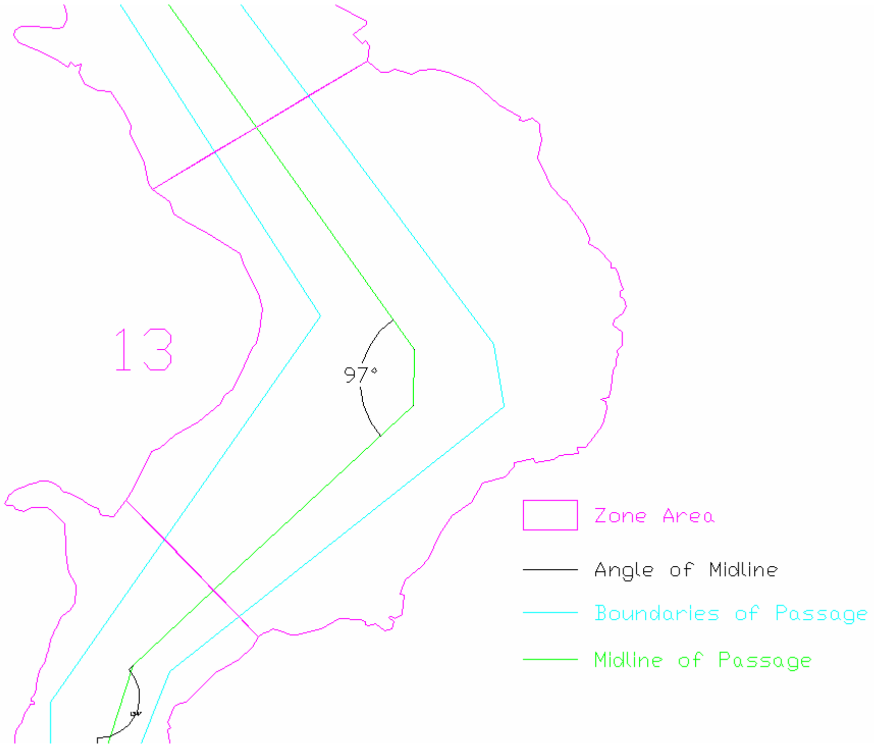


Figure 4.5 Parameters used on calculation of Average Turn

Table 4.9 Calculation of average passage width and RPA

Zone	**A_z (m^2)**	**A_2 (m^2)**	**Midline Length, L_m (m)**	**Average Width, W_p (m)**	***RPA*** **(A_2/A_z)**
2	3321947	1253537	1402.7	893.7	0.377
4	4213706	1908795	2438.5	782.8	0.453
6	3006050	1425715	2244.3	635.3	0.474
7	3147275	1905398	2557.7	745.0	0.605
8	1046010	607434	1058.3	574.0	0.581
9	1035761	521031	989.6	526.5	0.503
10	952701	583872	1091.1	535.1	0.613
11	1012611	605188	1179.3	513.2	0.598
12	1575214	810172	1486.0	545.2	0.514
13	6255780	2807393	3547.5	791.4	0.449
14	8517975	2821859	4556.3	619.3	0.331
15	4307094	1694551	3122.7	542.6	0.393
16	7890446	3603942	3735.6	964.8	0.457
17	4491221	1988848	1378.2	1443.1	0.443

Table 4.10 The turning angle

Zones	**Angle of Turn (Degree)**
2	0
4	51
6	0
7	36
8	0
9	23
10	39
11	0
12	46
13	83
14	75
15	7
16	14
17	0

Current velocity is determined by the current velocity map of Bosphorus taken from Ece (2005). In the computation of the average current values for each passage area in each zone, the registration of the map carried out firstly (Figure 4.6).

Representative current velocity for each passage area in each zone is obtained by computing aerial distribution of the current velocities given for each as shown in Figure 4.6. Since the velocity is given with a range the mid value is taken as representative. Average current velocities of the passage areas within the zone is valued as weighted averages obtained by summing up the multiplications of the segment areas with the current velocities assigned for this segment and dividing by the total area.

The average velocity computation is given as an example for zone 13 and presented in Table 4.11. The velocity is given with a range the mid value as representative i.e. for velocities between 0-25 cm/s, the average velocity is taken as 12.5 cm/s (Figure 4.7).

Table 4.11 Average current velocity for zone 13

Zone	**Velocity of Current Segments (cm/s)**	**Area of Current Segment (m^2)**	**Passage Area (m^2)**	**Multiplication of velocity with segment area (cm/s x m^2)**	**Average current velocity (cm/s)**
13	12.5	209523.6	2803002	2619044.9	71.18
	87.5	957961.2		83821607	
	125	332839.2		41604898	
	62.5	904738.9		56546179	
	37.5	397939.2		14922719	

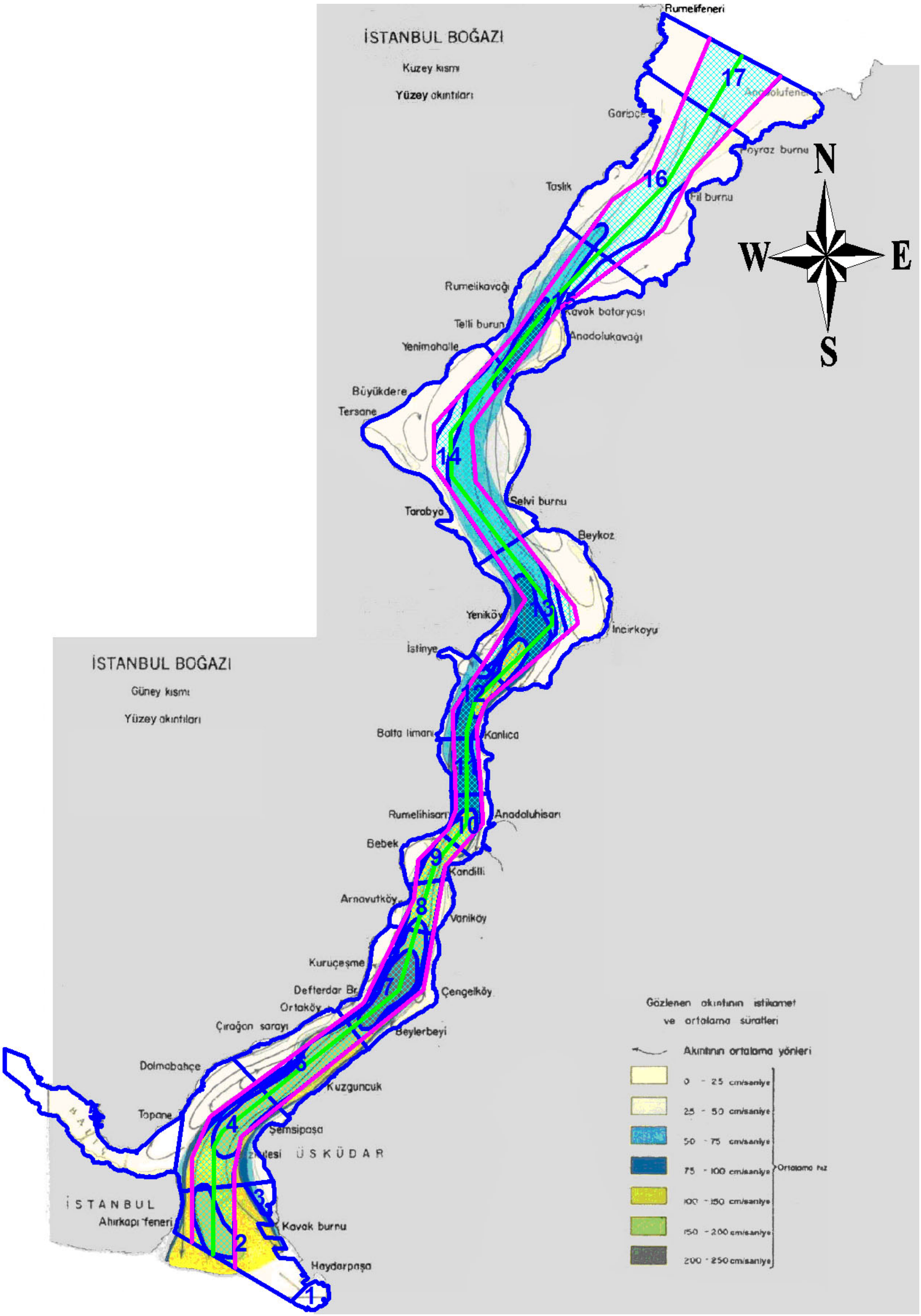


Figure 4.6 Digitized map of average current velocity

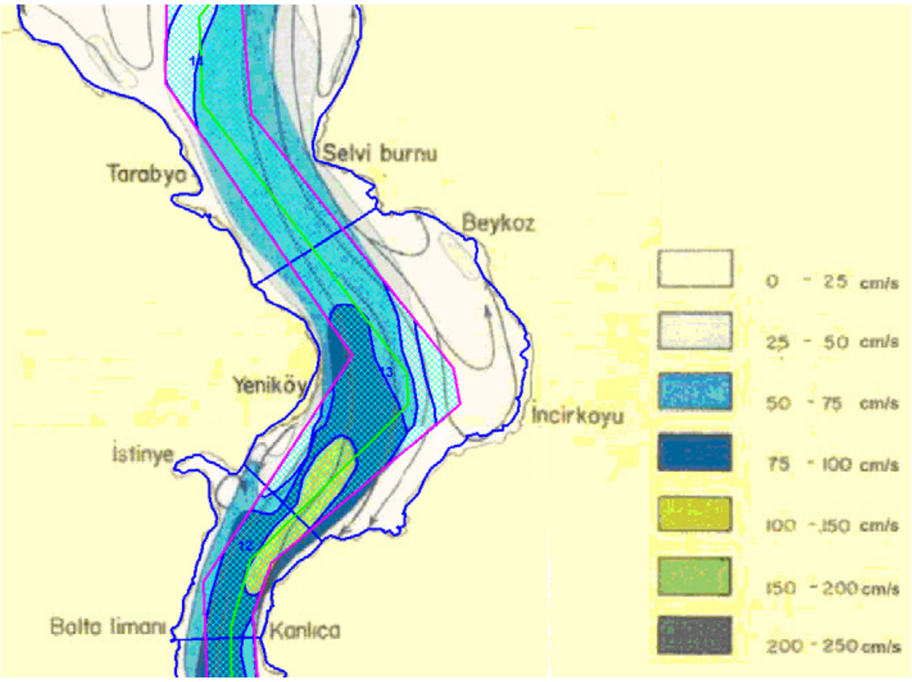


Figure 4.7 Calculation of average current velocity

The average current velocities determined for all the zones are given in Appendix C.

4.2.3 Weather Conditions Data of Turkish State Meteorological Service

Weather Data of Station Number 17061 called Kireçburnu in Sarıyer district has been compiled considering the date of maritime accident (Figure 4.8). All weather data of the station between January 2001 and February 2010 has been processed.

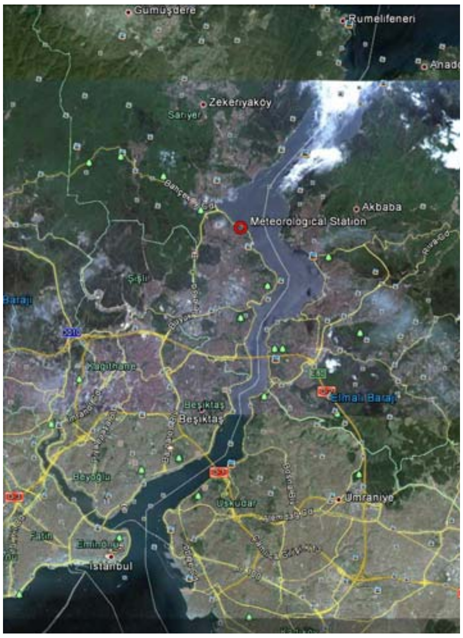


Figure 4.8 Kireçburnu meteorological station in Sariyer district (Google Earth, 2011)

Data of monthly average wind speed (m/s), number of monthly foggy day, monthly total precipitation (mm), sea condition, daily maximum wind speed (m/s), daily maximum wind direction, daily average wind speed (m/s), daily total precipitation (mm), hourly wind speed (m/s), hourly wind direction, weather event and density of the event at the time of the accident has been gathered and presented in Appendix A.

4.3 Selection of the Input Parameters

Since large number of the parameters involved in the maritime accident a correlation matrix analysis and ANFIS tool has been used to select the input parameters from the related data collected from different sources and processed in an appropriate form as represented in Section 4.2.

The input data consists of both categorical and continuous values. A categorical variable identify class or group for example gender. A continuous variable identify numerically continuous values for example wind speed. To select the input parameters continuous variables has been processed. In further studies categorical values can also be taken into consideration.

The input parameters used to estimate the probability of maritime accidents (collision, capsizing, grounding, fire and other) are:

- geomorphologic characteristics for the defined zones in Bosphorus, Average Width, Ratio Passage Area, Average Turn,
- vessel characteristics, GRT, LOA,
- weather characteristics, Monthly Total Precipitation, Daily maximum wind, Hourly Wind Speed, Daily Average Wind Speed, Monthly Average Wind Speed, Monthly Foggy Days, Daily Total Precipitation,
- hydraulic characteristics. Average Current Velocity.

Correlation matrix of the data has been analyzed to determine the input parameters and presented in Table 4.12. The computation procedure of correlation matrix is given in Appendix D-2. Continuous input parameters and accident probabilities have been processed to clarify the correlation coefficient (R_c) of the parameters to the probabilities. The absolute value of the determined correlation values have been calculated and these values have been ranked to see order of the input parameters according to accident probabilities. The selection of the parameters has been made considering the rank (from higher to lower R_c values) of the input parameters and the easiness of obtaining the data.

Table 4.12 The correlation matrix of the parameters

Total Accidents		**Collision Accidents**		**Capsizing Accidents**	
Parameters	$\boldsymbol{R_c}$	**Parameters**	$\boldsymbol{R_c}$	**Parameters**	$\boldsymbol{R_c}$
Average Passage Width	0.568	Average Current Velocity	0.508	Average Passage Width	0.727
Ratio Passage Area	0.540	Average Turn	0.448	Average Turn	0.468
Average Turn	0.224	Average Passage Width	0.269	Ratio Passage Area	0.268
Monthly Total Precipitation	0.186	Ratio Passage Area	0.259	Monthly Total Precipitation	0.163
Daily maximum wind	0.157	Daily Total Precipitation	0.107	Daily maximum wind	0.158
Vessel-2 GRT	0.108	Daily maximum wind	0.078	Vessel-2 GRT	0.151
Vessel-1 GRT	0.090	Monthly Total Precipitation	0.077	Hourly Wind Speed	0.147
Hourly Wind Speed	0.086	Vessel-2 GRT	0.063	Monthly Average Wind Speed	0.139
Daily Average Wind Speed	0.077	Hourly Wind Speed	0.060	Vessel-1 GRT	0.109
Monthly Average Wind Speed	0.057	Monthly Foggy Days	0.056	Average Current Velocity	0.102
Monthly Foggy Days	0.033	Monthly Average Wind Speed	0.056	Daily Average Wind Speed	0.072
Daily Total Precipitation	0.030	LOA	0.038	Daily Total Precipitation	0.049
Average Current Velocity	0.015	Vessel-1 GRT	0.013	LOA	0.030
LOA	0.003	Daily Average Wind Speed	0.010	Monthly Foggy Days	0.015

Table 4.12 The correlation matrix of the parameters (cont'd)

Grounding Accidents		**Fire Accidents**		**Other Accidents**	
Parameters	R_c	**Parameters**	R_c	**Parameters**	R_c
Average Turn	0.652	Average Passage Width	0.951	Average Passage Width	0.664
Ratio Passage Area	0.608	Average Current Velocity	0.467	Average Turn	0.515
Average Current Velocity	0.334	Average Turn	0.423	Ratio Passage Area	0.275
Average Passage Width	0.220	Vessel-2 GRT	0.184	Vessel-2 GRT	0.139
Monthly Total Precipitation	0.107	Ratio Passage Area	0.163	Monthly Average Wind Speed	0.081
Vessel-1 GRT	0.097	Daily Total Precipitation	0.155	Average Current Velocity	0.068
Daily Total Precipitation	0.085	Monthly Total Precipitation	0.144	Monthly Total Precipitation	0.065
Daily maximum wind	0.083	Hourly Wind Speed	0.136	Hourly Wind Speed	0.061
LOA	0.077	Daily maximum wind	0.108	Monthly Foggy Days	0.048
Vessel-2 GRT	0.066	Daily Average Wind Speed	0.073	Vessel-1 GRT	0.046
Daily Average Wind Speed	0.066	Monthly Average Wind Speed	0.071	LOA	0.024
Hourly Wind Speed	0.057	Vessel-1 GRT	0.038	Daily Total Precipitation	0.018
Monthly Average Wind Speed	0.032	LOA	0.036	Daily Average Wind Speed	0.002
Monthly Foggy Days	0.008	Monthly Foggy Days	0.010	Daily maximum wind	0.001

The highest correlation coefficient; between total accidents and average passage width is 0.568, between collision accidents and average current velocity is 0.508, between capsizing accidents and average passage width is 0.727, between grounding accidents and average turn is 0.652, between fire accidents and average width is 0.951, between other accidents and average width is 0.664. Average passage width W_p appears as the most important parameter for all type of accidents except grounding. This parameter is included in $RPA=W_p*L_m/A_z$.

The lowest correlation coefficient are: between total accidents and LOA is 0.003, between collision accidents and daily average wind speed is 0.010, between capsizing accidents and monthly foggy days is 0.015, between grounding accidents and monthly foggy days is 0.008, between fire accidents and monthly foggy days is 0.010, between other accidents and daily maximum wind is 0.001. The model development gives incompatible results if variables having lowest correlation coefficient will be selected.

ANFIS has been used as another tool to select the input parameters. In ANFIS the root mean square error (RMSE) between UMA data and forecasted probability has been considered and the input parameters which minimizes the error have been selected. 36 trials have been processed by ANFIS tool. The RMSE value is decreased from 1.90E-03 to 5.00E-04 through the trials 1 to 36. The computations for ANFIS tool is given in Appendix D-3.

In the model development in order to obtain more compatible results, parameters having highest correlation coefficient were selected. Therefore based on ANFIS results and correlation matrix, the parameters having highest relation and easily obtainable selected for the model. Selected parameters are: current velocity (*CV*), length overall ship (*LOA*), average turn of vessel (*AT*), daily maximum wind speed (*DWS*), ratio of passage area (*RPA*) to zone area and monthly total precipitation (*MTP*).

4.4 Forecasting Methods for The Maritime Accident Probabilities

In the development of forecasting methods for the maritime accidents five different type of maritime accident are taken into consideration. Namely collision, capsizing, grounding, fire and other accident types has been studied. Total Accident is the summation of collision, capsizing, grounding, fire and other accident types.

Maritime accident probabilities has been forecasted by the selected input parameters based on correlation coefficient obtained: current velocity (*CV*), length overall ship (*LOA*), average turn of vessel (*AT*), daily maximum wind speed (*DWS*), ratio of passage area (*RPA*) to zone area and monthly total precipitation (*MTP*). These parameters have been used to develop Formula 1, Formula 2, Model 1 and Model 2.

Formula 1 based on AASHTO (method II probability of aberrancy) and Formula 2 which is multiple linear regression analysis are on the basis of a function. The forecasted probabilities (dependent variable) can be calculated by using the input parameters (independent variables). The UMA data is used to determine the coefficients of the formulas. After determination of the coefficients, the probabilities can be estimated with simple calculations.

Model 1 which is an Adaptive Neuro Fuzzy Inference System (ANFIS) model and Model 2 which is an Artificial Neural Network (ANN) model have been used to forecast the probabilities. ANFIS tool of Fuzzy Logic Toolbox and the neural network fitting tool of Neural Network Toolbox of Matlab© program have been used to develop the model. The UMA data is used to develop the models. After training processes of the models, the probabilities can be forecasted.

4.4.1 Formula 1

Formula 1 has been developed to forecast the accident probabilities considering the accident types. Six types of accident probabilities such as probability of collision accident, probability of capsizing accident, probability of grounding accident, probability of fire accident, probability of other accident and total accident probability have been forecasted. Developed Formula 1 has 6 input parameters.

Developed Formula 1 is based on AASHTO (method II probability of aberrancy). The inputs of the formula are current velocity, vessel length, average turn, daily maximum wind speed, ratio passage area and monthly total precipitation as shown in Equation (4.1):

$$FP = X_1\left(X_2 + \frac{CV}{X_3}\right)\left(X_4 + \frac{LOA}{X_5}\right)\left(X_6 + \frac{AT}{X_7}\right)\left(X_8 + \frac{DWS}{X_9}\right)\left(X_{10} + \frac{RPA}{X_{11}}\right)\left(X_{12} + \frac{MTP}{X_{13}}\right) \quad (4.1)$$

where;

FP: Accident probability (accident/passage),

CV: current velocity (cm/s),

LOA: length overall ship (m),

AT: average turn of vessel (degree),

DWS: daily maximum wind speed (m/s),

RPA: Ratio of Passage Area to Zone Area,

MTP: Monthly Total Precipitation (mm),

$X_{1\text{-}13}$: Coefficients

Probability (FP) of accidents according to types has been calculated with the formula considering the archive data probabilities. Thus coefficients ($X_{1\text{-}13}$) of the Formula 1 have been determined. Current velocity (CV) is the average current velocity on the zone. Ratio of the passage area (*RPA*) has been determined for each zone by dividing the passage area to zone area.

4.4.2 Formula 2

The probabilities of accident according to types have also been forecasted by multiple linear regression analysis. The inputs of the multiple linear regression analysis are current velocity, vessel length, average turn, daily wind speed, ratio passage area and monthly total precipitation as shown in Equation (4.2):

$$FP = X_1\ CV + X_2\ LOA + X_3\ AT + X_4\ DWS + X_5\ RPA + X_6\ MTP \tag{4.2}$$

where;

FP: Accident probability (accident/passage),
CV: current velocity (cm/s),
LOA: length overall ship (m),
AT: average turn of vessel (degree),
DWS: daily maximum wind speed (m/s),
RPA: Ratio of Passage Area to Zone Area,
MTP: Monthly Total Precipitation (mm),
$X_{1\text{-}5}$: Coefficients

Probability (*FP*) of accidents according to types has been trained with the multiple regression analysis considering the archive data probabilities. Thus coefficients ($X_{1\text{-}6}$) of the Formula 2 have been determined.

4.4.3 Model 1 (Adaptive Neuro Fuzzy Inference System (ANFIS))

A model has been developed by ANFIS mathematical tool given in section 3.2.3. For model development selected 6 input parameters and 1 output have been trained on ANFIS considering the computational processor and time requirement. The train of the ANFIS model has been made by the full set of the prepared data. The test of the ANFIS model is performed by the same full set of the prepared data. Six types of accident probabilities such as probability of collision accident, probability of capsizing accident, probability of grounding accident, probability of fire accident, probability of other accident and total accident probability have been forecasted.

On ANFIS model development, after trials of triangular, trapezoidal, Gaussian, bell shaped and sigmoidal membership functions, the gaussian membership function was selected due to its minimum error in the models (Appendix E). The backpropagation optimization and 1000 iteration counts were selected. Two linguistic terms was used for membership functions. ANFIS model structure can be seen in Figure 4.9.

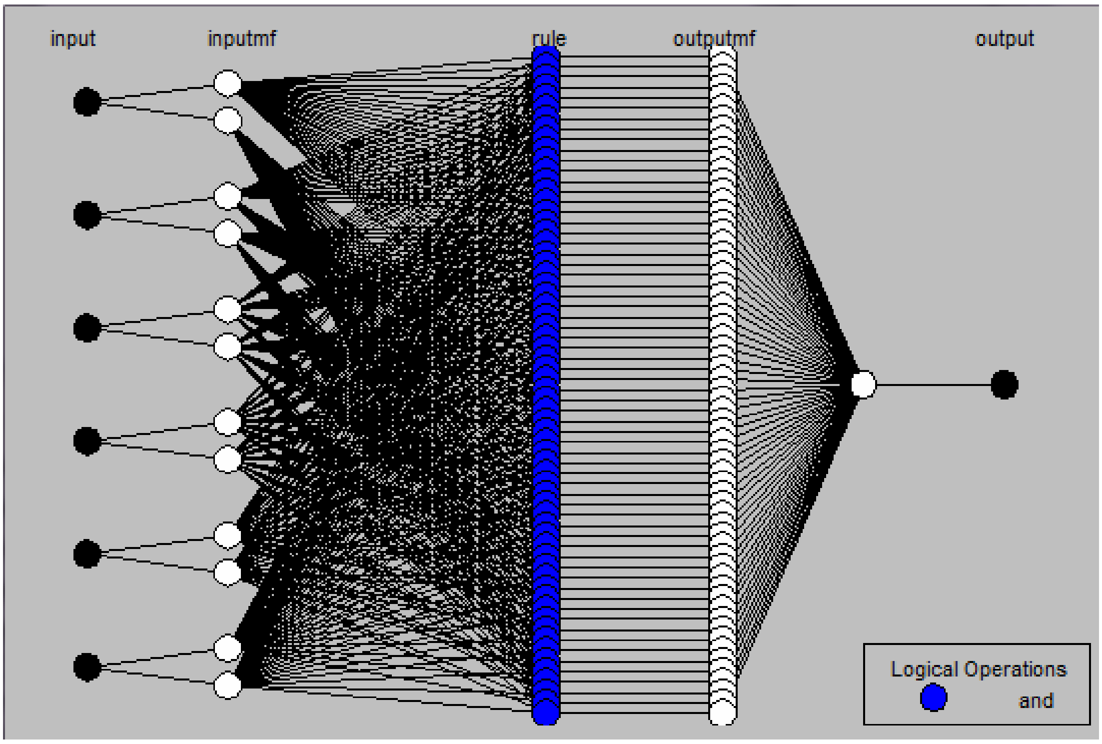


Figure 4.9 Model Structure of ANFIS

The rules were formed by zero order Sugeno fuzzy model (Sugeno, M. & Kang G.T., 1988; Takagi T. & Sugeno M., 1985).

4.4.4 Model 2 (Artificial Neural Network (ANN))

A model has been developed by ANN mathematical tool given in section 3.2.2. For model development selected 6 input parameters and 1 output have been trained on ANN. The train, test and validation of the ANN model have been made by the UMA accident data. Six types of accident probabilities such as probability of collision accident, probability of capsizing accident, probability of grounding accident, probability of fire accident, probability of other accident and total accident probability have been forecasted.

A feed-forward network with the tan-sigmoid transfer function in the hidden layer and linear transfer function in the output layer has been processed by using 10 neurons in the hidden layer (Figure 4.10). The network has one output neuron, because there is only one target value associated with each input vector.

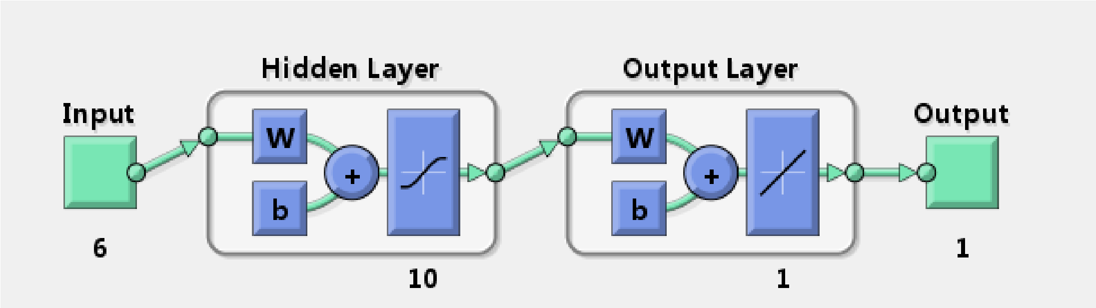


Figure 4.10 ANN model for 6 input parameters

The Levenberg-Marquardt algorithm has been used on the network for training. The input vectors and target vectors have been divided automatically by the Matlab© software into three sets as follows: 70% has been used for training, 15% for validating and the last 15% for testing of network. The training of the network has been stopped when the mean square error stabilize.

CHAPTER 5

APPLICATION OF THE APPROACHES USED IN ESTIMATING THE MARITIME ACCIDENT PROBABILITIES FOR BOSPHORUS

In this chapter application of Method II of American Association of State Highway and Transportation Officials (AASHTO), Formula 1 developed considering AASHTO, Formula 2 (Multiple Linear Regression), Model 1 (Adaptive Neuro Fuzzy Inference System (ANFIS)) and Model 2 (Artificial Neural Network) approaches will be presented to forecast maritime accident probabilities for Bosphorus.

5.1 Method II (AASHTO)

Equation (3.1) (Section 3.1.1), which gives the probability of vessel aberrancy (PA) (Method II, AASHTO,2009) is used to find out the probability of vessel aberrancy in Bosphorus:

$$PA = BR\ (R_B)\ (R_C)\ (R_{XC})\ R_D) \tag{3.1}$$

where;

PA: probability of aberrancy, BR: aberrancy base rate, R_B: correction factor for turning angle, R_C: correction factor for current acting parallel to vessel path, R_{XC}: correction factor for current acting perpendicular to vessel path, R_D: correction factor for vessel traffic density.

The parameters of Equation (3.1) are computed for Bosphorus zones, an example computation is presented in Appendix F for zone 14.

Aberrancy base rate (*BR*) is a standard value. The value (*BR*) is 0.6 x 10^{-4} for ships and 1.2 x 10^{-4} for barges. The value of 0.6 x 10^{-4} has been used on the calculation of *PA* to determine the probability for ships.

For the Bosphorus, the correction factor for turning angle (R_B) has been calculated and presented in Table 5.1 for each zones from 1 to 17 except Zones 1, 3 and 5, since these Zones are not located on the passage like Zone 18.

Table 5.1 The correction factor (R_B) for turning angle

Zones	**Angle of Turn (Degree)**	R_B
2	0	1.00
4	51	2.13
6	0	1.00
7	36	1.80
8	0	1.00
9	23	1.51
10	39	1.87
11	0	1.00
12	46	2.02
13	83	2.84
14	75	2.67
15	7	1.16
16	14	1.31
17	0	1.00

The correction factor for current has been calculated using the average current of the zones and estimated angle between current direction and vessel direction. Calculated average velocity unit has been converted to knot. According to angle between current direction and vessel direction, current velocity perpendicular to vessel path and parallel to vessel path has been determined. After the determination of current velocity perpendicular to vessel path and parallel to vessel path, R_C and R_{XC} has been calculated and presented in Table 5.2.

Table 5.2 The correction factor for bridge location

Zones	**Angle btw. Vessel Path & Current Direction (Degree)**	**Average Current (cm/s)**	**Average Current (knot)**	V_C	V_{XC}	R_C	R_{XC}
2	21	156.31	3.04	2.837	1.089	1.284	2.089
4	0	144.01	2.80	2.799	0.000	1.280	1.000
6	7	154.89	3.01	2.988	0.367	1.299	1.367
7	0	173.06	3.36	3.364	0.000	1.336	1.000
8	10	127.59	2.48	2.442	0.431	1.244	1.431
9	14	117.68	2.29	2.220	0.553	1.222	1.553
10	6	107.93	2.10	2.086	0.219	1.209	1.219
11	6	83.68	1.63	1.618	0.170	1.162	1.170
12	16	93.63	1.82	1.750	0.502	1.175	1.502
13	23	71.18	1.38	1.274	0.541	1.127	1.541
14	21	56.67	1.10	1.028	0.395	1.103	1.395
15	22	59.81	1.16	1.078	0.436	1.108	1.436
16	6	35.99	0.70	0.696	0.073	1.070	1.073
17	0	12.50	0.24	0.243	0.000	1.024	1.000

The correction factor for vessel traffic density (R_D) has defined by low, medium and high density traffic. The Bosphorus strait has a highly dense traffic. Therefore the correction factor for vessel traffic density has been taken as 1.60 for all zones.

Probability of aberrancy (PA) has been calculated using the determined BR, R_B, R_C, R_{XC}, R_D and presented in Table 5.3.

Table 5.3 The correction factor for bridge location

Zones	*BR*	R_B	R_C	R_{XC}	R_D	*PA*
2	0.00006	1.00	1.28	2.09	1.60	2.57E-04
4	0.00006	2.13	1.28	1.00	1.60	2.62E-04
6	0.00006	1.00	1.30	1.37	1.60	1.70E-04
7	0.00006	1.80	1.34	1.00	1.60	2.31E-04
8	0.00006	1.00	1.24	1.43	1.60	1.71E-04
9	0.00006	1.51	1.22	1.55	1.60	2.75E-04
10	0.00006	1.87	1.21	1.22	1.60	2.64E-04
11	0.00006	1.00	1.16	1.17	1.60	1.30E-04
12	0.00006	2.02	1.17	1.50	1.60	3.43E-04
13	0.00006	2.84	1.13	1.54	1.60	4.74E-04
14	0.00006	2.67	1.10	1.39	1.60	3.94E-04
15	0.00006	1.16	1.11	1.44	1.60	1.76E-04
16	0.00006	1.31	1.07	1.07	1.60	1.44E-04
17	0.00006	1.00	1.02	1.00	1.60	9.83E-05

A comparative presentation of the results obtained of Method II (AASHTO, 2009) and maritime accident data for Bosphorus zones is presented in Figure 5.1.

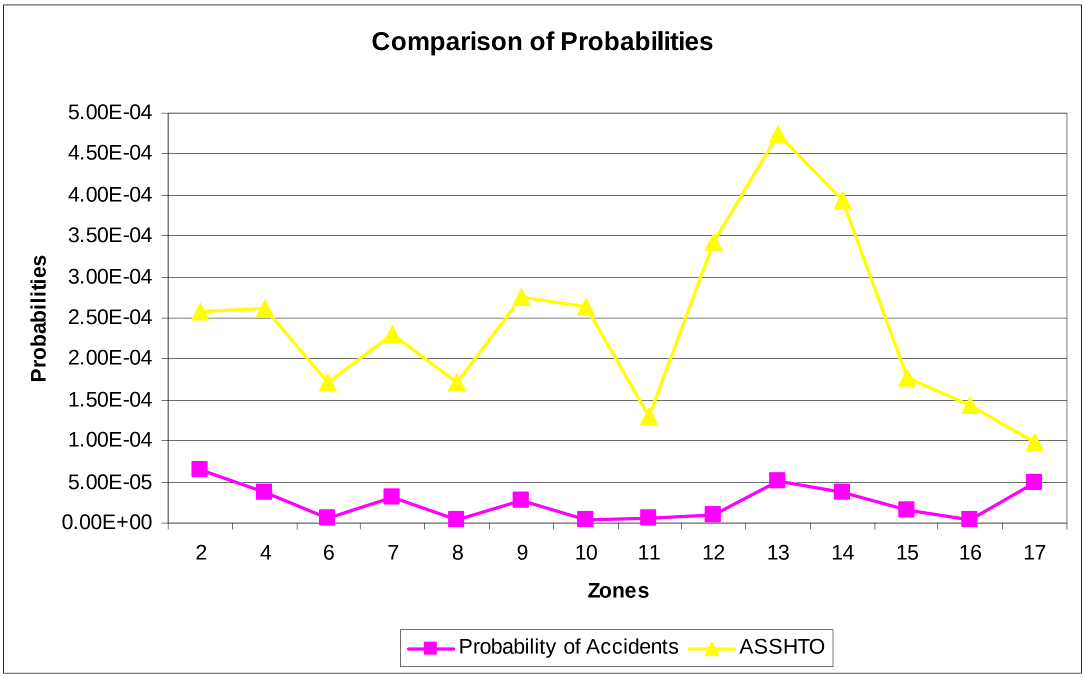


Figure 5.1 Comparison of Probabilities

As it is seen Figure 5.1 the forecasting studies obtained from Method II (AASHTO, 2009) is not compatible with the existing maritime accident data.

5.2 Formula 1

Equation (4.1) (Section 4.4.1) given as Formula 1 having six input parameters has been used to estimate the maritime accident probabilities for Bosphorus.

$$FP = X_1\left(X_2 + \frac{CV}{X_3}\right)\left(X_4 + \frac{LOA}{X_5}\right)\left(X_6 + \frac{AT}{X_7}\right)\left(X_8 + \frac{DWS}{X_9}\right)\left(X_{10} + \frac{RPA}{X_{11}}\right)\left(X_{12} + \frac{MTP}{X_{13}}\right) \quad (4.1)$$

The coefficients of the developed formula have been compiled by the UMA accident data given for Bosphorus. The coefficient of determination (R^2) has been considered to define the coefficients. Six different coefficient sets (X_1 to X_{13}) has been determined as; coefficients of the probability of total accidents, coefficients of the probability of collision accidents, coefficients of the probability of capsizing accidents, coefficients of the probability of grounding accidents, coefficients of the probability of fire accidents and coefficients of the probability of other accidents. The coefficient sets have been found for the Equation (4.1) and given in Table 5.4.

Table 5.4 The coefficient sets of the Equation (4.1)

Inputs	**Coefficients**	**Probability of Total Accidents**	**Probability of Collision Accidents**	**Probability of Capsizing Accidents**	**Probability of Grounding Accidents**	**Probability of Fire Accidents**	**Probability of Other Accidents**
	X_1	5.00E-07	2.10E-07	8.30E-08	1.60E-07	4.50E-08	4.80E-08
CV	X_2	2.00	1.90	2.00	2.00	1.80	1.80
	X_3	900	110	1000	1000	1000	1000
LOA	X_4	2.00	1.50	2.00	2.00	2.00	2.00
	X_5	900	600	1000	1000	750	750
AT	X_6	2.10	2.20	2.10	2.10	2.20	2.20
	X_7	1440	1440	1440	50	1440	1440
HWS	X_8	1.90	1.70	1.80	1.40	1.50	1.70
	X_9	35	35	21	30	20	60
RPA	X_{10}	1.80	1.90	1.75	1.85	1.75	2.10
	X_{11}	10	10	10	10	1.6	10
MTP	X_{12}	1.70	1.60	1.70	1.60	1.50	1.60
	X_{13}	500	450	350	400	300	700
R^2		**0.01556**	**0.16055**	**0.01813**	**0.26974**	**0.00363**	**-0.02436**

As it is seen in Table 5.4 R^2 values are not found satisfactory where the maximum is obtained for grounding accident type as 0.27. The average of the estimated probabilities and archive data has been presented between Figure 5.2 and Figure 5.7 for the visual comparison of the developed formula and archive data. All the computations of Formula 1 is given in Appendix G.

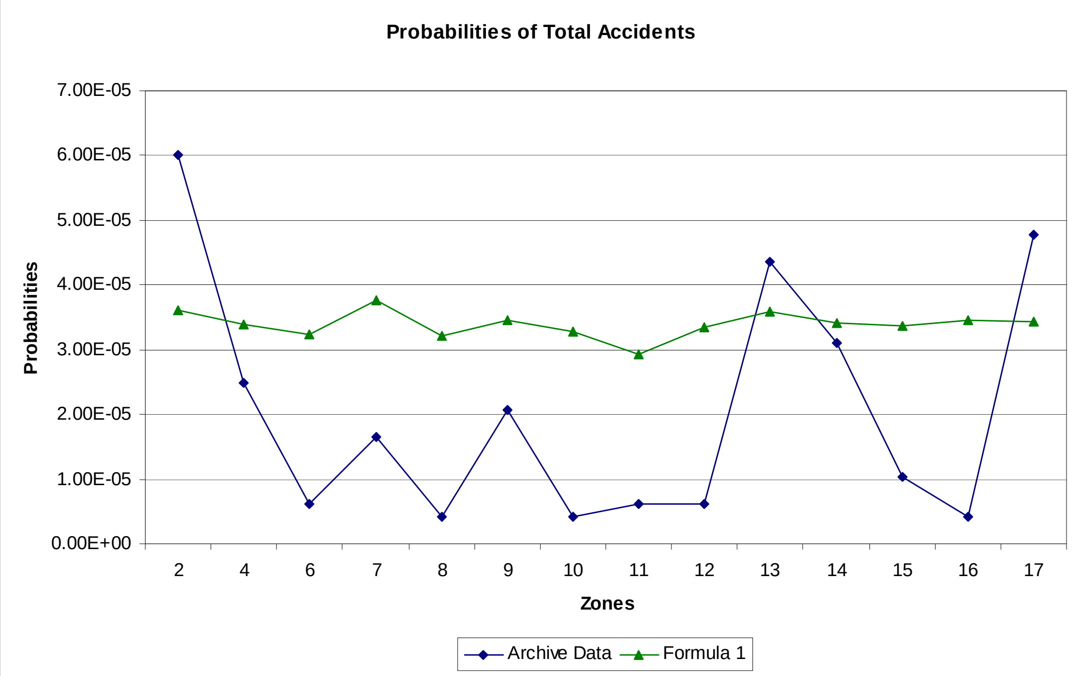


Figure 5.2 Probabilities of Total Accidents (Formula 1)

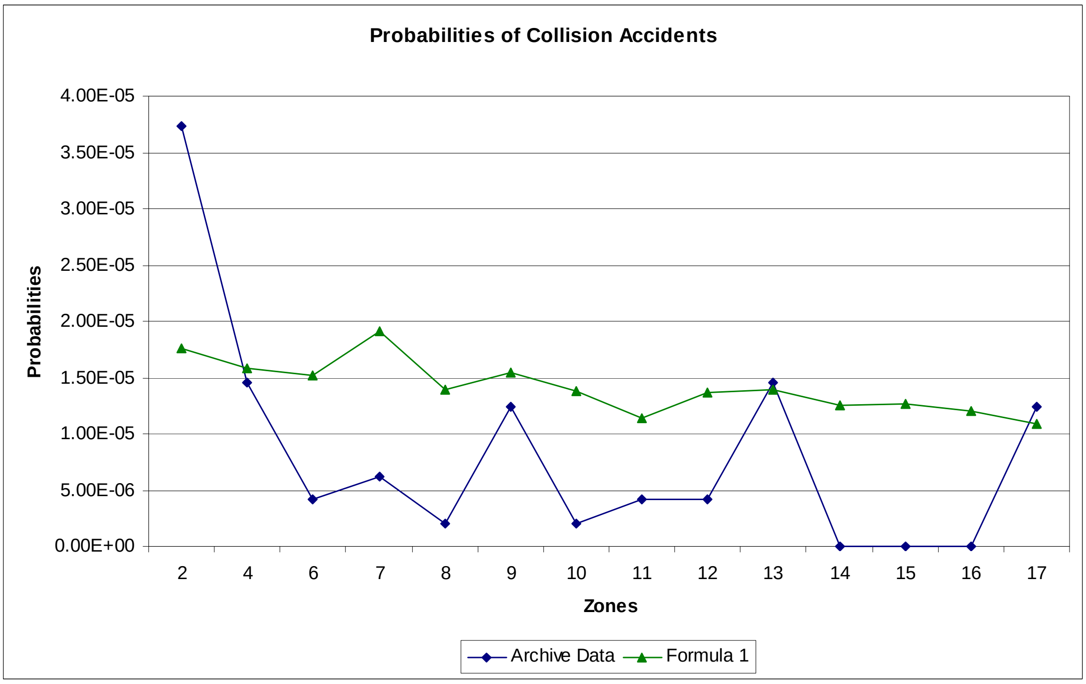


Figure 5.3 Probabilities of Collision Accidents (Formula 1)

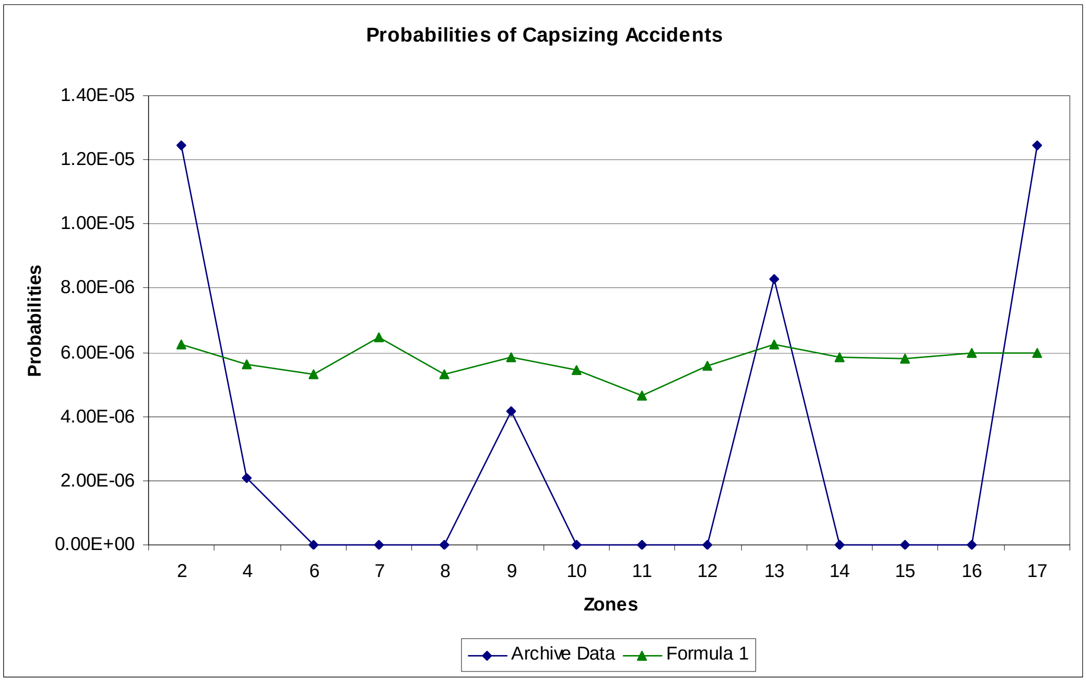


Figure 5.4 Probabilities of Capsizing Accidents (Formula 1)

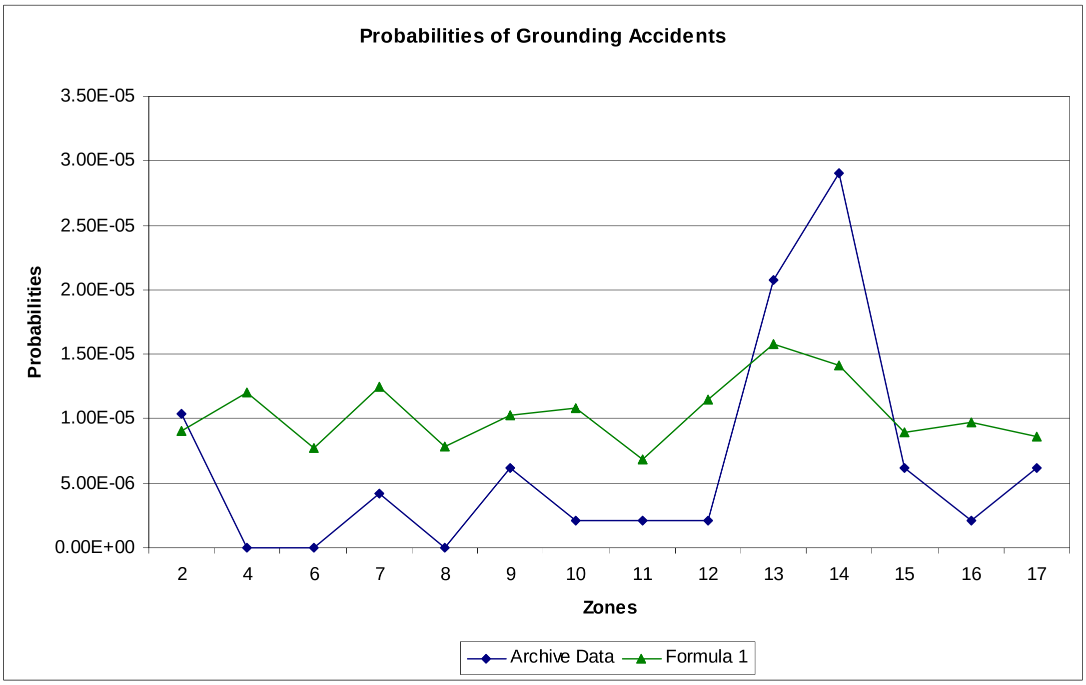


Figure 5.5 Probabilities of Grounding Accidents (Formula 1)

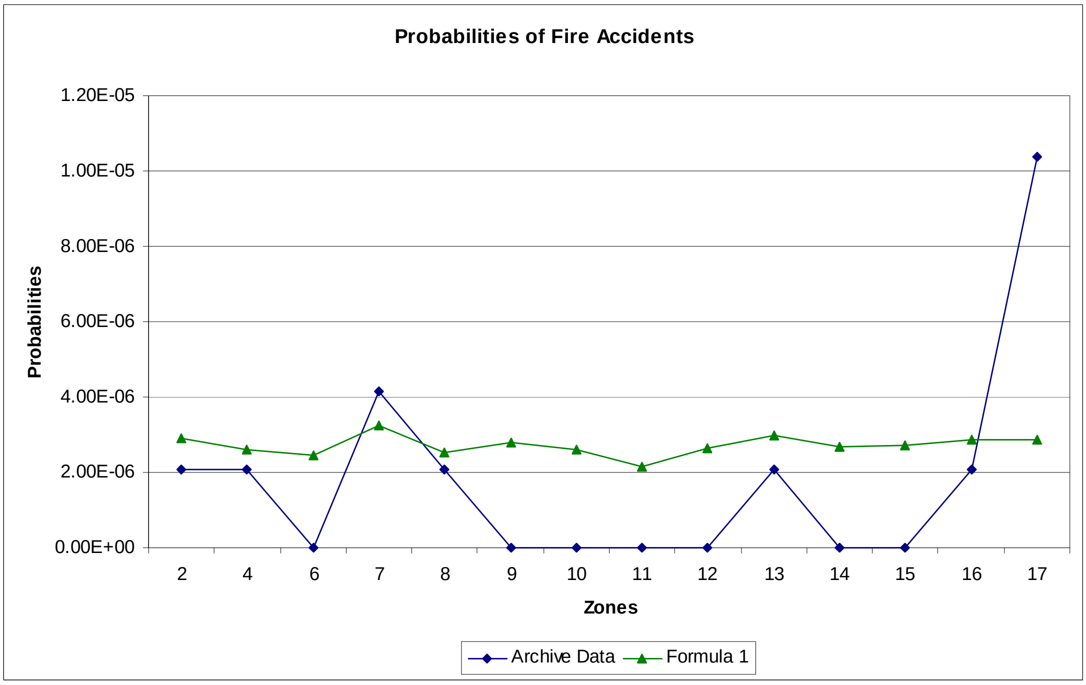


Figure 5.6 Probabilities of Fire Accidents (Formula 1)

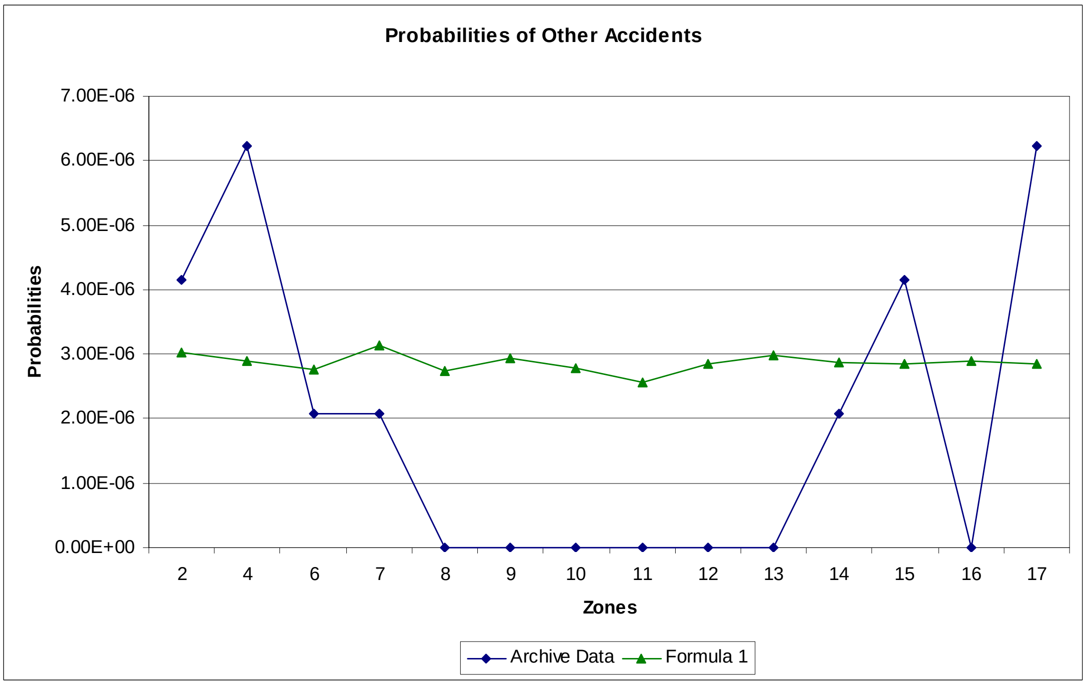


Figure 5.7 Probabilities of Other Accidents (Formula 1)

The outcomes of Formula 1 estimating the total, collision, capsizing, fire and other accidents were not found satisfactory when compared with the existing maritime accident data for Bosphorus.

5.3 Formula 2

The multiple linear regression analysis has been processed with input parameters: current velocity, vessel length, average turn, daily maximum wind speed, ratio passage area and monthly total precipitation as shown in Equation (4.2) (Section 4.4.2):

$$FP = X_1\ CV + X_2\ LOA + X_3\ AT + X_4\ DWS + X_5\ RPA + X_6\ MTP \tag{4.2}$$

The coefficients of the multiple linear regression analysis have been determined by the UMA accident data. The coefficient of determination (R^2) has been considered to define the coefficients. Six different coefficients has been determined as; coefficients of the probability of total accidents, coefficients of the probability of collision accidents, coefficients of the probability of capsizing accidents, coefficients of the probability of grounding accidents, coefficients of the probability of fire accidents and coefficients of the probability of other accidents. The coefficients has been found for the Equation (4.2) and presented in Table 5.5.

Table 5.5 The coefficients of the Equation (4.2)

Inputs	**Coefficients**	**Probability of Total Accidents**	**Probability of Collision Accidents**	**Probability of Capsizing Accidents**	**Probability of Grounding Accidents**	**Probability of Fire Accidents**	**Probability of Other Accidents**
CV	X_1	6.25E-08	1.41E-07	-3.77E-09	-8.58E-09	-3.63E-08	-3.75E-10
LOA	X_2	6.17E-08	2.72E-08	1.25E-08	1.77E-08	1.90E-09	7.00E-09
AT	X_3	-3.76E-08	-1.15E-07	-6.40E-08	2.05E-07	-4.76E-08	-2.99E-08
DWS	X_4	1.04E-06	4.75E-07	2.53E-07	2.87E-07	5.75E-08	5.50E-08
RPA	X_5	1.86E-05	-1.14E-05	8.21E-06	-4.45E-06	1.54E-05	5.30E-06
MTP	X_6	6.79E-08	2.39E-08	1.38E-08	2.49E-08	5.28E-09	4.41E-09
R^2		**-0.1561**	**0.4231**	**0.1502**	**0.4449**	**0.5369**	**0.0767**

As it is seen in Table 5.5 R^2 values were not found satisfactory where the maximum was obtained for fire accident type as ~0.54. In fact, these results are comparatively better than Formula 1. The average of the estimated probabilities and archive data has been presented between Figure 5.8 and Figure 5.13 for the visual comparison of the multiple linear regression analysis and archive data. All the computations of Formula 2 were given in Appendix H.

