THE RISK ASSESSMENT AND MANAGEMENT OF THE ISTANBUL STRAIT

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ABSTRACT

THE RISK ASSESSMENT AND MANAGEMENT OF THE ISTANBUL STRAIT

There are more than 260 straits in the world. But none of them even remotely resembles the Turkish Straits in terms of the geography and other factors as they are considered as one of the most strategic waterways of the world. The Turkish Straits comprising of the Istanbul Strait and the Çanakkale Strait, are the second highest congested international waterways (second only to the Malacca Strait), since they constitute the only waterway between the Black Sea and the Mediterranean Sea. Along with the sharp rise in the number of oil tankers and the amount of oil they carry, especially after the 1990's, the increasing maritime traffic in the Turkish Straits brings about a continuously growing risk of a large-scale accident in the Straits leading to huge environmental and material damage, as well as loss of human life. Earlier unfortunate examples show that such risk may turn into a nightmare at any time, unless the necessary measures are taken to ensure safety of navigation in the Straits. Potential maritime accidents, which impose serious risks on the nearby population, environment and property, as well as cultural and historical treasures of Istanbul, are the subject of this study. The objective is to measure the risk associated with the various environmental, physical and technical conditions related with the "potential accidents" in the Strait, based on the past accident and transit traffic data, along with the subjective expert evaluations of the accidents' consequences. In this context, the key factor is the likelihood of an accident, along with the consequences of this potential accident in the Strait. In this regard, the Istanbul Strait Risk Model consisting of three sub-models, namely econometric, probabilistic consequence and analytic hierarchy process (AHP) models, has been developed. In the framework of the development of the econometric model, logistic regression techniques are used based on the past accident statistics of 1995-2004, along with the year 2005 accident free transit data. This model is extensively used for testing the effects of the factors such as visibility, precipitation, wind speed, pilot utilization, local traffic and vessel characteristics, which may affect the accident probability in the Strait along with the scenario analysis. In the second part of the study, based on the experts' views, the realization of various consequences after an accident occurrence is estimated. This model also demonstrates the effects of factors, such as vessel type and its cargo status, vessel length and accident location, over the realization of any consequence. Finally the AHP model is deployed to present the effects of other factors that are not considered in the first and second phase models. The results of this study identify and, to a large degree, quantify the risks and their sources regarding the maritime traffic in the Strait. As such, it can be said that the obtained results can also be deployed in selecting and guiding the measure to be taken regarding the mitigation of these risks; and thus enhance the maritime safety in the Strait. Nevertheless, there is still room to improve the safety and to reduce the maritime risk stemming from the maritime accidents in the Istanbul Strait.

ÖZET

İSTANBUL BOĞAZI'NIN RİSK DEĞERLENDİRMESİ VE YÖNETİMİ

Dünyada 260'dan fazla boğaz bulunmaktadır. Fakat bu boğazların hiçbirisi dünyanın en stratejik su yollarından birisi olarak kabul edilen Türk Boğazlarına coğrafik veya diğer faktörler açısından azıcık dahi olsa benzerlik göstermemektedir. İstanbul ve Çanakkale Boğazlarından meydan gelen Türk Boğazları, Karadeniz ile Akdeniz'i birleştiren yegane su yoluna sahip olması dolayısıyla, dünyanın ikinci (Malaga Boğazı'ndan sonra) en yoğun uluslararası su yoludur. Özellikle 1990'lardan sonra tanker sayısında ve taşınan petrol miktarında meydana gelen keskin yükselişle birlikte Türk Boğazları'ndaki deniz trafiğindeki artış, büyük çevresel ve maddi hasar ile birlikte can kaybına da yol açabilecek boyutlarda Boğazlar'da meyadana gelebilecek bir kazaya ilişkin sürekli büyüyen bir riski de beraberinde getirmektedir. Geçmiş talihsiz örnekler, Boğaz'da seyir güvenliğini artırmak için gerekli tedbirlerin alınmaması halinde, bu riskin her an bir kabusa dönüşebileceğini göstermektedir. İstanbul'un tarihi ve kültürel hazinelerine, nüfusuna, çevresine ve mal varlığına büyük bir risk oluşturan deniz kazaları bu çalışmanın konusunu oluşturmaktadır. Amaç, geçmişte meydana gelen kazalara ve uğraksız geçişlere ait verilerle birlikte kaza sonuçlarının subjektif uzman değerlendirilmesini esas alarak, İstanbul Boğazı'ndaki "potansiyel kaza" ile ilgili çevresel, fiziksel ve teknik şartlarla ilişkili riski ölçmektir. Bu bağlamda, Boğaz'da potansiyel bir kazanın meydana gelmesi ile bu kazanın sonuçları esas unsur olmaktadır. Bu kapsamda, bir ekonometrik, bir olasılıksal sonuç ve bir analitik hiyerarşi sürec (AHP) modei olmak üzere, üç altmodelden oluşan İstanbul Boğazı Risk Modeli geliştirilmiştir. Ekonometrik modelin geliştirilmesi kapsamında 1995-2004 yılları arasındaki kazalara ait istatistikler ile 2005 yılına ait kazasız uğraksız geçiş verilerini esas alan lojistik regrasyon teknikleri kullanılmıştır. Bu model geliştirilen senaryolara istinaden, İstanbul Boğazı'nda bir kazanın meydana gelmesi olasılığı üzerinde etkisi olabilecek; görüş mesafesinin, yağışın, rüzgarın hızının, kılavuz almanın, yerel trafiğin ve gemi özelliklerinin etkilerini test etmek için kullanılmıştır. Çalışmanın ikinci kısmında uzman görüşleri esas alınarak, meydana gelen bir kazanın her çeşit sonucunun gerçekleşme olasılığı tahmin edilmiştir. Bu model aynı zamanda gemi tipi ve yük durumunun, gemi boyunun ve kaza yerinin herhangi bir kaza sonucunun oluşması üzerindeki etkilerini de göstermektedir. Son olarak, AHP modeli ilk iki kısımda modellenemeyen diğer faktörlerin etkisinin gösterilebilmesi için kullanılmaktadır. Bu çalışmanın neticeleri, İstanbul Boğazı'ndaki deniz trafiği ile ilişkili risk ile bu risklerin kaynaklarını teşhis etmekte ve büyük oranda ölçmektedir. Şöyle ki, elde edilen sonuçların bu risklerin azaltılmasında tedbirlerin seçilmesi ve yol göstermesinde kullanılabileceği söylenebilir ve böylece Boğaz güvenliği artırılabilir. Bununla beraber, şüphesiz İstanbul Boğazı'nda meydana gelen deniz kazalarının oluşturduğu riskin azaltılması ve emniyetin artırılması için hala yapılabilecek birçok husus bulunmaktadır.

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LIST OF SYMBOLS/ABBREVIATIONS

A	Maritime accident
B	Situation factors during the transit of the vessel in the Strait
C, c	Consequence of the accident
P	Probability of a maritime accident
R^2	Conventional measure of goodness of fit
AHP	Analytic Hierarchy Process
EIS	Energy Information Administration
H&M	Hull and machine
IMO	International Maritime Organization
ISPS	International ship and port facility security
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LPM	Linear probability model
LSE	Least Squares Estimation
MLE	Maximum likelihood estimation
nm	Nautical mile
SAR	Search and rescue
STCW	Standards of training, certification and watchkeeping for seafarers
TSS	Traffic Separation Scheme
TSVTS	Turkish Straits vessel traffic system
TUBRAP	Turkish Straits reporting system
TUDAV	Turkish Marine Research Foundation
UNESCO	United Nations Educational, Scientific and Cultural Organization
VHF	Very high frequency
VTS	Vessel Traffic Service

1. INTRODUCTION

The Turkish Straits comprise the Istanbul Strait, stretching from the Black Sea to the Marmara Sea, and the Canakkale Strait ranging from the Marmara to the Aegean Sea. As the gateway of two continents and three seas, these Straits have been fought over for longer than any other waterway in history, in conflicts dating as back as the Trojan War in 1200 B.C. Beside its geo-politic, strategic, historical and cultural importance, the Turkish Straits are highly congested with international maritime traffic, (the second most congested trade artery after the Malacca Strait [1]), due to their status of being the only waterway between the Black Sea and the Mediterranean Sea.

It is worthwhile to recall some of the specific characteristics of the Istanbul Strait with a view to having a better understanding of the difficulties that are inherent in this waterway. The total length of the Turkish Straits region is 164 nm (Istanbul Strait is 17 nm in length, Çanakkale Strait is 37 nm and 110 nm being the length of the stretch of the Marmara Sea between these two straits) and it is open to international maritime traffic, under the control of the Turkish Government. The total number of vessels transiting through the Istanbul Strait is more than 55.000 per year, along with about 2,500 ferries, smaller passenger boats and fishing vessels running between two shores of the Strait every day [2, 3]. The shorelines of Istanbul are densely populated and vessels often pass within just meters of houses, schools and historical places.

Figure 1.1. The view of the Istanbul Strait (Source: Google)

The 17-mile long Istanbul Strait, which is less than 0.5 miles at its narrowest point, is considered to be one of the world's most difficult to navigate waterways. The narrowest bend of the Istanbul Strait is located between Aşiyan and Kandilli, where the strait width is a mere 698 meters. Additionally, the Aşiyan and Kandilli bend requires a course alteration of 45 degrees and is only one of 12 sharp bends in the Istanbul Strait. The Yeniköy bend is another difficult area in the Istanbul Strait, where the course alteration is 80 degrees [4].

Current is one of the prevalent factors that trigger maritime accidents in the Strait. Actually, the direction and type of currents in the Strait are numerous: The Black Sea is 20 cm higher than Aegean Sea; therefore, the surface current direction is generally from north to south and can reach up to 7 to 8 knots. But the deep current direction is from south to north, due to the low seawater density of the Black Sea. Additionally, there are the local counter currents and the Orkoz current, which is caused by strong southerly wind, all increasing the difficulty of navigating the Istanbul Strait [4].

Another characteristic of the Turkish Straits that makes them more risky is the meteorological conditions of the region. Fog, wind and rain are the major factors that are affecting navigation in the Straits, either directly or through their effects on visibility and currents. Moreover, different intensities of these meteorological conditions can easily be encountered in the Strait throughout the passage of the year’s four seasons. Meteorological factors in the Strait are remarkably unpredictable, and it is not all unknown for a winter day to veer to fog or rain or snow. Sudden changes in weather resulting with strong winds and/or low visibility may increase the likelihood of an accident.

There are sixteen headlands affecting the navigation in the Strait – nine of them are on the European side and the remaining seven are on the Asian side. The trends and width of the Strait permit a significant range of visibility at many parts of the navigable channel [1].

Some physical structures also became additional navigational hazards in this busy and narrow winding Strait. Among these are the two suspension bridges spanning the Istanbul Strait, the Bogazici Bridge and the Fatih Sultan Mehmet Bridge. The clearance for both bridges is 58 meters [5]. Moreover there are power transmission lines and underwater telephone cables, water pipelines in Bebek-Kandilli and Rumelikavagi-Anadolukavagi regions, which influence navigation.

Not just only in confined waters but also upon the high seas, darkness is one of the major causes on maritime accidents and consequences. This implies extra concern for a safe navigation in the Istanbul Strait. The presence of bright background shore lights and proximity of navigational hazards, like abrupt and angular windings, reduce the safety of navigation in the Strait in darkness [6].

In the light of the above factors, it is not difficult to say that the Istanbul Strait is one of the most difficult to navigate and thus potentially dangerous waterways in the world for maritime traffic.

An accident is an event that has adverse consequences such as injury, loss of life, economic loss and/or environmental damage. Accidents are, by definition, unplanned and unforeseen events. Although the sea is not a particularly risky mode of transportation, accidents happen also at sea and especially in waterways. A total of 521 accidents occurred in the Istanbul Strait from 1953 to 2005 [1] and 170 accidents in 1995-2005. In 1963 one woman was actually killed in her bed after a vessel rammed in to her bedroom. Some of these collisions were very serious. For example in 1979, a collision between the Romanian tanker Independenta and a Greek freighter “Evriali” resulted in over 30 people dying, 30 million gallons of oil being burned and 64 million gallons of oil spilled into the sea at the entrance of the Istanbul Strait. In 1991, Lebanese “Rabunion” collided with another vessel in which eight crewmen were killed and the Lebanese vessel sank with its cargo of 20.000 live sheep, again causing serious environmental damage. In 1994, “Nassia” collided with “Shipbroker”-both Greek Cypriot flagged vessels. The fire on Nassia continued for over a week and resulted in the closure of the Strait to maritime traffic. The fire also spread on the freighter and caused the loss of 26 people and 20 million gallons of oil spilled [4]. These examples show that the risk and danger may turn into a nightmare at any time, unless the necessary measures are taken to ensure safety of navigation in the Straits.

It is assumed that a maritime accident may be dependent on three factors. The first is the conditions of the ship, specified by such factors like type, age, length, draught, maintenance and safety systems. Secondly it depends on environmental factors, such as weather and morphological conditions. Last, but not the least, are the organizational factors, such as the competence of the crew, characteristics of the maritime traffic, existence and level of the safety management system. To have an accident, all sets of factors must exert their influence, but the later factors are more crucial as they initiate the accident. So, any ship can be lost or damaged, when the third factor exerts its negative influence, no matter what the condition of the ship.

The reasons behind the occurrence of accidents in the Istanbul Strait are identified by Oguzulgen as follows [7];

- Insufficient pilotage skills,
- Natural structure of the Strait,
- Surface currents,
- Limited visibility,
- Local conditions,
- Breakdowns and technical deficiencies.

It is a well-known fact that factors causing the accidents cannot be removed completely. However, there are some international standards to reduce the possibility of accidents to the minimum level. Vessel safety rules and their enforcement aim to prevent and reduce the severity of the accidents. National safety rules are enforced by flag states, while uniform international vessel safety rules and standards are through the adaptation of safety conventions of the International Maritime Organization (IMO) by individual member states. Each ratifying member country is obligated to enact the convention into national law, thus standardizing the safety rules among the ratifying countries. Among these rules or standards are the seaworthiness of the ship for sea travels, the qualifications of the crew and the regulation of the traffic. The ineffective enforcement of international safety rules by flag states has led some countries to establish port state control systems. Port state control is the inspection of foreign ships in national ports to verify that the condition of the ship and its equipment comply with the requirements of international regulations and that the ship is manned and operated in compliance with these rules. If it is determined during the inspections that the vessels can not meet the IMO standards, they can be detained until it can proceed to sea without presenting a danger to the ship or people on board, or without presenting an unreasonable threat of harm to the marine environment [8].

Prevention is certainly preferred to clean up and mitigation, but prevention aimed efforts cannot eliminate all accidents. The accidents themselves result in a range of consequences, such as human casualty, infrastructure damage, environmental damage and negative impact over the waterway efficiency. These consequences and their levels are directly dependent on the type of accident, vessel involved, location of the accident and on the measures taken after the accident has occurred (such as the search and rescue (SAR) operations and damage containment measures). All vessels transporting hazardous cargo are required to have an action plan for accidents and are expected to conduct response actions according to this plan, if an accident occurs.

The first reaction when serious accidents occur is to demand more regulations and state control, as a solution to satisfy public opinion. It is also true that most of the related legislations were adopted after a major accident occurrence. Regulations should be based first on the proper diagnosis and mitigation of the possibility of a serious accident, while maximizing the effect of the usually scarce response resources devoted to it, once an accident occurs. Naturally, this diagnosis requires first quantification of the probable risks and then examination of the facts as to whether and by what percentage the measures implemented have reduced the magnitude of the corresponding risks.

After the wreck of the Erika on 12 December 1999 of the Atlantic coast of Europe and foundering of Prestige on 13 November 2002, off the coast of Galicia/Spain, European Union (EU) considerably reinforced its legislative arsenal to combat flags of convenience and give Europe better protection against the risk of accidental oil spills [9]. These legislative arrangements had the following objectives;

- To tighten existing legislation (port State control and monitoring of classification societies);
- To speed up the phasing-out of single hull oil tankers (single hull tankers will be banned from EU waters by 2015);

- The creation of a European Maritime Safety Agency charged with improving the enforcement of EU maritime safety rules;
- The establishment of an information system to improve the monitoring of traffic in European waters;
- To establish a mechanism to improve compensation for victims of oil spills;
- To publish an indicative black list of ships, which are to be banned from European ports.

The present legal regime of the Turkish Straits has been determined by the Convention Regarding the Regime of the Straits, 1936 (hereinafter referred as Montreux Convention). The Montreux Convention set forth the regime, primarily guided by the principle of the freedom of passage and navigation for merchant vessels under any flag and with any kind of cargo [10]. This general principle is subject to implementation of certain formalities by merchant ships. However, in 1936, the year in which the Montreux Convention was signed and brought into effect, the number of vessels that passed through the Strait was 4700 (aggregate tonnage and the average vessel size being 9.71 million NT and 2066 NT, respectively). A similar figure for the year 2006 is 54.880, of which 31.880 are in transit with an estimated aggregate tonnage around 476 millions GT and the average size per vessel is 8670 GT. These numbers clearly show that the maritime traffic in the Strait has increased by more than 10 times since 1936 [1].

The past maritime accidents in the Strait seem to have an increasing trend with respect to the nature, volume and frequency of vessel traffic, growing sizes of vessels and to the enhancing types of cargoes and the number of the vessels designed for these special cargoes. The increases regarding the number and size of transit vessels and the hazardous nature of their cargo is not only affecting the possibility of maritime accidents that may occur in the Istanbul Strait, but also enlarging the scope of their consequences, in terms of ecological, environmental and physical disasters. Based on the statistics given by Under-Secretariat for Maritime Affairs, almost 20 per cent of the vessels passing through the Istanbul Strait are carrying hazardous cargo. Naturally, hazardous materials are more risky than the other types of cargos, as the potential consequences of accidents involving such cargos are fearsome. Some of the hazardous materials that are transported in vessels are explosives, gases, flammable liquids and solids, oxidizing substances, toxics, radioactive materials and so forth.

According to the Third United Nations Conference and the Law of the Sea Convention (1982), countries will take measures that aim at eliminating pollution caused by ships and especially avoiding accidents and handling dangerous situations, thereby maintaining the safety of the activities in the sea. The coastal state has the authority to designate sea-lanes and traffic separation schemes (TSS), in case of a necessity for the safety of the navigation, both in its territorial waters and in the straits, which are used for international navigation. The TSS, according to the definition approved by IMO, is "*a routing management established to separate the opposite traffic flow by determining appropriate routes and traffic lines for the purpose of increasing the navigational safety in cases of factors that hinder navigating and limited depth or unsuitable weather conditions in the maritime regions where routes are close to each other, in the areas where there is dense traffic or in the areas where movement ability is hindered due to navigational space*" [11].

In order to differentiate among the size and number of the vessels, as well as the status of their cargo and the natural or non-natural factors affecting the safety of transportation in the Turkish Straits, the Turkish Authorities have been obligated to create some stringent rules and procedures for transit vessels. Thus Turkey introduced the traffic separation schemes, in full compliance with Rule 10 of the International Regulation for Preventing Collision at Sea 1972, in the Turkish Straits Region, to enhance safety of navigation, on 01st July 1994. These traffic separation schemes have been approved by the IMO and were formally adopted on 25th November 1994. According to the schemes, a transit route, divided into north and south bound traffic lanes, has been established all the way through the Strait and vessels, during transit of the Strait, shall not overtake, nor attempt to overtake, other vessels unless forced to do so and not to cross the median line of the transit route.

This implementation allows two-way traffic to ensure the "innocent passage" of any vessel. However, especially when large and/or hazardous cargo carrying vessels are enjoying the freedom of passage afforded by the Strait, an authoritative intervention of some sort is required to avoid a potential accident. For example, in order to prevent damage to coasts and coastal structures, vessels are to proceed at moderate speed all the way through the Strait. On no account is a speed of 10 knots to be exceeded by ships in the Strait throughout the passage. Another example, when a very large vessel (i.e. vessels longer than 250 meters in length, which are often unable to navigate within the appropriate traffic lane) to transit, the two-way traffic is suspended and the maritime traffic in the Strait is regulated as one-way, while maintaining a safe distance between vessels.

The Regulations for the Administration of Maritime Traffic in the Turkish Straits that was adopted on 6th November 1998 (hereinafter referred as the Regulations) is one of the main documents to regulate the passages in the Istanbul Strait [12]. The Regulations, which can generally be regarded as precautionary and preventative measures to mitigate accidents, have been considered a useful development in terms of the decrease in the risk of an accident. Also, the decrease in the rate of accident in recent years (when compared with the rate of the early 1990's) has shown the usefulness of the Regulations and the TSS. Comparison of the accident rates, based on annual shipping traffic through per ten thousand (1982-1994) and the TSS (1994-2005), indicate that the yearly accident rate has sharply reduced, especially after the full implementation of the Regulations. Average yearly casualty ratio is 12.2 for ten thousand, up to the implementation of the TSS (1982 to mid 1994). The same ratio for the 1995-2005 period however is 3.0 per ten thousand. It is therefore safe to say that the current regulations and measures taken have been helpful in enhancing navigation and environment safety in the Istanbul Strait [13].

Moreover, in order to improve the safety of navigation and to protect marine environment in the Turkish Straits, the Turkish Government has established the Turkish Straits Vessel Traffic System (TSVTS) in late 2003 (which had been in the planning phase for a long time) using the latest technology. The TSVTS Area is displayed in Figure 1.2 (in the near future the Marmara Sea area will also be covered, so that the entire area of the Turkish Straits will be included in the TSVTS service area). Additionally, the TSVTS is the first contact point in case of any ship emergency and/or maritime accident in the TSVTS area, and it distributes all related information to the concerning organizations. Directorate General of Coastal Safety under the Ministry of Transport is designated as TSVTS Authority (hereinafter referred as TSVTS Authority) [4].

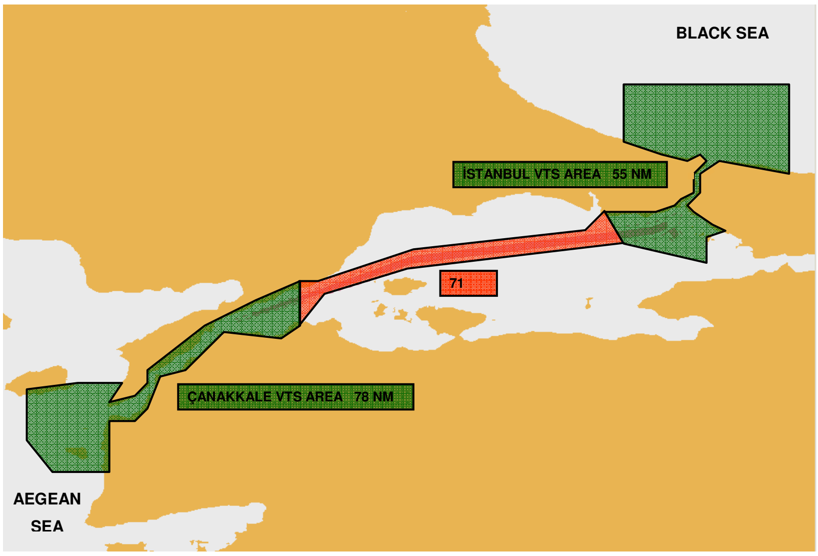


Figure 1.2. The Turkish Straits Vessel Traffic System Area

Transit vessels carrying dangerous cargo and vessels 20 meters in length or over, whether in stopover or non-stopover passage through the Turkish Straits, for whatever purpose, are designated as “Active Participant” vessels within the TSVTS Area and it is strongly recommended that active participant vessels comply with all the requirements of TUBRAP (Turkish Straits Reporting System). Transit vessels less than 20 meters in length and local traffic vessels within the TSVTS Area, for whatever purpose, are designated as “Passive Participant” vessels. Passive participants are not required to participate in the TUBRAP. However, the VHF frequency of the sector should be monitored at all times and all messages given by the TSVTS should be followed within the TSVTS area [4].

In addition to these safety measures to reduce the probability of a maritime accident in the Strait, currently there are 15 well-equipped Rescue Stations, eight of which are Boat Based Stations and seven of which are Shore Based Rescue Stations, on 24 hours basis in the Istanbul Strait. Additionally, seven rescue boats are stationed to carry out salvage and rescue operations after an accident. The TSVTS Authority has also the capability of responding marine oil spills during salvage operation or in case any emergency situation to respond to the marine oil spills.

Given this general framework, the next chapter presents the problem tacked along with the objectives of this study. Chapter 3 overviews the literature about the studies on narrow waterways in the world and in the Istanbul Strait as well as on the techniques deployed. Chapter 4 contains the details of the developed models. It includes discussions about the definition of risk, maritime transportation structure of the Strait and gives the details of developed conditional risk model (consisting of the Econometric Model, the Probabilistic Consequence Model and the Analytical Hierarchy Process Model). Chapter 5 focuses on validation of the model. Chapter 6 mainly focuses on data collection and analysis of this data. Chapter 7 presents different scenarios to analyze, along with the results of this analysis. Chapter 8 includes the conclusions, suggestions for risk mitigation measures in the Istanbul Strait and further studies. Relevant tables and figures referred to this study are given in Appendixes.

2. DISSERTATION OBJECTIVES

2.1. Problem Definition

The maritime system is formed by people, which interact with technology, environment, and organizational factors. Sometimes the weak link is with the people themselves; but more often the weak link is the way that technological, environmental, or organizational factors influence the way people perform that may cause an accident.

Traffic management measures are designed to prevent accidents. Unfortunately, in many cases, accidents cannot be prevented by traffic management instruments. The accidents are rooted on the characteristics of the system, such as the system's physical characteristics, traffic flows, traffic management system, and ship characteristics. The accidents themselves result in a range of consequences (on human life, property, cultural heritage and the environment), which are directly dependent on the type of accident and on the instruments and measures that are used after the accident has occurred.

The most widely accepted definition of risk associated with an undesirable event is the product of the likelihood of the occurrence of that undesirable event and some numeric measure of its potential negative consequence. In line with this general definition, maritime risk could be defined as the product of the likelihood of an accident occurrence and the expected value of its negative consequences or the potential damage caused. The criteria that make up the risk are the criteria that affect the accident probability and the criteria that affect the impacts or consequences. Thus, the maritime traffic regulations and rules first aim at minimizing the likelihood of an accident. Additionally, since the second element of risk is the potential damage in case an accident occurs, the services and regulations are also geared at reducing the intensity of the resulting damage. In other words, risks are very much related to population and property at the nearby land, environmental and cultural heritage concentration. For the Istanbul Strait case, the undesirable events can be fires, groundings, collisions, wrecked or stranded and related large-scale consequences can be explosions, gas releases and oil spills.

In recent years, not only the frequency of vessel traffic has increased, but also size of vessels and the nature of the cargoes have drastically changed. The ratio of oil, oil products and other dangerous and hazardous materials transported by large tankers has been rapidly increasing. Indeed, the number of oil tankers and other dangerous cargo vessels passing through the Istanbul Strait rose by 139 per cent in the last decade, from 4248 in 1996 to 10153 in 2006. The vast increase in the number of vessels and in the amount of hazardous cargo in recent years has caused considerable growth of the risk of maritime accidents in the Turkish Straits, the Istanbul Strait specific, which entail grave consequences on the nearby population, environment and property, as well as cultural and historical treasures of Istanbul at incomparable proportions. Numerous tragic accidents that have occurred in the Strait in the past are evidential in this regard.

Especially in the aftermath of the collision between two Greek Cypriots flagged vessels in 1994, public and private concern over the safety of marine transportation systems in the Turkish Straits, (and particularly the Istanbul Strait) has focused regional and national attention on ways to further reduce the risks of maritime accidents in this critical waterway. The increasingly congested maritime traffic in the Istanbul Strait causes serious concern from various respects. An accident in the Strait involving hazardous cargo has the potential of endangering the lives of hundreds of thousands of people, if not millions. Moreover, the effects of an environmental catastrophe resulting from such an accident would leave its scars for many decades. Additionally, a collision or an environmental disaster will force the closure of the Straits for unpredictable periods (as it happened several times in the past), which would negatively affect the economies of the Black Sea countries, as well as the land locked Caucasian and Central Asian States.

Due to the potential for a major accident with significant consequences on human life, property, cultural heritage, and the environment, risks associated with large-scale sea transport (and especially of hazardous substances) have been studied extensively in the literature. However, most of these risk assessment studies have been limited to ports. Analysis of risks at ports show some similarities to the analysis of risks from fixed installations, as well as the analysis of road and rail transport risks. Although the uniqueness of the Istanbul Strait complicates the study, it also provides us with an exciting academic and scientific challenge.

The possibility of having a maritime accident with major undesirable consequences in the Istanbul Strait is a very important concern. Potential maritime accidents, which impose serious risks to the nearby population, environment, property and as well as cultural and historical treasures of Istanbul, along with the traffic delays or even worse the closure of the Strait, are the subject of this study. The objective is to quantify and assess the risk associated with the various environmental, physical, technical conditions that may cause these accidents in the Strait, based on the past accident and transit traffic data, along with the subjective evaluations of the accidents' likelihood and consequences by experts in this sector.

2.2. Objectives

In a waterway, primary risk factors entail the physical waterway system, the vessels operating in the waterway, the behavior of the personnel, the waterway activity levels, any waterway or operating interventions and the meteorological conditions. It is important to note that some of the risk drivers are controllable, while others are beyond the direct control of waterway managers or others. In some cases, particular outcomes may be measured directly (e.g. reported casualties). In other cases, risk outcomes may be inferred because of the values of various risk drivers (e.g. collisions will increase because of increased vessel traffic). The focus of this maritime risk study is to identify and then try to reduce those risks generated or enlarged by the operation or existence of vessels and their interactions (with other vessels or with the nearby land mass) while in the waterway.

Since Istanbul is one of the most important cities of Turkey, a mosaic of many cultures with a population more than 12 million, the potential damage of an accident is indeed very important. Therefore analysis of accidents in the Strait, the risk management of these accidents and their negative consequences on human life, property, environment, infrastructure, cultural heritage and waterway efficiency become very much significant.

One of the oldest and most extensive data banks that are often the basis for most maritime studies is operated by Lloyds. The following categories of accidents are considered in this data bank [14] and are also being used in this study:

- Collision includes ships lost or damaged as a result of striking or being struck by another ship.
- Contact covers the cases in which ships collide with another external body, which is not a ship, nor the bottom.
- Wrecked or stranded (or sometimes called grounding) includes the ships lost or damaged as a result of touching the sea bottom.
- Foundered includes the ships that sank as a result of heavy weather, springing of leaks, breaking in two and other causes that do not fit in the other categories.
- Fire and explosion covers the cases in which fire and explosion are the first undesirable event reported.
- Hull or machinery failure includes the accidents that were initiated by one such failure.

It should be noted that this classification applies to the first event that have occurred and does not refer to the other consequences that may have occurred subsequently in the same accident.

Given the traffic density in and the topology of the Strait, collisions between vessels, and contact or stranding between a vessel and the land mass (grounding) can occur any time. All accident types will be considered in the research, but special emphasis will be given to collision, wrecked/stranded (grounding) and contact. The primary goal of this study is to make a quantitative assessment of the maritime traffic risk in terms of the accident probability and its various types of consequences, in order to arrive at operational policies that will mitigate the risk to the environment, Istanbul residents and the economy.

The following objectives are set out in order to achieve the dissertation goal:

- To identify the dominant risk factors in the Istanbul Strait, in regard to their contribution to likelihood and/or consequences of maritime accidents,
- To evaluate the influence of each risk factor over the likelihood of an accident, in regard to accident type and other factors,
- To identify the possible negative consequences of a maritime accident, in regard to accident type,

- To estimate the likelihood of each consequence, given a maritime accident occurred, in regard to accident type, vessels involved and other factors,
- To identify and subjectively evaluate the existing and other potential risk reduction interventions.

3. LITERATURE SURVEY

In this chapter, the definition of risk, its probabilistic aspects, its relation with the analytic hierarchy process, econometric models and their applications in maritime traffic risk models are examined. Also, some risk analysis studies, particularly probabilistic risk assessment models on the maritime traffic in the Istanbul Strait and in other narrow waterways around the world are examined, in order to have an insight on the topic.

There are numerous definitions of risk. Ross [15] provides 17 definitions of risk and this list is by no means exhaustive. The psychophysical approach to risk is hampered by the fact that there is no generally agreed definition of objective risk. Vlek and Stallen [16] list six definitions of risk, which are common in the literature:

- Risk is the probability of a loss
- Risk is the size of the possible loss
- Risk is a function, mostly the product of probability and size of loss
- Risk is equal to the variance of the probability distribution of all possible consequences of a risky course of action
- Risk is the semi-variance of the distribution of all consequences, taken over negative consequences only, and with respect to some adopted reference value
- Risk is a weighted linear combination of the variance of and the expected value of the distribution of all possible consequences.

Each of these definitions was developed to illustrate a particular aspect of risk and each has utility within the context for which it was developed. The reason risk can have so many different meanings, with each being right, is that risk, no matter how well founded in reality, is a mental and emotional construct rather than a physical reality. A common characteristic of these definitions is that they are context free, that is they refer only to abstract terms such as probability and loss which are designed for cross situational generality. A review by Erkut and Verter [17] revealed that, although several techniques have been suggested in the academic literature for transport risk assessment, there is no consensus among the authors regarding the proper representation of risk.

Risk has to do with feelings about a possible future that would be different than preferred or expected. Although there can be sufficient valid information about a specific identified risk for it to be treated as an “objective risk,” risk remains very much a perceptual and subjective construct. The proof that risk is a perception is simple: two observers looking at the same hypothetical scenario can legitimately see very different levels of risk. What all of the definitions have in common seems to be a future state for which the observer has an interest or concern and the possibility that that future state will not be what is desired or expected.

Probability is a basic notion in the evaluation of risk, which is not synonymous with risk. Rowe [18] describes risk estimation as a five-step process. The first four steps involve probabilities:

- The probability of the occurrence of a hazardous event
- The probabilities of the outcomes of this event
- The probability of exposure to the outcomes
- The probability of 'consequences'

Probability evaluations are used repeatedly in a risk calculation. The result of a risk study should be presented as the possible consequences together with their probabilities of occurrence.

Willis defined terrorism risk as a function of threat, vulnerability and consequences presented in Equation 3.1. He demonstrated how comparison of terrorism risks to other risk management decisions could provide benchmarks for which risk to be managed [19].

$$\begin{aligned}\text{Terrorism Risk } &= \textit{Probability}\text{ (attack occurs)} * \\ &\quad \textit{Probability}\text{ (attack results in damage} \mid \text{attack occurs)} * \\ &\quad \textit{Expected Value}\text{ [damage} \mid \text{attack occurs and results in damage]} \\ &= \text{Threat} * \text{Vulnerability} * \text{Consequence}\end{aligned} \tag{3.1}$$

The Risk Analysis Methodology is used to quantify the risk resulting from the exposure of the system to certain factors and thereafter takes specific measures to control the risk. Maritime accidents can be thought of as cases indicating pathology of the maritime safety system and satisfy the conditions for employing risk analysis technique [20]. The technique is divided into risk assessment and risk management. The task of risk assessment is to analyze scientific evidence in order to evaluate the relationship between exposure to certain factors and the potential occurrence of failure, thus quantifying the corresponding risk. Then, the risk management uses the results of the risk assessment procedure to produce a decision about actions to be taken.

An incident is defined as a triggering event, such as human error or a mechanical failure that creates an unsafe condition that may result in an accident. Dorp et all [21] shows the assessment framework consisting of a six stage causal chain: root/basic causes, immediate causes, triggering incidents, accidents, consequences, and impacts.

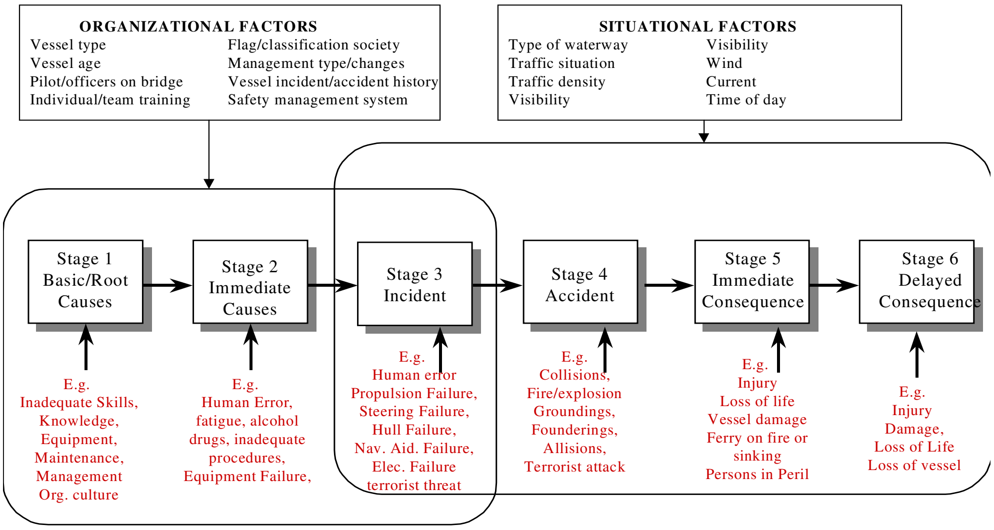


Figure 3.1. The maritime accident event chain

The combination of a triggering event and situational conditions (e.g. location, wind, weather) results in a hazard or a significant potential for an unwanted event. The assessment tool should take the role of these factors into account.

The overall quantification of the risk levels existing in maritime transportation can be estimated through studies based on accident statistics. These studies allow the identification of the time evolution of the levels of safety in the global activity, the differentiation of safety in the different types of ships, ship sizes, ages, etc. They were probably the first type of studies that addressed safety levels and updates based on data that are more recent have been regularly published [14].

3.1. Analytic Hierarchy Process (AHP) in Maritime Safety

People make three general types of judgments to express importance, preference, or likelihood and use them to choose the best among alternatives in the presence of environmental, social, political, and other influences. They make these judgments based on the knowledge in their memory or from analyzing benefits, costs, and risks. Sometimes standards of excellence and poorness can be developed from past knowledge, which are then deployed to rate the alternatives one at a time. A hierarchical decision model has a goal, criteria that are determined from the perspective of their importance to the goal, and alternatives that are evaluated based on how preferred they are with respect to each criterion. In this respect, the AHP transforms individual preferences for various criteria and sub-criteria into quantifiable weights that can be used to compare and rank many alternatives relevant and operating on those criteria. The AHP was developed by Dr. T. L. Saaty at the University of Pennsylvania. The AHP has been extensively applied (sometimes combined with mathematical programming) in developing business and manufacturing system performance evaluations, in capital rationing, capital investment decisions, as well as in many risk or safety related studies [22, 23].

In the AHP, a problem is structured as a hierarchy. An abstract view of such a hierarchy is shown in Figure 3.2. The central theme is a process of prioritization, which involves eliciting judgments in response to questions about the dominance of one element over another, when compared with respect to a property. A useful way to proceed in structuring a decision is to decompose the goal into the specific and more easily controlled and understood factors. One can then go up from the alternatives, beginning with the simplest sub-criteria that they must satisfy and aggregating the sub-criteria into generic higher-level criteria, until the levels of the two processes are linked in such a way to make comparison possible.

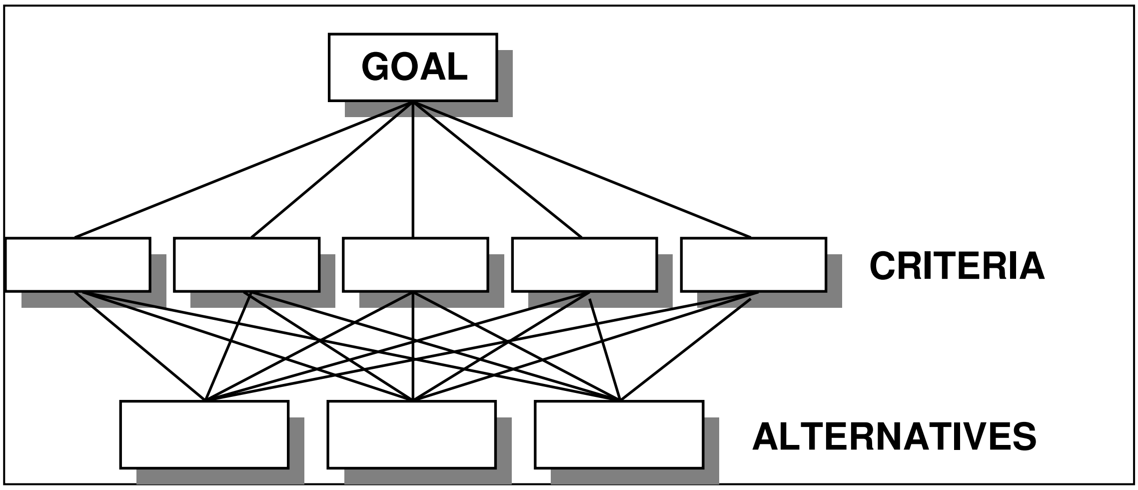


Figure 3.2. Abstract representation of a decision hierarchy

In this study the software package called Expert Choice [23] is utilized to structure and solve the AHP models. The Expert Choice software provides the necessary questionnaires consisting of pairwise comparisons of the criteria and sub-criteria, based on the AHP model formed. One of the most important features of the Expert Choice is its flexibility in terms of consistency of judgment. A measure, called the inconsistency index, allows detecting inadvertent misjudgments in comparison. This will both, reduce careless error, and also it can reveal unsuspected bias or exaggeration concerning one or more of the comparisons. A consistency index of 0.10 means that there is 10 per cent chance that the elements were compared in a purely random way. If the consistency index is larger than 0.10, it is recommended that the decision maker reevaluate the comparisons, since some of the judgments are contradictory. It is important to emphasize that the objective of the AHP to make “good” decisions, not to minimize the inconsistency index. Good decisions are most often based on consistent judgments, but the reverse is not necessarily true. It is easy to make perfectly consistent judgments that are nonsensical and result in terrible decisions.

There are two modes of synthesis in the AHP (and also in the Expert Choice), namely the distributive and the ideal modes, to derive results for the decisions, distributive or ideal. Synthesis converts all the local priorities into global priorities throughout the model, the objective being to obtain global weights for the alternatives. The global weights for each alternative are summed to get its final synthesized weight, or overall priority. The

AHP (and also the Expert Choice) has been extended to distinguish between two situations involving the alternatives of a decision. The first situation involves the choice of a best alternative that is influenced by what other alternatives there are and how many of them there are. In this situation the distributive mode is used. The distributive mode distributes the weights of the criteria among the alternatives, thereby dividing up the full criteria weights into proportions relative to the percentage of preference the alternatives. The ideal mode gives all the weight of each criterion to the alternative with the highest weight under that criterion. If the same alternative is best for all the criteria, after weighting by the priority of the criterion, that alternative receives an overall value of one while the other alternatives receive proportionately less [23].

The AHP methodology has been ingeniously and successfully deployed in many maritime safety related studies. Armacost [24] developed a high-level risk-based decision support tool that assesses waterway performance on two dimensions: realized risk outcomes and inferred risks. The assessment results, obtained through an application of the AHP, are represented as a performance map that can be used by waterway managers to compare the performance of different waterways. In addition, the underlying hierarchy can be used to identify those specific areas requiring remedial attention or additional analyses to reduce risk and improve safety. This decision support tool, called the Waterway Evaluation Tool, has been developed for the US Coast Guard to assist the management of maritime safety, enhance maritime mobility, and support the protection of natural resources in the maritime environment.

The Port and Waterway Safety Assessment (PAWSA) process was developed by the U.S. Coast Guard to satisfy objections to its previous approach for determining if a Vessel Traffic Service (VTS) would be an appropriate risk management tool in U.S. ports. As an early step in that process, a National Dialogue Group on National Needs for Vessel Traffic Services was convened in May 1998 under the auspices of the Marine Board of the National Research Council. Among many other findings, the National Dialogue Group identified twenty factors that affect port and waterway safety and which should be considered before establishing a VTS. Harrald and Merrick [25] used an Analytic Hierarchy Process approach for molding those twenty factors into a Port Risk Model, to develop a decision support tool to evaluate overall hazard risk and assess vessel traffic management alternatives for waterways.

The PAWSA process features significant stakeholder involvement, use of expert opinion and historical information, consideration of multiple alternative approaches to mitigating vessel traffic risk and a blend of several different analytic techniques. In the Port Risk Model, risk is defined as a function of the probability of a casualty and its consequences. Consequently, the model includes variables associated with both the causes and the effects of vessel casualties. The twenty port safety risk factors are grouped into one of six categories shown in Table 3.1.

Table 3.1. The PAWSA Port Risk Model factor and factor groups

Fleet Composition	Traffic Conditions	Navigational Condition	Waterway Configuration	Immediate Consequences	Subsequent Consequences
Percentage of High Risk Deep Draft	Volume of Deep Draft Vessels	Wind Conditions	Visibility Obstructions	Number of People on Waterway	Economic Impacts
Percentage of High Risk Shallow Draft	Volume of Shallow Draft Vessels	Visibility Conditions	Channel Width	Volume of Petroleum Cargoes	Environmental Impacts
	Volume of Fishing & Pleasure Craft	Tide & River Currents	Bottom Type	Volume of Hazardous Chemical Cargoes	Health & Safety Impacts
	Traffic Density	Ice Conditions	Waterway Complexity		

Tayanc [26] investigated maritime accident risks in the Istanbul Strait, associated with various physical, environmental and technical factors, which include not only those increasing accident probability, but also those affecting impact levels. A four level AHP model is developed to measure the relative importance of the identified risk factors based on various expert opinions. Risk contribution of each factor or sub factor, both as the percentage share in the overall risk and as an absolute value, are determined. The results provided a quantitative profile of the relative importance of the various factors.

Karakaya et all [27] studied to determine which one of the natural elements that cannot be controlled (such as current, wind, fog, precipitation) is more important than the others in contributing to maritime accidents. They applied the AHP methodology to determine which period of the year is more significant regarding maritime accidents, in order to enable the transit vessels in the Strait to take more safety measures in this period of the year. They also investigated the correlation among the maritime accidents and these meteorological factors. As a result of this study, it is suggested that December is the most risky month of the year followed by August with respect to the maritime accidents. It is also claimed that the meteorological factors are three times more influential on maritime safety, than oceanographical factors.

3.2. Econometric Models on Maritime Safety

Econometrics is concerned with the tasks of developing and applying quantitative or statistical methods to the study and elucidation of economic principles. Econometrics is derived from several disciplines, including mathematical economics, statistics, economic statistics, and economic theory. The statistical technique of regression analysis is the main tool of econometrics to obtain the parameters of the econometric models. Regression analysis has become a standard statistical tool in the social sciences. Its popularity stems from several sources: it provides much explanatory power, especially due to its multivariate nature; it is widely available in computer packages; it is easy to interpret, and there is a widespread belief that it remains a reasonable procedure even if some of the assumptions underlying it (such as robustness) are not met in the data [28]. In general, regression analysis is concerned with estimating and/or predicting the value (or mean) of a variable (dependent variable) in terms of the known or fixed values of one or more other explanatory (or independent) variables.

Econometric models also have been successfully deployed in many maritime safety related studies. Komhauser et all [29] provided a model that gives an estimate of additional vessel casualties that can be expected in the Istanbul Strait, due to the anticipated increase in oil tanker traffic. This study is limited to a quantitative forecast of the number of additional casualties that can be expected, by type (collision, ramming and grounding) at each of eight geographic segments along the Istanbul Strait. The casualty estimates were obtained by gathering and studying historical data on casualties and vessel flows in the Strait, as well as two other similar waterways, the Suez Canal Waterway and the Houston Ship Channel. Extrapolation of these historical rates to the future provided a nominal estimate of future, additional vessel casualties. As a second approach, a multiple linear regression model, which is developed using casualty and vessel transit data from numerous US waterways, was employed to estimate the future casualty. In this model, the casualty rate (dependent variable) is estimated based on waterway characteristics (such as current speed, visibility, wind speed, length of the waterway, minimum and average width in the Strait/region, minimum depth of the waterway, course change). This empirical model was applied with the waterway characteristics of the Istanbul Strait. As a result, the nominal forecast for the future casualty rates in the Istanbul Strait is computed as an average of historical and empirical rates.

Or et all [30] quantified the transport risks in the Istanbul Strait through statistical regression techniques by investigating the relationship between maritime accidents and suspected accident causing factors and conditions (such as current, wind, local traffic, channel width and bends, visibility, physical condition of the vessel, pilotage service). They developed two multiple linear regression models. In the first model, the Strait was divided into eight zones and number of accidents in each zone in 1982-1994 period was taken as independent variable. This model identified a relationship that total course change in the region and local traffic density are two critical factors having significant effect on the number of maritime accidents. In the second regression model, the Strait was considered as one region and the number of accidents in each season over five years period was taken as the dependent variable. This model identified a relationship that visibility, pilotage service and physical condition are three critical factors having significant effects on the number of accidents.

Roeleven et all [31] developed a Risk Effect Model to assess the effect and effectiveness of safety measures in Dutch inland waterway transport system. In this study, the probability of accident was modeled per elementary traffic situation and the number of accidents was estimated by the number of elementary situations multiplied by the probability of an accident per elementary traffic situation. The developed model forecasted the probability of accident (the predicted number of accidents) of as a function of waterway attributes and circumstances, by using Generalized Linear Models with a logit link function. The primary governing variables were visibility, wind speed, the ratio of the navigable width for an elementary traffic situation, and the bend radius of the waterway. The results showed that the circumstances (i.e. visibility and wind speed) were more explanatory with respect to the probability of accidents than the waterway characteristics were.

In all of these models the aim was to determine the relationship between accident rate and the number of accidents and the accident causing factors, rather than estimating the likelihood of an accident in the related waterway. Since the objective of this study is to estimate the probability of an accident and also the relationship between the accident and its causing factor, it is required to use a binary variable (which takes the value of one if the accident occurs, zero otherwise) as the dependent variable corresponding to the occurrence of a maritime accident. In other words, the dependent variable, Y, is a binary variable and the independent variables (e.g. *X*'s), could be continuous, integer or binary. These types of binary response regression models are often called as probability models. In this context Linear Probability Models (LPM), logit and probit models are the first models available in the literature [32]. The LPM, logit and probit models are defined respectively as follows;

$$LPM : Y_i = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_k X_{ki} + u_i \ \textit{where Y is binary} \tag{3.2}$$

$$\begin{aligned} &Logit = L_i = \ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_k X_{ki} \\ &where\ P_i = P(Y_i = 1|X_i) = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}} \end{aligned} \tag{3.3}$$

$$\begin{aligned} &\Pr obit\ Model : P_i = P(Y = 1|X_i) = P(I_i^* \le I_i) = P(Z_i \le I_i) = F(I_i) \\ &F(I_i) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{I_i} e^{z^2/2} dz \quad where\ I_i = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_k X_{ki} \end{aligned} \tag{3.4}$$

Unfortunately, the LPM poses several problems as stated by Gujarati [32]. Firstly, there is no guarantee that $\hat{Y}_i$, the estimator of P_i (where P_i is the probability which is the expected value of the dependent variable such $P_i = P(Y_i = 1|X_i))$ will necessarily fulfill the restriction that it must be between 0-1, and this is the real problem with the LPM. Additionally, the LPM assumes that P_i increases linearly with X (that is, the independent variables), which implies that the marginal effect of X remains constant throughout. In reality there is no reason to expect P_i being linearly related to X_i. Fortunately, the logit and probit models cover these stated weaknesses of the LPM. They make sure that the estimated probabilities will indeed lie between the theoretical limits 0-1 and allow for non-constant marginal effects.

In most applications, both the logit and the probit models behave similarly, the main difference between them being that the logistic probability distribution having slightly flatter tails, (as displayed in Figure 3.3).

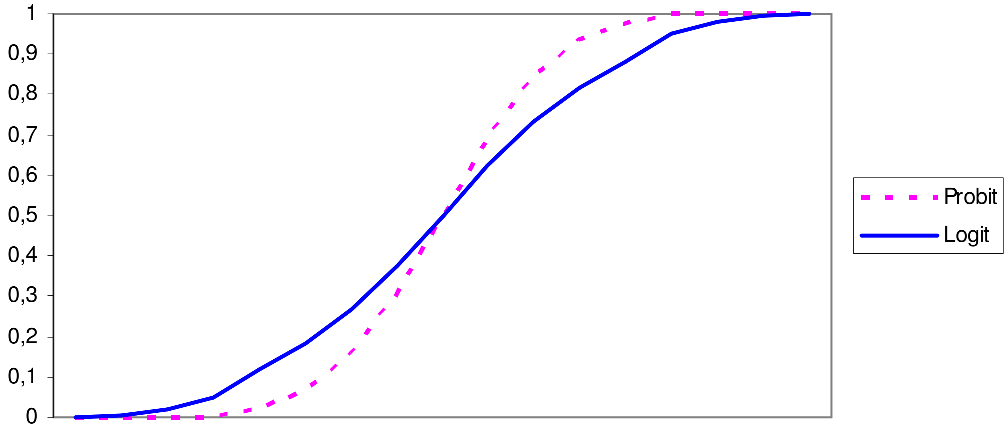


Figure 3.3. The logit and the probit cumulative probability distributions

In other words, the dependent variable P_i approaches zero or one at a slower rate in the logit than in the probit model. However, due to its mathematical simplicity, especially during the calculation of marginal effects, a logit model is preferred in this study for estimating the probability of maritime accidents in the Istanbul Strait.

The present practices of the logistic regression, case-control studies and discrete choice analyses have separate and distinct roots, often spreading back to achievements of the 19th century, when the logistic function was invented to describe population growth and given its name by the Belgian mathematician Verhulst. The development of these techniques has been facilitated by the immediate needs of such diverse disciplines as biology, epidemiology and social sciences, as well as by the personal interests of individual scholars. The ascent of the logit model in the statistical literature is illustrated in Table 3.2, which is drawn from the JSTOR electronic repertory of major statistical journals in the English language. The table shows the number of articles, which contain the word “probit” or “logit”. It must be borne in mind that the overall number of articles in these journals increases substantially over time; from 1935 to 1985 it increased about eightfold. Up to around 1970 the relative numbers shows the predominance of probit in bioassay; then logit soars ahead, because of its much wider use in statistical theory and applications generally [33].

Table 3.2. Number of articles in statistical journals containing the word “probit” and “logit”

Period	Probit	logit
1935-39	6	-
1940-44	3	1
1945-49	22	6
1950-54	50	15
1955-59	53	23
1960-64	41	27
1965-69	43	41
1970-74	48	61
1975-79	45	72
1980-84	93	147
1985-89	98	215
1990-94	127	311

The logit model has been used extensively in analyzing growth phenomena, such as population, gross national product [32], finance [34,35,36], quality assurance [37], banking industry [38]. Rodgers and Ghosh [37] used multinomial logit analysis to examine the relationship between student input quality and degree performance in UK higher education. The aim of the study is to quantify the quality of teaching in order to protect it. This measurement problem was the main question (what are the different factors which determine quality in terms of the degree class that the student achieves) addressed in the study. The classification, namely first/upper second class ("good degree"), lower-second class, third-class and general/pass degree are chosen as dependent variable. The data set off 5500 observations was derived from 5500 UK national survey of graduates and diplomats carried out in 1985. 30 different independent variables used in the model relate to: academic ability, motivation/effort levels, subject of study, ethnic origin and gender. The results of the study suggest that an increase in average "A" level points by one increase the probability of a "good degree" by 5.8 per cent. Similarly, studying economics reduces the probability of a "good degree" by 10.5 per cent. Additionally, student dissatisfaction with a course reduce the same probability by 15 per cent. The model results recommend potential students to note that taking subject like geography and history, other things being equal, increase the probability of a "good degree", while taking law reduces it.

Gujarati [32] states the features of the logit model as follows:

- As P goes from zero to one (i.e., as Z varies from $-\infty$ to $+\infty$), the logit L goes from $-\infty$ to $+\infty$. That is, although the probabilities lie between zero and one, the logits are not so bounded.
- Although L is linear in X, the probabilities themselves are not.
- It is possible to add as many independent variables as desired.

The maritime accidents in the Istanbul Strait were studied by Gören [39] through logistics regression technique and simulation methodology. Accident probability models were generated for different accident categories and integrated to a simulation model to make an assessment of the dynamic nature of risk in the Strait of Istanbul. However, Gören did not attempt to estimate the probability of an accident, rather pursued the relationship between the accident causing factors and the number of accidents.

Various regression analysis techniques have been also deployed to estimate the consequences of a maritime accident. Talley et all [40] investigated vessel oil differentials for vessel accident and transfer spills for the 1991-1995 period in US waters, utilizing tobit regression analysis over a oil spill equation. This oil spill equation is a function of vessel characteristics (such as type, age, flag, safety record), vessel operation phase (such as underway, moored, towed and anchored), weather/visibility conditions (cold weather, high wind, precipitation, time of spill), type of waterway (such as coast, ocean, lake, river, harbor or bay), vessel safety/environmental regulation enforcement activities (total time of activities by Coast Guard) and oil price.

Talley et all [41] investigated the determinants of the number of crew injuries and missing crew in freight ship, tanker and tugboat vessel accidents for the 1991-2001 period in US waters, by using Poisson and negative binomial regression models. The number of non-fatal crew injuries, fatal crew injuries and missing crew in a vessel accident were expressed separately as a function of the number of crew on board (function of vessel age and vessel size), vessel damage severity (function of type of accident, vessel characteristics, flag state, vessel operation phase, visibility and type of waterway) and vessel-injury prevention (function of vessel safety regulation and enforcement of these regulations).

3.3. Uncertainty Analysis and Probabilistic Risk Assessment in Maritime Domain

The presence of uncertainty in analyzing risk is well recognized in the literature. However, these uncertainties are often ignored or underreported in studies of controversial or politically sensitive issues. Two types of uncertainty are discussed in the literature: aleatory uncertainty (the randomness of the system itself) and epistemic uncertainty (the lack of knowledge about the system). In a modeling sense, aleatory uncertainty is represented by probability models that give probabilistic risk analysis its name, while epistemic uncertainty is represented by lack of knowledge concerning the parameters of the model. The Bayesian paradigm is widely accepted as a method for dealing with both types of uncertainty [42]. The Bayesian approach treats the population parameters as random, (not fixed) quantities, while the classical statistical approach considers them as fixed but unknown constants to be estimated using sample data taken randomly from the population of interest.

Risk management has become a major part of operating decisions for companies in the maritime transportation sector and thus an important research domain. Early work concentrated on assessing the safety of individual vessels or marine structures, such as nuclear powered vessels, vessels transporting liquefied natural gas, and offshore oil and gas platforms. Several major risk studies have been performed in recent years in the maritime transportation domain. These studies have had significant impact on management practices in the industry [14].

The Prince William Sound (PWS) risk assessment [43], Washington State Ferries (WSF) risk assessment [21] and an exposure assessment for ferries in the San Francisco Bay [42,44] are three examples of successful risk studies in this domain. The basic technique used in the PWS risk assessment is probabilistic risk analysis (PRA). In performing a PRA, first the series of events leading to an accident are identified and then the probabilities of these events are estimated and finally the consequences of the accident are evaluated. The PWS risk assessment differs from previous maritime risk assessments in capturing the dynamic nature of risk by integrating system simulation and expert judgment elicitation. In a maritime transportation system, traffic patterns change over a time in a complex manner. The dynamic nature of traffic patterns and other situational factors (such as wind, visibility, ice condition and precipitation) bring about a risk level changing over time. This accident probability model was constructed using the relationship between the vessel's operating environment, triggering incidents, and accidents. The combination of organizational and situational factors that describes the state of the system in which an accident may occur is termed an opportunity for incident (OFI). The model is based on three conditional probabilities;

- Probability (OFI): the probability that a particular system state occurs,
- Probability (Incident |OFI): the probability that a triggering incident occurs in this system state,
- Probability (Accident | Incident, OFI): the probability that an accident occurs given that a triggering incident has occurred in this system state.

The first probability term was estimated using a discrete-event simulation model that captures the complex dynamic nature of the system and models the interaction between the vessels and their environment. The second term was estimated through data analysis and use of expert judgment. Finally, for the last probability term, a log-linear probability model was deployed and the relative conditional probabilities were obtained through regression analysis of pairwise comparisons of the potential accident scenarios by maritime experts. The risk model claimed that actions taken prior to the study had reduced the risk of oil spill by 75 percent, and it identified measures estimated to reduce the accident frequency by an additional 68 percent.

The Prince William Sound risk assessment was reviewed by the National Research Council and found to be promising but incomplete, as the uncertainty in its results was not assessed. Merrick and Van Dorp noted that the difficulty in assessing this uncertainty arose from the different techniques that needed to be used to model risk in this dynamic and data-scarce application area [42]. Merrick et all [45,46] have developed the two pieces of methodology necessary to assess uncertainty in maritime risk assessment, a Bayesian simulation of the occurrence of situations with accident potential and a Bayesian multivariate regression analysis of the relationship between factors describing these situations and expert judgments of accident risk. Moreover, they combine the methods to perform a full-scale assessment of risk and uncertainty for two case studies, namely WSF risk assessment and an exposure assessment for ferries in the San Francisco Bay.

WSF risk assessment model is constructed to evaluate the level of risk present in the WSF system (the largest ferry system in US) and to develop recommendations for prioritized risk reduction measures. The focus of the study was on passenger safety, including consideration of both the probability of occurrence and the severity of consequence of collision type accidents. A similar methodology to PWS was deployed in WSF to estimate the probability of accident. Regarding consequence level estimations and evaluations, a measure termed maximum required response time (MRRT) was developed as a surrogate measure for the potential accident impact. The situational and organizational factors, (such as ferry route, ferry class, interacting vessel type, type of interaction, proximity of interacting vessel, wind speed, wind direction and visibility) are considered in the collision risk model. A consequence model was deployed to assess the damage to each ferry class in various collision scenarios. These consequence models followed the Minorsky method (which determines the damage size as a function of the collision energy, the colliding-vessel bow angle, and the effective deck thickness of the ferries) and then MRRT was calculated in three categories based on the given damage size. A total of 40 risk reduction measures in seven classes were tested to evaluate their effect on the annual frequency of collisions and on the annual frequency of collisions in each MRRT categories.

The original San Francisco Bay study was limited to a simulation model, similar to the one deployed in PWS and WSF models, to estimate the number of vessel interactions in the current system and their potential increases caused by alternative expansion plans [44]. Later on the accident probability part was included using expert judgment and data analysis [42].

In order to assess the maritime risk in the Istanbul Strait, a similar methodology is utilized. By a regression analysis using a logit model the relationship between accident causing factors and the accident is quantified. Then the relationship between the situational factors and the likelihood of an accident consequence is determined by expert judgments.

Gziakis and Bardi-Giziaki [47] tried to quantify the risk of an accident leading to environmental pollution, by employing Mantel-Haenszel chi-square to test the statistical significance of the risk involved in each type and age group for particular types for the pollution causing accidents that have occurred in the world during the 1993-1997 period. The results of the analysis claimed that the large tankers involved in pollution accidents, that happened in ports and regulated zones, present an almost seven times higher risk than smaller tankers. This implies the importance of proper inspections by port state controls.

The Netherlands Ministry of Transport, Public Works and Water Management asked RAND Europe to develop and apply an analytical framework to identify promising sea shipping safety policies. The study, POLicy for Sea Shipping Safety (POLSSS) included an assessment of the costs and benefits of a range of policy options for maintaining or improving safety in the North Sea, a survey of the perceptions of stakeholders about the safety situation in the North Sea, and a survey of the perceptions of stakeholders about the cost-effectiveness of some policy options [48].

3.4. The Correspondence Analysis

Correspondence analysis is an easy-to interpret perceptual tool, which can be used to provide visual relationships and differences in data. The main purpose of correspondence analysis is to reveal the structure of a complex data matrix by replacing the raw data with a more simple data matrix without losing essential information. The objective of correspondence analysis is to portray data geometrically in low-dimensional space. The only data requirement for correspondence analysis is a contingency table of non-negative entries. Correspondence analysis offers several advantages. First the data collection is quick and easy. Secondly, multiple categorical variables can be represented simply through cross-tabulated data. Finally, it provides an easy-to understand visual portray of both inter-category and intra-category relationships [49].

In a typical correspondence analysis, a cross-tabulation table of frequency is first standardized (the relative frequencies across all cells sum to 1.0), and this gives a set of so-called row and column profiles. Each row/column profile may be regarded as a mathematical vector, and a vector may be represented as a point in space, where each profile element constitutes a coordinate in space. In this way, every row/column profile may be represented as points in a three-dimensional space. The more similar the profiles of two rows are, then the closer to each other will be the points placed in space. Correspondingly, two very different profiles will produce points lying far away from each other. The average row profile is the total of numbers in the different columns divided by the total sum, and is the weighted average of the row profiles. This point often called the centroid and it is placed at the origin of the principal axes. If a profile is very different from the average profile, then the point will lie far from the origin, whereas that is close to the average will be represented by points close to the centroids. In correspondence analysis the variance (the term inertia is used as a synonymous term) concept is connected the chi-square distances. The chi-square distance is a weighted Euclidean distance as displayed in Equation 3.5, where the weight is the inverse of the respective average profile element.

$$d(i,i') = \sqrt{\sum_{j} \frac{(a_{ij} - a_{i'j})^2}{a_{.j}}} \tag{3.5}$$

where $d(i,i')$ is the chi-square distance between the points i and i', a_{ij} are elements in the row profile, and $a_{.j}$ are elements in the row profile. This implies that the categories with few observations contribute relatively more to the interpoint distances than categories with more observations [50].

Table 3.3. Number of activities observed in the areas (Source, 50)

Area	Activity 1	Activity 2	Activity 3	Total
A	395	2456	1758	4609
B	147	153	916	1216
C	694	327	1347	2368
Total	1236	2936	4021	8193

Assume that Table 3.3 shows the number of activities in three different areas and corresponding row and column profiles are displayed in Table 3.4.

Table 3.4. Profiles and masses for the data in Table 3.3

	Row Profiles				
Area	Activity 1	Activity 2	Activity 3	Total	Row Masses
A	0.086	0.533	0.381	1.000	0.563
B	0.121	0.126	0.753	1.000	0.148
C	0.293	0.138	0.569	1.000	0.289
Average row profile	0.151	0.358	0.491		
	Column Profiles				Average Column Profile
A	0.320	0.837	0.437		0.563
B	0.119	0.052	0.228		0.148
C	0.561	0.111	0.335		0.289
Total	1.000	1.000	1.000		
Column masses	0.151	0.358	0.491		

The Euclidean interpoint distances using the Pythagorean formula between areas and activities, consider this distance between Area A and B.

$$s(i,i') = \sqrt{\sum_j (a_{ij} - a_{i'j})^2} = \sqrt{(0.086-0.121)^2 + (0.533-0.126)^2 + (0.381-0.753)^2} = 0.553$$

The chi-square distance between Area A and B using the Equation 3.5 and row profile data displayed in Table 3.4 as follows;

$$d(A,B) = \sqrt{\frac{(0.086-0.121)^2}{0.151} + \frac{(0.533-0.126)^2}{0.358} + \frac{(0.381-0.753)}{0.491}} = 0.868$$

Note that the chi-square distances can only be calculated between categories of the same variable, not between categories of different variables. This means that the distances between areas and between activities are defined, but the distances between areas and activities are not. Correspondence analysis is based on this chi-square metric and may be described as a technique for decomposing the chi-square statistic [49,50]. Similarly the chi-square distance between A and C, and the chi-square distance between B and C can be computed as 0.890 and 0.515 respectively. The chi-square distances from A, B and C to centroid are 0.372, 0544 and 0.530 respectively.

Total inertia is a measure of the extent to which the profile points are spread around the centroid, and it is calculated as follows;

$$\Lambda^2 = \sum_i r_i d_i^2 \tag{3.6}$$

where d_i is the point *i*'s chi-square distance from the centroid and r_i is the point *i*'s mass (weight). Using the distances from centroid to areas and the values given in Table 3.4;

$$\Lambda^2 = \sum_i r_i d_i^2 = 0.563(0.372)^2 + 0.148(0.544)^2 + 0.289(0.530)^2 = 0.2029$$

Total inertia is related to Pearson’s chi-square statistics as follows [50];

$$\chi^2 = \Lambda^2 N \tag{3.7}$$

where N is the total number observations. Thus,

$$\chi^2 = 0.2029(8193) = 1662.6 \qquad \text{d.f.}= 4$$

It can be seen from Equation 3.7 that also the total inertia is like Pearson's contingency or phi-square (i.e. coefficient of mean square contingency) [50];

$$\varphi^2 = \frac{\chi^2}{N} = \Lambda^2 \tag{3.8}$$

In summary, correspondence analysis relies on a singular value decomposition of a matrix of chi-square distances. Using the distances between the areas and the distances between areas and centrod, it is possible to plot these points in a two dimensional space. Since there are three points, these can be described perfectly in two dimensions. The problem is to rotate the axis so that it lies as close as possible to the points, where the measure of closeness is the weighted sum of the squared distances (z^2) from the points to axis (in such the weights are the row masses, r). Thus, the intention is to minimize $\sum rz^2$, or maximizing the weighted sum of the squared coordinates ($\sum rf^2$). Figure 3.4 illustrates the problem of finding a space that lies closest to the points. This problem solved by means of principal component analysis. The coordinates of the points represent a decomposition of the squared chi-square distance to the origin [50].

The decomposition generates eigenvalues and eigenvectors that are applied to row and column distance matrices. These in turn produce the interpoint distances for mapping. The algorithm used in the correspondence analysis derives interpoint distances between the row and column categories, so that the numerical scores maximize the interrelationships (i.e. relationships between categories of same variable) between them. Among the computational techniques, correspondence analysis is most similar to factor analysis in that it produces maps which represent the configuration of points in projection planes formed by principal axes taken two at a time. Each of the principal axes is associated with an eigenstructure, which defines projections on the axes. Co-ordinates and contributions of the principal axes for the row and column points are interpreted similar to factor analysis.

The maximum number of dimensions for a correspondence analysis solution equals the smaller of number of rows minus one or the number of columns minus one. These eigenvalues express the relative importance of the dimensions or how large a share of the total inertia each of them explains. The shares are calculated so that the first dimension explains most, then the second, and so on [49].

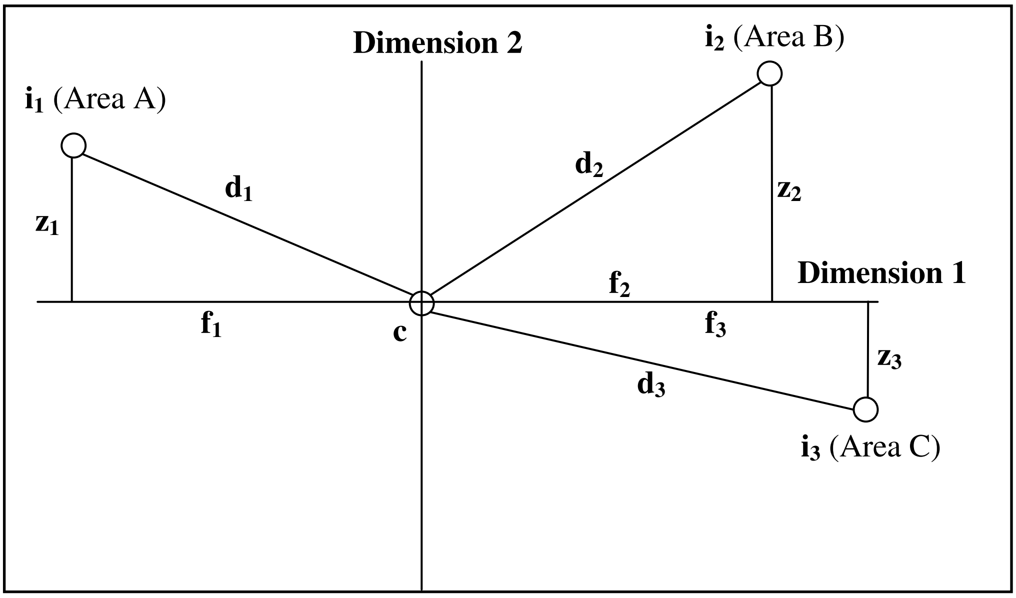


Figure 3.4. Illustration of the problem of finding a space that lies closest to the points

The eigenvalues are computed using Equation 3.9, which is also the objective of the algorithm to determine the coordinates [50].

$$\lambda_k^2 = \sum r_i f_{ik}^2 \tag{3.9}$$

where f_{ik}^2 is the square of point i's coordinate on dimension k and r_i is point i's mass. The results of the computation displayed in Table 3.5.

It is important to note that it is only the distance within each set of points that are defined, not the distances between points from different sets or variables. Each eigenvalue is the amount of variance (inertia) a given factor explains and also reflects the relative importance of the dimensions.

Table 3.5. Eigenvalues, percent inertia and the coordinates of the points

	Dimension 1	Dimension 2	Sum
Eigenvalue (λ^2)	0.1774	0.0255	0.2029
Percent variance	87.4	12.6	
	Coordinates		
Area A	-0.37	-0.11	
Area B	0.42	0.35	
Area C	0.51	-0.16	
Activity 1	0.51	-0.33	
Activity 2	-0.55	-0.05	
Activity 3	0.24	0.13	

Distances and coordinates are calculated separately within each category of points, and the solutions are represented in a common or joint space. This can be done because the two categories of points are related, (hence the name “correspondence analysis”) in the following ways [50];

- The space for the rows and the space for the columns have the same dimensionality.
- Eigenvalues are the same for two solutions.
- The coordinates of the row points can be calculated on the basis of the row profiles and the coordinates of the column points and vice versa for the other category of points as discussed in Section 3.4.

Sezgin and Kadıoğlu [51] analyzed the maritime accidents in the Istanbul Strait for the period 1982-1999 by correspondence analysis. These accidents are analyzed with respect to the time of the accident, reason of the accident, accident locations, size and flag state of the vessels involved in the accidents. The results suggest that during the winter season most of the accidents involving larger size vessels occurred at nighttime, while during the summer season, most of the accident involving tankers and recreational vessels occurred in the morning.

4. THE MODEL

In order to define the relationships between the various elements of the Istanbul Strait Maritime Traffic, Figure 4.1 is developed as a pictorial representation of the system. There are four different groups in the system to be considered:

- Physical Characteristics: aspects outside the control of any authorities, such as weather, wind, current, precipitation and morphological conditions.
- Ship Characteristic: Vessel length, draft, age and the maintenance quality of the ships, and the competence of the crew.
- Traffic Flows: Intensity and variety of the ships, as well as their cargoes on board.
- Traffic Management Instruments: The regulation enforced, navigational aids, availability of the pilot service.