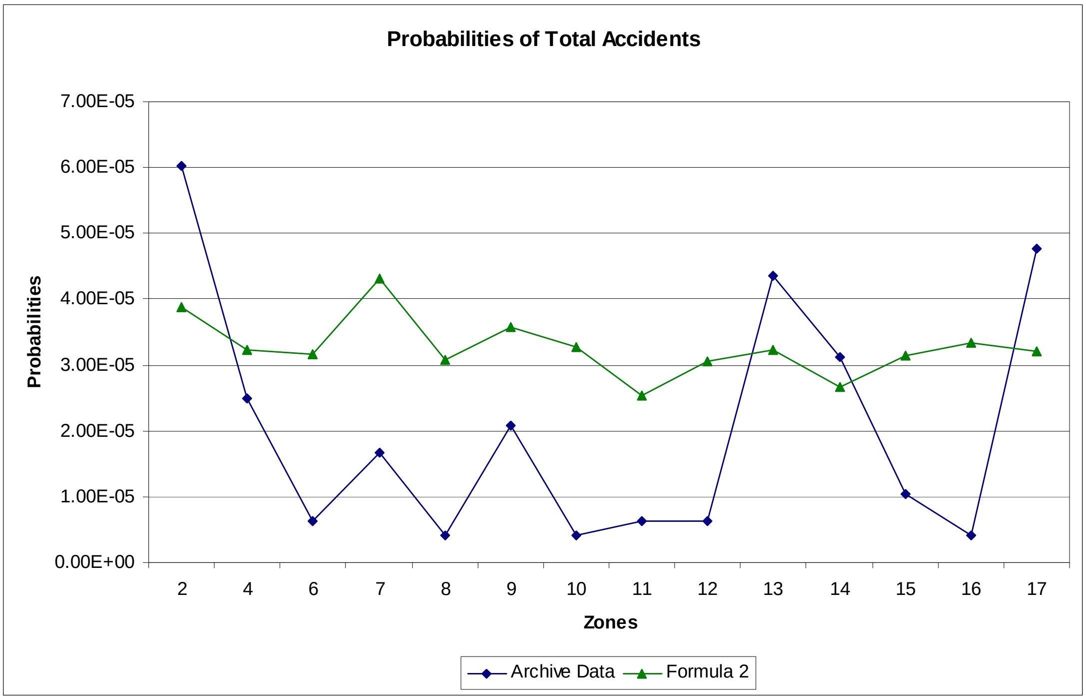


Figure 5.8 Probabilities of Total Accidents (Formula 2)

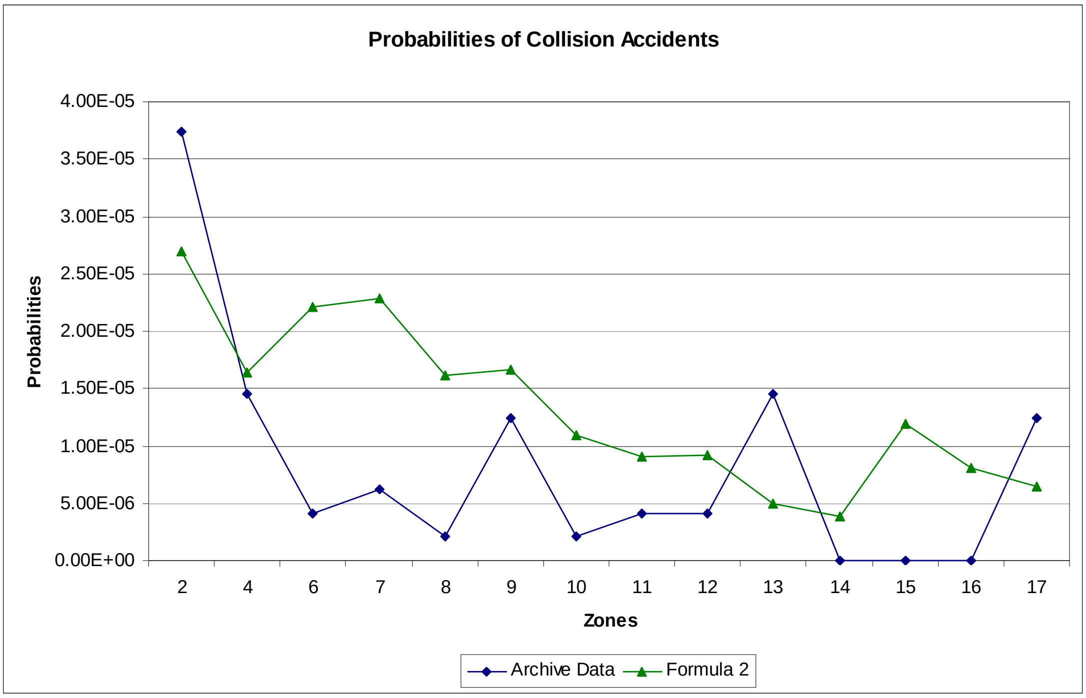


Figure 5.9 Probabilities of Collision Accidents (Formula 2)

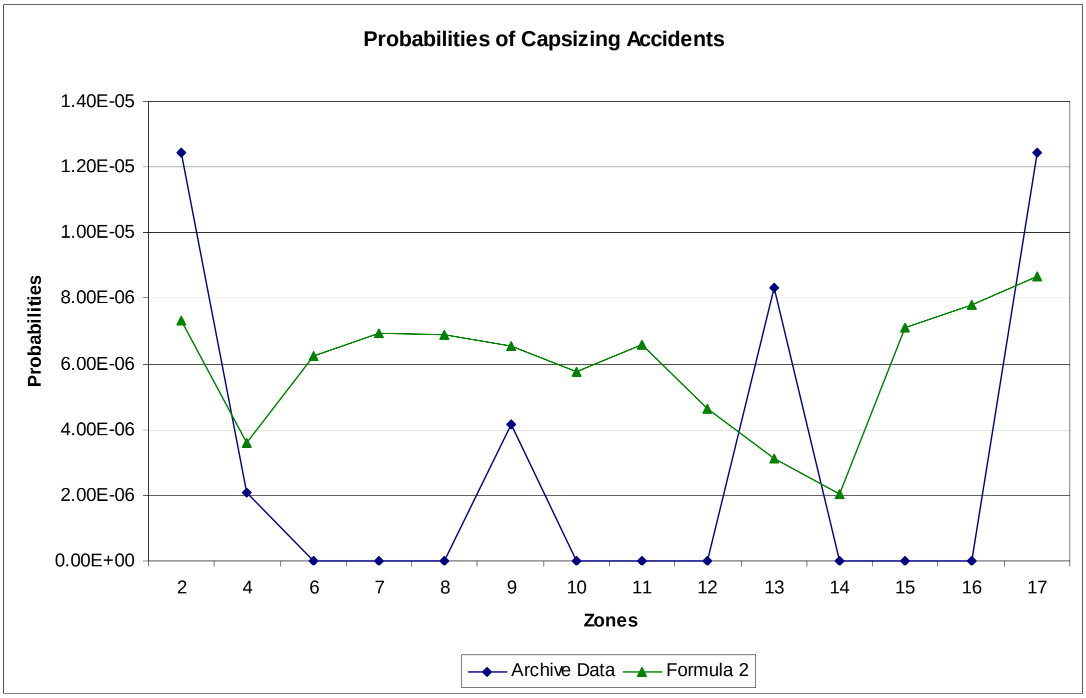


Figure 5.10 Probabilities of Capsizing Accidents (Formula 2)

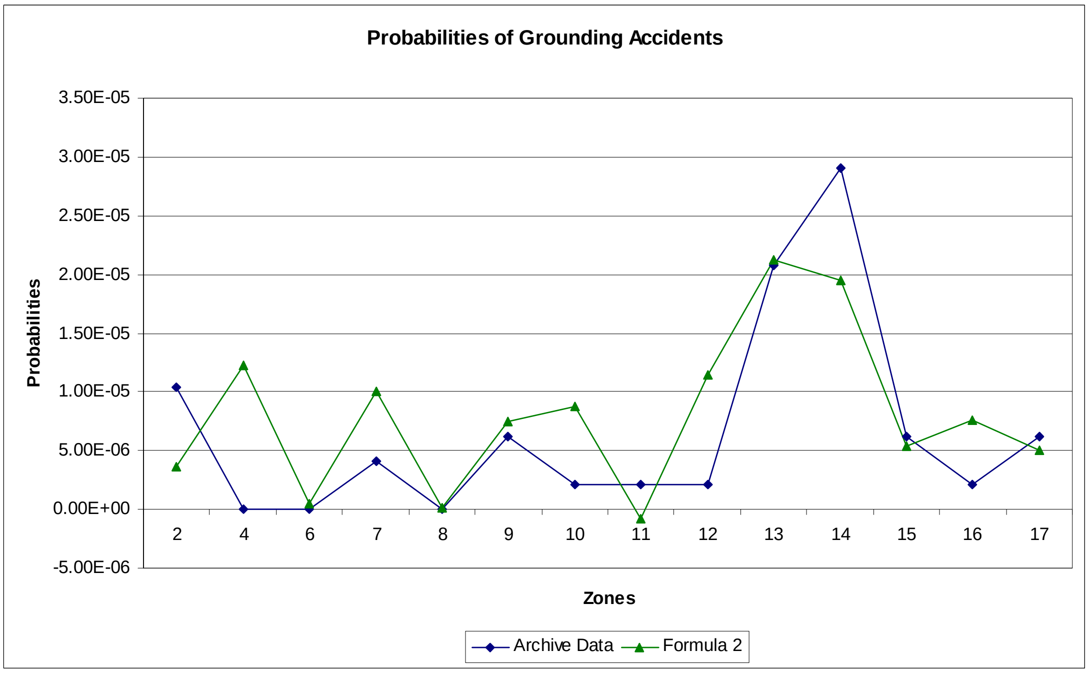


Figure 5.11 Probabilities of Grounding Accidents (Formula 2)

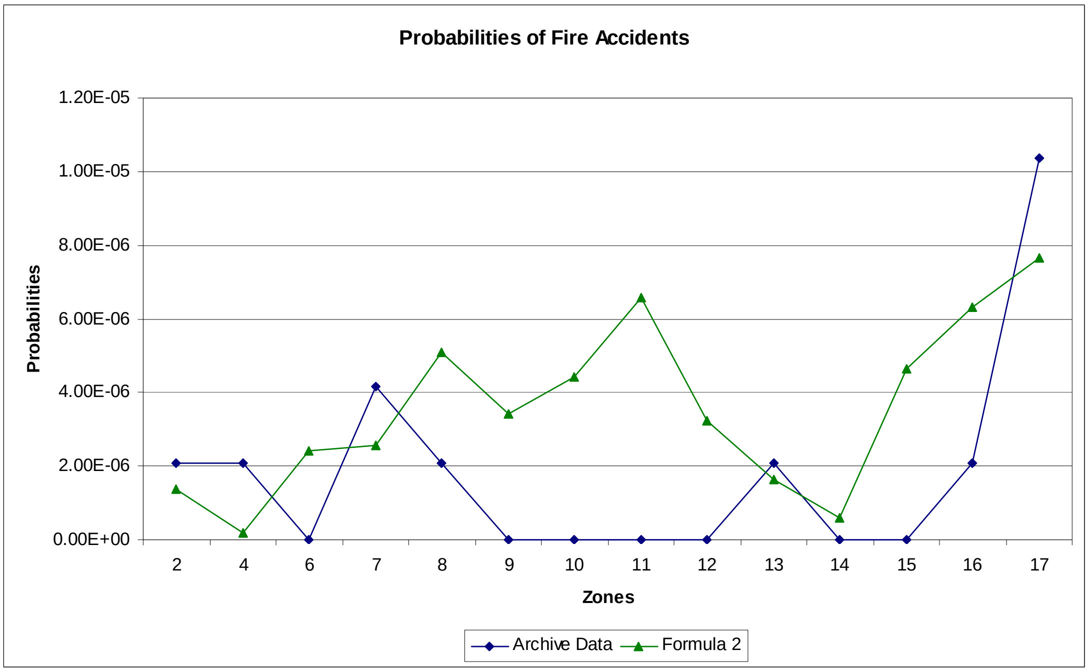


Figure 5.12 Probabilities of Fire Accidents (Formula 2)

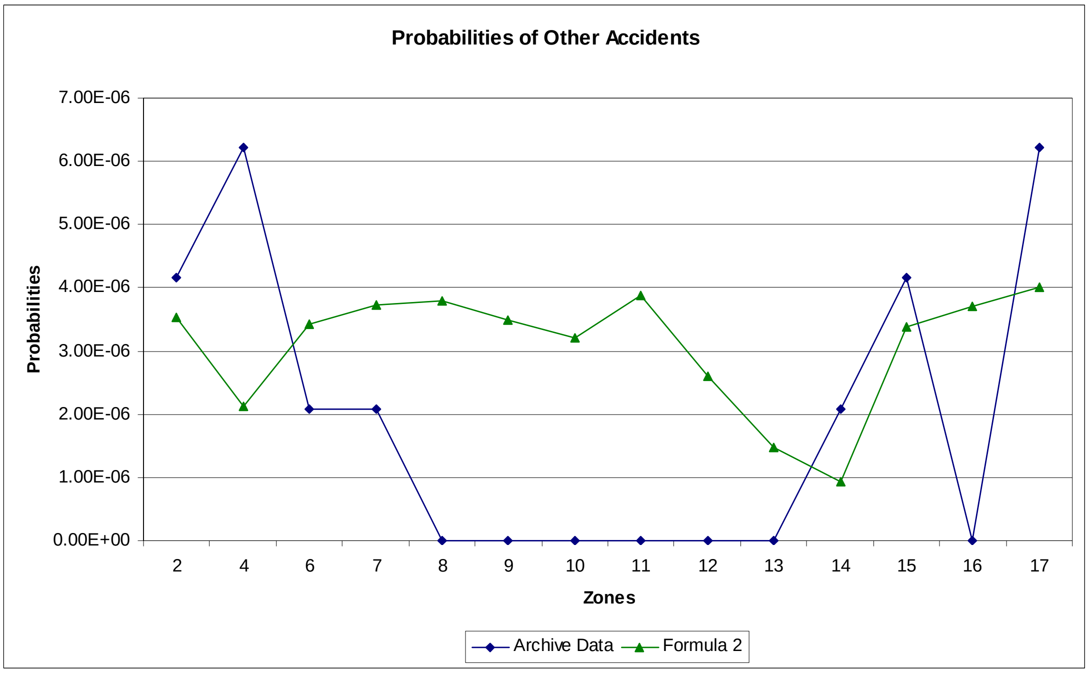


Figure 5.13 Probabilities of Other Accidents (Formula 2)

The outcomes of Formula 2 for total accidents, collision accidents, capsizing accidents, fire accidents and other accidents were not compatible with the existing maritime accident data.

5.4 Model 1

ANFIS analysis has been processed for 6 input parameters. The training and test of the ANFIS model has been made by the UMA accident data. Six probabilities consist of the probability of total accidents, the probability of collision accidents, the probability of capsizing accidents, the probability of grounding accidents, the probability of fire accidents and the probability of other accidents has been forecasted by the ANFIS model.

A constant sugeno type ANFIS model has been processed by backpropagation method with 1000 epoch, i.e. iterations.

The coefficient of determination (R^2) has been considered to define the compatibility of the model results with the existing data. As it is seen in Table 5.6 R^2 with all minus values are not acceptable.

Table 5.6 The coefficients of Determination, R^2 (Model 1)

	Probabilities					
Analysis	**Total Accidents**	**Collision Accidents**	**Capsizing Accidents**	**Grounding Accidents**	**Fire Accidents**	**Other Accidents**
Model 1	-4904.011	-9776.453	-43729.262	-19733.289	-119253.584	-228604.810

The average of the probabilities forecasted by the ANFIS model and archive data has been presented between Figure 5.14 and Figure 5.19 for the visual comparison of the

ANFIS model and archive data. All forecasted probabilities of the ANFIS model can be seen in Appendix I.

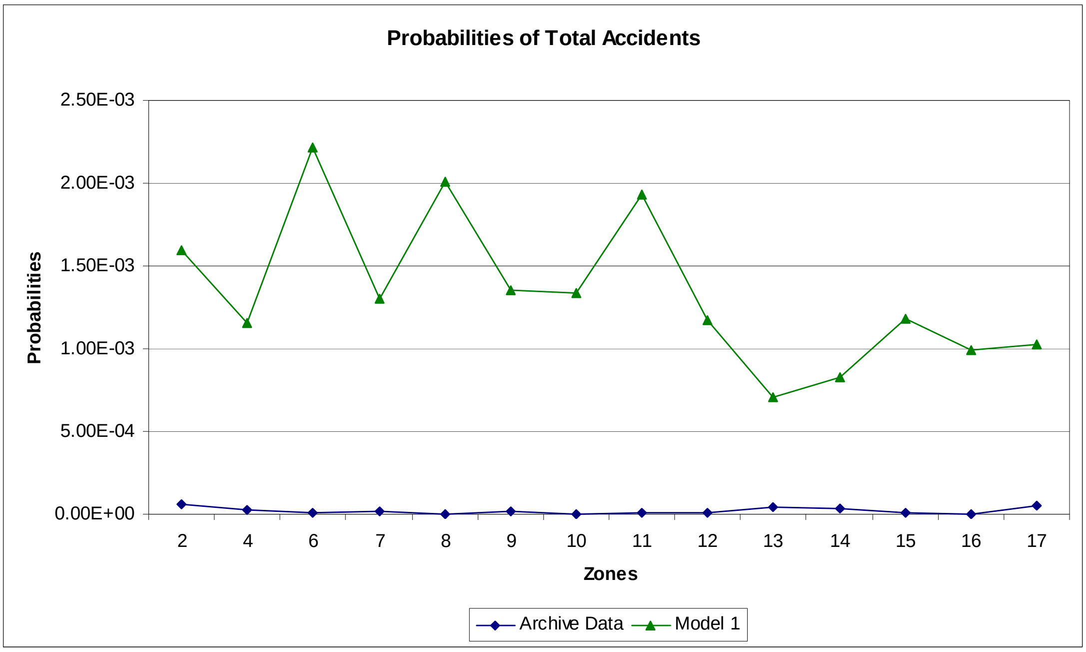


Figure 5.14 Probabilities of Total Accidents (Model 1)

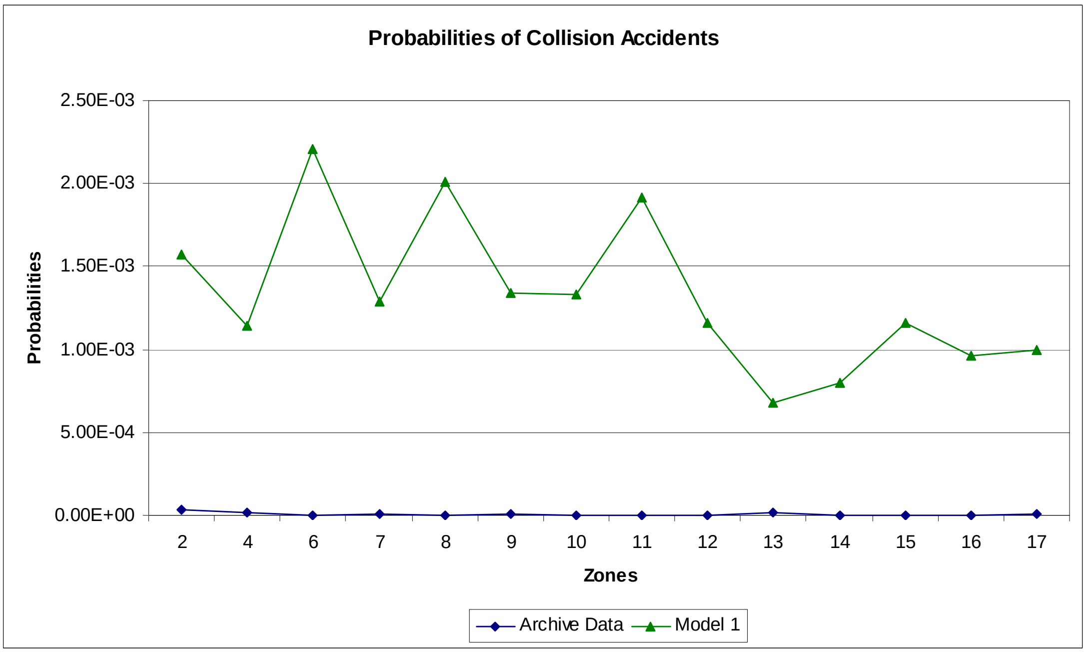


Figure 5.15 Probabilities of Collision Accidents (Model 1)

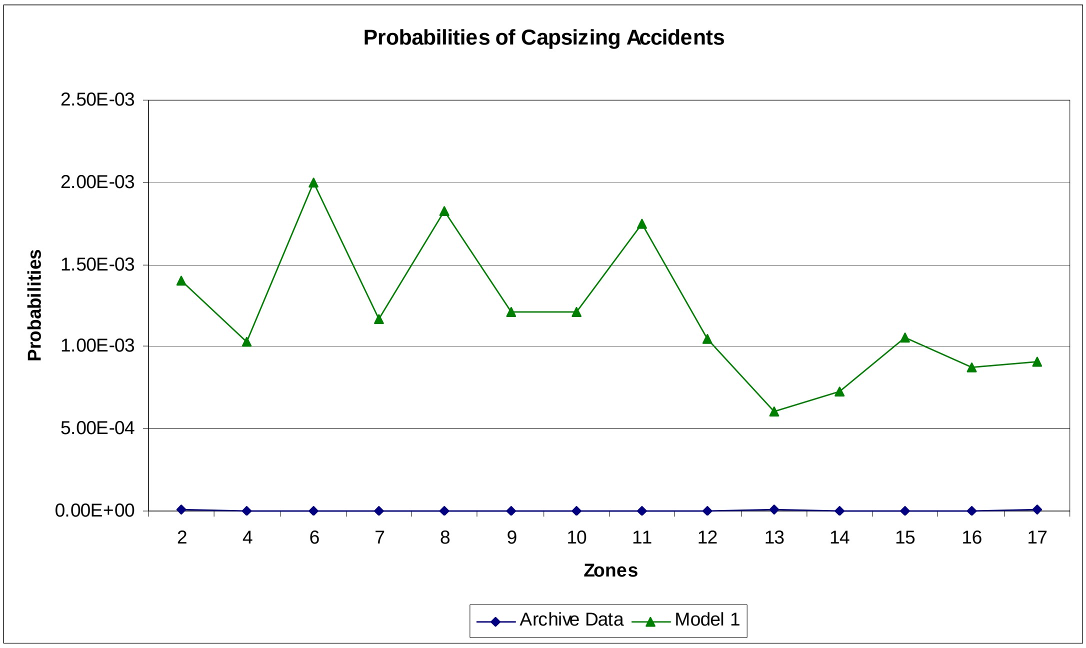


Figure 5.16 Probabilities of Capsizing Accidents (Model 1)

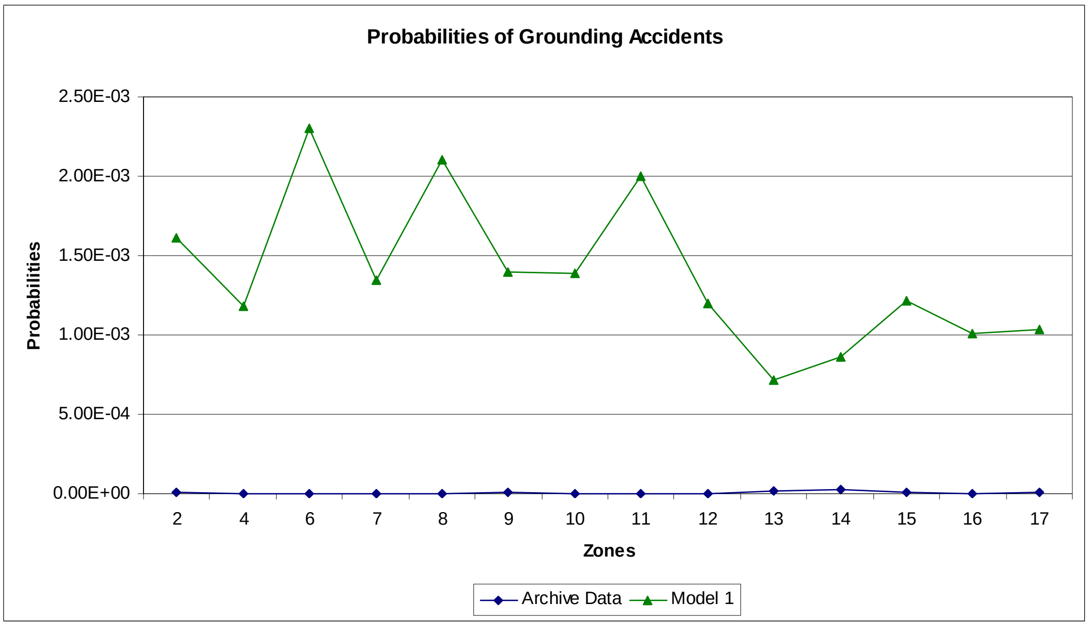


Figure 5.17 Probabilities of Grounding Accidents (Model 1)

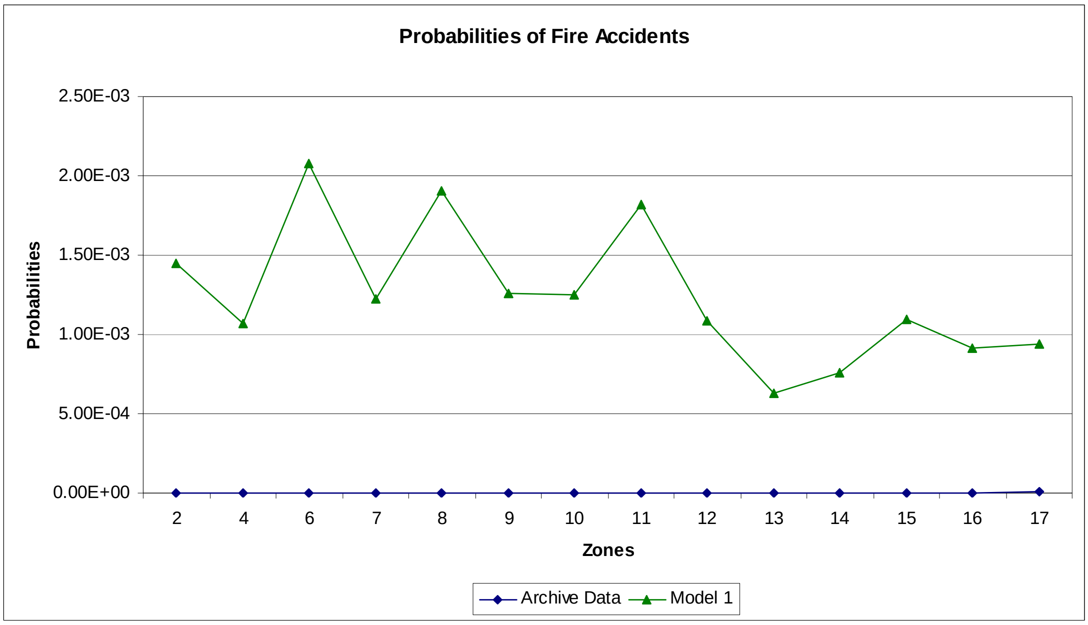


Figure 5.18 Probabilities of Fire Accidents (Model 1)

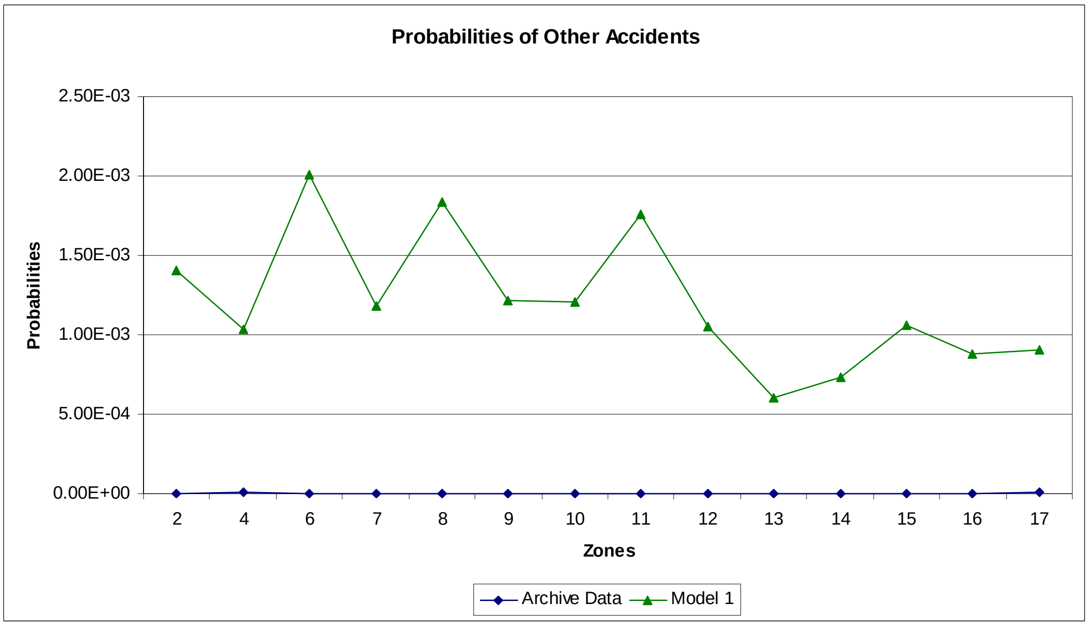


Figure 5.19 Probabilities of Other Accidents (Model 1)

The outcomes of Model 1 for total, collision, capsizing, fire and other accidents were not compatible with the existing maritime accident data. The order of the magnitude did not even match with the order of maritime accident data of UMA.

However the existing maritime accident data is very small such as E-05, E-06 and E-07 the results of the ANFIS tool might be not forecast the existing maritime data.

5.5 Model 2 (MAcRisk, Maritime Accident Risk Model)

In the development of this model ANN analysis has been processed for 6 input parameters. The train, test and validation of the ANN model have been made by the UMA accident data. Six probabilities consist of the probability of total accidents, the probability of collision accidents, the probability of capsizing accidents, the probability of grounding accidents, the probability of fire accidents and the probability of other accidents have been forecasted by the ANN model.

The average of the forecasted probabilities of the MAcRisk and archive data have been presented between Figure 5.20 and Figure 5.25 for the visual comparison of the probabilities of the maritime accidents obtained from MAcRisk and archive data given with its archive number. All forecasted probabilities of the MAcRisk is presented in Appendix J.

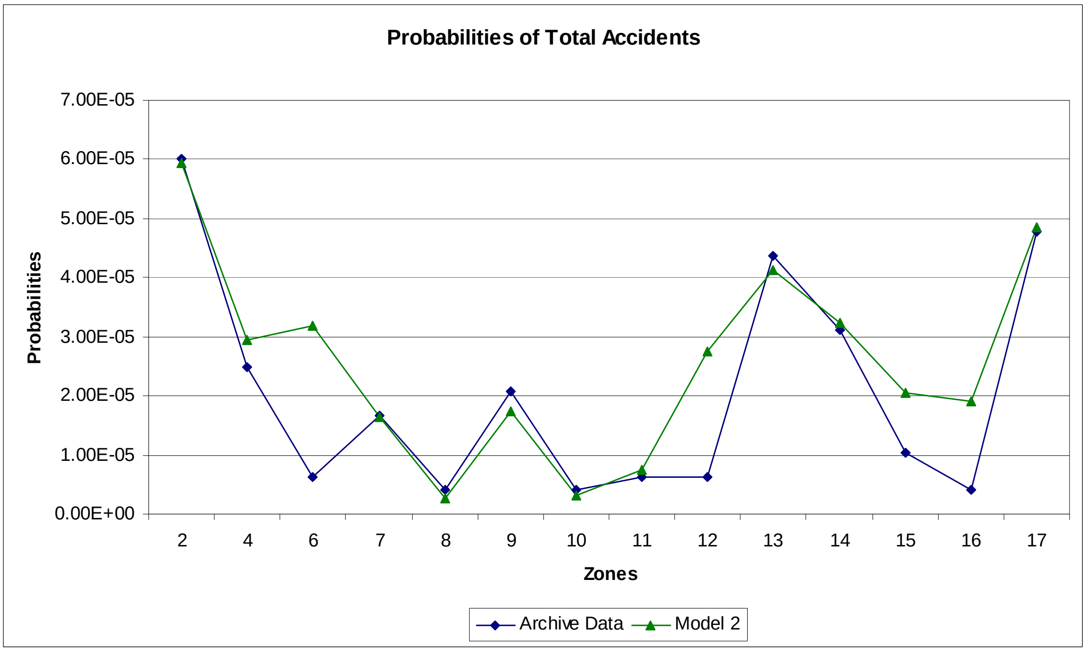


Figure 5.20 Probabilities of Total Accidents (MAcRisk)

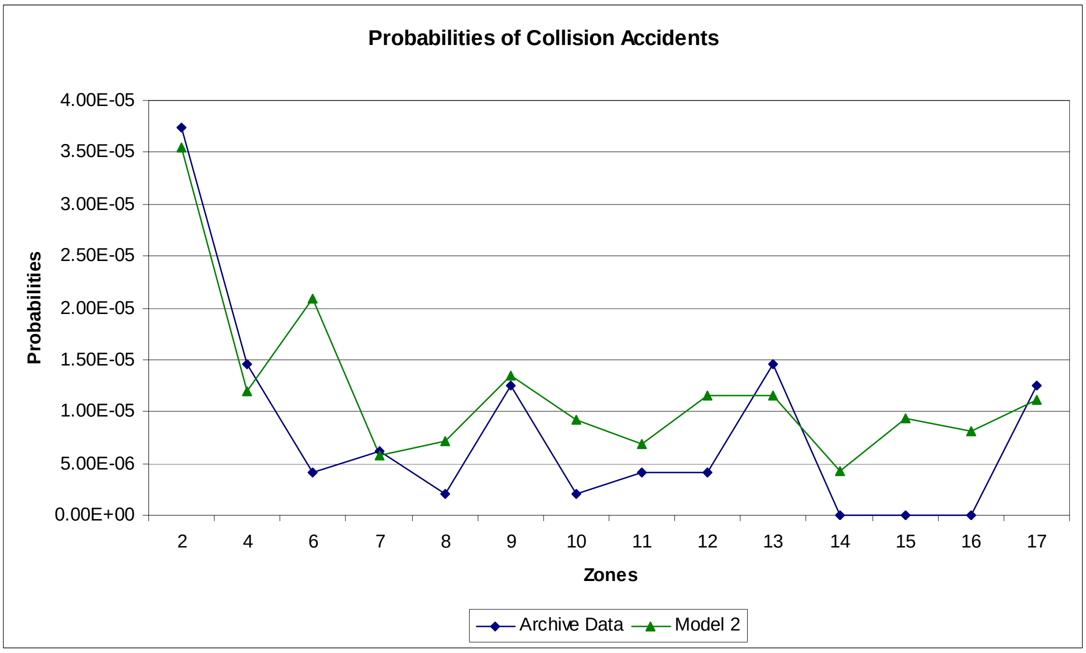


Figure 5.21 Probabilities of Collision Accidents (MAcRisk)

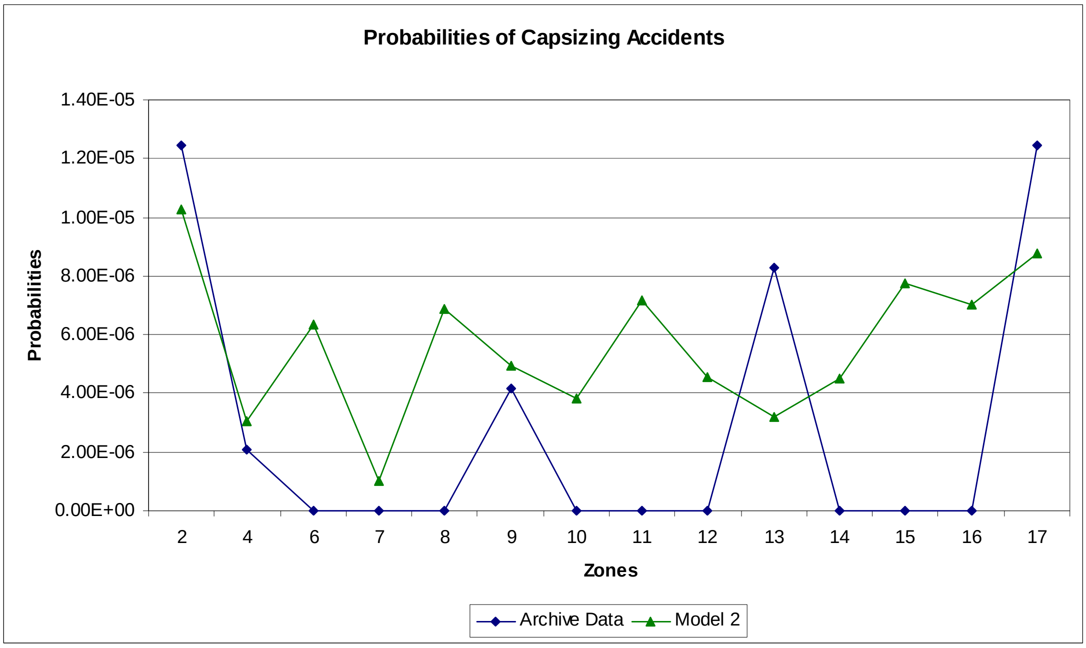


Figure 5.22 Probabilities of Capsizing Accidents (MAcRisk)

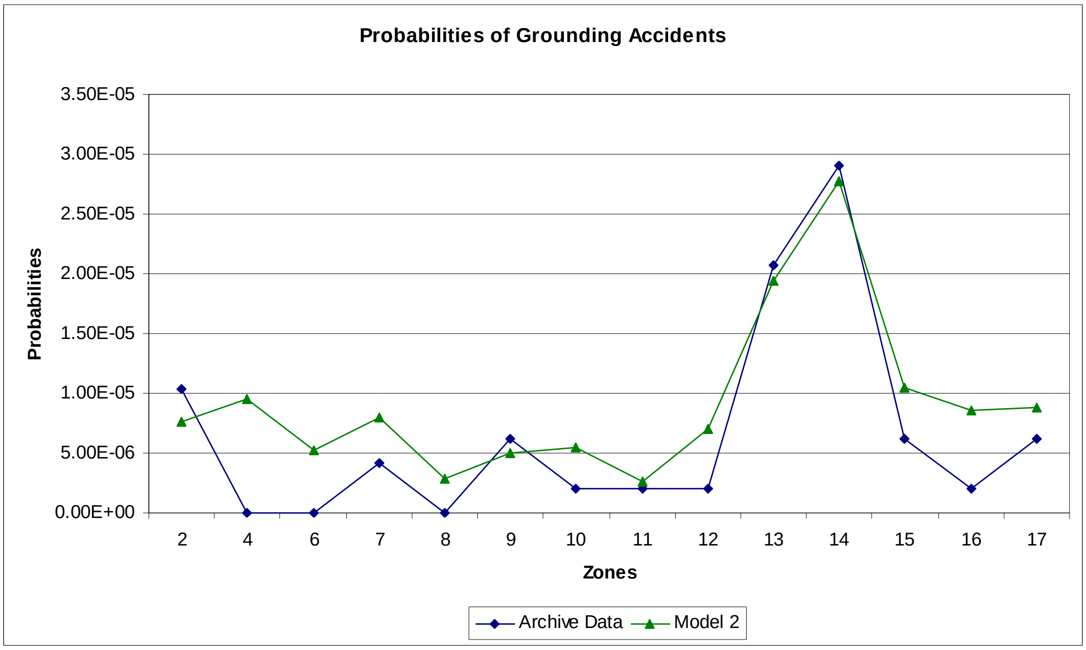


Figure 5.23 Probabilities of Grounding Accidents (MAcRisk)

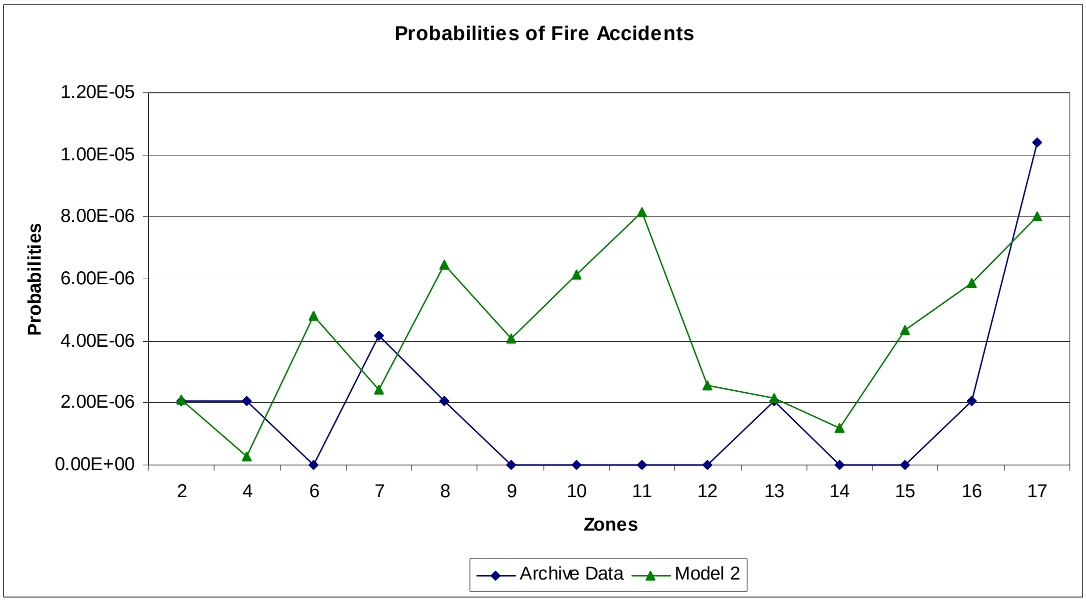


Figure 5.24 Probabilities of Fire Accidents (MAcRisk)

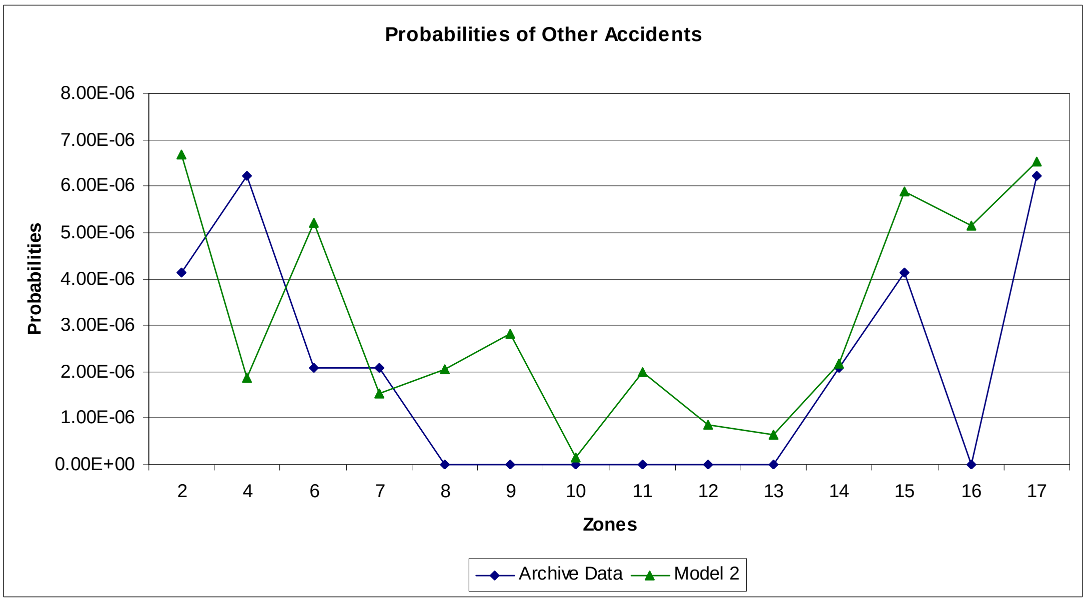


Figure 5.25 Probabilities of Others Accidents (MAcRisk)

The probabilities of accidents for Bosphorus (Appendix A) have been presented in Table 5.7. The probabilities of accidents for Bosphorus obtained by using MAcRisk (Appendix J) have been presented in Table 5.8.

Table 5.7 The probabilities of accidents for Bosphorus based on UMA data (*E-05)

Zones	Prob. of Collision	Prob. of Grounding	Prob. of Capsizing	Prob. of Fire	Prob. of Others	Prob. of Total Accidents
2	3.74	1.04	0.62	0.21	0.42	6.02
4	1.45	0.00	0.21	0.21	0.62	2.49
6	0.42	0.00	0.00	0.00	0.21	0.62
7	0.62	0.42	0.00	0.42	0.21	1.66
8	0.21	0.00	0.00	0.21	0.00	0.42
9	1.25	0.62	0.21	0.00	0.00	2.08
10	0.21	0.21	0.00	0.00	0.00	0.42
11	0.42	0.21	0.00	0.00	0.00	0.62
12	0.42	0.21	0.00	0.00	0.00	0.62
13	1.45	2.08	0.62	0.21	0.00	4.36
14	0.00	2.91	0.00	0.00	0.21	3.11
15	0.00	0.62	0.00	0.00	0.42	1.04
16	0.00	0.21	0.00	0.21	0.00	0.42
17	1.25	0.62	1.25	1.04	0.62	4.77

Prob. = Probability

Table 5.8 The probabilities of accidents for Bosphorus according to MAcRisk Forecast (*E-05)

Zones	Prob. of Collision	Prob. of Grounding	Prob. of Capsizing	Prob. of Fire	Prob. of Others	Prob. of Total Accidents
2	3.55	0.77	1.03	0.21	0.51	5.94
4	1.19	0.96	0.30	0.00	0.31	2.95
6	2.09	0.52	0.64	0.48	0.41	3.19
7	0.58	0.79	0.08	0.24	0.29	1.64
8	0.71	0.28	0.69	0.65	0.46	0.22
9	1.34	0.50	0.50	0.41	0.46	1.74
10	0.93	0.55	0.38	0.61	0.23	0.32
11	0.69	0.26	0.72	0.82	0.69	0.75
12	1.15	0.70	0.45	0.26	0.11	2.74
13	1.15	1.94	0.29	0.21	0.00	4.13
14	0.42	2.78	0.45	0.08	0.07	3.23
15	0.93	1.04	0.77	0.44	0.80	2.04
16	0.82	0.85	0.70	0.59	0.90	1.90
17	1.11	0.89	0.88	0.80	0.98	4.84

Prob. = Probability

The coefficient of determination (R^2) has been considered to define the compatibility of the probability of maritime accidents results obtained from MAcRisk with the existing UMA data. As it is seen in Table 5.9 R^2 has its maximum values compared to the results of all other approaches. It ranges between maximum for collision accidents with R^2 = 0.846 and minimum for the others with R^2 = 0.149 and R^2 for total accidents was ~0.87.

Table 5.9 The coefficients of Determination (R^2), (MAcRisk)

Analysis	**Total Accidents**	**Collision Accidents**	**Grounding Accidents**	**Capsizing Accidents**	**Fire Accidents**	**Other Accidents**
Model 2	0.867	0.846	0.781	0.386	0.279	0.149

The outcomes of MAcRisk (Model 2) for total, collision and grounding accidents are rather compatible with R^2 being around 0.8. For capsizing, fire and other accidents, R^2 obtained very small the compatibility is considered questionable. MAcRisk model at this stage found to be appropriate to estimate the probabilities of maritime accidents especially collision and grounding type of accidents using the basic parameters selected as current velocity (*CV*), length overall ship (*LOA*), average turn of vessel (*AT*), daily maximum wind speed (*DWS*), Ratio of Passage Area to Zone Area (*RPA*), and Monthly Total Precipitation (*MTP*). These basic parameters of the model being easily obtainable from the existing database and accepted as accurate enough under current circumstances, makes MAcRisk easily applicable to estimate the maritime accidents probabilities by different scenarios where the parameters are subject to changes expected in future.

Collision and grounding accidents are related strongly with the based parameters used in modeling yet capsizing accidents might be the outcome of collision and grounding where as fire and other accidents are mostly due to human errors difficult to define accurately enough.

Although MAcRisk is developed on basic parameters that could be defined mathematically the results the high compatibility of the estimated probabilities with the existing data which ensures the validity of the model developed, there are some differences in the results in the order of magnitude. This difference might be due to decreasing number of accidents which is due to the fact that the navigation management through the Bosphorus has been reorganized effectively since 2009 to minimize the accident risks.

The number of accidents (for 50000 vessels passage) based on UMA data is presented in Table 5.10 and in Table 5.11 number of accidents obtained from MAcRisk based on 50000 vessel passage which is the annual average of the vessels passing through Bosphorus obtained by averaging the data within the last 15 years.

Table 5.10 Number of accidents for Bosphorus based on UMA data
(for 50000 vessels passage)

Zones	**Collision**	**Grounding**	**Capsizing**	**Fire**	**Others**	**Total Accidents**
2	1.87	0.52	0.31	0.10	0.21	3.01
4	0.73	0.00	0.10	0.10	0.31	1.25
6	0.21	0.00	0.00	0.00	0.10	0.31
7	0.31	0.21	0.00	0.21	0.10	0.83
8	0.10	0.00	0.00	0.10	0.00	0.21
9	0.62	0.31	0.10	0.00	0.00	1.04
10	0.10	0.10	0.00	0.00	0.00	0.21
11	0.21	0.10	0.00	0.00	0.00	0.31
12	0.21	0.10	0.00	0.00	0.00	0.31
13	0.73	1.04	0.31	0.10	0.00	2.18
14	0.00	1.45	0.00	0.00	0.10	1.56
15	0.00	0.31	0.00	0.00	0.21	0.52
16	0.00	0.10	0.00	0.10	0.00	0.21
17	0.62	0.31	0.62	0.52	0.31	2.39

Table 5.11 Number of accidents for Bosphorus according to MAcRisk Forecast (for 50000 vessels passage)

Zones	**Collision**	**Grounding**	**Capsizing**	**Fire**	**Others**	**Total Accidents**
2	1.77	0.38	0.51	0.10	0.26	2.97
4	0.60	0.48	0.15	0.00	0.15	1.47
6	1.05	0.26	0.32	0.24	0.21	1.59
7	0.29	0.40	0.04	0.12	0.15	0.82
8	0.35	0.14	0.34	0.32	0.23	0.11
9	0.67	0.25	0.25	0.20	0.23	0.87
10	0.46	0.27	0.19	0.31	0.12	0.16
11	0.34	0.13	0.36	0.41	0.34	0.38
12	0.58	0.35	0.23	0.13	0.05	1.37
13	0.58	0.97	0.14	0.10	0.00	2.06
14	0.21	1.39	0.23	0.04	0.04	1.62
15	0.46	0.52	0.39	0.22	0.40	1.02
16	0.41	0.43	0.35	0.29	0.45	0.95
17	0.56	0.44	0.44	0.40	0.49	2.42

The differences in the number of collision (Zones 2, 6, 10, 14, 15 and 16) and grounding accidents (Zones 4, 6, 8 and 16) between UMA data and the model results are clearly seen from Table 5.10 and Table 5.11. Based on UMA data the occurrence of number of the accidents (collision and grounding) are much smaller than the estimated from the MAcRisk. This difference has been explained already by the change of navigation management in Bosphorus which is a positive step forward to minimize the risk of accidents. Besides any maritime accident in Bosphorus might result in devastating results not comparable to any other waterway because Istanbul, with her natural beauties and rich history, is a town with high local and international tourism potential, and from this view point one of the most attractive towns of the world. Besides her natural beauties, Istanbul has a lot of historical works remaining from the Byzantium and Ottoman periods. Due to her geographic location, Istanbul has always been a settlement area from early ages onwards. And besides connecting the two continents, Europe and Asia, Istanbul has become a center where various cultures and religions are combined, survived and succeeded each other.

Istanbul was chosen as a joint European Capital of Culture for 2010 and the European Capital of Sports for 2012.

Heritage is our legacy from the past, what we live with today, and what we pass on to future generations. Cultural and natural heritage of Istanbul are both irreplaceable sources of life and inspiration. Places as unique and diverse monuments are the cultural treasures especially those bordering the Bosphorus make up Istanbul world's heritage. Since World Heritage sites belong to all the peoples of the world, irrespective of the territory on which they are located The United Nations Educational, Scientific and Cultural Organization (UNESCO) seeks to encourage the identification, protection and preservation of cultural and natural heritage around the world considered to be of outstanding value to humanity.

This is the pressing concern for this study on the risk assessment of the maritime accidents in Bosphorus which is called the cradle of civilization.

Therefore the UMA results which gives almost zero probabilities especially for collision and grounding has to be interpreted cautiously and model results has to be taken as a possibility to take necessary steps in minimizing the risk. Regarding this outcome pilot service becomes a must under all circumstances.

Finally, one must keep in mind that the difficulties with maritime accident data sources are "challenging because they actually not intended to use for estimation of accident probabilities and maritime traffic risks and difficulties" as stated in literature by Dougherty (1995), Hashemi et al. (1995), Blanc et al. (2001), IAEA (2001), SKEMA (2009).

5.6 Discussion of the Results

In this section, application of Method II of American Association of State Highway and Transportation Officials (AASHTO), Formula 1 developed considering AASHTO, Formula 2 (Multiple Linear Regression), Model 1 (Adaptive Neuro Fuzzy Inference System (ANFIS)) and Model 2 (Artificial Neural Network) approaches have been used to forecast maritime accident probabilities for Bosphorus.

The estimated maritime accident probability results are not compatible with the existing maritime accident data (UMA) except MAcRisk model. This conclusion is based on the computations of coefficient of determination given in tables; Table 5.4, Table 5.5, Table 5.6 and Table 5.9. MAcRisk is the most suitable model among the other results to simulate the accident probability for Bosphorus giving the maximum coefficient of determination values.

The maritime accident probabilities and number of the maritime accidents for 50000 vessel passage for Bosphorus have been compiled considering the zones and presented in Table 5.8 (probability) and Table 5.11 (number of accidents) for different accidents types.

Maritime accident probabilities are listed in descending order starting from Rank 1 to Rank 14 for each type of accidents signifying the Zones in Table 5.12 and Table 5.13. Thus the zones under the risk of maritime accidents can easily be seen from these tables.

Table 5.12 The Rank of the zones for collision, capsizing and grounding type of accidents

	Collision		**Capsizing**		**Grounding**	
Rank	**Zones**	**Probabilities**	**Zones**	**Probabilities**	**Zones**	**Probabilities**
1	2	3.55E-05	2	1.03E-05	14	2.78E-05
2	6	2.09E-05	17	8.77E-06	13	1.94E-05
3	9	1.34E-05	15	7.74E-06	15	1.04E-05
4	4	1.19E-05	11	7.19E-06	4	9.55E-06
5	12	1.15E-05	16	7.01E-06	17	8.86E-06
6	13	1.15E-05	8	6.89E-06	16	8.52E-06
7	17	1.11E-05	6	6.36E-06	7	7.94E-06
8	15	9.28E-06	9	4.97E-06	2	7.65E-06
9	10	9.27E-06	12	4.54E-06	12	7.00E-06
10	16	8.16E-06	14	4.52E-06	10	5.50E-06
11	8	7.08E-06	10	3.83E-06	6	5.20E-06
12	11	6.86E-06	4	3.00E-06	9	4.98E-06
13	7	5.77E-06	13	2.86E-06	8	2.83E-06
14	14	4.20E-06	7	8.28E-07	11	2.56E-06

Table 5.13 The Rank of the zones for fire, others and total type of accidents

	Fire		**Others**		**Total**	
Rank	**Zones**	**Probabilities**	**Zones**	**Probabilities**	**Zones**	**Probabilities**
1	11	8.15E-06	17	9.75E-06	2	5.94E-05
2	17	8.03E-06	16	8.97E-06	17	4.84E-05
3	8	6.47E-06	15	8.02E-06	13	4.13E-05
4	10	6.14E-06	11	6.85E-06	14	3.23E-05
5	16	5.85E-06	2	5.14E-06	6	3.19E-05
6	6	4.79E-06	8	4.65E-06	4	2.95E-05
7	15	4.36E-06	9	4.62E-06	12	2.74E-05
8	9	4.08E-06	6	4.11E-06	15	2.04E-05
9	12	2.57E-06	4	3.05E-06	16	1.90E-05
10	7	2.44E-06	7	2.95E-06	9	1.74E-05
11	2	2.10E-06	10	2.32E-06	7	1.64E-05
12	13	2.07E-06	12	1.09E-06	11	7.54E-06
13	14	7.66E-07	14	7.36E-07	10	3.16E-06
14	4	0.00E+00	13	0.00E+00	8	2.21E-06

As it is seen from Table 5.12 and Table 5.13;

- For the collision type accident probabilities are ranked for zones as; Zone 2 (entrance); Zone 6; Zone 9; Zone 4; Zone 12 and Zone 13 (Figure 5.26).
- For the capsizing type accident probabilities are ranked for zones as; Zone 2; Zone 17; Zone 15; Zone 11; Zone 16; Zone 8 (Figure 5.27).
- For the grounding type accident probabilities are ranked for zones as; Zone 14; Zone 13; Zone 15; Zone 4; Zone 17; Zone 16 (Figure 5.28).
- For the fire type accident probabilities are ranked for zones as; Zone 11; Zone 17; Zone 8; Zone 10; Zone 16; Zone 6 (Figure 5.29).
- For the others type accident probabilities are ranked for zones as; Zone 17; Zone 16; Zone 15; Zone 11; Zone 2; Zone 8 (Figure 5.30).
- For the total accident probabilities are ranked for zones as; Zone 2; Zone 17; Zone 13; Zone 14; Zone 6; Zone 4 (Figure 5.31).

The results of probability computations of maritime accidents through Bosphorus and number of accidents computed from these probabilities based on UMA data and MAcRisk model are given in tables (Table 5.7, Table 5.8, Table 5.10 and Table 5.11). The forecasted maritime accidents for Bosphorus using MAcRisk are also presented in figures (Figure 5.26 - Figure 5.31) for different accident types and for Zones 2 to 17.

The map of each type of accidents has different intervals as seen on the legend of the figures. The rank of the intervals are also given in the legend with different colors.