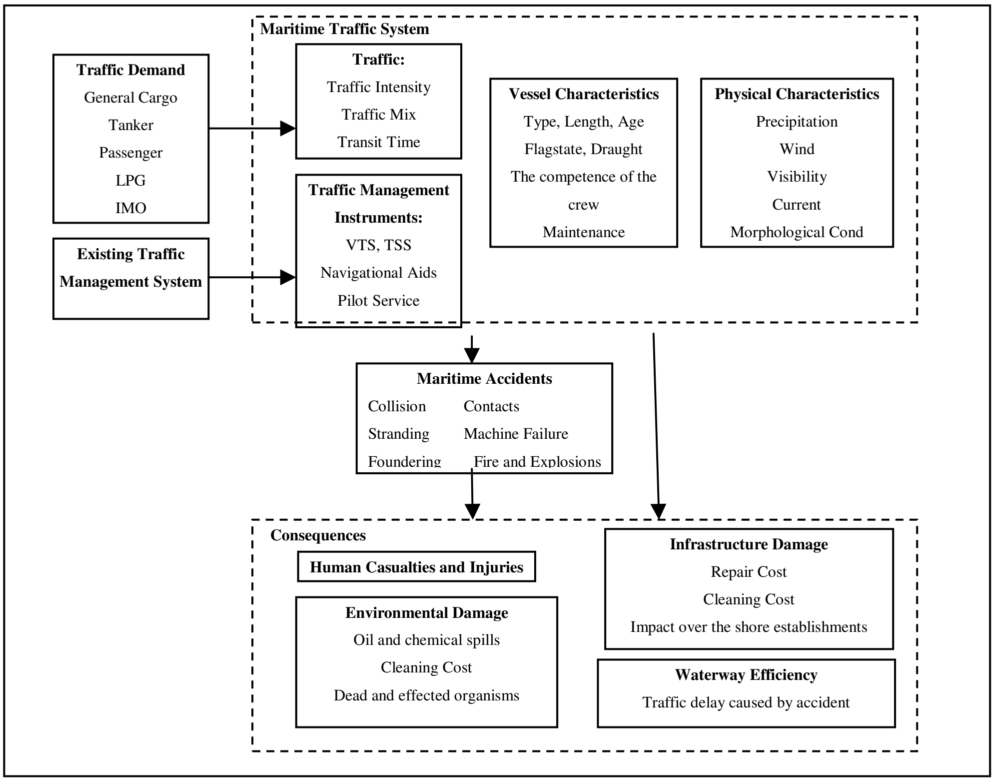


Figure 4.1. The system diagram of the Istanbul Strait maritime traffic

Consequence is the magnitude and type of damage resulting from a maritime accident realization. The term consequence is used to refer to the negative effects that result from an accident. To define a measure of consequence, specificity is required. Specificity necessarily involves treatment of two important considerations: how consequences are measured and how uncertainty is addressed. The maritime accidents have many different types of consequences, including effects on human life, property, environment, infrastructure, cultural heritage and waterway efficiency. In addition to the type of accident, the consequences of an accident depend on the types of ships that are involved (e.g. ferries and oil tankers).

4.1. Bayesian Approach to the Istanbul Strait Maritime Risk

It makes a great deal of practical sense to use all the information available, old and/or new, objective or subjective, when making decisions under certainty. This is especially true when the consequences of the decisions can have a significant impact, financial or otherwise. Most people make everyday personal decisions this way, using an intuitive process based on their experiences and subjective judgments. When there are few data available, subjective probability distributions may be used even if they are biased or not well calibrated. However, the determination of subjective probabilities should be based upon the total knowledge available, which relates to the problem or system under study. This knowledge may come from experience with similar situations, reasoning by analogy or symmetry and from knowledge of special features of the problem at hand. Then, the total information has to be transformed into numerical values by probability estimation. When several experts are used they may provide varying subjective evaluation leading to widely different set of parameters or even functional forms. This is not necessarily a contradiction. Even if two experts are each well calibrated in their subjective evaluations, they may differ in particular cases. From a statistical point of view, it would, in such cases, be justifiable to use some kind of an average subjective probability distribution [52]. The primary concepts of the Bayesian approach can be categorized as follows:

- The Bayesian approach is about “Taking a Probabilistic Approach”
- The Bayesian approach is about “Combining Expert Input and Data”
- The Bayesian approach is about “Building Complex and Uncertainty Application”

First of all, the Bayesian approach is about taking a probabilistic approach to analyzing data. It emphasizes probabilistic logic over Boolean logic (True or False) in the solution of problems. Given a set of data, a probabilistic approach can show the frequency at which cases have occurred, some more frequently, some less frequently. This is quite different from the traditional Boolean approach (i.e. either zero per cent or 100 per cent probability). The Boolean approach is well suited for the certainty applications, like an airline ticketing system, or a bank transactions system, that requires 100 per cent certainty (i.e. transfer money/don't transfer money) and accuracy. But in the real world things are not always black or white. In many applications one cannot simply assume that an answer will be 100 per cent correct.

Secondly, the Bayesian approach emphasizes the acquisition of expert input into a problem solution. In many situations, since not all information can be extracted from observed data, expert input becomes critical. This is engrained in the definition of the Bayesian probability (subjective probability based on an expert's opinion), versus physical probability, which is calculated from a complete set of observed data. The expert input (often referred as "prior" input in the Bayesian world) is not limited to probabilities only. It includes input regarding "prior" structures, "prior" models, or "prior" rules or definitions.

Fortunately no waterway in the world has enough accident data to develop fully observed data based, precise mathematical models to determine the probability of a maritime accident in this waterway, while identifying and deploying the relations between the accident factors and the accident itself. Thus, in order to develop models to determine reliable estimates of accident probabilities, it becomes unavoidable to combine expert input along with the available historical data.

Figure 4.2 is developed based on the interviews with the experts in the maritime sector to illustrate the causal relationships among the variables. In this case, this diagram includes all the accident causing factors deployed in the logit and the AHP models. It provides insights over the causal relationship among the variables, thereby facilitates understanding about the problem domain and predicting the consequences of intervention.

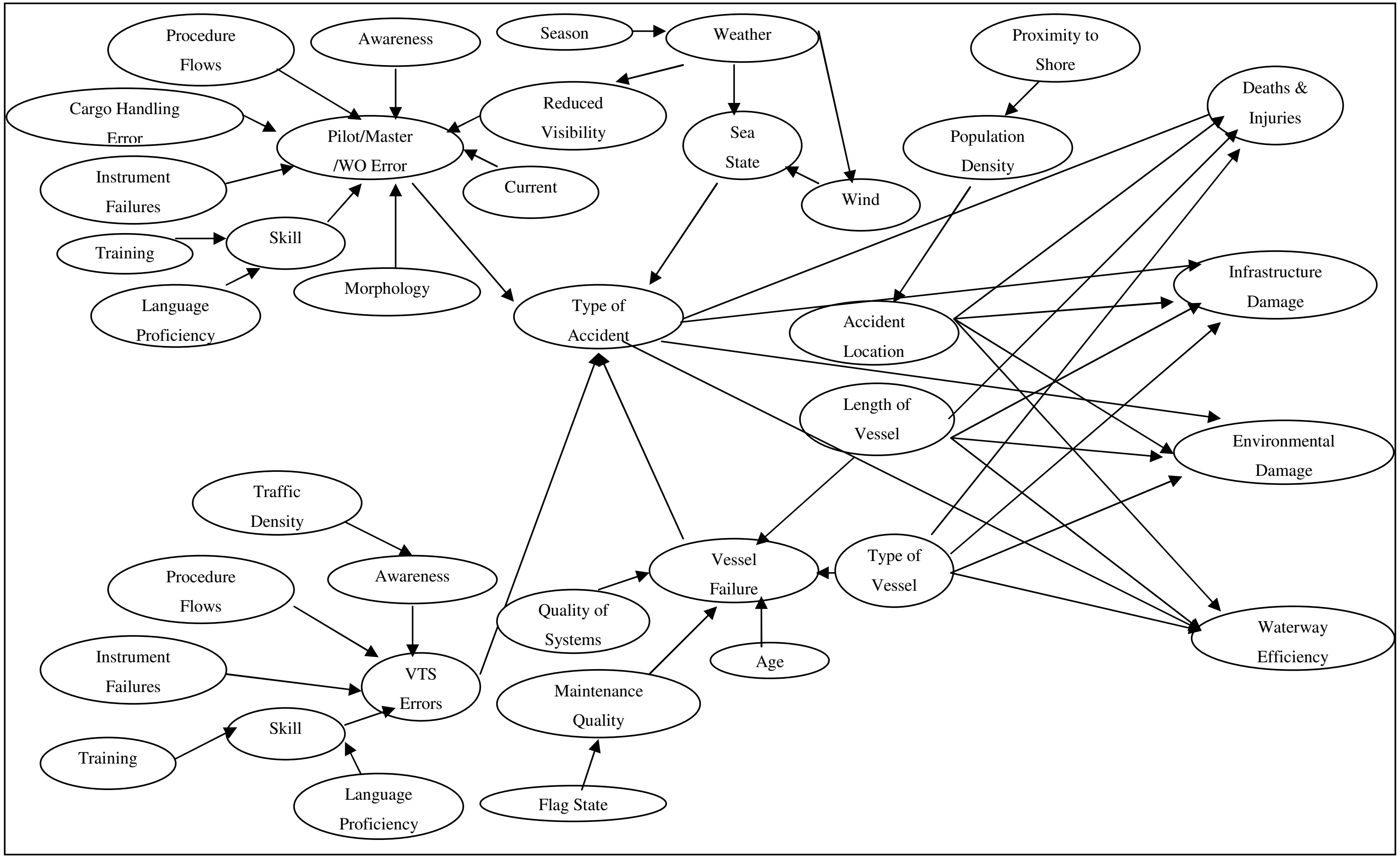


Figure 4.2. The cause – effect diagram of the maritime traffic system in the Istanbul Strait that cause risk

This diagram also provides a comprehensive list of all causes of maritime accidents in the Istanbul Strait, as well as the situation factors that affect the realization of the accidents' consequences. Left side of the diagram displays the relationships between certain situational and organizational factors, which may trigger an accident. Right side of the diagram illustrates the various consequences of accidents and the factors, which have an influence over the realization of these consequences.

In events like terrorism and maritime accidents, there is large uncertainty and limited historical information about events. Willis suggests that estimates of the worst-case outcomes will be very dependent upon assumptions. For this reason, Willis proposes to consider the expected value of the distribution of damage that a terrorism attack may cause [19]. Similarly, maritime accidents are also very rare events and there is also great deal of uncertainty involved about the incidents that trigger the accidents, as well as the consequences of the accidents. Thus, in this study the maritime accident risk is defined as, the product of the probability of occurrence of the accident and the consequences of that accident. Let m be the maritime accidents and j be the various consequences of these accidents;

$$Risk = E[Accident\ Consequence] = \sum_m \sum_j P(Accident_m) * Consequence_{mj} \tag{4.1}$$

However, the consequences of a given realized accident depend on the type of that accident and many factors (some of which are also accident causes) affect the impact level. In other words, both the accident probability and the probability distribution of the impact level of the consequences (given the accident realization) are conditional probabilities conditioned on sets of overlapping (if not the same) set of factors.

Let A_m denote the m^{th} type of accident, C_{mj} denote the j^{th} consequence of the m^{th} type of accident and B denote the possible combinations of values of the accident causing factors (for $l = 1, \ldots, k$ and k is the total number of possible combinations) that determine the level of accident potential in a situation and as well as affect the impact level in once an accident has occurred. Then, the expected value of the accident consequence is as follows;

$$\begin{aligned}Risk = E[AccidentConsequence] &= \sum_m \sum_j \sum_l E[C_{mj} | A_m, B_l\,] P(A_m, B_l\,) \\ &= \sum_m \sum_j \sum_l c_j P\left(C_{mj} | A_m, B_l\,\right) P(A_m, B_l\,) \\ &= \sum_m \sum_j \sum_l c_j\, P\left(C_{mj} | A_m, B_l\,\right) P\left(A_m | B_l\,\right) P(B_l) \end{aligned} \tag{4.2}$$

This conditional risk model consists of four parts:

- c_j : The ratio scale relative value of the j^{th} consequence;
- $P\left(C_{mj} | A_m, B_l\,\right)$: The conditional probability that a particular consequence occurs in a given particular accident A_m, while the situation factors which affect the impact level in this accident are at setting B_l ;
- $P\left(A_m | B_l\,\right)$: The conditional probability that a particular accident A_m occurs given that the situation factors influencing accident occurrence are at setting B_l ;
- $P(B_l)$: The probability that a certain combination of accident/consequence causing factors (with each individual factor achieving a specific setting) occurs in the system.

To perform an assessment of the risk of an accident using this model, each term in the probability model needs to be carefully estimated.

$P(B_l)$ could be estimated using a simulation model supplemented with meteorological conditions. Unfortunately, no such comprehensive simulation model was available, nor was attempted to be developed in this study. Additionally, the aim of the study is not solely and precisely to measure the risk value stemming from general and generic maritime accidents, but rather to focus on the quantitative assessment of the maritime traffic risk in terms of the accident probability and its various types of consequences under various accident and consequence causing factor setting. Then present the relationship between the situational factors and this risk value. Thus, this term is not attempted to be estimated and the conditional probability of the accident has been used. For this study, the situation factors, which affect the impact level and the realization of accident consequences, are subset of the situation factors which causing the accident itself.

But, there might be the situations which both situational factors are the same, or consisting of different factors. In this study, as displayed in Figure 4.3,

- $P(A_m|B_l)$ is estimated using an econometric model (i.e. the logit model) as fully described in the Section 4.2. However, the weights of certain accident causing factors, which are not included in the logit model, are estimated by using an AHP model, and then these factors are incorporated in the logit model.
- $P(C_{mj}|A_m, B_l)$ is estimated based on experts judgments, utilizing questionnaires, as explained in the Section 4.3. An AHP model is deployed to quantify the situational factors, some of which are qualitative in nature (such as accident location or vessel type).
- c_j is estimated relatively based on the experts judgment as a result of the pairwise comparisons shown in the Table 6.17.
- Correspondence analysis provides insights over the relationship between accident types and various factors, to facilitate the determination of variables (in logit model) and criteria (in AHP Models) to be included in this study.

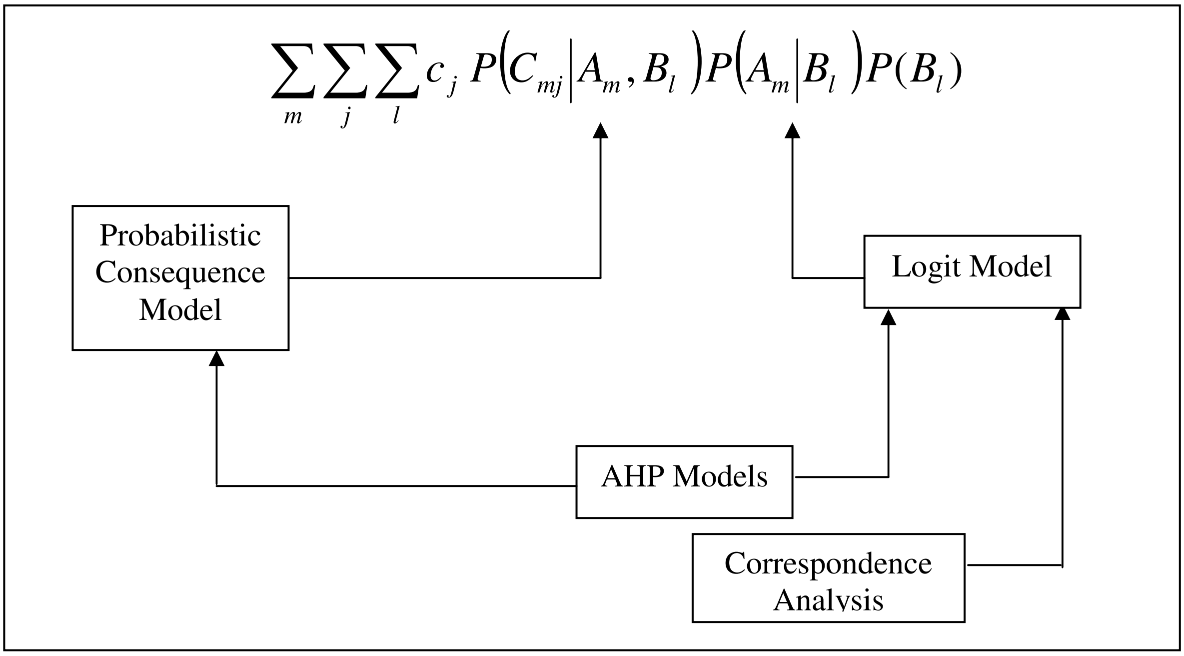


Figure 4.3. The interrelationships of the developed models

There are mainly two advantages of using this formulation to define the maritime accident risk. Firstly, it gives the opportunity to compare and aggregate maritime accident risk. In other words, through this formulation, it is possible to compare the risk of a specific type of accident and consequence with another. Secondly, this definition offers a clear mapping among risk and activities and efforts to managing or reducing the risk (that is, effects of risk mitigating measures can be investigated and evaluated through their quantitative effects on the defined risk function).

4.2. The Maritime Accident Econometric Model

The logit model described in Section 3.2 is quite suitable to represent the likelihood of the occurrence of a maritime accident as a vessel moves through the Istanbul Strait: Y_i is to denote the occurrence (or non occurrence) of an accident during the transit of vessel *i*, while vector $X_i = (X_{li}, l = 1,\ldots,K)$ are to represent the various accident causing factors influencing the vessel *i* during its transit; P_i is the probability of a maritime accident in the Istanbul Strait during the transit of vessel *i*. It then remains to estimate the parameter set $\beta = (\beta_l, l = 1,\ldots,K)$, where *l* denotes the accident causing factors (*l*=1,...,*K*), as the parameters of the logit function based conditional accident probability function, conditioned on the given levels ***X_i*** of the various factors influencing accident probability. Data associated with past accidents is to be deployed in the estimation of the parameter set $(\beta = \beta_l, l = 1,\ldots,K)$, where *l* denotes the accident causing factors (*l*=1…K).

$$P_i = P(Y_i = 1 | X_i) = \frac{1}{1+e^{-(\beta_0+\beta_1 X_{1i}+\beta_2 X_{2i}+\ldots+\beta_k X_{ki})}} = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}}$$

$$L_i = \ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_k X_{ki} + u_i \tag{4.3}$$

Equation 4.3 represents what is known as the (cumulative) logistic distribution function. It is easy to verify that as Z_i ranges from -∞ to +∞, P_i ranges between zero and one and that P_i is nonlinearly related to Z_i (i.e. X_i), thus satisfying the two requirements emphasized earlier [32].

(1 - P_i), the probability of not having an accident during the transit of a given maritime vessel *i*, is

$$\begin{gathered} 1-P_i=\frac{1}{1+e^{Z_i}} \\ Z_i=\beta_0+\beta_1X_{1i}+\beta_2X_{2i}+\ldots+\beta_kX_{ki}+u_i \end{gathered} \tag{4.4}$$

Therefore,

$$\frac{P_i}{1-P_i}=\frac{1+e^{Z_i}}{1+e^{-Z_i}}=e^{Z_i} \tag{4.5}$$

where $\frac{P_i}{1-P_i}$ is called odds ratio in favor of maritime accident [32].

The logit model given in Equation 4.3 has another intuitive interpretation: β_l, the slope, measures the change in logit (L_i) for a unit change in X_{li}. Additionally, using calculus, it can be shown that,

$$dP_i/dX_{li}=P_i(1-P_i)\beta_l \tag{4.6}$$

which shows that the rate of change in probability with respect to X_{li} (e.g. marginal effect of the independent variable) involves not only β_l, but also the level of probability from which the change is measured. Moreover, once the logit (L_i^*) is estimated, by taking the antilog of this estimated logit, the odds ratio, (that is $P_i/1-P_i$) is obtained.

$$\frac{\hat{P}_i}{1-\hat{P}_i}=e^{-\hat{\beta}_0+\hat{\beta}_1X_{1i}^*+\ldots\hat{\beta}_kX_{ki}^*} \tag{4.7}$$

This means that, it is possible to calculate the percent change in odds for a unit increase in a given independent variable. In general, if the antilog of the l^{th} slope coefficient is taken and then one is subtract from it, and, the result multiply by 100, the percent change in odds for a unit increase in the X_l is obtained as shown in Equation 4.8 [32].

$$\% \frac{d(\frac{\hat{P}_i}{1-\hat{P}_i})}{dX_{li}} = (e^{\hat{\beta}_l} - 1) * 100 \tag{4.8}$$

4.2.1. Accident Causing Factors Included in the Logit Model

Actually, the estimation of the β parameters is then quite similar to a statistical regression process. So, not surprisingly, the choice of the independent variables (i.e. X_{li}, l=1,...,K) to be used is a very critical step. If important variables are excluded, poor or misleading findings may result.

Or and Kahraman [53] stated that the following characteristics and local conditions have been especially emphasized as possible accident causing factors:

- Types and characteristics of the vessels passing through the Strait
- Meteorological/environmental conditions (such as rain, wind, visibility, currents)
- The Strait naval traffic density and the geographical characteristics of the Strait (such as width, number of bends, sharpness of bends)

Similarly, during the PAWSA process [25] the following accident causing factors were considered as shown in Table 3.1;

- Fleet composition,
- Traffic conditions,
- Navigational conditions,
- Waterway conditions,

In the Istanbul Strait several meteorological factors such as heavy rain, snow and fog act on independently or together to restrict visibility, adversely affecting navigation. Deep and steep coastal structure also contributes to poor visibility for ships passing through in the Istanbul Strait. According to the Article 36 of the Regulations [12], when visibility is 2 nm or less, at any area in the Istanbul Strait, vessels passing through the Strait will keep their radars turned on constantly to provide radar heading. When visibility in the Strait is one nm or less, vessels carrying dangerous cargo and large vessels shall not enter the Strait and the Strait traffic will be operated on one-way basis. When visibility in any part of the Strait is less than 0.5 nm, the traffic flow in the Strait shall be closed in both directions. These specific measures imply the importance of the visibility on the Strait maritime traffic as one of the factor that may impact the accident risk in the Istanbul Strait. Thus, the visibility range in kilometers at transit time of the vessel measured by Kirec Burnu Meteorology Office is included in the model. Similarly, another accident causing factor might be, as suggested by Or and Kahraman [53], the amount of the precipitation at the time of the transit. This value (as measured by Kirec Burnu Meteorology Office in millimeters) is included in the model as well.

The most frequently seen winds in the Strait are those from north and northeast. South winds are usually strong, sometimes reaching to gale force and causing Orkoz current in the Istanbul Strait [4]. Accordingly, as pointed out by Or and Kahraman [53] and also presented by PAWSA study [25], the transit time wind speed in kilometers per hour (measured by Kirec Burnu Meteorology Office) is included in the model.

Darkness is one of the major causes of maritime accidents and undesirable consequences, not only in confined waters but also upon the high seas. In daytime and in a visual situation it is easier to determine speed and distance, and likewise to notice any change of aspect of other vessels around. To determine distance and understand actions and intentions of other vessel is rather difficult at night and can even lead to confusion as visibility naturally deteriorates. Therefore navigating in darkness, even on a clear night, may require special care. One advice in the Admiralty publication, The Black Sea Pilot, states "*no stranger should attempt to navigate the Strait by night*" [54]; this is a sincere warning for all those interested in safer navigation in the Istanbul Strait, as darkness is one of the dominant factors on maritime accidents in the Strait. It should also be noted that in case of an accident realization in darkness, measures to reduce or avoid negative consequences will also be greatly hindered. Therefore, the transit time (i.e day or night) of the vessel is included in the model (as a binary variable) as an accident causing factor.

Due to the morphological characteristics of the Istanbul Strait, vessel characteristics (such as length, tonnage, draught of the vessel) should be considered and included in the model, as also suggested by Or and Kahraman [53]. In this respect, the results of the International Navigation Association (PIANC) study for narrow channels are also noteworthy. This study shows that vessels of 155 m and above in length, proceeding reciprocally and entering a bend at the same time, are most likely to touch one another after they start rounding the bend [1]. Therefore, the length of the vessel (in meters) is included in the model, as one of the accident causing factor. In this context, the current application of the Regulations [12] with regard to larger vessels is as follows;

- Tankers of 200 meters and above in length can effect their passage through the Strait during daytime only,
- Tankers of 250 to 300 meters range in length can only pass through after temporarily suspension of the two-way traffic and hence one-way traffic is regulated,
- Vessels of 300 meters and above in length are subject to specific terms and conditions based on the safety measures of the Turkish Administration.

In this regard, vessel type is suggested as one the key accident causing factor, widely in the literature [25, 53]. It should be also noted that in case of an accident realization, the type of the vessel and its cargo will greatly impact the negative consequences of the accident. Thus, five binary variables, as shown in Table 4.1, are defined in the model to represent the type of the vessel transiting through the Strait.

As shown by Or et all [30], local maritime traffic density has significant effects on the number of maritime accidents in the Istanbul Strait. Ferries, intra-city passenger vessels, fast ferries, passenger boats engaged in regular scheduled or unscheduled trips, pleasure crafts, fishing boats, agent boats, tug boats and all other similar vessels constitute the local traffic. A recent study by Karayakali and Mırık shows that there are around 2500 local vessel movements during a day in the Istanbul Strait [3]. Based on the result of this study, the local traffic intensities with respect to the time of the day (in two hours intervals) are calculated and included in the logit model.

A pilot is a local and experienced mariner, who guides vessels through dangerous or congested waters, such as harbors or waterways. The maritime pilot's role is to assist the master of a vessel during the ship's passage to and from a berth in a given pilotage area, by providing local knowledge of navigational and operational matters, combined with specialist ship-handling experience. Maritime pilots are one of the main elements which provide maritime safety in high risk marine environments. According to the Montreux Convention, pilotage is optional in the Istanbul Strait. Mitropoulos underlined the importance of skill, experience and local knowledge, while transiting the Turkish Straits and declared the Straits to be the "spiritual home" of pilotage [55]. Therefore, the pilotage status during the transit of a vessel is included in the model as a binary variable (i.e. pilot on board corresponds to one and zero otherwise).

In summary, as a consequence of the above arguments and as a result of the elicitation sessions with experts (such as dock and harbor authorities, captains, pilots and VTS officials), the factors denoted in Table 4.1 are taken as the independent variables of the logit model.

As a result, the following logit model is developed, in order to estimate the conditional probability of a maritime accident during the transit of a given vessel *i* (and given the levels of the considered and above described accident causing factors).

$$\begin{aligned} P_i &= P(Y_i = 1 | X_{li}) = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}} \\ Z_i &= \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \\ &\quad \beta_8 X_{8i} + \beta_9 X_{9i} + \beta_{10} X_{10i} + \beta_{11} X_{11i} + \beta_{12} X_{12i} + u_i \end{aligned} \tag{4.9}$$

Using this methodology, it is also possible to estimate the conditional probability of a specific type of an accident, with the binary variables as the dependent variable (Y_i = ACCTYPE$_i$) shown in Table 4.2.

Table 4.1. Variables included in the logit model

Accident Causing Factor	Variable (X_{li})	Remarks
Transit Time	X_1	It takes one if the transit time is between sun rise and sun set, zero otherwise
Precipitation	X_2	The amount of precipitation during the transit time in millimeters
Visibility	X_3	Sighting distance in kilometers
Wind Speed	X_4	Wind speed in m/sec during the transit of the vessel
Pilot Utilization	X_5	It takes the value of one, if pilot is onboard during the transit, zero otherwise
Vessel Length	X_6	Length of vessel in meters
Local Traffic	X_7	Local traffic intensity during transit time.
Vessel Type	Binary variable for the vessel type;	
	X_8	Equals to one, if the vessel is a passenger ship
	X_9	Equals to one, if the vessel is general cargo ship
	X_{10}	Equals to one, if the vessel is LNG and LPG tanker
	X_{11}	Equals to one, if the vessel is carrying dangerous cargo
	X_{12}	Equals to one, if the vessel is tanker

For each type of accident;

$$\begin{aligned}P_i &= P(ACCTYPE_{ji}=1|X_{li}) = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}} \qquad j=1,\ldots,6\\ Z_i &= \beta_0+\beta_1X_{1i}+\beta_2X_{2i}+\beta_3X_{3i}+\beta_4X_{4i}+\beta_5X_{5i}+\beta_6X_{6i}+\beta_7X_{7i}+\beta_8X_{8i}+\\ &\quad \beta_9X_{9i}+\beta_{10}X_{10i}+\beta_{11}X_{11i}+\beta_{12}X_{12i}+u_i\end{aligned} \tag{4.10}$$

In the logit function, binary variables associated with LNG and LPG tankers (X_{10}) and with vessel carrying dangerous cargo (X_{11}) are not deployed, in order to prevent the perfect collinearity or dummy trap. If a qualitative variable has *n* categories (in this study vessel type has five categories), it is suggested to introduce only *n*-1 binary or dummy variables [32]. Moreover, since the accident data set deployed (covering all Istanbul Strait maritime accidents in the 1995-2004 period) contains no accidents involving LPG/LNG tankers, nor vessels carrying dangerous cargo, the logit model is unable to estimate coefficients for these variables. Therefore, these variables are not introduced into the general logit and other accident type logit models.

Table 4.2. The dependent variables' definition for the accident types

$$ACCTYPE = \left\{ \begin{array}{l} ACCTYPE_1(A_1) = \left\{ \begin{array}{ll} 1 & Collision \\ 0 & o/w \end{array} \right\} \\ ACCTYPE_2(A_2) = \left\{ \begin{array}{ll} 1 & Contact \\ 0 & o/w \end{array} \right\} \\ ACCTYPE_3(A_3) = \left\{ \begin{array}{ll} 1 & Stranded \\ 0 & o/w \end{array} \right\} \\ ACCTYPE_4(A_4) = \left\{ \begin{array}{ll} 1 & Fire \\ 0 & o/w \end{array} \right\} \\ ACCTYPE_5(A_5) = \left\{ \begin{array}{ll} 1 & Foundered \\ 0 & o/w \end{array} \right\} \\ ACCTYPE_6(A_6) = \left\{ \begin{array}{ll} 1 & Hull\,Machine\,Failure \\ 0 & o/w \end{array} \right\} \end{array} \right\}$$

These models have been solved via the software EViews 5.0 [56] based on the data, which is derived from the accident records between 1995-2005 (Appendix F), obtained from Under-Secretariat for Maritime Affairs, along with the transit vessel traffic of the year 2005 at Istanbul Strait.

Additionally, the probabilistic arrival processes of vessels in the Istanbul Strait, based on vessel types and characteristics of the year 2005 transit passages, are taken as baseline for the generation of the data for the year 1997-2003 transit passages, as discussed in Chapter 6. Due to the size of the full data (a matrix of 386,575 by 19), it is not possible to provide the complete data set. But, in order to give a flavor of it, a sample of the data format is presented in Table 4.3 and in Appendix F as well. Data collection is discussed in the Chapter 6. The validation and the results of the model are discussed in Chapter 5 and 6 respectively.

Table 4.3. Sample data set of the logit model

i	Y_i	X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	X_{7i}	X_{8i}	X_{9i}	X_{10i}	X_{11i}	X_{12i}	A_{1i}	A_{2i}	A_{3i}	A_{4i}	A_{5i}	A_{6i}
1	0	1	0	20	1.7	1	182	28.92	0	1	0	0	0	0	0	0	0	0	0
2	0	0	0.3	10	5.3	0	97	0.24	0	0	0	0	1	0	0	0	0	0	0
3	1	1	1.6	10	2.3	1	73	29.08	0	1	0	0	0	0	0	0	0	1	0
4	0	0	3.1	10	1.2	0	190	9.58	0	0	0	1	0	0	0	0	0	0	0

4.2.2. Potential Accident Causing Factors Not Included in the Logit Model

Since the choice of the independent variables (i.e. X_{li}, *l*=1,...*K*) to be used in the model is a very critical step, ideally it is desirable to include all potential accident causing factors in the model. However, in reality, primarily due to the scarce data about some of the factors and also due to modeling difficulties, some potential accident causing factors have not been included in the model. Accordingly, the following factors are not incorporated into the logit model.

As pointed out by some earlier studies [25,53] the waterway conditions or specifically the geographical characteristics of the Istanbul Strait (such as width, number of bends, sharpness of bends) are considered as key accident causing factors. Accordingly, it was attempted to divide the Strait into eight regions (as suggested by Kahraman and Or [53]) and define a binary variable for each region as follows;

$$Accident\_\mathrm{Re}\,gion_{ni} = \begin{Bmatrix} 1 \quad if \quad an \quad accident \quad occured\ in\ region\ n \\ \quad during\ the\ transit\ of\ vessel\ i \\ 0 \quad o/w \end{Bmatrix} \quad n = 1...8 \qquad (4.11)$$

Unfortunately, no feasible solution has been obtained with these binary variables. The reason might be, since the dependent variable (i.e. $Y_i = 1$) equals to zero for the accident free transit passages, same as all the corresponding region variables are also zero for the same transit passages. Thus, this perfect match or relatıonshıp does not explain the variation in the dependent variable and prevents the feasible solution. Therefore, the definition of the variable was changed as follows;

$$Accident\_\mathrm{Re}\,gion_{ni} = \left\{ \begin{array}{ll} 1 & if\ no\ accident\ occured\ in\ region\ n \\ & during\ the\ passage\ of\ vessel\ i \\ 0 & o/w \end{array} \right\} n = 1...8 \qquad (4.12)$$

Similarly, no feasible solution was obtained for this modeling. In order to compensate for the non-inclusion of location/region in the logit model, in Chapter 6, a variation of the accident probability over Strait regions, based on accident statistics and correspondence analysis is introduced and examined.

Another important prevalent factor suspected of causing/triggering maritime accidents in the Strait is the current. Actually, the direction and type of currents in the Strait are numerous: The Black Sea is 20 cm higher than Aegean Sea; therefore, the surface current direction is generally from north to south and can reach up to 7 to 8 knots. But the deep current direction is from south to north due to low seawater density of the Black Sea. Additionally, there are the local counter currents and the Orkoz current, which is caused by strong southerly winds, all increasing the difficulty of navigation in the Istanbul Strait. Unfortunately, the current type and speed in the Istanbul Strait depend on the region. Thus, it has not been possible to model and determine the effect of current over a maritime accident in the Istanbul Strait.

Another key factor that may have impact over the accident risk is the flag state of the vessel considered. Flag states or governments are responsible for implementing the legislation adopted by the IMO; however the problem is that some countries lack the expertise, experience and resources necessary to do this implementation properly. Others may place enforcement fairly low down their list of priorities. The result is that accident and casualty rates vary enormously from flag to flag. Some fleets have accident rates that are a hundred times worse than some others.

During 1995-2004 period, among the 188 vessels which were involved in an accident in the Istanbul Strait, nearly one third were Turkish flagged vessels, (including local vessels such as passenger ships, leisure boats and fishing vessels), while nine per cent of the vessels belonged to Malta and 7.5 per cent carried the Cambodian flag. Thus, it is important to seek, determine and quantify the relation between accidents and the vessel flag states.

Summary of the port state controls are published as “Black – Grey – White Lists” by regional MOU Organizations. In this list the performance of each flag state, called excess factor, is calculated using a standard formula. These excess factors could be used as an independent variable in the logit model; unfortunately, it was not possible to obtain the flag state data for the accident free transit passages of the year 2005. In order to compensate for the non-inclusion of the flag state of the vessel in the logit model, in Chapter 6, the relationship between the flag states and accidents are examined by correspondence analysis.

4.3. The Probabilistic Consequence Model for Maritime Accidents

The accidents themselves result in a range of consequences such as human casualty, infrastructure damage, environmental damage and negative impact over the waterway efficiency. Interviews with various experts suggest that these consequences are directly dependent on the type of accident, vessel and cargo involved, and location of the accident. Moreover, the following accident-consequence relation table is obtained with respect to the three accident classes considered in this study: collision, contact and stranding. Once an accident has occurred, the probability of a consequence type and the level of its negative effects are assumed to depend on the factors in Table 4.4.

During the development of the model, first the probability of consequence j being realized as a result of accident type m (A_m), where the situational factors, which affect the impact level in this accident, are at level $l(B_l)$, is assumed to have the following functional form [21].

$$P(C_{mj} | A_m, B_l) = \rho_{mj} * e^{\beta * B_l} \quad \forall m, j, l \tag{4.13}$$

where β is a vector of parameters and ρ is the normalization factor.

Table 4.4. The consequences of the accidents considered in the model

	Human Casualty	Infrastructure Damage	Environmental Damage	Waterway Efficiency
Collision	X		X	X
Stranded		X	X	X
Contact	X	X	X	X

Then, in line with this model, situational factors, which affect the consequence type and the level of its negative effects, are determined (through a series of interviews with various experts on maritime activities and accidents). The factors shown in Table 4.5 are further discussed in Section 4.4.2.

Table 4.5. The situational factors affecting the consequence type and the level of its negative effects

Situational Factors	Variable (B_l)	Possible Levels/Status
Type of the first vessel and its cargo status	b_1	Full Tanker, Empty Tanker General Cargo, Passenger
Length of the first vessel	b_2	0-50 m , 50-150 m 150-250 m, Above 250 m
Type of the second vessel and its cargo status	b_3	Same as b_1
Length of the second vessel	b_4	Same as b_2
Accident location	b_5	Istanbul Strait divided into three regions as shown in Figure 4.6

These situation factors are qualitative in nature (such as vessel type and cargo status or accident location) or categorical variables (vessel length). Therefore, cardinal value should be determined (or being quantified) to these variables to compute the probability of an accident consequence in accordance with Equation 4.13. This quantitative representation could be accomplished in many ways, such as asking experts to provide a cardinal value for each factor. In this study, an AHP model is developed to quantify these qualitative factors as discussed in Section 4.4.2.

In order to demonstrate how the parameters and normalization factors of Equation 4.13 can be determined through the elicitation of expert judgment, consider the collision of two full loaded tankers, (both in the 50-150 length range) at the south entrance of the Istanbul Strait. As a second scenario, let us assume a similar collision with one of the tankers being empty. Let us consider and compare the probability of a consequence type *j* being realized as a result of these two accidents. These two situations can be shown as follows;

1^{st} *Situation*

$$P(C_{1j} / A = collision, b_1 = Full Tan\text{ker}, b_2 = 50-150, b_3 = F.Tan\text{ker}, b_4 = 50-150, b_5 = 1)$$

2^{nd} *Situation*

$$P(C_{1j} / A = collision, b_1 = Empty Tan\text{ker}, b_2 = 50-150, b_3 = F.Tan\text{ker}, b_4 = 50-150, b_5 = 1)$$

where C_{1j} denotes the j th consequence type given a collision type accident. In this specific example C_{11}, C_{13}, C_{14} would denote the negative effects of a collision accident on human casualty, environmental damage and waterway efficiency respectively, in accordance with Table 4.4.

An examination of the relative probabilities of consequence types (i.e. human casualty, infrastructure damage, environmental damage and waterway efficiency) reveals the convenience of this form. The relative probability is the ratio of the consequence types' probabilities, specifically,

$$\frac{P(1^{st}\ Situation)}{P(2^{nd}\ Situation)} = \frac{P\left(C_{mj}) / A_m, B_1\right)}{P\left(C_{mj} / A_m, B_2\right)} = e^{(B_1 - B_2)\beta} \tag{4.14}$$

where ($B_1 - B_2$) denotes the difference vector (that is the type of the first vessel involved in the accidents) between the situation attribute vectors associated with the two accident scenarios. Thus, the relative probability of each consequence type (given a specific accident occurrence) regarding the two considered scenarios, depends solely upon the difference between the two situations, as denoted by the difference of their 'situation' vectors and the parameter vector $\boldsymbol{\beta}$. Therefore, if each question in the questionnaire given to the experts involves the assessment of the relative likelihood of a consequence in two distinct accident situations, the response of the expert would allow the estimation of the parameter vector $\boldsymbol{\beta}$, without considering the absolute level of consequence likelihood.

Multiple experts are referred to each questionnaire, so there are multiple responses to each question. Let the questions be indexed by o (o=1,...,n) and experts be indexed by v (v=1,...,p), so that the experts' responses can be denoted $z_{o,v}$. To pool the expert responses for a given question, the geometric mean of the expert responses is taken to obtain,

$$(\bar{z}_o) = \left(\prod_{v=1}^{p} z_{o,v} \right)^{1/p} \tag{4.15}$$

The geometric mean is appropriate as the responses represent ratios of probabilities. Thus, the $\bar{z}_o$ is the grouped expert estimate of the relative probability of a consequence in two distinct situations given by the o-th question, while the model gives the relative probability as $\exp\{\underline{\beta}^T \underline{D}_o\}$, where $\underline{D}_o$ is a vector representing the difference between the two situations in question o. This gives the basis for the regression equation used, specifically

$$\ln(\bar{z}_o) = \underline{\beta}^T \underline{D}_o + \varepsilon, \tag{4.16}$$

where ε is the residual error term.

Assuming that ε is normally distributed, this equation is a standard multiple linear regression, where the grouped expert response is the dependent variable, $\underline{D}_o$ is the vector of independent variables, $\underline{\beta}$ is a vector of regression parameters and ε is the error term. Using a standard inference procedure for multiple linear regression, estimates for the parameter vector $\underline{\beta}$ are obtained.

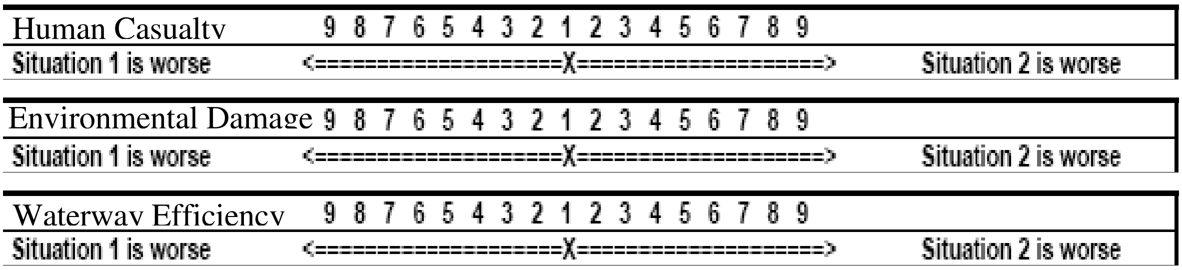
To assess this probability, experts are asked to compare two accident situations for three different types of accidents (i.e. collision, stranded and contact), using the scale provided in Figure 4.4 [21]. The expert is asked to consider two situations in which only one factor is changed. A typical example question is as follows:

Sample Question

- Comparing the two accident situations displayed in Table 4.6, how would you assess the relative likelihood of the damage/consequence types presented in Figure 4.4 as a result of collision type accident?

Table 4.6. Sample situations for consequence analysis scenarios

Situation 1		Situation 2
50-150 mt	X1: The length of the 1st vessel	Same
50-150 mt	X2: The length of the 2nd vessel	Same
Full Tanker	X3: The cargo status and/or type of the 1st vessel	Empty Tanker
Full Tanker	X4: The cargo status and/or type of the 2nd vessel	Same
1st Region	X5: Accident Region	Same



Human Casualty 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9
Situation 1 is worse <===================X===================> Situation 2 is worse

Environmental Damage 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9
Situation 1 is worse <===================X===================> Situation 2 is worse

Waterway Efficiency 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9
Situation 1 is worse <===================X===================> Situation 2 is worse

Figure 4.4. The comparison scale for the consequence analysis scenarios

The situation presented in the sample question is actually the comparison of the effects of the collision of two full tankers with the collision of one full tanker with an empty one, while the accident place and the length of the vessels remain the same.

The experts are asked to complete a booklet of 63 such questions and the responses received are presented in Appendix J. The responses are given according to the scale displayed in Figure 4.4. The feedbacks obtained from a set of 13 experts are analyzed using statistical regression. These experts are captains/masters (seven such experts), officials at Under-Secretariat for Maritime Affairs (two such experts) and officers at Coast Guard (two such experts) and managers at shipping companies (two such experts).

Finally, as a last step of the consequence analysis, the adverse effects of a given accident (i.e. c_j) have to be determined and quantified. The main difficulty of the quantification is stemming from finding a common unit for all types of consequences (For example, it is very difficult to set common units to human casualties (i.e. human lives) and infrastructure damage (i.e. monetary loss)). Additionally, the estimation of the cost/damage of the Strait closure or damage caused by oil or chemical spill is non-unique and controversial. Another practical difficulty is to obtain such data for past accidents. For this purpose, experts are asked to make pairwise comparisons among the four accident consequences and then the full pairwise comparison matrix is obtained through the Expert Choice software. The weights of each consequence are than obtained by solving for the eigenvectors. These ratio scale values show the perception of the interviewees over the accident consequences and their relative importance (or worth) with respect to each other, based on their knowledge and experience about maritime accidents in the Strait. The interpretation of the findings is discussed in Section 6.4.3.

4.4. AHP Models for Maritime Accidents

In this study two distinct AHP models are developed. The first model is used to determine the effect of each accident causing factor in the likelihood of an accident in the Istanbul Strait. In this respect, special consideration is given to the factors that could not be covered by the logit model. The second model is aimed at quantifying the situational factors, some of which featured only ordinal levels reflecting their qualitative nature (such as accident location or vessel type), that affect the probability of consequence type and impact level after the occurrence of an accident. In general, an AHP model can include more than one criterion of performance and can integrate all related criteria into a single overall performance score of a system. In this approach, information is decomposed into a hierarchy of criteria and sub-criteria. After forming the hierarchical structure, pairwise comparisons between criteria are made to establish their relative weights, which reflect the relative importance of each criterion, and the performance of a system is rated. Therefore, during the development process of both models, firstly the criteria and sub-criteria are determined, with respect to the overall goal of each model and then the relevant hierarchy is composed. During the pairwise comparisons of the AHP style preferences, a 1-9 scale shown in Table 4.7 is used to express the decision maker's subjective assessment of the relative contribution of criteria with respect to their immediate upper level objective. Then the set of all obtained pairwise comparisons are processed through the Expert Choice software [23], to generate the overall weights of each criteria and sub-criteria, as well as a consistency ratio of the experts interviewed.

Table 4.7. The fundamental scale for making subjective comparisons

Numerical Rate	Verbal Judgment
1	Equal
2	Between Equal and Moderate
3	Moderate
4	Between Moderate and Strong
5	Strong
6	Between Strong and Very Strong
7	Very Strong
8	Between Very Strong and Extreme
9	Extreme
	Decimal judgments, such as 3.5, are allowed for fine-tuning, and judgments greater than 9 may be entered, though it is suggested that they be avoided.

In the implementation of the models;

- First criteria and sub-criteria of the models (i.e. for the first model the potential accident causing factors and for the second model the situational factors which affect the probability of consequence type and its impact level) are determined based on a series of interviews with various experts;
- The hierarchy for each model is established;
- Questionnaires are prepared for the pairwise comparisons of criteria and sub-criteria, using the scale presented in Table 4.7;
- Interviews are held with experts;
- The key issue during the interviews is how to phrase the questions so that the interviewee will correctly comprehend and focus on the comparison indicated. Since the assessment is based on the knowledge or perception of the interviewees, it is required to ensure that the interviewee understands the comparison questions and judge the factors properly. Each question asked is composed of two parts. In the first part, the interviewees are requested to make a comparison, in the second part they are requested to scale the importance of one factor over other from 1 (equal) to 9 (extremely more important).
- The geometric mean is used to aggregate the responses;
- The geometric mean value of each pairwise comparison included in the questionnaires is fed to the Expert Choice software, in order to determine the weights of each factor and also to calculate the consistency ratio,
- If the consistency ratio value is greater than 10 per cent (i.e. inconsistency greater than 10 %), the experts who gave the most inconsistent response with respect to the geometric mean are contacted in order to explain the inconsistency in their original responses and also to obtain revised responses, if possible.
- As a final step, synthesis of the model is carried out. The global weights for each alternative are summed to get its final synthesized weight, or overall priority. In this situation the distributive mode is used.

4.4.1. An AHP Model to Estimate the Likelihood of a Maritime Accident

The main goal of this AHP model is to determine the effect of each accident causing factor in the likelihood of an accident; especially the factors that could not be covered by the logit model. In accordance with the AHP methodology described in Section 4.4 and based on interviews with experts and stakeholders, such as captains, officials at Under-Secretariat for Maritime Affairs and private ship company managers, the following factors are determined as criteria of the model.

- The vessel characteristics: Type, length, draught, age and flag state of the vessel.
- Maritime traffic characteristics: The intensity of the local traffic (e.g. between two shores of the Strait) and transit traffic, as well as the time of passage (namely daytime or nighttime).
- Environmental conditions: Wind speed, visibility, current and precipitation during the passage, as well as the morphological characteristics of the Istanbul Strait.
- Organizational factors: The knowledge or competence of the crew on board, pilot service, navigational aids, Vessel Traffic System (VTS), violation of the regulation enforced and the quality of cargo handling.

After the determination of the criteria and their sub-criteria, the hierarchy in Figure 4.5 is established. Subsequently, the questionnaire presented in Appendix M (Figure M.1 through Figure M.5) consisting of the pairwise comparisons of criteria and sub-criteria, is distributed to 18 experts in the maritime sector and their responses to the carefully selected and worded pairwise comparisons are elicited. These experts are captains/masters (eleven such experts), officials at Under-Secretariat for Maritime Affairs (two such experts) and officers at Coast Guard (three such experts) and managers at shipping companies (two such experts). The responses to each question are pooled by taking their geometric mean. The results are complied within the framework of the AHP to compute the weights of each factor.

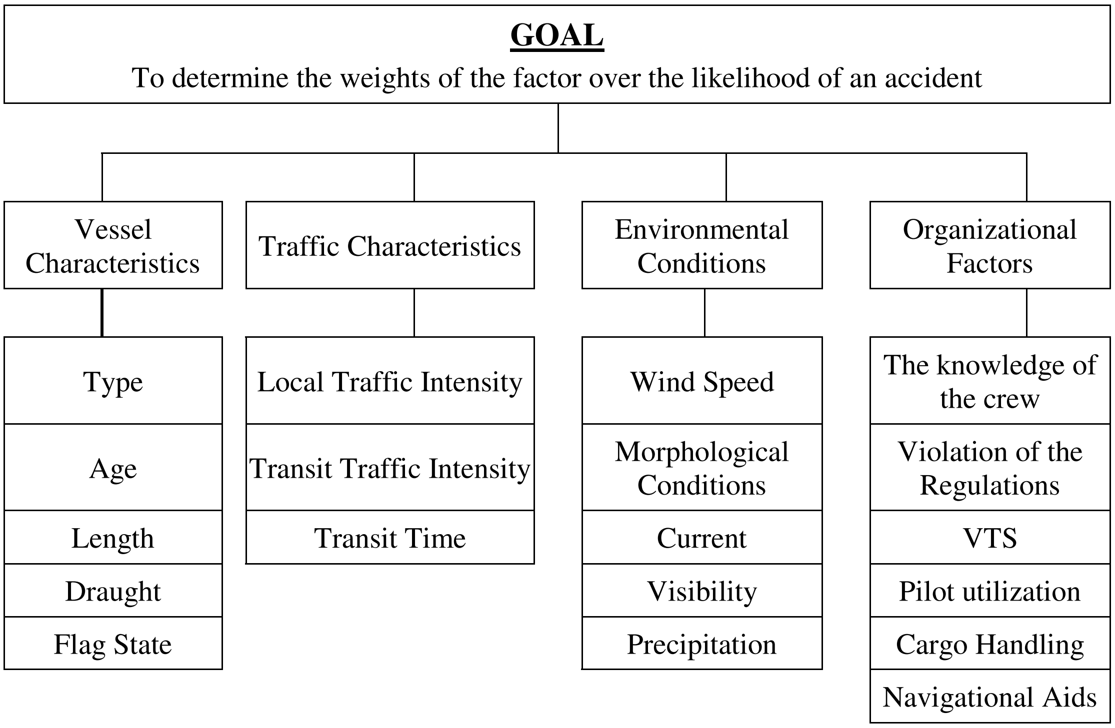


Figure 4.5. The AHP model hierarchy for determining the weights of the factor in a maritime accident

4.4.2. The AHP Model to Quantify the Levels of the Accident Consequence Situation Attributes

The goal of this AHP model is to quantify the situational factors that affect the probability of consequence type and its impact level, after the occurrence of an accident. These factors are mostly in a qualitative nature (such as vessel type and cargo status or accident location), so the values, which are determined by this AHP model, are the quantitative representation of the situation factors. These cardinal values are used in the probabilistic consequence model as the level of situational factors (i.e. B). In order to accomplish this, first a series of interviews are held with various experts in the maritime sector (such as VTS authorities and captains), in order to determine the criteria (situational factors that affect the probability of consequence type and its impact level after the occurrence of an accident). As a result, the following factors are determined as criteria of the model;

- The length of the vessels involved in the accident: This factor is considered in four categories, such 0-50 m vessels, 50-150 m vessels, 150 – 250 m vessels and finally above 250 m vessels.
- The type and the cargo status of the vessel: This factor is considered in four categories, such full loaded tankers, empty tankers, passenger ships and cargo ships.
- The accident region: The Istanbul Strait divided into three regions as shown in Figure 4.6.

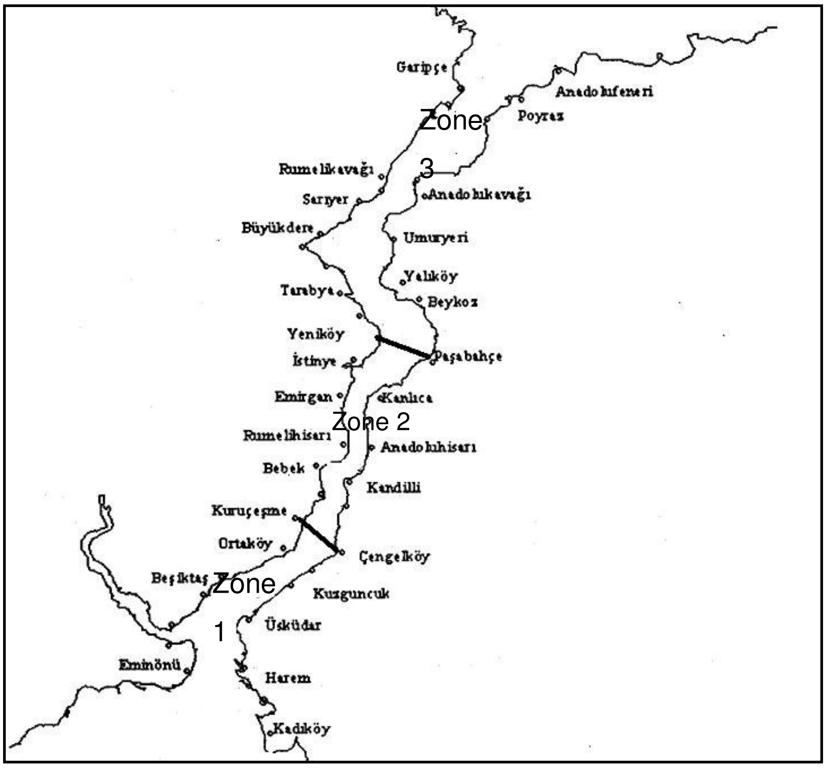


Figure 4.6. The accident regions for probabilistic consequence model

After the determination of the criteria and the sub-criteria, the hierarchy in Figure 4.7 is established. Subsequently, four questionnaires (one for each type of the accident consequence and all displayed in Appendix M, Figure M.6 through M.9) consisting of the pairwise comparisons of the determined criteria and sub-criteria are distributed to five experts (two of them being captains, two of them being officials at Under-Secretariat for Maritime Affairs and one of them being manager in a shipping company) in the field of maritime accidents and related activities and their responses to the carefully selected and worded pairwise comparisons are elicited. The responses to each question are pooled by taking their geometric mean. The results are complied within the framework of the AHP to compute the weights of each factor.

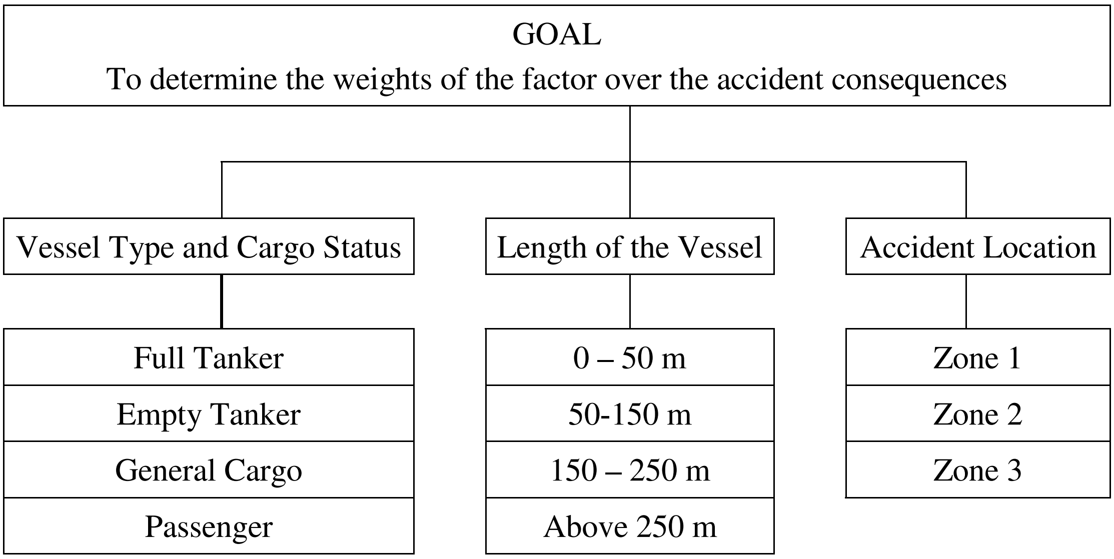


Figure 4.7. The AHP model for determining the weights of the accident consequence factors

5. VALIDATION

Validation is concerned with accurate representation of the real system through the model developed. There are two important goals in the validation process. The first one is to produce a model to represent the real system behavior close enough to be used for experimentation purposes. The second is to build a credible model to be used by managers and other decision makers [57].

As mentioned before, the objective of this study is to investigate the effects and the interrelations of several factors affecting the risk emanating from potential maritime accidents in the Istanbul Strait. In line with this objective, there have been some assumptions and simplifications to facilitate the development and utilization of the logit and probabilistic consequence models. Thus, the developed models do not aim to provide complete representations of the overall system, but to take into account the major components to reflect the important facts and to test the effects of concerned factors on the system through scenario analysis.

For validation purposes, the developed logit model is tested over the data of year 2005, since both accidents and passages of this year are available. Based on the estimated coefficients of any accident or a specific type of accident, the probability of an accident or a specific type of accident is calculated for given set of situational factor levels, such as weather conditions, characteristics of the vessel etc. As an example, consider the transit passage of a general cargo ship of length 115.8 m, on 01st January 2005, at 4:45 AM and without a pilot onboard. The following information is extracted from the year 2005 data based on the above input;

- Wind Speed: 1.20 m/sec
- Visibility: 20 km
- Precipitation: 1.0 mm
- Local Traffic Intensity: 0.24

Then the following probabilities are computed based on the estimated coefficients by logit model (see Table 5.3 and Table B.1 through Table B.5);

- Accident probability: 0.000391309
- Collision probability: 0.000122565
- Contact probability: 0.0000519085
- Stranded probability: 0.000135219
- Hull and machine failure probability: 0.0000235992
- Foundered probability: 0.000000354239
- Fire probability: 0.0000246125

Fortunately the computed accident probabilities are very low; however, as such, they do not provide much useful information to enable to make any comments over the model results nor to validate the model itself. On the other hand, when this procedure is applied to all passages of the year 2005 and the obtained individual probabilities are aggregated, model based annual accident probabilities are obtained (for all passages of the year 2005), which then can be compared with the actual accident statistics of this year. The following results obtained;

Table 5.1. The comparison of the results obtained by the logit model and observed statistics

Type of Accident	Logit Model Estimations	Observed in 2005	Statistics for 8 Years	Average per Year
General	21.50	23	154	19.25
Collision	8.45	6	57	7.125
Contact	2.79	7	19	2.375
Stranded	6.02	5	43	5.375
Foundered	0.36	1	3	0.375
H&M Failure	3.90	2	27	3.375
Fire and Explosion	0.89	2	5	0.625

Another important analysis is the comparison of the time of the accidents (i.e. day or night) that occurred in 2005, with the total estimated accident probability values of the same year with respect to the transit time. This comparison demonstrates how the developed model forecasts the annual accident probability regarding to the time of day. Moreover, similar analysis can be carried out with respect to the type of vessel transited through in Istanbul Strait in 2005, in order to see the competence of the model for estimating the accident probability with respect to vessel type. The results are displayed in Table 5.2.

Table 5.2. Comparison of the logit model results with the 2005 accident statistics

		Day	Night	Cargo	Tanker	Passenger	IMO	Total
Total Accidents	Estimated	7.69	13.81	16.81	3.01	1.67	0	21.50
	Realized	9	14	18	3	1	1	23
Collisions	Estimated	2.39	6.05	6.42	1.12	0.91	0	8.45
	Realized	4	2	5	1	0	0	6
Contacts	Estimated	0.87	1.92	2.33	0.28	0.18	0	2.79
	Realized	3	4	5	2	0	0	7
Strandings	Estimated	1.93	4.09	4.97	0.69	0.36	0	6.02
	Realized	1	4	5	0	0	0	5
H&M Failure	Estimated	2.12	1.78	2.79	0.79	0.32	0	3.90
	Realized	1	1	1	0	0	1	2
Foundered	Estimated	0.18	0.18	0.12	0.24	0	0	0.36
	Realized	0	1	1	0	0	0	1
Fire	Estimated	0.50	0.39	0.89	0	0	0	0.89
	Realized	0	2	1	0	1	0	2

When the results of the logit model are compared with the actual accident statistics of the year 2005, the following observations are made;

- The total number of accidents occurred in the year 2005 is slightly underestimated, (with less than seven per cent error).

- There are overestimations for the number of collision, stranded and hull & machine failure types of accidents.
- On the other hand, the number of contact, foundered and fire & explosions types of accidents are underestimated. However when the results of the logit model are compared with 8 years (1997-2004) statistics presented in Table 5.1, they are close to the average numbers.
- The number of accidents during nighttime and the tankers involved in an accident are accurately estimated by the developed model.
- During 1995-2004 no dangerous cargo-carrying vessel (designated as IMO) has been involved in any accident. Similarly, no passenger ship has been involved in fire accidents in this period. Hence, the logit models (i.e. the general model, the machine and hull failure model and the fire accident model) were unable to estimate coefficients for these types of vessels. The non-inclusion of these two accident types illustrates the importance of the calibration of the estimated parameters. Thus, the model requires to be continuously updated with available data in order to improve its estimation accuracy.

Table 5.3. The sign check for the coefficients of the general accident model

Variable	Coefficients	Sign Check	Significance ($p = 0.1$)
Transit Time	-0.33212	As expected	Significant
Wind Speed	0.202904	As expected	Significant
Precipitation	-0.074817	Not expected	
Visibility	-0.079267	As expected	Significant
Pilotage	-0.679201	As expected	Significant
Vessel Length	0.000312	As expected	
Local Traffic	-0.002638	Not expected	
Passenger	23.52085	As expected	
Cargo	22.11361	As expected	
Tanker	22.10535	As expected	

Another aspect of the logit model, as stressed out by Guajarati [32] is that; "*The expected signs of the regression coefficients and their statistical and/or practical* *significance matters*". Thus, the sanity check in Table 5.3 is performed over the signs of coefficients estimated.

A close examination of Table 5.3 reveals that, except the variables for the precipitation and local traffic, the rest of the independent variables' coefficients signs are estimated as anticipated. Moreover, if the vessel passes through the Strait during daytime (i.e. Transit Time equals to one), the probability of a potential accident decreases significantly. Likewise, when wind speed increases, the probability of an accident increases considerably too. Similarly, when visibility decreases, the accident probability increases significantly. More importantly, if the vessel utilizes the available pilot service (in other words takes a pilot on board), the accident probability decreases drastically. Regarding vessel types, passenger, cargo and tanker type of vessels seem to have higher accident probability. It is clear that if there is no vessel to pass through the Strait, there will be no accident probability. Since no LPG tanker or vessel carrying dangerous cargo has been involved any accident so far, no coefficients are estimated for these types of vessels.

Unfortunately, the signs of two independent variable coefficients, precipitation and local traffic, are not in line with the "usual expectations". In other words, usually more precipitation is expected to lead to more accidents (since visibility is restricted with precipitation). However, even though the estimated coefficient of the precipitation is not statistically significant (p=0.1131), the model results suggest that the probability of accidents be decreasing with increasing precipitation. There might be two reasons for this anomaly: first there may be multicollinearity between the independent variables, especially between visibility and precipitation. Secondly, the master or pilot on board might be more alert or the measures taken by the ship during transit could be stricter if there is a precipitation.

Multicollinearity is a statistical term for the existence of a high degree of linear correlation amongst two or more independent variables in a regression model. In the presence of multicollinearity, it would be difficult to assess the effect of the independent variables on the dependent variable. Multicollinearity may also result in wrong signs and magnitudes of regression coefficient estimates, and consequently in incorrect conclusions about relationships between independent and dependent variables [58]. Multicollinearity is first investigated by checking the correlation between the precipitation and other suspected independent variables through the correlation coefficients displayed in Appendix C. The correlation coefficient between precipitation and visibility is -0.286, which is a relatively large value (compared to the other correlation coefficient values) and negative as anticipated. Menard [59] suggests that much of the diagnostic information for multicollinearity (e.g. VIFs) can be obtained by calculating an Ordinary Least Square (OLS) regression model using the same dependent and independent variables used in the logit model. The Variance Inflation Factors (VIF) show how much the variance of the coefficient estimate is being inflated by multicollinearity. The square root of the VIF illustrates how much larger the standard error is, compared with what it would be if the variable were uncorrelated with other independent variables in the model. A commonly given rule of thumb is that VIFs of 10 or higher may be a reason for concern [60]. The VIF figures for the general logit model data is computed by SPSS 11 [61] and are displayed in Table 5.4.

Table 5.4. The variance inflation factors and the tolerance figures for the independent variables

	Collinearity Statistics			Collinearity Statistics	
	Tolerance	VIF		Tolerance	VIF
Transit Time	0.805	1.242	Passenger	0.387	2.587
Precipitation	0.912	1.097	General Cargo	0.089	11.254
Visibility	0.905	1.105	LPG and LNG Tanker	0.724	1.381
Wind Speed	0.984	1.016	Tanker	0.100	9.958
Vessel Length	0.765	1.307	Pilot Utilization	0.789	1.268
Local Traffic	0.808	1.238			

The results suggest that except the binary variable associated with general cargo vessels, there is no sufficient evidence for multicollinearity among the independent variables based on VIF figures.

Regarding remedies for multicollinearity, one option is dropping one of the "suspected correlated variables" (due to its suppresser effect over the other independent variable) in order to produce a model without multicollinearity. Following this lead, the logit model is run, while excluding the independent variable of visibility from the model, in order to observe the dependency relation between the visibility and precipitation, if there exist one. The results of this run are provided in Table 5.5.

Table 5.5. The results of the logit model run without the visibility variable

Variable	Coefficient	z-Statistic	Probability	Sign Check
Transit Time	-0.368494	-2,250,139	0.0244	As expected
Wind Speed	0.187133	3,682,187	0.0002	As expected
Precipitation	-0.015684	-0.406958	0.6840	Not expected
Pilotage	-0.675316	-3,326,604	0.0009	As expected
Vessel Length	0.000230	0.106407	0.9153	As expected
Local Traffic	-0.002462	-0.930915	0.3519	Not Expected

As can be seen from Table 5.5, there is no significant difference between the results of the model with or without the independent variable of visibility. Still, as statistically insignificant, the signs of the estimated coefficients for the precipitation and the local traffic variables are opposite of the "usual expectations".

Another remedy for multicollinearity is to conduct Factor Analysis or a similar methodology to discover, if observed variables can be explained largely or entirely in terms of a much smaller number of unobserved variables called factors. As a preliminary analysis, it is suggested to check the determinant of the correlation matrix and also correlation coefficients between the variables. For the data of this study, the determinant of the matrix is 0.046, which is greater than the necessary value of 0.00001. Therefore, multicollinearity is not a problem for these data. Another statistics, which shows the measure of sampling adequacy, is the Kaiser-Meyer-Olkin (KMO) statistics. Additionally, KMO statistics illustrates if the factor analysis is appropriate for the data set. Kaiser recommends values greater than 0.5 as acceptable. For the data set of this study KMO statistic is 0.333, which suggest the factor analysis is not appropriate. However, for the same data a similar statistics, Barletts,s Test of Spherecity is highly significant ($p<0.0001$) and therefore factor analysis is appropriate. The results of these statistics are displayed in Table 5.6 [62].

Table 5.6. The KMO and Barlett's test results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.333
Bartlett's Test of Sphericity	Approx. Chi-Square	1190416.495
	df	55
	Sig.	0.000

It is suggested to drop all factors with eigenvalues under 1.0 (Guttman-Kaiser Rule), while keeping enough factors to account 70-80 per cent of the variance [62]. Table 5.7 illustrates the results of the factor analysis (using the Principal Component Analysis for extraction), which is applied to the data set of independent variables displayed in Table 4.1. The results in Table 5.7 suggest retaining eight factors (which are significant) using Guttman-Kaiser Rule and these seven factors account for about 83.583 % of the variance.

The eigenvalues associated with each factor (component) represent the variance explained by that particular linear component in terms of the percentage of the variance explained. It should be clear that the first few factors explain relatively large amounts of variance (especially first factor), whereas subsequent factors explain only small amounts of variance. In the second part of Table 5.7 (labeled Rotation Sums of Squared Loadings), the eigenvalues of the factors after the rotation are displayed. Rotation has the effect of optimizing the factor structure and one consequence for these data is that relative importance of the seven factors is equalized. Before rotation, Factor 1 accounted for considerably more variance than the remaining six (20.013 per cent compared to 13.177, 11.649, 10.423, 9.811, 9.337 and 9.174 per cent), however after extraction it accounts for only 16.957 per cent of variance (compared to 13.079, 12.746, 11.699, 10.452, 9.387 and 9.264 per cent respectively).

Table 5.7. The eigenvalues and the total variation explained

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.201	20.013	20.013	1.865	16.957	16.957
2	1.449	13.177	33.190	1.439	13.079	30.036
3	1.281	11.649	44.839	1.402	12.746	42.782
4	1.147	10.423	55.262	1.287	11.699	54.481
5	1.079	9.811	65.073	1.150	10.452	64.933
6	1.027	9.337	74.409	1.033	9.387	74.320
7	1.009	9.174	83.583	1.019	9.264	83.583
8	0.684	6.214	89.797			
9	0.559	5.077	94.875			
10	0.519	4.723	99.598			
11	0.044	0.402	100.000			

Table 5.8 shows the communalities before and after the extraction. The communality of a variable represents the proportion of the variance in that variable that can be accounted for by all extracted factors. Thus, if the communality of a variable is high, the extracted factors account for a big proportion of the variable's variance. This thus means that this particular variable is reflected well via the extracted factors, and hence that the factor analysis is reliable. When the communalities are not very high, the sample size has to compensate for this. Principal component analysis works on the initial assumption that all variance is common; therefore, before extraction the communalities are all 1.0 [62]. The communalities in the column labeled *Extraction* reflect the common variance in the data structure. For example, it is possible to suggest that 71.9 per cent of the variance associated with transit time is common, or shared, variance.

Table 5.8. The communalities before and after extraction

	Initial	Extraction
Transit Time	1.000	0.719
Precipitation	1.000	0.697
Visibility	1.000	0.684
Wind Speed	1.000	0.936
Vessel Length	1.000	0.759
Passenger	1.000	0.938
General Cargo	1.000	0.979
LPG and LNG Tanker	1.000	0.999
Tanker	1.000	0.971
Pilot Utilization	1.000	0.790
Local Traffic	1.000	0.722

At this stage it is important to determine the number of factors to extract. Kaiser Criterion suggest that if there are less than 30 variables and communalities after extraction are greater than 0.7, or, if the sample size exceeds 250 and the average communality is greater than 0.6, then retain all factors with eigenvalues above 1.0 [62]. Otherwise the scree plot should be used for determining the number of factors to extract. As displayed in Table 5.8 there are two variables, having communalities less than 0.7, while the average communality is calculated as 0.818. The scree plot displayed in Figure 5.1 suggests retaining either two or seven factors. Therefore on both Caiser's criterion and scree plot it is appropriate to retain seven factors after extraction.

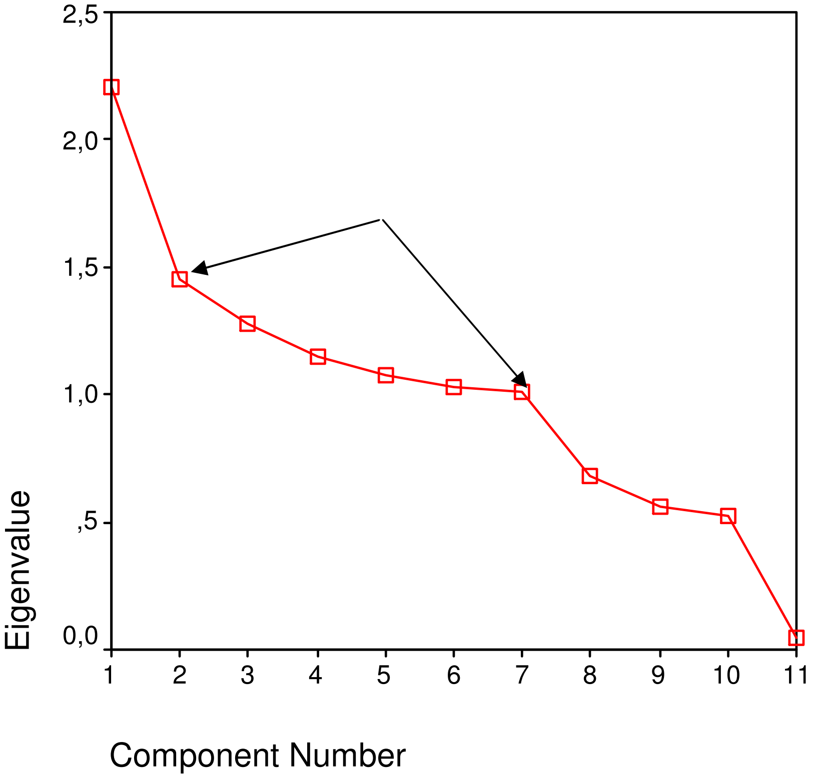


Figure 5.1. The scree plot output of SPSS

Another important output of the factor analysis is the factor loadings, which provide the correlation coefficients between the variables and factors as displayed in Table 5.9 after seven factors extracted. These factor loadings are important for interpretation of the factors, especially high ones. Stevens [63] recommends interpreting only factor loadings with an absolute value greater than 0.4, thus the factor loadings less than 0.4 have not been displayed in Table 5.9.