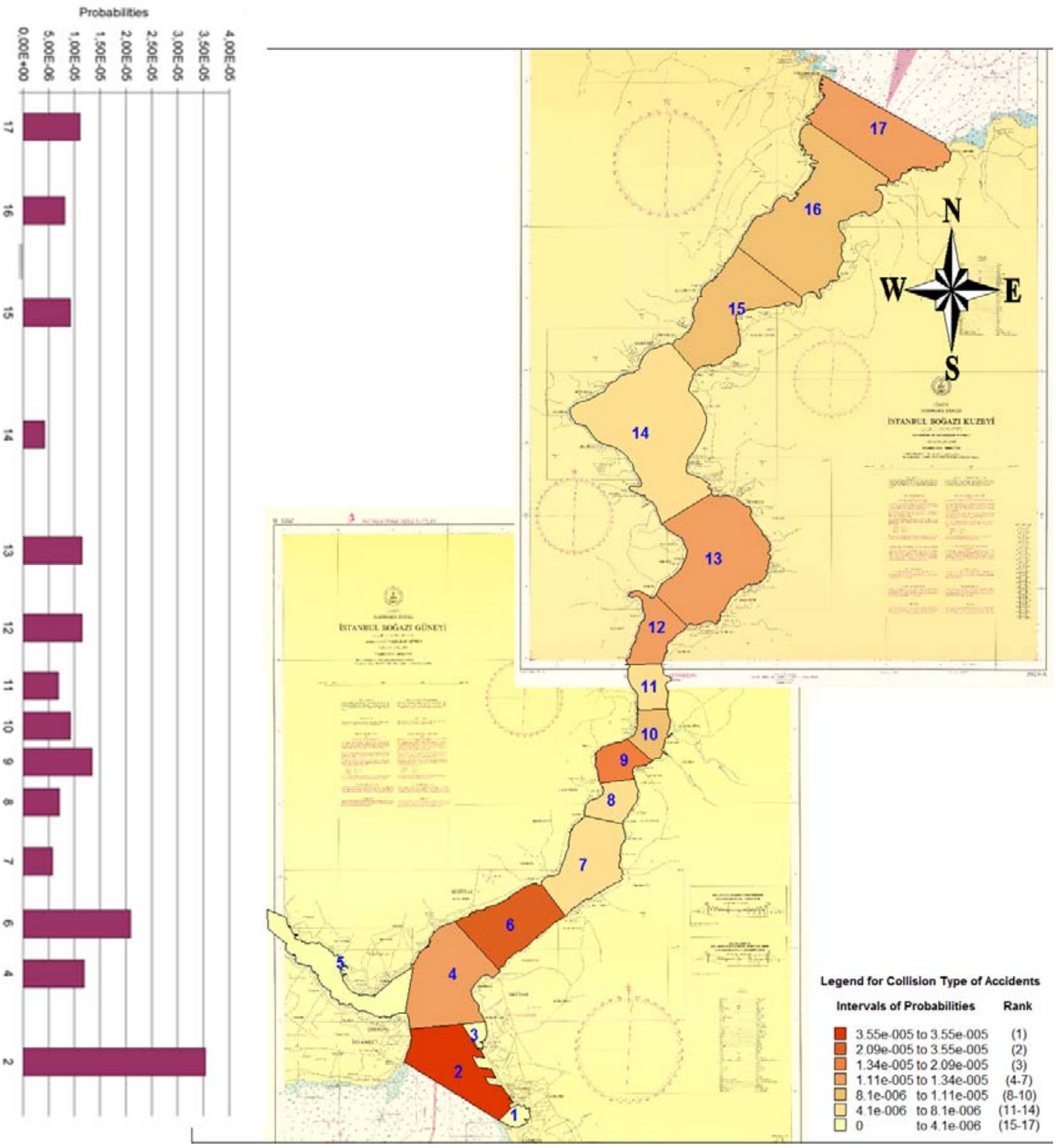


Figure 5.26 Map of probability of collision type of accidents

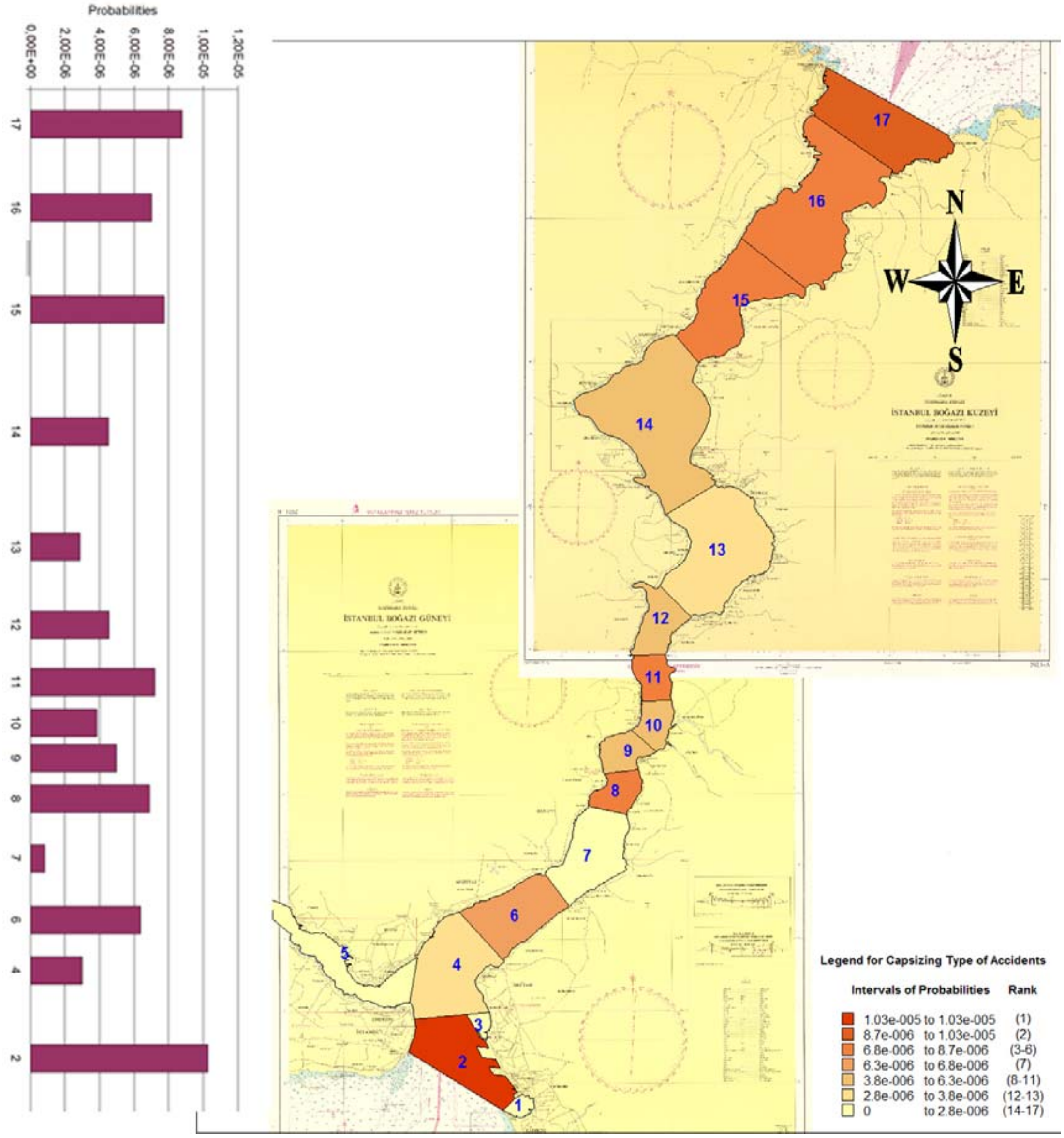


Figure 5.27 Map of probability of capsizing type of accidents

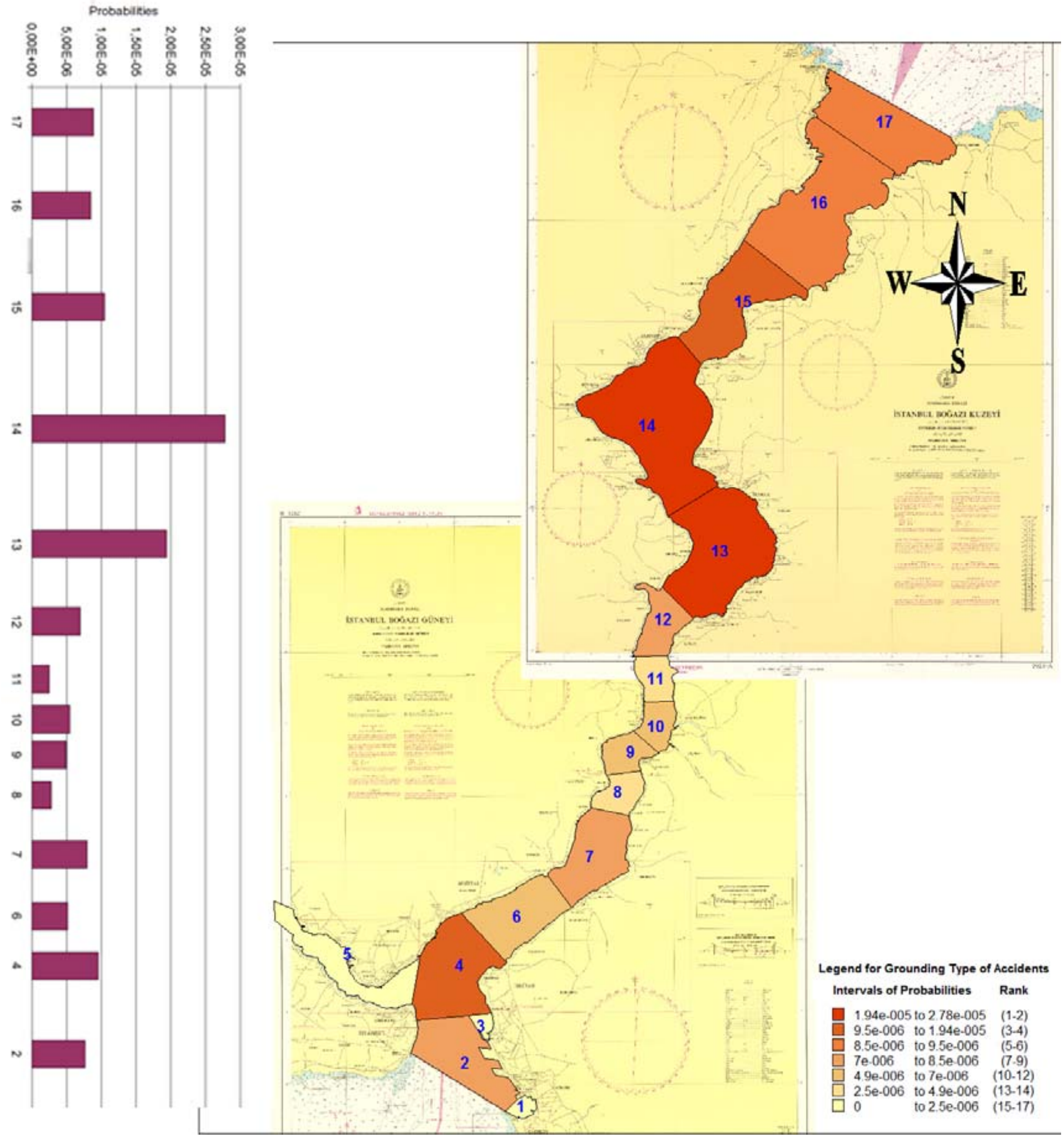


Figure 5.28 Map of probability of grounding type of accidents

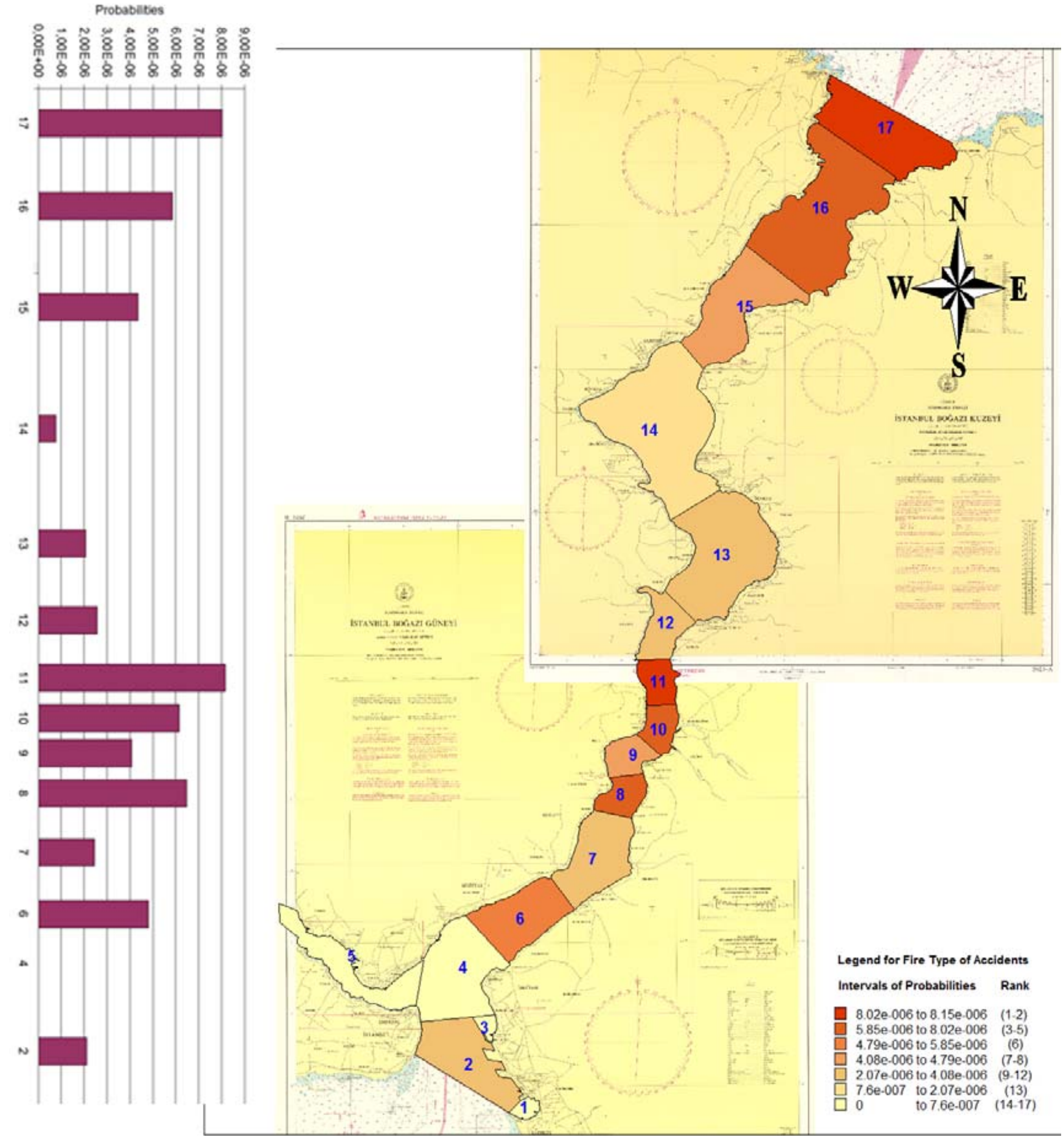


Figure 5.29 Map of probability of fire type of accidents

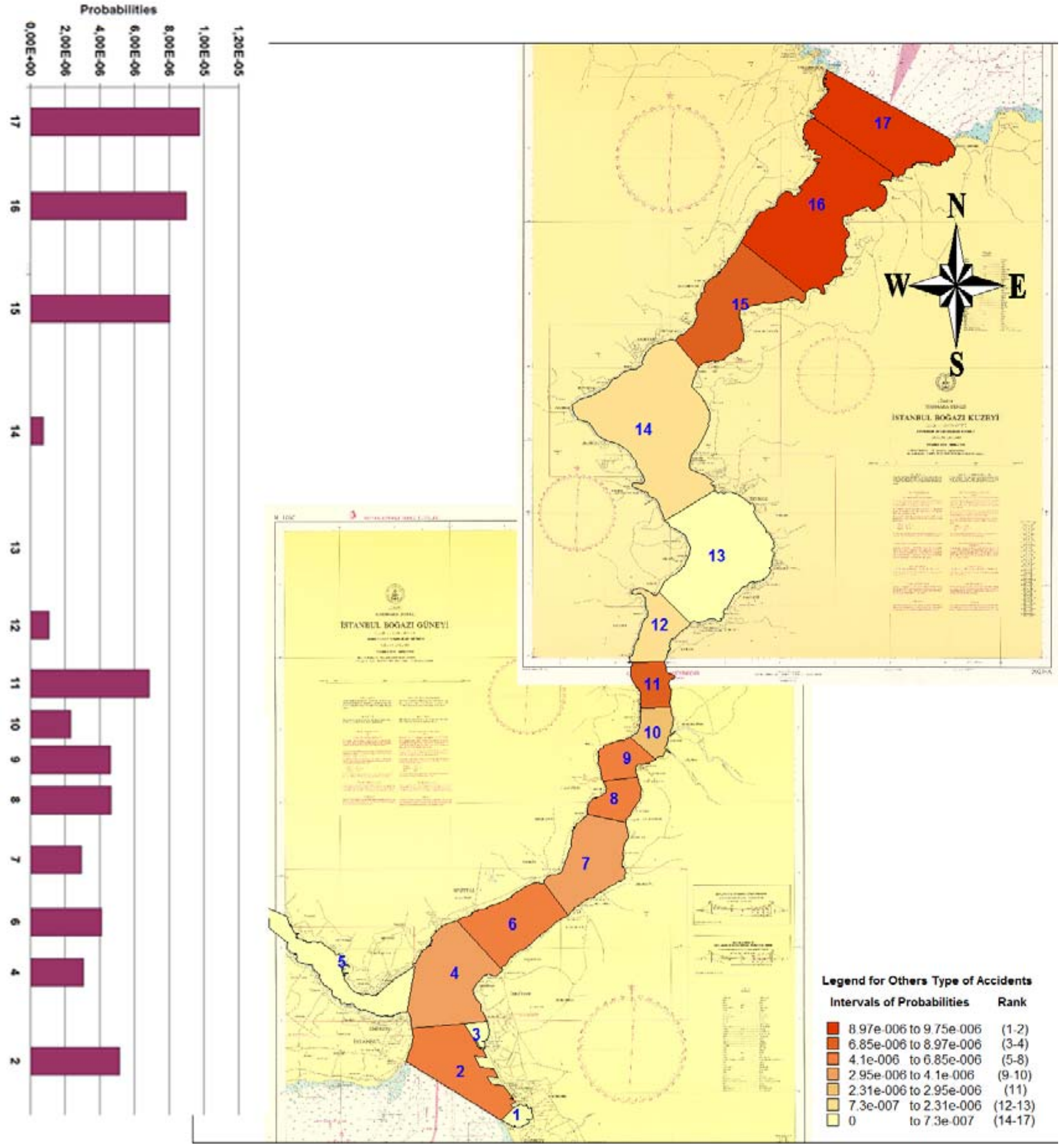


Figure 5.30 Map of probability of others type of accidents

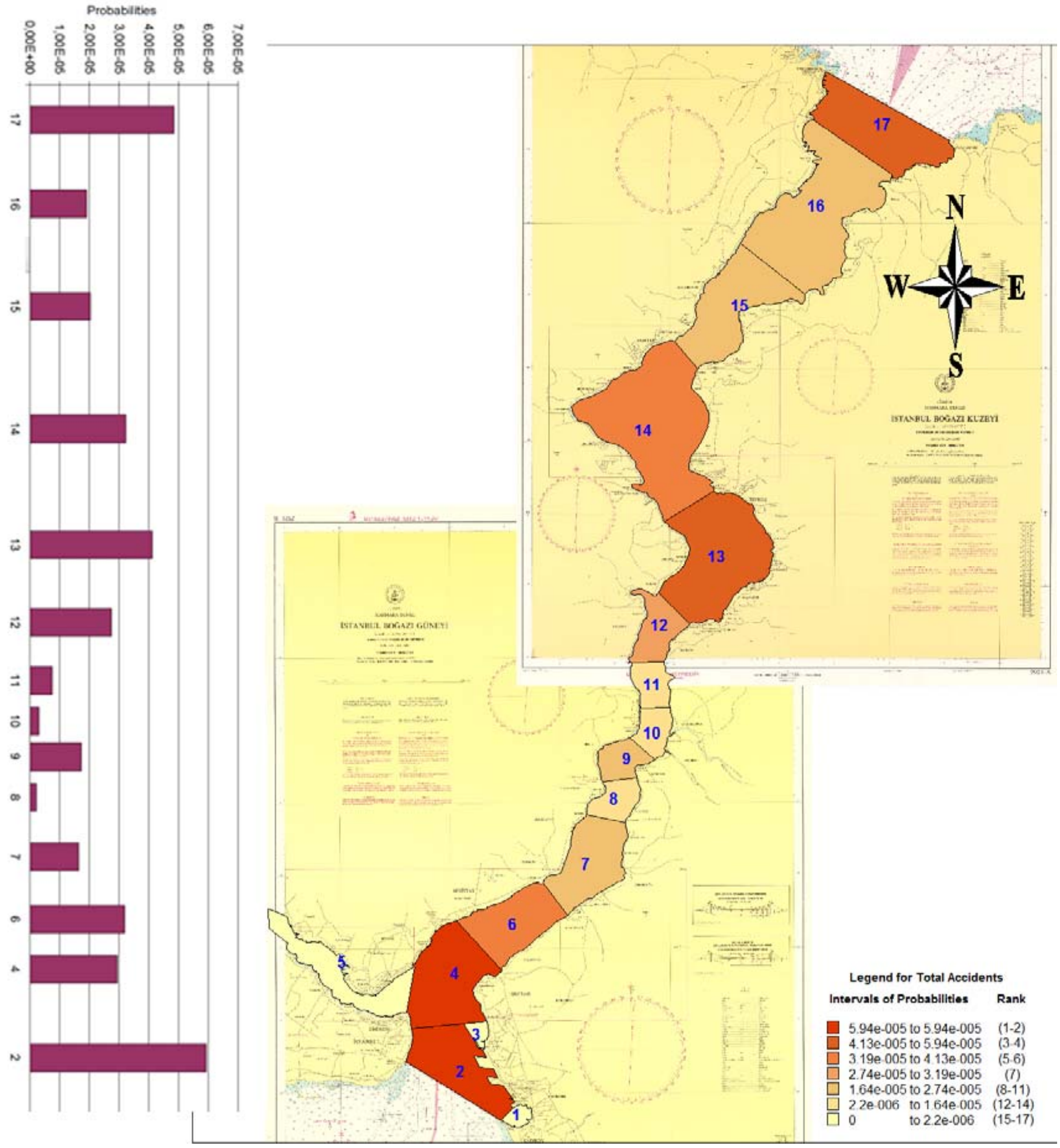


Figure 5.31 Map of probability of total accidents

Based on these results presented, it is seen that Zone 2 and Zone 17 take place in the top ranks. This result might be due to the fact that in UMA data the accidents taking place in the anchoring places within vicinity of Zone 2 and Zone 17 were being recorded with unclear location. In the probability computations these type of data is considered to take place in Zone 2 and 17 within the Bosphorus.

Bosphorus has historical and cultural heritages located on the shore as, Dolmabahce Palace, Ciragan Palace, Maiden's Tower and Beylerbeyi Palace (Figure 5.32). These heritages are also under threat because of the maritime accidents on Bosphorus where taken place in Zone 4, Zone 6 and Zone 7. These results show the threat of the historical heritages on the Bosphorus. It has to be remembered that waterfront houses decorating the Bosphorus are the main target of such a devastating maritime accidents where human life is in danger as well.

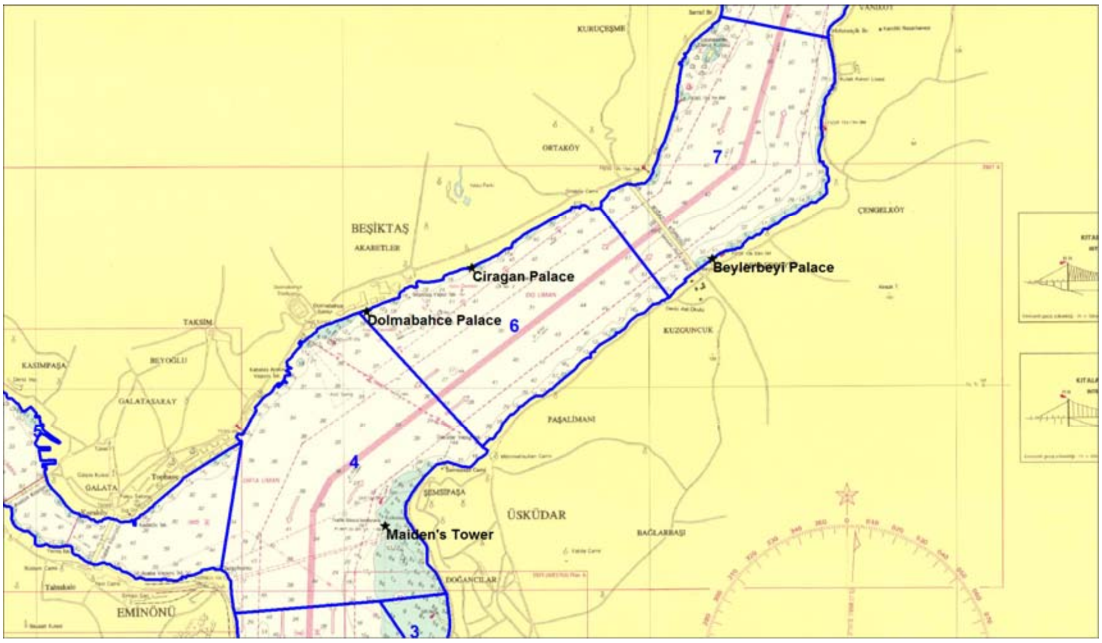


Figure 5.32 Locations of the Heritages on Bosphorus

Computational result can be viewed in two parts: firstly in terms of physical characteristics of Bosphorus, turn or bend region, the width and shoals secondly in terms of accidents types.

Zone 4, Zone 9, Zone 13 and Zone 14 are within the turn or bend region in the Bosphorus passage (Figure 5.26). This geomorphologic condition results in high rank of collision and capsizing type of accidents in zone 4, 9 and 13 whereas in zone 14 where Umur Banks (shoals) together with turn or bend region make the grounding type of accident more important.

Zone 15 takes place in the top ranks of the grounding type accident. The narrowing of the passage in Zone 15 can explain the reason of the top place of Zone 15 for the grounding type accident (Figure 5.28).

High occurrence probability of collision type of accidents in Zone 4 could be related to the fact that bend and turn and strong currents. Similarly probability of collision type of accidents is high in Zone 13 might be due to the existing of local currents which is especially high in summer months (Appendix H).

Probabilities of collision, grounding, capsizing types of accidents and total accidents have been forecasted by MAcRisk (which has been trained for the data between 01.01.2001 and 13.05.2010) are presented in Table 5.14 for Zones 4, 9, 13, 14 and 15 taken from Table 5.10 and Table 5.11.

Table 5.14 The UMA data and MAcRisk forecast for 50000 vessel passage

	Archive Data		**Forecast Average of MAcRisk**	
Zones	**Collision Accidents**	**Grounding Accidents**	**Collision Accidents**	**Grounding Accidents**
4	0.73	0.00	0.60	0.48
9	0.62	0.31	0.67	0.25
13	0.73	1.04	0.58	0.97
14	0.00	1.45	0.21	1.39
15	0.00	0.31	0.46	0.52

As its seen from Table 5.14, MAcRisk results are compatible for collision for Zones 4, 9 and 13. Similarly for grounding for all zones MAcRisk results are compatible with UMA data except Zone 14.

However in Zone 14 and 15 for collision there is a big difference in forecasted and existing data. Similarly for grounding in Zone 4 the forecast data is not compatible with archive data. This incompatibility can be explained by the improvement of the management of the Bosphorus strait to minimize the risk of accidents for critical zones Zone 4, Zone 14 and Zone 15 after year 2009. This discussion is sported by the plot of accidents versus years 2001 to 2011. This can be better seen by the graph given in Figure 5.33 where there is a tendency in decreasing the number of accidents.

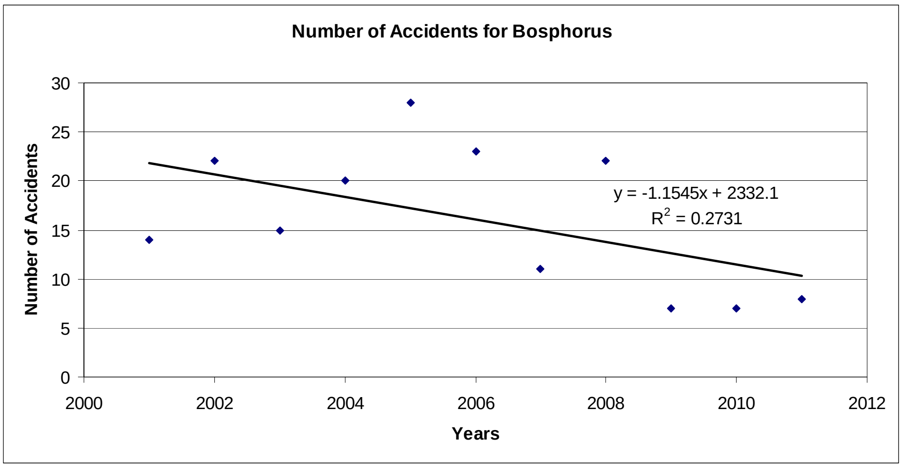


Figure 5.33 Change of the number of accidents in Bosphorus

Fire type of accidents could be occurred mainly from human resources and vessel resources which has no relation with Bosphorus characteristics. Therefore it has no relation with the Zones specified in Bosphorus. Others type of accident is a general concept gives all accident not covered by collision, capsizing, grounding and fire. Therefore forecasting fire and other type of accidents gives very low probabilities and compatible with the UMA data.

Human parameters could not be included in the MAcRisk. Because there is no available dependable source accurate enough to use human parameters effectively in MAcRisk model. However it should always be kept in mind that together with all the parameters taking role effectively in maritime accidents human parameters must also be taken into consideration in future studies.

5.6.1 Future Scenarios

Future scenarios are worked out based on increasing number of vessel passage through Bosphorus (Scenario 1:annual 60000 vessels, and Scenario 2: annual 70000 vessels, passage) by MAcRisk considering only the collision and grounding type of accidents at the most critical zones 4, 9, 13, 14 and 15. The results of the Scenario 1 and 2 are presented in Table 5.15 together with results of MAcRisk for annual 50000 vessels from Table 5.14. It is best that annual number of vessels passing through Bosphorus not being higher than 50000 vessels passing to minimize the accident risk. In recent years 2009-2011 this requirement is being satisfied where the annual number of ships is around 50000 (Table 1.3). The scenarios 1 and 2 are prepared to show possibility of the increase in risk of accidents in case of annual number of ships passing through Bosphorus increase.

Table 5.15 The forecast of MAcRisk for 50000 vessels passage, Scenario 1 (annual 60000 vessels) and Scenario 2 (annual 70000 vessels)

	50000 vessel passage		**Scenario 1**		**Scenario 2**	
Zones	**Collision Accidents**	**Grounding Accidents**	**Collision Accidents**	**Grounding Accidents**	**Collision Accidents**	**Grounding Accidents**
4	0.60	0.48	0.71	0.57	0.83	0.67
9	0.67	0.25	0.80	0.30	0.94	0.35
13	0.58	0.97	0.69	1.16	0.81	1.36
14	0.21	1.39	0.25	1.67	0.29	1.95
15	0.46	0.52	0.56	0.62	0.65	0.73

As its seen in Table 5.15, there is an increase in the number of accidents for all Zones for all type of accidents for Scenario 1 and Scenario 2. This difference is more announced for passage of annual 70000 vessels through Bosphorus.

There is always a possibility of number of vessels passing through Bosphorus increasing which definitely increases the number of accidents taking place in

Bosphorus resulting in high risks for the cultural and natural heritage of Istanbul which are considered to be outstanding value to humanity.

Change in maritime accident probabilities on seasonal variation of current data could not be carried out because of the lack of accurate enough data and remains as a potential study for future.

5.6.2 Recommendations for Improving the Navigation Aids in Bosphorus

Based on the estimations of the maritime accident in Bosphorus obtained from the MAcRisk model to improve the navigation conditions in Bosphorus and to minimize the risk of accidents the following recommendations are given for the critical zones.

5.6.2.1 Zone 4

Zone 4 has a location near the Bosphorus entrance (from Marmara Sea to Black Sea, Figure 5.34). The probability of accidents for Zone 4 and rank of the Zone 4 are presented in Table 5.16.

Table 5.16 The probability of accidents for Zone 4 and rank of Zone 4

Type of Accidents	**Probabilities**	**Rank**
Collision accidents	1.19 E-05	4
Capsizing accidents	3.00 E-06	3
Grounding accidents	9.55 E-06	4
Others accidents	3.05 E-06	9
Fire accidents	0.00 E+00	14
Total accidents	2.95 E-05	6

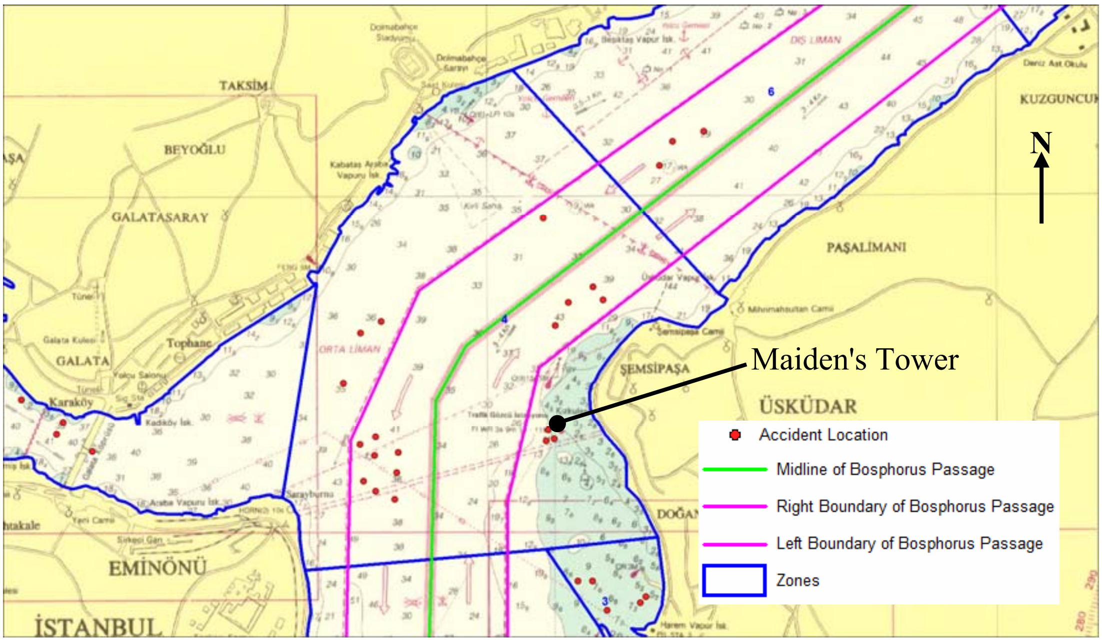


Figure 5.34 Accident locations for Zone 4

Zone 4 is within the turn or bend region in the Bosphorus (Figure 5.34). This geomorphologic condition might results the top ranks for collision and capsizing type of accidents. Although Zone 4 have a shallowing region, it takes a place in the last ranks for grounding type of accidents in forecast also in UMA data. The reason for this situation might be the Maiden's Tower (Figure 5.34) by giving an advice for the passing vessels. Therefore for Zone 4 navigation aids are considered to be worked effectively.

5.6.2.2 Zone 9

Zone 9 has a location near the mid of the Bosphorus (Figure 5.35). The probability of accidents for Zone 9 and rank of the Zone 9 are presented in Table 5.17.

Table 5.17 The probability of accidents for Zone 9 and rank of Zone 9

Type of Accidents	Probabilities	Rank
Collision accidents	1.34 E-05	3
Capsizing accidents	4.97 E-06	8
Grounding accidents	4.98 E-06	12
Others accidents	4.62 E-06	7
Fire accidents	4.08 E-06	8
Total accidents	1.74 E-05	10

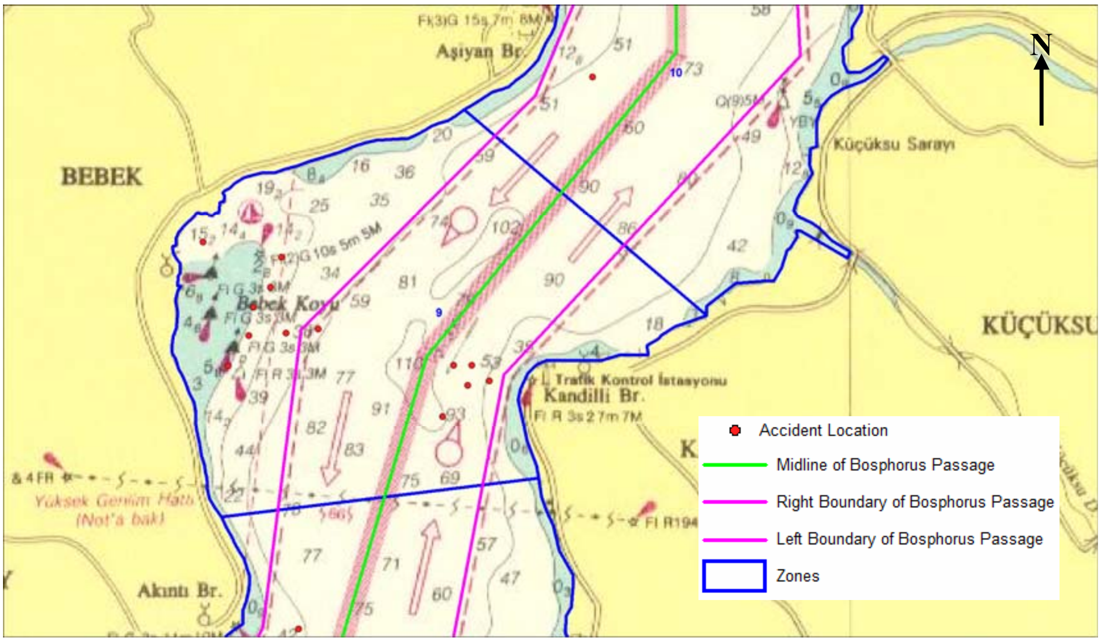


Figure 5.35 Accident locations for Zone 9

Zone 9 is within the turn or bend region in the Bosphorus (Figure 5.35). This geomorphologic condition might results the top ranks for collision type of accidents. Zone 9 have also a shallowing region, it takes a place in the last ranks for grounding type of accidents in forecast. However in UMA data it takes a place in the fourth rank. Although there are navigation aids to reduce the grounding type of accident in Zone 9, navigation aids can be improved by a lighthouse to guide the captains for their routes.

5.6.2.3 Zone 13

Zone 13 has a location near the mid of the Bosphorus (Figure 5.36). The probability of accidents for Zone 13 and rank of the Zone 13 are presented in Table 5.18.

Table 5.18 The probability of accidents for Zone 13 and rank of Zone 13

Type of Accidents	Probabilities	Rank
Collision accidents	1.15 E-05	6
Capsizing accidents	2.86 E-06	13
Grounding accidents	1.94 E-05	2
Others accidents	0.00 E+00	14
Fire accidents	2.07 E-06	12
Total accidents	4.13 E-05	3

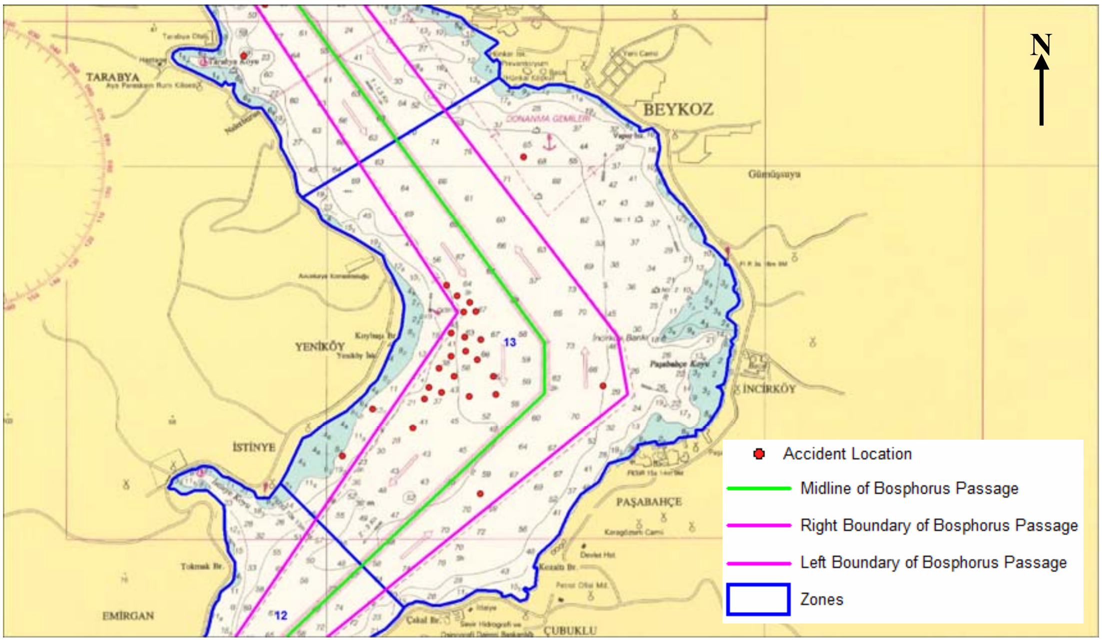


Figure 5.36 Accident locations for Zone 13

Zone 13 is within the turn or bend region in the Bosphorus (Figure 5.36). This geomorphologic condition might results the top ranks for grounding type of accidents. Zone 13 have the highest turning angle with 83 degree in Bosphorus. This geomorphologic condition might be result local currents however more detailed measurement should be undertaken to understand the reason of grounding type of accident in Zone 13. Additional navigational aids near Yeniköy region can also be considered.

5.6.2.4 Zone 14

Zone 14 has a location upper of Zone 13 in Bosphorus (Figure 5.37). The probability of accidents for Zone 14 and rank of the Zone 14 are presented in Table 5.19.

Table 5.19 The probability of accidents for Zone 14 and rank of Zone 14

Type of Accidents	Probabilities	Rank
Collision accidents	4.20 E-06	14
Capsizing accidents	4.52 E-06	10
Grounding accidents	2.78 E-05	1
Others accidents	7.36 E-07	13
Fire accidents	7.66 E-07	13
Total accidents	3.23 E-05	4

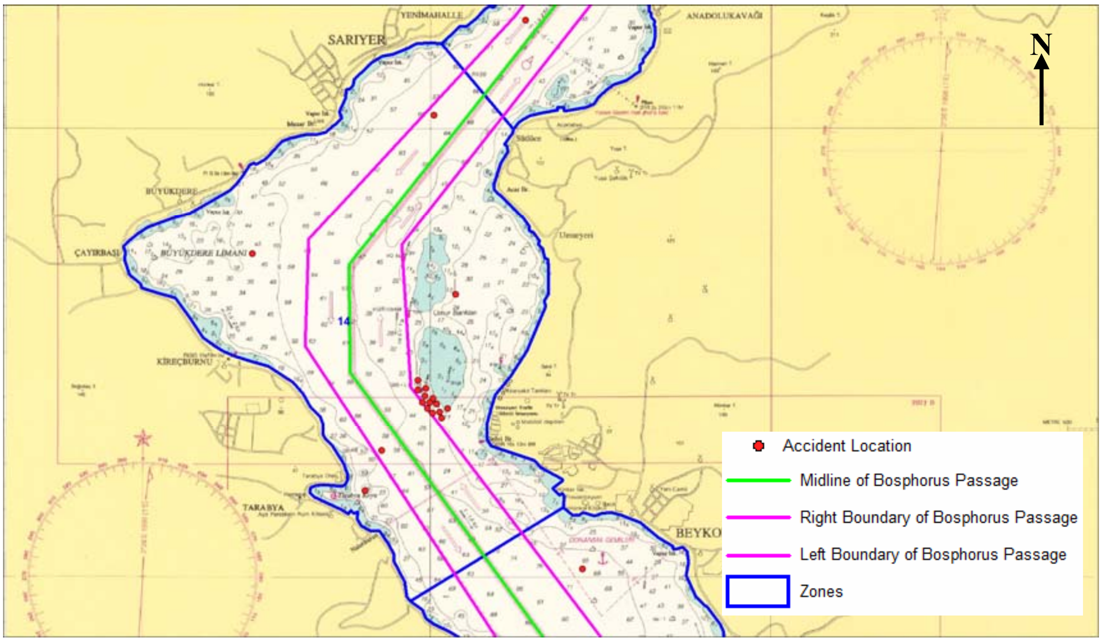


Figure 5.37 Accident locations for Zone 14

Zone 14 is within the turn or bend region in the Bosphorus and have a shallow region (Figure 5.37). This geomorphologic condition might results the top ranks for grounding type of accidents. Although there are navigation aids to reduce the grounding type of accident in Zone 14, navigation aids can be improved by a lighthouse to guide the captains for their routes.

5.6.2.5 Zone 15

Zone 15 has a location upper of Zone 14 in Bosphorus (Figure 5.38). The probability of accidents for Zone 15 and rank of the Zone 15 is presented in Table 5.20.

Table 5.20 The probability of accidents for Zone 15 and rank of Zone 15

Type of Accidents	**Probabilities**	**Rank**
Collision accidents	9.28 E-06	8
Capsizing accidents	7.74 E-06	3
Grounding accidents	1.04 E-05	3
Others accidents	8.02 E-06	3
Fire accidents	4.36 E-06	7
Total accidents	2.04 E-05	8

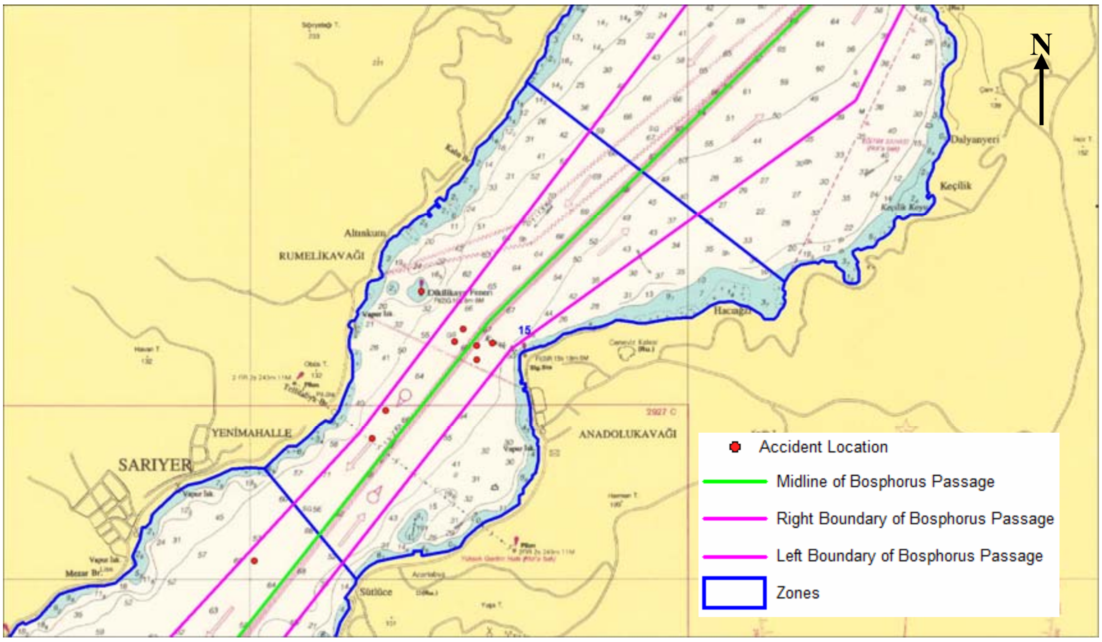


Figure 5.38 Accident locations for Zone 15

There is a narrowing part in Zone 15 (Figure 5.38). This geomorphologic condition might results the third rank for grounding and capsizing type of accidents. To reduce these type of accidents pilot service can be taken to pass Zone 15 which must be an applied practice not only for Zone 15 but for all through the Bosphorus.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

The maritime accident data of the Undersecretariat Maritime Affairs Search and Rescue Department has been compiled to estimate the maritime accident probabilities for the Bosphorus. The accident data archive between 01.01.2001 and 13.05.2010 has been plotted on the Admiralty maps 2921A and 2921B (ONHO) with appropriate coordinates based on approximation since the exact coordinates of the accident location were not available in the archives.

In the beginning stage of the study the maritime accidents have been grouped according to accident types such as collision, capsizing, grounding, fire and other accidents for the years between 01.01.2001 and 13.05.2010 (UMA archive).

The basic parameters for maritime accidents for Bosphorus has been selected by correlation coefficient and ANFIS studies as, current velocity (*CV*), length overall ship (*LOA*), average turn of vessel (*AT*), daily maximum wind speed (*DWS*), ratio of passage area (*RPA*) to zone area and monthly total precipitation (*MTP*).

The data related to these parameters obtained from the related sources:

- weather characteristics (Monthly Total Precipitation, Daily maximum wind, Hourly Wind Speed, Daily Average Wind Speed, Monthly Average Wind Speed, Monthly Foggy Days, Daily Total Precipitation) data from Turkish State Meteorological Service,
- geomorphologic characteristics (Average Width, Ratio Passage Area, Average Turn) data from the maps of Office of Navigation, Hydrography,

- vessel characteristics (GRT, LOA) from the UMA data and OCDI standard,
- hydraulic characteristics (Average Current Velocity) from the surface current velocity map, have been used to prepare the input data for the analysis.

In the development of the model for the Bosphorus has been divided to 17 zones based on the grouping of accidents from the archive data. Zone 1 (Kadıköy pier and breakwater), Zone 3 (Harem pier) and Zone 5 (Golden Horn) are not located on the Bosphorus passage of the vessels, therefore these zones are not included in forecast analysis. The ratio passage area to zone area (*RPA*), average turn (*AT*) and the average current velocity (*CV*) has been determined for the remaining 14 zones.

The weather data (daily maximum wind speed, *DWS*; monthly total precipitation, *MTP*) has been used to compose the input data by considering the accident time. Length overall ship (*LOA*) is compiled by using the OCDI standard and UMA data.

The accident probabilities are forecasted by five different approaches as, Method II of American Association of State Highway and Transportation Officials (AASHTO), Formula 1 developed considering AASHTO, Formula 2 (Multiple Linear Regression), Model 1 (Adaptive Neuro Fuzzy Inference System, ANFIS) and MAcRisk (Artificial Neural Network, ANN).

In the development of a model for estimating the maritime accidents in Bosphorus among the several approaches tried, MAcRisk gives the best result. The maritime accident data for Bosphorus was rather limited and questionable. Since the importance of data collection is now becoming more recognizable compared to earlier years. Yet the results obtained form MAcRisk were compatible with the existing UMA data in most of the cases and found satisfactory.

The results of probability computations of maritime accidents through Bosphorus and number of accidents computed from these probabilities based on UMA data and MAcRisk model are given in tables (Table 5.7, Table 5.8, Table 5.10 and Table

5.11). The forecasted maritime accidents for Bosphorus using MAcRisk are also presented in figures (Figure 5.26 - Figure 5.31) for different accident types and for Zones 2 to 17.

Zone 4, Zone 9, Zone 13, Zone 14 and Zone 15 are determined as critical zones. Zone 4, Zone 9, Zone 13 and Zone 14 are within the turn or bend region in the Bosphorus passage (Figure 5.26). This geomorphologic condition results in high rank of collision and capsizing type of accidents in zone 4, 9 and 13 whereas in zone 14 where Umur Banks (shoals) together with turn or bend region make the grounding type of accident more important.

Zone 15 takes place in the top ranks of the grounding type accident. The narrowing of the passage in Zone 15 can explain the reason of the top place of Zone 15 for the grounding type accident (Figure 5.28).

The scenarios 1 and 2 are prepared to show possibility of the increase in risk of accidents in case of annual number of ships passing through Bosphorus increase. As its seen in Table 5.15, there is an increase in the number of accidents for all Zones for all type of accidents for Scenario 1 and Scenario 2. This difference is more announced for passage of annual 70000 vessels through Bosphorus.

Recommendation aids to minimize the maritime accidents in the Zone 4, Zone 9, Zone 13, Zone 14 and Zone 15 is presented above in Section 5.6.2.

Although Bosphorus is one of the most difficult strait, it has a good maritime traffic management. Decreasing number of accidents indicates also good management efforts.

Although Zone 2 (entrance) and Zone 17 (exit) has high accident probabilities, comments has not been made for Zone 2 and Zone 17 because there is rear coordinates on the all UMA data for maritime accidents. This situation brings up the possible mistake on accident locations.

Because of the weather conditions, maritime accidents have been observed on the vessels waiting in anchoring area for Bosphorus passage. A safe anchoring area for vessels can be generated to avoid them from weather conditions and to decrease the number of accidents in the anchoring area.

It is expected an increase on the accidents for big vessels passage, however using pilot service for Bosphorus passage decrease the accident probability. This result sputs more emphasize on the neccesssity of pilot service through Bosphorus regardless of the size of the vessels. This conclusion is based on the UMA data where average size of commercial ships on average ~6500 GT (maximum ~58000 GT) causing accidents because of lack of pilot service.

The considerations discussed in detail in conclusion is to reinforce the protection and preservation of historical, cultural and natural heritage of Istanbul.

6.1 Recommendations for future studies

It is suggested that the weather conditions (wind speed), physical conditions (current velocity), maritime accident coordinates data are also included in the UMA accident archive data.

A specific study on Tanker and Hazardous cargo transport through Bosphorus has to be carried out since the resulting accidents will cause drastic damages. In such studies the size and the construction specifications of tankers are the controlling parameters.

Data on pilot assistance for Bosphorus has to be collected accurately enough to be included in the future studies for the further development of the model.

Seasonal studies including current velocities can be carried on to determine the current effect on the maritime accident probabilities.

The data for the years between 01.01.2001 and 13.05.2010 can be used to develop the model. However increasing the training data gives more compatible results and ideas to clarify the relations.

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APPENDIX A

DATA

A.1 PREPARED DATA

In the prepared data -999 defines that there is no data.

Table A.1 Prepared Data

Accident Number	Date	Hour	Zone	Vessel-1 GRT	Vessel-2 GRT	Vessel-1 Type
611	09.11.2006	11:45	2	38.1	-999	Agent Boat
891	29.09.2004	07:10	2	-999	-999	Barge
1334	31.01.2001	09:30	2	755	-999	Dry Cargo Ship
332	01.09.2008	19:04	2	4638	-999	Dry Cargo Ship
413	06.04.2008	08:15	2	-999	-999	Passenger Ship
462	15.01.2008	14:15	2	11977	299	Dry Cargo Ship
633	20.09.2006	16:19	2	15.46	1850	Fishing Vessel
672	17.04.2006	20:40	2	4277	2457	Dry Cargo Ship
690	17.02.2006	22:50	2	29.97	-999	Pilot Boat
718	29.10.2005	21:27	2	431	-999	Sea Bus Catamaran Type (Passenger + Car)
977	13.02.2004	04:20	2	2550	5934	Dry Cargo Ship
999	11.01.2004	12:05	2	39997	-999	Dry Cargo Ship
1065	25.07.2003	13:00	2	58.2	31.5	Passenger Ship
1152	25.08.2002	17:00	2	47	-999	Passenger Ship
1209	04.01.2002	17:20	2	4034	1539	Dry Cargo Ship
1244	01.11.2001	23:30	2	2553	3964	Dry Cargo Ship
1279	18.07.2001	21:15	2	780	610	Passenger Ship
98	26.12.2009	15:40	2	456	-999	Passenger Ship
939	13.06.2004	22:45	2	-999	-999	Other (Unidentified) Yachts
1232	14.11.2001	03:15	2	4544	-999	Dry Cargo Ship

Table A.1 Prepared Data (cont'd)

Accident Number	Date	Hour	Zone	Vessel-1 GRT	Vessel-2 GRT	Vessel-1 Type
609	11.11.2006	00:15	2	12215	-999	Dry Cargo Ship
705	29.12.2005	15:15	2	-999	-999	Passenger Ship
529	25.08.2007	22:45	2	15122	-999	Container Vessel
698	21.01.2006	12:05	2	197	-999	Water Tanker
1000	09.01.2004	18:45	2	20885	-999	Bulk Cargo Vessel
1204	23.01.2002	08:10	2	1823	-999	Dry Cargo Ship
1301	12.05.2001	23:20	2	4289	-999	Dry Cargo Ship
387	20.06.2008	17:50	2	19031	13420	Bulk Cargo Vessel
642	31.08.2006	22:52	2	906	4277	Dry Cargo Ship
680	11.03.2006	19:43	2	2457	-999	Dry Cargo Ship
950	14.05.2004	14:00	2	6765	-999	Chemical Cargo Vessel
1170	06.06.2002	16:20	4	14.15	-999	Commercial Yacht
527	28.08.2007	04:45	4	699	-999	Tug Boats
557	05.05.2007	08:57	4	456	456	Passenger Ship
745	10.09.2005	14:00	4	456	-999	Passenger Ship
840	20.01.2005	22:15	4	23100	456	Other (Unidentified) Tanker
1070	03.07.2003	05:40	4	12	10	Passenger Ship
461	25.01.2008	15:55	4	-999	-999	Passenger Ship
1015	23.11.2003	12:15	4	3703	-999	Dry Cargo Ship
361	03.08.2008	08:47	4	5469	-999	General Cargo
689	21.02.2006	14:56	4	25449	-999	Tanker
725	15.10.2005	14:40	4	25407	-999	Exact Container Vessel
763	04.08.2005	17:58	4	2592	-999	Dry Cargo Ship
795	27.05.2005	23:25	4	-999	-999	Private Powerboat
1210	04.01.2002	04:15	4	-999	-999	Other (Unidentified) Vessel
532	20.08.2007	11:55	4	1790	-999	Passenger Ship
797	22.05.2005	21:00	4	-999	-999	Sea Bus Catamaran Type (Passenger + Car)

Table A.1 Prepared Data (cont'd)

Accident Number	Date	Hour	Zone	Vessel-1 GRT	Vessel-2 GRT	Vessel-1 Type
1190	11.04.2002	07:55	4	41342	-999	Bulk Cargo Vessel
648	09.08.2006	18:41	4	-999	-999	
173	18.07.2009	23:43	6	456	1987	Passenger Ship
945	03.06.2004	17:33	6	307	289	Passenger Ship
409	01.05.2008	19:23	6	-999	-999	Boat
322	22.09.2008	20:25	7	-999	-999	Amateur Fishing Boat
347	15.08.2008	10:10	7	-999	-999	Private Yacht
1167	16.06.2002	00:10	7	1694	705	Dry Cargo Ship
889	03.10.2004	15:40	7	8239	-999	Other Unidentified (Special Load) Vessel
907	02.09.2004	02:45	7	6116	-999	Dry Cargo Ship
1055	01.09.2003	18:00	7	3451	-999	Dry Cargo Ship
1186	19.04.2002	06:35	7	53974	-999	Other (Unidentified) Tanker
1268	26.08.2001	13:40	7	96	-999	Dry Cargo Ship
366	29.07.2008	22:32	7	-999	-999	Other (Unidentified) Yacht
13	30.04.2010	11:40	7	3515	-999	Tanker
1222	02.12.2001	10:05	7	49526	-999	Chemical/Oil Tanker
544	29.06.2007	15:23	7	6390	-999	Dry Cargo Ship
1157	08.08.2002	09:30	7	6459	-999	Dry Cargo Ship
542	14.07.2007	23:11	7	-999	-999	Yacht
1059	12.08.2003	00:30	7	16.52	-999	Private Yacht
851	05.01.2005	19:00	8	14.62	-999	Commercial Yacht
790	08.06.2005	07:40	8	46	-999	Private Yacht
653	20.06.2006	11:40	9	-999	-999	Private Yacht
1125	02.12.2002	04:00	9	993	6442	Other (Unidentified Mixed Cargo) Vessel

Table A.1 Prepared Data (cont'd)

Accident Number	Date	Hour	Zone	Vessel-1 GRT	Vessel-2 GRT	Vessel-1 Type
515	01.10.2007	06:00	9	2650	-999	Dry Cargo Ship
872	21.11.2004	02:37	9	5306	-999	Dry Cargo Ship
925	21.07.2004	20:04	9	1846	-999	Dry Cargo Ship
1080	27.05.2003	22:00	9	14513	-999	Other (Unidentified) Tanker
594	16.12.2006	02:30	9	7960	-999	Exact Container Vessel
604	28.11.2006	15:00	9	11116	-999	Exact Container Vessel
266	29.12.2008	13:21	9	1539	-999	Tanker
801	17.05.2005	21:36	9	1995	-999	Passenger Ship (Catamaran Type)
1099	17.02.2003	21:00	9	10230	-999	Dry Cargo Ship
19	19.04.2010	10:00	9	-999	-999	Yacht
565	12.03.2007	00:25	9	14141	14.55	Dry Cargo Ship
46	19.03.2010	21:00	10	37709	5993	Dry Cargo Ship
193	16.06.2009	09:10	10	2659	-999	Dry Cargo Ship
663	19.05.2006	18:00	11	905	-999	Dry Cargo Ship
802	10.05.2005	23:47	11	1768	-999	Dry Cargo Ship
408	02.05.2008	12:54	11	-999	-999	Private Yacht
32	04.04.2010	14:00	12	2426	-999	Dry Cargo Ship
460	25.01.2008	02:52	12	1239	-999	Dry Cargo Ship
878	12.11.2004	21:30	12	1995	-999	Dry Cargo Ship
1138	06.10.2002	19:30	12	7159	-999	Dry Cargo Ship
8	13.05.2010	13:00	12	-999	-999	Yacht
311	27.09.2008	01:20	13	-999	-999	Commercial Yacht
1160	31.07.2002	16:30	13	3119	-999	Dry Cargo Ship
1278	22.07.2001	13:00	13	-999	-999	Passenger Ship
331	02.09.2008	20:35	13	-999	-999	Private Yacht
451	17.02.2008	03:55	13	1543	-999	Dry Cargo Ship
701	13.01.2006	17:12	13	3712	-999	Dry Cargo Ship
769	29.07.2005	19:30	13	126	-999	Other (Unidentified) Tanker

Table A.1 Prepared Data (cont'd)

Accident Number	Date	Hour	Zone	Vessel-1 GRT	Vessel-2 GRT	Vessel-1 Type
824	22.03.2005	23:35	13	1772	-999	Dry Cargo Ship
849	06.01.2005	19:42	13	18526	-999	Other (Unidentified) Tanker
996	11.01.2004	07:49	13	3422	-999	Dry Cargo Ship
1118	20.12.2002	15:20	13	15.44	-999	Other (Unidentified) Tankers
1151	26.08.2002	16:45	13	914	-999	Dry Cargo Ship
38	25.03.2010	23:49	13	6178	-999	Dry Cargo Ship
203	28.05.2009	16:10	13	10762	-999	Dry Cargo Ship
380	03.07.2008	00:50	13	13656	-999	Bulk Cargo Vessel
625	18.10.2006	21:30	13	2688	-999	Other Unidentified (Special Load) Vessel
934	24.06.2004	13:52	13	3982	-999	Dry Cargo Ship
940	11.06.2004	18:55	13	26	-999	Dry Cargo Ship
981	11.02.2004	04:32	13	2690	-999	Other (Unidentified) Tankers
1034	18.10.2003	06:20	13	2426	-999	Dry Cargo Ship
1208	05.01.2002	23:00	13	4923	-999	Dry Cargo Ship
1240	04.11.2001	20:00	13	2842	-999	Dry Cargo Ship
400	20.05.2008	00:05	13	-999	-999	Tour Vessel
1323	09.03.2001	21:00	13	2854	-999	Dry Cargo Ship
399	21.05.2008	18:55	13	-999	-999	Boat
1104	07.02.2003	20:50	14	1639	-999	Dry Cargo Ship
1130	16.11.2002	21:30	14	4989	-999	Dry Cargo Ship
1154	24.08.2002	17:15	14	1891	-999	Dry Cargo Ship
113	08.12.2009	15:10	14	466	-999	Tug Boat
163	13.08.2009	03:40	14	4669	-999	Dry Cargo Ship
378	12.07.2008	08:42	14	58129	-999	Tanker

Table A.1 Prepared Data (cont'd)

Accident Number	Date	Hour	Zone	Vessel-1 GRT	Vessel-2 GRT	Vessel-1 Type
517	24.09.2007	07:58	14	417	-999	Dry Cargo Ship
538	30.07.2007	04:56	14	2430	-999	Dry Cargo Ship
638	12.09.2006	09:12	14	1344	-999	Dry Cargo Ship
708	16.12.2005	04:40	14	1285	-999	Dry Cargo Ship
783	20.06.2005	03:42	14	885	-999	Dry Cargo Ship
845	13.01.2005	20:30	14	156.01	-999	Passenger Ship
1076	07.06.2003	23:40	14	843	-999	Dry Cargo Ship
1148	02.09.2002	09:35	14	2550	-999	Dry Cargo Ship
1164	29.06.2002	02:30	14	1741	-999	Dry Cargo Ship
1195	28.02.2002	23:40	14	2406	-999	Dry Cargo Ship
1206	08.01.2002	03:35	14	2938	-999	Dry Cargo Ship
1233	13.11.2001	03:15	14	1866	-999	Dry Cargo Ship
768	31.07.2005	01:37	15	1805	-999	Chemical Cargo Vessel
842	17.01.2005	14:03	15	1193	-999	Other (Unidentified Mixed Cargo) Vessels
600	06.12.2006	14:43	15	6172	-999	Dry Cargo / Ro-Ro
646	21.08.2006	15:45	15	606	-999	Other (Unidentified) Tug Boat
504	07.11.2007	20:15	15	1927	-999	Dry Cargo Ship
221	22.04.2009	17:04	15	44887	-999	OBO Vessel
346	19.08.2008	14:50	15	-999	-999	Amateur Fishing Boat
430	24.03.2008	17:55	15	-999	-999	Passenger Boat
965	29.03.2004	02:59	16	17825	-999	Other (Unidentified) Tankers
628	15.10.2006	00:45	16	400	-999	Ro-Ro / Cargo Vessel
714	09.11.2005	23:50	17	-999	-999	Other (Unidentified) Yachts

Table A.1 Prepared Data (cont'd)

Accident Number	**Date**	**Hour**	**Zone**	**Vessel-1 GRT**	**Vessel-2 GRT**	**Vessel-1 Type**
827	12.03.2005	22:38	17	1387	-999	Dry Cargo Ship
970	13.03.2004	12:40	17	7871	-999	Dry Cargo Ship
1020	10.11.2003	20:10	17	16216	-999	Dry Cargo Ship
1051	11.09.2003	02:15	17	20.67	-999	Other (Unidentified) Tankers
620	24.10.2006	00:11	17	3511	228	Chemical Cargo Vessel
775	05.07.2005	23:45	17	7468	77	Dry Cargo Ship
834	19.02.2005	14:55	17	2406	80637	Dry Cargo Ship
1083	23.04.2003	05:40	17	746	1612	Dry Cargo Ship
1337	21.01.2001	06:33	17	654	487	Dry Cargo Ship
1207	05.01.2002	05:00	17	183	-999	Other (Unidentified Tug Boat)
980	12.02.2004	22:00	17	3994	-999	Dry Cargo Ship
1216	09.12.2001	13:20	17	6986	-999	Dry Cargo Ship
1218	08.12.2001	01:10	17	5654	-999	Dry Cargo Ship
978	13.02.2004	02:55	17	3884	-999	Dry Cargo Ship
1117	01.01.2003	19:00	17	8670	-999	Dry Cargo Ship
77	28.01.2010	07:20	17	98	-999	Dry Cargo Ship
715	07.11.2005	15:00	17	451.89	1700	Other Unidentified (Special Load) Vessel
1022	10.11.2003	20:10	17	16216	-999	Dry Cargo Ship
647	16.08.2006	11:40	17	832	-999	Dry Cargo Ship
676	24.03.2006	13:45	17	4963	-999	Exact Container Vessel
722	21.10.2005	03:10	17	2794	-999	Dry Cargo Ship
741	24.09.2005	20:20	17	-999	-999	Amateur Fishing Vessel
799	18.05.2005	21:38	17	3493	-999	Other (Unidentified Mixed Cargo) Vessels