When the factor loadings in Table 5.9 are examined, following conclusions could be made with respect to the relationship between visibility and precipitation, as well as between transit time and local traffic intensity;

- The loadings on second factor are relatively large for transit time and local traffic intensity. This factor expresses the relationship between transit time (since it equals to one when the transit time is daytime) and local traffic intensity, which will be discussed later in this section.

- Even though their signs are opposite, the loadings on third factor is relatively large for precipitation and visibility. This illustrates that the negative relationship between visibility and precipitation might be accounted by third factor.

Table 5.9. The factor loadings when eight components extracted

	Component						
	1	2	3	4	5	6	7
General Cargo	-0.905						
Tanker	0.852				-0.482		
Transit Time		0.835					
Local Traffic		0.820					
Visibility			-0.783				
Precipitation			0.779				
Passenger				-0.826	0.431		
Vessel Length	0.563			0.573			
Pilot Utilization	0.533				0.690		
Wind Speed						0.954	
LPG and LNG Tanker							0.,982

As a result;

- The determinant of the correlation matrix (0.046) is greater than 0.00001,
- The correlation coefficients between the variables are relatively small as displayed in Appendix C,
- The KMO statistic is 0.333, which suggest the factor analysis is not appropriate for this data set,

- The VIF figures suggest that except the variable of general cargo vessel, there is no sufficient evidence for multicollinearity among the independent variables,
- Since the aim of this study to evaluate the influence of each risk factor over the likelihood of an accident, it is better to keep all independent observed variables in the logit model for determining their marginal effects over the accident probability, instead of explaining them in a smaller set of unobserved factors (by conducting factor analysis).

Similarly, the model suggests that when the local traffic intensity increases, (which implies more ferries or fishing vessels traveling between the two shores of the Strait) the accident probability decreases, which is a contradiction to the general opinion regarding the effect of local traffic over accident probability. Since local traffic during night time is very low, (close to zero) and almost 54 per cent of the past accidents occurred during night time, the model could be establishing such a relation between the accident probability and the local traffic intensity factors, while ignoring the darkness effect for night time accidents. In order to pursue this issue further, the model is solved for only daytime data (e.g. day time passages with day time accidents) and the results in Table 5.10 are obtained;

Table 5.10. The results of the logit model run with only day time data

Variable	Coefficient	z-Statistic	Probability	Sign Check
Wind Speed	0.368954	5.216906	0	As expected
Precipitation	-0.08562	-1.15923	0.2464	Not expected
Visibility	-0.09956	-3.92727	0.0001	As expected
Pilotage	-0.58603	-1.90144	0.0572	As expected
Vessel Length	0.000942	0.291741	0.7705	As expected
Local Traffic	0.009596	2.439967	0.0147	As expected

As can be seen in Table 5.10, in this case (i.e. daytime conditions), the sign of the local traffic intensity coefficient is in line with “expectations” (implying that when the local traffic increases, the accident probability will also increase). Therefore, for accidents occurring during daytime, local traffic intensity is statistically a key factor that may affect the accident probability as suggested by the literature [1,7,30]. This result can also be seen by analyzing the accident times with respect to the local traffic, as shown in Figure 5.2.

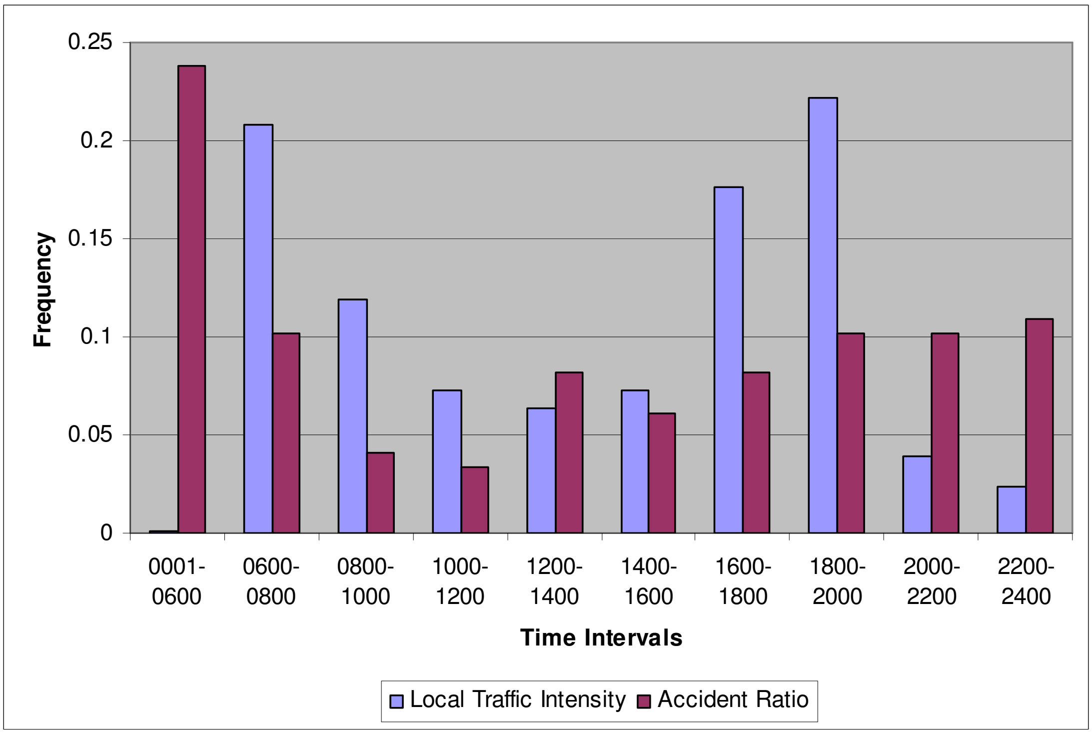


Figure 5.2. The local traffic intensity and the accident time distributions in 1995-2004

During the daytime (i.e. 0600 – 2000), in general, higher local traffic intensity leads to higher accident rates. For instance, the highest daytime accident rates occur in periods 0600 – 0800 and 1800 – 2000, which also feature the highest local traffic intensities. But when the coefficient of the local traffic factor is estimated along with the nighttime data, since 54 percent of the past accidents occurred during nighttime, this important relationship between accident probability and local traffic intensity is clouded.

Similar sign checks are also carried out for all accident types. As an example, the results in Table 5.11 are obtained for collision accidents. In this case, (even though they are not statistically significant), there are three contradictions to the usual expectations, namely precipitation, vessel length and local traffic intensity. As previously stated, the reasons of these anomalies about local traffic and precipitation might be the correlation between visibility and precipitation factors, as well as the darkness effect over the accident, which has an influence over the local traffic intensity and accidents. In addition, collision probability seems to be decreasing with increasing vessel length. One reason for this anomaly might be the lack of accident data, since there are only 53 collisions in the model to estimate the parameters from. The second reason might be high degree of linear correlation amongst two or more independent variables in the regression model, namely multi-collinearity. However, when the correlation matrix provided in Appendix C is examined, it can be seen that the correlation coefficients amongst the all factors are less than 0.4. So it is difficult to state that there is a high correlation amongst the factors. Finally, since there are specific measures taken by the TSVTS Authority for longer vessels during their transit in the Istanbul Strait (in order to reduce the likelihood of an accident), these measures might reverse the effect of vessel length over accident probability, leading to the situation observed in Table 5.11.

Table 5.11. Sign check of the estimated factor coefficients for collision type accidents

Variable	Coefficient	Sign Check	Significance
Transit Time	-0.54244	As expected	Significant
Wind Speed	0.130223	As expected	
Precipitation	-0.53183	Not expected	
Visibility	-0.09897	As expected	Significant
Pilotage	-0.68275	As expected	Significant
Vessel Length	-0.00049	Not expected	
Local Traffic	-0.0051	Not expected	
Passenger	22.07897	As expected	
Cargo	22.10962	As expected	
Tanker	23.77655	As expected	

The rest of the sign check tables for other types of accidents are provided in Table B.1 through Table B.5. As can be seen from these tables, similar anomalies are observed for transit time, vessel length, local traffic intensity, visibility, and precipitation factors. As already mentioned, the first reason might be the lack of accident data for the rest of the accident types in the modes to estimate the parameters from. The second reason might be the multi-collinearity between the factors. It is also important to note that in all models the pilotage and wind speed factors are the most statistically significant factors, while always being in line with the “expectations”. This implies the importance of these factors in the likelihood of accident, which is examined in the following chapters.

6. DATA COLLECTION AND ANALYSIS

The availability of suitable data is very important for risk analysis methodology. When historic data is not available, expert judgment, physical models, simulations and analytical models may be used to generate additional data. In this study, three distinct data compilation methods are used: Expert opinion, databases from various agencies, and simulation model. Expert opinions, extracted through interviews and questionnaires, provide valuable insight into the parameters of the model being developed. The vessel arrival distributions of the simulation model of the Istanbul Strait developed by Ozbas [64] and Almaz [65] are used to generate the accident free passages of 1997-2003 period. Finally, the historic accident data are obtained from the Under-Secretariat for Maritime Affairs [66] and Turkish Marine Research Foundation (TUDAV).

Several national and international agencies keep databases. Some of the data that can be obtained in this fashion are the number, frequency and composition of sea vessels transiting the Istanbul Strait, environmental and meteorological conditions, past accidents and physical and technical characteristics of the Strait. Based on the information obtained from the Under-Secretariat for Maritime Affairs and Turkish Marine Research Foundation (TUDAV), an accident database of the Istanbul Strait, for the 1995 – 2005 period has been established. Moreover, the TSVTS Authority provided the accident free transit ship information for the year 2005 at the Istanbul Strait.

Unfortunately, during the early stages of the accident data collection, it is observed that, (even in the same organization) there is neither accepted standards nor procedures to store the accident data. Furthermore, much dissimilarity over the same accident data has been identified. So, in order to have reliable and consistent accident data for the model, additional efforts were spent to confirm the accuracy and the reliability of data. However, it should also be noted that the collection, storage and as well as comprehensiveness of data has much improved since the establishment of the TSVTS Centre in 2003.

Figure 6.1 is the Entity Relationship Diagram (ERD) that shows the conceptual relationships among the data used in this study.

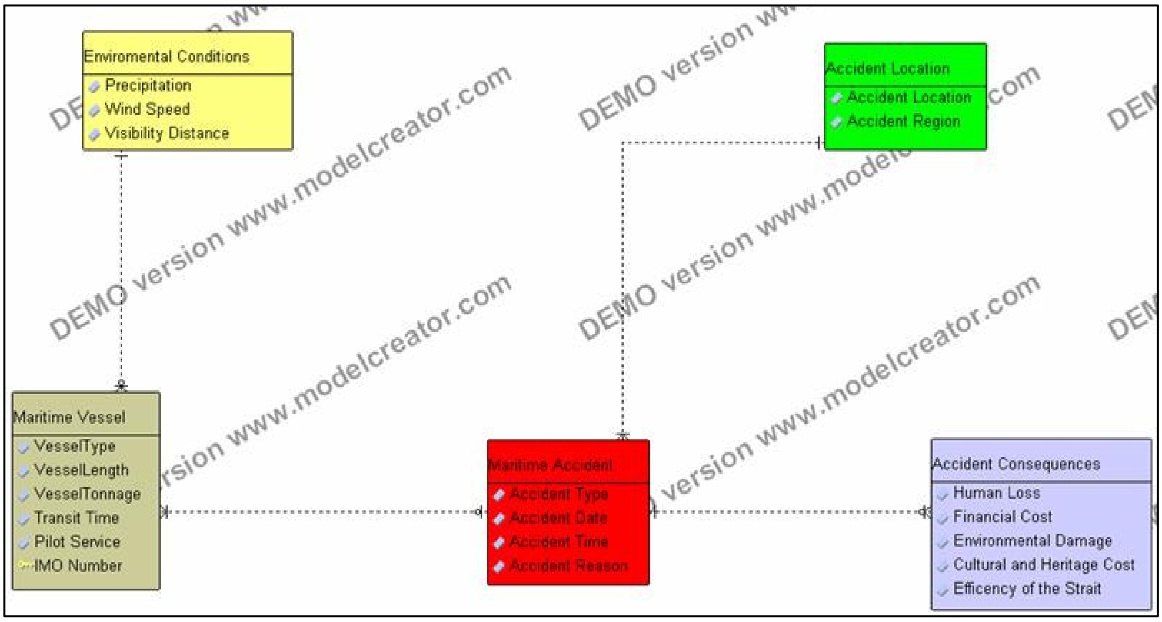


Figure 6.1. Entity Relationship Diagram for the developed model

The following information for the vessels transiting through Istanbul Strait, (including the ones involved in accident) is available in the database;

- Date and time (of the accident, of the transit passage)
- Type of the vessel
- Meteorological conditions during the transit or at time of accident
- Availability of pilot onboard
- Vessel tonnage
- Vessel length
- For each maritime accident recorded
  - Accident location
  - Vessel name
  - Type of the accident
  - Results of the accident
  - Cause of the accident
  - Flag State of the vessel

Unfortunately, the unavailability of certain information or missing data in the 2005 transit passages, such as flag state and tonnage, somewhat hampered the efforts to establish all the links between passages with and without accidents, which is very important for the next step of this study (curiously this data is available at the Agency, but not open to public).

Between 1995 and 2004, 147 maritime accidents occurred in the Istanbul Strait. 190 vessels were involved in these accidents and 28 of the vessels were the small fishing vessels, pleasure boats or ferries running between two shores of the Strait (in other words, part of the local traffic). These vessels are excluded from the logit model. Moreover, due to various reasons, such as inconsistency and lack of certain information (time, the characteristics of the vessel or accident location) 8 vessels' data also had to be disregarded. Furthermore, the accident data is associated with 1995-2004 years' maritime activities, while the accident-free transit data of just one year (2005) has been available. In order to compensate this important imbalance, 1997-2003 years accident-free transit are artificially generated, based on the transit vessel arrival distributions (for each vessel type) obtained from the year 2005 transit data by Özbaş and Almaz [64,65], using statistical techniques. The computer program deployed in this artificial vessel generation is displayed in Figure 6.2.

```
For i=1997 to 2003, begin
    Determine the number of vessels for type and length considered;
        For j=1 to number of vessels for each type length combination;
            Generate inter-arrival times based on arrival processes at Appendix A;
        end j;
    Compute transit date and time for year i;
    Determine the weather conditions and local traffic data for transit time;
end i;
```

Figure 6.2. The pseudo code for generation of artificial accident-free transit passages in 1997-2003 period

As a result, more than 330,000 accident-free transit passages and related information are generated (in addition to the year 2005 transit passage data), so that in total 386,750 accident free transit passages are included in the model. The fitted probability distributions to vessel arrivals (in each class) and pilot demands (as obtained from the year 2005 transit data by Özbaş and Almaz [64,65]) are presented in Table A.1 and A.2.

While there are more than 50 different vessel type-length combination passing through the Istanbul Strait, the TSVTS Authority classify all vessels into 11 treatment classes, based on their types, lengths and drafts, in a way reflecting the vessels' navigational complexity, potential risk, special needs and the associated transition rules and restrictions. These 11 treatment classes differentiate five vessel types, which are Passenger Vessels, LNG – LPG Carrying Vessels, Hazardous Material Carrying Vessels (designated as IMO), Tankers and General Cargo Carrying Vessels. These vessel types are also considered in this study, similar to other studies by Özbaş and Almaz [64,65]. The classification of the different types of vessels into five categories is shown in Table 6.1 and the frequencies of each type are provided in Appendix D.

Table 6.1. Vessel treatment classes

Length (meter)	Draught (meter)	Type				
		Tanker	LNG-LPG	IMO	General Cargo	Passenger
<50	<15	T1	T4		T8	T10
50-100	<15					
100-150	<15	T2				
150-200	<15	T3	T5		T9	
200-250	<15	T6				
250-300	>15	T7				
>300	>15	T11				

6.1. Basic Statistics

In recent years, not only the frequency of vessel arrivals has increased, but also size of vessels and the nature of the cargoes carried have drastically changed. The ratio of oil, oil products and other dangerous and hazardous materials transported by large tankers has been rapidly increasing. The total number of vessels passing through the Istanbul Strait and their pilot utilization, along with the number of tankers passing, between 1995 and 2006 is given in Table 6.2 and in Figure 6.3. The 17 per cent increase in total number of vessels passed and 139 per cent increase in the number of tankers passed, signifies the increasing trend, as well as the changes in the vessel profile.

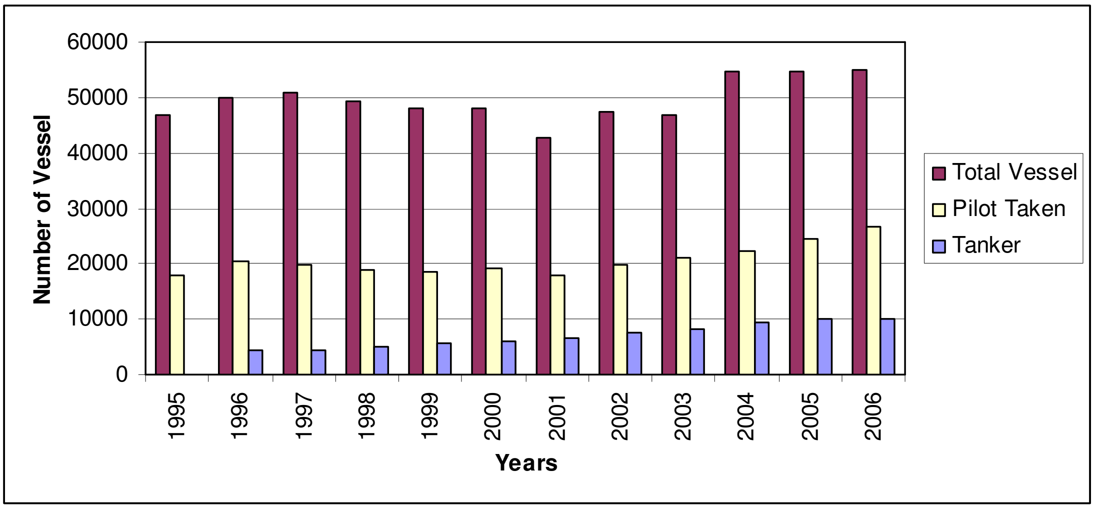


Figure 6.3. Total number of maritime vessels, their pilot utilization and tankers passing through the Istanbul Strait 1995 – 2006

Table 6.2. Total number of maritime vessels, their pilot utilization and tankers passing through the Istanbul Strait 1995 – 2006

Years	Total Number of Vessel	Pilot Taken	Tanker
1995	46954	17772	NA
1996	49952	20317	4248
1997	50942	19753	4303
1998	49304	18881	5142
1999	47906	18424	5504
2000	48079	19209	6093
2001	42637	17767	6516
2002	47283	19905	7427
2003	46939	21175	8107
2004	54564	22318	9399
2005	54794	24494	10027
2006	54880	26589	10153

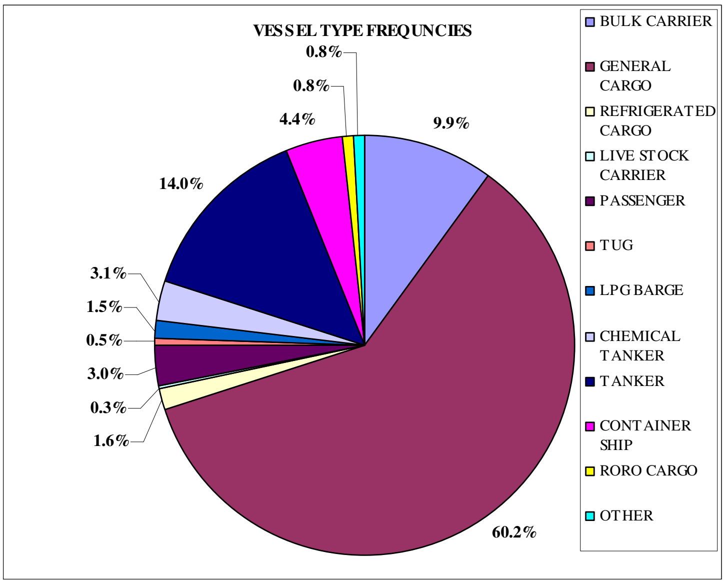


Figure 6.4. The percentages of different transit vessel types for the year 2006

The percentage distribution of all transit vessel types for 2006 is given in Figure 6.4 and Table 6.3. Vessel characteristics are another important issue, since these characteristics are taken as independent variables of the logit model and considered to affect the accident probability.

Table 6.3. The percentages of different transit vessel types for the year 2006

Vessel Type	Frequency
Bulk Carrier	9.9%
General Cargo	60.2%
Refrigerated Cargo	1.6%
Live Stock Carrier	0.3%
Passenger	3.0%
Tug	0.5%
LPG Barge	1.5%
Chemical Tanker	3.1%
Tanker	14.0%
Container Ship	4.4%
RORO Cargo	0.8%
Other	0.8%

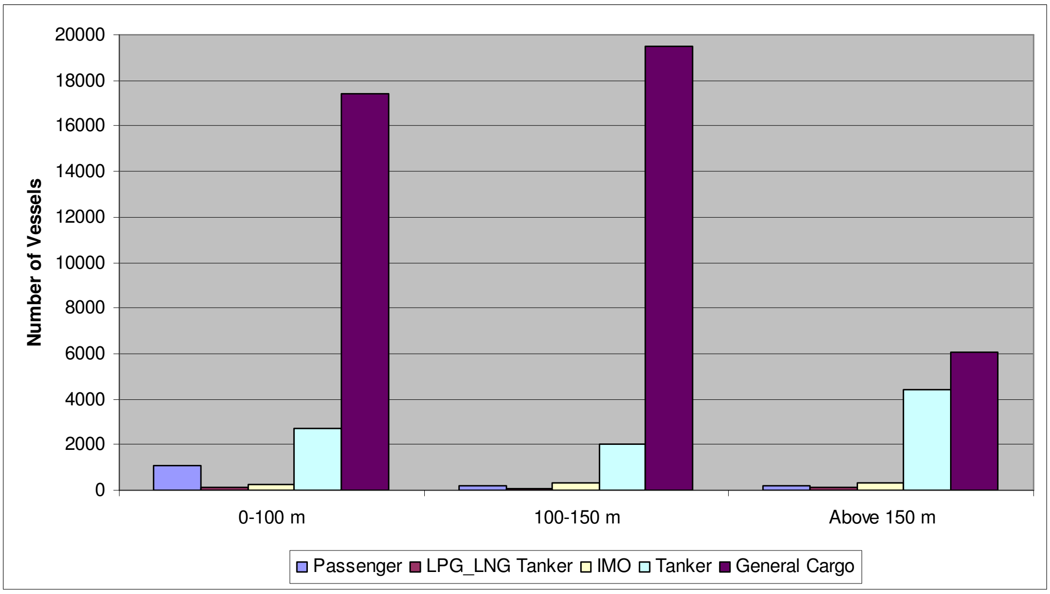


Figure 6.5. The vessel length frequencies for the year 2005

Figure 6.5 and Table 6.4 display the frequency distribution of the length of vessels passing through the Istanbul Strait in 2005.

Table 6.4. The vessel length frequencies for the year 2005

	0-50 m	50-100 m	100-150 m	150-200 m	200-250 m	250-300 m	Above 300 m
Passenger	88	992	216	54	24	2	122
LPG_LNG Tanker		127	83	71	52		
IMO	1	225	290	220	95	14	
Tanker	5	2716	2038	2369	1321	712	
General Cargo	482	16900	19487	4795	1167	117	5

Figure 6.6 displays the number of vessels deploying pilot captains, with respect to the vessel length, for the year 2006. Even though the average pilotage service ratio for the year is around 47 per cent, the realized ratio for different vessel types/lengths varies considerably, (this ratio is more than 95 per cent for vessels which are 200 meters or longer). Unfortunately, for vessels having lengths between 150 and 200 meters, this ratio is approximately 78 per cent, which needs to be improved.

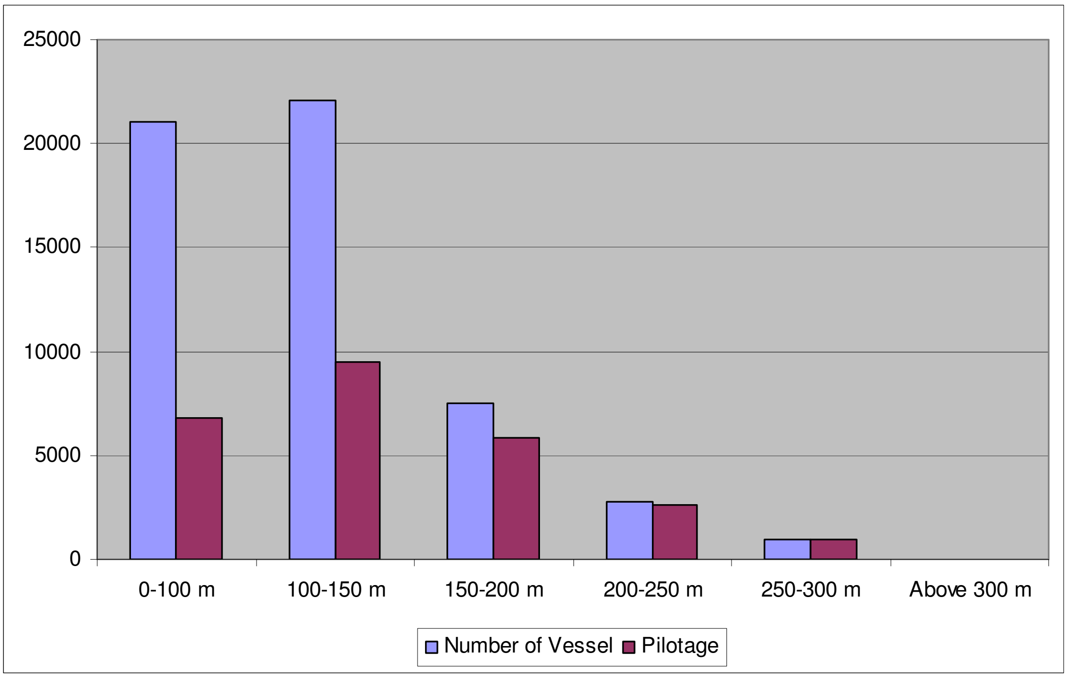


Figure 6.6. The vessel length frequencies with respect to the pilotage for the year 2006

As mentioned earlier, between 1995 and 2004, 147 maritime accidents occurred in the Istanbul Strait. The accident type and vessel type distributions of these accidents are shown in the Figure 6.7 and Figure 6.8 respectively. The 50 per cent of the accidents are consisting of groundings and collisions, which imply the importance of their consequences for being considered.

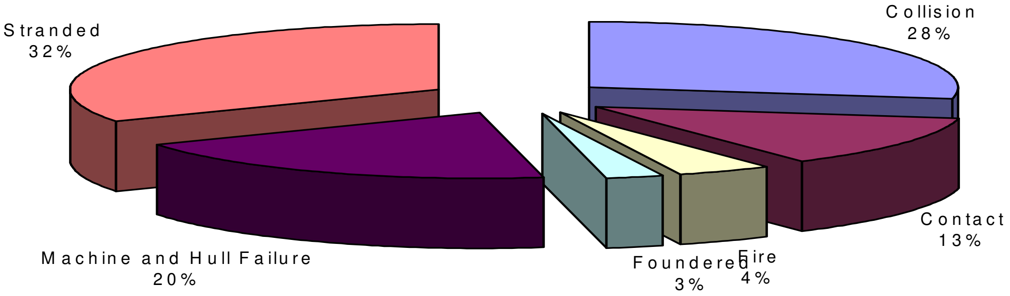


Figure 6.7. The percentages of different accident types in the Istanbul Strait in the 1995-2004 period

Among these accidents, 54 per cent occurred at night, while 41 per cent occurred during the day. Unfortunately, the accident time is unknown in five per cent of the cases. Additionally, 38 per cent of the accident occurred in winter, while 20 per cent, 22 per cent and 20 per cent of the accidents occurred during spring, summer and fall seasons respectively.

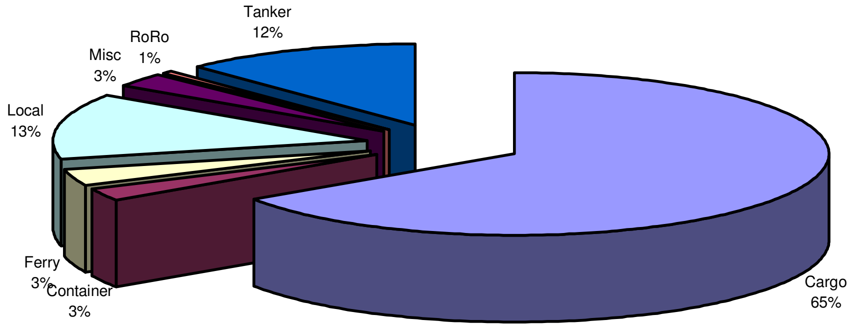


Figure 6.8. The percentage distributions of vessel types involved in accidents in the Istanbul Strait in the 1995-2004 period

The causes of past accidents are displayed in the Figure 6.9. This figure reveals that the major reasons for the accidents in the Istanbul Strait are improper navigation and machine or equipment failures, which again highlights the importance of the pilotage given to and the reliability of the vessel passing through the Strait.

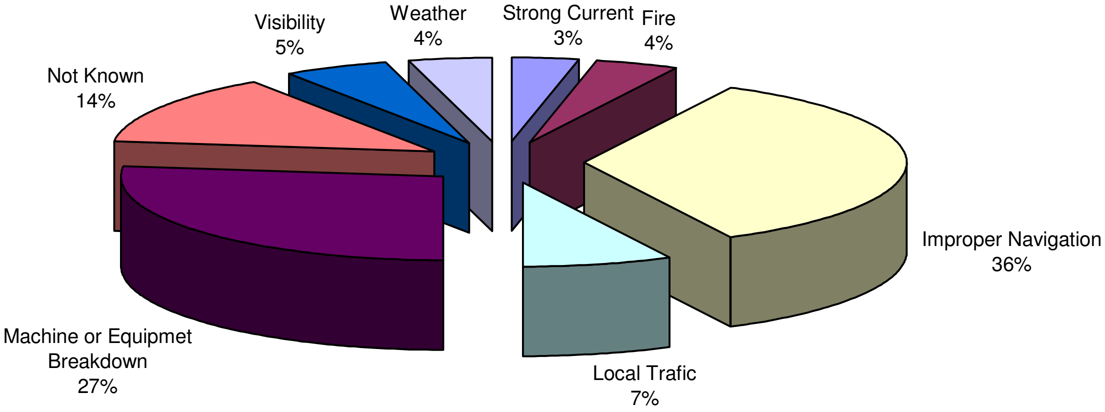


Figure 6.9. The percentage distributions of causes of the accidents occurred in the Istanbul Strait in the 1995-2004 period

The data regarding meteorological conditions (such as precipitation, wind speed and visibility) on daily bases (measured three times a day) for the 1995–2005 period in the Istanbul Strait is obtained from the Turkish State Meteorological Service (by Kirec Burnu Meteorological Station). The general statistics of this data are displayed in Table 6.5.

Table 6.5. The statistics of the weather condition in the Istanbul Strait in the 1995-2005 period

	Average	Maximum	Minimum
Visibility (km)	17.32	30	0.05
Precipitation (mm)	0.73	69.5	0
Wind Speed (m/sec)	1.99	11.7	0

Another important factor, which has an effect over the likelihood of maritime accidents, is the density of the local traffic between two shores of the Strait [7,30]. In this respect, Karakayakali and Mırık [3] quantified the local traffic density in the Istanbul Strait by a simulation model. In this study, all related local traffic movements are considered. The model enables the tracking of the number of different type of local vessels in each of the Strait’s 21 regions, in 10 minute intervals. Then, overall local traffic density in every region is generated (again in 10 minute intervals) by weighted aggregation of different vessel types (in the base run, a weight of one is assigned to ferries, while a weight of 0.3 is assigned to mid size passenger boats and 0.1 to small size fishing boats).

Table 6.6. The local traffic intensities in the Istanbul Strait

Period	Average Number of Movements	Intensity	Period	Average Number of Movements	Intensity
06:00-08:00	83.14	0.20863	16:00-18:00	70.27	0.17632
08:00-10:00	47.48	0.11913	18:00-20:00	88.56	0.22222
10:00-12:00	28.92	0.07256	20:00-22:00	15.75	0.03952
12:00-14:00	25.50	0.06399	22:00-24:00	9.58	0.02405
14:00-16:00	29.08	0.07298	00:00-0600	0.24	0.00059

As a result, Table 6.6 is obtained with respect to two hour time periods, by taking the average of the respective twelve 10 minutes intervals. The average of the weighted movements with respect to the transit or accident time is used in the logit model.

6.2. The Correspondence Analysis

Correspondence analysis provides an easy-to understand visual portray of both inter-category and intra-category relationships. It is important to realize that it is only the distance (that is called chi-square distance) within each category of points that are defined on the figures, not the distances between points from different categories of variables are explicitly defined. This means that, the distances between accident types and between accident locations in Figure 6.10 are defined, but the distances between accident types and accident locations are not. However, it is legitimate to interpret a point's relative position in relation to all the points in the other set. Correspondence analysis provides insights into similarities and differences within the rows (for Figure 6.10 accident locations) with respect to a given column category (for Figure 6.10 accident types), similarities and differences within the column categories with respect to the individual row categories, or the relationships between both rows and columns as it's the main objective of this study.

Table 6.7. The results of the correspondence analysis

Correspondence Analysis	p value	Test Result
Accident Month vs. Accident Type	0.630	Accept the null hypothesis H_0.
Vessel Type vs. Accident Type	0.393	Accept the null hypothesis H_0.
Accident Time vs. Accident Type	0.558	Accept the null hypothesis H_0.
Accident Location vs. Accident Type	$\cong 0.000$	Reject the null hypothesis H_0.
Accident Season vs. Accident Type	0.071	Accept the null hypothesis H_0.
Vessel Flag State vs. Accident Type	0.534	Accept the null hypothesis H_0.
Accident Cause vs. Accident Type	<0.001	Reject the null hypothesis H_0.
Vessel Length vs. Accident Type	0.969	Accept the null hypothesis H_0.

Various correspondence analyses (shown in Table 6.7) have been carried out over the accident data, by utilizing XLSTAT 2006 software [67], to examine the inter or intra-relationships between accident types and various factors related to accidents. The details of each analysis can be seen in the Appendix I.

Even though, correspondence analysis is an exploratory technique to provide a clear picture of the nature of the relationships among the variables, it is still possible to implement hypothesis testing (relationship between rows and columns) via the XLSTAT 2006 software. The independency of the rows and columns is taken as the null hypothesis with significance level of 0.05 in this hypothesis testing. The analysis results for two cases (accident location vs. accident type and accident cause vs. accident type) suggest that the null hypothesis should be rejected.

The correspondence analysis of accident locations and accident types clearly reveals that the rows (which represent accident location and accident reasons) and the column (which represents accident types) are related, as seen in Table 6.7 and Figure 6.10 as a result of Chi-square test. As displayed in Figure 6.10, the first two dimensions generated in the analysis of accident location with accident types, account for about 56.32 per cent of the total variance. While the addition of a third dimension improves the explained variance by 21.8 per cent, for the sake of ease of display and interpretability, a two-dimensional solution is retained. A very useful piece of information provided by correspondence analysis is absolute contributions to variances of each dimension. These statistics indicate the percentage of variance explained by each row and column item in relation to each of the dimensions. The larger the absolute contribution of an item to a dimension, the more important that item is in determining the underlying structure of that dimension.

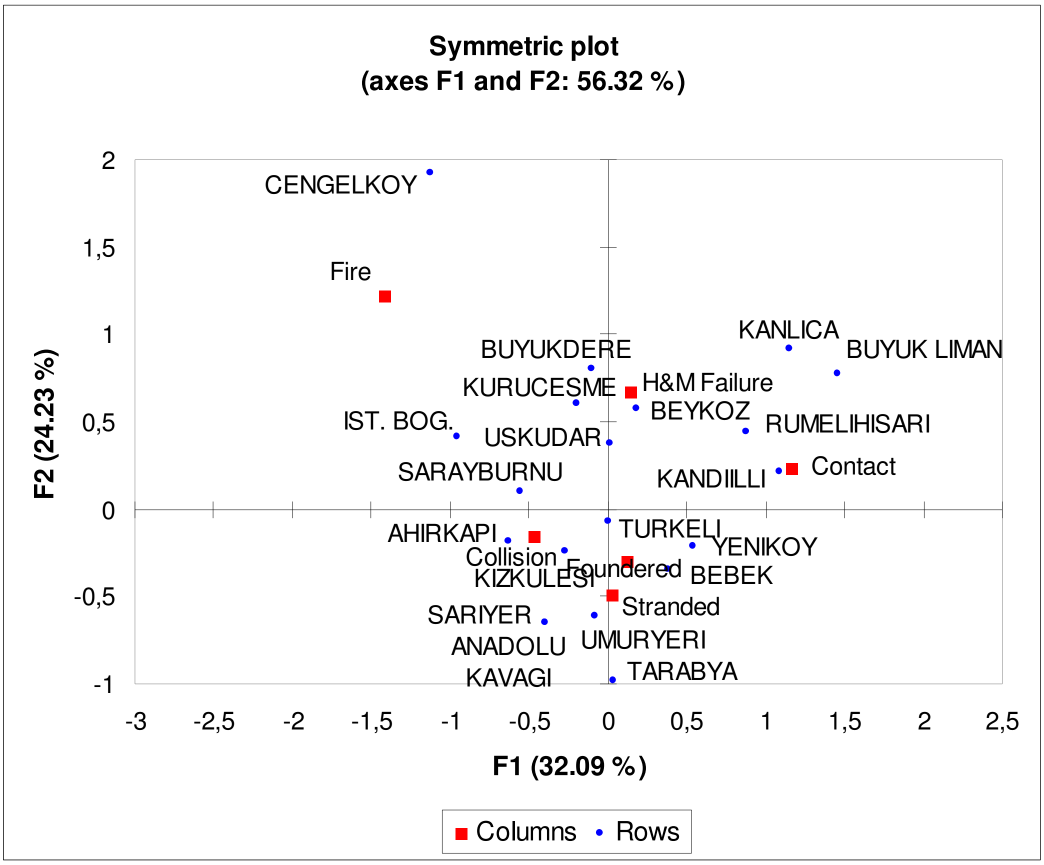


Figure 6.10. The symmetric plot of accident type vs. accident location

Figure 6.10 reveals critical evidence of how various accident locations relate to different types of accidents. For instance, the collision type accident is positioned close to the location of Ahirkapi and Kiz Kulesi. This is understandable because this region is the south entrance of the Strait where there is a high local traffic. Likewise, the stranded type accident is positioned in the plot close to Umuryeri, where there is strong current and the necessity of completing a 70º at sharp turn. Also, note the proximity between contact type accidents and the regions of Kandilli and Rumelihisar, which feature the narrowest point of the Strait, a shallows, a 45º turn at Kandilli and a 80º turn at Yenikoy. Finally, foundered type accident is positioned close to Turkeli (at the North Entrance), where actually the rough sea conditions in the area are like to cause foundering.

The analysis of the interactions between the accident month and accident type, as displayed in Figure 6.11, suggests that (even though not being statistically significant), there might be a relationship between strandings and months of January, March, February and December. Similarly, there might exist a relationship between collisions and months of September, August and July, which feature relatively higher local traffic in the Strait, due to the increases in tourist boats, pleasure boats and small passenger vessels.

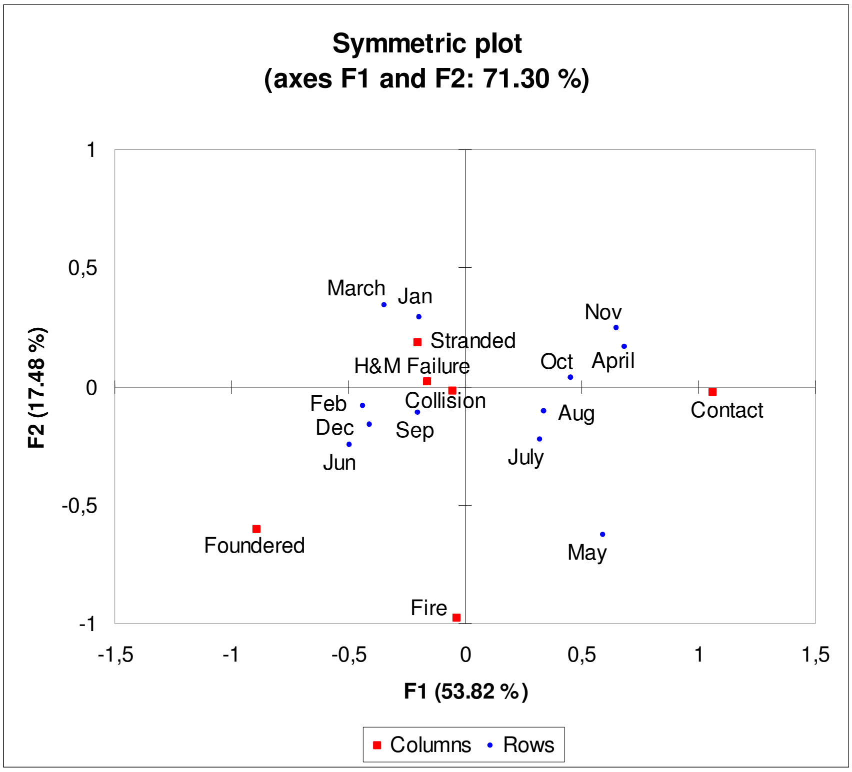


Figure 6.11. The symmetric plot of accident type vs. accident month

The analysis of the interactions between the vessel types involved in an accident and the accident type (as displayed in Figure I.2) hint that there is a statistically insignificant relationship between cargo vessels and the accident types other than foundering. As displayed in Table 6.11, approximately 80 per cent of the vessels involved in an accident and accident free transits are general cargo vessels. This implies that the average profile for vessel type in the Strait is general cargo vessel, and thus, it is located close the centroid. Moreover, this point is also close to most of the accident types points in Figure I.2, which shows the interrelationship among them.

Figure 6.12 shows that there might be a relationship between carrying the Turkish flag vessels and collision type accidents. Another important observation that can be made from this figure is the analysis results suggesting a relationship between hull and machine failures with the flag states of St.Vincent, Panama, Bahama, Malta and Marshall Islands.

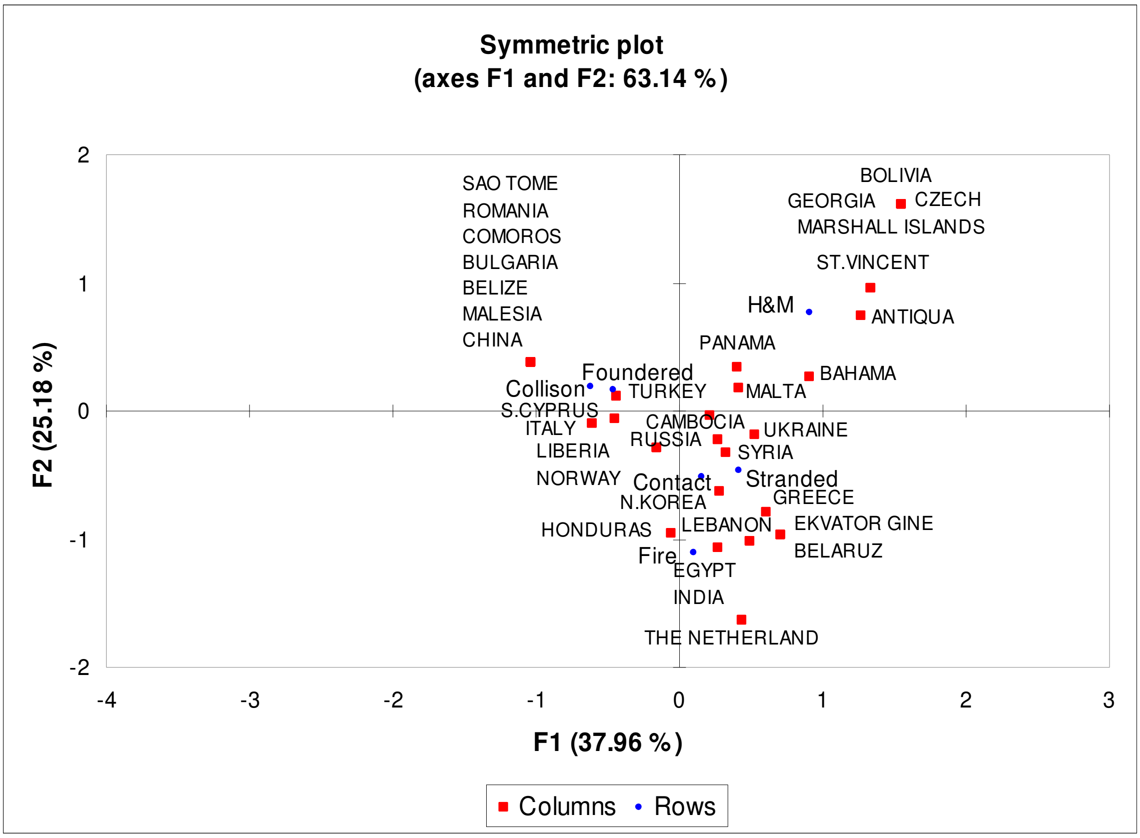


Figure 6.12. The symmetric plot of accident type vs. the flag states of vessels involved in accidents

As can be seen in Figure 6.13, the correspondence analysis results regarding accident season versus accident type indicate that there may be a relationship between the accident types of collision, strandings and foundered with the season of winter. Since the rough sea and weather conditions are the main causes of foundering, this result is quite intuitive. Secondly, these results are also in line with the findings of the regression analysis. In this regard, the effects of the visibility and wind speed over the accident probability are discussed in the following section.

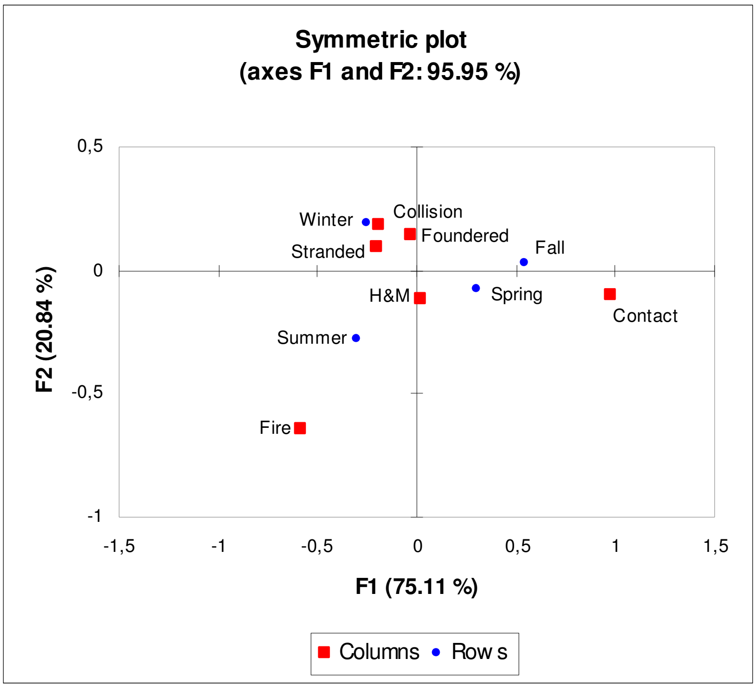


Figure 6.13. The symmetric plot of accident type vs. the season of accidents

Finally, the correspondence analysis results regarding the accident type versus the accident cause (displayed in Figure 6.14) suggest that there is a statistically significant relationship between them. Since hull and machine failure and fire are also the cause of these types of accident, there is perfect match among them; this result is also in line with expectations. Moreover, the results show that there exist a significant relationship amongst the accident types collision, strandings and contacts with other accident causes such as, current, improper navigation, poor visibility and human error, as displayed in Figure 6.14. This is also understandable because all of these causes are the basic causes and/or triggering incidents that result in an accident.

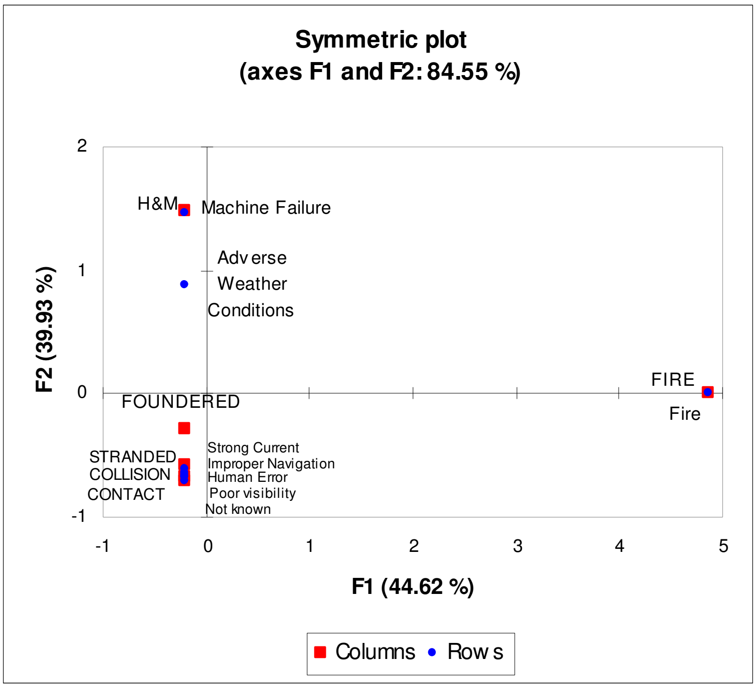


Figure 6.14. The symmetric plot of accident type vs. accident cause

6.3. The Regression Analysis

As discussed in Section 4.2, one of the objectives of this study is to estimate the probability, P_i, that a vessel i is involved in a maritime accident during its transit in the Istanbul Strait, given X_i (representing the various accident causing factors influencing the vessel i during its transit). This probability is expressed by the logistic function (Equation 4.3), which is displayed in Equation 6.1 for convenience.

$$P_i = \frac{1}{1+e^{-(\beta_0+\beta_1 X_{1i}+\beta_2 X_{2i}+\ldots+\beta_k X_{ki})}} \tag{6.1}$$

Actually, only the maritime accident, Y_i (Y_i=1 if vessel i involves in a maritime accident during its transit, Y_i=0 otherwise) is observed. Since each Y_i is a Bernoulli random variable, it follows that;

$$\begin{aligned} P(Y_i = 1 \mid X_i) &= P_i \\ P(Y_i = 0 \mid X_i) &= 1 - P_i \end{aligned} \tag{6.2}$$

Consider a random sample of n observations (vessel transits), $Y_i, i = 1,\ldots,n.$ Letting $f_i(Y_i)$ denote the probability that Y_i=1 or 0, the joint probability of observing the n Y_i values (i.e. $f(Y_1,Y_2,\ldots,Y_n)$) is given as:

$$f(Y_1,Y_2,\ldots,Y_n) = \prod_1^n f_i(Y_i) = \prod_1^n P_i^{Y_i}(1-P_i)^{1-Y_i} \tag{6.3}$$

Equation 6.3 is known as the likelihood function. If its natural logarithm is taken, Equation 6.4 what is called log likelihood function is obtained [32].

$$\begin{aligned} \ln f(Y_1,Y_2,\ldots,Y_n) &= \sum_1^n \left[Y_i \ln P_i + (1-Y_i)\ln(1-P_i)\right] \\ &= \sum_1^n \left[Y_i \ln(\frac{P_i}{1-P_i})\right] + \sum_1^n \ln(1-P_i) \end{aligned} \tag{6.4}$$

Using Equation 6.3 and 6.4, the following log likelihood function is obtained. The log likelihood function in Equation 6.5 is a function of the parameters, β_i (which are called the logit parameters), since the X_i are known.

$$\ln f(Y_1,Y_2,\ldots,Y_n) = \sum_1^n Y_i(\beta_0 + \beta_1 X_{1i} + \ldots + \beta_k X_{ki}) - \sum_1^n \ln(1 + e^{\beta_0+\beta_1 X_{1i}+\ldots+\beta_k X_{ki}}) \tag{6.5}$$

The logit parameters are typically estimated by a method called Maximum Likelihood Estimation (MLE), in contrast to ordinary regression models, where the parameters are estimated by the method of Least Squares Estimation (LSE). In MLE, the objective is to determine the unknown parameters of the likelihood function (or the log likelihood function), $f(Y_1,Y_2,\ldots,Y_n)$ displayed in Equation 6.5, in such manner that the probability of observing the given *Y*’s is as large as possible.

The conceptual difference between LSE and MLE is that LSE is concerned with picking parameter estimates that yield the smallest sum of squared errors in the fit between model, (i.e. the fitted probability distribution) and data, while MLE is concerned with picking parameter estimates that provide the highest probability (or likelihood) of having obtained the observed sample *Y*. The details of the MLE method can be found in [32,68].

Table 6.8. Coefficients of the general logit model estimated through the MLE method

Method: ML - Binary Logit (Newton-Raphson)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-28.57869	37922.63	-0.000754	0.9994
Transit Time	-0.33212	0.163994	-2.025201	0.0428
Wind Speed	0.202904	0.049339	4.112431	0
Precipitation	-0.074817	0.047225	-1.584256	0.1131
Visibility	-0.079267	0.016856	-4.702579	0
Pilot	-0.679201	0.203151	-3.343332	0.0008
Vessel Length	0.000312	0.002154	0.144943	0.8848
Local Traffic	-0.002638	0.00265	-0.9971	0.3187
Passenger	22.10535	37922.63	0.000583	0.9995
Cargo	22.11361	37922.63	0.000583	0.9995
Tanker	23.52085	37922.63	0.00062	0.9995
Mean dependent var	0.000398	S.D. dependent var		0.019951
S.E. of regression	0.019948	Akaike info criterion		0.006919
Sum squared resid	153.8825	Schwarz criterion		0.007228
Log likelihood	-1326.934	Hannan-Quinn criter.		0.007008
Restr. log likelihood	-1359.562	Avg. log likelihood		-0.00343
LR statistic (10 df)	65.25729	McFadden R-squared		0.023999
Probability(LR stat)	3.62E-10			
Obs with Dep=0	386575	Obs with Dep=1	154	

The parameter values and other statistical characteristics of the logit model discussed in Section 4.2, whose parameters are estimated through the MLE method, are displayed in Table 6.8. The independent variables, transit time, wind speed, visibility and pilot utilization are statistically significant. The parameters of the other logit models (associated with individual accident types), obtained through the MLE method are presented in Appendix L, Table L.1 through Table L.6.

As already discussed in Section 4.2; "the percent change in odds" for a unit increase in the X_{li}, (which is determined by "subtracting one from the antilog of the l^{th} slope coefficient" and multiply the result by 100) is displayed in Equation 4.9.

Table 6.9. Logit coefficients' effect over odds (in per cent) associated with the overall accident probabilities

Variable	Coefficient	$\%(P/(1-P))$	Variable	Coefficient	$\%(P/(1-P))$
Transit Time	-0.33212	-28.25987705	Vessel Length	0.000312	0.031204868
Wind Speed	0.202904	22.49548669	Local Traffic	-0.002638	-0.263452354
Precipitation	-0.074817	-7.208672108	Passenger	22.10535	1.6405E+12
Visibility	-0.079267	-7.620676128	Cargo	22.11361	4.01623E+11
Pilot	-0.679201	-49.29780589	Tanker	23.52085	3.98319E+11

These results reveal that a unit change in pilot utilization (i.e not taking a pilot instead of taking a pilot during the transit), increases accident odds by 49 per cent. In other words, taking a pilot decreases the probability of accident over the probability of not having accident by 49 per cent. Note that the accident probability is very low and close to zero;

$$\frac{P}{1-P} \cong P \tag{6.6}$$

Therefore, taking a pilot instead of not having him onboard decreases the probability of the accident nearly 49 per cent. Similarly, Table 6.9 indicates that passing Istanbul Strait during daytime instead of nighttime decreases the probability of an accident (over the probability of not having an accident) by 28 per cent. This is also in line with the following recommendation of the IMO [69], on navigation through the Istanbul Strait;

"Vessels having a maximum draught of 15 m or more and vessels over 200 m in length are advised to navigate the Strait in daylight."

On the other hand, it seems "meaningless" to have values such as, 1.64E+12, 4.01E+11 and 3.98E+11 percent change in odds for the factor of vessel type (namely passenger, cargo and tanker respectively). However, it is clear that there might be an accident, only if there is a vessel to involve. The interpretation of these values is as follows: the odds will increase by 1.64E+12 per cent, when the corresponding binary variable (i.e. X_{8i}) takes values of 1 instead of 0, (which means a passenger vessel is transiting through the Istanbul Strait). So, it is important to determine which vessel type affects more "the per cent change in odds" with respect to each other. In other words, this important relationship illustrates the ratio scale contribution of each vessel type to the probability of accident, as displayed in Table 6.10.

Table 6.10. Ratio scale effects of vessel type over odds

	Cargo	Tanker
Passenger	1.64E+12/4.01E+11= 4.08	1.64E+12/3.98E+11 = 4.12
Cargo		4.01E+11/3.98E+11 = 1.01

The results displayed in Table 6.10 indicate that having a passenger vessel in transit in the Strait increases the probability of accident (over the probability of not having accident) by almost four times, comparing with the other type of vessels. In other words, passenger vessels are more prone to be involved in accidents. This result seems contradictory to the opinion that passenger vessels are safer than other types of vessels, in regard to the navigational and control systems on board and the competence of crew. However, as displayed in Table 6.11, the accident free transit passage statistics of the year 2005 indicates that 2.7 per cent of the total number of vessels is passenger vessels. On the other hand, the accident statistics of 1995-2004 period shows that 6.49 per cent of the vessels involved in accidents are passenger vessels. Table 6.11 shows the results of this comparison, which are in line with the results obtained from the logit model.

Similarly, Table 6.9 indicates that wind speed has a significant effect over the accident probability as well. When the wind speed increases by one m/sec, the accident probability increases by more than 22 per cent. Likewise, when the visibility range increases by one km, the accident probability decreases by more than seven per cent.

Table 6.11. The frequencies of the vessel types with respect to accidents and transit passages

	Accident (1995-2004)	No Accident (2005)	Ratio in the accidents	Ratios in the no accidents
Passenger	10	1498	0.064935	0.027346
Tanker	22	9158	0.142857	0.167181
Cargo	122	42946	0.792207	0.783987
LPG	0	332	0	0.006061
IMO	0	845	0	0.015426
Total	154	54779		

Table 6.9 shows that the effects of vessel length and local traffic intensity over the odds, (0.03 and -0.2 per cent respectively), are close to zero, which implies that they have statistically little impact over accident probabilities. However, the effect of local traffic intensity over the odds based on just daytime data (as presented in Table 5.10) is very significant at 0.96 per cent.

Table 6.12. The effect of the local traffic over the odds

Number of Movements	$\%(P/(1-P))$
1	0.96
10	9.6
25	24
50	48
100	96

Table 6.12 presents the marginal effect of additional daytime local traffic movements over the odds. During the most congested interval for the local traffic, (around at 18:00)

there are around 160 individual vessel movements in the Istanbul Strait and the average local traffic rate for the daytime is around 53.27. So, the difference between the most congested time and the average local traffic, causes almost 100 per cent increase in the accident probability.

In the logit model the slope coefficient of a variable gives the change in the log of the odds associated with a unit change in that variable, again holding all other variables constant. But as noted previously, for the logit model, the rate of change in the probability of an accident is given by Equation 6.7, with the inclusion of all variables in the evaluation of $\hat{P}_i$.

$$dP_i / dX_{li} = \hat{P}_i(1 - \hat{P}_i)\hat{\beta}_{li} \tag{6.7}$$

In the evaluation of the $\hat{P}_i$, the continuous variables are set at their average value. However, for the binary variables (such as transit time and pilot utilization), the average value may mislead the calculation. Additionally, since the effect of each vessel type is different, the vessel type needs to be pre-determined for the calculation. Therefore, as displayed in Table 6.13, the continuous variables are set at their average value, and the accident probability is calculated for two values of the binary variables. As a result, for any accident, in which a passenger vessel is involved, the figures in the table present the contribution of a unit change in each independent variable to accident probabilities. The independent variables such as, pilot utilization, transit time and wind speed are the main contributors.

The effect of pilot deployment over the accident probability can be seen by comparing the values of the accident probabilities with and without pilots, during daytime and night time. The effect of transit time over the accident probability could be seen in similar way. For example, if a passenger vessel (length of 118 meters) passes through the Strait during daytime (with average local traffic intensity of 34 movements) without pilot onboard having average meteorological conditions (such visibility being 17.32 kilometers, 0.73 millimeters precipitation and wind speed being 1.99 m/sec), the accident probability is calculated as 0.001548851 using Equation 6.1. However, if it takes a pilot during this passage and holding all other variables without change (at their previous values), the accident probability decreases nearly 49.3 per cent and gets the value of 0.000785902. This reduction in the accident probability is also in line with the findings shown in Table 6.9.

Table 6.13. The marginal effects of the independent variables on accident probabilities

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P_i	0.000785902	0.001548851	0.00109515	0.002157659
$P_i(1-P_i)$	0.000785284	0.001546452	0.00109395	0.002153003
Transit Time	-0.000260809	-0.000513608	-0.0003633	-0.000715055
Wind Speed	0.000159337	0.000313781	0.00022197	0.000436853
Precipitation	-5.87526E-05	-0.000115701	-8.185E-05	-0.000161081
Visibility	-6.22471E-05	-0.000122583	-8.671E-05	-0.000170662
Pilot Utilization	-0.000533366	-0.001050352	-0.000743	-0.001462322
Vessel Length	2.45009E-07	4.82493E-07	3.4131E-07	6.71737E-07
Local Traffic	-2.07158E-06	-4.07954E-06	-2.886E-06	-5.67962E-06
Passenger Vessel	0.018470548	0.036373875	0.02573053	0.050640463

If transit time is scrutinized in a similar manner, such as comparing passenger ship transits through the Strait during nighttime without a pilot versus daytime passage, the difference in accident probabilities is observed as 28 per cent, which is also in line with the results shown in Table 6.9. The rest of the results for other type of vessels and different types of accidents are presented in Appendix G.

The conventional measure of goodness of fit, R^2, is of limited value in the binary response models [32] and in the logit models the traditional R^2 measure can lie outside the [0-1] interval [70]. However, a series of measure similar to R^2, called pseudo R^2, are available, and there are a variety of them. EViews [56] presents one such measure, named the McFadden R^2, whose value is 0.023999 for the developed model. The computation of the McFadden R^2 starts with the log likelihood reported for the model. The log likelihood can be thought of as a measure of the magnitude of the error terms in the estimation. If the log likelihood is smaller (ie farther from zero), then the error is greater. The McFadden R^2 compares the log likelihood in two models. The first model runs a regression including only the constant term, with no other independent variables. It's not expected to explain much of the variation, since there are no independent, or explanatory, variables (base case). The log likelihood from the base case is then compared to the log likelihood calculated from the full model, including the independent variables using the following formula [70];

$$McFadden\, R^2 = 1 - \frac{L(full)}{L(0)} \tag{6.8}$$

where L(full) is the log likelihood from the model with the all independent variables, X_i's, and L(0) is the log likelihood from the base case model with just the constant term. For the general logit model, L(full) (EViews called as Restricted log likelihood) is equal to -1359.562 and L(0) (EViews called as Log likelihood) is equal to -1326.934 as displayed in Table 6.8.

It should be noted, however, that in the binary response models, goodness of fit is of secondary importance. What matters are the expected signs of the regression coefficients and their statistical and/or practical significance [32]. The sign checks of the estimated coefficients are already presented in Chapter 5.

The likelihood ratio (LR) statistic, which is the equivalent of the F test in the linear regression model, is used to test the null hypothesis that all the slope coefficients are simultaneously zeros. Given the null hypothesis, the LR statistic (follows the Chi-Square (χ^2) distribution with degrees of freedom equal to number of explanatory variables) equals to 65.25729 (with the probability (p) value of 3.62E-10). This result suggests that all independent variables of the general logit model have a significant impact over the accident probability.

6.3.1. The Variation of the Accident Probability over Regions of the Strait

As already explained in Section 4.3, despite efforts to model the effect of the various regions of the Strait over the accident probability, it was not possible to incorporate the accident region as a variable in the logit model. In other words, the logit model results provide an accident probability, which is constant through entire Strait. However, as the correspondence analysis results of Section 6.2 indicate, statistically there is a relationship between the accident types and the accident location. Unfortunately, it has not been possible to quantify the level of this relationship (such as the per cent change in the probability of accident) using the results of correspondence analysis. Furthermore, when the past accident data is analyzed with respect to the accident location, the results illustrate that the accident frequency (in general or for the specific accident type), varies with respect to the accident location. When frequencies of different accident types are plotted with respect to the accident locations, Figure 6.15 is obtained (the associated historic data is displayed in Appendix E).

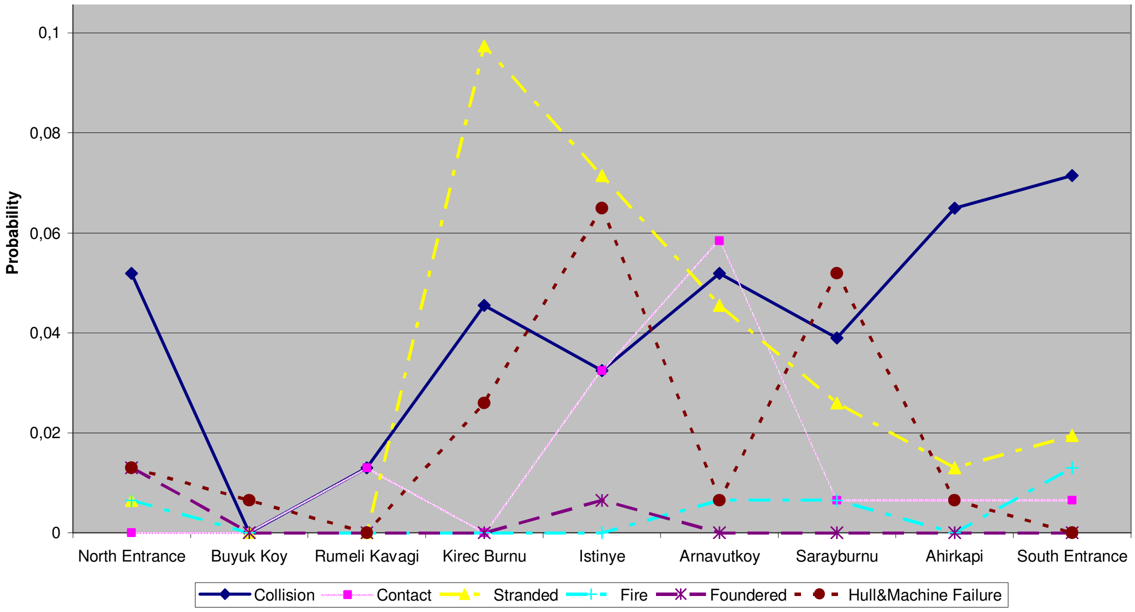


Figure 6.15. The variation of historic accident frequencies with respect to accident locations

Figure 6.15 shows that frequency of collision is relatively high at the south entrance of the Strait (probably due to the high local traffic in the area). The frequency of contacts increases in the vicinity of Arnavutkoy and Kandilli (probably due to the morphological conditions of the Strait, which impose sharp turns in this region). Stranded type accidents increase in the area between Rumeli Kavagi and Kirec Burnu or in the vicinity of Umuryeri Bank (probably because of the current, the depth of the water and the morphological conditions in the area). These observations and deductions are further supported by the following data: the following sharp turns are required during a transit; 45º at Kandilli, 80º at Yenikoy, 70º at Umuryeri; the narrowest part of the Strait, (namely the line of Istinye and Kandilli), is merely 0.4 nm and also features a strong current with an average speed of four knots, increasing up to eight knots [1]. It is therefore quite natural to expect that these factors also contribute to the accident probability, especially collisions, contacts and strandings in these areas.

Another observation based on Figure 6.15 is the increase in the frequency of machine failure in the area of Sarayburnu, Istinye and Kirecburnu. Since Sarayburnu is close to the south entrance of the Strait, there exists high level of maritime traffic in the area, along with a sharp turn at the vicinity of Kiz Kulesi. Accordingly, the relatively higher utilization of navigational systems (especially the engine and the rudder systems), in order to avoid the local traffic and complete the sharp turn, may cause an increase in machine breakdowns or their consequences. This may also be the case for Istinye and Kirecburnu, since the width of the Strait is very limited and there is a strong current in these areas as well.

Table 6.14 shows the relative variation of the historic accident frequencies for a specific accident type or any maritime accident with respect to the accident locations based on the past accident data.

Table 6.14. The relative variation of historic accident frequencies with respect to the accident locations in the Istanbul Strait

Region	Collision	Contact	Stranded	Fire	Foundered	Machine Failure	Accident Prob.
North Entrance	26%	-100%	-79%	80%	500%	-33%	-18%
Buyuk Koy	-100%	-100%	-100%	-100%	-100%	-67%	-94%
Rumeli Kavagi	-68%	-5%	-100%	-100%	-100%	-100%	-77%
Kirec Burnu	11%	-100%	214%	-100%	-100%	33%	52%
Istinye	-21%	137%	130%	-100%	200%	233%	87%
Arnavutkoy	26%	326%	47%	80%	-100%	-67%	52%
Sarayburnu	-5%	-53%	-16%	80%	-100%	167%	17%
Ahirkapi	58%	-53%	-58%	-100%	-100%	-67%	-18%
South Entrance	74%	-53%	-37%	260%	-100%	-100%	-1%

In general, the historic accident frequency varies with respect to the accident location as displayed in Figure 6.16.

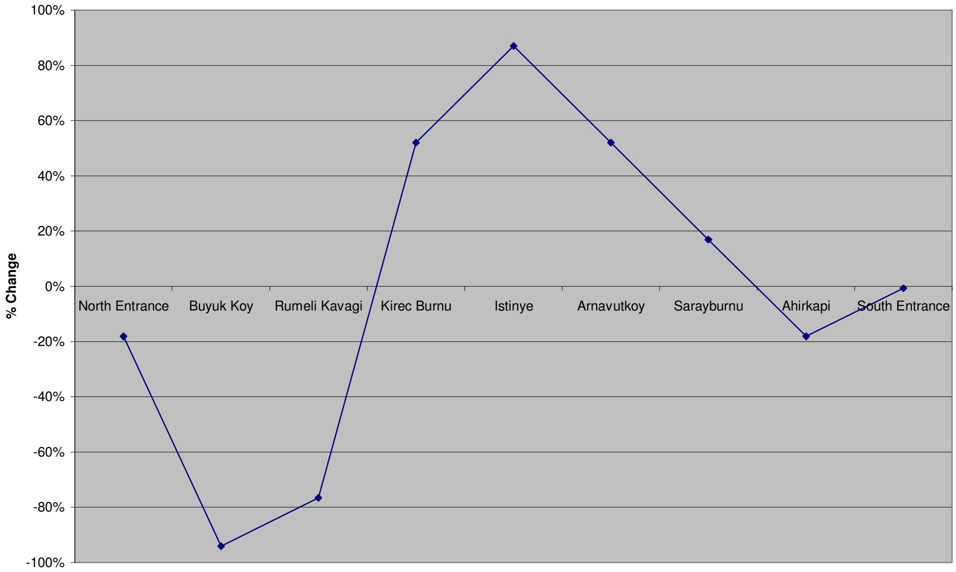


Figure 6.16. The relative variation of historic accident frequencies with respect to the accident locations in the Istanbul Strait

The figures in the y-axis (of Figure 6.16) show the relative change of the accident frequency with respect to the average historic accident frequency in the Istanbul Strait.

Since the logit model provides an average accident probability (for any accident or for a specific type of accident), it is possible to adjust this accident probability with respect to the various regions of the Istanbul Strait based on the past accident frequency as follows:

The average maritime accident probability in the Istanbul Strait (based on the average values of the situation factors) estimated by the logit model is 0.000212 (this value being constant for entire Strait according to the original general logit model). Figure 6.17 shows how this probability value may be adjusted with respect to strait regions by multiplying the constant value with the relative historic frequency values obtained from past accident/location data. Red line in Figure 6.17 illustrates the average accident probability estimated by logit model for entire Istanbul Strait.

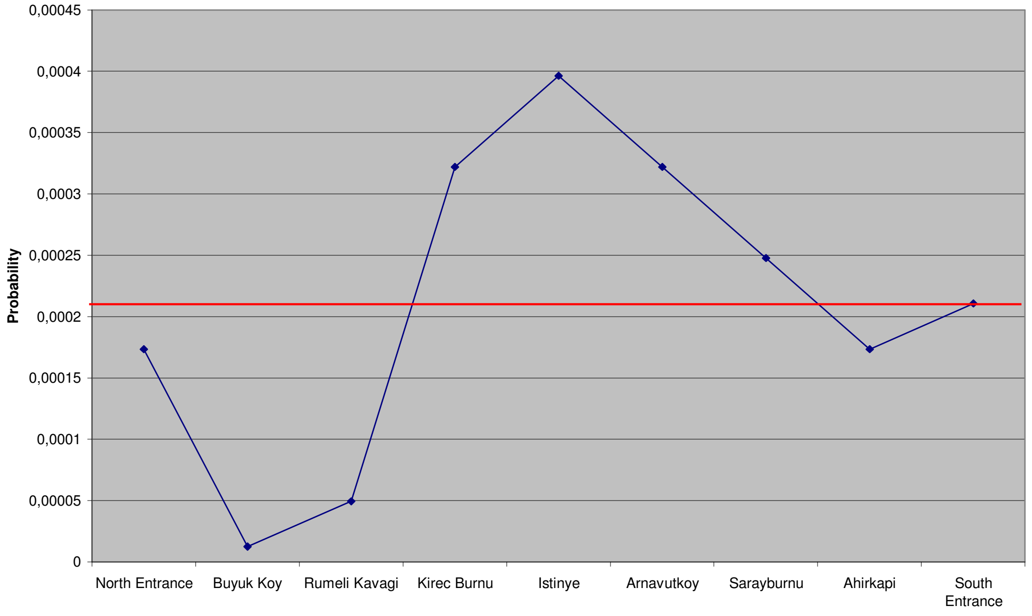


Figure 6.17. The adjustment of accident probability estimated by the general logit model, with respect to the regions of the Istanbul Strait

Similarly, it is possible to adjust specific accident type probabilities (estimated by the associated logit models) with respect to the regions of the Istanbul Strait, based on the relative historic frequency values (of accident type-region combinations) displayed in Table 6.14.