Table A.1 Prepared Data (cont'd)

Accident Number	**Location**	**Reason of Accident**	**Type of Accident**	**Rescued People**	**Missing People**
611	Inci Point	Unknown	Capsizing	3	0
891	Haydarpasa	Unknown	Capsizing	1	0
1334	TCDD Haydarpasa Port	Unknown	Capsizing	0	0
332	Off the coast of Haydarpasa	Unknown	Collision	0	0
413	Haydarpasa Port Berth 3	Machine Failure	Collision	0	0
462	Haydarpasa	Faulty Maneuvering	Collision	0	0
633	Ahirkapi	Unknown	Collision	3	0
672	Ahirkapi	Faulty Maneuvering	Collision	0	0
690	At the coast of Haydarpasa Breakwater	Unknown	Collision	0	0
718	Haydarpasa	Unknown	Collision	1	0
977	Ahirkapi	Anchor Draging	Collision	0	0
999	Ahirkapi	Unknown	Collision	0	0
1065	Haydarpasa	Unknown	Collision	0	0
1152	At the Coast of Ahirkapi	Human Error	Collision	0	0
1209	Ahirkapi	Faulty Navigation	Collision	0	0
1244	Ahirkapi	Faulty Navigation	Collision	0	0
1279	Haydarpasa Breakwater	Faulty Navigation	Collision	0	0
98	Haydarpasa	Fault	Stroke	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	**Location**	**Reason of Accident**	**Type of Accident**	**Rescued People**	**Missing People**
939	At the coast of Ahirkapi	Machine Failure	Hazardous Incident	5	0
1232	Ahirkapi	Anchor Draging	Hazardous Incident	0	0
609	South Entrance of Bosphorus	Unknown	Others	0	0
705	Haydarpasa Breakwater	Rudder Failure	Others	0	0
529	Haydarpasa Port Berth 10	Unknown	Stranding/ Grounding	0	0
698	Ahirkapi Lighthouse	Unknown	Stranding/ Grounding	0	0
1000	Ahirkapi	Human Error	Stranding/ Grounding	0	0
1204	Ahirkapi	Faulty Navigation	Stranding/ Grounding	0	0
1301	Off the Coast of Ahirkapi	Fire	Stranding/ Grounding	0	0
387	Haydarpasa Breakwater	Unknown	Contact	0	0
642	Ahirkapi	Faulty Maneuvering	Contact	0	0
680	Ahirkapi	Weather Opposition	Contact	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
950	Istanbul Port Area	Electrical Short Circuit	Fire	17	0
1170	Southern of Maiden's Tower	Faulty Navigation	Capsizing	0	0
527	Sarayburnu	Faulty Maneuvering	Collision	0	0
557	Off the Coast of Sali Bazaar	Faulty Maneuvering	Collision	0	0
745	At the Coast of Uskudar	Unknown	Collision	1	0
840	Maiden's Tower Position	Dense Fog	Collision	0	0
1070	Sarayburnu	Unknown	Collision	0	0
461	Sali Bazaar Position	Unknown	Stroke	0	1
1015	At the Coast of Uskudar	Faulty Navigation	Stroke	0	0
361	At the Coast of Sali Bazaar	Chain Twine to Propeller	Hazardous Incident	0	0
689	At the Coast of Dolmabahce	Rudder Lock	Hazardous Incident	0	0
725	Maiden's Tower	Faulty Navigation	Hazardous Incident	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
763	Off the Coast of Saray Point	Touch	Hazardous Incident	0	0
795	At the Coast of Uskudar	Rope Stuck	Hazardous Incident	0	0
1210	Sarayburnu	Technical Failure	Hazardous Incident	0	0
532	Sarayburnu	Rope Failure	Others	0	0
797	Sarayburnu	Suicide	Others	0	1
1190	At the Coast of Uskudar	Machine Failure	Others	0	0
648	Sarayburnu	Unknown	Fire	0	0
173	At the Coast of Besiktas	Unknown	Collision	0	0
945	At the Coast of Besiktas	Fast Navigation	Collision	0	0
409	At the Coast of Besiktas	Water Intake	Others	0	0
322	Kurucesme	Close Navigation	Collision	0	0
347	Cengelkoy	Touch	Collision	0	0
1167	Kurucesme	Faulty Navigation	Collision	0	2

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
544	At the Coast of Ortakoy	Rudder Failure	Stranding/ Grounding	0	0
1157	Off the Coast of Ortakoy	Machine Failure	Stranding/ Grounding	0	0
542	Beylerbeyi Pier	Unknown	Fire	0	0
1059	Kurucesme	Unknown	Fire	0	0
851	At the Coast of Arnavut	Unknown	Collision	0	0
790	Off the Coast of Arnavutkoy	Unknown	Fire	0	0
653	Bebek Bay	Unknown	Capsizing	0	0
1125	At the Coast of Kandilli	Human Error	Collision	0	0
515	Kandilli	Machine Failure	Stroke	0	0
872	At the Coast of Kandilli	Stroke to the Beach	Stroke	18	0
925	Bebek Bay	Rudder Failure	Stroke	0	0
1080	Bebek Bay	Faulty Navigation	Stroke	0	0
594	Kandilli Point	Unknown	Hazardous Incident	0	0
604	Bebek Coast	Machine Failure	Hazardous Incident	0	0
266	Bebek Bay	Unknown	Machinery Damage	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	**Location**	**Reason of Accident**	**Type of Accident**	**Rescued People**	**Missing People**
801	Kandilli Point	Rudder Failure	Stranding/ Grounding	0	0
1099	Bebek Bay	Faulty Navigation	Stranding/ Grounding	0	0
19	Bebek Bay	Fault	Drift	2	0
565	Bebek Bay	Rudder Failure	Contact	0	0
46	Asiyan Point	Rudder Failure	Collision	0	0
193	Anadolu Fort	Rudder Failure	Stranding/ Grounding	0	0
663	Around Rumeli Fort	Faulty Maneuvering	Stroke	0	0
802	At the Coast of Rumeli	Faulty Navigation	Stroke	0	0
408	Fatih Sultan Mehmet Bridge	Machine Failure	Drift	0	0
32	At the Coast of Kanlica	Unknown	Collision	1	0
460	At the Coast of Kanlica	Faulty Navigation	Stroke	0	0
878	At the Coast of Kanlica	Human Error	Hazardous Incident	0	0
1138	Emirgan Pier	Unknown	Hazardous Incident	0	0
8	At the Coast of Kanlica	Machine Failure	Drift	4	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
311	Pasabahce	Weather Opposition	Capsizing	0	0
1160	Off the Coast of Yenikoy	Water Intake	Capsizing	0	0
1278	Beykoz	Fire	Capsizing	0	0
331	At the Coast of Cubuklu	Unknown	Collision	0	0
451	Yeniköy Coast	Unknown	Stroke	0	0
701	At the Coast of Yenikoy	Faulty Maneuvering	Stroke	0	0
769	At the Coast of Yenikoy	Unknown	Stroke	3	0
824	Yenikoy	Faulty Navigation	Stroke	0	0
849	Off the Coast of Yenikoy	Faulty Navigation	Stroke	0	0
996	Yeniköy	Technical Failure	Hazardous Incident	0	0
1118	Yeniköy	Weather Opposition	Hazardous Incident	0	0
1151	Yeniköy Lighthouse	Rudder Failure	Damages to Ship or Equipment	0	0
38	Bosphorus Strait	Unknown	Machinery Damage	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
203	At the Coast of Yenikoy	Rudder Lock	Stranding/ Grounding	0	0
380	At the Coast of Yenikoy	Unknown	Stranding/ Grounding	0	0
625	At the Coast of Sait Halim Pasa Waterfront House	Rudder Failure	Stranding/ Grounding	0	0
934	Yenikoy Turn	Current Drift	Stranding/ Grounding	0	0
940	Yenikoy	Machine Failure	Stranding/ Grounding	0	0
981	Yenikoy	Rudder Failure	Stranding/ Grounding	0	0
1034	Yenikoy	Faulty Navigation	Stranding/ Grounding	0	0
1208	Yenikoy	Rudder Failure	Stranding/ Grounding	0	0
1240	Yenikoy Lighthouse	Faulty Maneuvering	Stranding/ Grounding	0	0
400	At the Coast of Yenikoy	Machine Failure	Drift	0	0
1323	Yenikoy	Rudder Failure	Contact	0	0
399	Off the Coast of Yenikoy	Unknown	Fire	0	0
1104	Büyükdere Bay	Machine Failure	Hazardous Incident	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
1130	Umuryeri	Faulty Navigation	Hazardous Incident	0	0
1154	Tarabya Bay	Touch	Hazardous Incident	0	0
113	At the Coast of Tarabya	Death	Others	0	0
163	South Lighthouse of Umuryeri	Unknown	Stranding/ Grounding	0	0
378	At the Coast of Sariyer	Rudder Failure	Stranding/ Grounding	0	0
517	Umuryeri Position	Faulty Navigation	Stranding/ Grounding	0	0
538	Umurbeyi Banks	Rudder Failure	Stranding/ Grounding	0	0
638	Umuryeri	Unknown	Stranding/ Grounding	0	0
708	Umuryeri	Faulty Navigation	Stranding/ Grounding	0	0
783	Umuryeri	Faulty Navigation	Stranding/ Grounding	0	0
845	Umur Banks Position	Dense Fog	Stranding/ Grounding	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
1076	Umuryeri	Unknown	Stranding/ Grounding	0	0
1148	Umuryeri	Rudder Failure	Stranding/ Grounding	0	0
1164	Umuryeri	Machine Failure	Stranding/ Grounding	0	0
1195	Umuryeri	Unreceiving Pilot	Stranding/ Grounding	0	0
1206	Umuryeri	Faulty Navigation	Stranding/ Grounding	0	0
1233	Umur Banks	Faulty Navigation	Stranding/ Grounding	0	0
768	Kavak Position	Generator Failure	Hazardous Incident	0	0
842	Kavak Position	Unknown	Hazardous Incident	0	0
600	Kavak Position	Unknown	Others	0	0
646	Kavak Position	Rope Failure	Others	0	0
504	Telli Tabya Position	Machine Failure	Machinery Damage	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
221	Dikilikaya Lighthouse	Machine Failure	Stranding/ Grounding	0	0
346	Anadolu Kavagi	Rope Twine	Stranding/ Grounding	5	0
430	At the Coast of Telli Baba	Machine Failure	Drift	0	0
965	Buyuk Port	Machine Failure	Stranding/ Grounding	0	0
628	Turkeli Garipce Position	Unknown	Fire	3	0
714	Turkeli	Water Intake	Capsizing	3	0
827	Turkeli Lighthouse	Cargo Shift	Capsizing	10	0
970	Turkeli Lighthouse	Weather Opposition	Capsizing	0	15
1020	Turkeli	Storm	Capsizing	0	0
1051	Turkeli Lighthouse	Unknown	Capsizing	0	0
620	Turkeli	Rudder Failure	Collision	0	0
775	Rumeli Lighthouse	Weather Opposition	Collision	0	0
834	Turkeli Lighthouse	Captain Failure	Collision	0	0
1083	Turkeli	Faulty Maneuvering	Collision	0	0
1337	Turkeli Entrance	Unknown	Collision	7	0

Table A.1 Prepared Data (cont'd)

Accident Number	Location	Reason of Accident	Type of Accident	Rescued People	Missing People
1207	North Entrance of Bosphorus	Weather Opposition	Hazardous Incident	0	0
980	North Entrance of Bosphorus	Anchor Draging	Others	11	0
1216	North Entrance of Bosphorus	Weather Opposition	Others	0	0
1218	North Entrance of Bosphorus	Weather Opposition	Others	0	0
978	Turkeli	Anchor Draging	Stranding/ Grounding	0	0
1117	Turkeli Lighthouse	Weather Opposition	Stranding/ Grounding	0	0
77	Norht Exit of Bosphorus	Machine Failure	Drift	0	0
715	Turkeli	Faulty Maneuvering	Contact	0	0
1022	Turkeli	Storm	Listing	0	0
647	North Entrance of Bosphorus	Unknown	Fire	0	0
676	Turkeli	Electrical Failure	Fire	0	0
722	Rumeli Lighthouse	Unknown	Fire	0	0
741	Rumeli Lighthouse	Gas Compression	Fire	1	0
799	Rumeli Lighthouse	Unknown	Fire	0	0

Table A.1 Prepared Data (cont'd)

Accident Number	**Dead People**	**Injured People**	**Patient people**	**Monthly Average Wind Speed (m/s)**	**Monthly Foggy Days**	**Monthly Total Precipitation (mm)**
611	0	0	0	1.5	3	187.4
891	0	0	0	2.2	1	12.8
1334	0	0	0	2.3	0	56.3
332	0	0	0	3.4	0	162.1
413	0	0	0	2.3	0	14.4
462	0	0	0	2.2	0	61
633	0	0	0	1.7	0	182.1
672	0	0	0	1.7	3	15
690	0	0	0	1.8	5	149.5
718	0	0	0	2.3	0	60.7
977	0	0	0	1.6	2	59.7
999	0	0	0	2.3	0	151.4
1065	0	0	0	1.9	0	5.7
1152	0	0	0	1.8	0	120
1209	0	0	0	1.7	6	84.4
1244	0	0	0	2.1	2	166.4
1279	0	0	0	2.1	0	9.2
98	0	0	0	2.9	1	207
939	0	0	0	1.4	0	72.5
1232	0	0	0	2.1	2	166.4
609	0	0	0	1.5	3	187.4
705	0	0	0	1.9	1	149.1
529	0	0	0	7.2	0	21.8
698	0	0	0	2.9	3	141.4
1000	0	0	0	2.3	0	151.4
1204	0	0	0	1.7	6	84.4
1301	0	0	0	1.7	0	21.3
387	0	0	0	3.5	0	20.8
642	0	0	0	1.7	0	16.4
680	0	0	0	1.6	0	105.2

Table A.1 Prepared Data (cont'd)

Accident Number	Dead People	Injured People	Patient people	Monthly Average Wind Speed (m/s)	Monthly Foggy Days	Monthly Total Precipitation (mm)
950	1	0	0	1.8	0	28.5
1170	5	0	0	1.9	0	56.6
527	0	0	0	7.2	0	21.8
557	0	0	0	5	0	44
745	0	0	0	1.8	1	98.6
840	0	0	0	1.7	6	163.3
1070	0	0	0	1.9	0	5.7
461	0	0	0	2.2	0	61
1015	0	0	0	1.9	7	59.2
361	0	0	0	5	0	0
689	0	0	0	1.8	5	149.5
725	0	0	0	2.3	0	60.7
763	0	0	0	2.3	0	16.6
795	0	0	0	1.4	4	10.1
1210	0	0	0	1.7	6	84.4
532	1	3	0	7.2	0	21.8
797	0	0	0	1.4	4	10.1
1190	0	0	0	1.8	5	43
648	0	0	0	1.7	0	16.4
173	0	0	0	3.8	1	22.8
945	0	0	0	1.4	0	72.5
409	0	0	0	2.6	1	4.5
322	0	0	0	3.4	0	162.1
347	0	0	0	5	0	0
1167	2	0	0	1.9	0	56.6
889	0	0	0	2	0	126.2
907	0	0	0	2.2	1	12.8
1055	0	0	0	2.1	0	51.7
1186	0	0	0	1.8	5	43
1268	0	0	0	2.9	0	95.3
366	0	0	0	3.7	0	59.3

Table A.1 Prepared Data (cont'd)

Accident Number	**Dead People**	**Injured People**	**Patient people**	**Monthly Average Wind Speed (m/s)**	**Monthly Foggy Days**	**Monthly Total Precipitation (mm)**
13	0	0	0	-999	-999	-999
1222	0	0	0	3.5	3	337.8
544	0	0	0	6.4	0	28.2
1157	0	0	0	1.8	0	120
542	0	0	0	8	0	7.6
1059	0	0	0	2.5	0	5.1
851	0	0	0	1.7	6	163.3
790	0	0	0	1.7	0	18.1
653	0	0	0	1.6	0	22.4
1125	0	0	0	2.3	1	82.5
515	0	0	0	5.7	0	118.3
872	0	0	0	1.8	1	106.7
925	0	0	0	2.2	0	18.4
1080	0	0	0	2	2	2.3
594	0	0	0	1.5	9	16.4
604	0	0	0	1.5	3	187.4
266	0	0	0	2.5	0	109.8
801	0	0	0	1.4	4	10.1
1099	0	0	0	3.3	0	154.2
19	0	0	0	-999	-999	-999
565	0	0	0	3.5	0	35.8
46	0	0	0	-999	-999	-999
193	0	0	0	2.8	1	0.4
663	0	0	0	1.6	0	5.1
802	0	0	0	1.4	4	10.1
408	0	0	0	2.6	1	4.5
32	0	0	0	-999	-999	-999
460	0	0	0	2.2	0	61
878	0	0	0	1.8	1	106.7
1138	0	0	0	1.3	1	34
8	0	0	0	-999	-999	-999

Table A.1 Prepared Data (cont'd)

Accident Number	**Dead People**	**Injured People**	**Patient people**	**Monthly Average Wind Speed (m/s)**	**Monthly Foggy Days**	**Monthly Total Precipitation (mm)**
311	0	0	0	3.4	0	162.1
1160	0	0	0	1.7	0	39
1278	0	0	0	2.1	0	9.2
331	0	0	0	3.4	0	162.1
451	0	0	0	3.5	3	57.6
701	0	0	0	2.9	3	141.4
769	0	0	0	2.3	0	44.6
824	0	0	0	2.2	2	62.9
849	0	0	0	1.7	6	163.3
996	0	0	0	2.3	0	151.4
1118	0	0	0	2.3	1	82.5
1151	0	0	0	1.8	0	120
38	0	0	0	-999	-999	-999
203	0	0	0	3.2	1	9.6
380	0	0	0	3.7	0	59.3
625	0	0	0	2.1	0	109.2
934	0	0	0	1.4	0	72.5
940	0	0	0	1.4	0	72.5
981	0	0	0	1.6	2	59.7
1034	0	0	0	1.9	1	139.1
1208	0	0	0	1.7	6	84.4
1240	0	0	0	2.1	2	166.4
400	0	0	0	2.6	1	4.5
1323	0	0	0	2.2	2	44.8
399	0	0	0	2.6	1	4.5
1104	0	0	0	3.3	0	154.2
1130	0	0	0	1.1	7	97.6
1154	0	0	0	1.8	0	120
113	1	0	0	2.9	1	207
163	0	0	0	5.9	0	26.1
378	0	0	0	3.7	0	59.3

Table A.1 Prepared Data (cont'd)

Accident Number	Dead People	Injured People	Patient people	Monthly Average Wind Speed (m/s)	Monthly Foggy Days	Monthly Total Precipitation (mm)
517	0	0	0	6.6	0	20.3
538	0	0	0	8	0	7.6
638	0	0	0	1.7	0	182.1
708	0	0	0	1.9	1	149.1
783	0	0	0	1.7	0	18.1
845	0	0	0	1.7	6	163.3
1076	0	0	0	2.1	0	1.9
1148	0	0	0	1	2	133.4
1164	0	0	0	1.9	0	56.6
1195	0	0	0	1.5	5	48.7
1206	0	0	0	1.7	6	84.4
1233	0	0	0	2.1	2	166.4
768	0	0	0	2.3	0	44.6
842	0	0	0	1.7	6	163.3
600	0	0	0	1.5	9	16.4
646	0	0	0	1.7	0	16.4
504	0	0	0	2.1	0	150.4
221	0	0	0	3.7	3	31
346	0	0	0	5	0	0
430	0	0	0	2.6	2	86.4
965	0	0	0	2.1	1	73.2
628	0	0	0	2.1	0	109.2
714	0	0	0	1.8	0	206.1
827	0	0	0	2.2	2	62.9
970	5	0	0	2.1	1	73.2
1020	0	0	0	1.9	7	59.2
1051	0	0	0	2.1	0	51.7
620	0	0	0	2.1	0	109.2
775	0	0	0	2.3	0	44.6
834	0	0	0	2.1	4	151
1083	0	0	0	1.9	3	77.6

Table A.1 Prepared Data (cont'd)

Accident Number	**Dead People**	**Injured People**	**Patient people**	**Monthly Average Wind Speed (m/s)**	**Monthly Foggy Days**	**Monthly Total Precipitation (mm)**
1337	0	0	0	2.3	0	56.3
1207	0	0	0	1.7	6	84.4
980	0	0	0	1.6	2	59.7
1216	0	0	0	3.5	3	337.8
1218	0	0	0	3.5	3	337.8
978	0	0	0	1.6	2	59.7
1117	0	0	0	2.1	2	65.9
77	0	0	0	3.1	0	212.8
715	0	0	0	1.8	0	206.1
1022	0	0	0	1.9	7	59.2
647	0	0	0	1.7	0	16.4
676	0	0	0	1.6	0	105.2
722	0	0	0	2.3	0	60.7
741	0	0	0	1.8	1	98.6
799	0	0	0	1.4	4	10.1

Table A.1 Prepared Data (cont'd)

Accident Number	**Sea Condition**	**Speed of Daily maximum wind (m/s)**	**Direction of Daily maximum wind**	**Daily Average Wind Speed (m/s)**	**Daily Total Precipitation (mm)**	**Hourly Wind Speed (m/s)**
611	1	5	SW	1.2	0	3
891	1	5.3	NNE	1.3	0	2.5
1334	1	8.9	SW	0.9	0	3.2
332	-999	16	NNE	7.6	0	7.5
413	-999	11.4	SW	1.7	0.4	0.9
462	-999	2.9	SE	0.3	0	0.6
633	1	3.1	NNE	1.3	0	2.2
672	1	4	NNE	0.8	0	0
690	1	10.4	SW	3.3	0	3.1
718	3	12.9	NNE	5.3	2.2	5.5
977	3	10	NNE	6.3	21.4	8.6
999	3	11.9	N	4.6	0	5.8
1065	2	6.8	NNE	2.8	0	3.7
1152	3	10.7	NNE	4.1	0	4.4
1209	3	22.9	N	6.5	0.9	6.6
1244	1	4.8	SW	0.9	0	0.4
1279	1	6.4	NNE	1.6	0	0.9
98	-999	13.7	SSE	2.6	0.5	2
939	1	2.9	N	1.1	0	0.2
1232	2	14.1	SW	1.4	0	4.7
609	1	11.5	N	3.2	10.2	1.9
705	1	4	SSW	1.3	0.6	0.9
529	-999	14	NNE	9.7	0	2.3
698	1	6	SW	1.4	2.4	2.9
1000	1	2.2	SW	0.7	0	0.6
1204	0	6.8	SW	0.9	0	0.9
1301	3	5.8	NNE	2.3	0	3
387	-999	10.1	NE	3.8	6.2	5.3

Table A.1 Prepared Data (cont'd)

Accident Number	**Sea Condition**	**Speed of Daily maximum wind (m/s)**	**Direction of Daily maximum wind**	**Daily Average Wind Speed (m/s)**	**Daily Total Precipitation (mm)**	**Hourly Wind Speed (m/s)**
642	1	9	N	1	0.8	0.1
680	1	11.4	SW	2.9	0	2.7
950	1	5.9	NNE	1.1	0	1.7
1170	1	3.5	E	0.9	2.7	1.3
527	-999	19	NNE	7.2	8.8	0
557	-999	7.3	N	3.5	0	3.6
745	2	4.1	NNE	1	0	2.6
840	1	2.5	N	1	0	0.3
1070	1	5.9	N	1.2	0	0
461	-999	9.8	NE	3.7	1.3	4.2
1015	0	2.3	SSW	0.4	0	1.1
361	-999	11.1	NNE	5.8	0	7.1
689	1	3.4	SW	0.4	0	1.3
725	2	3.8	NNE	1.3	0	2.2
763	3	7.7	N	3.1	0	3.3
795	1	3.8	NNE	1.8	1.2	1.7
1210	2	22.9	N	6.5	0.9	2.1
532	-999	10.1	NNE	6.6	0	6.5
797	1	4.2	WSW	0.8	4.8	0.1
1190	2	7.4	NNE	3.4	0	3
648	1	5	N	2	8.5	0.8
173	-999	6.5	NNE	1.6	0	0
945	3	5.3	NNE	2.5	0	3.1
409	-999	6.1	S	1.2	0	0.4
322	-999	7.7	ENE	1.7	5.6	0.8
347	-999	9.6	NE	3.5	0	6.3
1167	1	5	NNE	2	0	1.5
889	2	6	NE	3	0	2.9
907	1	5.7	N	1.7	0	0.3
1055	2	7.1	N	1.4	0	2.8

Table A.1 Prepared Data (cont'd)

Accident Number	Sea Condition	Speed of Daily maximum wind (m/s)	Direction of Daily maximum wind	Daily Average Wind Speed (m/s)	Daily Total Precipitation (mm)	Hourly Wind Speed (m/s)
1186	1	4.8	N	1.2	0	1.1
1268	1	7.2	N	3.2	0	4.1
366	-999	14.3	NE	4.9	29.8	4.7
13	-999	-999		-999	-999	-999
1222	2	20.2	NNE	7.7	19	5.4
544	-999	13.7	NNE	10.5	0	6.9
1157	1	10.2	N	0.4	16.1	1.1
542	-999	11.6	NNE	7.6	0.4	0
1059	2	13.8	N	2.9	0	2.8
851	1	4	W	0.7	2.2	0.6
790	2	5.1	N	2	0	2.2
653	2	4.9	NNE	2.4	0	2.3
1125	1	6.7	ENE	1	0	1.7
515	-999	-999		-999	0	6.1
872	1	6.8	N	1	22.6	1.5
925	2	8.7	NE	3.9	0	2.4
1080	0	3.1	NNE	1.2	0	1
594	0	1.5	S	0	0	0
604	2	5.6	NNE	1.8	0	2.2
266	-999	15.4	N	5.4	5.4	3.6
801	1	4.3	NNE	1.9	0	1.5
1099	2	14.6	N	4.7	0.2	6.1
19	-999	-999		-999	-999	-999
565	-999	6.7	NNE	2.8	0	6.7
46	-999	-999		-999	-999	-999
193	-999	10.1	NE	3.8	0	6.5
663	1	4.1	NNE	1	0	0.9
802	1	3.8	N	0.8	0	1.6
408	-999	10.7	NE	1.4	0	0.7
32	-999	-999		-999	-999	-999

Table A.1 Prepared Data (cont'd)

Accident Number	**Sea Condition**	**Speed of Daily maximum wind (m/s)**	**Direction of Daily maximum wind**	**Daily Average Wind Speed (m/s)**	**Daily Total Precipitation (mm)**	**Hourly Wind Speed (m/s)**
460	-999	9.8	NE	3.7	1.3	4
878	1	4.4	NE	1.1	0	0.3
1138	1	5.4	NNE	1.6	0	0.6
8	-999	-999		-999	-999	-999
311	-999	14.6	NNE	4.7	35.6	3.9
1160	1	5.6	N	1.3	11.4	3
1278	1	9.3	N	2.4	0	2.4
331	-999	15.1	NE	6.5	0	3.8
451	-999	25.8	NE	13.2	8.2	18
701	3	11	NNE	5.8	6.1	3.8
769	3	9.1	NNE	4	0	4.3
824	2	7.8	N	2.4	0	0.8
849	1	6.1	SW	0.9	0	0.1
996	1	11.9	N	4.6	0	2.5
1118	2	17.1	NE	4.3	10.1	3.1
1151	2	8.6	N	3.8	0	3.9
38	-999	-999		-999	-999	-999
203	-999	10.8	NE	3.9	0	5.4
380	-999	10.1	NE	4.1	0	3.5
625	3	13.7	NNE	5.7	8.1	5
934	1	3.2	NNE	0.6	15.4	1.3
940	1	4.3	N	1.9	0	1.8
981	1	6.3	SW	1.7	0	1.7
1034	1	8.2	N	2.2	6.9	0.1
1208	2	16.9	N	4.7	15.8	2.8
1240	3	16.4	N	6	7.7	5.1
400	-999	5.5	WSW	1.1	0	0.5
1323	2	8.1	ENE	3.1	0	2.6
399	-999	7.9	NE	1.7	0	1.1
1104	3	20.2	N	5.3	13	5.8

Table A.1 Prepared Data (cont'd)

Accident Number	**Sea Condition**	**Speed of Daily maximum wind (m/s)**	**Direction of Daily maximum wind**	**Daily Average Wind Speed (m/s)**	**Daily Total Precipitation (mm)**	**Hourly Wind Speed (m/s)**
1130	1	9.9	WSW	1.4	0	0
1154	2	6.6	NNE	2.5	0	3.9
113	-999	3.4	ENE	0.8	0.2	0
163	-999	11.9	NNE	5.5	0	5.3
378	-999	14.4	NE	6.5	0	9.6
517	-999	9.5	N	4.8	0	0
538	-999	9.2	NNE	7.2	0	0.6
638	2	6.7	NNE	3	4.7	1.9
708	1	5.6	SSW	1.2	4.8	0.9
783	1	3.6	NNE	0.5	1	0.1
845	1	3.3	NNE	0.4	0	0
1076	1	3.9	N	1.8	0	1.1
1148	1	3.2	NNE	0.9	53.8	0.1
1164	2	4.4	N	1.4	0	0
1195	1	10	SW	2.5	0	2.1
1206	1	9.6	NNE	3.3	2.4	0.8
1233	1	5.9	SW	0.8	0	0.9
768	2	5.2	NNE	2.6	0	2.5
842	4	17.2	N	5.7	27.1	6.1
600	1	2.3	NNE	1	0	1.8
646	1	3.6	NNE	0.7	0	2.2
504	-999	6.7	NE	1.6	3.4	1.2
221	-999	20.7	NNE	9.2	0.1	13.2
346	-999	15.7	NNE	7.3	0	8.4
430	-999	13.3	SW	2.8	0	5.7
965	1	7.2	N	3.2	15.4	3.9
628	1	12	NE	3.6	0.3	4.4
714	2	8.2	NNE	3.7	0	2.6
827	1	12	SW	2.8	0.8	3.6
970	2	7.4	NNE	2.7	1.7	2.9

Table A.1 Prepared Data (cont'd)

Accident Number	Sea Condition	Speed of Daily maximum wind (m/s)	Direction of Daily maximum wind	Daily Average Wind Speed (m/s)	Daily Total Precipitation (mm)	Hourly Wind Speed (m/s)
1020	3	15.2	N	6.4	15.3	7.8
1051	1	7.4	SW	1.3	0	0.3
620	1	1.2	SW	0.2	0	0
775	1	9.2	N	1.8	36	0.2
834	1	2.6	N	0.7	2.4	1.7
1083	1	5.5	N	2.4	0	0.9
1337	2	10.5	N	4.5	0	4.7
1207	3	16.9	N	4.7	15.8	5.7
980	4	13	NNE	4.5	0	7.5
1216	4	22.3	N	5.6	8.3	6.7
1218	4	22.3	N	9	24	8.6
978	3	10	NNE	6.3	21.4	10
1117	2	5.8	W	1.3	2.3	2.8
77	-999	3.1	N	0.6	5.6	0.6
715	1	5.8	NNE	2.1	0.4	1.5
1022	3	15.2	N	6.4	15.3	7.8
647	2	8.6	N	3.9	0	4.7
676	2	9.9	WSW	3.8	5.5	5.6
722	1	5.6	NNE	1.3	0	0.8
741	1	1.9	NNE	0.7	0.6	0.1
799	2	5.2	N	2.2	0	2.4

Table A.1 Prepared Data (cont'd)

Accident Number	Hourly Wind Direction	Average Width	Ratio Passage Area	Ave Turn	Average Current Velocity
611	SW	893.7	0.377	0	156.311
891	NE	893.7	0.377	0	156.311
1334	SSW	893.7	0.377	0	156.311
332	NE	893.7	0.377	0	156.311
413	NE	893.7	0.377	0	156.311
462	SE	893.7	0.377	0	156.311
633	NNE	893.7	0.377	0	156.311
672	C	893.7	0.377	0	156.311
690	SW	893.7	0.377	0	156.311
718	NNE	893.7	0.377	0	156.311
977	NNE	893.7	0.377	0	156.311
999	NE	893.7	0.377	0	156.311
1065	N	893.7	0.377	0	156.311
1152	NNE	893.7	0.377	0	156.311
1209	NNE	893.7	0.377	0	156.311
1244	S	893.7	0.377	0	156.311
1279	NNE	893.7	0.377	0	156.311
98	S	893.7	0.377	0	156.311
939	NNE	893.7	0.377	0	156.311
1232	SW	893.7	0.377	0	156.311
609	N	893.7	0.377	0	156.311
705	SE	893.7	0.377	0	156.311
529	NNE	893.7	0.377	0	156.311
698	SW	893.7	0.377	0	156.311
1000	SE	893.7	0.377	0	156.311
1204	SSW	893.7	0.377	0	156.311
1301	NE	893.7	0.377	0	156.311
387	NE	893.7	0.377	0	156.311
642	S	893.7	0.377	0	156.311
680	SW	893.7	0.377	0	156.311

Table A.1 Prepared Data (cont'd)

Accident Number	Hourly Wind Direction	Average Width	Ratio Passage Area	Ave Turn	Average Current Velocity
950	N	893.7	0.377	0	156.311
1170	NNE	782.8	0.453	51	144.011
527	C	782.8	0.453	51	144.011
557	NNE	782.8	0.453	51	144.011
745	NNE	782.8	0.453	51	144.011
840	ENE	782.8	0.453	51	144.011
1070	C	782.8	0.453	51	144.011
461	NE	782.8	0.453	51	144.011
1015	S	782.8	0.453	51	144.011
361	NE	782.8	0.453	51	144.011
689	SSW	782.8	0.453	51	144.011
725	NNE	782.8	0.453	51	144.011
763	NNE	782.8	0.453	51	144.011
795	NNE	782.8	0.453	51	144.011
1210	N	782.8	0.453	51	144.011
532	NE	782.8	0.453	51	144.011
797	SSW	782.8	0.453	51	144.011
1190	NNE	782.8	0.453	51	144.011
648	NE	782.8	0.453	51	144.011
173	C	635.3	0.474	0	154.891
945	NNE	635.3	0.474	0	154.891
409	SSE	635.3	0.474	0	154.891
322	ENE	745.0	0.605	36	173.061
347	NE	745.0	0.605	36	173.061
1167	NNE	745.0	0.605	36	173.061
889	NNE	745.0	0.605	36	173.061
907	N	745.0	0.605	36	173.061
1055	NE	745.0	0.605	36	173.061
1186	NE	745.0	0.605	36	173.061
1268	NNE	745.0	0.605	36	173.061
366	NE	745.0	0.605	36	173.061

Table A.1 Prepared Data (cont'd)

Accident Number	Hourly Wind Direction	Average Width	Ratio Passage Area	Ave Turn	Average Current Velocity
13		745.0	0.605	36	173.061
1222	NNE	745.0	0.605	36	173.061
544	NNE	745.0	0.605	36	173.061
1157	S	745.0	0.605	36	173.061
542	C	745.0	0.605	36	173.061
1059	WSW	745.0	0.605	36	173.061
851	WSW	574.0	0.581	0	127.59
790	NNE	574.0	0.581	0	127.59
653	NNE	526.5	0.503	23	117.683
1125	E	526.5	0.503	23	117.683
515	NE	526.5	0.503	23	117.683
872	NNW	526.5	0.503	23	117.683
925	NE	526.5	0.503	23	117.683
1080	NE	526.5	0.503	23	117.683
594	C	526.5	0.503	23	117.683
604	NNE	526.5	0.503	23	117.683
266	NE	526.5	0.503	23	117.683
801	NE	526.5	0.503	23	117.683
1099	N	526.5	0.503	23	117.683
19		526.5	0.503	23	117.683
565	NNE	526.5	0.503	23	117.683
46		535.1	0.613	39	107.93
193	NE	535.1	0.613	39	107.93
663	NNE	513.2	0.598	0	83.6804
802	NNE	513.2	0.598	0	83.6804
408	WNW	513.2	0.598	0	83.6804
32		545.2	0.514	46	93.6324
460	NNE	545.2	0.514	46	93.6324
878	NNE	545.2	0.514	46	93.6324
1138	NE	545.2	0.514	46	93.6324
8		545.2	0.514	46	93.6324

Table A.1 Prepared Data (cont'd)

Accident Number	**Hourly Wind Direction**	**Average Width**	**Ratio Passage Area**	**Ave Turn**	**Average Current Velocity**
311	N	791.4	0.449	83	71.1788
1160	NNE	791.4	0.449	83	71.1788
1278	NNE	791.4	0.449	83	71.1788
331	NE	791.4	0.449	83	71.1788
451	NE	791.4	0.449	83	71.1788
701	NNE	791.4	0.449	83	71.1788
769	NE	791.4	0.449	83	71.1788
824	SSE	791.4	0.449	83	71.1788
849	S	791.4	0.449	83	71.1788
996	NNE	791.4	0.449	83	71.1788
1118	NNW	791.4	0.449	83	71.1788
1151	NNE	791.4	0.449	83	71.1788
38		791.4	0.449	83	71.1788
203	NE	791.4	0.449	83	71.1788
380	NE	791.4	0.449	83	71.1788
625	NE	791.4	0.449	83	71.1788
934	NNE	791.4	0.449	83	71.1788
940	NNE	791.4	0.449	83	71.1788
981	W	791.4	0.449	83	71.1788
1034	ENE	791.4	0.449	83	71.1788
1208	N	791.4	0.449	83	71.1788
1240	N	791.4	0.449	83	71.1788
400	E	791.4	0.449	83	71.1788
1323	NNE	791.4	0.449	83	71.1788
399	SW	791.4	0.449	83	71.1788
1104	N	619.3	0.331	75	56.6703
1130	C	619.3	0.331	75	56.6703
1154	NNE	619.3	0.331	75	56.6703
113	C	619.3	0.331	75	56.6703
163	NE	619.3	0.331	75	56.6703
378	NE	619.3	0.331	75	56.6703

Table A.1 Prepared Data (cont'd)

Accident Number	Hourly Wind Direction	Average Width	Ratio Passage Area	Ave Turn	Average Current Velocity
517	C	619.3	0.331	75	56.6703
538	NNE	619.3	0.331	75	56.6703
638	NE	619.3	0.331	75	56.6703
708	W	619.3	0.331	75	56.6703
783	E	619.3	0.331	75	56.6703
845	C	619.3	0.331	75	56.6703
1076	ENE	619.3	0.331	75	56.6703
1148	WSW	619.3	0.331	75	56.6703
1164	C	619.3	0.331	75	56.6703
1195	WSW	619.3	0.331	75	56.6703
1206	W	619.3	0.331	75	56.6703
1233	SW	619.3	0.331	75	56.6703
768	NNE	542.6	0.393	7	59.8078
842	N	542.6	0.393	7	59.8078
600	NNE	542.6	0.393	7	59.8078
646	N	542.6	0.393	7	59.8078
504	SSW	542.6	0.393	7	59.8078
221	NE	542.6	0.393	7	59.8078
346	NE	542.6	0.393	7	59.8078
430	SW	542.6	0.393	7	59.8078
965	N	964.8	0.457	14	35.9923
628	NE	964.8	0.457	14	35.9923
714	NE	1443.1	0.443	0	12.5
827	SW	1443.1	0.443	0	12.5
970	NNE	1443.1	0.443	0	12.5
1020	NNE	1443.1	0.443	0	12.5
1051	NE	1443.1	0.443	0	12.5
620	C	1443.1	0.443	0	12.5
775	NE	1443.1	0.443	0	12.5
834	NNE	1443.1	0.443	0	12.5
1083	NE	1443.1	0.443	0	12.5

Table A.1 Prepared Data (cont'd)

Accident Number	**Hourly Wind Direction**	**Average Width**	**Ratio Passage Area**	**Ave Turn**	**Average Current Velocity**
1337	E	1443.1	0.443	0	12.5
1207	N	1443.1	0.443	0	12.5
980	NNE	1443.1	0.443	0	12.5
1216	NNE	1443.1	0.443	0	12.5
1218	NNE	1443.1	0.443	0	12.5
978	NNE	1443.1	0.443	0	12.5
1117	NNW	1443.1	0.443	0	12.5
77	NNW	1443.1	0.443	0	12.5
715	NNE	1443.1	0.443	0	12.5
1022	NNE	1443.1	0.443	0	12.5
647	N	1443.1	0.443	0	12.5
676	NNE	1443.1	0.443	0	12.5
722	SE	1443.1	0.443	0	12.5
741	WNW	1443.1	0.443	0	12.5
799	NNE	1443.1	0.443	0	12.5

Table A.1 Prepared Data (cont'd)

Accident Number	**Probability of Total Accidents**	**Probability of Collision Accidents**	**Probability of Capsizing Accidents**	**Probability of Grounding Accidents**	**Probability of Fire Accidents**	**Probability of Other Accidents**
611	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
891	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1334	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
332	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
413	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
462	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
633	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
672	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
690	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
718	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
977	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
999	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1065	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1152	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1209	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1244	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1279	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
98	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
939	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1232	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
609	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
705	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
529	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
698	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1000	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1204	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1301	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
387	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
642	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06

Table A.1 Prepared Data (cont'd)

Accident Number	**Probability of Total Accidents**	**Probability of Collision Accidents**	**Probability of Capsizing Accidents**	**Probability of Grounding Accidents**	**Probability of Fire Accidents**	**Probability of Other Accidents**
680	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
950	6.02E-05	3.74E-05	6.23E-06	1.04E-05	4.15E-06	2.08E-06
1170	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
527	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
557	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
745	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
840	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
1070	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
461	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
1015	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
361	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
689	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
725	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
763	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
795	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
1210	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
532	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
797	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
1190	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
648	2.49E-05	1.45E-05	2.08E-06	0.00E+00	6.23E-06	2.08E-06
173	6.23E-06	4.15E-06	0.00E+00	0.00E+00	2.08E-06	0.00E+00
945	6.23E-06	4.15E-06	0.00E+00	0.00E+00	2.08E-06	0.00E+00
409	6.23E-06	4.15E-06	0.00E+00	0.00E+00	2.08E-06	0.00E+00
322	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
347	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
1167	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
889	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
907	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
1055	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
1186	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
1268	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06

Table A.1 Prepared Data (cont'd)

Accident Number	Probability of Total Accidents	Probability of Collision Accidents	Probability of Capsizing Accidents	Probability of Grounding Accidents	Probability of Fire Accidents	Probability of Other Accidents
366	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
13	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
1222	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
544	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
1157	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
542	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
1059	1.66E-05	6.23E-06	0.00E+00	4.15E-06	2.08E-06	4.15E-06
851	4.15E-06	2.08E-06	0.00E+00	0.00E+00	0.00E+00	2.08E-06
790	4.15E-06	2.08E-06	0.00E+00	0.00E+00	0.00E+00	2.08E-06
653	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
1125	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
515	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
872	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
925	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
1080	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
594	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
604	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
266	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
801	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
1099	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
19	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
565	2.08E-05	1.25E-05	2.08E-06	6.23E-06	0.00E+00	0.00E+00
46	4.15E-06	2.08E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
193	4.15E-06	2.08E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
663	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
802	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
408	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
32	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
460	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
878	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
1138	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00

Table A.1 Prepared Data (cont'd)

Accident Number	**Probability of Total Accidents**	**Probability of Collision Accidents**	**Probability of Capsizing Accidents**	**Probability of Grounding Accidents**	**Probability of Fire Accidents**	**Probability of Other Accidents**
8	6.23E-06	4.15E-06	0.00E+00	2.08E-06	0.00E+00	0.00E+00
311	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1160	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1278	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
331	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
451	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
701	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
769	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
824	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
849	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
996	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1118	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1151	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
38	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
203	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
380	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
625	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
934	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
940	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
981	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1034	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1208	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1240	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
400	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1323	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
399	4.36E-05	1.45E-05	6.23E-06	2.08E-05	0.00E+00	2.08E-06
1104	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1130	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1154	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
113	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
163	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00

Table A.1 Prepared Data (cont'd)

Accident Number	Probability of Total Accidents	Probability of Collision Accidents	Probability of Capsizing Accidents	Probability of Grounding Accidents	Probability of Fire Accidents	Probability of Other Accidents
378	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
517	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
538	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
638	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
708	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
783	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
845	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1076	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1148	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1164	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1195	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1206	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
1233	3.11E-05	0.00E+00	0.00E+00	2.91E-05	2.08E-06	0.00E+00
768	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
842	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
600	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
646	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
504	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
221	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
346	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
430	1.04E-05	0.00E+00	0.00E+00	6.23E-06	4.15E-06	0.00E+00
965	4.15E-06	0.00E+00	0.00E+00	2.08E-06	0.00E+00	2.08E-06
628	4.15E-06	0.00E+00	0.00E+00	2.08E-06	0.00E+00	2.08E-06
714	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
827	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
970	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1020	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1051	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
620	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
775	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
834	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05

Table A.1 Prepared Data (cont'd)

Accident Number	**Probability of Total Accidents**	**Probability of Collision Accidents**	**Probability of Capsizing Accidents**	**Probability of Grounding Accidents**	**Probability of Fire Accidents**	**Probability of Other Accidents**
1083	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1337	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1207	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
980	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1216	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1218	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
978	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1117	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
77	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
715	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
1022	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
647	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
676	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
722	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
741	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05
799	4.77E-05	1.25E-05	1.25E-05	6.23E-06	6.23E-06	1.04E-05

A.2 BASIC STATISTICS OF THE PARAMETERS

Average, variance and standard deviation values of the input parameters are calculated. LOA, average current velocity, vessel-1 GRT, average turn, monthly average wind speed, monthly foggy days, hourly wind speed, daily total precipitation, daily average wind speed, daily maximum wind, monthly total precipitation, ratio passage area, average passage width is used as input parameters. The calculated values is presented in Table A.2.

Table A.2 Basic Statistics of the Parameters

Parameters	**Average**	**Variance**	**Standard Deviation**
LOA	93.728	2257.0	47.51
Average Current Velocity	96.963	2981.9	54.61
Vessel-1 GRT	6901.284	151322643.6	12301.33
Average Turn	32.551	1101.1	33.18
Monthly Average Wind Speed	2.401	1.6	1.27
Monthly Foggy Days	1.618	5.1	2.25
Hourly Wind Speed	2.996	7.9	2.82
Daily Total Precipitation	3.517	61.0	7.81
Daily Average Wind Speed	3.018	5.7	2.39
Daily Maximum Wind	8.659	25.4	5.04
Monthly Total Precipitation	85.890	4818.0	69.41
Ratio Passage Area	0.439	0.0	0.08
Average Passage Width	840.510	82272.1	286.83

A.3 PRINCIPAL COMPONENT ANALYSIS

Principal component analysis is used to see the relationship of the input parameters. Two principal components are determined by the principal component analysis. The scatterplot of the principal components is presented in Figure A.1. Hourly wind speed, daily maximum wind speed and daily average wind, vessel-1 GRT and LOA speed have grouped as seen in Figure A.1.

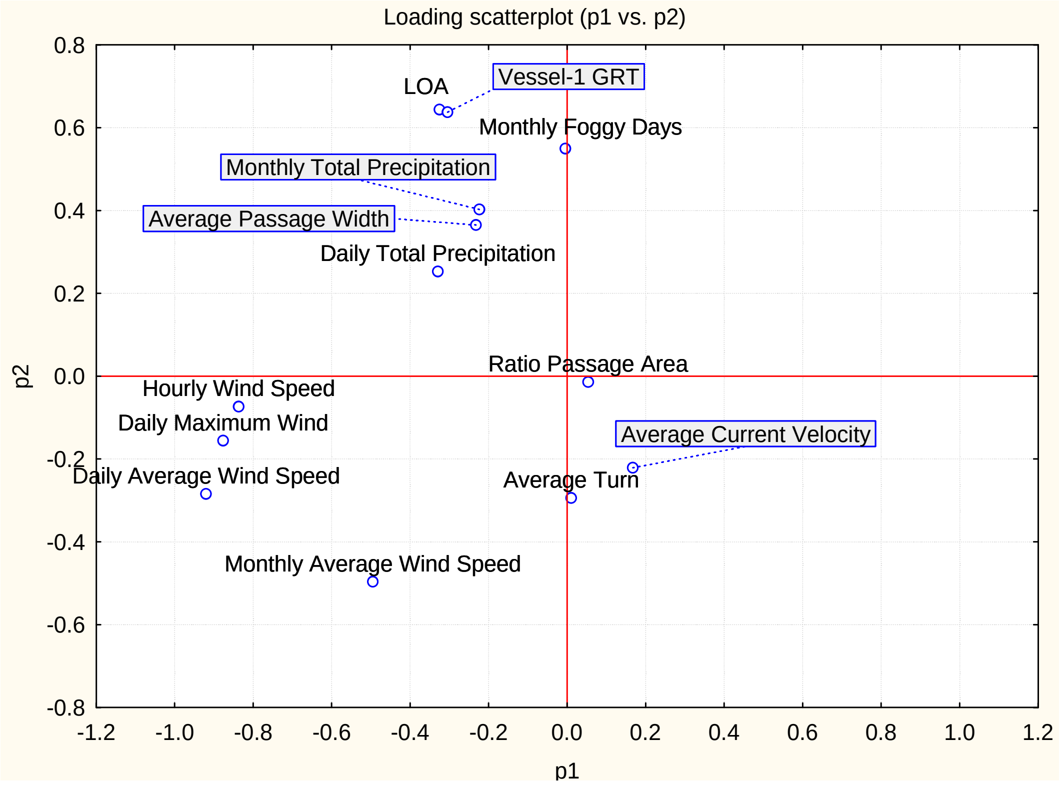


Figure A.1 Loading Scatterplot of Principal Component 1 versus Principal Component 2

The data was found homogenous. Since the scattering is negligible (Figure A.2).

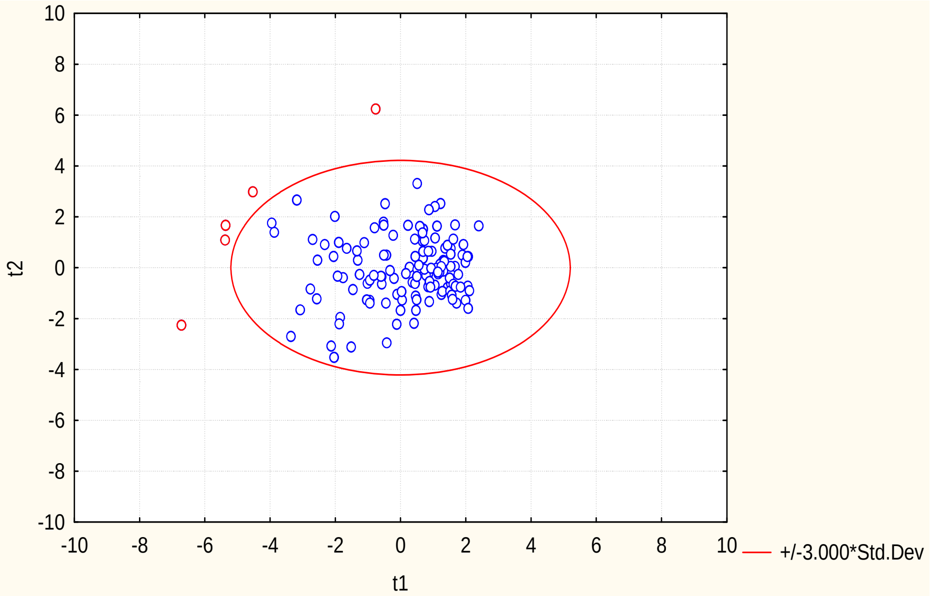


Figure A.2 Score Scatterplot of Principal Component 1 versus Principal Component 2

APPENDIX B

THE COEFFICIENT OF DETERMINATION

The reliability of the estimated data by a model is controlled by carrying out the estimation of model coefficients where coefficient of determination R^2 is maximized.

In this study the accident probability of archive data (UMA) has been used to determine the coefficients of the formulas. The coefficient of determination (R^2) has been considered to estimate the reliable coefficients (X_i) of the formulas and to define reliable model. R^2 value provides a measure of how well the regression line predicts the outcome.

R^2 can be calculated as;

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \tag{B.1}$$

where;
SS_{res} is residual sum of squares and SS_{tot} is total sum of squares. The residual sum of squares can be calculated with the following formula:

$$SS_{res} = \sum_i (y_i - f_i)^2 \tag{B.2}$$

where;
y_i is the observed/obtained data and f_i is the estimated data. The total sum of square has been determined as:

$$SS_{tot} = \sum_i (y_i - \bar{y})^2 \tag{B.3}$$

where, $\bar{y}$ is the mean of the observed/obtained data which can be calculated with the (B.4) formula:

$$\bar{y} = \frac{1}{n}\sum_i y_i \tag{B.4}$$

APPENDIX C

CALCULATION OF AVERAGE CURRENT VELOCITY

Current velocity has been calculated considering the current areas on zones. Each current segment area has been measured individually and multiplied by current segment average velocity. The summation of all current segments on passage has been divided to the passage area. Thus average current velocity can be determined for each zone.

Table C.1 Average current velocity for each zone

Zone	Velocity of Current segments (cm/s)	Area of Current Segment (m^2)	Passage Area (m^2)	Multiplication of velocity with segment area (cm/s x m^2)	Average current velocity (cm/s)
2	175	783258.1	1250788	137070169	156.31
	125	467530		58441250	
4	87.5	76955.49	1905617	6733605.4	144.01
	62.5	53778.58		3361161.3	
	175	849500		148662491	
	125	925382.6		115672828	
6	62.5	24143.44	1423737	1508965	154.89
	12.5	51236.1		640451.25	
	175	1132432		198175633	
	125	110267.6		13783444	
	37.5	56590.64		2122149	
	87.5	49067.15		4293375.6	
7	12.5	38947.08	1902691	486838.5	173.06
	37.5	62506.87		2344007.6	
	175	573540		100369493	
	225	848107.7		190824233	
	125	195696.3		24462041	
	87.5	77973.37		6822669.9	
	37.5	105919.2		3971970.8	

Table C.1 Average current velocity for each zone (continued)

Zone	**Velocity of Current segments (cm/s)**	**Area of Current Segment (m^2)**	**Passage Area (m^2)**	**Multiplication of velocity with segment area (cm/s x m^2)**	**Average current velocity (cm/s)**
8	12.5	861.372	606529	10767.15	127.59
	125	518181.1		64772643	
	175	65627.22		11484764	
	37.5	15880.98		595536.75	
	87.5	5978.36		523106.5	
9	37.5	31531.53	520223	1182432.4	117.68
	125	460764		57595503	
	87.5	27927.5		2443656.3	
10	87.5	238970.8	583007	20909948	107.93
	125	332537.3		41567160	
	62.5	626.552		39159.5	
	37.5	10872.82		407730.75	
11	62.5	92311.77	604198	5769485.6	83.68
	87.5	511885.8		44790003	
12	37.5	6193.06	808858	232239.75	93.63
	62.5	104352		6521999.4	
	87.5	488214.4		42718763	
	125	210098.2		26262270	
13	12.5	209523.6	2803002	2619044.9	71.18
	87.5	957961.2		83821607	
	125	332839.2		41604898	
	62.5	904738.9		56546179	
	37.5	397939.2		14922719	
14	62.5	2060543	2817619	128783958	56.67
	87.5	98249.81		8596858.4	
	12.5	96457.39		1205717.4	
	37.5	562368.4		21088815	
15	12.5	195813.9	1691951	2447673.6	59.81
	62.5	660655.9		41290994	
	37.5	313028.2		11738557	
	87.5	522453.4		45714670	
16	62.5	136541.9	3599157	8533868.8	35.99
	12.5	353598.1		4419975.8	
	37.5	3109017		116588132	
17	12.5	1989630	1989630	24870375	12.50

APPENDIX D

SELECTION OF THE PARAMETERS

D.1 AVERAGE WIDTHS WITHIN THE ZONES

Widths within the zones have been calculated and presented in Table D.1

Table D.1 Widths within Zones

Zone	**A_2 (m^2)**	**Midline Length, L_m (m)**	**Average Width (m)**	**Minimum Width (m)**
2	1253537	1402.7	893.7	875.91
4	1908795	2438.5	782.8	687.05
6	1425715	2244.3	635.3	584.34
7	1905398	2557.7	745.0	584.34
8	607434	1058.3	574.0	519.31
9	521031	989.6	526.5	465.96
10	583872	1091.1	535.1	465.01
11	605188	1179.3	513.2	496.64
12	810172	1486.0	545.2	496.64
13	2807393	3547.5	791.4	634.41
14	2821859	4556.3	619.3	488.41
15	1694551	3122.7	542.6	431.89
16	3603942	3735.6	964.8	729.58
17	1988848	1378.2	1443.1	1195.09

D.2 COMPUTATION OF CORRELATION COEFFICIENT

The correlation coefficient which is also known as Pearson correlation coefficient and Pearson's product- moment coefficient shows the relationship between two sets of variables (Paulson, 2007).

It is possible to measure the dependency between two quantities by correlation coefficient. The correlation coefficient can take values between -1 and +1. If the value is +1 the correlation has a positive linear relationship. If the value is -1 the correlation has a negative linear relationship.

The correlation coefficient can be obtained by dividing the covariance of the two variables sets to the products of the variable sets standard deviations as given in Equation (D.1):

$$\rho_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y} \tag{D.1}$$

where;

$\rho_{X,Y}$: the correlation coefficient of variables X and Y,

cov(X,Y): the covariance of the variables X and Y,

σ_X : the standard deviation of variable X,

σ_Y : the standard deviation of variable Y.

If we have a series of n values, the correlation coefficient can also be calculated with the Equation (D.2):

$$\rho_{X,Y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{D.2}$$

where;

$\rho_{X,Y}$: the correlation coefficient of variables X and Y,

x_i: the variables of X set,

y_i: the variables of Y set,

$\bar{x}$: the mean of variables of X set,

$\bar{y}$: the mean of variables of Y set.

D.3 SELECTION OF THE PARAMETERS BY ANFIS

The error of the ANFIS tool has been considered and the input parameters minimizing the error has been selected. The examined parameters and error on the ANFIS tool has been given in Table D.2.