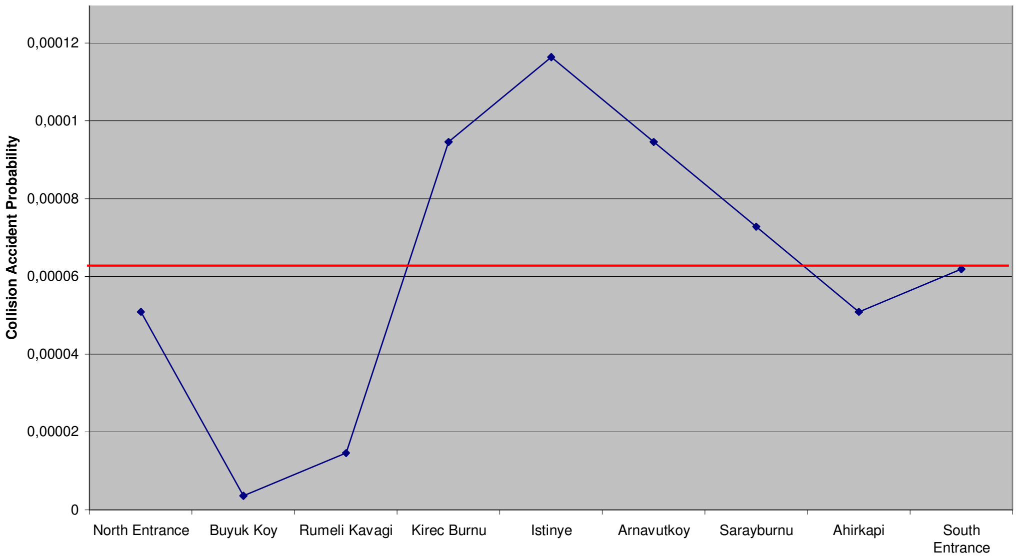


Figure 6.18. The adjustment of collision type accident probability estimated by the collision type logit model, with respect to the regions of the Istanbul Strait

As an example, Figure 6.18 displays the results of this adjustment for the collision type accident probability given the average collision accident probability estimated using the collision type logit model (i.e. 0.0000622 as displayed with red line in the Figure 6.18).

6.4. The AHP Models Analysis

Once the AHP model is formed, the experts are requested to respond to a questionnaire. In this questionnaire, they make a series of pair-wise comparisons between many pairs of the risk factors. Each comparison gives the dominance of one factor over another and answers the question: "*Comparing the two factors; which one is more important with respect to the directly related higher level criteria?*" The experts' subjective judgments are compiled within the framework of the AHP.

6.4.1. The AHP Model Analysis to Estimate the Likelihood of an Maritime Accident

In order to determine the weight of each factor, 18 experts from different expertise groups and stakeholders such as, officials at Under-Secretariat for Maritime Affairs, masters and managers in the maritime transportation industry are interviewed. Their judgments are compiled by utilizing geometric means and then solved by the Expert

Choice software. The results in Table 6.15, obtained in the distributive mode of the AHP model, provide a quantitative profile of the relative importance of the various risk factors.

Table 6.15. The results of the AHP model

Goal	First Level Factors (Criteria)	Sub-criteria	Weights
	Vessel Characteristics **(0.151)**	Length	0.049
		Draught	0.039
		Age	0.027
		Type	0.021
		Flag state	0.015
	Maritime Traffic Characteristics **(0.218)**	Transit Time	0.121
		Transit Traffic Intensity	0.053
		Local Traffic Intensity	0.044
	Environmental Conditions **(0.244)**	Visibility	0.099
		Current	0.064
		Wind speed	0.033
		Morphological Conditions	0.028
		Precipitation	0.019
	Organizational Factors **(0.387)**	The Knowledge of the Crew	0.083
		Pilot Utilization	0.082
		VTS	0.067
		Violation of the Regulations	0.057
		Navigational Aids	0.053
		Cargo Handling	0.045

It can be observed from these results that the most important factor group is the organizational factors, which consists of crew knowledge/training level, pilot utilization, VTS, compliance with enforced regulations, sufficiency of cargo handling and the available navigational aids in the Strait.

The sub-criteria, which received the highest weight within the organizational factors, namely “knowledge of the crew” is associated with “human element”, which recently has received great attention in the international literature. The human element is a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection, involving the entire spectrum of human activities performed by ships' crews, shore based management, regulatory bodies and others. Moreover, about 75-90 per cent of maritime accidents are caused, at least in part, by some forms of human error. Studies showed that human error contributes 84-88 per cent of tanker accidents, 89-96 per cent of collisions and 75 per cent of fire and explosions [71]. The last decade statistics show that 36 per cent of the accidents are directly caused by human error. The IMO has been laboring since 1978 in order to address human element issues effectively. The IMO's International Convention in on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), was the first internationally agreed Convention to address the issue of minimum standards of competence for seafarers. In 1995, the STCW Convention was completely revised and updated, to clarify the standards of competence required and to provide effective mechanisms for enforcement of its provisions. So, in order to make a greater strides towards reducing maritime accidents and consequences, it is required first to focus on the types of human errors.

Unfortunately, despite the efforts of the IMO regarding the competence of the crew, due to the lack of authority vested on the Turkish State to verify the competence of the crew on board before starting to transit the Strait, there is a high risk emanating from the failure of fulfilling the STCW requirement. According to the Regulation, transit ships only require to verify the availability of the crew in line with STCW 78-95. Even though it is found in the AHP study as one of the most important factors influencing the accident probability in the Strait, currently this factor is not directly under the control of the Strait Authorities.

According to the accomplished AHP study, the second important sub-criteria (under organizational factors) is the pilot utilization during the transit. Statistics of the last decade show that only 42 per cent of the transit vessels requested and deployed pilotage services in the Istanbul Strait, even though this service "strongly recommended" by the IMO for the Turkish Straits [72]. Since in 36 per cent of the accidents the primary reason is improper navigation during the transit (see Figure 6.9), pilot utilization becomes one of the most important factors in reducing accident probabilities. This AHP result is also in line with the results of the logit model (where it was demonstrated that having a pilot onboard reduced accident probability by 49 per cent). Accordingly, stricter rules should be considered regarding pilot utilization.

The third and the fourth sub-criteria under the organizational factors (that is Vessel Traffic Service and compliance with enforced regulations) are also in line with the efforts of the Turkish Government to enhance maritime safety in the Strait.

The second important factor group is environmental conditions. Even though almost all of the interviewees had transited through the Strait many times and they are very much familiar with the meteorological and the morphological conditions of the Strait, still they put a lot of importance over the environmental conditions of the Strait. This emphasizes that it is the geography of the Istanbul Strait, which makes it difficult for navigation. Because of the many sharp turns of the Strait, a vessel passing through the Strait must sharply alter course many times, to avoid stranding and/or contact. Moreover, unstable weather conditions and strong currents further complicate the navigation.

The time of transit (namely daytime versus nighttime transit), as well as the intensity of both local and transit traffic during passage are also important. The AHP model gives considerable support to the claim that daytime considerably decreases the accident probability (This is also indicated by the logit model and suggested by the IMO). On the other hand, the possible effects of traffic congestion (local or transit) on accidents are downplayed in the AHP model.

Finally, the physical characteristics of vessel are the last group affecting the likelihood of an accident. Among these, the AHP model identifies vessel length as the most important vessel characteristics affecting accident probability. This is in line with the central philosophy of the Regulations, which define most of their restrictions and measures regarding the vessels passing through the Strait, based on their length.

6.4.2. The Determination of the Probabilistic Consequence Model Situation Attributes Weights by the AHP Model

The second AHP model in this study is deployed to quantify the situational factors that affect the probability of consequence type and its impact level, after the occurrence of an accident, as discussed in Section 4.4.2. These factors are mostly in a qualitative nature (such as vessel type and cargo status or accident location), so the values, which are determined by this AHP model, are the quantitative representation of the situation factors. These cardinal values are used in the probabilistic consequence model displayed in Equation 6.9 as the levels of the situational factors (i.e. B).

$$P(C_{mj} \mid A_m, B_l) = \rho_{mj} * e^{\beta * B_l} \quad \forall m, j, l \tag{6.9}$$

In this context, for each type of consequence, the experts' subjective judgments are obtained by the questionnaires shown in Appendix M. The results of these pairwise comparisons are pooled by their geometric means and then compiled within the framework of the AHP. The results are shown in Table 6.16.

Table 6.16. The results of the AHP model

Factors	Sub-criteria	Human Casualty	Infrastructure Damage	Environmental Damage	Waterway Efficiency
Vessel Type and Cargo Status	Full Tanker	0.33	0.156	0.412	0.066
	Empty Tanker	0.128	0.066	0.036	0.018
	General Cargo	0.05	0.038	0.104	0.031
	Passenger	0.118	0.022	0.04	0.013
	Total	0.626	0.282	0.592	0.128
Length of the Vessel	Above 250 m	0.082	0.054	0.148	0.17
	150 – 250 m	0.037	0.024	0.069	0.074
	50-150 m	0.018	0.012	0.036	0.039
	0 – 50 m	0.008	0.005	0.016	0.016
	Total	0.145	0.095	0.269	0.299
Accident Location	Zone 1	0.149	0.313	0.045	0.211
	Zone 2	0.056	0.236	0.061	0.274
	Zone 3	0.025	0.074	0.033	0.092
	Total	0.23	0.623	0.139	0.577

The results of the model suggest that the key factors, which are affecting the realization of accident consequences in the Istanbul Strait, depend on the type of the consequence considered. For instance, in case of an accident occurrence, the vessel type and its cargo are the most important factors regarding human casualties and environmental damage, whereas the location of the accident is most important regarding infrastructure damage and waterway efficiency. These observations are quite important, since the mitigation measures for the consequences of accidents could be taken based on these result. Another important result of the AHP analysis is that the significance of full tankers for almost all type of consequences. This result is very much in line with the Regulations, which define many restrictions and measures solely on the movements of tankers.

The other important factor highlighted by the AHP analysis regarding accident consequences (especially for the environmental damage and the waterway efficiency), is the length of the vessel. As it is discussed in the next section, the length of the vessel is an important factor on the realization of accident consequences; however, this impact does not change drastically according to different length intervals, as displayed in Figure 4.7.

6.4.3. Determination of the Ratio Scale Value of the Consequences

In concert with this model, the ratio scale relative values of the consequences are determined based on interviews with the experts participated in the previous AHP model. For this purpose, experts are asked to make pairwise comparisons among the four accident consequences and then the full pairwise comparison matrix is formed via the Expert Choice software. The weights of each consequence are than obtained by solving for the eigenvector. A computational shortcut to get the eigenvector is to raise the pairwise comparison matrix to powers that are successively squared each time. The row sums are then calculated and normalized to get an approximation of the eigenvector. This calculation is terminated when the difference between the sums in two consecutive calculations is smaller than a prescribed value. The results are displayed in Table 6.17.

These ratio scale values show the perception of the interviewees regarding the accident consequences and their relative importance (or worth) with respect to each other, based on their knowledge and experience about maritime accidents in the Strait. For example, according to Table 6.17, once an accident has occurred in the Strait, experts attach more than five times value or cost to potential environmental harm, as compared to the potential harm to waterway efficiency, as a consequence of this accident. These figures can also be used to express the cost of an accident consequence in terms of each other. For example, if the closure time in the Istanbul Strait resulting from accident were known, then the cost of the environmental harm could be estimated as five times of the waterway efficiency cost (expressed in terms/units of strait closure time). Similarly, the value attached to the human casualty is approximately half of the cost associated with environmental harm. These results highlight the public concern and sensitivity with respect to possible environmental damage, as a consequence of a maritime accident in the Istanbul Strait.

Table 6.17. The ratio scale value of the consequences

Consequence	Weight
Human Casualty	0.244
Infrastructure Damage	0.154
Environmental Harm	0.508
Waterway Efficiency	0.094

6.5. The Interaction between the AHP and the Logit Models

As discussed in Chapter 2, the primary goal of this study is to make a quantitative assessment of the maritime traffic risk, in terms of the accident probability and its various types of consequences, in order to arrive at operational policies that will mitigate the risk to the environment, Istanbul residents and the economy. Hence, in order to make a quantitative assessment, first it is required to identify the dominant risk factors and to evaluate their influence over the likelihood of an accident in the Istanbul Strait. However, as discussed in Section 4.2, there are various difficulties (such as scarce data and/or measurement/quantification problems of some of the factors) emerging for evaluating the influences of certain risk factors, even when they are identified as dominant risk factors.

The first setback is tried to be solved by developing an AHP model to quantify and reconsider the factors not included in the logit model. Even though the weight or influence of these factors over accident probability are quantified in the AHP framework, (along with the factors already included in the logit model), it is still a challenge to project and integrate these influences into the accident probabilities estimated by the logit model. In other words, the following logit model (which is developed and its parameters $\beta_1 \ldots \beta_k$ are estimated through regression analysis)

$$\begin{aligned} &Logit = L_i = \ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_k X_{ki} \\ &where\ P_i = P(Y_i = 1 | X_i) = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}} \end{aligned} \qquad (6.10)$$

is extended into

$$\begin{aligned} &Logit = L_i = \ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_k X_{ki} + \beta_{k+1} X_{(k+1)i} + \ldots + \beta_{k+m} X_{(k+m)i} \\ &where\ P_i = P(Y_i = 1 | X_i) = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}} \end{aligned} \qquad (6.11)$$

where $X_{(k+1)i} \ldots X_{(k+m)i}$ are the factors considered/quantified in the AHP model. The challenge is the estimation of $\beta_{k+1} \ldots \beta_{k+m}$, based on the relationships among $X_{1i}, X_{2i}, \ldots, X_{(k+m)i}$ as quantified in the AHP model. This challenge may be overcome by determining regression parameter values (that is $\beta_{k+1} \ldots \beta_{k+m}$) in the logit model for similar factors based on their weights in the AHP model. However, inclusion of new variables and their associated parameters into the logit model (without the calibration and adjustment of the existing logit parameters) may unduly distort the accident probability, and thus mislead into wrong conclusions. The second complexity is the determination of the level or value of the variable (after a certain coefficient assigned to it) during the estimation of the accident probability. This is a twofold problem where sometimes the value of the variable is difficult to be observed, and in some cases, due to certain political sensitivities, the data is available, but not open to the public. This problem is also very much related with the first complexity of the calibration process.

When the sub-criteria of the AHP model in Table 6.15 are examined, the following factors, (which are not included in the logit model) might be categorized in four different groups as follows;

(i) The factors for which the associated data is compiled or observed, but not open to public: the draught, age, flag state of the vessel and Regulation compliance (or violation of it).

(ii) The factors whose values are unknown: the knowledge of the crew and proper cargo handling. In accordance with the Regulations, TSVTS Authority is unable to confirm the value of these factors during the transit of the vessels; nevertheless it is assumed that vessels fulfill the standards set by the Regulations and the relevant IMO resolutions.

(iii) The factor whose value is difficult to be estimated or calculated: the intensity of the transit traffic.

(iv) The factors whose values vary with respect to the regions of the Istanbul Strait (such as current, morphological conditions and navigational aids).

Among these factors, the second factor group (the knowledge of the crew and proper cargo handling) is not included in the model, since the TSVTS Authority is unable to determine the level of these variables, but only assumed as fulfilling the standards. The last factor group is also omitted, since the model extension discussed in Section 6.3.1 is considered sufficient regarding region based factor differences.

In order to incorporate the first group factors (the draught, age and the flag state of the vessel and Regulations compliance) into the logit model, first it is required to assess their variation characteristics and their potential effects over the accident probability. Wind speed and pilot utilization variables of the logit model are matched with these new factors, based on the type of the variable (such as binary or continuous) and its weight in the AHP model, as displayed in Table 6.15.

The general logit model slightly underestimated (with less than seven per cent error) the total number of accidents occurred in the year 2005, as discussed in Chapter 5. This result implies that, adding new variables should not significantly alter this performance, such as increasing or decreasing the maritime accident probability of a vessel transiting through the Istanbul Strait. This could be achieved by determining the regression parameters of the new variables such that the associated term in the logit model (that is $\beta_{k+1}X_{(k+1)i}$) does not significantly change the total accident probability for a given year.

Therefore, it is required to determine how much the accident probability might be affected by the inclusion of these new variables. Then the logit coefficients should be determined for these variables based on their AHP weights (comparing and relating to wind speed and pilot utilization variables and their potential effects on the accident probability). This methodology is first tested on the visibility variable, since it was excluded during the multicollinearity test, as discussed in Chapter 5. The regression parameters with and without the visibility variable in Table 6.18 indicate how the accident probability and the other model parameters are affected by the inclusion or deletion of this new variable.

Table 6.18. The effect of the exclusion of the visibility from the general logit model

Variable	General Logit Model Coefficient	General Logit Model Coefficient without Visibility	Change (%)	Percent Change in odds **(1)**	Percent Change in odds (no visibility) **(2)**	% (1-2)
Constant	-28.5787	-29.9196	-4.7	NA	NA	NA
Transit Time	-0.33212	-0.368494	-10.95	-28.259877	-30.822464	9.07
Wind Speed	0.202904	0.187133	-7.77	22.495486	20.578764	-8.52
Precipitation	-0.07482	-0.015684	79.04	-7.2086721	-1.5561647	-78.41
Visibility	-0.07927	0	NA	-7.6206761	0	NA
Pilot Utilization	-0.6792	-0.675316	0.57	-49.297806	-49.100445	-0.40
Vessel Length	0.000312	0.00023	-26.28	0.0312048	0.0230026	-26.29
Local Traffic Intensity	-0.00264	-0.002462	6.67	-0.2634524	-0.2458972	-6.66
Cargo Vessel	22.11361	22.14184	0.13	4.0162E+1	4.1312E+1	2.86
Tanker	22.10535	22.13801	0.15	3.9832E+1	4.1154E+1	3.32
Passenger Vessel	23.52085	23.54609	0.11	1.6405E+1	1.6824E+1	2.56

Table 6.18 illustrates that except the precipitation and vessel length variables, the exclusion of the visibility factor has a limited effect over the other variables (less than 10 per cent change in their effect over the accident odds). Even though the effect over precipitation seems significant (per cent change in its coefficient is around 79 per cent), still the effect of precipitation over accident odds is insignificant, around less than two percent (-1.55 per cent). A similar result is observed for the vessel length factor: even though its logit coefficient changes around 26 per cent; its effect over the accident odd is less than one per cent. If the data were available for the new variables (that is draught, age, flag state of vessels that have realized accident free transits), it would have been possible to calibrate all parameters based on the number of accidents estimated and realized in the year 2005. Unfortunately, no data is available neither for the accidents, nor for the accident free passages of the year 2005. Thus, it is assumed that the exclusion or inclusion of a new variable in the logit model mainly affects the value of constant term and there is a linear relationship between the regression coefficients and the weight of the variable estimated by AHP model.

The average visibility range in 2005 is 17.75 km. The average contribution of this variable in the logit model (Z term) in accordance with Equation 6.10 and Table 6.8 is 1.211 ($\beta_{3i} * \overline{X}_{3i}$), whereas the change in the constant term (β_0) is -1.34091 (from Table 6.19).

$$\begin{aligned} P_i &= P(Y_i = 1 | X_{li}) = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}} \\ Z_i &= \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \\ &\quad \beta_8 X_{8i} + \beta_9 X_{9i} + \beta_{10} X_{10i} + \beta_{11} X_{11i} + \beta_{12} X_{12i} + u_i \end{aligned} \tag{6.12}$$

When the number of accidents in the year 2005 is estimated by deploying the logit model results with and without the visibility variable, 21.50 and 21.91 are obtained respectively.

The following variable values are set for determining their contribution to Z term in the logit model as follows;

- Age of the vessel: The average age for vessels transiting the Istanbul Strait in 2005 is around 23.3 years old [73].
- Draught of the vessel: Annual statistics for the year 2007 shows that approximately 90 per cent of vessels transiting the Istanbul Strait have a draught of less than 10 meters [73]. Moreover, Tayanc [26] claimed that vessels, which have a draught larger than 15 meters, are more risky. The results of Tayanc's work regarding the draught of vessel is displayed in Table 6.19. Taking account the results of Tayanc's work with the annual statistics for the year 2007, draught of 10 meters is taken as the reference figure for this factor .
- Flag state of the vessel: The results of the port state control (that is the excess factor index of the flag states in the relevant regional MOU Organization published in annual "Black-Gray-White List") are used to represent the vessel flag state factor. Hence, the average excess factor index in the Paris MOU Black-Gray-White List for the year 2006 [74] for vessels transiting the Istanbul Strait is 0.93591 (the average value corresponds the Gray List which indicates the risk in the Istanbul Strait).
- Regulations compliance: The annual average number for the violation of the Regulations in 2005 is 4.6 per thousand transits [73].

Table 6.19. The states and associated weights assumed for vessel draught

Variable	States in AHP	Weight in Maritime Risk
Draught of vessel	The vessel draft being less than 5 meters	0.002
	The vessel draft being between 5-15 meters	0.003
	The vessel draft being more than 15 meters	0.010

Based on these values the total contribution of the new variables in Z term is computed as 1.6885302. Thus, the constant term in the new model is reduced by 1.6885302 as displayed in Table 6.20 to -26.8901598 (from Table 6.18).

In general, if there is no multi-collinearity among the variables, it is expected that the accident probability increases as the age and the draught of vessel and the excess factor of flag state increase. Thus, it is assumed that if the age of the vessel transiting in the Strait is greater than the annual age of the vessel average (23.3 years old), the age of the vessel will increase the accident probability. Similarly, the accident probability for a vessel will increase, if its draught is greater than 10 meters and its excess factor of Flag State is greater than 0.93591. Additionally, if this vessel fulfills the requirements of the Regulations during its transit, there is to be no change in the accident probability, while a violation of the Regulations is to increase the accident probability. Table 6.20 displays the results of this schema. The last column illustrates the percent change over the accident odds as a result of a unit increase in a given independent variable. Results shows that violation of the Regulation increases the accident odd by 2.44 E+68 per cent, one unit increase in the excess factor of Flag State causes approximately 22 per cent increase in the accident odd and one meter increase in the draught of the vessel results in approximately five per cent increase in the accident odd as well. Unfortunately, it is not possible to validate and then calibrate the new model parameters, since no data is available neither for the accidents, nor for the accident free passages of the year 2005.

Table 6.20. The regression parameters for the new variables added to the logit model

	Reference Value	Weight in AHP	Regression Parameter	Contribution to Z	Assigned Regression Parameter	Change in odds
Wind	1.99	0.033	0.202904	0.40377896	NA	22.49548
Draught	10	0.039	NA	0.47719332	0.04771933	4.887623
Age	23.3	0.027	NA	0.3303646	0.01417874	1.427973
Flag State	0.93591	0.015	NA	0.18353589	0.1961043	21.66538
Visibility	17.75	0.099	-0.079267	1.21133688	-0.0682443	-6.59678
Pilot Utilization	0.45	0.082	-0.679201	1.00332954	NA	-49.2978
Violation of the Regulations	0.004563	0.057	NA	0.69743639	152.86132	2.44E+68
Total contribution of draught, age and Flag State of the vessel and violation of the Regulations in Z term				1.6885302	NA	NA

6.6. Consequence Analysis

The theory and the development process of the probabilistic consequence model are discussed in Section 4.3. As a result of this discussion, the following equation (as displayed in Equation 4.16) is developed. In this form;

- The difference vector of the situation factor, (that is $\underline{D}_o$) is derived from the results of the AHP model (as discussed in the previous section),
- The vector of regression parameters, (that is $\underline{\beta}$) is estimated by using a standard inference procedure for multiple linear regression,
- $\bar{z}_o$ is the dependent variable representing the grouped, (by geometric mean), expert responses,
- ε is the residual error term.

$$\ln(\bar{z}_o) = \underline{\beta}^T \, \underline{D}_o + \varepsilon, \tag{6.13}$$

The levels of the attributes in each question in the scenarios, along with the responses given by the experts during interviews are given in Appendix J. A typical example of the question and scenarios are displayed in Table 4.6 and Figure 4.4. The probabilistic consequence model features are as follows;

- Equation set 6.11, (which encompasses, 10 regression models, 63 equations and 40 unknowns) are solved by multiple linear regression methods.
- There is one regression model for each accident type and consequence combination as displayed in Table 4.4.
- There are seven pairwise situation comparisons for collision type accident scenarios, with three questions relating the consequences of each collision situation (total of 21 questions).
- There are six pairwise situation comparisons for contact type accident scenarios with four questions relating the consequences of each contact situation (total of 24 questions).

- There are six pairwise situation comparisons for stranded type accident scenarios with three questions relating the consequences of each stranded situation (total of 18 questions).
- In each regression model, there are one constant term and three parameters (that is the $\underline{\beta}$ vector) for the three situation factors (i.e. vessel type and cargo status, vessel length and accident location)
- The cardinal values of the situation factors (that is B_l, which are originally qualitative in nature) are obtained by the AHP model discussed in Section 6.4.2.
- It is possible to compute the probability of the realization of any accident consequence, given the accident type and situation factors as displayed in Equation 6.11.
- The determination of the normalization factor (ρ) is discussed at the end of this section.

$$P(C_{mj} \mid A_m, B_l) = \rho_{mj} * e^{\beta * B_l} \quad \forall m, j, l \tag{6.14}$$

The resulting estimates for the parameter vector $\underline{\hat{\beta}}$, (and other related statistics) for each type of accident considered and with respect to all type of the consequences, are given in the Table 6.21.

The R^2 value for a statistical regression gives an indication of the fit of the model to the data. For these regression models, the R^2 values, except for the human casualty and infrastructure damage as a result contact type accident, are above 85 per cent (indicating a good fit), which implies that more than 85 per cent of the variation on the dependent variables (relative comparison of the consequence probabilities) explained by the models.

Table 6.21. Results of the statistical regression for the determination of the regression parameters in the probabilistic consequence model

<table>
<tr><th colspan="7">Human Casualty</th></tr>
<tr><th></th><th>Location of the Accident (β_3)</th><th>Length of the Vessel (β_2)</th><th>Type of the Vessel (β_1)</th><th>Constant (β_0)</th><th>R^2</th><th>F-Statistics</th></tr>
<tr><td>Collision</td><td>10.06438074</td><td>10.37832</td><td>5.4332</td><td>-0.89675</td><td>0.428401</td><td>0.749479</td></tr>
<tr><td>Contact</td><td>1.60967319</td><td>19.66566</td><td>5.311124</td><td>-0.20725</td><td>0.685054</td><td>1.450096</td></tr>
<tr><th colspan="7">Infrastructure Damage</th></tr>
<tr><td>Stranded</td><td>4.974549676</td><td>17.95928</td><td>14.73342</td><td>-0.48996</td><td>0.853047</td><td>3.869929</td></tr>
<tr><td>Contact</td><td>3.538141309</td><td>37.95703</td><td>11.21315</td><td>-0.09022</td><td>0.724325</td><td>1.751639</td></tr>
<tr><th colspan="7">Environmental Damage</th></tr>
<tr><td>Collision</td><td>4.624905687</td><td>12.89856</td><td>6.510438</td><td>-0.52218</td><td>0.970044</td><td>32.38208</td></tr>
<tr><td>Stranded</td><td>22.28542578</td><td>4.388146</td><td>6.210886</td><td>-0.35603</td><td>0.970699</td><td>22.08562</td></tr>
<tr><td>Contact</td><td>20.15158216</td><td>12.4465</td><td>4.018974</td><td>-0.14968</td><td>0.921552</td><td>7.831483</td></tr>
<tr><th colspan="7">Waterway Efficiency</th></tr>
<tr><td>Collision</td><td>9.089463722</td><td>6.820856</td><td>35.70284</td><td>-0.56583</td><td>0.974603</td><td>38.37538</td></tr>
<tr><td>Stranded</td><td>11.94155607</td><td>0.763769</td><td>39.78064</td><td>-1.1287</td><td>0.984286</td><td>41.7588</td></tr>
<tr><td>Contact</td><td>2.810927604</td><td>7.907326</td><td>24.48549</td><td>-0.4875</td><td>0.938824</td><td>10.23083</td></tr>
</table>

Since Equation 6.11 provides the probability of a consequence type realization as a result of a given accident and situation factors during the accident, it is possible to determine the relative contribution of each situation factor into this probability, by the results displayed in Table 6.16 and Table 6.21. For example, given the occurrence of a collision, the relative contribution of each situation attribute to the human casualty (as a result of this accident) can be determined as displayed in Table 6.22.

Table 6.22. The computations of the relative contribution of situation factors to the consequences of a collision type accident

Situation Factor	Cardinal Values (Table 6.16)	Average of Cardinal Values **(1)**	Regression Parameter (Table 6.21) **(2)**	Contribution of Factor **(3)=1*2**	Relative Contribution (per cent) **(3)/(4)**
Vessel Type and Cargo Status	0.33, 0.128 0.05, 0.118	0.15650	5.4332	0.850295725	38.61
Vessel Length	0.082, 0.037, 0.018, 0.008	0.03625	10.37832	0.376214196	18.82
Accident Location	0.149, 0.056, 0025	0.0767	10.06438074	0.771602524	42.55
Total **(4)**				1.998112445	

Table 6.23. The computational results of the relative contribution of situation factors to accident consequences

Accident Type	Consequence Type	Accident Location	Vessel Length	Type of Vessel
Collision	Human Casualty	**0.771602524 (0.39)**	**0.376214196 (0.19)**	**0850295725 (0.43)**
	Environmental Damage	0.214287297 (0.10)	0.867428172 (0.42)	0.963544876 (0.47)
	Waterway Efficiency	1.748206856 (0.51)	0.509859018 (0.15)	1.142491039 (0.34)
Contact	Human Casualty	0.123408278 (0.07)	0.712880208 (0.43)	0.831190872 (0.50)
	Infrastructure Damage	0.734754012 (0.30)	0.901479361 (0.37)	0.790527018 (0.33)
	Environmental Damage	0.933689973 (0.40)	0.837026933 (0.35)	0.594808079 (0.35
	Waterway Efficiency	0.540635076 (0.28)	0.591072625 (0.31)	0.783535574 (0.41)
Stranded	Infrastructure Damage	1.033048149 (0.41)	0.426532959 (0.17)	1.038706148 (0.42)
	Environmental Damage	1.032558061 (0.46)	0.29510284 (0.13)	0.919211138 (0.41)
	Waterway Efficiency	2.296759284 (0.63)	0.057091724 (0.02)	1.272980498 (0.35)

Similar computations are also carried out for the other types of consequences and results of these computations are displayed in Table 6.23. The figures in the parenthesis show the contribution of each factor to the relevant consequence in per cent. The relative contributions of the situation attributes to the realization of different consequences (given that a collision has occurred) are displayed in Figure 6.19.

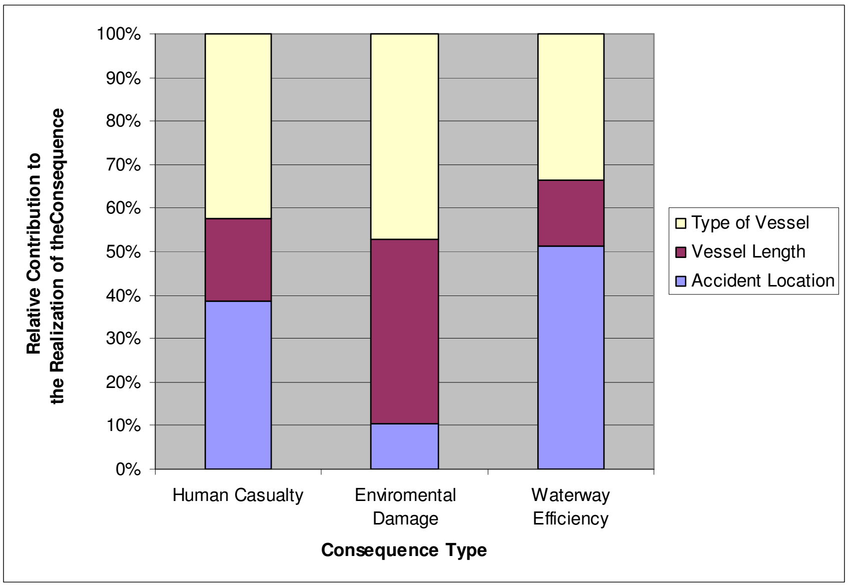


Figure 6.19. The relative contribution of the attributes to the realization of different consequences given that a collision has occurred

When the results of the regression model for estimating the $\underline{\beta}$ vector is examined, it is observed that almost 39 per cent of human casualty during a collision is due to accident location, while more than 43 per cent of the casualty is due to the vessel type and its cargo and rest of the human casualty is due to the length of the vessel. For the environmental damages, while the contribution of the vessel type is again around 45 per cent, the contribution of the vessel length is significantly enlarged. Finally, the likelihood of a strait closure primarily depends on the accident location (around 51 per cent) and the vessel types involved in a collision (around 32 per cent).

Figure 6.20 shows that for a given contact type accident, the primary factor that contributes to the realization of the consequences is the type of the vessel and its cargo.

The second important factor for the consequences of a contact is the length of the vessel involved in the accident.

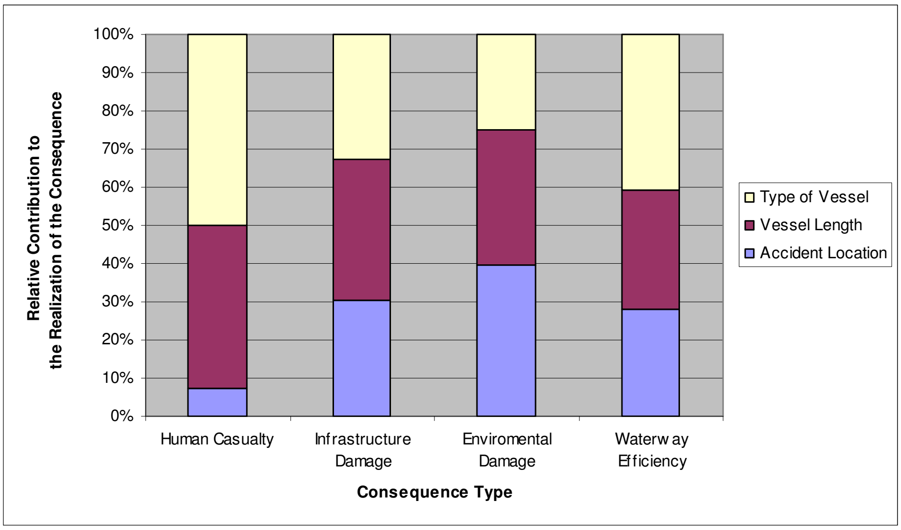


Figure 6.20. The relative contribution of the attributes to the realization of different consequences given that a contact has occurred

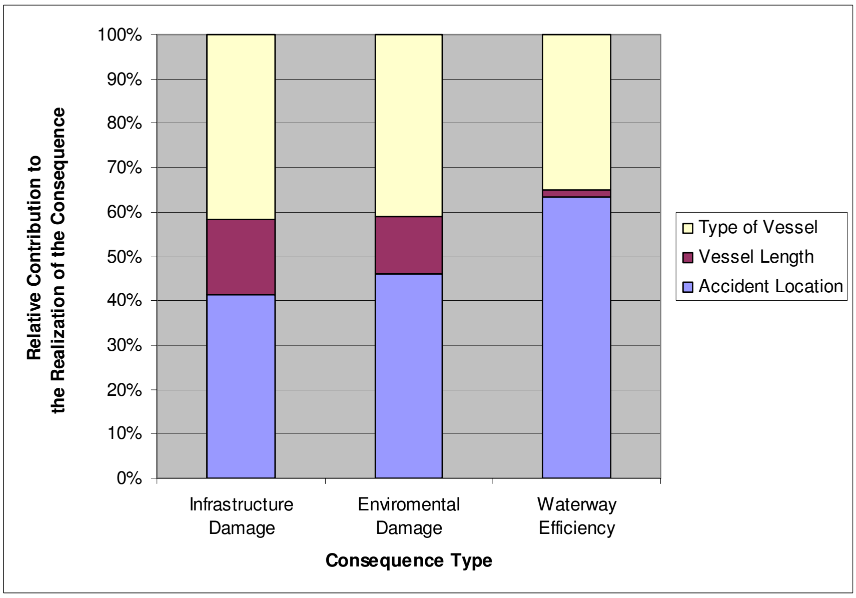


Figure 6.21. The relative contribution of the attributes to the realization of different consequences given that a stranding has occurred

Figure 6.21 shows the relative contribution of each factor to the realization of the consequences, after a vessel is stranded. The vessel type and the accident location are the primary factors, which contribute to the realization of different consequences.

Table 6.24. The computations of vessel length's contribution to the realization of human casualty given a contact has occurred

Factor Level	Cardinal Value (Table 6.16) **(b)**	Regression Parameter (Table 6.21)(β)	Contribution at Level (b) $e^{\beta b}$
0-50 meters	0.008	19.66566	1.170376261
50-150 meters	0.018		1.424729394
150-250 meters	0.037		2.070167359
Above 250 m	0.082		5.015756

Another analysis carried out is the determination of the contribution of different levels of each factor to the realization of consequences. This will show how the realization of a given consequence is affected by the different levels of the each factor. For example, the vessel length's contribution (at its different levels) to the realization of human casualty, given that a contact has occurred, can be determined through Equation 6.11, as displayed in Table 6.24.