Table D.2 ANFIS examination

Trials of ANFIS	**Input 1**	**Input 2**	**Input 3**	**Input 4**
1	Daily Average Wind	Daily Maximum Wind	Monthly Total Precipitation	Ratio Passage Area
2	Daily Total Precipitation	Daily Average Wind	Daily Maximum Wind	Monthly Total Precipitation
3	Average Turn	Monthly Foggy Days	Hourly Wind Speed	Monthly Total Precipitation
4	Average Current Velocity	GRT of Vessel-1	Average Turn	Hourly Wind Speed
5	Average Current Velocity	GRT of Vessel-1	Average Turn	Hourly Wind Speed
6	Average Current Velocity	LOA	Average Turn	Hourly Wind Speed
7	Average Current Velocity	Monthly Average Wind	Average Turn	Hourly Wind Speed
8	Average Current Velocity	Monthly Foggy Days	Average Turn	Hourly Wind Speed

Table D.2 ANFIS examination (continued)

Trials of ANFIS	**Input 1**	**Input 2**	**Input 3**	**Input 4**
9	Average Current Velocity	Daily Total Precipitation	Average Turn	Hourly Wind Speed
10	Average Current Velocity	Daily Average Wind	Average Turn	Hourly Wind Speed
11	Average Current Velocity	Daily Maximum Wind	Average Turn	Hourly Wind Speed
12	Average Current Velocity	Monthly Total Precipitation	Average Turn	Hourly Wind Speed
13	LOA	Monthly Average Wind	Average Turn	Hourly Wind Speed
14	LOA	Monthly Foggy Days	Average Turn	Hourly Wind Speed
15	LOA	Daily Total Precipitation	Average Turn	Hourly Wind Speed
16	LOA	Daily Average Wind	Average Turn	Hourly Wind Speed
17	LOA	Daily Maximum Wind	Average Turn	Hourly Wind Speed
18	LOA	Monthly Total Precipitation	Average Turn	Hourly Wind Speed
19	GRT of Vessel-1	Monthly Average Wind	Average Turn	Hourly Wind Speed
20	GRT of Vessel-1	Monthly Total Precipitation	Average Turn	Hourly Wind Speed
21	LOA	Average Current Velocity	Monthly Average Wind	Hourly Wind Speed
22	LOA	Average Current Velocity	Monthly Foggy Days	Hourly Wind Speed
23	LOA	Average Current Velocity	Daily Total Precipitation	Hourly Wind Speed

Table D.2 ANFIS examination (continued)

Trials of ANFIS	**Input 1**	**Input 2**	**Input 3**	**Input 4**
24	LOA	Average Current Velocity	Daily Average Wind	Hourly Wind Speed
25	LOA	Average Current Velocity	Daily Maximum Wind	Hourly Wind Speed
26	LOA	Average Current Velocity	Monthly Total Precipitation	Hourly Wind Speed
27	LOA	Average Current Velocity	Monthly Total Precipitation	Average Turn
28	LOA	Average Current Velocity	Monthly Total Precipitation	Monthly Average Wind
29	LOA	Average Current Velocity	Monthly Total Precipitation	Monthly Foggy Days
30	LOA	Average Current Velocity	Monthly Total Precipitation	Hourly Wind Speed
31	LOA	Average Current Velocity	Monthly Total Precipitation	Daily Total Precipitation
32	LOA	Average Current Velocity	Monthly Total Precipitation	Daily Average Wind
33	LOA	Average Current Velocity	Monthly Total Precipitation	Daily Maximum Wind
34	Average Turn	LOA	Average Current Velocity	Monthly Total Precipitation
35	Average Turn	LOA	Average Current Velocity	Monthly Total Precipitation
36	Average Turn	LOA	Average Current Velocity	Monthly Total Precipitation

Table D.2 ANFIS examination (continued)

Trials of ANFIS	Input 5	Input 6	Output	Error
1	Average Width		Probability	1.90E-03
2	Ratio Passage Area		Probability	1.56E-03
3	Average Width		Probability	1.25E-03
4	Average Width		Probability	1.66E-03
5	Ratio Passage Area		Probability	1.45E-03
6	Ratio Passage Area		Probability	1.11E-03
7	Ratio Passage Area		Probability	1.24E-03
8	Ratio Passage Area		Probability	1.24E-03
9	Ratio Passage Area		Probability	1.50E-03
10	Ratio Passage Area		Probability	1.20E-03
11	Ratio Passage Area		Probability	1.09E-03
12	Ratio Passage Area		Probability	1.07E-03
13	Ratio Passage Area		Probability	1.29E-03
14	Ratio Passage Area		Probability	1.27E-03
15	Ratio Passage Area		Probability	1.51E-03
16	Ratio Passage Area		Probability	1.25E-03

Table D.2 ANFIS examination (continued)

Trials of ANFIS	**Input 5**	**Input 6**	**Output**	**Error**
17	Ratio Passage Area		Probability	1.12E-03
18	Ratio Passage Area		Probability	1.12E-03
19	Ratio Passage Area		Probability	1.70E-03
20	Ratio Passage Area		Probability	1.47E-03
21	Ratio Passage Area		Probability	1.11E-03
22	Ratio Passage Area		Probability	1.12E-03
23	Ratio Passage Area		Probability	1.32E-03
24	Ratio Passage Area		Probability	1.09E-03
25	Ratio Passage Area		Probability	9.80E-04
26	Ratio Passage Area		Probability	9.80E-04
27	Ratio Passage Area		Probability	9.60E-04
28	Ratio Passage Area		Probability	9.70E-04
29	Ratio Passage Area		Probability	1.00E-03
30	Ratio Passage Area		Probability	9.80E-04
31	Ratio Passage Area		Probability	1.16E-03
32	Ratio Passage Area		Probability	8.90E-04
33	Ratio Passage Area		Probability	8.50E-04

Table D.2 ANFIS examination (continued)

Trials of ANFIS	**Input 5**	**Input 6**	**Output**	**Error**
34	Daily Maximum Wind	Ratio Passage Area	Probability	5.60E-04
35	Hourly Wind Speed	Ratio Passage Area	Probability	6.50E-04
36	Daily Maximum Wind	Ratio Passage Area	Probability	5.00E-04

APPENDIX E

MODEL 1 MEMBERSHIP FUNCTIONS

On ANFIS model development, after trials of triangular, trapezoidal, gaussian and bell shaped membership functions, the gaussian membership function was selected due to its minimum error in the trials. Two linguistic term was used for membership functions. The rules are formed by Sugeno fuzzy model. ANFIS model structure is presented in Figure E.1.

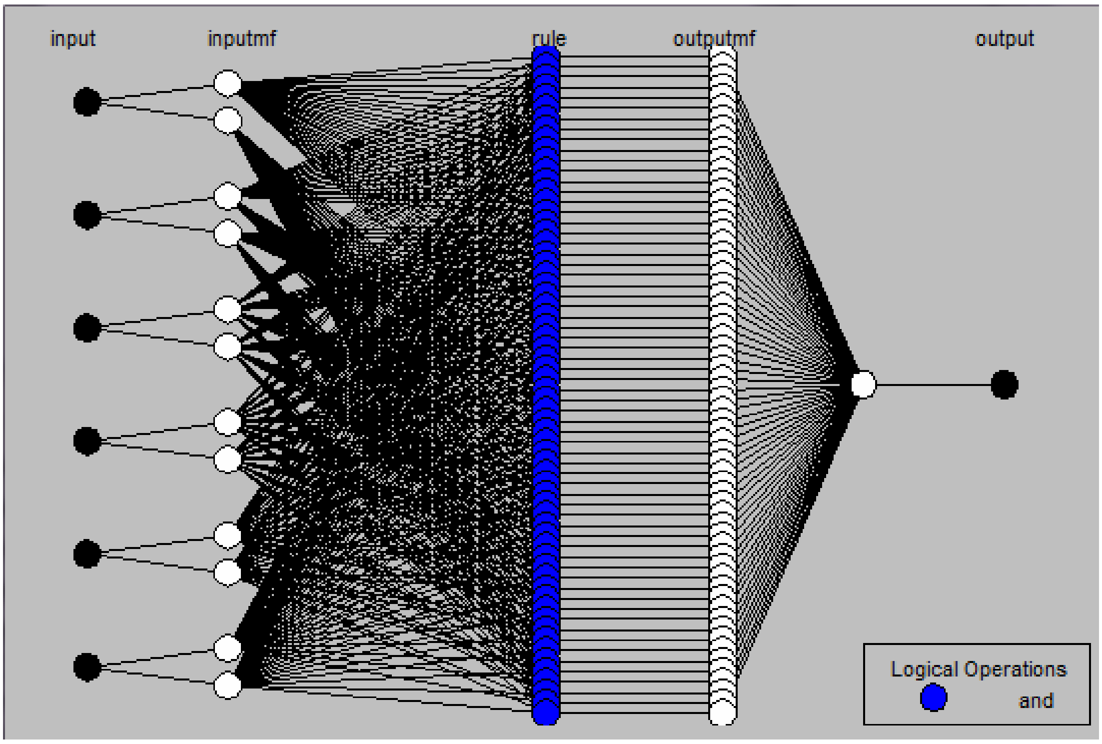
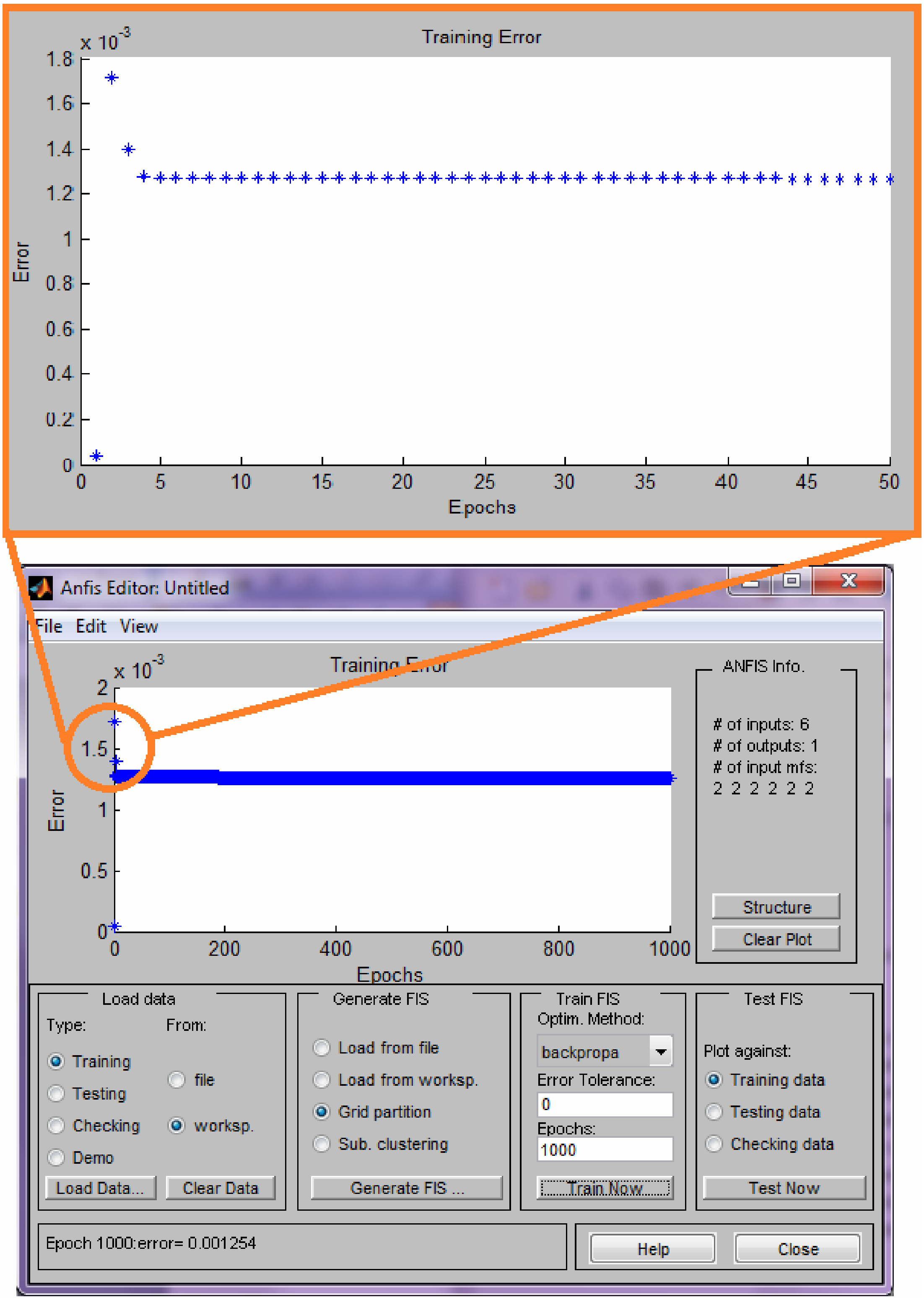


Figure E.1 Model 1 Structure of ANFIS

The change of the training error of the triangular membership function trials is presented in Figure E.2 and membership functions of the inputs are shown in Figure E.3.



# of inputs: 6
# of outputs: 1
# of input mfs:
2 2 2 2 2 2

Load data — Type: ○ Training ○ Testing ○ Checking ○ Demo; From: ○ file ● worksp.

Type: ● Training

Generate FIS: ○ Load from file ○ Load from worksp. ● Grid partition ○ Sub. clustering

Train FIS — Optim. Method: backpropa

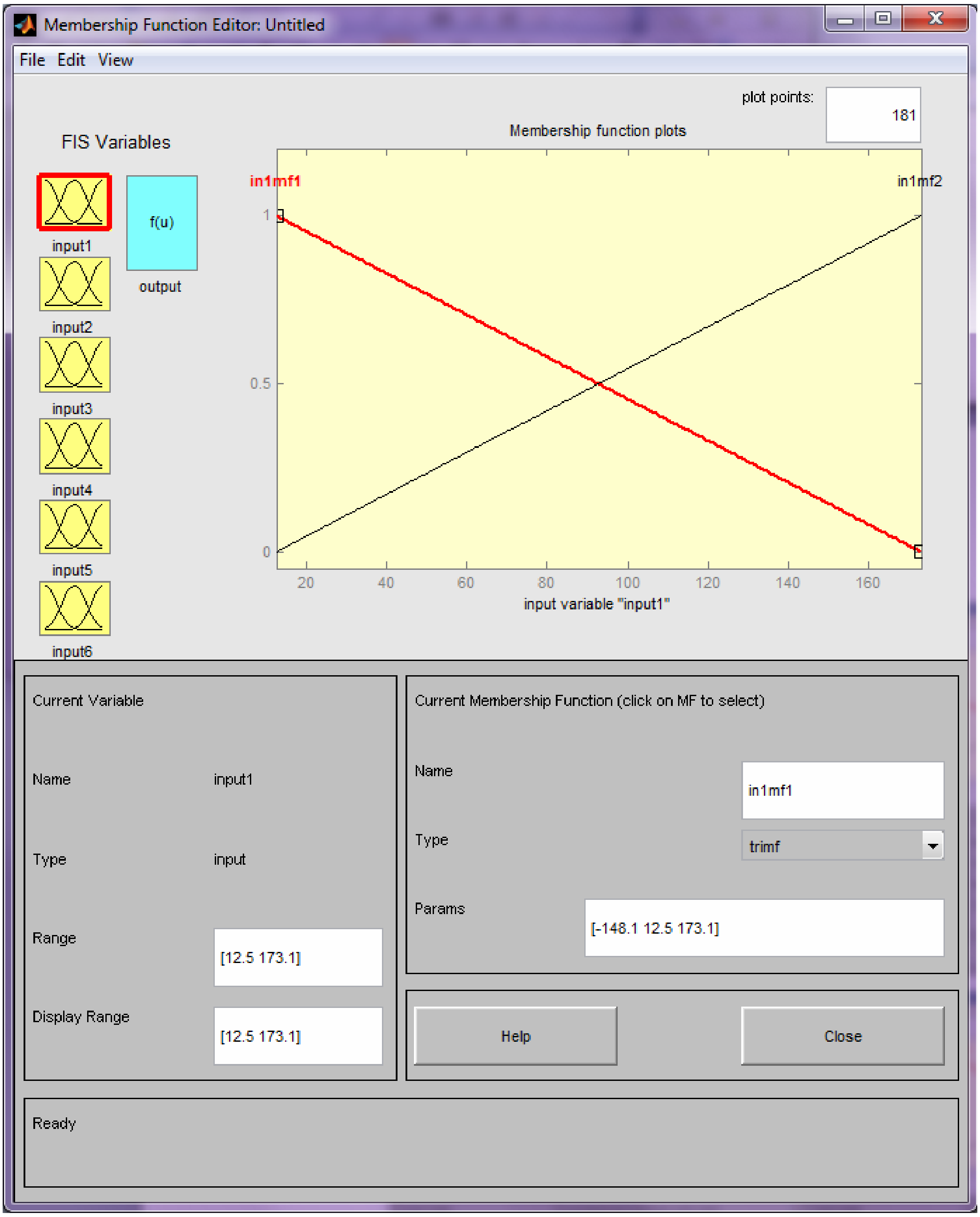
Error Tolerance: 0

Epochs: 1000

Test FIS — Plot against: ● Training data ○ Testing data ○ Checking data

Epoch 1000:error= 0.001254

Figure E.2 Training error of the triangular membership function trials



plot points: 181

Current Variable

Name input1

Type input

Range [12.5 173.1]

Display Range [12.5 173.1]

Current Membership Function (click on MF to select)

Name in1mf1

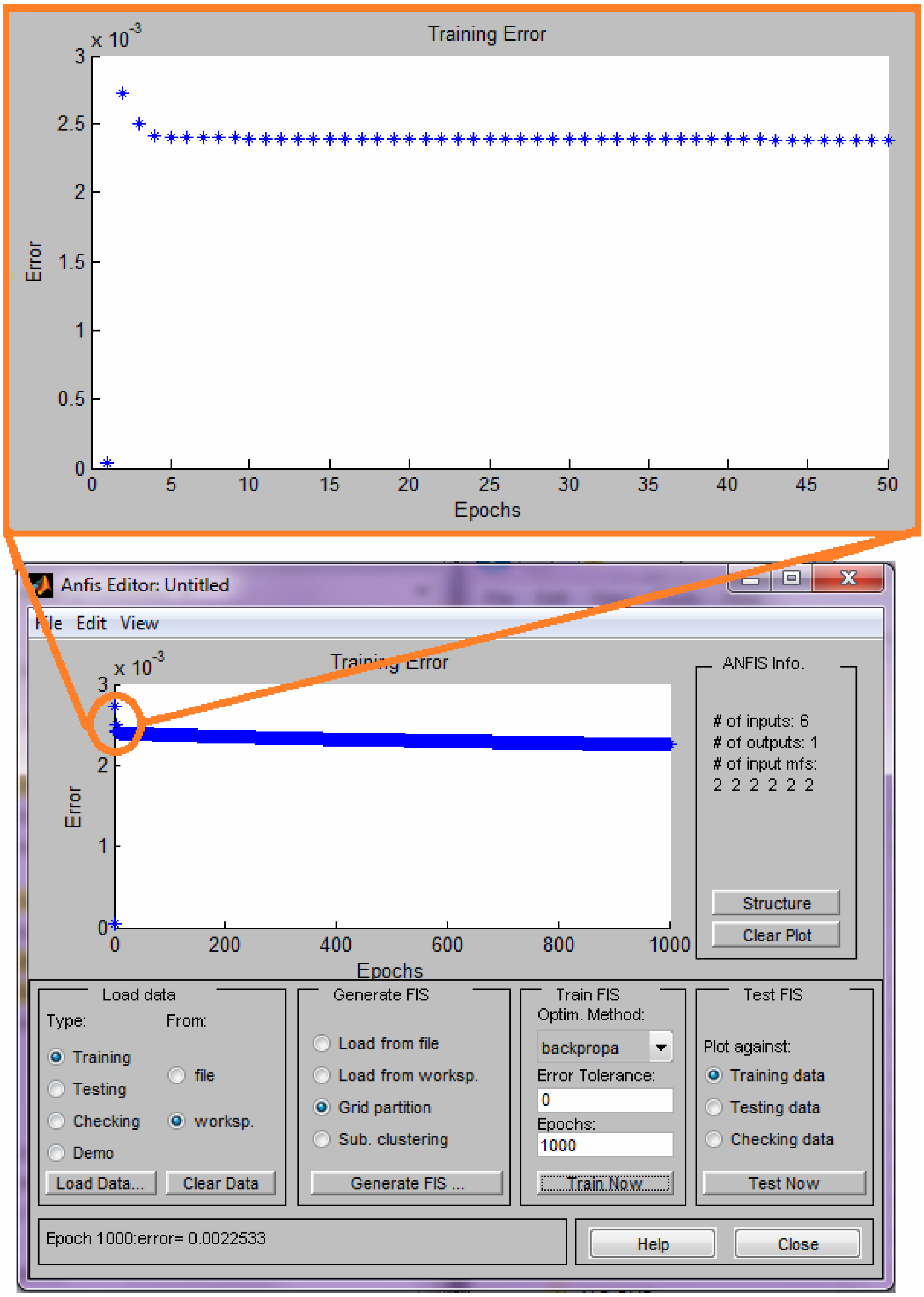
Type trimf

Params [-148.1 12.5 173.1]

Ready

Figure E.3 Membership function of input 1 for the triangular membership function trials

The change of the training error of the trapezoidal membership function trials is presented in Figure E.4 and membership functions of the inputs are shown in Figure E.5.



# of inputs: 6
# of outputs: 1
# of input mfs:
2 2 2 2 2 2

Type: ● Training ○ Testing ○ Checking ○ Demo

From: ○ file ● worksp.

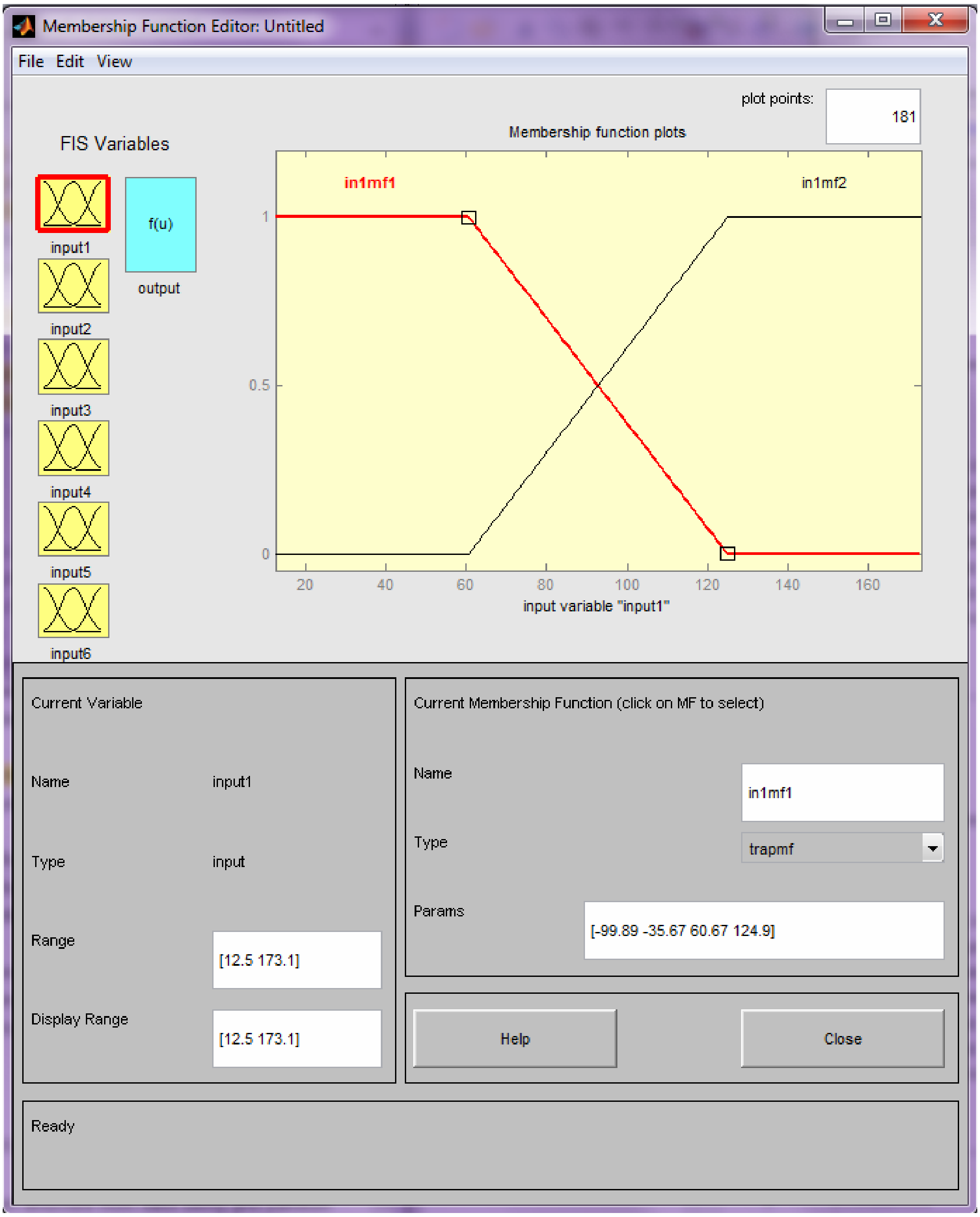
○ Load from file
○ Load from worksp.
● Grid partition
○ Sub. clustering

Optim. Method: backpropa
Error Tolerance: 0
Epochs: 1000

Plot against: ● Training data ○ Testing data ○ Checking data

Epoch 1000:error= 0.0022533

Figure E.4 Training error of the trapezoidal membership function trials



plot points: 181

Current Variable

Name input1

Type input

Range [12.5 173.1]

Display Range [12.5 173.1]

Current Membership Function (click on MF to select)

Name in1mf1

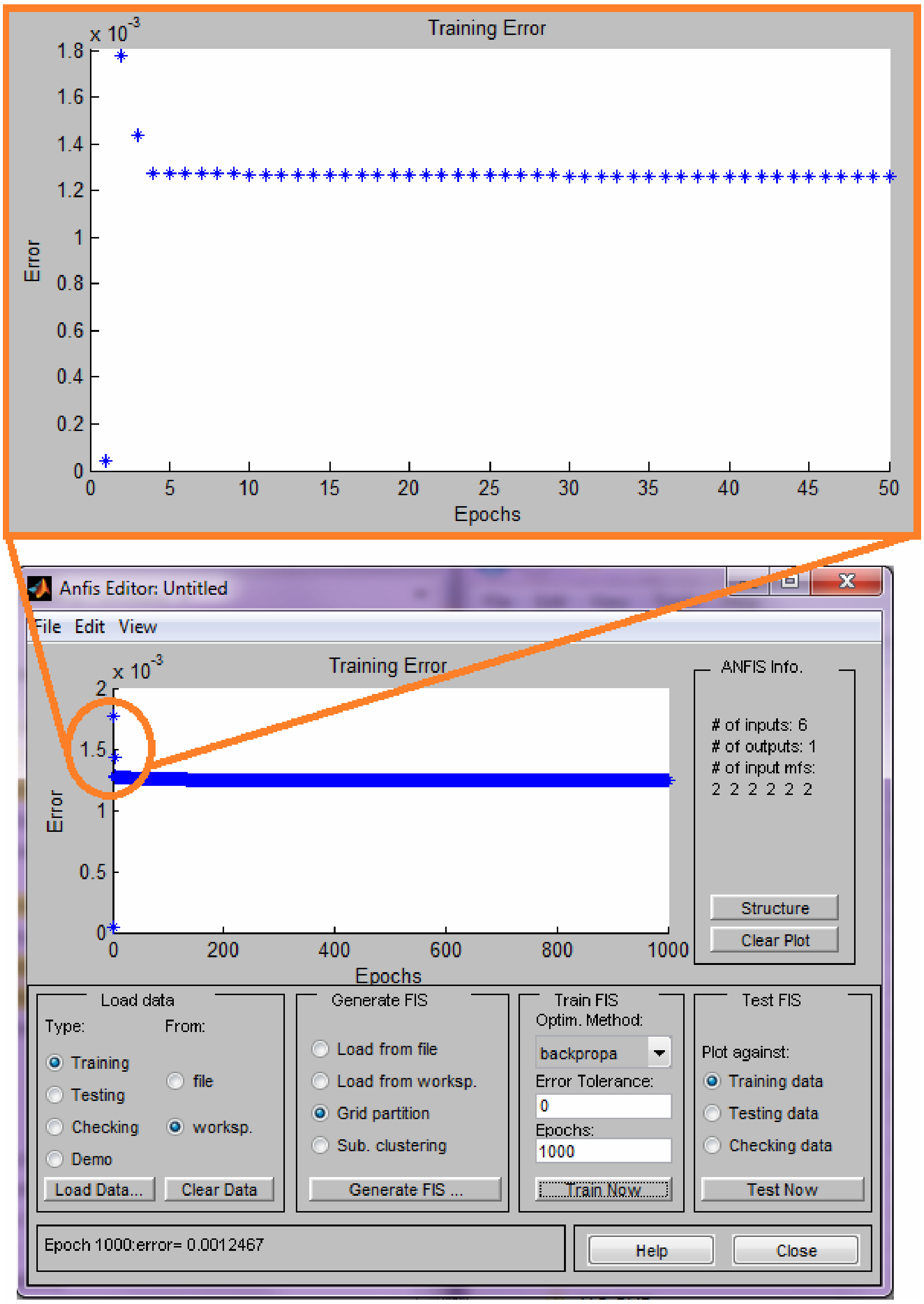
Type trapmf

Params [-99.89 -35.67 60.67 124.9]

Ready

Figure E.5 Membership function of input 1 for the trapezoidal membership function trials

The change of the training error of the gaussian membership function trials is presented in Figure E.2 and membership functions of the inputs are shown in Figure E.3.



ANFIS Info.

# of inputs: 6

# of outputs: 1

# of input mfs:
2 2 2 2 2 2

Load data

Type: ● Training ○ Testing ○ Checking ○ Demo

From: ○ file ● worksp.

Generate FIS

○ Load from file
○ Load from worksp.
● Grid partition
○ Sub. clustering

Train FIS

Optim. Method: backpropa

Error Tolerance: 0

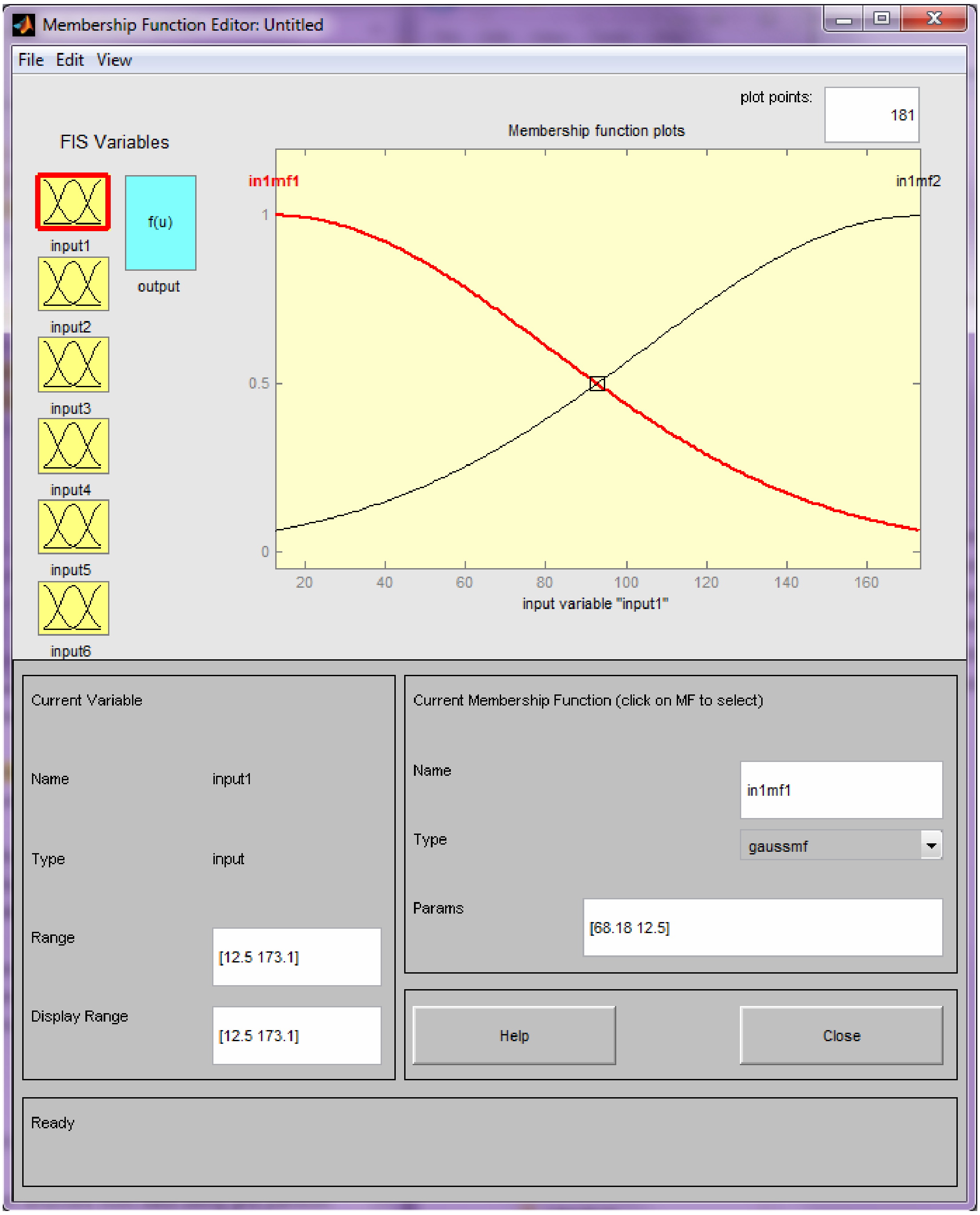
Epochs: 1000

Test FIS

Plot against: ● Training data ○ Testing data ○ Checking data

Epoch 1000:error= 0.0012467

Figure E.6 Training error of the gaussian triangular membership function trials



plot points: 181

Current Variable

Name input1

Type input

Range [12.5 173.1]

Display Range [12.5 173.1]

Current Membership Function (click on MF to select)

Name in1mf1

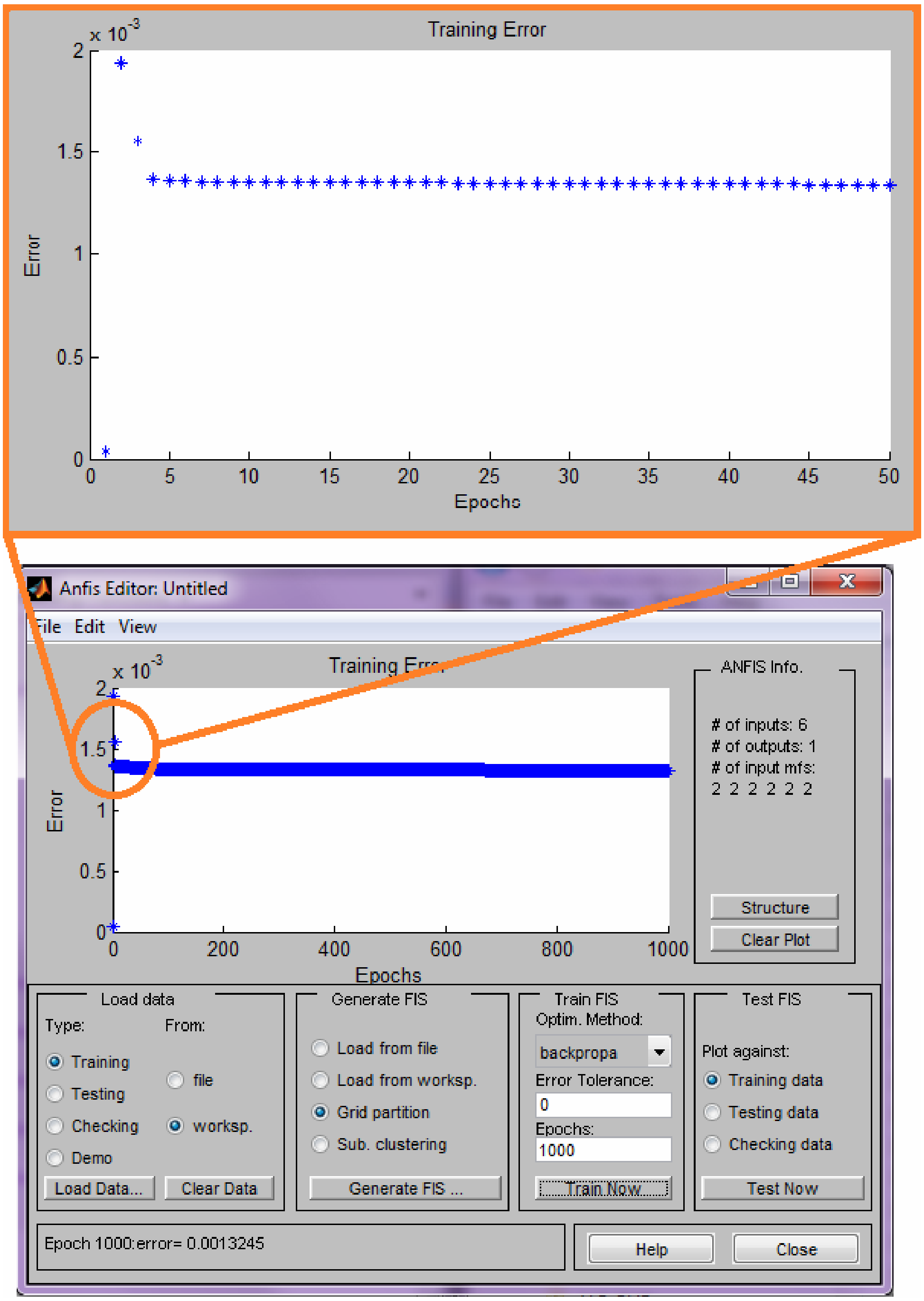
Type gaussmf

Params [68.18 12.5]

Ready

Figure E.7 Membership function of input 1 for the gaussian membership function trials

The change of the training error of the bell shaped membership function trials is presented in Figure E.2 and membership functions of the inputs are shown in Figure E.3.



# of inputs: 6
# of outputs: 1
# of input mfs:
2 2 2 2 2 2

Type: ● Training ○ Testing ○ Checking ○ Demo

From: ○ file ● worksp.

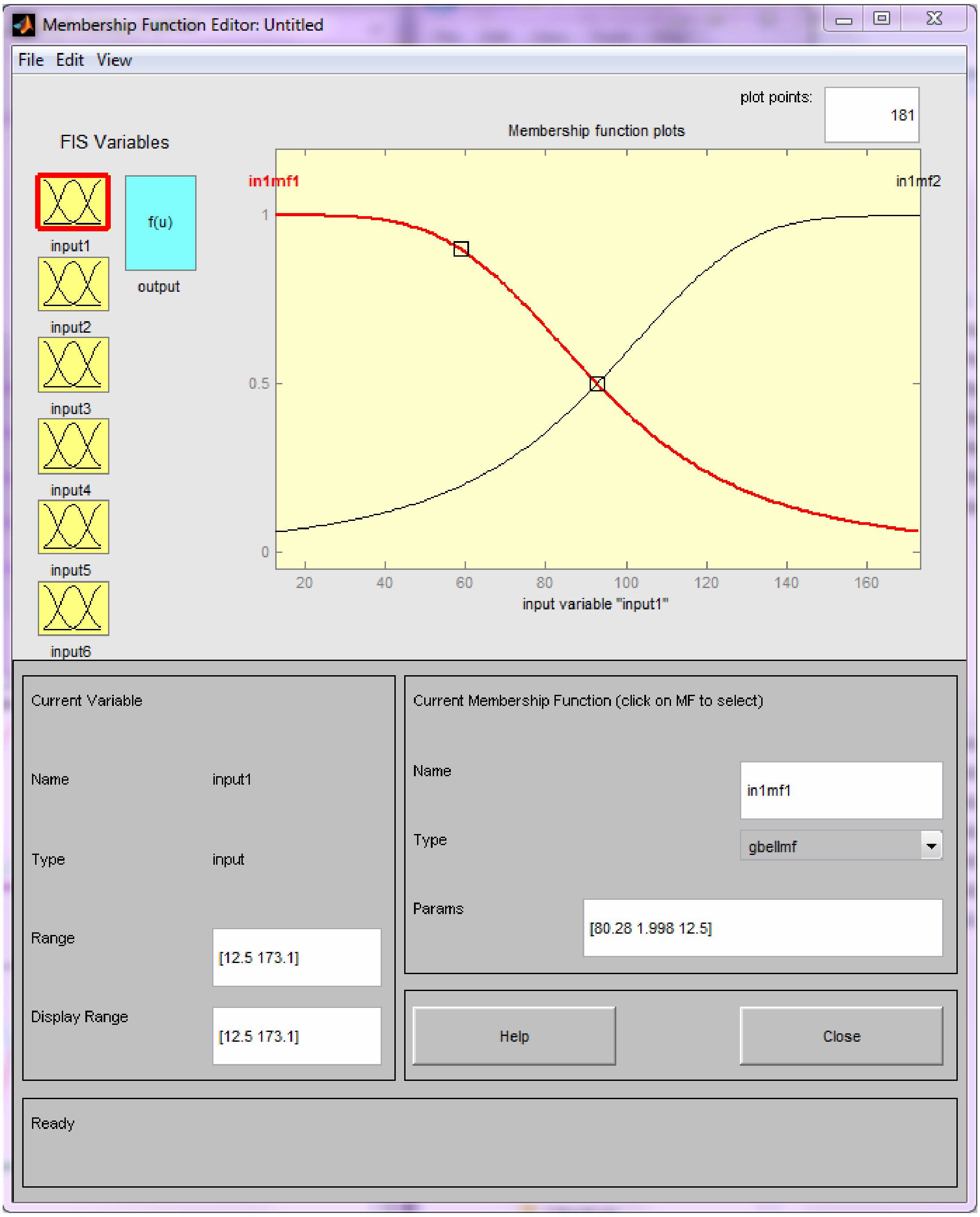
○ Load from file
○ Load from worksp.
● Grid partition
○ Sub. clustering

Optim. Method: backpropa
Error Tolerance: 0
Epochs: 1000

Plot against: ● Training data ○ Testing data ○ Checking data

Epoch 1000:error= 0.0013245

Figure E.8 Training error of the bell shaped membership function trials



plot points: 181

Current Variable

Name input1

Type input

Range [12.5 173.1]

Display Range [12.5 173.1]

Current Membership Function (click on MF to select)

Name in1mf1

Type gbellmf

Params [80.28 1.998 12.5]

Ready

Figure E.9 Membership function of input 1 for the bell shaped membership function trials

The error of the triangular membership function trial is 0.001254, trapezoidal membership function trial is 0.0022533, gaussian membership function trial is 0.0012467 and bell shaped membership function trial is 0.0013245.

The shape of the triangular, trapezoidal, gaussian and bell shaped membership functions are presented in Figure E.10.

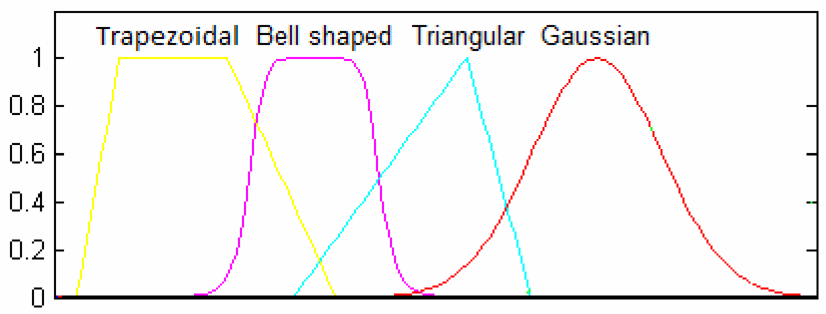


Figure E.10 Shape of the membership functions

APPENDIX F

THE PARAMETERS OF METHOD II (AASHTO)

Probability of aberrancy (*PA*) has been calculated using the determined *BR*, R_B, R_C, R_{XC}, R_D. Aberrancy base rate (*BR*) is a standard value. Correction factor for turning angle (R_B) has been calculated based on turning angle of the vessel. by measuring the angle of midline of passage (Figure F.1). The turning angle has been measured as 75^o (180^o - 105^o = 75^o) for zone 14. The zone is a Turn/Bend Region $R_B = 1 + 75^o/45^o = \sim 2.67$

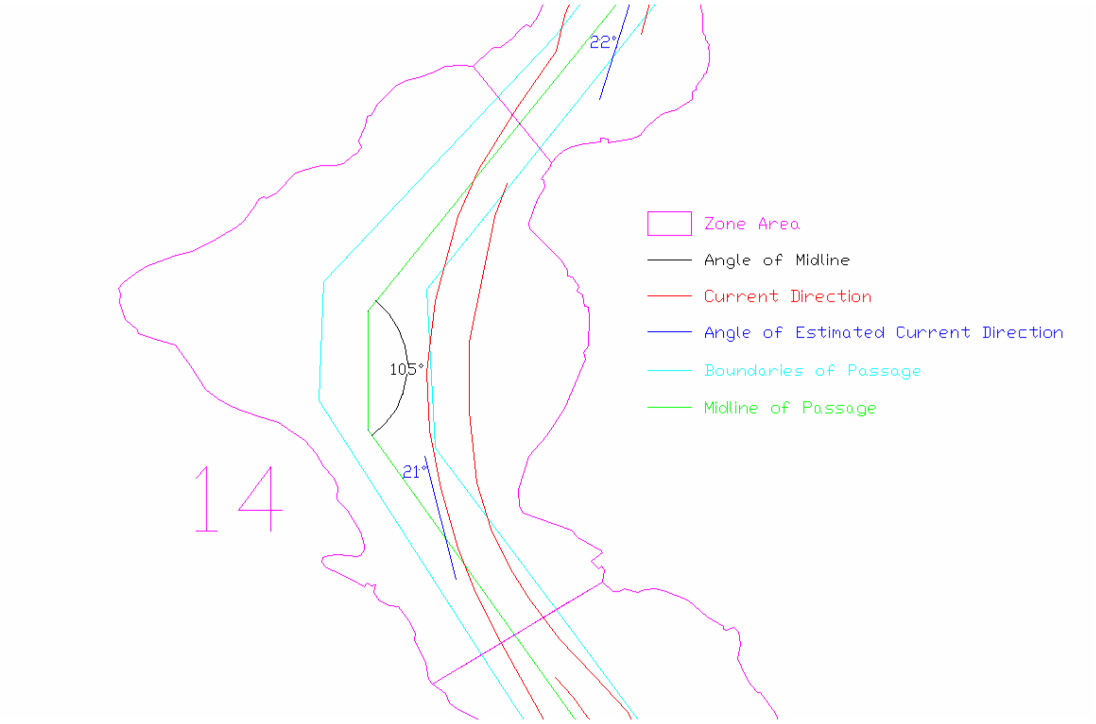


Figure F.1 Sketch for the Parameters Method II (AASHTO)

The angle between current direction and vessel path has been determined by assuming and judgment. The measured angle between current direction and vessel path is 21^o for zone 14. Calculated average for zone 14 is 56.67 cm/s (Appendix C). 1 cm/s is 0.019438 knot, therefore 56.67 cm/s is calculated as ~1.1 knot.

The current component parallel to vessel path (V_C) is the multiplication of average current (1.10 knot) with cosines of angle btw vessel path and current direction ($\text{Cos}(21^o)$). ($V_C = 1.028 = 1.10 \text{ x } \text{Cos}(21^o)$)

The current component perpendicular to vessel path (V_{XC}) is the multiplication of average current (1.10 knot) with sinus of angle btw vessel path and current direction ($\text{Sin}(21^o)$). ($V_{XC} = 0.395 = 1.10 \text{ x } \text{Sin}(21^o)$)

The correction factor for current acting parallel to vessel path (R_C) is calculated as $R_C = 1 + V_C / 10 = 1 + 1.028/10 = \sim 1.103$.

The correction factor for current acting perpendicular to vessel path (R_{XC}) is calculated as $R_{XC} = 1 + V_{XC} = 1 + 0.395 = 1.395$.

Where Probability of aberrancy (PA) has been calculated using the determined BR, R_B, R_C, R_{XC}, R_D ➔ $PA = .00006 \text{ x } 2.67 \text{ x } 1.10 \text{ x } 1.39 \text{ x } 1.60 = 3.94 \text{ E-04}$

APPENDIX G

FORMULA 1 RESULTS

The Formula 1 has been used to estimate the accident probabilities. Input parameters used in the analysis are presented in Table G.1. All estimated probabilities can be seen in Table G.2 and between Figure G.1 and Figure G.6 .

Table G.1 Input parameters used in the analysis

Accident Number	***CV***	***LOA***	***AT***	***DWS***	***RPA***	***MTP***
611	156.31	25	0	5.0	0.377	187.4
1334	156.31	60	0	8.9	0.377	56.3
332	156.31	105	0	16.0	0.377	162.1
462	156.31	144	0	2.9	0.377	61.0
633	156.31	80	0	3.1	0.377	182.1
672	156.31	103	0	4.0	0.377	15.0
690	156.31	22	0	10.4	0.377	149.5
718	156.31	51	0	12.9	0.377	60.7
977	156.31	115	0	10.0	0.377	59.7
999	156.31	200	0	11.9	0.377	151.4
1065	156.31	25	0	6.8	0.377	5.7
1152	156.31	24	0	10.7	0.377	120.0
1209	156.31	103	0	22.9	0.377	84.4
1244	156.31	101	0	4.8	0.377	166.4
1279	156.31	67	0	6.4	0.377	9.2
98	156.31	52	0	13.7	0.377	207.0
1232	156.31	104	0	14.1	0.377	166.4
609	156.31	145	0	11.5	0.377	187.4
529	156.31	153	0	14.0	0.377	21.8
698	156.31	30	0	6.0	0.377	141.4
1000	156.31	167	0	2.2	0.377	151.4
1204	156.31	78	0	6.8	0.377	84.4
1301	156.31	104	0	5.8	0.377	21.3

Table G.1 Estimated probabilities for the Formula 1 (continued)

Accident Number	***CV***	***LOA***	***AT***	***DWS***	***RPA***	***MTP***
387	156.31	165	0	10.1	0.377	20.8
642	156.31	103	0	9.0	0.377	16.4
680	156.31	88	0	11.4	0.377	105.2
950	156.31	118	0	5.9	0.377	28.5
1170	144.01	15	51	3.5	0.453	56.6
527	144.01	20	51	19.0	0.453	21.8
557	144.01	52	51	7.3	0.453	44.0
745	144.01	52	51	4.1	0.453	98.6
840	144.01	164	51	2.5	0.453	163.3
1070	144.01	15	51	5.9	0.453	5.7
1015	144.01	99	51	2.3	0.453	59.2
361	144.01	115	51	11.1	0.453	0.0
689	144.01	168	51	3.4	0.453	149.5
725	144.01	180	51	3.8	0.453	60.7
763	144.01	89	51	7.7	0.453	16.6
532	144.01	70	51	10.1	0.453	21.8
1190	144.01	203	51	7.4	0.453	43.0
173	154.89	83	0	6.5	0.474	22.8
945	154.89	40	0	5.3	0.474	72.5
1167	173.06	70	36	5.0	0.605	56.6
889	173.06	120	36	6.0	0.605	126.2
907	173.06	112	36	5.7	0.605	12.8
1055	173.06	97	36	7.1	0.605	51.7
1186	173.06	213	36	4.8	0.605	43.0
1268	173.06	30	36	7.2	0.605	95.3
1222	173.06	210	36	20.2	0.605	337.8
544	173.06	113	36	13.7	0.605	28.2
1157	173.06	114	36	10.2	0.605	120.0
1059	173.06	15	36	13.8	0.605	5.1
851	127.59	15	0	4.0	0.581	163.3
790	127.59	18	0	5.1	0.581	18.1
1125	117.68	117	23	6.7	0.503	82.5
872	117.68	110	23	6.8	0.503	106.7
925	117.68	80	23	8.7	0.503	18.4
1080	117.68	143	23	3.1	0.503	2.3
594	117.68	120	23	1.5	0.503	16.4
604	117.68	160	23	5.6	0.503	187.4
266	117.68	68	23	15.4	0.503	109.8
801	117.68	94	23	4.3	0.503	10.1

Table G.1 Estimated probabilities for the Formula 1 (continued)

Accident Number	***CV***	***LOA***	***AT***	***DWS***	***RPA***	***MTP***
1099	117.68	138	23	14.6	0.503	154.2
565	117.68	151	23	6.7	0.503	35.8
193	107.93	88	39	10.1	0.613	0.4
663	83.68	66	0	4.1	0.598	5.1
802	83.68	78	0	3.8	0.598	10.1
460	93.63	70	46	9.8	0.514	61.0
878	93.63	83	46	4.4	0.514	106.7
1138	93.63	120	46	5.4	0.514	34.0
1160	71.18	95	83	5.6	0.449	39.0
451	71.18	75	83	25.8	0.449	57.6
701	71.18	99	83	11.0	0.449	141.4
769	71.18	40	83	9.1	0.449	44.6
824	71.18	81	83	7.8	0.449	62.9
849	71.18	162	83	6.1	0.449	163.3
996	71.18	97	83	11.9	0.449	151.4
1118	71.18	30	83	17.1	0.449	82.5
1151	71.18	63	83	8.6	0.449	120.0
203	71.18	138	83	10.8	0.449	9.6
380	71.18	147	83	10.1	0.449	59.3
625	71.18	89	83	13.7	0.449	109.2
934	71.18	101	83	3.2	0.449	72.5
940	71.18	30	83	4.3	0.449	72.5
981	71.18	84	83	6.3	0.449	59.7
1034	71.18	87	83	8.2	0.449	139.1
1208	71.18	105	83	16.9	0.449	84.4
1240	71.18	92	83	16.4	0.449	166.4
1323	71.18	92	83	8.1	0.449	44.8
1104	56.67	77	75	20.2	0.331	154.2
1130	56.67	109	75	9.9	0.331	97.6
1154	56.67	81	75	6.6	0.331	120.0
113	56.67	30	75	3.4	0.331	207.0
163	56.67	106	75	11.9	0.331	26.1
378	56.67	220	75	14.4	0.331	59.3
517	56.67	45	75	9.5	0.331	20.3
538	56.67	88	75	9.2	0.331	7.6
638	56.67	72	75	6.7	0.331	182.1
708	56.67	71	75	5.6	0.331	149.1
783	56.67	63	75	3.6	0.331	18.1
845	56.67	35	75	3.3	0.331	163.3

Table G.1 Estimated probabilities for the Formula 1 (continued)

Accident Number	***CV***	***LOA***	***AT***	***DWS***	***RPA***	***MTP***
1076	56.67	62	75	3.9	0.331	1.9
1148	56.67	89	75	3.2	0.331	133.4
1164	56.67	78	75	4.4	0.331	56.6
1195	56.67	90	75	10.0	0.331	48.7
1206	56.67	94	75	9.6	0.331	84.4
1233	56.67	81	75	5.9	0.331	166.4
768	59.81	73	7	5.2	0.393	44.6
842	59.81	70	7	17.2	0.393	163.3
600	59.81	115	7	2.3	0.393	16.4
646	59.81	52	7	3.6	0.393	16.4
504	59.81	82	7	6.7	0.393	150.4
221	59.81	206	7	20.7	0.393	31.0
965	35.99	152	14	7.2	0.457	73.2
628	35.99	75	14	12.0	0.457	109.2
827	12.50	73	0	12.0	0.443	62.9
970	12.50	125	0	7.4	0.443	73.2
1020	12.50	156	0	15.2	0.443	59.2
1051	12.50	20	0	7.4	0.443	51.7
620	12.50	91	0	1.2	0.443	109.2
775	12.50	113	0	9.2	0.443	44.6
834	12.50	242	0	2.6	0.443	151.0
1083	12.50	77	0	5.5	0.443	77.6
1337	12.50	51	0	10.5	0.443	56.3
1207	12.50	30	0	16.9	0.443	84.4
980	12.50	102	0	13.0	0.443	59.7
1216	12.50	120	0	22.3	0.443	337.8
1218	12.50	112	0	22.3	0.443	337.8
978	12.50	101	0	10.0	0.443	59.7
1117	12.50	130	0	5.8	0.443	65.9
77	12.50	35	0	3.1	0.443	212.8
715	12.50	78	0	5.8	0.443	206.1
647	12.50	60	0	8.6	0.443	16.4
676	12.50	108	0	9.9	0.443	105.2
722	12.50	92	0	5.6	0.443	60.7
799	12.50	98	0	5.2	0.443	10.1

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	**Total Accidents**		**Collision Accidents**		**Capsizing Accidents**	
	Archive Data	**Formula 1**	**Archive Data**	**Formula 1**	**Archive Data**	**Formula 1**
611	6.02E-05	3.60E-05	3.74E-05	1.70E-05	1.25E-05	6.20E-06
1334	6.02E-05	3.38E-05	3.74E-05	1.60E-05	1.25E-05	5.73E-06
332	6.02E-05	4.24E-05	3.74E-05	2.11E-05	1.25E-05	7.84E-06
462	6.02E-05	3.27E-05	3.74E-05	1.60E-05	1.25E-05	5.23E-06
633	6.02E-05	3.60E-05	3.74E-05	1.74E-05	1.25E-05	6.04E-06
672	6.02E-05	3.09E-05	3.74E-05	1.47E-05	1.25E-05	4.90E-06
690	6.02E-05	3.73E-05	3.74E-05	1.76E-05	1.25E-05	6.63E-06
718	6.02E-05	3.56E-05	3.74E-05	1.69E-05	1.25E-05	6.23E-06
977	6.02E-05	3.55E-05	3.74E-05	1.73E-05	1.25E-05	6.05E-06
999	6.02E-05	4.18E-05	3.74E-05	2.15E-05	1.25E-05	7.46E-06
1065	6.02E-05	3.05E-05	3.74E-05	1.40E-05	1.25E-05	4.96E-06
1152	6.02E-05	3.64E-05	3.74E-05	1.71E-05	1.25E-05	6.42E-06
1209	6.02E-05	4.23E-05	3.74E-05	2.09E-05	1.25E-05	7.93E-06
1244	6.02E-05	3.67E-05	3.74E-05	1.79E-05	1.25E-05	6.23E-06
1279	6.02E-05	3.11E-05	3.74E-05	1.46E-05	1.25E-05	5.05E-06
98	6.02E-05	4.18E-05	3.74E-05	2.03E-05	1.25E-05	7.75E-06
1232	6.02E-05	4.15E-05	3.74E-05	2.06E-05	1.25E-05	7.60E-06
609	6.02E-05	4.19E-05	3.74E-05	2.12E-05	1.25E-05	7.56E-06
529	6.02E-05	3.65E-05	3.74E-05	1.81E-05	1.25E-05	6.29E-06
698	6.02E-05	3.50E-05	3.74E-05	1.65E-05	1.25E-05	5.99E-06
1000	6.02E-05	3.60E-05	3.74E-05	1.80E-05	1.25E-05	5.91E-06
1204	6.02E-05	3.43E-05	3.74E-05	1.64E-05	1.25E-05	5.76E-06
1301	6.02E-05	3.19E-05	3.74E-05	1.53E-05	1.25E-05	5.17E-06
387	6.02E-05	3.49E-05	3.74E-05	1.73E-05	1.25E-05	5.84E-06
642	6.02E-05	3.32E-05	3.74E-05	1.59E-05	1.25E-05	5.50E-06
680	6.02E-05	3.74E-05	3.74E-05	1.82E-05	1.25E-05	6.58E-06
950	6.02E-05	3.25E-05	3.74E-05	1.57E-05	1.25E-05	5.28E-06
1170	2.49E-05	3.11E-05	1.45E-05	1.39E-05	2.08E-06	5.03E-06
527	2.49E-05	3.67E-05	1.45E-05	1.66E-05	2.08E-06	6.57E-06
557	2.49E-05	3.30E-05	1.45E-05	1.51E-05	2.08E-06	5.49E-06
745	2.49E-05	3.35E-05	1.45E-05	1.54E-05	2.08E-06	5.54E-06
840	2.49E-05	3.71E-05	1.45E-05	1.81E-05	2.08E-06	6.14E-06
1070	2.49E-05	3.04E-05	1.45E-05	1.35E-05	2.08E-06	4.91E-06
1015	2.49E-05	3.21E-05	1.45E-05	1.49E-05	2.08E-06	5.11E-06
361	2.49E-05	3.41E-05	1.45E-05	1.60E-05	2.08E-06	5.71E-06
689	2.49E-05	3.72E-05	1.45E-05	1.81E-05	2.08E-06	6.17E-06
725	2.49E-05	3.43E-05	1.45E-05	1.66E-05	2.08E-06	5.52E-06
763	2.49E-05	3.28E-05	1.45E-05	1.52E-05	2.08E-06	5.40E-06

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Formula 1	Archive Data	Formula 1	Archive Data	Formula 1
532	2.49E-05	3.37E-05	1.45E-05	1.55E-05	2.08E-06	5.68E-06
1190	2.49E-05	3.57E-05	1.45E-05	1.75E-05	2.08E-06	5.90E-06
173	6.23E-06	3.21E-05	4.15E-06	1.52E-05	0.00E+00	5.24E-06
945	6.23E-06	3.26E-05	4.15E-06	1.52E-05	0.00E+00	5.39E-06
1167	1.66E-05	3.34E-05	6.23E-06	1.64E-05	0.00E+00	5.45E-06
889	1.66E-05	3.74E-05	6.23E-06	1.90E-05	0.00E+00	6.32E-06
907	1.66E-05	3.28E-05	6.23E-06	1.63E-05	0.00E+00	5.27E-06
1055	1.66E-05	3.46E-05	6.23E-06	1.73E-05	0.00E+00	5.75E-06
1186	1.66E-05	3.53E-05	6.23E-06	1.84E-05	0.00E+00	5.68E-06
1268	1.66E-05	3.51E-05	6.23E-06	1.70E-05	0.00E+00	5.95E-06
1222	1.66E-05	5.70E-05	6.23E-06	3.15E-05	0.00E+00	1.13E-05
544	1.66E-05	3.71E-05	6.23E-06	1.87E-05	0.00E+00	6.40E-06
1157	1.66E-05	3.92E-05	6.23E-06	2.00E-05	0.00E+00	6.85E-06
1059	1.66E-05	3.43E-05	6.23E-06	1.64E-05	0.00E+00	5.89E-06
851	4.15E-06	3.44E-05	2.08E-06	1.50E-05	0.00E+00	5.83E-06
790	4.15E-06	3.00E-05	2.08E-06	1.28E-05	0.00E+00	4.84E-06
1125	2.08E-05	3.47E-05	1.25E-05	1.54E-05	4.15E-06	5.81E-06
872	2.08E-05	3.55E-05	1.25E-05	1.58E-05	4.15E-06	6.02E-06
925	2.08E-05	3.25E-05	1.25E-05	1.41E-05	4.15E-06	5.40E-06
1080	2.08E-05	3.05E-05	1.25E-05	1.35E-05	4.15E-06	4.77E-06
594	2.08E-05	3.00E-05	1.25E-05	1.31E-05	4.15E-06	4.64E-06
604	2.08E-05	3.88E-05	1.25E-05	1.79E-05	4.15E-06	6.68E-06
266	2.08E-05	3.89E-05	1.25E-05	1.72E-05	4.15E-06	7.06E-06
801	2.08E-05	3.05E-05	1.25E-05	1.32E-05	4.15E-06	4.86E-06
1099	2.08E-05	4.18E-05	1.25E-05	1.92E-05	4.15E-06	7.65E-06
565	2.08E-05	3.35E-05	1.25E-05	1.50E-05	4.15E-06	5.50E-06
193	4.15E-06	3.28E-05	2.08E-06	1.39E-05	0.00E+00	5.46E-06
663	6.23E-06	2.92E-05	4.15E-06	1.14E-05	0.00E+00	4.65E-06
802	6.23E-06	2.95E-05	4.15E-06	1.15E-05	0.00E+00	4.68E-06
460	6.23E-06	3.43E-05	4.15E-06	1.40E-05	0.00E+00	5.87E-06
878	6.23E-06	3.37E-05	4.15E-06	1.38E-05	0.00E+00	5.60E-06
1138	6.23E-06	3.22E-05	4.15E-06	1.33E-05	0.00E+00	5.23E-06
1160	4.36E-05	3.19E-05	1.45E-05	1.22E-05	8.30E-06	5.22E-06
451	4.36E-05	4.13E-05	1.45E-05	1.61E-05	8.30E-06	7.80E-06
701	4.36E-05	3.83E-05	1.45E-05	1.51E-05	8.30E-06	6.83E-06
769	4.36E-05	3.27E-05	1.45E-05	1.23E-05	8.30E-06	5.54E-06
824	4.36E-05	3.35E-05	1.45E-05	1.28E-05	8.30E-06	5.65E-06
849	4.36E-05	3.79E-05	1.45E-05	1.53E-05	8.30E-06	6.52E-06

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Formula 1	Archive Data	Formula 1	Archive Data	Formula 1
996	4.36E-05	3.91E-05	1.45E-05	1.54E-05	8.30E-06	7.05E-06
1118	4.36E-05	3.75E-05	1.45E-05	1.42E-05	8.30E-06	6.84E-06
1151	4.36E-05	3.57E-05	1.45E-05	1.37E-05	8.30E-06	6.20E-06
203	4.36E-05	3.38E-05	1.45E-05	1.32E-05	8.30E-06	5.69E-06
380	4.36E-05	3.56E-05	1.45E-05	1.41E-05	8.30E-06	6.09E-06
625	4.36E-05	3.82E-05	1.45E-05	1.49E-05	8.30E-06	6.86E-06
934	4.36E-05	3.21E-05	1.45E-05	1.24E-05	8.30E-06	5.21E-06
940	4.36E-05	3.14E-05	1.45E-05	1.17E-05	8.30E-06	5.17E-06
981	4.36E-05	3.28E-05	1.45E-05	1.25E-05	8.30E-06	5.45E-06
1034	4.36E-05	3.66E-05	1.45E-05	1.43E-05	8.30E-06	6.38E-06
1208	4.36E-05	3.90E-05	1.45E-05	1.53E-05	8.30E-06	7.09E-06
1240	4.36E-05	4.19E-05	1.45E-05	1.66E-05	8.30E-06	7.82E-06
1323	4.36E-05	3.32E-05	1.45E-05	1.27E-05	8.30E-06	5.56E-06
1104	3.11E-05	4.22E-05	0.00E+00	1.59E-05	0.00E+00	8.04E-06
1130	3.11E-05	3.57E-05	0.00E+00	1.34E-05	0.00E+00	6.21E-06
1154	3.11E-05	3.45E-05	0.00E+00	1.27E-05	0.00E+00	5.89E-06
113	3.11E-05	3.49E-05	0.00E+00	1.27E-05	0.00E+00	5.98E-06
163	3.11E-05	3.38E-05	0.00E+00	1.25E-05	0.00E+00	5.79E-06
378	3.11E-05	3.84E-05	0.00E+00	1.51E-05	0.00E+00	6.76E-06
517	3.11E-05	3.15E-05	0.00E+00	1.13E-05	0.00E+00	5.30E-06
538	3.11E-05	3.17E-05	0.00E+00	1.15E-05	0.00E+00	5.27E-06
638	3.11E-05	3.65E-05	0.00E+00	1.36E-05	0.00E+00	6.39E-06
708	3.11E-05	3.48E-05	0.00E+00	1.28E-05	0.00E+00	5.96E-06
783	3.11E-05	2.93E-05	0.00E+00	1.05E-05	0.00E+00	4.67E-06
845	3.11E-05	3.35E-05	0.00E+00	1.21E-05	0.00E+00	5.65E-06
1076	3.11E-05	2.89E-05	0.00E+00	1.03E-05	0.00E+00	4.57E-06
1148	3.11E-05	3.35E-05	0.00E+00	1.24E-05	0.00E+00	5.56E-06
1164	3.11E-05	3.12E-05	0.00E+00	1.13E-05	0.00E+00	5.09E-06
1195	3.11E-05	3.36E-05	0.00E+00	1.24E-05	0.00E+00	5.73E-06
1206	3.11E-05	3.48E-05	0.00E+00	1.29E-05	0.00E+00	6.01E-06
1233	3.11E-05	3.58E-05	0.00E+00	1.33E-05	0.00E+00	6.17E-06
768	1.04E-05	3.05E-05	0.00E+00	1.12E-05	0.00E+00	4.99E-06
842	1.04E-05	4.03E-05	0.00E+00	1.53E-05	0.00E+00	7.56E-06
600	1.04E-05	2.90E-05	0.00E+00	1.07E-05	0.00E+00	4.54E-06
646	1.04E-05	2.86E-05	0.00E+00	1.03E-05	0.00E+00	4.55E-06
504	1.04E-05	3.50E-05	0.00E+00	1.31E-05	0.00E+00	6.05E-06
221	1.04E-05	3.91E-05	0.00E+00	1.55E-05	0.00E+00	7.08E-06
965	4.15E-06	3.35E-05	0.00E+00	1.18E-05	0.00E+00	5.64E-06

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	**Total Accidents**		**Collision Accidents**		**Capsizing Accidents**	
	Archive Data	**Formula 1**	**Archive Data**	**Formula 1**	**Archive Data**	**Formula 1**
628	4.15E-06	3.56E-05	0.00E+00	1.23E-05	0.00E+00	6.34E-06
827	4.77E-05	3.32E-05	1.25E-05	1.04E-05	1.25E-05	5.82E-06
970	4.77E-05	3.25E-05	1.25E-05	1.04E-05	1.25E-05	5.50E-06
1020	4.77E-05	3.60E-05	1.25E-05	1.18E-05	1.25E-05	6.40E-06
1051	4.77E-05	3.00E-05	1.25E-05	9.09E-06	1.25E-05	5.06E-06
620	4.77E-05	3.04E-05	1.25E-05	9.55E-06	1.25E-05	4.92E-06
775	4.77E-05	3.21E-05	1.25E-05	1.02E-05	1.25E-05	5.44E-06
834	4.77E-05	3.50E-05	1.25E-05	1.18E-05	1.25E-05	5.79E-06
1083	4.77E-05	3.10E-05	1.25E-05	9.69E-06	1.25E-05	5.18E-06
1337	4.77E-05	3.20E-05	1.25E-05	9.89E-06	1.25E-05	5.52E-06
1207	4.77E-05	3.53E-05	1.25E-05	1.09E-05	1.25E-05	6.46E-06
980	4.77E-05	3.41E-05	1.25E-05	1.08E-05	1.25E-05	5.99E-06
1216	4.77E-05	5.01E-05	1.25E-05	1.69E-05	1.25E-05	1.02E-05
1218	4.77E-05	4.99E-05	1.25E-05	1.68E-05	1.25E-05	1.01E-05
978	4.77E-05	3.28E-05	1.25E-05	1.04E-05	1.25E-05	5.63E-06
1117	4.77E-05	3.16E-05	1.25E-05	1.01E-05	1.25E-05	5.26E-06
77	4.77E-05	3.36E-05	1.25E-05	1.05E-05	1.25E-05	5.76E-06
715	4.77E-05	3.55E-05	1.25E-05	1.13E-05	1.25E-05	6.22E-06
647	4.77E-05	3.00E-05	1.25E-05	9.21E-06	1.25E-05	5.00E-06
676	4.77E-05	3.45E-05	1.25E-05	1.10E-05	1.25E-05	6.03E-06
722	4.77E-05	3.08E-05	1.25E-05	9.65E-06	1.25E-05	5.10E-06
799	4.77E-05	2.90E-05	1.25E-05	9.02E-06	1.25E-05	4.67E-06

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Formula 1**	**Archive Data**	**Formula 1**	**Archive Data**	**Formula 1**
611	1.04E-05	8.98E-06	2.08E-06	2.91E-06	4.15E-06	2.99E-06
1334	1.04E-05	8.32E-06	2.08E-06	2.63E-06	4.15E-06	2.85E-06
332	1.04E-05	1.12E-05	2.08E-06	3.86E-06	4.15E-06	3.40E-06
462	1.04E-05	7.69E-06	2.08E-06	2.36E-06	4.15E-06	2.86E-06
633	1.04E-05	8.79E-06	2.08E-06	2.83E-06	4.15E-06	3.03E-06
672	1.04E-05	7.22E-06	2.08E-06	2.17E-06	4.15E-06	2.70E-06
690	1.04E-05	9.53E-06	2.08E-06	3.15E-06	4.15E-06	3.04E-06
718	1.04E-05	8.99E-06	2.08E-06	2.90E-06	4.15E-06	2.95E-06
977	1.04E-05	8.77E-06	2.08E-06	2.81E-06	4.15E-06	2.99E-06
999	1.04E-05	1.07E-05	2.08E-06	3.66E-06	4.15E-06	3.45E-06
1065	1.04E-05	7.27E-06	2.08E-06	2.19E-06	4.15E-06	2.62E-06
1152	1.04E-05	9.24E-06	2.08E-06	3.02E-06	4.15E-06	2.99E-06
1209	1.04E-05	1.13E-05	2.08E-06	3.87E-06	4.15E-06	3.38E-06
1244	1.04E-05	9.04E-06	2.08E-06	2.94E-06	4.15E-06	3.08E-06
1279	1.04E-05	7.40E-06	2.08E-06	2.24E-06	4.15E-06	2.69E-06
98	1.04E-05	1.10E-05	2.08E-06	3.81E-06	4.15E-06	3.34E-06
1232	1.04E-05	1.08E-05	2.08E-06	3.73E-06	4.15E-06	3.36E-06
609	1.04E-05	1.08E-05	2.08E-06	3.72E-06	4.15E-06	3.42E-06
529	1.04E-05	9.09E-06	2.08E-06	2.93E-06	4.15E-06	3.07E-06
698	1.04E-05	8.68E-06	2.08E-06	2.78E-06	4.15E-06	2.92E-06
1000	1.04E-05	8.64E-06	2.08E-06	2.76E-06	4.15E-06	3.10E-06
1204	1.04E-05	8.37E-06	2.08E-06	2.65E-06	4.15E-06	2.90E-06
1301	1.04E-05	7.58E-06	2.08E-06	2.31E-06	4.15E-06	2.77E-06
387	1.04E-05	8.50E-06	2.08E-06	2.69E-06	4.15E-06	2.99E-06
642	1.04E-05	8.02E-06	2.08E-06	2.49E-06	4.15E-06	2.83E-06
680	1.04E-05	9.47E-06	2.08E-06	3.12E-06	4.15E-06	3.09E-06
950	1.04E-05	7.73E-06	2.08E-06	2.38E-06	4.15E-06	2.81E-06
1170	0.00E+00	1.08E-05	2.08E-06	2.27E-06	6.23E-06	2.67E-06
527	0.00E+00	1.38E-05	2.08E-06	3.10E-06	6.23E-06	2.98E-06
557	0.00E+00	1.17E-05	2.08E-06	2.53E-06	6.23E-06	2.81E-06
745	0.00E+00	1.18E-05	2.08E-06	2.57E-06	6.23E-06	2.85E-06
840	0.00E+00	1.31E-05	2.08E-06	2.93E-06	6.23E-06	3.17E-06
1070	0.00E+00	1.05E-05	2.08E-06	2.19E-06	6.23E-06	2.61E-06
1015	0.00E+00	1.10E-05	2.08E-06	2.32E-06	6.23E-06	2.79E-06
361	0.00E+00	1.22E-05	2.08E-06	2.64E-06	6.23E-06	2.91E-06
689	0.00E+00	1.31E-05	2.08E-06	2.95E-06	6.23E-06	3.17E-06
725	0.00E+00	1.18E-05	2.08E-06	2.56E-06	6.23E-06	2.98E-06
763	0.00E+00	1.15E-05	2.08E-06	2.47E-06	6.23E-06	2.81E-06

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Formula 1**	**Archive Data**	**Formula 1**	**Archive Data**	**Formula 1**
532	0.00E+00	1.21E-05	2.08E-06	2.62E-06	6.23E-06	2.85E-06
1190	0.00E+00	1.26E-05	2.08E-06	2.77E-06	6.23E-06	3.08E-06
173	0.00E+00	7.67E-06	0.00E+00	2.40E-06	2.08E-06	2.76E-06
945	0.00E+00	7.87E-06	0.00E+00	2.50E-06	2.08E-06	2.77E-06
1167	4.15E-06	1.06E-05	4.15E-06	2.60E-06	2.08E-06	2.86E-06
889	4.15E-06	1.22E-05	4.15E-06	3.14E-06	2.08E-06	3.15E-06
907	4.15E-06	1.03E-05	4.15E-06	2.49E-06	2.08E-06	2.84E-06
1055	4.15E-06	1.11E-05	4.15E-06	2.78E-06	2.08E-06	2.95E-06
1186	4.15E-06	1.10E-05	4.15E-06	2.75E-06	2.08E-06	3.08E-06
1268	4.15E-06	1.15E-05	4.15E-06	2.90E-06	2.08E-06	2.93E-06
1222	4.15E-06	2.10E-05	4.15E-06	6.32E-06	2.08E-06	4.40E-06
544	4.15E-06	1.23E-05	4.15E-06	3.15E-06	2.08E-06	3.10E-06
1157	4.15E-06	1.31E-05	4.15E-06	3.46E-06	2.08E-06	3.25E-06
1059	4.15E-06	1.13E-05	4.15E-06	2.82E-06	2.08E-06	2.85E-06
851	0.00E+00	8.46E-06	2.08E-06	2.83E-06	0.00E+00	2.87E-06
790	0.00E+00	7.11E-06	2.08E-06	2.23E-06	0.00E+00	2.58E-06
1125	6.23E-06	1.02E-05	0.00E+00	2.77E-06	0.00E+00	2.94E-06
872	6.23E-06	1.06E-05	0.00E+00	2.89E-06	0.00E+00	2.99E-06
925	6.23E-06	9.54E-06	0.00E+00	2.51E-06	0.00E+00	2.77E-06
1080	6.23E-06	8.53E-06	0.00E+00	2.16E-06	0.00E+00	2.70E-06
594	6.23E-06	8.31E-06	0.00E+00	2.09E-06	0.00E+00	2.65E-06
604	6.23E-06	1.17E-05	0.00E+00	3.30E-06	0.00E+00	3.25E-06
266	6.23E-06	1.22E-05	0.00E+00	3.50E-06	0.00E+00	3.15E-06
801	6.23E-06	8.66E-06	0.00E+00	2.21E-06	0.00E+00	2.67E-06
1099	6.23E-06	1.32E-05	0.00E+00	3.87E-06	0.00E+00	3.39E-06
565	6.23E-06	9.72E-06	0.00E+00	2.58E-06	0.00E+00	2.89E-06
193	2.08E-06	1.08E-05	0.00E+00	2.60E-06	0.00E+00	2.79E-06
663	2.08E-06	6.85E-06	0.00E+00	2.14E-06	0.00E+00	2.55E-06
802	2.08E-06	6.89E-06	0.00E+00	2.16E-06	0.00E+00	2.57E-06
460	2.08E-06	1.20E-05	0.00E+00	2.80E-06	0.00E+00	2.87E-06
878	2.08E-06	1.16E-05	0.00E+00	2.65E-06	0.00E+00	2.86E-06
1138	2.08E-06	1.09E-05	0.00E+00	2.43E-06	0.00E+00	2.78E-06
1160	2.08E-05	1.33E-05	2.08E-06	2.38E-06	0.00E+00	2.75E-06
451	2.08E-05	1.93E-05	2.08E-06	3.83E-06	0.00E+00	3.27E-06
701	2.08E-05	1.71E-05	2.08E-06	3.33E-06	0.00E+00	3.15E-06
769	2.08E-05	1.40E-05	2.08E-06	2.55E-06	0.00E+00	2.75E-06
824	2.08E-05	1.43E-05	2.08E-06	2.63E-06	0.00E+00	2.84E-06
849	2.08E-05	1.64E-05	2.08E-06	3.16E-06	0.00E+00	3.18E-06

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	Grounding Accidents		Fire Accidents		Other Accidents	
	Archive Data	**Formula 1**	**Archive Data**	**Formula 1**	**Archive Data**	**Formula 1**
996	2.08E-05	1.76E-05	2.08E-06	3.45E-06	0.00E+00	3.19E-06
1118	2.08E-05	1.71E-05	2.08E-06	3.29E-06	0.00E+00	3.03E-06
1151	2.08E-05	1.56E-05	2.08E-06	2.95E-06	0.00E+00	2.96E-06
203	2.08E-05	1.44E-05	2.08E-06	2.63E-06	0.00E+00	2.88E-06
380	2.08E-05	1.54E-05	2.08E-06	2.89E-06	0.00E+00	3.01E-06
625	2.08E-05	1.72E-05	2.08E-06	3.33E-06	0.00E+00	3.12E-06
934	2.08E-05	1.33E-05	2.08E-06	2.38E-06	0.00E+00	2.77E-06
940	2.08E-05	1.32E-05	2.08E-06	2.35E-06	0.00E+00	2.68E-06
981	2.08E-05	1.39E-05	2.08E-06	2.51E-06	0.00E+00	2.79E-06
1034	2.08E-05	1.61E-05	2.08E-06	3.06E-06	0.00E+00	3.04E-06
1208	2.08E-05	1.77E-05	2.08E-06	3.45E-06	0.00E+00	3.17E-06
1240	2.08E-05	1.94E-05	2.08E-06	3.91E-06	0.00E+00	3.35E-06
1323	2.08E-05	1.41E-05	2.08E-06	2.57E-06	0.00E+00	2.82E-06
1104	2.91E-05	1.91E-05	0.00E+00	3.91E-06	2.08E-06	3.34E-06
1130	2.91E-05	1.50E-05	0.00E+00	2.88E-06	2.08E-06	2.98E-06
1154	2.91E-05	1.43E-05	0.00E+00	2.70E-06	2.08E-06	2.89E-06
113	2.91E-05	1.45E-05	0.00E+00	2.75E-06	2.08E-06	2.91E-06
163	2.91E-05	1.41E-05	0.00E+00	2.62E-06	2.08E-06	2.85E-06
378	2.91E-05	1.63E-05	0.00E+00	3.18E-06	2.08E-06	3.21E-06
517	2.91E-05	1.29E-05	0.00E+00	2.35E-06	2.08E-06	2.67E-06
538	2.91E-05	1.29E-05	0.00E+00	2.33E-06	2.08E-06	2.71E-06
638	2.91E-05	1.54E-05	0.00E+00	2.98E-06	2.08E-06	3.02E-06
708	2.91E-05	1.45E-05	0.00E+00	2.74E-06	2.08E-06	2.92E-06
783	2.91E-05	1.15E-05	0.00E+00	2.01E-06	2.08E-06	2.55E-06
845	2.91E-05	1.38E-05	0.00E+00	2.57E-06	2.08E-06	2.82E-06
1076	2.91E-05	1.13E-05	0.00E+00	1.96E-06	2.08E-06	2.52E-06
1148	2.91E-05	1.36E-05	0.00E+00	2.52E-06	2.08E-06	2.85E-06
1164	2.91E-05	1.25E-05	0.00E+00	2.25E-06	2.08E-06	2.69E-06
1195	2.91E-05	1.39E-05	0.00E+00	2.60E-06	2.08E-06	2.83E-06
1206	2.91E-05	1.46E-05	0.00E+00	2.76E-06	2.08E-06	2.91E-06
1233	2.91E-05	1.49E-05	0.00E+00	2.86E-06	2.08E-06	2.98E-06
768	6.23E-06	7.79E-06	0.00E+00	2.24E-06	4.15E-06	2.63E-06
842	6.23E-06	1.14E-05	0.00E+00	3.72E-06	4.15E-06	3.21E-06
600	6.23E-06	7.15E-06	0.00E+00	1.99E-06	4.15E-06	2.56E-06
646	6.23E-06	7.14E-06	0.00E+00	1.99E-06	4.15E-06	2.49E-06
504	6.23E-06	9.31E-06	0.00E+00	2.85E-06	4.15E-06	2.92E-06
221	6.23E-06	1.08E-05	0.00E+00	3.41E-06	4.15E-06	3.22E-06
965	2.08E-06	9.25E-06	2.08E-06	2.66E-06	0.00E+00	2.86E-06

Table G.2 Estimated probabilities for the Formula 1 (continued)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Formula 1**	**Archive Data**	**Formula 1**	**Archive Data**	**Formula 1**
628	2.08E-06	1.03E-05	2.08E-06	3.05E-06	0.00E+00	2.93E-06
827	6.23E-06	8.40E-06	1.04E-05	2.74E-06	6.23E-06	2.76E-06
970	6.23E-06	7.99E-06	1.04E-05	2.57E-06	6.23E-06	2.76E-06
1020	6.23E-06	9.20E-06	1.04E-05	3.08E-06	6.23E-06	2.98E-06
1051	6.23E-06	7.37E-06	1.04E-05	2.30E-06	6.23E-06	2.54E-06
620	6.23E-06	7.22E-06	1.04E-05	2.24E-06	6.23E-06	2.63E-06
775	6.23E-06	7.91E-06	1.04E-05	2.53E-06	6.23E-06	2.72E-06
834	6.23E-06	8.44E-06	1.04E-05	2.76E-06	6.23E-06	3.02E-06
1083	6.23E-06	7.56E-06	1.04E-05	2.39E-06	6.23E-06	2.65E-06
1337	6.23E-06	8.00E-06	1.04E-05	2.57E-06	6.23E-06	2.67E-06
1207	6.23E-06	9.25E-06	1.04E-05	3.10E-06	6.23E-06	2.85E-06
980	6.23E-06	8.63E-06	1.04E-05	2.84E-06	6.23E-06	2.83E-06
1216	6.23E-06	1.42E-05	1.04E-05	5.39E-06	6.23E-06	3.82E-06
1218	6.23E-06	1.42E-05	1.04E-05	5.37E-06	6.23E-06	3.81E-06
978	6.23E-06	8.16E-06	1.04E-05	2.64E-06	6.23E-06	2.76E-06
1117	6.23E-06	7.67E-06	1.04E-05	2.43E-06	6.23E-06	2.71E-06
77	6.23E-06	8.35E-06	1.04E-05	2.72E-06	6.23E-06	2.80E-06
715	6.23E-06	8.97E-06	1.04E-05	3.00E-06	6.23E-06	2.94E-06
647	6.23E-06	7.30E-06	1.04E-05	2.27E-06	6.23E-06	2.55E-06
676	6.23E-06	8.70E-06	1.04E-05	2.88E-06	6.23E-06	2.87E-06
722	6.23E-06	7.45E-06	1.04E-05	2.34E-06	6.23E-06	2.64E-06
799	6.23E-06	6.87E-06	1.04E-05	2.09E-06	6.23E-06	2.52E-06

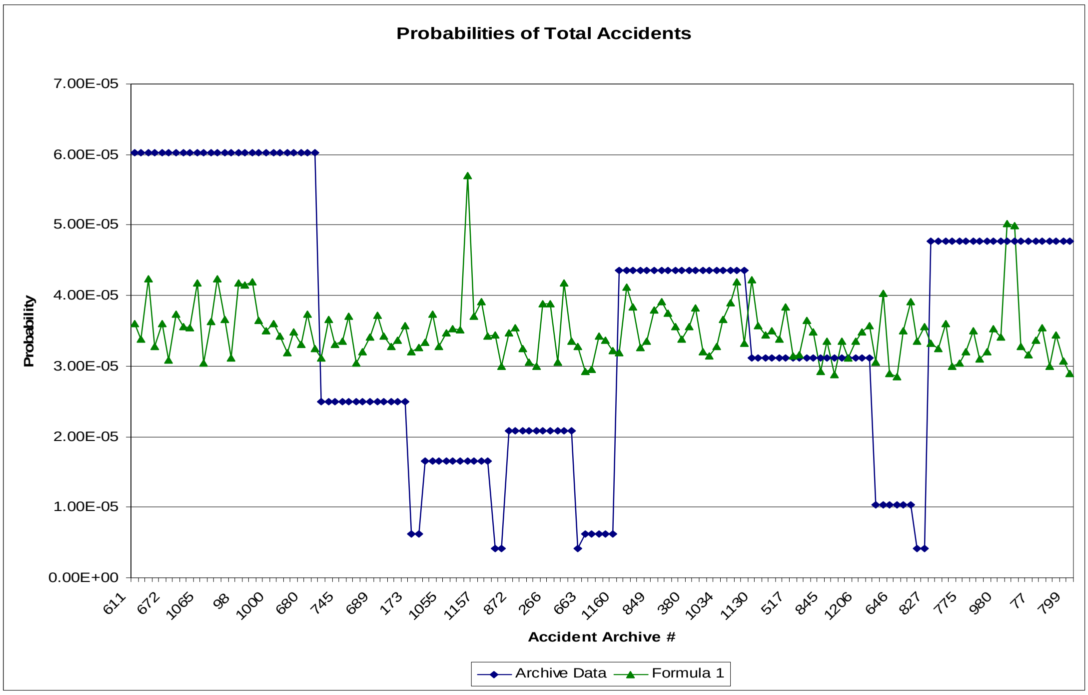


Figure G.1 Probabilities of Total Accidents (Formula 1)

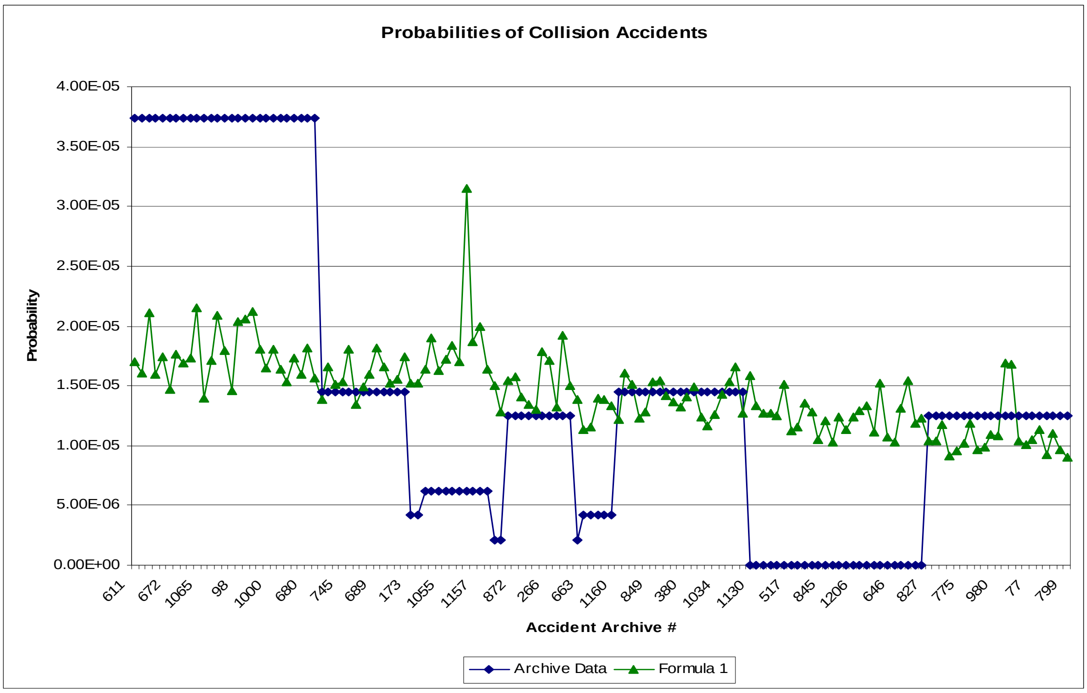


Figure G.2 Probabilities of Collision Accidents (Formula 1)

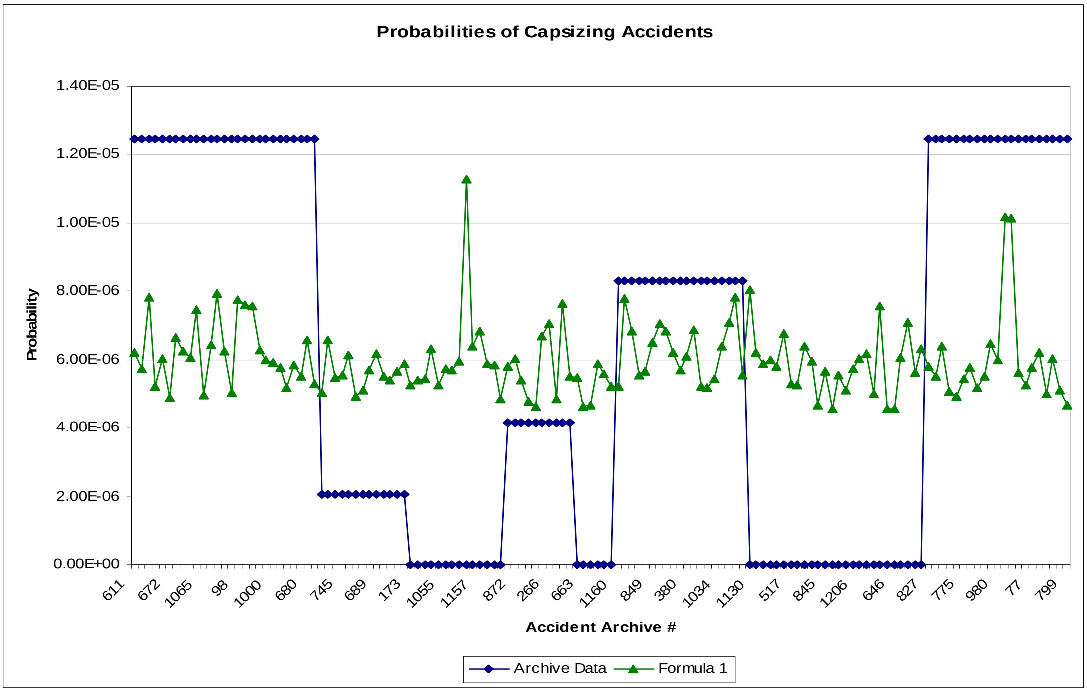


Figure G.3 Probabilities of Capsizing Accidents (Formula 1)

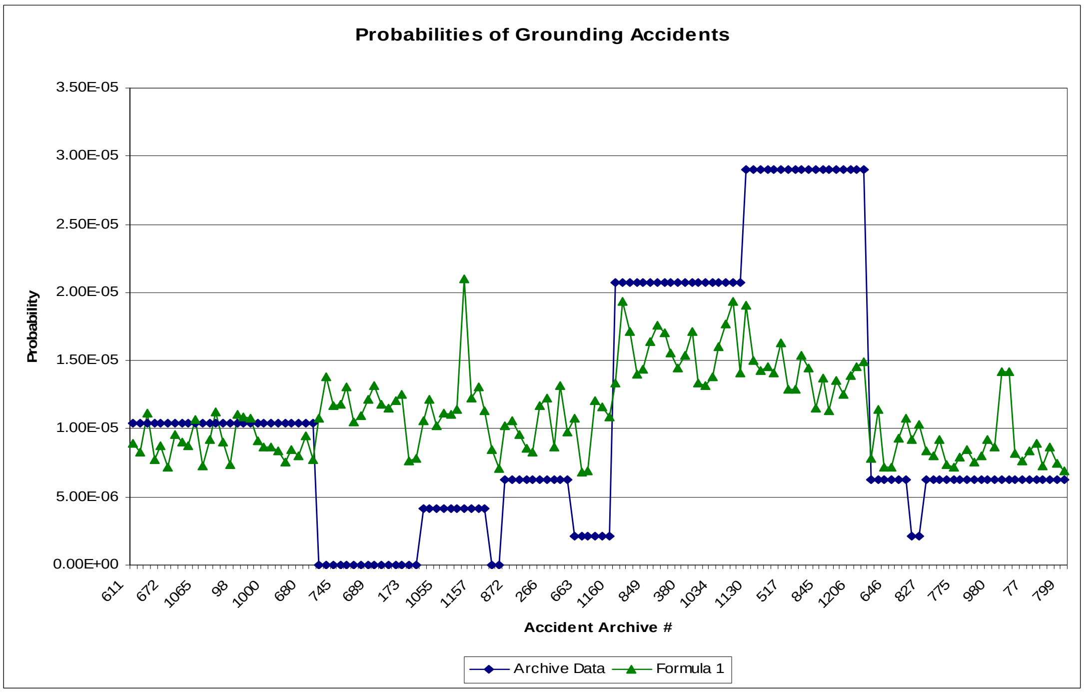


Figure G.4 Probabilities of Grounding Accidents (Formula 1)

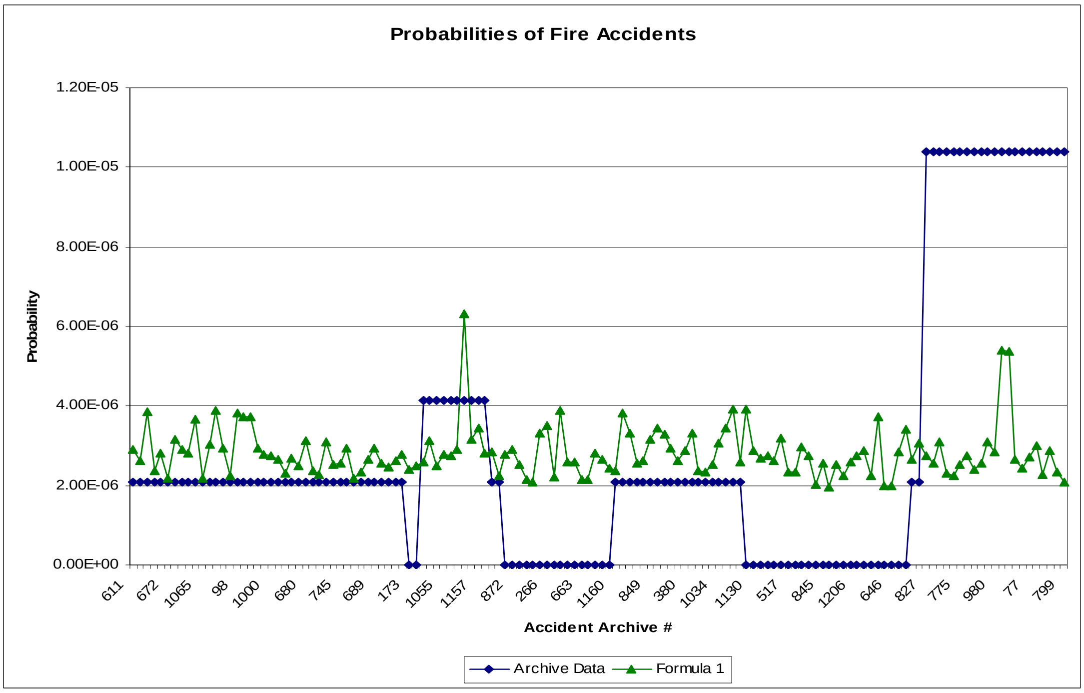


Figure G.5 Probabilities of Fire Accidents (Formula 1)

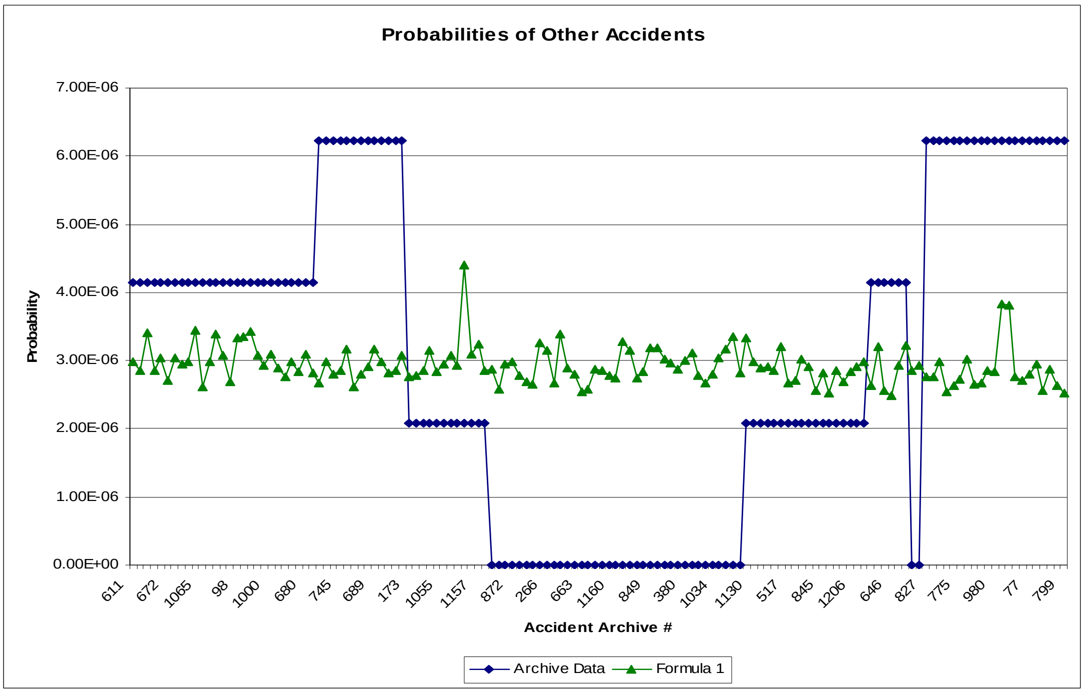


Figure G.6 Probabilities of Other Accidents (Formula 1)

APPENDIX H

FORMULA 2 RESULTS

The multiple linear regression analysis has been used to estimate the accident probabilities. All estimated probabilities of multiple linear regression analysis can be seen in Table H.1 and between Figure H.1 and Figure H.6 .

Table H.1 Estimated probabilities for the Formula 2

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Formula 2	Archive Data	Formula 2	Archive Data	Formula 2
611	6.02E-05	3.63E-05	3.74E-05	2.53E-05	1.25E-05	6.66E-06
1334	6.02E-05	3.36E-05	3.74E-05	2.49E-05	1.25E-05	6.28E-06
332	6.02E-05	5.09E-05	3.74E-05	3.21E-05	1.25E-05	1.01E-05
462	6.02E-05	3.28E-05	3.74E-05	2.45E-05	1.25E-05	5.88E-06
633	6.02E-05	3.73E-05	3.74E-05	2.57E-05	1.25E-05	6.80E-06
672	6.02E-05	2.83E-05	3.74E-05	2.28E-05	1.25E-05	5.02E-06
690	6.02E-05	3.91E-05	3.74E-05	2.69E-05	1.25E-05	7.47E-06
718	6.02E-05	3.75E-05	3.74E-05	2.67E-05	1.25E-05	7.24E-06
977	6.02E-05	3.83E-05	3.74E-05	2.70E-05	1.25E-05	7.30E-06
999	6.02E-05	5.18E-05	3.74E-05	3.25E-05	1.25E-05	1.01E-05
1065	6.02E-05	2.58E-05	3.74E-05	2.18E-05	1.25E-05	4.62E-06
1152	6.02E-05	3.75E-05	3.74E-05	2.63E-05	1.25E-05	7.17E-06
1209	6.02E-05	5.27E-05	3.74E-05	3.34E-05	1.25E-05	1.07E-05
1244	6.02E-05	3.93E-05	3.74E-05	2.67E-05	1.25E-05	7.28E-06
1279	6.02E-05	2.82E-05	3.74E-05	2.28E-05	1.25E-05	5.09E-06
98	6.02E-05	4.83E-05	3.74E-05	3.06E-05	1.25E-05	9.47E-06
1232	6.02E-05	4.92E-05	3.74E-05	3.12E-05	1.25E-05	9.67E-06
609	6.02E-05	5.04E-05	3.74E-05	3.16E-05	1.25E-05	9.81E-06
529	6.02E-05	4.23E-05	3.74E-05	2.91E-05	1.25E-05	8.26E-06
698	6.02E-05	3.45E-05	3.74E-05	2.48E-05	1.25E-05	6.35E-06
1000	6.02E-05	3.97E-05	3.74E-05	2.69E-05	1.25E-05	7.24E-06
1204	6.02E-05	3.44E-05	3.74E-05	2.51E-05	1.25E-05	6.37E-06
1301	6.02E-05	3.07E-05	3.74E-05	2.38E-05	1.25E-05	5.57E-06

Table H.1 Estimated probabilities for the Formula 2 (continued)

Accident Number	**Total Accidents**		**Collision Accidents**		**Capsizing Accidents**	
	Archive Data	**Formula 2**	**Archive Data**	**Formula 2**	**Archive Data**	**Formula 2**
387	6.02E-05	3.89E-05	3.74E-05	2.75E-05	1.25E-05	7.41E-06
642	6.02E-05	3.36E-05	3.74E-05	2.52E-05	1.25E-05	6.30E-06
680	6.02E-05	4.12E-05	3.74E-05	2.81E-05	1.25E-05	7.94E-06
950	6.02E-05	3.21E-05	3.74E-05	2.44E-05	1.25E-05	5.87E-06
1170	2.49E-05	2.39E-05	1.45E-05	1.27E-05	2.08E-06	1.76E-06
527	2.49E-05	3.80E-05	1.45E-05	1.93E-05	2.08E-06	5.26E-06
557	2.49E-05	2.93E-05	1.45E-05	1.52E-05	2.08E-06	3.01E-06
745	2.49E-05	2.97E-05	1.45E-05	1.50E-05	2.08E-06	2.95E-06
840	2.49E-05	3.93E-05	1.45E-05	1.88E-05	2.08E-06	4.84E-06
1070	2.49E-05	2.30E-05	1.45E-05	1.26E-05	2.08E-06	1.67E-06
1015	2.49E-05	2.80E-05	1.45E-05	1.45E-05	2.08E-06	2.54E-06
361	2.49E-05	3.41E-05	1.45E-05	1.77E-05	2.08E-06	4.15E-06
689	2.49E-05	3.96E-05	1.45E-05	1.90E-05	2.08E-06	4.93E-06
725	2.49E-05	3.47E-05	1.45E-05	1.74E-05	2.08E-06	3.96E-06
763	2.49E-05	3.01E-05	1.45E-05	1.57E-05	2.08E-06	3.20E-06
532	2.49E-05	3.18E-05	1.45E-05	1.65E-05	2.08E-06	3.64E-06
1190	2.49E-05	3.86E-05	1.45E-05	1.93E-05	2.08E-06	4.91E-06
173	6.23E-06	3.19E-05	4.15E-06	2.23E-05	0.00E+00	6.30E-06
945	6.23E-06	3.14E-05	4.15E-06	2.18E-05	0.00E+00	6.15E-06
1167	1.66E-05	3.41E-05	6.23E-06	1.90E-05	0.00E+00	4.93E-06
889	1.66E-05	4.29E-05	6.23E-06	2.25E-05	0.00E+00	6.77E-06
907	1.66E-05	3.44E-05	6.23E-06	1.94E-05	0.00E+00	5.03E-06
1055	1.66E-05	3.76E-05	6.23E-06	2.06E-05	0.00E+00	5.73E-06
1186	1.66E-05	4.18E-05	6.23E-06	2.25E-05	0.00E+00	6.48E-06
1268	1.66E-05	3.65E-05	6.23E-06	1.99E-05	0.00E+00	5.52E-06
1222	1.66E-05	7.76E-05	6.23E-06	3.67E-05	0.00E+00	1.44E-05
544	1.66E-05	4.39E-05	6.23E-06	2.36E-05	0.00E+00	7.28E-06
1157	1.66E-05	4.65E-05	6.23E-06	2.42E-05	0.00E+00	7.67E-06
1059	1.66E-05	3.63E-05	6.23E-06	2.04E-05	0.00E+00	5.76E-06
851	4.15E-06	3.50E-05	2.08E-06	1.76E-05	0.00E+00	7.73E-06
790	4.15E-06	2.64E-05	2.08E-06	1.47E-05	0.00E+00	6.05E-06
1125	2.08E-05	3.56E-05	1.25E-05	1.66E-05	4.15E-06	6.51E-06
872	2.08E-05	3.70E-05	1.25E-05	1.70E-05	4.15E-06	6.78E-06
925	2.08E-05	3.11E-05	1.25E-05	1.50E-05	4.15E-06	5.67E-06
1080	2.08E-05	2.81E-05	1.25E-05	1.36E-05	4.15E-06	4.82E-06
594	2.08E-05	2.59E-05	1.25E-05	1.26E-05	4.15E-06	4.32E-06
604	2.08E-05	4.43E-05	1.25E-05	1.97E-05	4.15E-06	8.21E-06
266	2.08E-05	4.35E-05	1.25E-05	2.00E-05	4.15E-06	8.47E-06

Table H.1 Estimated probabilities for the Formula 2 (continued)

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Formula 2	Archive Data	Formula 2	Archive Data	Formula 2
801	2.08E-05	2.68E-05	1.25E-05	1.31E-05	4.15E-06	4.61E-06
1099	2.08E-05	5.00E-05	1.25E-05	2.26E-05	4.15E-06	9.75E-06
565	2.08E-05	3.46E-05	1.25E-05	1.64E-05	4.15E-06	6.29E-06
193	4.15E-06	3.26E-05	2.08E-06	1.09E-05	0.00E+00	5.79E-06
663	6.23E-06	2.50E-05	4.15E-06	8.87E-06	0.00E+00	6.52E-06
802	6.23E-06	2.58E-05	4.15E-06	9.17E-06	0.00E+00	6.67E-06
460	6.23E-06	3.23E-05	4.15E-06	1.01E-05	0.00E+00	5.12E-06
878	6.23E-06	3.06E-05	4.15E-06	8.94E-06	0.00E+00	4.54E-06
1138	6.23E-06	2.90E-05	4.15E-06	8.68E-06	0.00E+00	4.26E-06
1160	4.36E-05	2.40E-05	1.45E-05	1.52E-06	8.30E-06	1.24E-06
451	4.36E-05	4.50E-05	1.45E-05	1.10E-05	8.30E-06	6.35E-06
701	4.36E-05	3.68E-05	1.45E-05	6.65E-06	8.30E-06	4.07E-06
769	4.36E-05	2.46E-05	1.45E-05	1.83E-06	8.30E-06	1.51E-06
824	4.36E-05	2.71E-05	1.45E-05	2.76E-06	8.30E-06	1.95E-06
849	4.36E-05	3.71E-05	1.45E-05	6.56E-06	8.30E-06	3.92E-06
996	4.36E-05	3.83E-05	1.45E-05	7.26E-06	8.30E-06	4.41E-06
1118	4.36E-05	3.49E-05	1.45E-05	6.26E-06	8.30E-06	3.93E-06
1151	4.36E-05	3.07E-05	1.45E-05	4.02E-06	8.30E-06	2.71E-06
203	4.36E-05	3.01E-05	1.45E-05	4.46E-06	8.30E-06	2.69E-06
380	4.36E-05	3.33E-05	1.45E-05	5.56E-06	8.30E-06	3.31E-06
625	4.36E-05	3.68E-05	1.45E-05	6.89E-06	8.30E-06	4.18E-06
934	4.36E-05	2.42E-05	1.45E-05	1.35E-06	8.30E-06	1.17E-06
940	4.36E-05	2.09E-05	1.45E-05	-6.01E-08	8.30E-06	5.59E-07
981	4.36E-05	2.55E-05	1.45E-05	2.05E-06	8.30E-06	1.56E-06
1034	4.36E-05	3.30E-05	1.45E-05	4.94E-06	8.30E-06	3.18E-06
1208	4.36E-05	3.94E-05	1.45E-05	8.25E-06	8.30E-06	4.85E-06
1240	4.36E-05	4.37E-05	1.45E-05	9.62E-06	8.30E-06	5.69E-06
1323	4.36E-05	2.68E-05	1.45E-05	2.77E-06	8.30E-06	1.91E-06
1104	3.11E-05	4.31E-05	0.00E+00	1.09E-05	0.00E+00	5.89E-06
1130	3.11E-05	3.05E-05	0.00E+00	5.57E-06	0.00E+00	2.91E-06
1154	3.11E-05	2.69E-05	0.00E+00	3.77E-06	0.00E+00	2.04E-06
113	3.11E-05	2.63E-05	0.00E+00	2.95E-06	0.00E+00	1.79E-06
163	3.11E-05	2.76E-05	0.00E+00	4.72E-06	0.00E+00	2.40E-06
378	3.11E-05	3.94E-05	0.00E+00	9.81E-06	0.00E+00	4.91E-06
517	3.11E-05	2.09E-05	0.00E+00	1.78E-06	0.00E+00	9.46E-07
538	3.11E-05	2.24E-05	0.00E+00	2.51E-06	0.00E+00	1.23E-06
638	3.11E-05	3.07E-05	0.00E+00	5.06E-06	0.00E+00	2.80E-06
708	3.11E-05	2.72E-05	0.00E+00	3.72E-06	0.00E+00	2.06E-06

Table H.1 Estimated probabilities for the Formula 2 (continued)

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Formula 2	Archive Data	Formula 2	Archive Data	Formula 2
783	3.11E-05	1.57E-05	0.00E+00	-5.82E-07	0.00E+00	-3.50E-07
845	3.11E-05	2.36E-05	0.00E+00	1.99E-06	0.00E+00	1.22E-06
1076	3.11E-05	1.49E-05	0.00E+00	-8.55E-07	0.00E+00	-5.10E-07
1148	3.11E-05	2.48E-05	0.00E+00	2.69E-06	0.00E+00	1.46E-06
1164	3.11E-05	2.01E-05	0.00E+00	1.13E-06	0.00E+00	5.70E-07
1195	3.11E-05	2.61E-05	0.00E+00	3.93E-06	0.00E+00	2.03E-06
1206	3.11E-05	2.84E-05	0.00E+00	4.70E-06	0.00E+00	2.47E-06
1233	3.11E-05	2.93E-05	0.00E+00	4.55E-06	0.00E+00	2.50E-06
768	1.04E-05	2.37E-05	0.00E+00	8.67E-06	0.00E+00	5.40E-06
842	1.04E-05	4.41E-05	0.00E+00	1.71E-05	0.00E+00	1.00E-05
600	1.04E-05	2.14E-05	0.00E+00	7.76E-06	0.00E+00	4.80E-06
646	1.04E-05	1.89E-05	0.00E+00	6.67E-06	0.00E+00	4.34E-06
504	1.04E-05	3.30E-05	0.00E+00	1.22E-05	0.00E+00	7.35E-06
221	1.04E-05	4.71E-05	0.00E+00	1.93E-05	0.00E+00	1.08E-05
965	4.15E-06	3.21E-05	0.00E+00	7.57E-06	0.00E+00	7.45E-06
628	4.15E-06	3.47E-05	0.00E+00	8.62E-06	0.00E+00	8.19E-06
827	4.77E-05	3.03E-05	1.25E-05	5.92E-06	1.25E-05	8.40E-06
970	4.77E-05	2.94E-05	1.25E-05	5.40E-06	1.25E-05	8.03E-06
1020	4.77E-05	3.85E-05	1.25E-05	9.62E-06	1.25E-05	1.02E-05
1051	4.77E-05	2.15E-05	1.25E-05	2.03E-06	1.25E-05	6.42E-06
620	4.77E-05	2.33E-05	1.25E-05	2.39E-06	1.25E-05	6.53E-06
775	4.77E-05	2.86E-05	1.25E-05	5.24E-06	1.25E-05	7.94E-06
834	4.77E-05	3.69E-05	1.25E-05	8.16E-06	1.25E-05	9.35E-06
1083	4.77E-05	2.48E-05	1.25E-05	3.30E-06	1.25E-05	7.01E-06
1337	4.77E-05	2.69E-05	1.25E-05	4.46E-06	1.25E-05	7.65E-06
1207	4.77E-05	3.42E-05	1.25E-05	7.60E-06	1.25E-05	9.40E-06
980	4.77E-05	3.29E-05	1.25E-05	7.11E-06	1.25E-05	8.97E-06
1216	4.77E-05	6.25E-05	1.25E-05	1.87E-05	1.25E-05	1.54E-05
1218	4.77E-05	6.20E-05	1.25E-05	1.85E-05	1.25E-05	1.53E-05
978	4.77E-05	2.97E-05	1.25E-05	5.66E-06	1.25E-05	8.20E-06
1117	4.77E-05	2.75E-05	1.25E-05	4.60E-06	1.25E-05	7.59E-06
77	4.77E-05	2.89E-05	1.25E-05	4.25E-06	1.25E-05	7.74E-06
715	4.77E-05	3.39E-05	1.25E-05	6.54E-06	1.25E-05	8.87E-06
647	4.77E-05	2.28E-05	1.25E-05	2.84E-06	1.25E-05	6.74E-06
676	4.77E-05	3.31E-05	1.25E-05	6.89E-06	1.25E-05	8.89E-06
722	4.77E-05	2.46E-05	1.25E-05	3.35E-06	1.25E-05	6.99E-06
799	4.77E-05	2.12E-05	1.25E-05	2.11E-06	1.25E-05	6.27E-06

Table H.1 Estimated probabilities for the Formula 2 (continued)

Accident Number	Grounding Accidents		Fire Accidents		Other Accidents	
	Archive Data	Formula 2	Archive Data	Formula 2	Archive Data	Formula 2
611	1.04E-05	3.52E-06	2.08E-06	1.47E-06	4.15E-06	3.22E-06
1334	1.04E-05	2.00E-06	2.08E-06	1.07E-06	4.15E-06	3.10E-06
332	1.04E-05	7.46E-06	2.08E-06	2.12E-06	4.15E-06	4.27E-06
462	1.04E-05	1.88E-06	2.08E-06	9.05E-07	4.15E-06	3.38E-06
633	1.04E-05	3.81E-06	2.08E-06	1.43E-06	4.15E-06	3.47E-06
672	1.04E-05	3.23E-07	2.08E-06	6.48E-07	4.15E-06	2.95E-06
690	1.04E-05	4.07E-06	2.08E-06	1.57E-06	4.15E-06	3.33E-06
718	1.04E-05	3.10E-06	2.08E-06	1.30E-06	4.15E-06	3.27E-06
977	1.04E-05	3.37E-06	2.08E-06	1.25E-06	4.15E-06	3.56E-06
999	1.04E-05	7.70E-06	2.08E-06	2.01E-06	4.15E-06	4.66E-06
1065	1.04E-05	-4.82E-07	2.08E-06	6.11E-07	4.15E-06	2.51E-06
1152	1.04E-05	3.46E-06	2.08E-06	1.44E-06	4.15E-06	3.23E-06
1209	1.04E-05	7.48E-06	2.08E-06	2.10E-06	4.15E-06	4.29E-06
1244	1.04E-05	4.28E-06	2.08E-06	1.49E-06	4.15E-06	3.65E-06
1279	1.04E-05	2.32E-07	2.08E-06	6.87E-07	4.15E-06	2.80E-06
98	1.04E-05	6.98E-06	2.08E-06	2.12E-06	4.15E-06	3.97E-06
1232	1.04E-05	7.01E-06	2.08E-06	2.03E-06	4.15E-06	4.18E-06
609	1.04E-05	7.51E-06	2.08E-06	2.07E-06	4.15E-06	4.42E-06
529	1.04E-05	4.25E-06	2.08E-06	1.35E-06	4.15E-06	3.88E-06
698	1.04E-05	2.75E-06	2.08E-06	1.29E-06	4.15E-06	3.10E-06
1000	1.04E-05	4.33E-06	2.08E-06	1.39E-06	4.15E-06	3.90E-06
1204	1.04E-05	2.41E-06	2.08E-06	1.13E-06	4.15E-06	3.23E-06
1301	1.04E-05	1.01E-06	2.08E-06	7.87E-07	4.15E-06	3.08E-06
387	1.04E-05	3.32E-06	2.08E-06	1.15E-06	4.15E-06	3.74E-06
642	1.04E-05	1.80E-06	2.08E-06	9.43E-07	4.15E-06	3.23E-06
680	1.04E-05	4.43E-06	2.08E-06	1.52E-06	4.15E-06	3.65E-06
950	1.04E-05	1.47E-06	2.08E-06	8.57E-07	4.15E-06	3.22E-06
1170	0.00E+00	9.88E-06	2.08E-06	-1.42E-07	6.23E-06	1.37E-06
527	0.00E+00	1.36E-05	2.08E-06	5.75E-07	6.23E-06	2.10E-06
557	0.00E+00	1.13E-05	2.08E-06	8.03E-08	6.23E-06	1.78E-06
745	0.00E+00	1.17E-05	2.08E-06	1.84E-07	6.23E-06	1.85E-06
840	0.00E+00	1.49E-05	2.08E-06	6.47E-07	6.23E-06	2.83E-06
1070	0.00E+00	9.30E-06	2.08E-06	-2.73E-07	6.23E-06	1.28E-06
1015	0.00E+00	1.11E-05	2.08E-06	-3.77E-08	6.23E-06	1.90E-06
361	0.00E+00	1.24E-05	2.08E-06	1.87E-07	6.23E-06	2.24E-06
689	0.00E+00	1.49E-05	2.08E-06	6.33E-07	6.23E-06	2.85E-06
725	0.00E+00	1.30E-05	2.08E-06	2.11E-07	6.23E-06	2.56E-06
763	0.00E+00	1.14E-05	2.08E-06	2.91E-08	6.23E-06	1.94E-06

Table H.1 Estimated probabilities for the Formula 2 (continued)

Accident Number	Grounding Accidents		Fire Accidents		Other Accidents	
	Archive Data	Formula 2	Archive Data	Formula 2	Archive Data	Formula 2
532	0.00E+00	1.19E-05	2.08E-06	1.58E-07	6.23E-06	1.97E-06
1190	0.00E+00	1.40E-05	2.08E-06	3.68E-07	6.23E-06	2.84E-06
173	0.00E+00	4.63E-07	0.00E+00	2.34E-06	2.08E-06	3.49E-06
945	0.00E+00	5.93E-07	0.00E+00	2.45E-06	2.08E-06	3.35E-06
1167	4.15E-06	7.28E-06	4.15E-06	2.06E-06	2.08E-06	3.08E-06
889	4.15E-06	1.02E-05	4.15E-06	2.58E-06	2.08E-06	3.80E-06
907	4.15E-06	7.13E-06	4.15E-06	1.95E-06	2.08E-06	3.22E-06
1055	4.15E-06	8.24E-06	4.15E-06	2.20E-06	2.08E-06	3.37E-06
1186	4.15E-06	9.41E-06	4.15E-06	2.25E-06	2.08E-06	4.01E-06
1268	4.15E-06	8.17E-06	4.15E-06	2.31E-06	2.08E-06	3.09E-06
1222	4.15E-06	2.11E-05	4.15E-06	4.68E-06	2.08E-06	6.14E-06
544	4.15E-06	9.83E-06	4.15E-06	2.49E-06	2.08E-06	3.74E-06
1157	4.15E-06	1.11E-05	4.15E-06	2.78E-06	2.08E-06	3.96E-06
1059	4.15E-06	7.56E-06	4.15E-06	2.19E-06	2.08E-06	2.95E-06
851	0.00E+00	1.80E-06	2.08E-06	5.44E-06	0.00E+00	4.07E-06
790	0.00E+00	-1.45E-06	2.08E-06	4.75E-06	0.00E+00	3.52E-06
1125	6.23E-06	7.51E-06	0.00E+00	3.43E-06	0.00E+00	3.49E-06
872	6.23E-06	8.02E-06	0.00E+00	3.55E-06	0.00E+00	3.55E-06
925	6.23E-06	5.84E-06	0.00E+00	3.14E-06	0.00E+00	3.05E-06
1080	6.23E-06	4.94E-06	0.00E+00	2.85E-06	0.00E+00	3.12E-06
594	6.23E-06	4.42E-06	0.00E+00	2.79E-06	0.00E+00	2.93E-06
604	6.23E-06	1.06E-05	0.00E+00	4.01E-06	0.00E+00	4.19E-06
266	6.23E-06	9.82E-06	0.00E+00	3.98E-06	0.00E+00	3.74E-06
801	6.23E-06	4.61E-06	0.00E+00	2.87E-06	0.00E+00	2.87E-06
1099	6.23E-06	1.19E-05	0.00E+00	4.31E-06	0.00E+00	4.38E-06
565	6.23E-06	6.95E-06	0.00E+00	3.25E-06	0.00E+00	3.52E-06
193	2.08E-06	8.81E-06	0.00E+00	4.43E-06	0.00E+00	3.22E-06
663	2.08E-06	-9.06E-07	0.00E+00	6.57E-06	0.00E+00	3.85E-06
802	2.08E-06	-6.56E-07	0.00E+00	6.60E-06	0.00E+00	3.93E-06
460	2.08E-06	1.19E-05	0.00E+00	3.36E-06	0.00E+00	2.61E-06
878	2.08E-06	1.17E-05	0.00E+00	3.32E-06	0.00E+00	2.61E-06
1138	2.08E-06	1.09E-05	0.00E+00	3.06E-06	0.00E+00	2.60E-06
1160	2.08E-05	1.87E-05	2.08E-06	1.10E-06	0.00E+00	1.02E-06
451	2.08E-05	2.46E-05	2.08E-06	2.32E-06	0.00E+00	2.07E-06
701	2.08E-05	2.28E-05	2.08E-06	1.95E-06	0.00E+00	1.80E-06
769	2.08E-05	1.88E-05	2.08E-06	1.22E-06	0.00E+00	8.50E-07
824	2.08E-05	1.96E-05	2.08E-06	1.32E-06	0.00E+00	1.15E-06
849	2.08E-05	2.31E-05	2.08E-06	1.91E-06	0.00E+00	2.06E-06

Table H.1 Estimated probabilities for the Formula 2 (continued)

Accident Number	Grounding Accidents		Fire Accidents		Other Accidents	
	Archive Data	Formula 2	Archive Data	Formula 2	Archive Data	Formula 2
996	2.08E-05	2.33E-05	2.08E-06	2.05E-06	0.00E+00	1.87E-06
1118	2.08E-05	2.19E-05	2.08E-06	1.86E-06	0.00E+00	1.39E-06
1151	2.08E-05	2.10E-05	2.08E-06	1.63E-06	0.00E+00	1.32E-06
203	2.08E-05	2.02E-05	2.08E-06	1.32E-06	0.00E+00	1.48E-06
380	2.08E-05	2.14E-05	2.08E-06	1.56E-06	0.00E+00	1.72E-06
625	2.08E-05	2.26E-05	2.08E-06	1.92E-06	0.00E+00	1.73E-06
934	2.08E-05	1.89E-05	2.08E-06	1.15E-06	0.00E+00	1.08E-06
940	2.08E-05	1.80E-05	2.08E-06	1.07E-06	0.00E+00	6.39E-07
981	2.08E-05	1.92E-05	2.08E-06	1.22E-06	0.00E+00	1.07E-06
1034	2.08E-05	2.18E-05	2.08E-06	1.76E-06	0.00E+00	1.55E-06
1208	2.08E-05	2.32E-05	2.08E-06	2.00E-06	0.00E+00	1.91E-06
1240	2.08E-05	2.49E-05	2.08E-06	2.38E-06	0.00E+00	2.15E-06
1323	2.08E-05	1.95E-05	2.08E-06	1.26E-06	0.00E+00	1.16E-06
1104	2.91E-05	2.44E-05	0.00E+00	1.60E-06	2.08E-06	1.83E-06
1130	2.91E-05	2.06E-05	0.00E+00	7.74E-07	2.08E-06	1.23E-06
1154	2.91E-05	1.97E-05	0.00E+00	6.49E-07	2.08E-06	9.55E-07
113	2.91E-05	2.01E-05	0.00E+00	8.27E-07	2.08E-06	8.05E-07
163	2.91E-05	1.93E-05	0.00E+00	5.06E-07	2.08E-06	1.01E-06
378	2.91E-05	2.29E-05	0.00E+00	1.04E-06	2.08E-06	2.09E-06
517	2.91E-05	1.74E-05	0.00E+00	2.22E-07	2.08E-06	4.22E-07
538	2.91E-05	1.78E-05	0.00E+00	2.19E-07	2.08E-06	6.51E-07
638	2.91E-05	2.11E-05	0.00E+00	9.65E-07	2.08E-06	1.17E-06
708	2.91E-05	2.00E-05	0.00E+00	7.26E-07	2.08E-06	9.58E-07
783	2.91E-05	1.60E-05	0.00E+00	-9.51E-08	2.08E-06	2.14E-07
845	2.91E-05	1.90E-05	0.00E+00	6.00E-07	2.08E-06	6.42E-07
1076	2.91E-05	1.57E-05	0.00E+00	-1.65E-07	2.08E-06	1.52E-07
1148	2.91E-05	1.92E-05	0.00E+00	5.40E-07	2.08E-06	8.83E-07
1164	2.91E-05	1.75E-05	0.00E+00	1.83E-07	2.08E-06	5.33E-07
1195	2.91E-05	1.91E-05	0.00E+00	4.86E-07	2.08E-06	8.90E-07
1206	2.91E-05	1.99E-05	0.00E+00	6.59E-07	2.08E-06	1.05E-06
1233	2.91E-05	2.07E-05	0.00E+00	8.54E-07	2.08E-06	1.12E-06
768	6.23E-06	3.06E-06	0.00E+00	4.24E-06	4.15E-06	2.85E-06
842	6.23E-06	9.41E-06	0.00E+00	5.55E-06	4.15E-06	4.01E-06
600	6.23E-06	2.27E-06	0.00E+00	4.00E-06	4.15E-06	2.86E-06
646	6.23E-06	1.53E-06	0.00E+00	3.96E-06	4.15E-06	2.49E-06
504	6.23E-06	6.28E-06	0.00E+00	4.90E-06	4.15E-06	3.46E-06
221	6.23E-06	9.53E-06	0.00E+00	5.31E-06	4.15E-06	4.57E-06
965	2.08E-06	7.10E-06	2.08E-06	6.16E-06	0.00E+00	3.77E-06

Table H.1 Estimated probabilities for the Formula 2 (continued)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Formula 2**	**Archive Data**	**Formula 2**	**Archive Data**	**Formula 2**
628	2.08E-06	8.02E-06	2.08E-06	6.48E-06	0.00E+00	3.66E-06
827	6.23E-06	4.22E-06	1.04E-05	7.54E-06	6.23E-06	3.79E-06
970	6.23E-06	4.08E-06	1.04E-05	7.43E-06	6.23E-06	3.95E-06
1020	6.23E-06	6.52E-06	1.04E-05	7.86E-06	6.23E-06	4.53E-06
1051	6.23E-06	1.69E-06	1.04E-05	7.11E-06	6.23E-06	3.12E-06
620	6.23E-06	2.59E-06	1.04E-05	7.20E-06	6.23E-06	3.53E-06
775	6.23E-06	3.67E-06	1.04E-05	7.36E-06	6.23E-06	3.84E-06
834	6.23E-06	6.70E-06	1.04E-05	7.78E-06	6.23E-06	4.85E-06
1083	6.23E-06	2.79E-06	1.04E-05	7.25E-06	6.23E-06	3.53E-06
1337	6.23E-06	3.24E-06	1.04E-05	7.38E-06	6.23E-06	3.52E-06
1207	6.23E-06	5.41E-06	1.04E-05	7.85E-06	6.23E-06	3.85E-06
980	6.23E-06	4.95E-06	1.04E-05	7.63E-06	6.23E-06	4.03E-06
1216	6.23E-06	1.49E-05	1.04E-05	9.67E-06	6.23E-06	5.90E-06
1218	6.23E-06	1.47E-05	1.04E-05	9.65E-06	6.23E-06	5.84E-06
978	6.23E-06	4.07E-06	1.04E-05	7.46E-06	6.23E-06	3.86E-06
1117	6.23E-06	3.53E-06	1.04E-05	7.31E-06	6.23E-06	3.86E-06
77	6.23E-06	4.72E-06	1.04E-05	7.74E-06	6.23E-06	3.70E-06
715	6.23E-06	6.09E-06	1.04E-05	7.95E-06	6.23E-06	4.12E-06
647	6.23E-06	1.86E-06	1.04E-05	7.07E-06	6.23E-06	3.31E-06
676	6.23E-06	5.29E-06	1.04E-05	7.71E-06	6.23E-06	4.11E-06
722	6.23E-06	2.67E-06	1.04E-05	7.19E-06	6.23E-06	3.56E-06
799	6.23E-06	1.40E-06	1.04E-05	6.92E-06	6.23E-06	3.36E-06

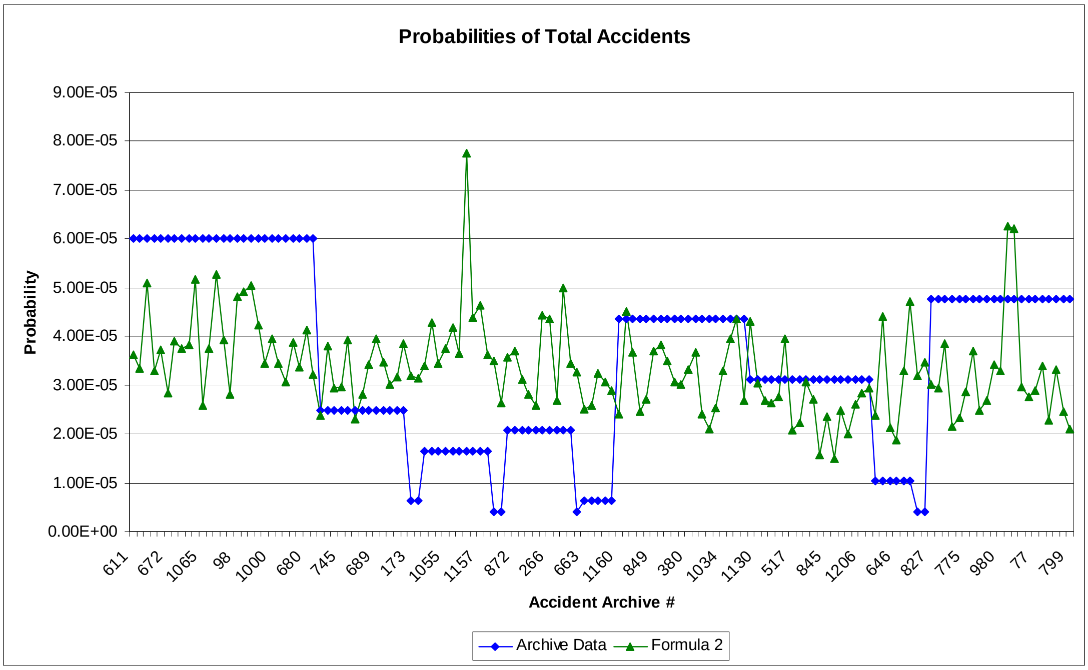


Figure H.1 Probabilities of Total Accidents (Formula 2)

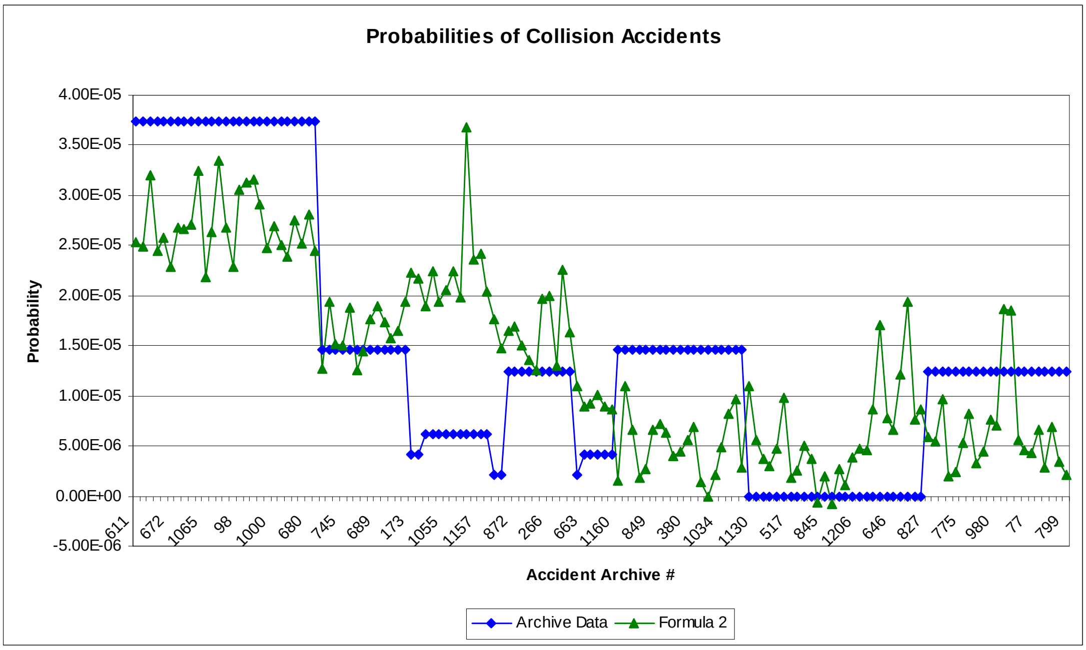


Figure H.2 Probabilities of Collision Accidents (Formula 2)

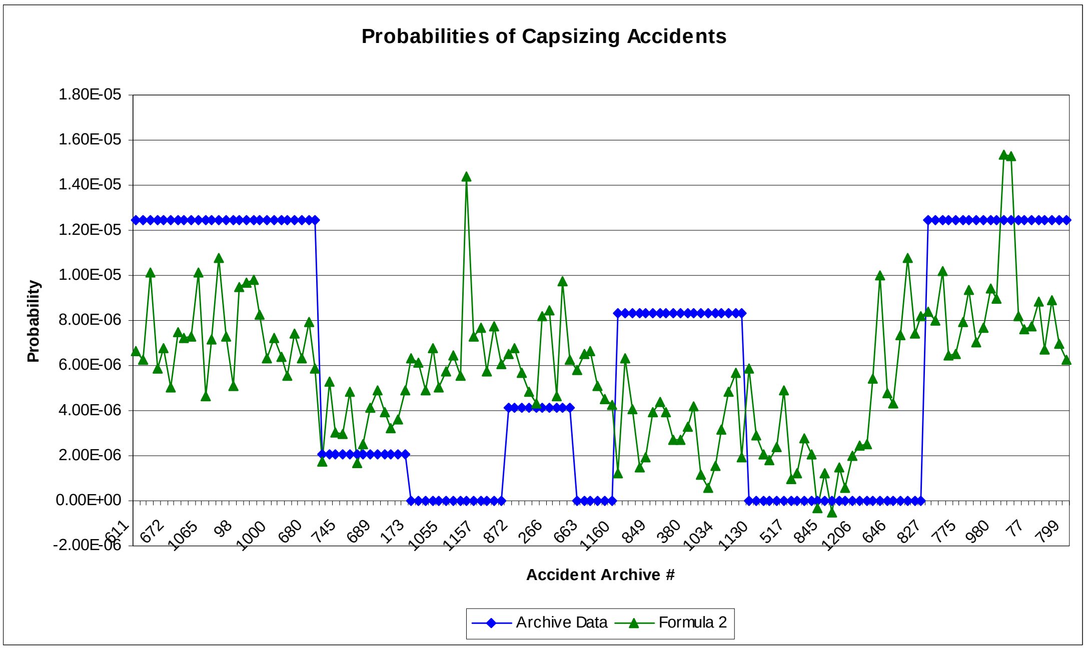


Figure H.3 Probabilities of Capsizing Accidents (Formula 2)

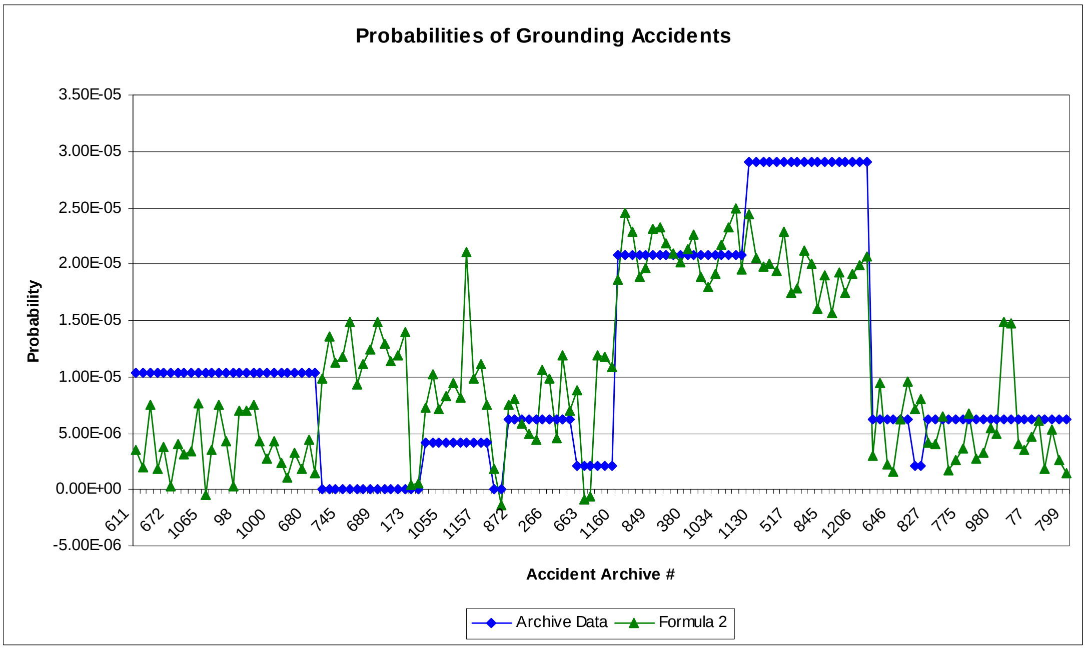


Figure H.4 Probabilities of Grounding Accidents (Formula 2)

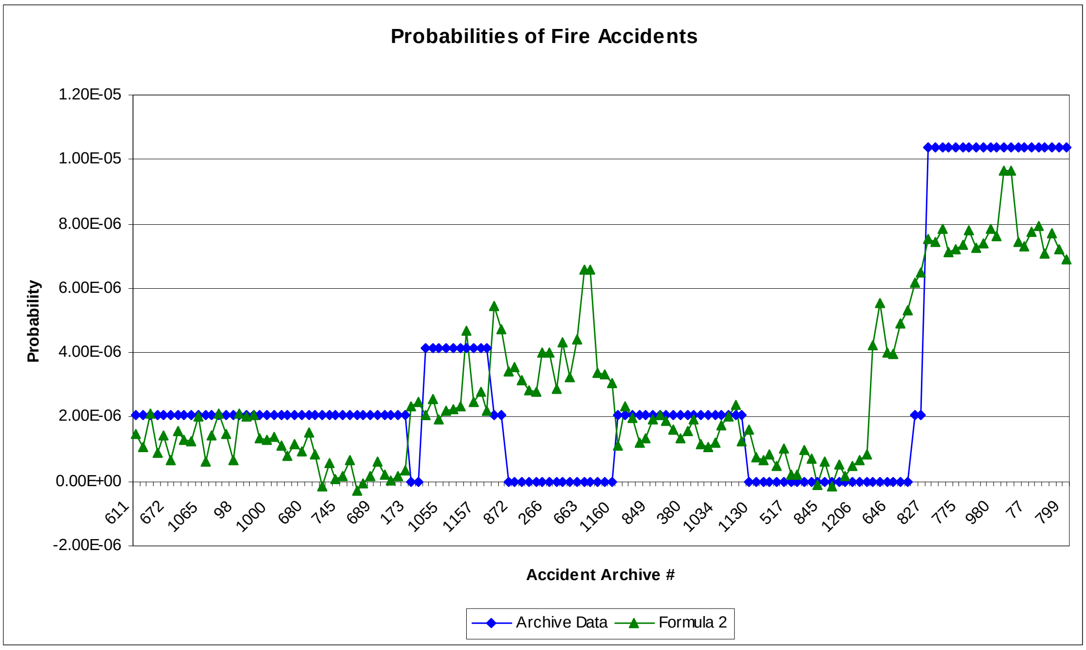


Figure H.5 Probabilities of Fire Accidents (Formula 2)

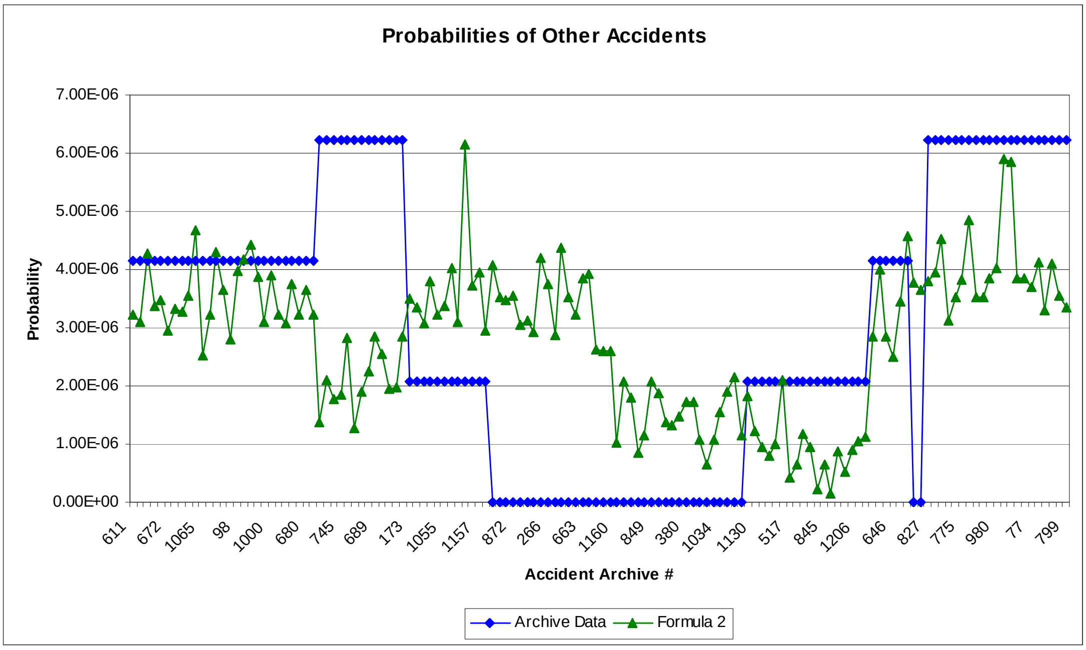


Figure H.6 Probabilities of Other Accidents (Formula 2)

APPENDIX I

MODEL 1 RESULTS

The ANFIS model established six input parameters has been used to forecast the accident probabilities. All forecasted probabilities of ANFIS model can be seen in Table I.1 and between Figure I.1 and Figure I.6.

Table I.1 Forecasted probabilities of the Model 1

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Model 1	Archive Data	Model 1	Archive Data	Model 1
611	6.02E-05	1.59E-03	3.74E-05	1.56E-03	1.25E-05	1.40E-03
1334	6.02E-05	2.08E-03	3.74E-05	2.06E-03	1.25E-05	1.85E-03
332	6.02E-05	9.45E-04	3.74E-05	9.22E-04	1.25E-05	8.17E-04
462	6.02E-05	1.74E-03	3.74E-05	1.72E-03	1.25E-05	1.54E-03
633	6.02E-05	1.52E-03	3.74E-05	1.50E-03	1.25E-05	1.34E-03
672	6.02E-05	2.17E-03	3.74E-05	2.15E-03	1.25E-05	1.93E-03
690	6.02E-05	1.61E-03	3.74E-05	1.58E-03	1.25E-05	1.42E-03
718	6.02E-05	1.75E-03	3.74E-05	1.73E-03	1.25E-05	1.55E-03
977	6.02E-05	1.67E-03	3.74E-05	1.65E-03	1.25E-05	1.48E-03
999	6.02E-05	8.25E-04	3.74E-05	8.02E-04	1.25E-05	7.08E-04
1065	6.02E-05	2.46E-03	3.74E-05	2.44E-03	1.25E-05	2.20E-03
1152	6.02E-05	1.76E-03	3.74E-05	1.74E-03	1.25E-05	1.56E-03
1209	6.02E-05	8.57E-04	3.74E-05	8.32E-04	1.25E-05	7.35E-04
1244	6.02E-05	1.49E-03	3.74E-05	1.46E-03	1.25E-05	1.31E-03
1279	6.02E-05	2.32E-03	3.74E-05	2.30E-03	1.25E-05	2.07E-03
98	6.02E-05	1.01E-03	3.74E-05	9.89E-04	1.25E-05	8.77E-04
1232	6.02E-05	1.04E-03	3.74E-05	1.02E-03	1.25E-05	9.03E-04
609	6.02E-05	9.04E-04	3.74E-05	8.81E-04	1.25E-05	7.79E-04
529	6.02E-05	1.20E-03	3.74E-05	1.18E-03	1.25E-05	1.05E-03
698	6.02E-05	1.89E-03	3.74E-05	1.87E-03	1.25E-05	1.68E-03
1000	6.02E-05	1.22E-03	3.74E-05	1.19E-03	1.25E-05	1.06E-03
1204	6.02E-05	2.02E-03	3.74E-05	2.00E-03	1.25E-05	1.79E-03

Table I.1 Forecasted probabilities of the Model 1 (cont'd)

Accident Number	**Total Accidents**		**Collision Accidents**		**Capsizing Accidents**	
	Archive Data	**Model 1**	**Archive Data**	**Model 1**	**Archive Data**	**Model 1**
1301	6.02E-05	2.08E-03	3.74E-05	2.06E-03	1.25E-05	1.85E-03
387	6.02E-05	1.38E-03	3.74E-05	1.36E-03	1.25E-05	1.21E-03
642	6.02E-05	1.92E-03	3.74E-05	1.90E-03	1.25E-05	1.70E-03
680	6.02E-05	1.58E-03	3.74E-05	1.55E-03	1.25E-05	1.39E-03
950	6.02E-05	1.95E-03	3.74E-05	1.93E-03	1.25E-05	1.73E-03
1170	2.49E-05	1.58E-03	1.45E-05	1.57E-03	2.08E-06	1.42E-03
527	2.49E-05	8.24E-04	1.45E-05	8.13E-04	2.08E-06	7.28E-04
557	2.49E-05	1.42E-03	1.45E-05	1.41E-03	2.08E-06	1.27E-03
745	2.49E-05	1.37E-03	1.45E-05	1.36E-03	2.08E-06	1.22E-03
840	2.49E-05	7.19E-04	1.45E-05	7.08E-04	2.08E-06	6.32E-04
1070	2.49E-05	1.60E-03	1.45E-05	1.59E-03	2.08E-06	1.44E-03
1015	2.49E-05	1.35E-03	1.45E-05	1.34E-03	2.08E-06	1.20E-03
361	2.49E-05	1.07E-03	1.45E-05	1.05E-03	2.08E-06	9.46E-04
689	2.49E-05	7.43E-04	1.45E-05	7.32E-04	2.08E-06	6.54E-04
725	2.49E-05	9.07E-04	1.45E-05	8.96E-04	2.08E-06	8.04E-04
763	2.49E-05	1.33E-03	1.45E-05	1.31E-03	2.08E-06	1.18E-03
532	2.49E-05	1.28E-03	1.45E-05	1.26E-03	2.08E-06	1.14E-03
1190	2.49E-05	7.93E-04	1.45E-05	7.81E-04	2.08E-06	6.99E-04
173	6.23E-06	2.16E-03	4.15E-06	2.16E-03	0.00E+00	1.95E-03
945	6.23E-06	2.27E-03	4.15E-06	2.26E-03	0.00E+00	2.05E-03
1167	1.66E-05	1.82E-03	6.23E-06	1.82E-03	0.00E+00	1.65E-03
889	1.66E-05	1.24E-03	6.23E-06	1.23E-03	0.00E+00	1.12E-03
907	1.66E-05	1.65E-03	6.23E-06	1.64E-03	0.00E+00	1.48E-03
1055	1.66E-05	1.61E-03	6.23E-06	1.60E-03	0.00E+00	1.45E-03
1186	1.66E-05	1.05E-03	6.23E-06	1.03E-03	0.00E+00	9.34E-04
1268	1.66E-05	1.70E-03	6.23E-06	1.69E-03	0.00E+00	1.53E-03
1222	1.66E-05	1.65E-04	6.23E-06	1.55E-04	0.00E+00	1.35E-04
544	1.66E-05	1.15E-03	6.23E-06	1.14E-03	0.00E+00	1.03E-03
1157	1.66E-05	1.13E-03	6.23E-06	1.13E-03	0.00E+00	1.02E-03
1059	1.66E-05	1.47E-03	6.23E-06	1.46E-03	0.00E+00	1.32E-03
851	4.15E-06	1.64E-03	2.08E-06	1.64E-03	0.00E+00	1.49E-03
790	4.15E-06	2.38E-03	2.08E-06	2.38E-03	0.00E+00	2.16E-03
1125	2.08E-05	1.44E-03	1.25E-05	1.43E-03	4.15E-06	1.29E-03
872	2.08E-05	1.39E-03	1.25E-05	1.38E-03	4.15E-06	1.25E-03
925	2.08E-05	1.71E-03	1.25E-05	1.70E-03	4.15E-06	1.54E-03
1080	2.08E-05	1.52E-03	1.25E-05	1.51E-03	4.15E-06	1.37E-03
594	2.08E-05	1.71E-03	1.25E-05	1.71E-03	4.15E-06	1.54E-03
604	2.08E-05	7.97E-04	1.25E-05	7.87E-04	4.15E-06	7.08E-04

Table I.1 Forecasted probabilities of the Model 1 (cont'd)

Accident Number	**Total Accidents**		**Collision Accidents**		**Capsizing Accidents**	
	Archive Data	**Model 1**	**Archive Data**	**Model 1**	**Archive Data**	**Model 1**
266	2.08E-05	1.04E-03	1.25E-05	1.04E-03	4.15E-06	9.34E-04
801	2.08E-05	1.85E-03	1.25E-05	1.84E-03	4.15E-06	1.67E-03
1099	2.08E-05	7.17E-04	1.25E-05	7.05E-04	4.15E-06	6.34E-04
565	2.08E-05	1.32E-03	1.25E-05	1.31E-03	4.15E-06	1.18E-03
193	4.15E-06	1.34E-03	2.08E-06	1.33E-03	0.00E+00	1.21E-03
663	6.23E-06	1.96E-03	4.15E-06	1.95E-03	0.00E+00	1.77E-03
802	6.23E-06	1.90E-03	4.15E-06	1.89E-03	0.00E+00	1.72E-03
460	6.23E-06	1.18E-03	4.15E-06	1.16E-03	0.00E+00	1.04E-03
878	6.23E-06	1.19E-03	4.15E-06	1.17E-03	0.00E+00	1.06E-03
1138	6.23E-06	1.16E-03	4.15E-06	1.15E-03	0.00E+00	1.04E-03
1160	4.36E-05	9.15E-04	1.45E-05	8.90E-04	8.30E-06	8.05E-04
451	4.36E-05	4.07E-04	1.45E-05	3.77E-04	8.30E-06	3.38E-04
701	4.36E-05	5.99E-04	1.45E-05	5.71E-04	8.30E-06	5.14E-04
769	4.36E-05	9.45E-04	1.45E-05	9.19E-04	8.30E-06	8.31E-04
824	4.36E-05	8.79E-04	1.45E-05	8.53E-04	8.30E-06	7.71E-04
849	4.36E-05	4.76E-04	1.45E-05	4.48E-04	8.30E-06	4.03E-04
996	4.36E-05	5.58E-04	1.45E-05	5.29E-04	8.30E-06	4.76E-04
1118	4.36E-05	5.95E-04	1.45E-05	5.68E-04	8.30E-06	5.12E-04
1151	4.36E-05	7.85E-04	1.45E-05	7.58E-04	8.30E-06	6.84E-04
203	4.36E-05	6.60E-04	1.45E-05	6.34E-04	8.30E-06	5.72E-04
380	4.36E-05	6.14E-04	1.45E-05	5.87E-04	8.30E-06	5.29E-04
625	4.36E-05	6.04E-04	1.45E-05	5.75E-04	8.30E-06	5.18E-04
934	4.36E-05	8.83E-04	1.45E-05	8.58E-04	8.30E-06	7.76E-04
940	4.36E-05	1.03E-03	1.45E-05	1.01E-03	8.30E-06	9.10E-04
981	4.36E-05	9.10E-04	1.45E-05	8.84E-04	8.30E-06	8.00E-04
1034	4.36E-05	6.97E-04	1.45E-05	6.70E-04	8.30E-06	6.05E-04
1208	4.36E-05	5.08E-04	1.45E-05	4.77E-04	8.30E-06	4.29E-04
1240	4.36E-05	4.23E-04	1.45E-05	3.91E-04	8.30E-06	3.50E-04
1323	4.36E-05	8.63E-04	1.45E-05	8.37E-04	8.30E-06	7.57E-04
1104	3.11E-05	3.99E-04	0.00E+00	3.69E-04	0.00E+00	3.35E-04
1130	3.11E-05	7.48E-04	0.00E+00	7.14E-04	0.00E+00	6.49E-04
1154	3.11E-05	8.67E-04	0.00E+00	8.34E-04	0.00E+00	7.58E-04
113	3.11E-05	7.08E-04	0.00E+00	6.77E-04	0.00E+00	6.16E-04
163	3.11E-05	7.78E-04	0.00E+00	7.44E-04	0.00E+00	6.76E-04
378	3.11E-05	3.84E-04	0.00E+00	3.53E-04	0.00E+00	3.21E-04
517	3.11E-05	1.03E-03	0.00E+00	1.00E-03	0.00E+00	9.11E-04
538	3.11E-05	9.53E-04	0.00E+00	9.19E-04	0.00E+00	8.35E-04
638	3.11E-05	6.94E-04	0.00E+00	6.62E-04	0.00E+00	6.02E-04

Table I.1 Forecasted probabilities of the Model 1 (cont'd)

Accident Number	**Total Accidents**		**Collision Accidents**		**Capsizing Accidents**	
	Archive Data	**Model 1**	**Archive Data**	**Model 1**	**Archive Data**	**Model 1**
708	3.11E-05	8.22E-04	0.00E+00	7.90E-04	0.00E+00	7.18E-04
783	3.11E-05	1.16E-03	0.00E+00	1.13E-03	0.00E+00	1.03E-03
845	3.11E-05	8.62E-04	0.00E+00	8.31E-04	0.00E+00	7.56E-04
1076	3.11E-05	1.17E-03	0.00E+00	1.14E-03	0.00E+00	1.04E-03
1148	3.11E-05	8.60E-04	0.00E+00	8.26E-04	0.00E+00	7.51E-04
1164	3.11E-05	1.06E-03	0.00E+00	1.02E-03	0.00E+00	9.29E-04
1195	3.11E-05	8.80E-04	0.00E+00	8.46E-04	0.00E+00	7.69E-04
1206	3.11E-05	8.29E-04	0.00E+00	7.96E-04	0.00E+00	7.23E-04
1233	3.11E-05	7.40E-04	0.00E+00	7.07E-04	0.00E+00	6.43E-04
768	1.04E-05	1.60E-03	0.00E+00	1.58E-03	0.00E+00	1.43E-03
842	1.04E-05	6.60E-04	0.00E+00	6.44E-04	0.00E+00	5.85E-04
600	1.04E-05	1.49E-03	0.00E+00	1.47E-03	0.00E+00	1.33E-03
646	1.04E-05	1.77E-03	0.00E+00	1.75E-03	0.00E+00	1.59E-03
504	1.04E-05	1.13E-03	0.00E+00	1.11E-03	0.00E+00	1.01E-03
221	1.04E-05	4.40E-04	0.00E+00	4.27E-04	0.00E+00	3.88E-04
965	4.15E-06	9.66E-04	0.00E+00	9.42E-04	0.00E+00	8.56E-04
628	4.15E-06	1.01E-03	0.00E+00	9.87E-04	0.00E+00	8.97E-04
827	4.77E-05	1.13E-03	1.25E-05	1.10E-03	1.25E-05	1.00E-03
970	4.77E-05	1.09E-03	1.25E-05	1.07E-03	1.25E-05	9.71E-04
1020	4.77E-05	6.76E-04	1.25E-05	6.43E-04	1.25E-05	5.86E-04
1051	4.77E-05	1.51E-03	1.25E-05	1.47E-03	1.25E-05	1.34E-03
620	4.77E-05	1.28E-03	1.25E-05	1.25E-03	1.25E-05	1.14E-03
775	4.77E-05	1.14E-03	1.25E-05	1.11E-03	1.25E-05	1.01E-03
834	4.77E-05	6.15E-04	1.25E-05	5.79E-04	1.25E-05	5.28E-04
1083	4.77E-05	1.37E-03	1.25E-05	1.34E-03	1.25E-05	1.22E-03
1337	4.77E-05	1.29E-03	1.25E-05	1.25E-03	1.25E-05	1.14E-03
1207	4.77E-05	8.76E-04	1.25E-05	8.41E-04	1.25E-05	7.66E-04
980	4.77E-05	9.84E-04	1.25E-05	9.51E-04	1.25E-05	8.66E-04
1216	4.77E-05	2.31E-04	1.25E-05	1.90E-04	1.25E-05	1.74E-04
1218	4.77E-05	2.16E-04	1.25E-05	1.89E-04	1.25E-05	1.73E-04
978	4.77E-05	1.14E-03	1.25E-05	1.11E-03	1.25E-05	1.01E-03
1117	4.77E-05	1.13E-03	1.25E-05	1.10E-03	1.25E-05	1.00E-03
77	4.77E-05	9.03E-04	1.25E-05	8.68E-04	1.25E-05	7.90E-04
715	4.77E-05	8.23E-04	1.25E-05	7.89E-04	1.25E-05	7.19E-04
647	4.77E-05	1.43E-03	1.25E-05	1.40E-03	1.25E-05	1.27E-03
676	4.77E-05	1.01E-03	1.25E-05	9.77E-04	1.25E-05	8.89E-04
722	4.77E-05	1.34E-03	1.25E-05	1.31E-03	1.25E-05	1.20E-03
799	4.77E-05	1.40E-03	1.25E-05	1.38E-03	1.25E-05	1.25E-03

Table I.1 Forecasted probabilities of the Model 1 (cont'd)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Model 1**	**Archive Data**	**Model 1**	**Archive Data**	**Model 1**
611	1.04E-05	1.60E-03	2.08E-06	1.44E-03	4.15E-06	1.40E-03
1334	1.04E-05	2.12E-03	2.08E-06	1.91E-03	4.15E-06	1.85E-03
332	1.04E-05	9.35E-04	2.08E-06	8.39E-04	4.15E-06	8.14E-04
462	1.04E-05	1.76E-03	2.08E-06	1.59E-03	4.15E-06	1.54E-03
633	1.04E-05	1.54E-03	2.08E-06	1.38E-03	4.15E-06	1.34E-03
672	1.04E-05	2.22E-03	2.08E-06	2.00E-03	4.15E-06	1.94E-03
690	1.04E-05	1.63E-03	2.08E-06	1.46E-03	4.15E-06	1.42E-03
718	1.04E-05	1.78E-03	2.08E-06	1.60E-03	4.15E-06	1.55E-03
977	1.04E-05	1.69E-03	2.08E-06	1.53E-03	4.15E-06	1.48E-03
999	1.04E-05	8.10E-04	2.08E-06	7.26E-04	4.15E-06	7.05E-04
1065	1.04E-05	2.52E-03	2.08E-06	2.28E-03	4.15E-06	2.20E-03
1152	1.04E-05	1.79E-03	2.08E-06	1.61E-03	4.15E-06	1.56E-03
1209	1.04E-05	8.41E-04	2.08E-06	7.54E-04	4.15E-06	7.31E-04
1244	1.04E-05	1.50E-03	2.08E-06	1.35E-03	4.15E-06	1.31E-03
1279	1.04E-05	2.38E-03	2.08E-06	2.15E-03	4.15E-06	2.08E-03
98	1.04E-05	1.01E-03	2.08E-06	9.03E-04	4.15E-06	8.76E-04
1232	1.04E-05	1.03E-03	2.08E-06	9.29E-04	4.15E-06	9.01E-04
609	1.04E-05	8.92E-04	2.08E-06	8.00E-04	4.15E-06	7.77E-04
529	1.04E-05	1.20E-03	2.08E-06	1.08E-03	4.15E-06	1.05E-03
698	1.04E-05	1.93E-03	2.08E-06	1.74E-03	4.15E-06	1.68E-03
1000	1.04E-05	1.22E-03	2.08E-06	1.10E-03	4.15E-06	1.06E-03
1204	1.04E-05	2.06E-03	2.08E-06	1.86E-03	4.15E-06	1.80E-03
1301	1.04E-05	2.13E-03	2.08E-06	1.92E-03	4.15E-06	1.86E-03
387	1.04E-05	1.39E-03	2.08E-06	1.25E-03	4.15E-06	1.21E-03
642	1.04E-05	1.95E-03	2.08E-06	1.76E-03	4.15E-06	1.71E-03
680	1.04E-05	1.60E-03	2.08E-06	1.44E-03	4.15E-06	1.39E-03
950	1.04E-05	1.98E-03	2.08E-06	1.79E-03	4.15E-06	1.73E-03
1170	0.00E+00	1.62E-03	2.08E-06	1.47E-03	6.23E-06	1.43E-03
527	0.00E+00	8.35E-04	2.08E-06	7.58E-04	6.23E-06	7.38E-04
557	0.00E+00	1.46E-03	2.08E-06	1.32E-03	6.23E-06	1.29E-03
745	0.00E+00	1.40E-03	2.08E-06	1.27E-03	6.23E-06	1.24E-03
840	0.00E+00	7.25E-04	2.08E-06	6.58E-04	6.23E-06	6.41E-04
1070	0.00E+00	1.65E-03	2.08E-06	1.50E-03	6.23E-06	1.45E-03
1015	0.00E+00	1.38E-03	2.08E-06	1.25E-03	6.23E-06	1.22E-03
361	0.00E+00	1.09E-03	2.08E-06	9.85E-04	6.23E-06	9.57E-04
689	0.00E+00	7.49E-04	2.08E-06	6.81E-04	6.23E-06	6.63E-04
725	0.00E+00	9.22E-04	2.08E-06	8.37E-04	6.23E-06	8.14E-04
763	0.00E+00	1.36E-03	2.08E-06	1.23E-03	6.23E-06	1.20E-03

Table I.1 Forecasted probabilities of the Model 1 (cont'd)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Model 1**	**Archive Data**	**Model 1**	**Archive Data**	**Model 1**
532	0.00E+00	1.31E-03	2.08E-06	1.18E-03	6.23E-06	1.15E-03
1190	0.00E+00	8.02E-04	2.08E-06	7.28E-04	6.23E-06	7.08E-04
173	0.00E+00	2.25E-03	0.00E+00	2.03E-03	2.08E-06	1.96E-03
945	0.00E+00	2.35E-03	0.00E+00	2.13E-03	2.08E-06	2.06E-03
1167	4.15E-06	1.90E-03	4.15E-06	1.72E-03	2.08E-06	1.66E-03
889	4.15E-06	1.29E-03	4.15E-06	1.17E-03	2.08E-06	1.13E-03
907	4.15E-06	1.71E-03	4.15E-06	1.55E-03	2.08E-06	1.50E-03
1055	4.15E-06	1.67E-03	4.15E-06	1.52E-03	2.08E-06	1.47E-03
1186	4.15E-06	1.08E-03	4.15E-06	9.76E-04	2.08E-06	9.42E-04
1268	4.15E-06	1.77E-03	4.15E-06	1.60E-03	2.08E-06	1.55E-03
1222	4.15E-06	1.60E-04	4.15E-06	1.45E-04	2.08E-06	1.38E-04
544	4.15E-06	1.19E-03	4.15E-06	1.08E-03	2.08E-06	1.04E-03
1157	4.15E-06	1.17E-03	4.15E-06	1.06E-03	2.08E-06	1.03E-03
1059	4.15E-06	1.53E-03	4.15E-06	1.38E-03	2.08E-06	1.33E-03
851	0.00E+00	1.71E-03	2.08E-06	1.55E-03	0.00E+00	1.50E-03
790	0.00E+00	2.49E-03	2.08E-06	2.26E-03	0.00E+00	2.18E-03
1125	6.23E-06	1.49E-03	0.00E+00	1.34E-03	0.00E+00	1.30E-03
872	6.23E-06	1.44E-03	0.00E+00	1.30E-03	0.00E+00	1.26E-03
925	6.23E-06	1.78E-03	0.00E+00	1.60E-03	0.00E+00	1.55E-03
1080	6.23E-06	1.57E-03	0.00E+00	1.42E-03	0.00E+00	1.37E-03
594	6.23E-06	1.78E-03	0.00E+00	1.60E-03	0.00E+00	1.55E-03
604	6.23E-06	8.16E-04	0.00E+00	7.33E-04	0.00E+00	7.09E-04
266	6.23E-06	1.08E-03	0.00E+00	9.69E-04	0.00E+00	9.38E-04
801	6.23E-06	1.92E-03	0.00E+00	1.73E-03	0.00E+00	1.68E-03
1099	6.23E-06	7.29E-04	0.00E+00	6.55E-04	0.00E+00	6.33E-04
565	6.23E-06	1.36E-03	0.00E+00	1.23E-03	0.00E+00	1.19E-03
193	2.08E-06	1.39E-03	0.00E+00	1.25E-03	0.00E+00	1.21E-03
663	2.08E-06	2.03E-03	0.00E+00	1.84E-03	0.00E+00	1.78E-03
802	2.08E-06	1.97E-03	0.00E+00	1.79E-03	0.00E+00	1.73E-03
460	2.08E-06	1.20E-03	0.00E+00	1.08E-03	0.00E+00	1.05E-03
878	2.08E-06	1.21E-03	0.00E+00	1.10E-03	0.00E+00	1.06E-03
1138	2.08E-06	1.19E-03	0.00E+00	1.08E-03	0.00E+00	1.04E-03
1160	2.08E-05	9.38E-04	2.08E-06	8.32E-04	0.00E+00	8.04E-04
451	2.08E-05	4.00E-04	2.08E-06	3.46E-04	0.00E+00	3.32E-04
701	2.08E-05	6.03E-04	2.08E-06	5.29E-04	0.00E+00	5.10E-04
769	2.08E-05	9.67E-04	2.08E-06	8.59E-04	0.00E+00	8.30E-04
824	2.08E-05	8.99E-04	2.08E-06	7.97E-04	0.00E+00	7.70E-04
849	2.08E-05	4.75E-04	2.08E-06	4.13E-04	0.00E+00	3.98E-04

Table I.1 Forecasted probabilities of the Model 1 (cont'd)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Model 1**	**Archive Data**	**Model 1**	**Archive Data**	**Model 1**
996	2.08E-05	5.59E-04	2.08E-06	4.89E-04	0.00E+00	4.72E-04
1118	2.08E-05	6.01E-04	2.08E-06	5.27E-04	0.00E+00	5.09E-04
1151	2.08E-05	7.99E-04	2.08E-06	7.07E-04	0.00E+00	6.82E-04
203	2.08E-05	6.69E-04	2.08E-06	5.89E-04	0.00E+00	5.69E-04
380	2.08E-05	6.21E-04	2.08E-06	5.45E-04	0.00E+00	5.26E-04
625	2.08E-05	6.07E-04	2.08E-06	5.33E-04	0.00E+00	5.14E-04
934	2.08E-05	9.04E-04	2.08E-06	8.02E-04	0.00E+00	7.75E-04
940	2.08E-05	1.06E-03	2.08E-06	9.42E-04	0.00E+00	9.10E-04
981	2.08E-05	9.32E-04	2.08E-06	8.27E-04	0.00E+00	7.99E-04
1034	2.08E-05	7.07E-04	2.08E-06	6.24E-04	0.00E+00	6.02E-04
1208	2.08E-05	5.04E-04	2.08E-06	4.40E-04	0.00E+00	4.23E-04
1240	2.08E-05	4.14E-04	2.08E-06	3.58E-04	0.00E+00	3.44E-04
1323	2.08E-05	8.82E-04	2.08E-06	7.82E-04	0.00E+00	7.55E-04
1104	2.91E-05	4.15E-04	0.00E+00	3.49E-04	2.08E-06	3.40E-04
1130	2.91E-05	7.75E-04	0.00E+00	6.75E-04	2.08E-06	6.55E-04
1154	2.91E-05	9.01E-04	0.00E+00	7.89E-04	2.08E-06	7.65E-04
113	2.91E-05	7.37E-04	0.00E+00	6.41E-04	2.08E-06	6.23E-04
163	2.91E-05	8.06E-04	0.00E+00	7.04E-04	2.08E-06	6.82E-04
378	2.91E-05	3.98E-04	0.00E+00	3.34E-04	2.08E-06	3.26E-04
517	2.91E-05	1.08E-03	0.00E+00	9.49E-04	2.08E-06	9.20E-04
538	2.91E-05	9.89E-04	0.00E+00	8.69E-04	2.08E-06	8.43E-04
638	2.91E-05	7.21E-04	0.00E+00	6.27E-04	2.08E-06	6.08E-04
708	2.91E-05	8.55E-04	0.00E+00	7.48E-04	2.08E-06	7.26E-04
783	2.91E-05	1.21E-03	0.00E+00	1.07E-03	2.08E-06	1.03E-03
845	2.91E-05	8.98E-04	0.00E+00	7.87E-04	2.08E-06	7.64E-04
1076	2.91E-05	1.22E-03	0.00E+00	1.08E-03	2.08E-06	1.05E-03
1148	2.91E-05	8.93E-04	0.00E+00	7.82E-04	2.08E-06	7.58E-04
1164	2.91E-05	1.10E-03	0.00E+00	9.67E-04	2.08E-06	9.37E-04
1195	2.91E-05	9.13E-04	0.00E+00	8.00E-04	2.08E-06	7.76E-04
1206	2.91E-05	8.60E-04	0.00E+00	7.52E-04	2.08E-06	7.30E-04
1233	2.91E-05	7.68E-04	0.00E+00	6.69E-04	2.08E-06	6.49E-04
768	6.23E-06	1.65E-03	0.00E+00	1.49E-03	4.15E-06	1.44E-03
842	6.23E-06	6.77E-04	0.00E+00	6.08E-04	4.15E-06	5.92E-04
600	6.23E-06	1.53E-03	0.00E+00	1.38E-03	4.15E-06	1.34E-03
646	6.23E-06	1.83E-03	0.00E+00	1.66E-03	4.15E-06	1.60E-03
504	6.23E-06	1.17E-03	0.00E+00	1.05E-03	4.15E-06	1.02E-03
221	6.23E-06	4.52E-04	0.00E+00	4.04E-04	4.15E-06	3.94E-04
965	2.08E-06	9.80E-04	2.08E-06	8.89E-04	0.00E+00	8.57E-04

Table I.1 Forecasted probabilities of the Model 1 (cont'd)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Model 1**	**Archive Data**	**Model 1**	**Archive Data**	**Model 1**
628	2.08E-06	1.03E-03	2.08E-06	9.31E-04	0.00E+00	8.97E-04
827	6.23E-06	1.14E-03	1.04E-05	1.04E-03	6.23E-06	1.00E-03
970	6.23E-06	1.11E-03	1.04E-05	1.01E-03	6.23E-06	9.74E-04
1020	6.23E-06	6.66E-04	1.04E-05	6.08E-04	6.23E-06	5.85E-04
1051	6.23E-06	1.54E-03	1.04E-05	1.39E-03	6.23E-06	1.35E-03
620	6.23E-06	1.31E-03	1.04E-05	1.19E-03	6.23E-06	1.15E-03
775	6.23E-06	1.16E-03	1.04E-05	1.05E-03	6.23E-06	1.02E-03
834	6.23E-06	5.98E-04	1.04E-05	5.47E-04	6.23E-06	5.25E-04
1083	6.23E-06	1.39E-03	1.04E-05	1.27E-03	6.23E-06	1.22E-03
1337	6.23E-06	1.31E-03	1.04E-05	1.19E-03	6.23E-06	1.14E-03
1207	6.23E-06	8.71E-04	1.04E-05	7.95E-04	6.23E-06	7.64E-04
980	6.23E-06	9.88E-04	1.04E-05	8.99E-04	6.23E-06	8.66E-04
1216	6.23E-06	1.90E-04	1.04E-05	1.78E-04	6.23E-06	1.67E-04
1218	6.23E-06	1.94E-04	1.04E-05	1.79E-04	6.23E-06	1.71E-04
978	6.23E-06	1.15E-03	1.04E-05	1.05E-03	6.23E-06	1.01E-03
1117	6.23E-06	1.15E-03	1.04E-05	1.04E-03	6.23E-06	1.00E-03
77	6.23E-06	9.00E-04	1.04E-05	8.20E-04	6.23E-06	7.89E-04
715	6.23E-06	8.19E-04	1.04E-05	7.46E-04	6.23E-06	7.18E-04
647	6.23E-06	1.46E-03	1.04E-05	1.32E-03	6.23E-06	1.28E-03
676	6.23E-06	1.02E-03	1.04E-05	9.24E-04	6.23E-06	8.91E-04
722	6.23E-06	1.37E-03	1.04E-05	1.24E-03	6.23E-06	1.20E-03
799	6.23E-06	1.44E-03	1.04E-05	1.31E-03	6.23E-06	1.26E-03

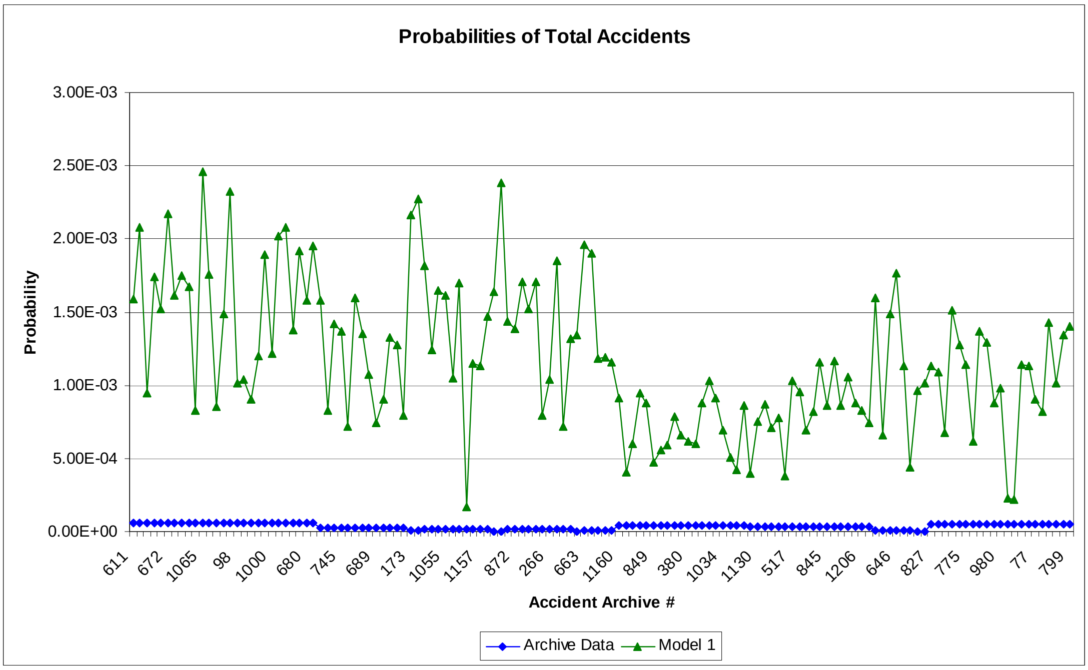


Figure I.1 Probabilities of Total Accidents (Model 1)

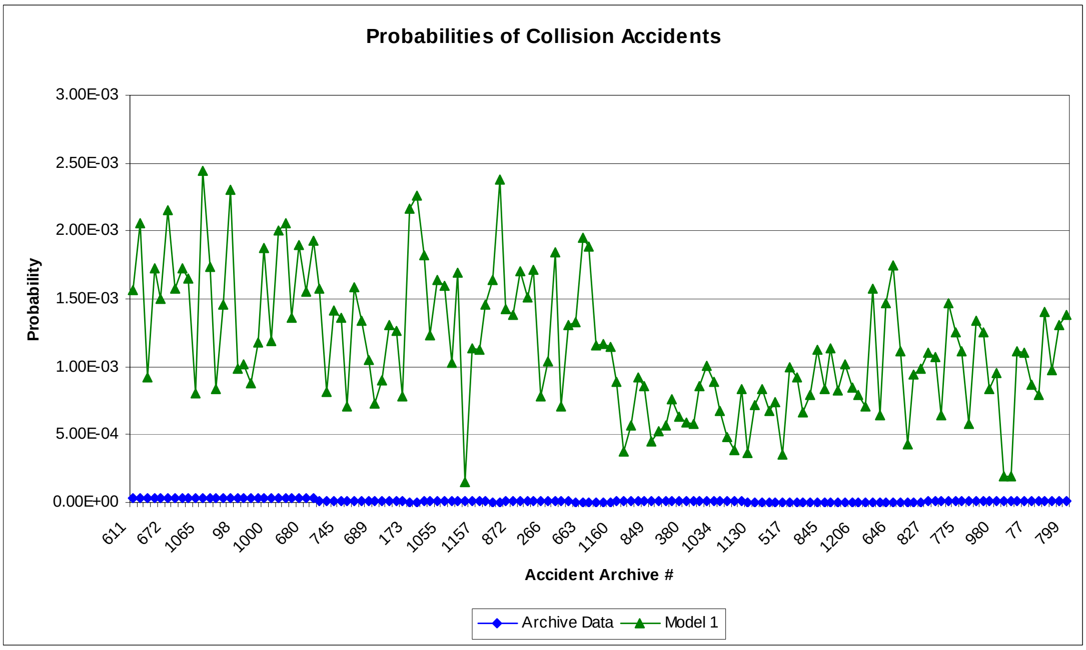


Figure I.2 Probabilities of Collision Accidents (Model 1)

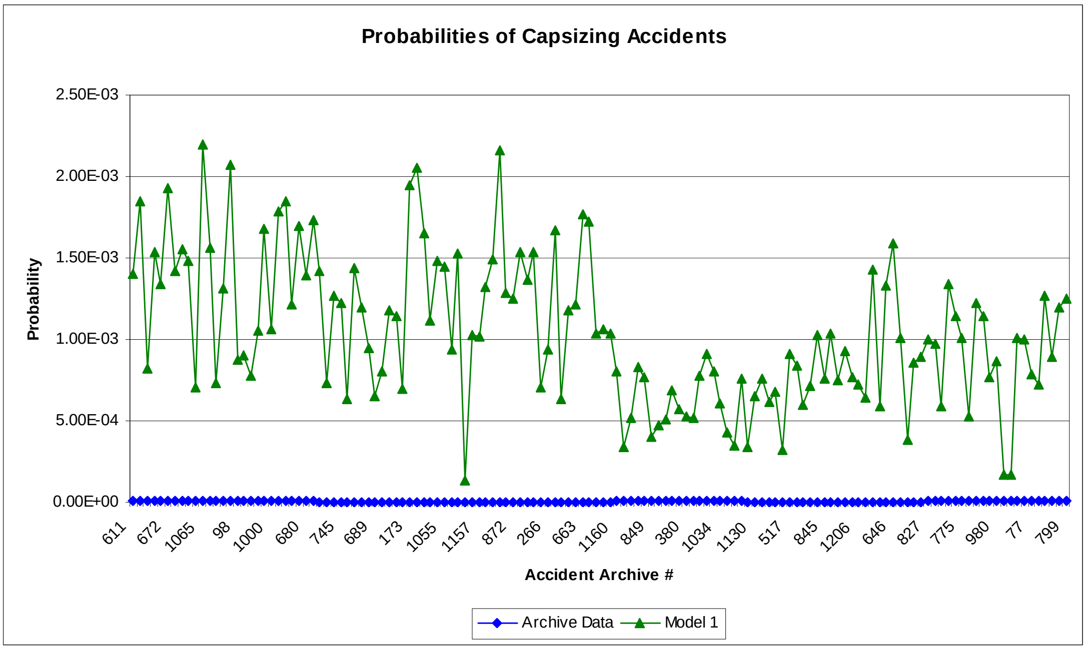


Figure I.3 Probabilities of Capsizing Accidents (Model 1)

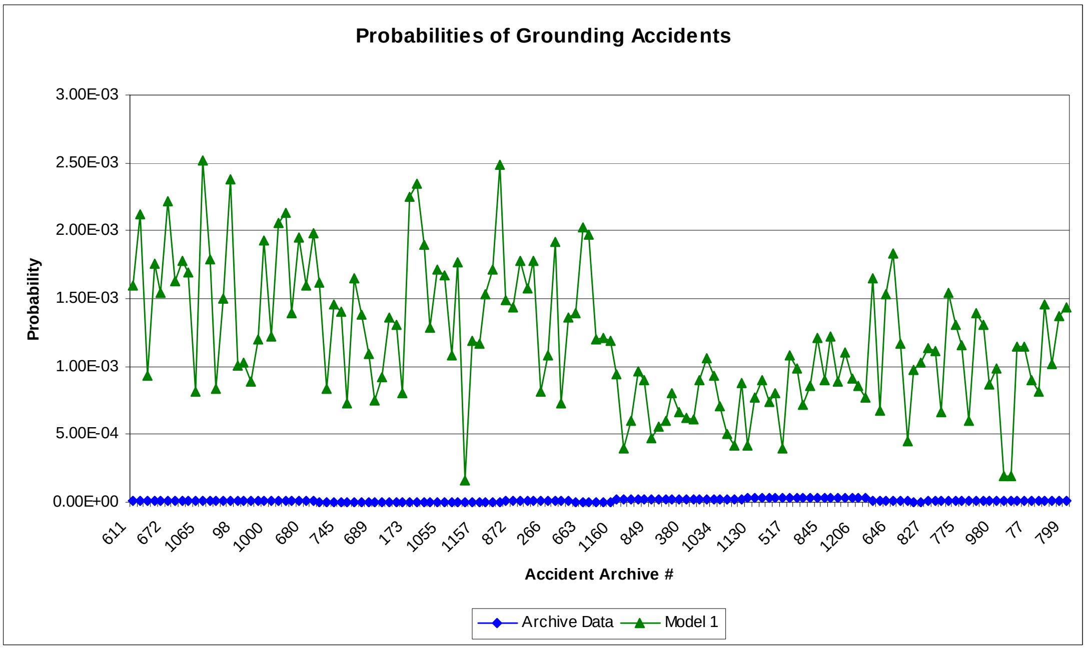


Figure I.4 Probabilities of Grounding Accidents (Model 1)

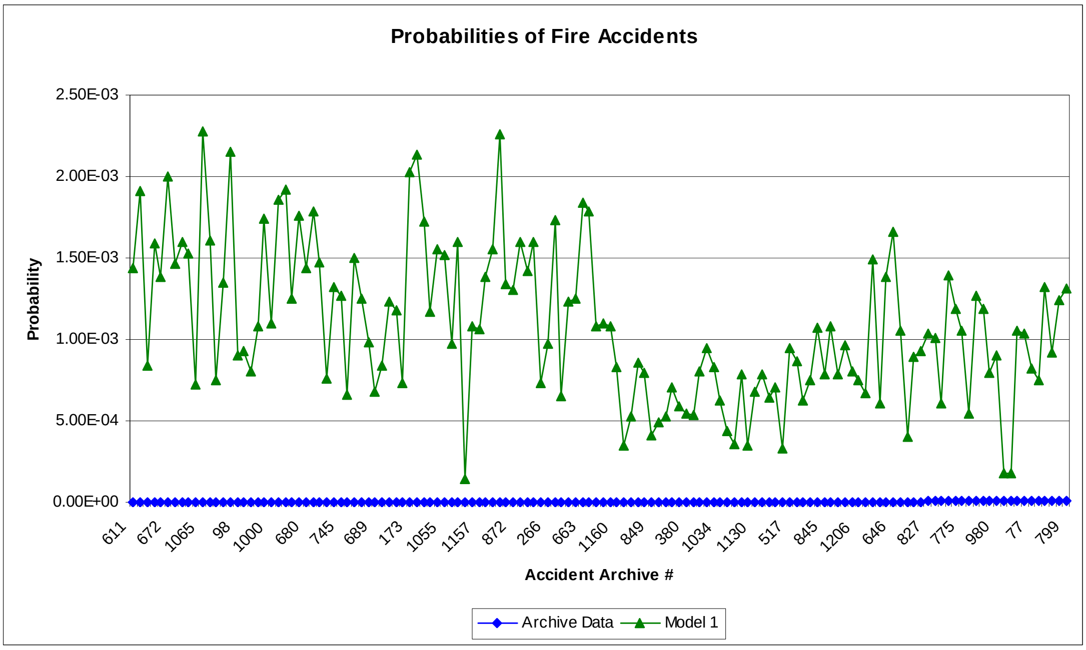


Figure I.5 Probabilities of Fire Accidents (Model 1)

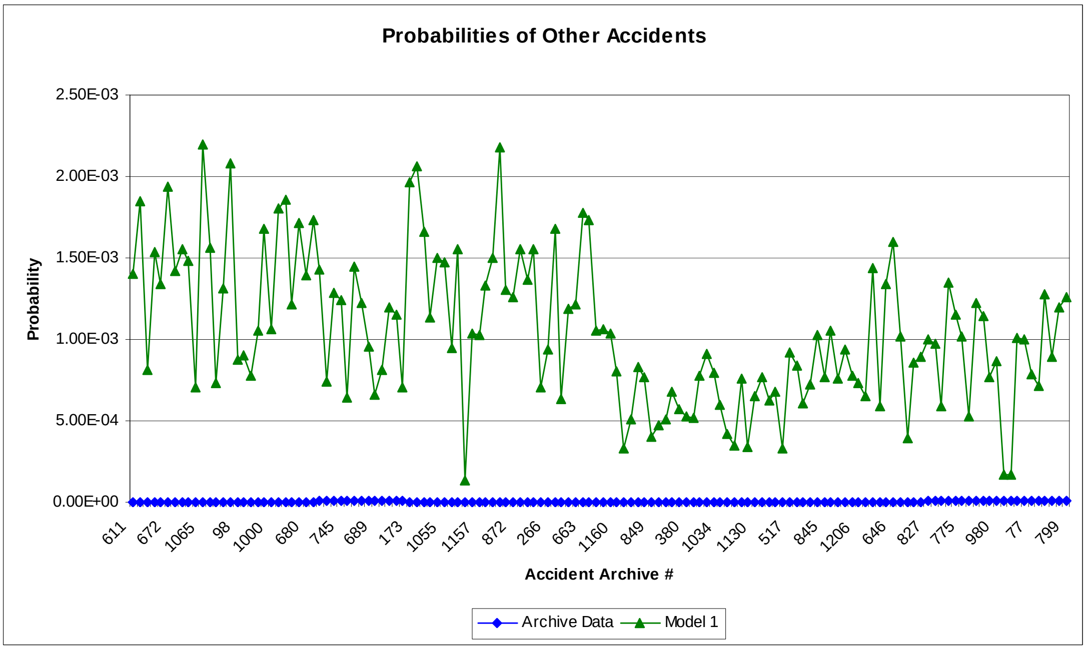


Figure I.6 Probabilities of Other Accidents (Model 1)

APPENDIX J

MACRISK RESULTS

The ANN model established six input parameters has been used to forecast the accident probabilities. All forecasted probabilities of ANN model can be seen in Table J.1 and between Figure J.1 and Figure J.6.

Table J.1 Forecasted probabilities of the Model 2

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Model 2	Archive Data	Model 2	Archive Data	Model 2
611	6.02E-05	5.65E-05	3.74E-05	3.84E-05	1.25E-05	8.78E-06
1334	6.02E-05	5.90E-05	3.74E-05	3.26E-05	1.25E-05	1.07E-05
332	6.02E-05	6.24E-05	3.74E-05	3.54E-05	1.25E-05	9.91E-06
462	6.02E-05	5.93E-05	3.74E-05	4.17E-05	1.25E-05	1.02E-05
633	6.02E-05	5.48E-05	3.74E-05	4.15E-05	1.25E-05	9.11E-06
672	6.02E-05	5.92E-05	3.74E-05	3.53E-05	1.25E-05	9.59E-06
690	6.02E-05	5.90E-05	3.74E-05	3.52E-05	1.25E-05	1.03E-05
718	6.02E-05	5.91E-05	3.74E-05	3.10E-05	1.25E-05	1.10E-05
977	6.02E-05	6.23E-05	3.74E-05	3.68E-05	1.25E-05	1.13E-05
999	6.02E-05	6.17E-05	3.74E-05	3.22E-05	1.25E-05	1.12E-05
1065	6.02E-05	5.45E-05	3.74E-05	2.60E-05	1.25E-05	9.52E-06
1152	6.02E-05	5.81E-05	3.74E-05	3.34E-05	1.25E-05	1.04E-05
1209	6.02E-05	5.69E-05	3.74E-05	2.87E-05	1.25E-05	7.84E-06
1244	6.02E-05	5.69E-05	3.74E-05	4.11E-05	1.25E-05	1.03E-05
1279	6.02E-05	5.82E-05	3.74E-05	3.04E-05	1.25E-05	9.88E-06
98	6.02E-05	6.33E-05	3.74E-05	3.78E-05	1.25E-05	1.08E-05
1232	6.02E-05	6.27E-05	3.74E-05	3.65E-05	1.25E-05	1.06E-05
609	6.02E-05	6.22E-05	3.74E-05	3.57E-05	1.25E-05	1.13E-05
529	6.02E-05	6.12E-05	3.74E-05	3.34E-05	1.25E-05	1.04E-05
698	6.02E-05	5.62E-05	3.74E-05	3.62E-05	1.25E-05	9.04E-06
1000	6.02E-05	5.48E-05	3.74E-05	4.16E-05	1.25E-05	1.11E-05
1204	6.02E-05	5.89E-05	3.74E-05	3.67E-05	1.25E-05	1.04E-05
1301	6.02E-05	6.04E-05	3.74E-05	3.53E-05	1.25E-05	1.02E-05

Table J.1 Forecasted probabilities of the Model 2 (cont'd)

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	Model 2	Archive Data	Model 2	Archive Data	Model 2
387	6.02E-05	6.25E-05	3.74E-05	3.69E-05	1.25E-05	1.09E-05
642	6.02E-05	6.16E-05	3.74E-05	3.37E-05	1.25E-05	1.08E-05
680	6.02E-05	6.15E-05	3.74E-05	3.67E-05	1.25E-05	1.13E-05
950	6.02E-05	6.11E-05	3.74E-05	3.71E-05	1.25E-05	1.04E-05
1170	2.49E-05	3.08E-05	1.45E-05	1.38E-05	2.08E-06	3.92E-06
527	2.49E-05	3.42E-05	1.45E-05	1.47E-05	2.08E-06	-6.01E-07
557	2.49E-05	3.08E-05	1.45E-05	1.27E-05	2.08E-06	3.37E-06
745	2.49E-05	3.05E-05	1.45E-05	1.36E-05	2.08E-06	3.12E-06
840	2.49E-05	2.51E-05	1.45E-05	1.01E-05	2.08E-06	2.21E-06
1070	2.49E-05	3.02E-05	1.45E-05	1.24E-05	2.08E-06	4.40E-06
1015	2.49E-05	2.79E-05	1.45E-05	1.43E-05	2.08E-06	3.90E-06
361	2.49E-05	3.00E-05	1.45E-05	9.66E-06	2.08E-06	2.62E-06
689	2.49E-05	2.65E-05	1.45E-05	9.71E-06	2.08E-06	2.25E-06
725	2.49E-05	2.69E-05	1.45E-05	1.08E-05	2.08E-06	4.08E-06
763	2.49E-05	2.91E-05	1.45E-05	1.20E-05	2.08E-06	3.76E-06
532	2.49E-05	3.01E-05	1.45E-05	1.15E-05	2.08E-06	2.93E-06
1190	2.49E-05	3.09E-05	1.45E-05	9.42E-06	2.08E-06	3.05E-06
173	6.23E-06	3.25E-05	4.15E-06	2.07E-05	0.00E+00	7.12E-06
945	6.23E-06	3.13E-05	4.15E-06	2.11E-05	0.00E+00	5.60E-06
1167	1.66E-05	1.45E-05	6.23E-06	5.39E-06	0.00E+00	2.00E-06
889	1.66E-05	1.40E-05	6.23E-06	1.09E-05	0.00E+00	6.09E-07
907	1.66E-05	1.79E-05	6.23E-06	5.33E-06	0.00E+00	1.41E-06
1055	1.66E-05	1.65E-05	6.23E-06	5.31E-06	0.00E+00	9.93E-07
1186	1.66E-05	1.85E-05	6.23E-06	1.15E-05	0.00E+00	3.38E-07
1268	1.66E-05	1.25E-05	6.23E-06	4.88E-06	0.00E+00	3.10E-06
1222	1.66E-05	1.78E-05	6.23E-06	5.75E-06	0.00E+00	4.74E-07
544	1.66E-05	1.80E-05	6.23E-06	-6.68E-07	0.00E+00	-1.34E-06
1157	1.66E-05	1.57E-05	6.23E-06	8.18E-06	0.00E+00	-3.71E-07
1059	1.66E-05	1.88E-05	6.23E-06	1.07E-06	0.00E+00	1.06E-06
851	4.15E-06	5.29E-06	2.08E-06	1.08E-05	0.00E+00	7.50E-06
790	4.15E-06	-8.78E-07	2.08E-06	3.36E-06	0.00E+00	6.29E-06
1125	2.08E-05	1.75E-05	1.25E-05	1.36E-05	4.15E-06	4.39E-06
872	2.08E-05	1.97E-05	1.25E-05	1.36E-05	4.15E-06	3.97E-06
925	2.08E-05	1.39E-05	1.25E-05	1.09E-05	4.15E-06	5.36E-06
1080	2.08E-05	1.55E-05	1.25E-05	1.57E-05	4.15E-06	6.62E-06
594	2.08E-05	1.78E-05	1.25E-05	1.50E-05	4.15E-06	6.19E-06
604	2.08E-05	2.53E-05	1.25E-05	1.62E-05	4.15E-06	3.15E-06
266	2.08E-05	1.65E-05	1.25E-05	1.22E-05	4.15E-06	4.43E-06

Table J.1 Forecasted probabilities of the Model 2 (cont'd)

Accident Number	Total Accidents		Collision Accidents		Capsizing Accidents	
	Archive Data	**Model 2**	**Archive Data**	**Model 2**	**Archive Data**	**Model 2**
801	2.08E-05	1.61E-05	1.25E-05	1.23E-05	4.15E-06	5.99E-06
1099	2.08E-05	1.71E-05	1.25E-05	1.03E-05	4.15E-06	3.81E-06
565	2.08E-05	1.42E-05	1.25E-05	1.44E-05	4.15E-06	5.74E-06
193	4.15E-06	3.16E-06	2.08E-06	9.27E-06	0.00E+00	3.83E-06
663	6.23E-06	7.89E-06	4.15E-06	6.42E-06	0.00E+00	7.24E-06
802	6.23E-06	7.19E-06	4.15E-06	7.30E-06	0.00E+00	7.14E-06
460	6.23E-06	2.51E-05	4.15E-06	1.08E-05	0.00E+00	4.37E-06
878	6.23E-06	3.46E-05	4.15E-06	1.09E-05	0.00E+00	4.28E-06
1138	6.23E-06	2.26E-05	4.15E-06	1.28E-05	0.00E+00	4.97E-06
1160	4.36E-05	4.04E-05	1.45E-05	9.73E-06	8.30E-06	4.88E-06
451	4.36E-05	3.28E-05	1.45E-05	1.40E-05	8.30E-06	-5.72E-06
701	4.36E-05	4.41E-05	1.45E-05	1.06E-05	8.30E-06	2.88E-06
769	4.36E-05	4.45E-05	1.45E-05	1.37E-05	8.30E-06	4.68E-06
824	4.36E-05	4.29E-05	1.45E-05	1.09E-05	8.30E-06	4.17E-06
849	4.36E-05	3.70E-05	1.45E-05	8.12E-06	8.30E-06	2.97E-06
996	4.36E-05	4.44E-05	1.45E-05	1.01E-05	8.30E-06	2.74E-06
1118	4.36E-05	4.54E-05	1.45E-05	1.66E-05	8.30E-06	2.32E-06
1151	4.36E-05	4.46E-05	1.45E-05	1.23E-05	8.30E-06	4.35E-06
203	4.36E-05	3.15E-05	1.45E-05	1.36E-05	8.30E-06	3.23E-06
380	4.36E-05	3.53E-05	1.45E-05	1.28E-05	8.30E-06	2.71E-06
625	4.36E-05	4.41E-05	1.45E-05	1.23E-05	8.30E-06	1.96E-06
934	4.36E-05	4.13E-05	1.45E-05	8.61E-06	8.30E-06	4.71E-06
940	4.36E-05	4.44E-05	1.45E-05	1.32E-05	8.30E-06	5.41E-06
981	4.36E-05	4.26E-05	1.45E-05	1.01E-05	8.30E-06	4.48E-06
1034	4.36E-05	4.31E-05	1.45E-05	1.10E-05	8.30E-06	3.88E-06
1208	4.36E-05	3.89E-05	1.45E-05	1.34E-05	8.30E-06	-6.87E-07
1240	4.36E-05	4.59E-05	1.45E-05	6.93E-06	8.30E-06	1.16E-06
1323	4.36E-05	4.05E-05	1.45E-05	1.07E-05	8.30E-06	4.18E-06
1104	3.11E-05	4.19E-05	0.00E+00	-1.83E-06	0.00E+00	8.28E-08
1130	3.11E-05	3.29E-05	0.00E+00	3.00E-06	0.00E+00	3.14E-06
1154	3.11E-05	3.47E-05	0.00E+00	4.49E-06	0.00E+00	4.77E-06
113	3.11E-05	2.59E-05	0.00E+00	7.29E-06	0.00E+00	6.23E-06
163	3.11E-05	2.97E-05	0.00E+00	4.69E-06	0.00E+00	3.09E-06
378	3.11E-05	2.68E-05	0.00E+00	4.22E-06	0.00E+00	1.53E-06
517	3.11E-05	3.54E-05	0.00E+00	6.29E-06	0.00E+00	4.72E-06
538	3.11E-05	3.01E-05	0.00E+00	4.10E-06	0.00E+00	4.29E-06
638	3.11E-05	3.22E-05	0.00E+00	3.60E-06	0.00E+00	4.64E-06
708	3.11E-05	3.35E-05	0.00E+00	4.85E-06	0.00E+00	5.09E-06

Table J.1 Forecasted probabilities of the Model 2 (cont'd)

Accident Number	**Total Accidents**		**Collision Accidents**		**Capsizing Accidents**	
	Archive Data	**Model 2**	**Archive Data**	**Model 2**	**Archive Data**	**Model 2**
783	3.11E-05	3.30E-05	0.00E+00	3.80E-06	0.00E+00	6.80E-06
845	3.11E-05	3.11E-05	0.00E+00	7.36E-06	0.00E+00	6.20E-06
1076	3.11E-05	3.23E-05	0.00E+00	3.91E-06	0.00E+00	6.76E-06
1148	3.11E-05	3.08E-05	0.00E+00	3.50E-06	0.00E+00	5.76E-06
1164	3.11E-05	3.31E-05	0.00E+00	3.67E-06	0.00E+00	6.13E-06
1195	3.11E-05	3.24E-05	0.00E+00	4.74E-06	0.00E+00	3.75E-06
1206	3.11E-05	3.40E-05	0.00E+00	4.27E-06	0.00E+00	3.57E-06
1233	3.11E-05	3.21E-05	0.00E+00	3.58E-06	0.00E+00	4.75E-06
768	1.04E-05	1.54E-05	0.00E+00	1.13E-05	0.00E+00	7.65E-06
842	1.04E-05	2.04E-05	0.00E+00	6.31E-06	0.00E+00	7.63E-06
600	1.04E-05	1.67E-05	0.00E+00	1.28E-05	0.00E+00	7.65E-06
646	1.04E-05	1.52E-05	0.00E+00	1.31E-05	0.00E+00	8.05E-06
504	1.04E-05	1.99E-05	0.00E+00	8.18E-06	0.00E+00	7.34E-06
221	1.04E-05	3.49E-05	0.00E+00	4.00E-06	0.00E+00	8.13E-06
965	4.15E-06	1.85E-05	0.00E+00	9.26E-06	0.00E+00	7.21E-06
628	4.15E-06	1.95E-05	0.00E+00	7.06E-06	0.00E+00	6.81E-06
827	4.77E-05	4.83E-05	1.25E-05	1.01E-05	1.25E-05	8.21E-06
970	4.77E-05	4.64E-05	1.25E-05	9.79E-06	1.25E-05	8.39E-06
1020	4.77E-05	4.96E-05	1.25E-05	9.42E-06	1.25E-05	5.74E-06
1051	4.77E-05	4.76E-05	1.25E-05	1.25E-05	1.25E-05	1.03E-05
620	4.77E-05	4.60E-05	1.25E-05	9.92E-06	1.25E-05	9.70E-06
775	4.77E-05	4.79E-05	1.25E-05	1.15E-05	1.25E-05	8.01E-06
834	4.77E-05	4.57E-05	1.25E-05	2.17E-05	1.25E-05	7.81E-06
1083	4.77E-05	4.59E-05	1.25E-05	1.05E-05	1.25E-05	9.54E-06
1337	4.77E-05	4.80E-05	1.25E-05	1.14E-05	1.25E-05	9.05E-06
1207	4.77E-05	4.82E-05	1.25E-05	1.14E-05	1.25E-05	7.91E-06
980	4.77E-05	4.87E-05	1.25E-05	9.45E-06	1.25E-05	7.25E-06
1216	4.77E-05	5.20E-05	1.25E-05	1.41E-05	1.25E-05	1.08E-05
1218	4.77E-05	5.23E-05	1.25E-05	1.31E-05	1.25E-05	1.08E-05
978	4.77E-05	4.77E-05	1.25E-05	1.01E-05	1.25E-05	8.14E-06
1117	4.77E-05	4.62E-05	1.25E-05	1.10E-05	1.25E-05	8.55E-06
77	4.77E-05	5.73E-05	1.25E-05	7.45E-06	1.25E-05	9.31E-06
715	4.77E-05	5.05E-05	1.25E-05	3.65E-06	1.25E-05	9.18E-06
647	4.77E-05	4.86E-05	1.25E-05	1.34E-05	1.25E-05	8.93E-06
676	4.77E-05	4.63E-05	1.25E-05	6.70E-06	1.25E-05	8.37E-06
722	4.77E-05	4.62E-05	1.25E-05	1.13E-05	1.25E-05	9.17E-06
799	4.77E-05	4.77E-05	1.25E-05	1.49E-05	1.25E-05	8.89E-06

Table J.1 Forecasted probabilities of the Model 2 (cont'd)

Accident Number	Grounding Accidents		Fire Accidents		Other Accidents	
	Archive Data	**Model 2**	**Archive Data**	**Model 2**	**Archive Data**	**Model 2**
611	1.04E-05	8.68E-06	2.08E-06	2.12E-07	4.15E-06	-1.87E-06
1334	1.04E-05	8.11E-06	2.08E-06	2.02E-06	4.15E-06	1.48E-06
332	1.04E-05	4.33E-06	2.08E-06	2.40E-06	4.15E-06	8.45E-08
462	1.04E-05	1.06E-05	2.08E-06	3.64E-06	4.15E-06	2.61E-06
633	1.04E-05	9.74E-06	2.08E-06	9.33E-07	4.15E-06	-9.17E-07
672	1.04E-05	1.06E-05	2.08E-06	2.86E-06	4.15E-06	2.92E-06
690	1.04E-05	6.59E-06	2.08E-06	5.37E-07	4.15E-06	-1.27E-06
718	1.04E-05	6.60E-06	2.08E-06	1.53E-06	4.15E-06	1.08E-06
977	1.04E-05	7.29E-06	2.08E-06	2.34E-06	4.15E-06	2.40E-06
999	1.04E-05	5.81E-06	2.08E-06	4.29E-06	4.15E-06	1.92E-06
1065	1.04E-05	1.01E-05	2.08E-06	2.39E-06	4.15E-06	1.78E-06
1152	1.04E-05	6.90E-06	2.08E-06	9.02E-07	4.15E-06	-7.73E-07
1209	1.04E-05	3.68E-06	2.08E-06	2.18E-06	4.15E-06	1.58E-06
1244	1.04E-05	9.01E-06	2.08E-06	1.86E-06	4.15E-06	-1.04E-07
1279	1.04E-05	9.68E-06	2.08E-06	2.40E-06	4.15E-06	2.65E-06
98	1.04E-05	3.97E-06	2.08E-06	4.85E-07	4.15E-06	-1.54E-06
1232	1.04E-05	4.98E-06	2.08E-06	2.27E-06	4.15E-06	-2.20E-08
609	1.04E-05	5.79E-06	2.08E-06	3.10E-06	4.15E-06	3.64E-07
529	1.04E-05	5.84E-06	2.08E-06	1.71E-06	4.15E-06	2.97E-06
698	1.04E-05	8.81E-06	2.08E-06	8.98E-07	4.15E-06	-1.13E-06
1000	1.04E-05	1.03E-05	2.08E-06	3.68E-06	4.15E-06	1.49E-06
1204	1.04E-05	8.75E-06	2.08E-06	2.32E-06	4.15E-06	1.29E-06
1301	1.04E-05	9.52E-06	2.08E-06	2.56E-06	4.15E-06	2.86E-06
387	1.04E-05	7.07E-06	2.08E-06	2.36E-06	4.15E-06	3.05E-06
642	1.04E-05	7.99E-06	2.08E-06	1.97E-06	4.15E-06	2.90E-06
680	1.04E-05	6.63E-06	2.08E-06	2.11E-06	4.15E-06	9.94E-07
950	1.04E-05	9.30E-06	2.08E-06	2.67E-06	4.15E-06	2.85E-06
1170	0.00E+00	1.07E-05	2.08E-06	-1.60E-06	6.23E-06	-7.56E-06
527	0.00E+00	1.32E-05	2.08E-06	-1.24E-06	6.23E-06	-8.13E-06
557	0.00E+00	9.73E-06	2.08E-06	-5.10E-07	6.23E-06	-7.81E-06
745	0.00E+00	9.13E-06	2.08E-06	-1.50E-06	6.23E-06	-8.12E-06
840	0.00E+00	7.45E-06	2.08E-06	-2.83E-07	6.23E-06	-7.43E-06
1070	0.00E+00	1.12E-05	2.08E-06	-7.24E-07	6.23E-06	-7.30E-06
1015	0.00E+00	9.90E-06	2.08E-06	2.87E-07	6.23E-06	-6.75E-06
361	0.00E+00	9.52E-06	2.08E-06	1.10E-06	6.23E-06	-5.51E-06
689	0.00E+00	7.44E-06	2.08E-06	-1.07E-08	6.23E-06	-7.10E-06
725	0.00E+00	8.39E-06	2.08E-06	5.15E-07	6.23E-06	-3.90E-06
763	0.00E+00	9.66E-06	2.08E-06	7.85E-07	6.23E-06	-6.60E-06

Table J.1 Forecasted probabilities of the Model 2 (cont'd)

Accident Number	**Grounding Accidents**		**Fire Accidents**		**Other Accidents**	
	Archive Data	**Model 2**	**Archive Data**	**Model 2**	**Archive Data**	**Model 2**
532	0.00E+00	9.82E-06	2.08E-06	2.65E-07	6.23E-06	-7.44E-06
1190	0.00E+00	8.01E-06	2.08E-06	4.29E-07	6.23E-06	-2.70E-06
173	0.00E+00	5.35E-06	0.00E+00	4.81E-06	2.08E-06	-2.78E-08
945	0.00E+00	5.04E-06	0.00E+00	4.77E-06	2.08E-06	-1.54E-06
1167	4.15E-06	6.41E-06	4.15E-06	3.56E-06	2.08E-06	-6.42E-06
889	4.15E-06	5.21E-06	4.15E-06	1.24E-06	2.08E-06	-6.33E-06
907	4.15E-06	6.65E-06	4.15E-06	3.79E-06	2.08E-06	-4.74E-06
1055	4.15E-06	6.84E-06	4.15E-06	3.12E-06	2.08E-06	-5.86E-06
1186	4.15E-06	4.93E-06	4.15E-06	5.98E-07	2.08E-06	-3.23E-06
1268	4.15E-06	7.23E-06	4.15E-06	2.35E-06	2.08E-06	-6.77E-06
1222	4.15E-06	1.15E-05	4.15E-06	1.92E-06	2.08E-06	-6.94E-06
544	4.15E-06	1.07E-05	4.15E-06	2.80E-06	2.08E-06	-5.20E-06
1157	4.15E-06	7.52E-06	4.15E-06	1.35E-06	2.08E-06	-6.43E-06
1059	4.15E-06	1.24E-05	4.15E-06	3.71E-06	2.08E-06	-6.58E-06
851	0.00E+00	2.08E-06	2.08E-06	6.52E-06	0.00E+00	-1.64E-06
790	0.00E+00	3.59E-06	2.08E-06	6.43E-06	0.00E+00	-2.34E-06
1125	6.23E-06	4.61E-06	0.00E+00	4.15E-06	0.00E+00	-4.56E-06
872	6.23E-06	4.35E-06	0.00E+00	4.09E-06	0.00E+00	-5.36E-06
925	6.23E-06	5.42E-06	0.00E+00	4.19E-06	0.00E+00	-4.01E-06
1080	6.23E-06	5.44E-06	0.00E+00	4.61E-06	0.00E+00	-9.44E-07
594	6.23E-06	5.59E-06	0.00E+00	5.26E-06	0.00E+00	-2.22E-06
604	6.23E-06	3.64E-06	0.00E+00	3.47E-06	0.00E+00	-5.87E-06
266	6.23E-06	5.04E-06	0.00E+00	2.28E-06	0.00E+00	-6.49E-06
801	6.23E-06	5.52E-06	0.00E+00	5.08E-06	0.00E+00	-3.10E-06
1099	6.23E-06	5.19E-06	0.00E+00	3.85E-06	0.00E+00	-6.63E-06
565	6.23E-06	5.01E-06	0.00E+00	3.81E-06	0.00E+00	-1.78E-06
193	2.08E-06	5.50E-06	0.00E+00	6.14E-06	0.00E+00	-6.76E-06
663	2.08E-06	2.62E-06	0.00E+00	8.05E-06	0.00E+00	-2.06E-06
802	2.08E-06	2.50E-06	0.00E+00	8.26E-06	0.00E+00	-1.97E-06
460	2.08E-06	8.30E-06	0.00E+00	2.75E-06	0.00E+00	-8.53E-06
878	2.08E-06	5.93E-06	0.00E+00	2.00E-06	0.00E+00	-8.51E-06
1138	2.08E-06	6.77E-06	0.00E+00	2.96E-06	0.00E+00	-6.35E-06
1160	2.08E-05	2.24E-05	2.08E-06	1.49E-07	0.00E+00	-8.47E-06
451	2.08E-05	2.16E-05	2.08E-06	9.71E-06	0.00E+00	-9.19E-06
701	2.08E-05	1.57E-05	2.08E-06	2.24E-06	0.00E+00	-1.05E-05
769	2.08E-05	2.25E-05	2.08E-06	5.96E-07	0.00E+00	-9.15E-06
824	2.08E-05	2.16E-05	2.08E-06	6.90E-07	0.00E+00	-9.20E-06
849	2.08E-05	1.65E-05	2.08E-06	1.15E-07	0.00E+00	-1.03E-05

Table J.1 Forecasted probabilities of the Model 2 (cont'd)

Accident Number	Grounding Accidents		Fire Accidents		Other Accidents	
	Archive Data	Model 2	Archive Data	Model 2	Archive Data	Model 2
996	2.08E-05	1.49E-05	2.08E-06	2.70E-06	0.00E+00	-1.06E-05
1118	2.08E-05	1.96E-05	2.08E-06	4.30E-06	0.00E+00	-9.79E-06
1151	2.08E-05	1.85E-05	2.08E-06	3.88E-07	0.00E+00	-1.01E-05
203	2.08E-05	2.23E-05	2.08E-06	1.85E-06	0.00E+00	-7.44E-06
380	2.08E-05	2.03E-05	2.08E-06	2.06E-06	0.00E+00	-8.52E-06
625	2.08E-05	1.70E-05	2.08E-06	3.72E-06	0.00E+00	-1.01E-05
934	2.08E-05	2.15E-05	2.08E-06	-7.66E-07	0.00E+00	-8.96E-06
940	2.08E-05	2.20E-05	2.08E-06	-1.16E-06	0.00E+00	-9.23E-06
981	2.08E-05	2.19E-05	2.08E-06	1.77E-07	0.00E+00	-9.03E-06
1034	2.08E-05	1.72E-05	2.08E-06	4.97E-07	0.00E+00	-1.04E-05
1208	2.08E-05	1.76E-05	2.08E-06	5.83E-06	0.00E+00	-9.70E-06
1240	2.08E-05	1.42E-05	2.08E-06	5.17E-06	0.00E+00	-1.06E-05
1323	2.08E-05	2.21E-05	2.08E-06	1.03E-06	0.00E+00	-8.76E-06
1104	2.91E-05	2.12E-05	0.00E+00	8.19E-06	2.08E-06	-5.39E-06
1130	2.91E-05	2.86E-05	0.00E+00	1.92E-06	2.08E-06	-5.20E-06
1154	2.91E-05	2.86E-05	0.00E+00	8.09E-08	2.08E-06	-5.23E-06
113	2.91E-05	2.63E-05	0.00E+00	-1.91E-07	2.08E-06	-5.78E-06
163	2.91E-05	2.96E-05	0.00E+00	2.20E-06	2.08E-06	-4.57E-06
378	2.91E-05	2.73E-05	0.00E+00	4.33E-06	2.08E-06	-4.27E-06
517	2.91E-05	3.01E-05	0.00E+00	-3.12E-07	2.08E-06	-4.14E-06
538	2.91E-05	2.97E-05	0.00E+00	3.28E-07	2.08E-06	-4.30E-06
638	2.91E-05	2.69E-05	0.00E+00	1.10E-06	2.08E-06	-5.86E-06
708	2.91E-05	2.80E-05	0.00E+00	-1.04E-08	2.08E-06	-5.48E-06
783	2.91E-05	2.73E-05	0.00E+00	-1.85E-06	2.08E-06	-4.20E-06
845	2.91E-05	2.73E-05	0.00E+00	-9.55E-07	2.08E-06	-5.29E-06
1076	2.91E-05	2.72E-05	0.00E+00	-1.81E-06	2.08E-06	-4.10E-06
1148	2.91E-05	2.79E-05	0.00E+00	-8.99E-07	2.08E-06	-5.42E-06
1164	2.91E-05	2.82E-05	0.00E+00	-1.35E-06	2.08E-06	-4.56E-06
1195	2.91E-05	2.96E-05	0.00E+00	1.14E-06	2.08E-06	-4.66E-06
1206	2.91E-05	2.90E-05	0.00E+00	1.35E-06	2.08E-06	-5.00E-06
1233	2.91E-05	2.75E-05	0.00E+00	5.37E-07	2.08E-06	-5.78E-06
768	6.23E-06	1.14E-05	0.00E+00	4.53E-06	4.15E-06	-7.39E-07
842	6.23E-06	6.66E-06	0.00E+00	3.55E-06	4.15E-06	-1.64E-06
600	6.23E-06	1.28E-05	0.00E+00	5.38E-06	4.15E-06	3.39E-07
646	6.23E-06	1.28E-05	0.00E+00	4.51E-06	4.15E-06	-4.51E-07
504	6.23E-06	9.84E-06	0.00E+00	4.27E-06	4.15E-06	-1.80E-06
221	6.23E-06	9.08E-06	0.00E+00	3.91E-06	4.15E-06	1.05E-06
965	2.08E-06	8.28E-06	2.08E-06	5.80E-06	0.00E+00	-1.94E-06

Table J.1 Forecasted probabilities of the Model 2 (cont'd)

Accident Number	Grounding Accidents		Fire Accidents		Other Accidents	
	Archive Data	Model 2	Archive Data	Model 2	Archive Data	Model 2
628	2.08E-06	8.76E-06	2.08E-06	5.90E-06	0.00E+00	-3.15E-06
827	6.23E-06	8.58E-06	1.04E-05	7.41E-06	6.23E-06	-6.90E-07
970	6.23E-06	8.49E-06	1.04E-05	8.25E-06	6.23E-06	-1.02E-06
1020	6.23E-06	1.06E-05	1.04E-05	7.91E-06	6.23E-06	-4.97E-07
1051	6.23E-06	8.47E-06	1.04E-05	5.68E-06	6.23E-06	-4.06E-07
620	6.23E-06	9.90E-06	1.04E-05	8.96E-06	6.23E-06	-1.31E-06
775	6.23E-06	8.26E-06	1.04E-05	7.70E-06	6.23E-06	-6.68E-07
834	6.23E-06	9.78E-06	1.04E-05	6.65E-06	6.23E-06	5.93E-07
1083	6.23E-06	8.67E-06	1.04E-05	8.01E-06	6.23E-06	-1.02E-06
1337	6.23E-06	8.21E-06	1.04E-05	6.75E-06	6.23E-06	-4.95E-07
1207	6.23E-06	9.36E-06	1.04E-05	7.24E-06	6.23E-06	4.64E-08
980	6.23E-06	9.08E-06	1.04E-05	7.85E-06	6.23E-06	-8.54E-07
1216	6.23E-06	9.67E-06	1.04E-05	1.25E-05	6.23E-06	-2.16E-07
1218	6.23E-06	9.68E-06	1.04E-05	1.22E-05	6.23E-06	-1.08E-07
978	6.23E-06	8.40E-06	1.04E-05	7.83E-06	6.23E-06	-8.95E-07
1117	6.23E-06	8.62E-06	1.04E-05	8.24E-06	6.23E-06	-8.06E-07
77	6.23E-06	7.99E-06	1.04E-05	6.89E-06	6.23E-06	-2.53E-06
715	6.23E-06	8.00E-06	1.04E-05	7.95E-06	6.23E-06	-2.28E-06
647	6.23E-06	8.17E-06	1.04E-05	6.65E-06	6.23E-06	-2.49E-07
676	6.23E-06	8.78E-06	1.04E-05	8.53E-06	6.23E-06	-1.44E-06
722	6.23E-06	8.64E-06	1.04E-05	8.06E-06	6.23E-06	-9.05E-07
799	6.23E-06	8.73E-06	1.04E-05	7.40E-06	6.23E-06	-2.04E-07

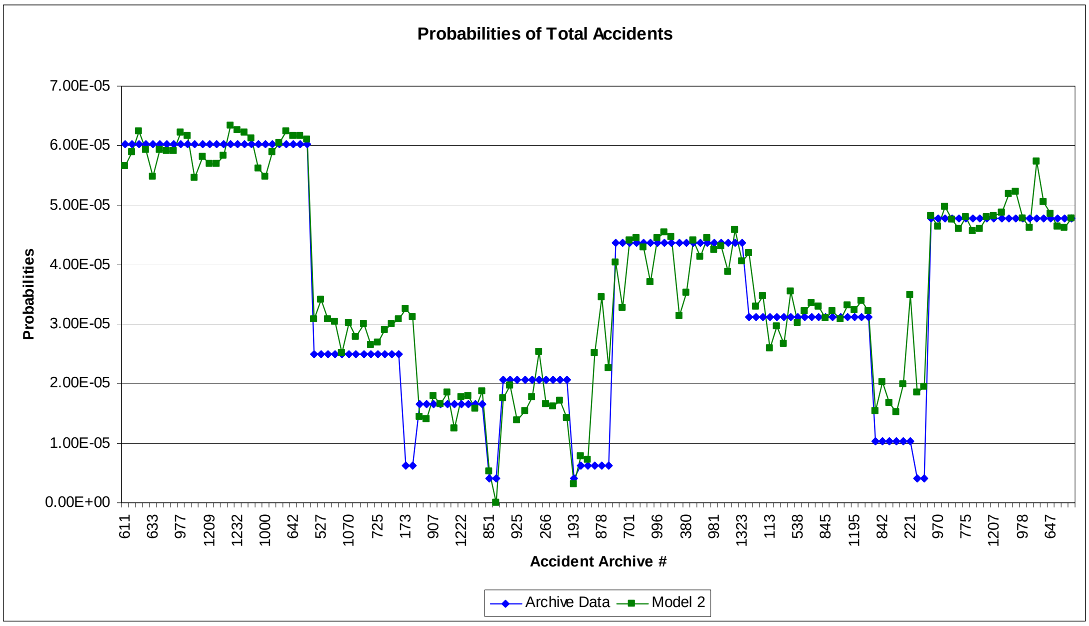


Figure J.1 Probabilities of Total Accidents (MAcRisk)

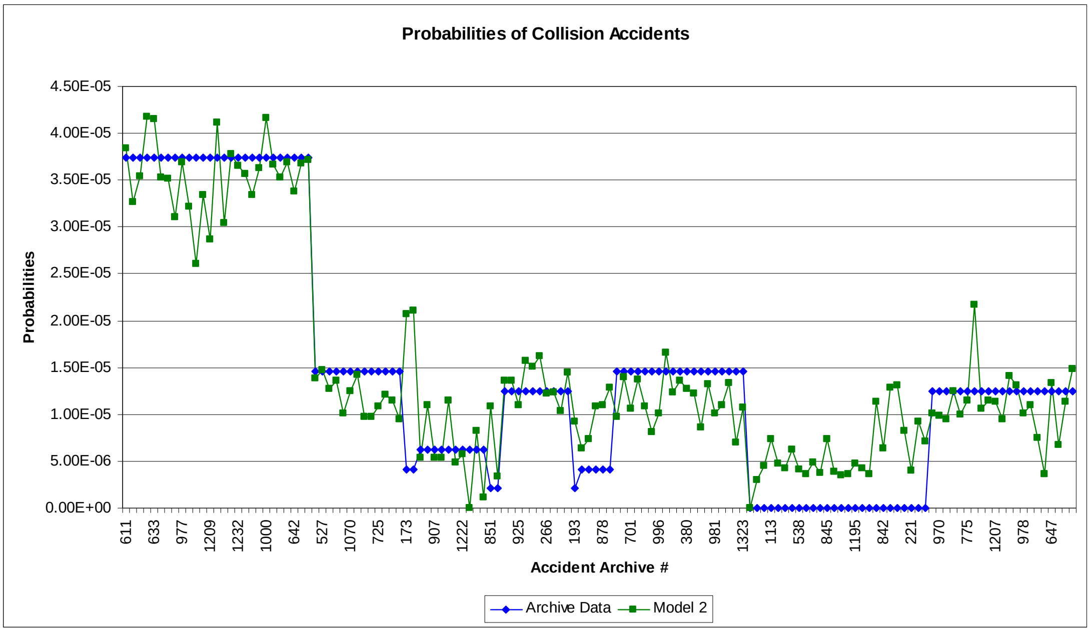


Figure J.2 Probabilities of Collision Accidents (MAcRisk)

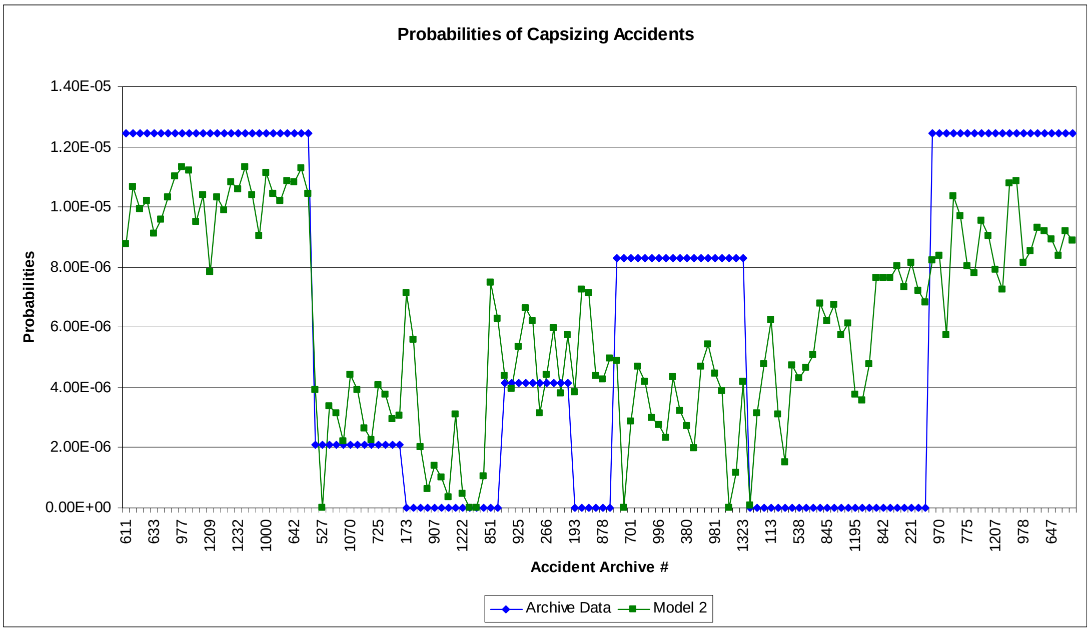


Figure J.3 Probabilities of Capsizing Accidents (MAcRisk)

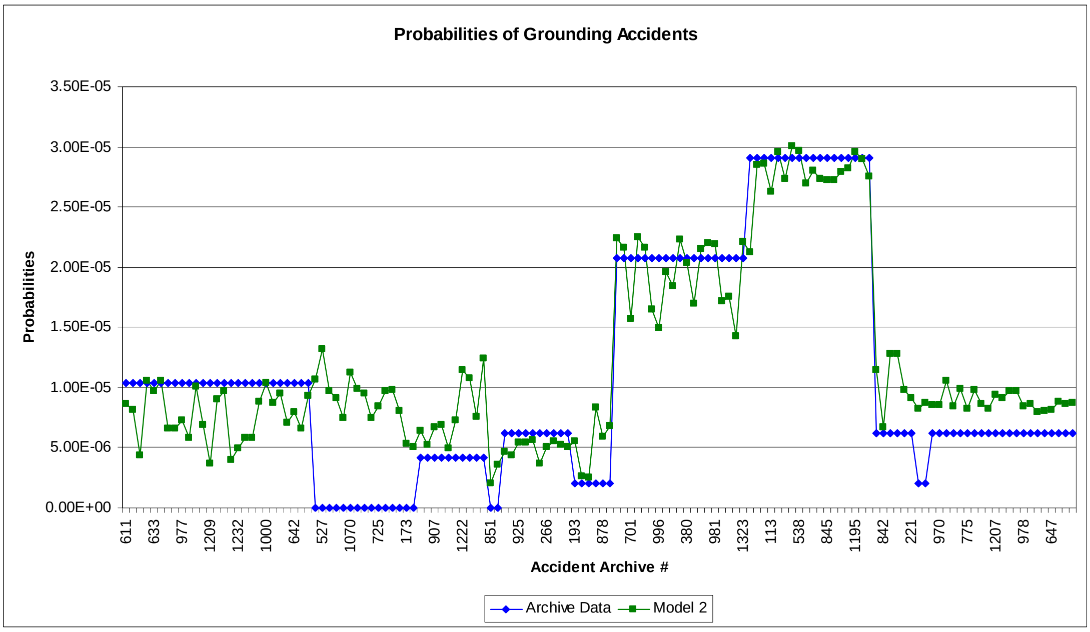


Figure J.4 Probabilities of Grounding Accidents (MAcRisk)

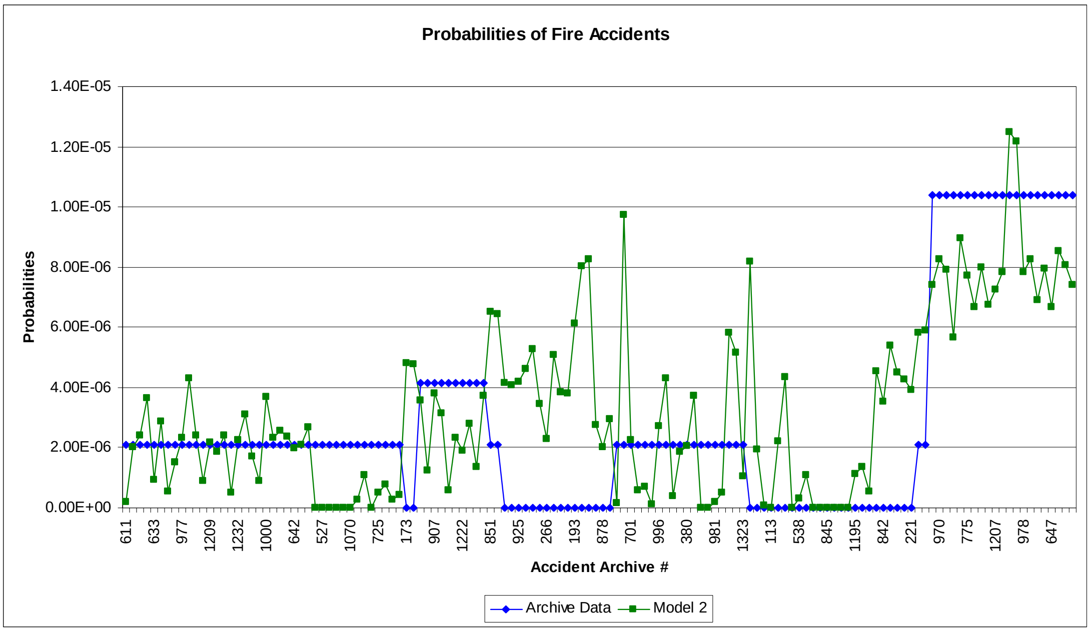


Figure J.5 Probabilities of Fire Accidents (MAcRisk)

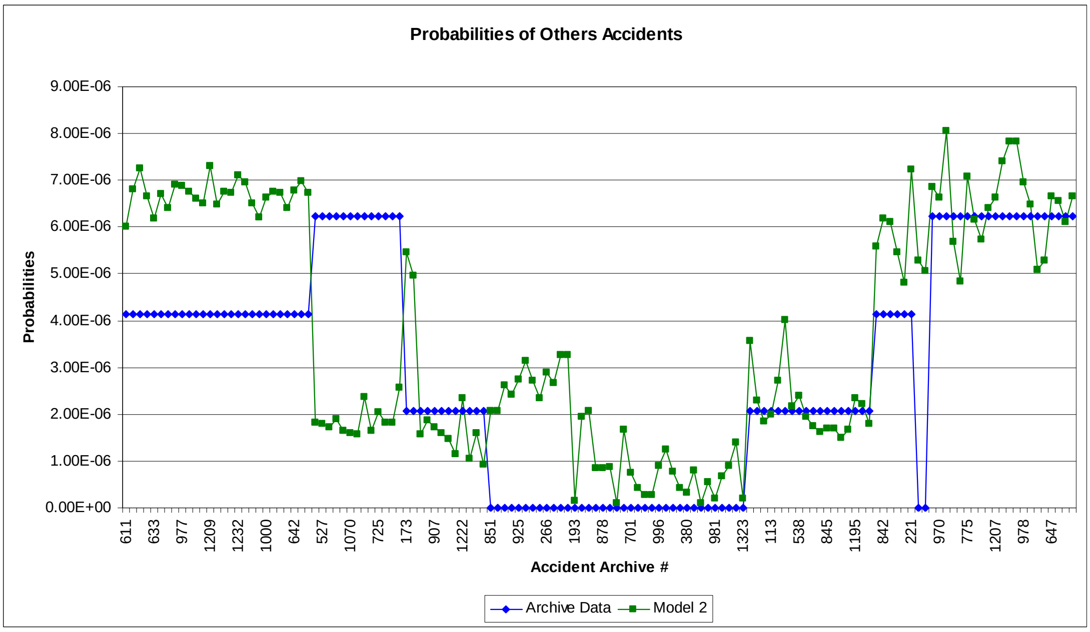


Figure J.6 Probabilities of Others Accidents (MAcRisk)

APPENDIX K

SEASONAL CURRENT VELOCITIES

Seasonal current velocities for Bosphorus has been measured by Office of Navigation, Hydrography and Oceanography (ONHO) and presented in year 2009.

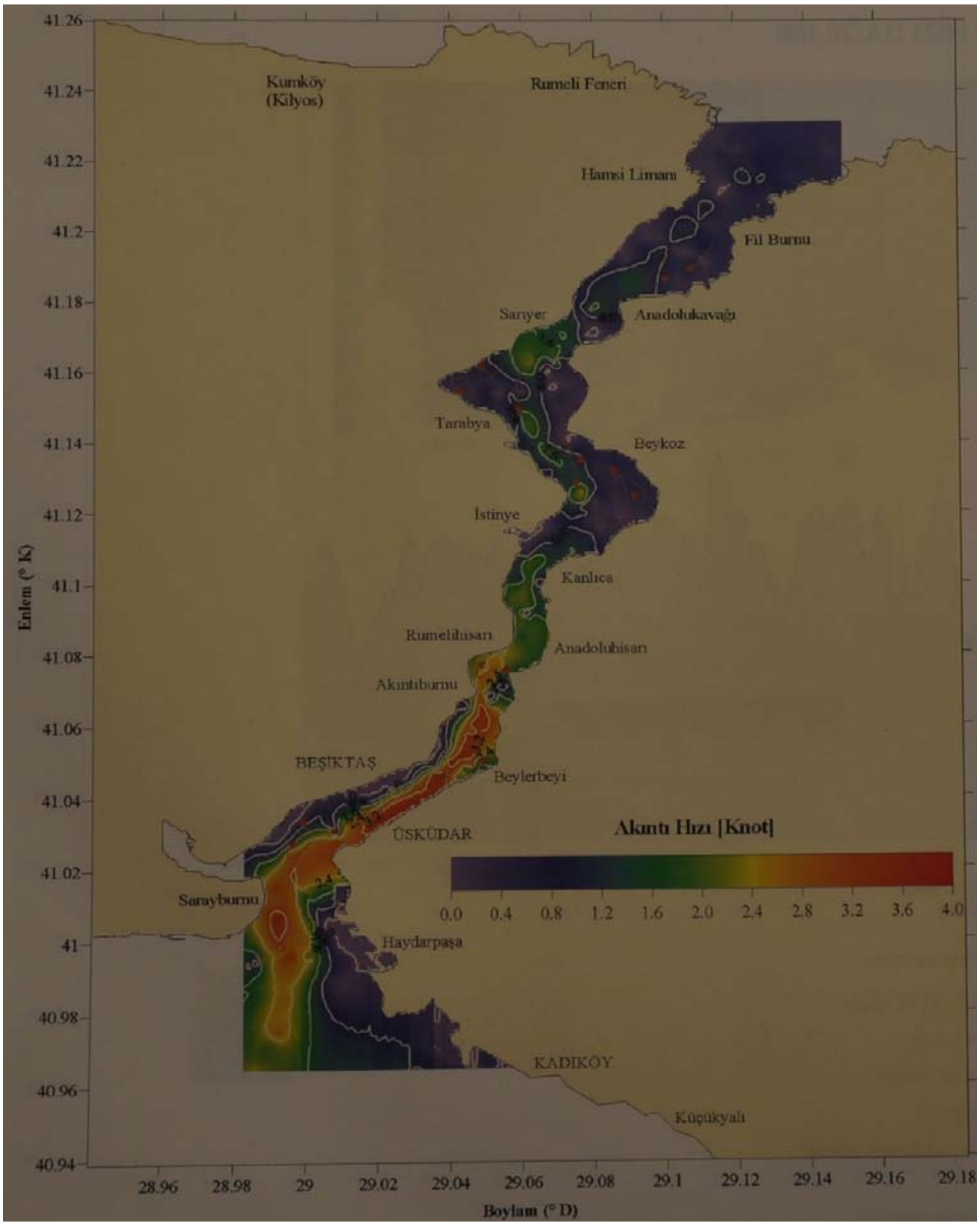


Figure K.1 Surface current velocities of Bosphorus (06/02/2008) (ONHO, 2009)

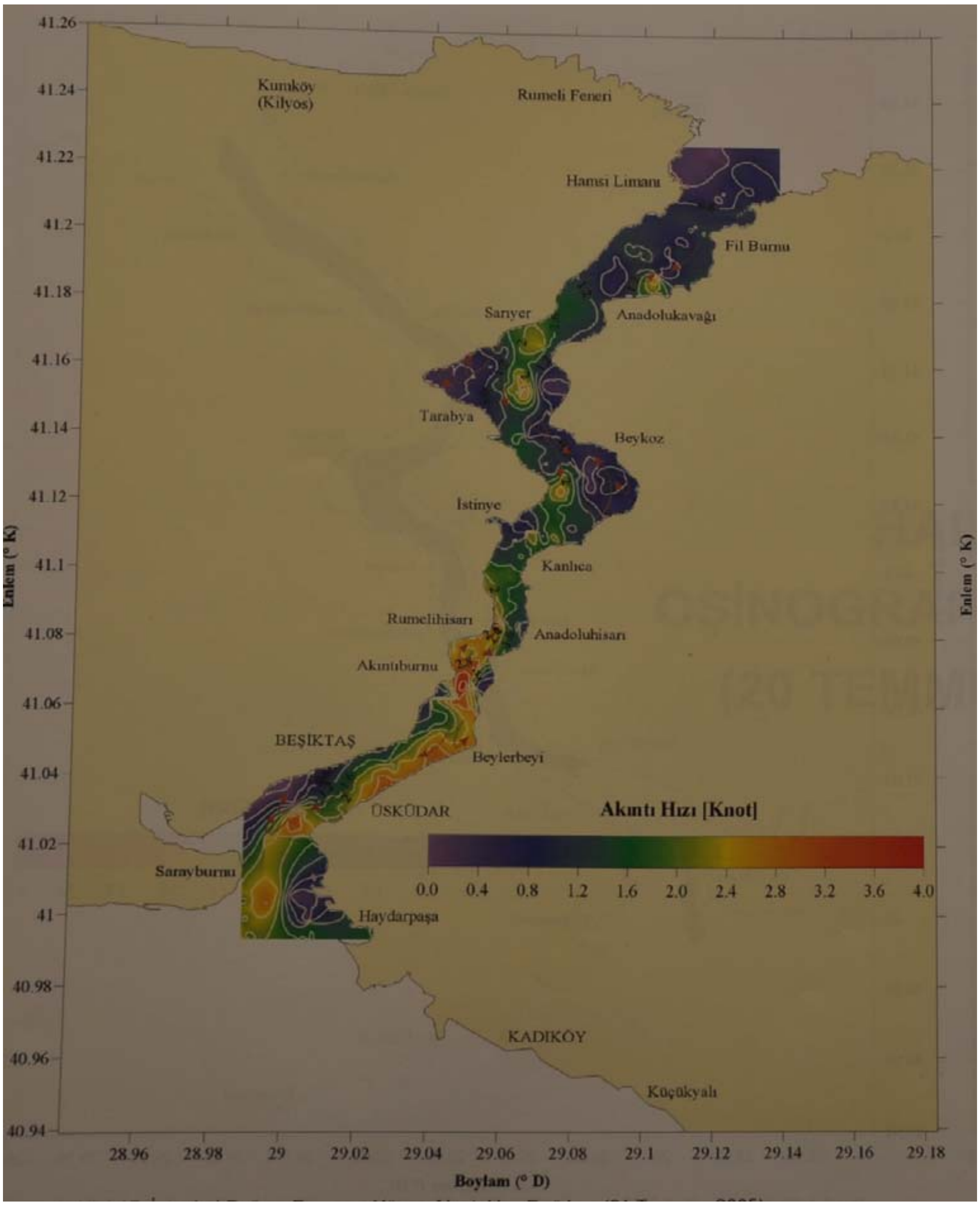


Figure K.2 Surface current velocities of Bosphorus (07/21/2008) (ONHO, 2009)

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2009 - Present	Ministry of Transportation, Maritime Affairs and Communications General Directorate of Railways, Ports and Airports Construction Research Department Hydraulic Laboratory Division	Civil Engineer
2007 - 2009	Gazi University Institute Science and Technology Environmental and Technical Research of Accidents Department	Research Assistant
2005	Military Service	Soldier
2003 - 2005	Gazi University Faculty of Engineering and Architecture Civil Engineering Department	Research Assistant
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FOREIGN LANGUAGES

English, German

PUBLICATIONS

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8. Küçükosmanoğlu Alp, Özbahçeci Berguzar Öztunalı ve Bilyay Engin, “Dalgakıranların Koruma Tabakasında, Tek Sıra Antifer ve Küp Blok Kullanılması”, Türkiye’nin Kıyı ve Deniz Alanları VIII. Ulusal Konferansı, 27 Nisan-1 Mayıs 2010, Trabzon, Cilt 3, Sayfa 1297-1304.
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HOBBIES

Music, Computer.