Table 6.25. The computational results of the contribution of vessel length to the realization of various consequences given a contact has occurred

	0-50 m	50-150 m	150-250 m	Above 250
Human Casualty	**1.170376261**	**1.424729394**	**2.070167359**	**5.015756**
Infrastructure Damage	1.208989792	1.576936922	2.486730057	7.765411
Environmental Damage	1.220357629	1.565294362	2.3603462	6.309659
Waterway Efficiency	1.13486899	1.361225936	1.795246127	3.835291

Similar computations are also carried out for the other types of consequences and results of these computations are displayed in Table 6.25.

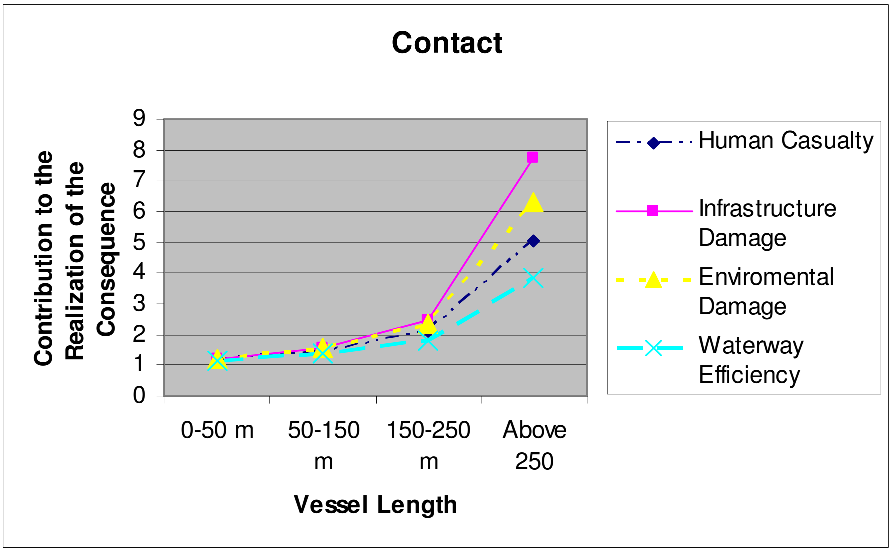


Figure 6.22. The contribution of the vessel length to the realization of various consequences given a contact has occurred

Figure 6.22 (based on the results displayed in Table 6.25) shows that, for a vessel involved in a contact type accident, the realization of all consequences are sharply increasing, especially when its length is above 250 m, which brings the suggestion of taking special measures for such long vessels.

Table 6.26. The computational results of the contribution of vessel type and cargo status to the realization of various consequences given a collision has occurred

	Full Tanker	Empty Tanker	Cargo	Passenger
Human Casualty	6.007183	2.004610021	1.312141	1.898601
Environmental Damage	14.61869	1.264119435	1.968133	1.297472
Waterway Efficiency	10.55276	1.901515518	3.024628	1.590641

Similar computations are also carried out for the collision type accident with respect to vessel type and cargo status and results of these computations are displayed in Table 6.26. Figure 6.23 (based on Table 6.26) illustrates that, excluding full loaded tankers, there is no significance difference between the remaining vessel types, regarding their contribution to the realization of various accident consequences.

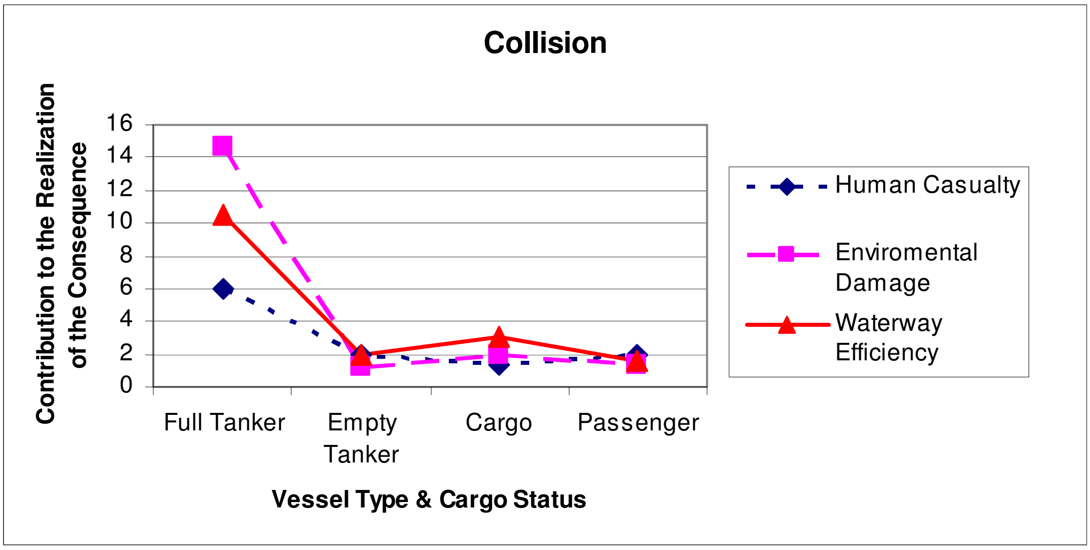


Figure 6.23. The contribution of the vessel length to the probability of the realization of various consequences given a collision has occurred

Similar computations are also carried out for the stranded type accident with respect to accident location and results of these computations are displayed in Table 6.27. Figure 6.24 (based on Table 6.27) shows the contribution of the accident location to the realization of various accident consequences (based on the regions displayed in Figure 4.6). The second region, namely the area between the line of Kurucesme – Cengelkoy and Yenikoy - Pasabahce, is the major contributor to the realization of a potential closure of the Strait, if a vessel is stranded in this region. This result is quite intuitive if one takes a close look to the morphological characteristics of this region: This region is the narrowest part of the Strait and there exist a sharp turn in the area along with the various types of currents. All of these factors definitely have an impact over the consequences of accidents, but especially the waterway efficiency (namely the delay on the traffic or even worse the closure of the Strait). Because clearly these factors will hamper the efforts of diminishing the negative impacts of the accident; additionally, the maritime traffic in the Strait will be certainly affected due to the width of the region.

Table 6.27. The computational results of the contribution of accident location to the realization of various consequences given a vessel has stranded

	Zone 1	Zone 2	Zone 3
Infrastructure Damage	4.744727723	3.234886115	1.445010627
Environmental Damage	2.726024062	3.893899013	2.086356099
Waterway Efficiency	12.42447517	26.36365517	3.00003261

The rest of the figures (and the relevant computation results) showing the contribution of the attributes to the realization of various consequences for a given type of accident are displayed in Appendix K.

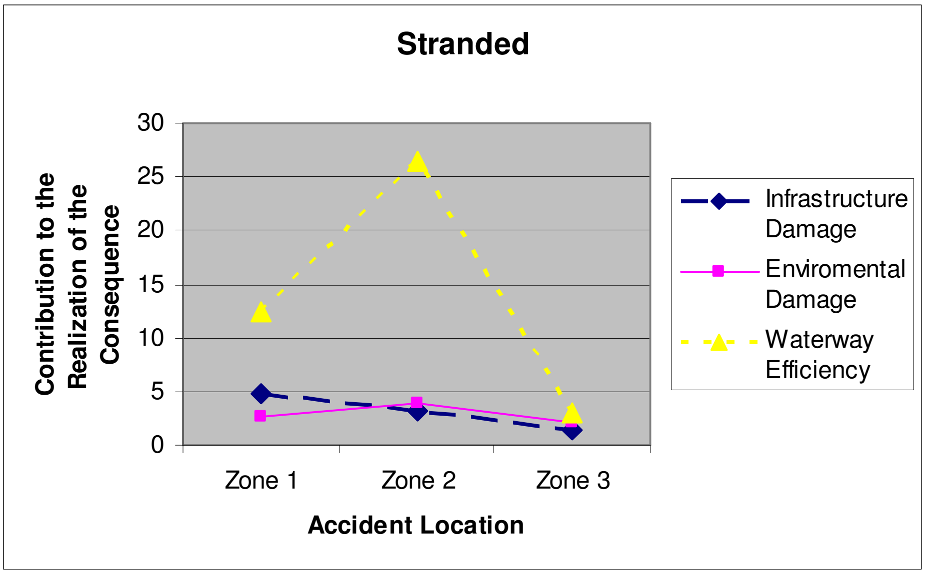


Figure 6.24. The contribution of the accident location to the realization of various consequences given a vessel has stranded

6.6.1. The Normalization of the Likelihood of Accident Consequences

As a result of the discussion in Section 4.3, the likelihood of accident consequences is expressed as follows;

$$P(C_{mj} | A_m, B_l) = \rho_{mj} * e^{\beta * B_l} \qquad \forall m, j, l \tag{6.15}$$

Unfortunately, without the normalization factor (ρ), this equation itself does not guarantee a probability value less than the theoretical limit of one. Thus, calibration or normalization is required once the likelihood of the consequence is calculated. There might be different methods to achieve this. The first method could be to normalize with respect to the worst-case scenario or the possible maximum value of the likelihood of a consequence for a given accident. This value could be computed using Equation 6.13 for each consequence and accident type pair. In Equation 6.13, the cardinal value of situation factor is the maximum of the relevant situation factor and consequence type combination determined by the AHP model displayed in Table 6.16. The regression parameter (that is β) is obtained from Table 6.21 for the relevant situation factor, consequence and accident type combination.

$$\rho_{i,j} = \max(P(C_{ij} | A_i, B_l)) = e^{\sum_l \beta_{i,j,l} \max(b_{j,l})} \qquad \forall i, j \tag{6.16}$$

Another method might be to assume that once an accident has occurred, at least one of the accident consequences is bound to be realized as a result. Based on this assumption, the following equation holds;

$$\sum_j P(C_{ij} | A_i, B_l) = 1.0 \qquad \forall i \tag{6.17}$$

Therefore each of the calculated values of the consequence likelihood can be normalized with respect to the summation over the all types of the consequence probability values, for a given accident.

As an example, let’s assume that two full loaded tankers, having lengths 50-150 meters, collided in the second zone of the Istanbul Strait. Now the likelihood of the realization of each type of consequences are computed based on the results displayed in Table 6.16, Table 6.21 and Equation 6.12 as follows;

- The likelihood of the realization of human casualty as a result of the given scenario:

$$= e^{-0.89675+5.4332*0.33+10.37832*0.018+5.4332*0.33+10.37832*0.018*10.06438074*0.056} =37.57696579$$

- When similar computations for environmental damage and waterway efficiency are carried out, the values of 425.4886189 and 1299.179076 are obtained (as the likelihood of the realization of environmental damage and a negative impact over waterway efficiency respectively), as a result of the given scenario;
- Now, if Equation 6.14 holds, the normalized value for the likelihood of the realization of a human casualty is computed as follows: 37.57696579/(37.57696579+425.4886189 + 1299.179076) = 0.021323353,

Based on the results displayed in Table 6.16 and Table 6.21, the worst-case scenario (that is the maximum likelihood values) is the collision of two full loaded tankers, both having length greater than 250 meters. In accordance with the AHP model results, as displayed in Table 6.16, the maximum of the cardinal values for accident location varies with the consequence type (for human casualty and infrastructure damage, the cardinal value of Zone 1 is the maximum, where as, for environmental damage and waterway efficiency the cardinal value of Zone 2 is maximum) So, the relevant maximum cardinal value is taken with respect to the consequence type. If the similar computations are carried out for this worst case scenario, as discussed in the previous paragraphs, the following figures are obtained, (as the likelihood of the realization of different accident consequences);

- The probability of the realization of human casualty: 361.695956
- The probability of the realization of environmental damage: 7650.418873
- The probability of the realization of a negative impact over the waterway efficiency: 7758.5617

These figures now can be normalized with respect to the worst-case scenario as well. The results of these two normalization methods are displayed in Table 6.28.

The normalization method, based on Equation 6.14, presents the relative probability of each consequence with respect to others. Accordingly, if one of the consequences takes place as a result of the above collision, most probable effect on the Strait would be the closure of it (with a probability of nearly 74 per cent). However, if the likelihood values are normalized with respect to the worst case based on Equation 6.13, still the negative effect over the waterway efficiency is the most likely outcome of the accident, but there is a significant possibility of human casualty as well. As a summary, the normalization method using Equation 6.14 provides the "relative" probability of the consequences, whereas the Equation 6.13 presents "absolute" probability values of the consequences.

Table 6.28. The normalization of the likelihood of the consequences

	Human Casualty	Environmental Damage	Waterway Efficiency
Before Normalization	37.57696579	425.4886189	1299.179076
Normalization assuming at least one of the consequences occurred	0.021323353	0.241446962	0.737229685
Worst Case	361.695956	7650.418873	7758.5617
Normalization with respect to the worst case scenario	0.103891031	0.055616382	0.167451021

7. SCENARIO ANALYSIS AND RESULTS

In this chapter, the scenario analysis performed in order to understand and control the effects of the key factors, influencing the probability and the consequences of accidents, is discussed. Since there is no general prescription to specify the levels of the factors under consideration, it requires further discussion. Generally, the levels should not be very far apart from each other and levels of different factors can be determined in a sense to balance the output values. On the other hand, if the response is not very sensitive, the short separation between consecutive levels may cause the misleading conclusion that estimated factor effect is insignificant. Thus, intuitive feel for the model and what is meant by normal/realistic conditions is first sought, in order to specify reasonable values for the quantitative factors and meaningful options for the qualitative factors [75,76].

In the logit model, 20 distinct scenarios are analyzed with respect to the probability of accidents. These scenarios are determined by adjusting the level of the eight situational factors determined in Section 4.2. The aim of this analysis is to help determine the measures that could be taken in order to reduce probability of maritime accidents and thus enhance the maritime safety of the Istanbul Strait. The levels of the factors are determined as follows;

- If there exist special measures in the Regulations with respect to certain levels of the factors (such as visibility, vessel length), these levels in the Regulation are selected;
- Some basic statistics regarding the historic data on the meteorological factors (such as precipitation, wind speed), as displayed in Table 6.5, are utilized;
- Regarding daytime versus nighttime transit and pilot deployment (since they are binary variables), both levels are used;
- Regarding local traffic, the intensity level at various time of the day and average intensity figures are used.

In the second part of the scenario analysis, the probabilistic consequence model outcomes associated with some of the selected scenarios are compared with one another, in order to enhance the understanding of factors' effects on various consequences of the maritime accidents. This analysis aims to determine what kinds of measures are required to be taken or in order to reduce the impact of a given accident.

7.1. The Logit Model Scenario Analysis

The eight factors and their levels set in the 20 distinct scenarios are displayed in Table 7.1. Since the aim of the study is to help determine the measures enhancing the safety in the Strait or mitigating maritime accident probabilities, the primary output for the scenario analysis is the likelihood of an accident in the Istanbul Strait, under predetermined levels of the situational factors. The details of the factor levels for each scenario used by the logit model are shown in Appendix H.

Table 7.1. Factors and their levels in the logit model scenario analysis

Variable	Level 1	Level 2	Level 3	Level 4	Level 5
Transit Time	Day	Night			
Wind Speed (m/sec)	0	2	10		
Precipitation (mm)	0	10	20	35	
Visibility (nm)	0.5	1	2	5	10
Pilot Utilization	Yes	No			
Vessel Length (m)	100	200	300		
Local Traffic (# of movements)	0.24	83.14	28.92	29.08	88.56
Vessel Type	Passenger	Cargo	Tanker		

Fortunately, since there has been no LPG tanker or dangerous cargo vessel (IMO) involved in any accident in the 1995-2004 period, it was not possible to estimate a coefficient for these types of vessels by the logit model. However, it is still possible to make probability estimations involving LPG tankers or IMO vessels, by taking the average values of the coefficients associated with passenger, cargo and tanker type vessels. As already discussed in Section 6.3, passenger vessels have the maximum coefficient value for vessel type, whereas the coefficients of cargo vessels and tankers are smaller and close to each other. Hence, it is appropriate to take the average value of vessel type coefficients, in order to observe the values in between the maximum and the minimum values. Moreover, based on the past accident data, it is not prudent to assume that the coefficients for LPG tankers and IMO vessels would be greater or smaller than the coefficients of other types of vessels. However, still a value between the maximum and the minimum of the coefficients, such as much closer to the maximum or the minimum coefficients values than the average of them could have been considered.

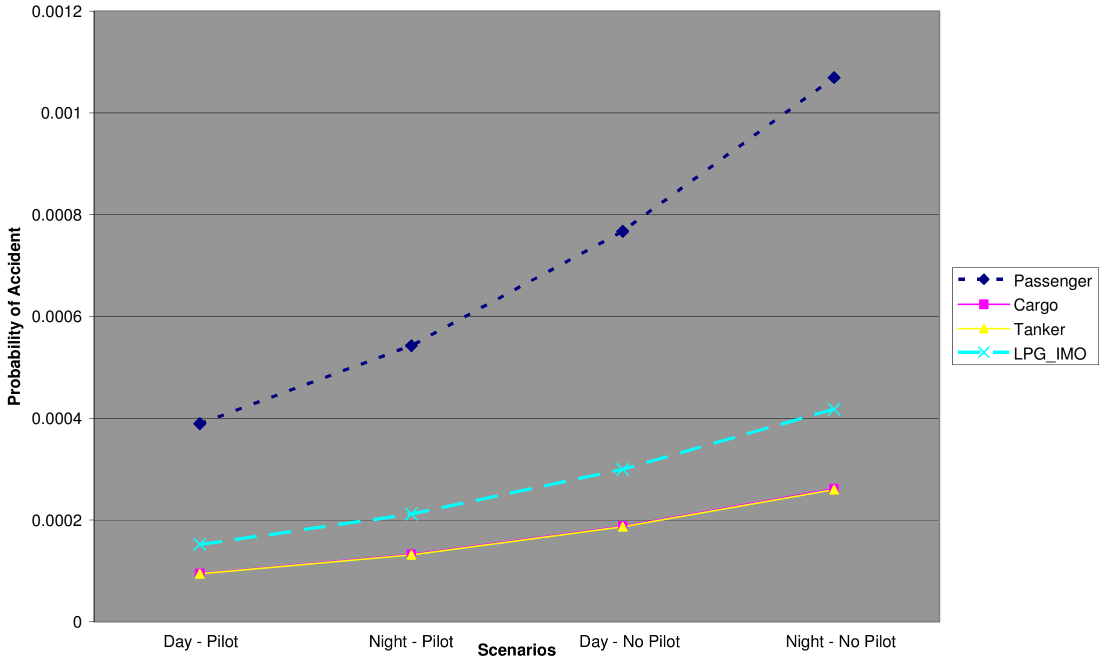


Figure 7.1. The accident probability in the Strait under the best situational conditions

Accident probabilities under the best and worst navigational conditions in the Strait (such as no/maximum wind or precipitation, maximum/minimum visibility and minimum/maximum local traffic intensity) are displayed in Figure 7.1 and Figure 7.2 respectively. These figures show that the difference in the accident probability between these two somewhat extreme scenarios (that is transiting the Strait during daytime with pilot onboard and transiting the Strait at night without a pilot) is more than twice;

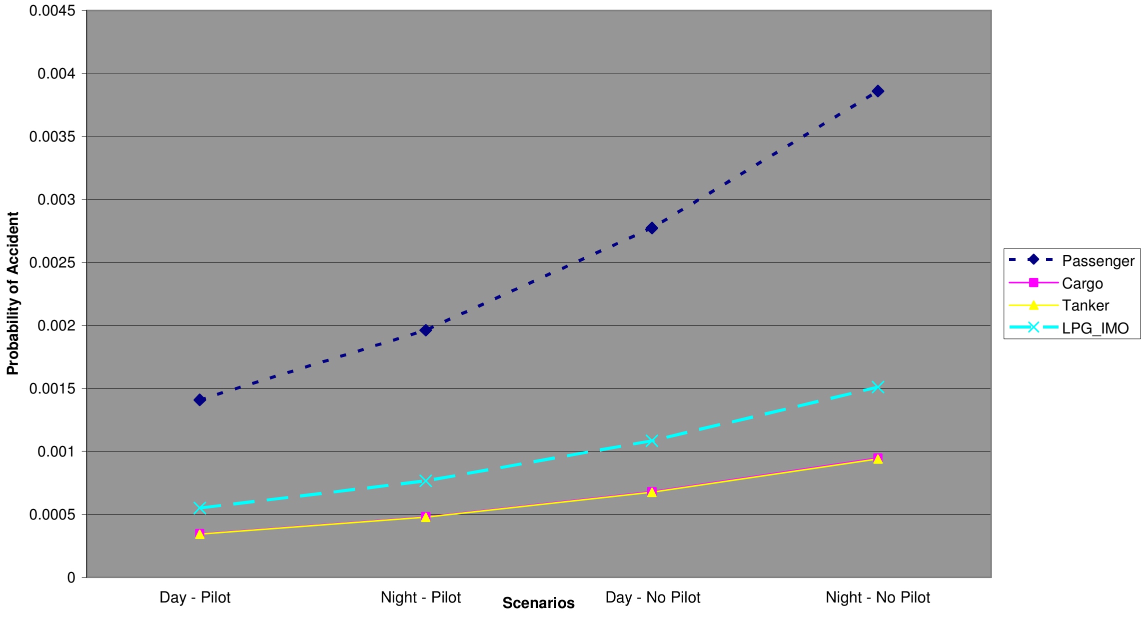


Figure 7.2. The accident probability in the Strait under the worst situational conditions

Table 7.2. The factor levels and accident probabilities of best case versus worst case scenarios

	Estimated Coefficients	Best Scenario	Worst Case Scenario
Constant	-28.57869		
Transit Time	-0.33212	Daytime	Nighttime
Wind Speed	0.202904	0	10.00
Precipitation	-0.074817	0	34.00
Visibility	-0.079267	20.00	0.93
Pilot	-0.679201	Onboard	No pilot
Vessel Length	0.000312	118.93	300.00
Local Traffic	-0.002638	88.56	0.24
		Accident Probability	
Passenger Ship	23.52085	0.00038921	0.00386084
Cargo Ship	22.11361	9.5313E-05	0.000947967
Tanker	22.10535	9.4529E-05	0.000940177

Figure 7.3 shows the difference in the accident probability between the best and the worst-case scenarios described in Table 7.2. The coefficients in Table 7.2 are estimated by deploying the results of the logit model, as presented in Section 6.3 and the level of factors are determined to create the most possible favorable and unfavorable situations (that is the minimum and the maximum accident probabilities). For the binary variables (transit time and pilot utilization), best case considers a transit during daytime and pilot onboard, where as worst case considers nighttime and no pilot deployment. Then, accident probabilities are computed based on Equation 4.3. Similar computational method also used for the rest of the scenario analysis, using the situational factor values provided in Appendix H and the coefficients presented in Section 6.3.

As indicated by Figure 7.3, the difference between the best and worst case conditions for a given vessel varies more than three times, (3.54 times). This result illustrates the significance of the situational factors over accident probabilities.

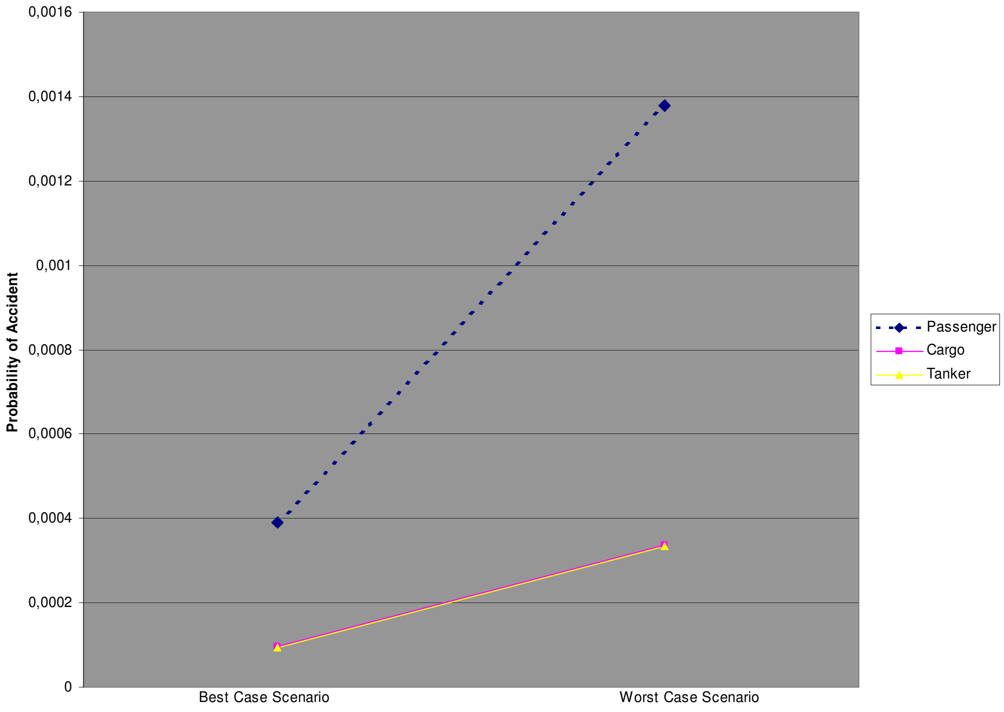


Figure 7.3. The comparison of the best and worst case scenarios

The logit model results suggest that one km (i.e. ≈ 0.54 nm) decrease in visibility results seven per cent increase in the overall accident probability. Figure 7.4 displays how (lightly or severely) the accident probability is affected as visibility decreases, for different vessel types and other conditions. Actually, these results are very much in line with the general risk expectations of the TSVTS Authority regarding visibility: There are specific and strict rules in the Regulations [12] regarding visibility during transit.

Figure 7.4 clearly shows that the accident probability of a passenger vessel without a pilot on board increases more than five times for the 10 nm and 0.5 nm visibility levels. This result also justifies the strict rules imposed by the Regulations with respect to low visibility conditions.

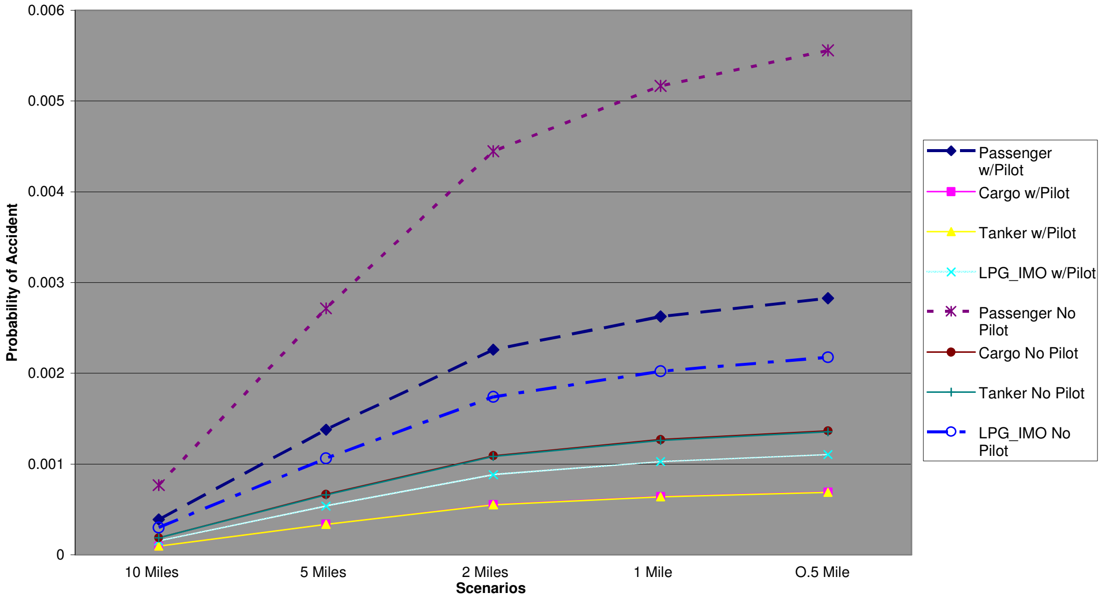


Figure 7.4. The sighting distance effect over the accident probability

Another important meteorological factor suggested by the logit model is the wind speed. Even though currently there is no specific regulation enforced, Figure 7.5 shows the effect of wind speed over accident probability. Figure 7.5 is based on the average daytime and nighttime accident probability of a vessel with or without a pilot on board.

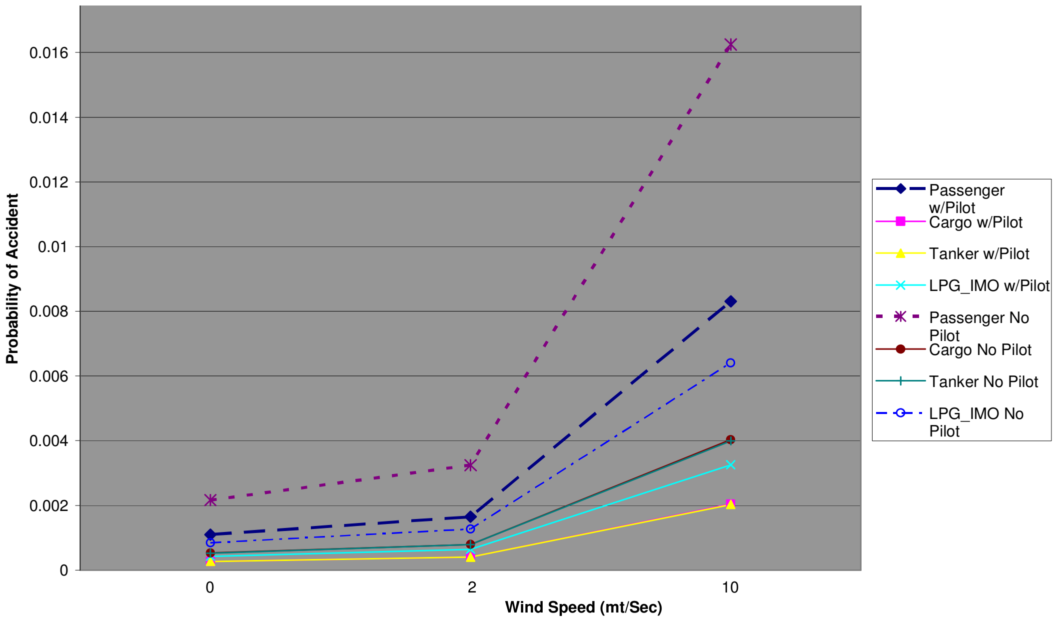


Figure 7.5. The effects of wind speed over accident probabilities

On the other hand, as presented in Figure 7.6 and 7.8 respectively, local traffic and vessel length do not seem to have much influence over accident probability (as estimated by the logit model).

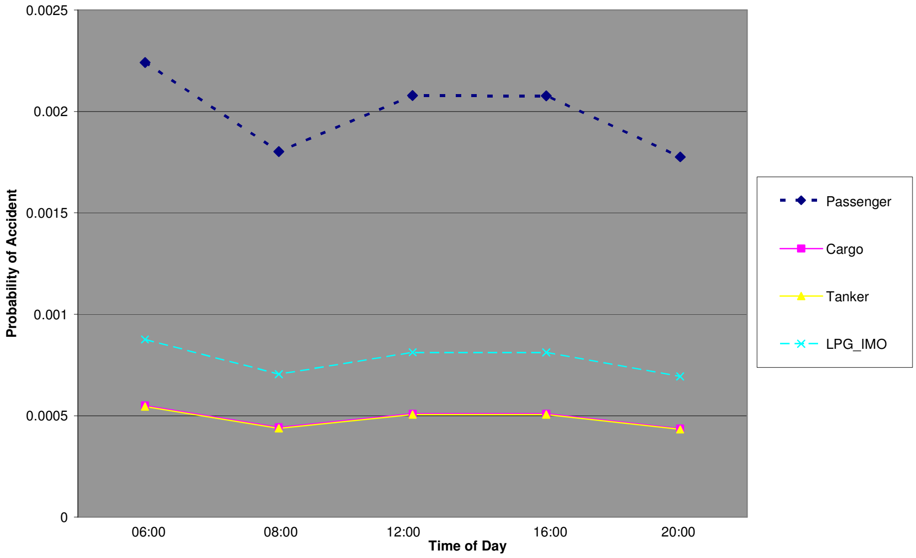


Figure 7.6. The effects of local traffic intensity over accident probabilities

Figure 7.6 displays the effect of the local traffic intensity over accident probabilities, based on the whole data. However, if a similar figure is generated with only daytime data (as presented in Table 5.5), the effects of local traffic intensity over accident probabilities become very significant, as displayed in Figure 7.7, (this issue is already discussed in Section 6.3)

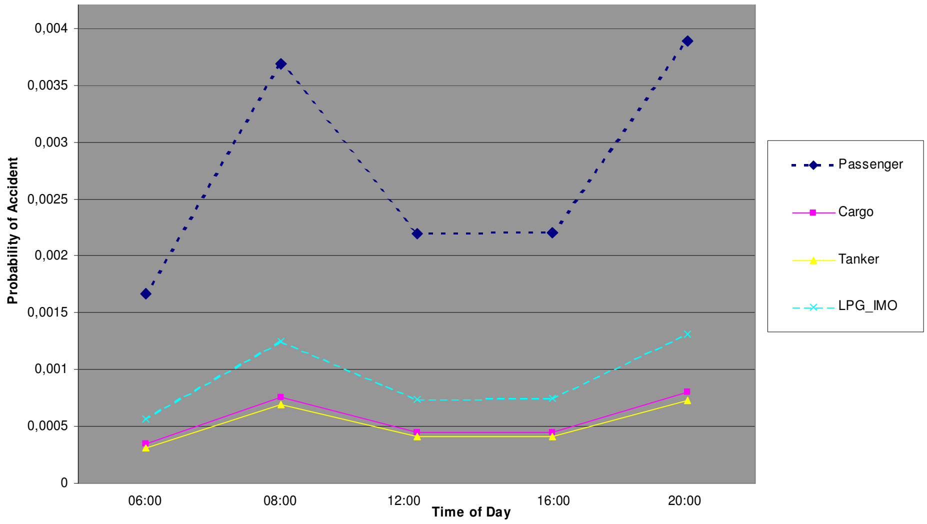


Figure 7.7. The effects of local traffic intensity over accident probabilities

Figure 7.7 illustrates that the difference between the most congested time intervals of local traffic (i.e. around 08:00 and 20:00) and the rest of day causes almost 100 per cent increase in the accident probability.

Regarding vessel length, the model results are not in line with the general expectations. Generally, an increase in accident probability is expected as a result of an increase in vessel length, while no such relationship is observed in the model results, as displayed in Figure 7.8. The reason for this anomaly may be the extra measures and precautions taken by the TSVTS Authority for the longer vessels during their transit in the Istanbul Strait (in order to reduce the likelihood of an accident). These measures may be having a positive effect on accident realizations, leading to the situation observed.

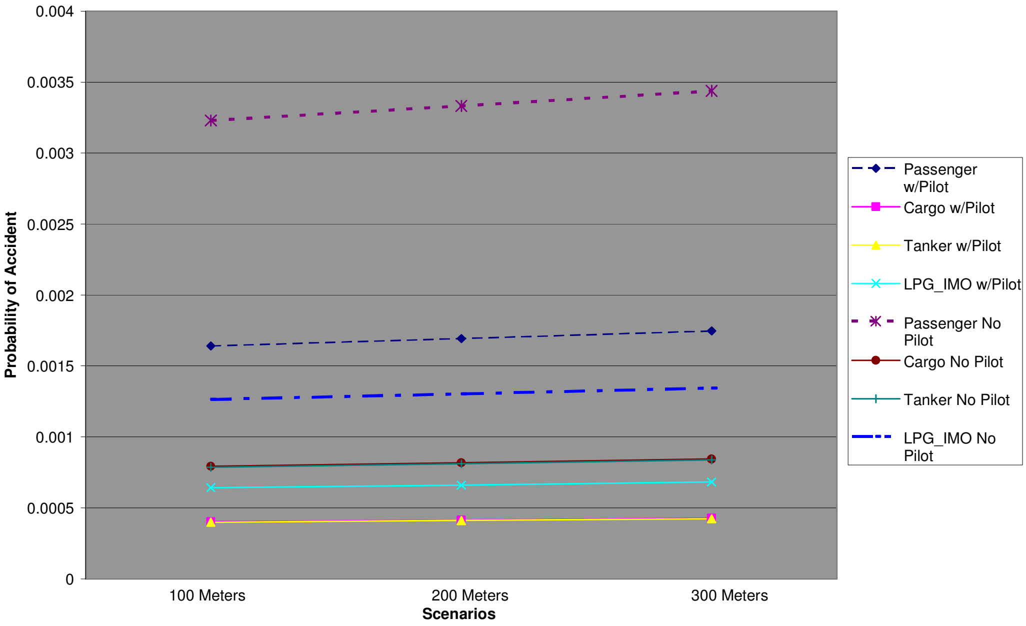


Figure 7.8. The vessel length effect over the accident probability

7.2. The Probabilistic Consequence Model Scenario Analysis

In this section, various scenarios regarding possible measures for decreasing the consequence impact levels and their projected effects are discussed. The key output factor in the analysis is the probability of various consequences, given that an accident has occurred, under the pre-determined setting of certain situational factors. In general, similar scenarios to those presented to experts during the interviews to determine the probabilities for various consequences are deployed. Moreover, in addition to the usual vessel characteristics observed in the Strait, some worst-case accident scenarios (which might result in “catastrophe”) are also constructed, in order to see the effects of these factors over the realization of various consequences. Table 7.3 presents the factors and their levels deployed in the consequence model scenario analysis.

Table 7.3. Factors and their levels in the scenario analysis

	Type of the Vessel	Length of the Vessel	Accident Location	Accident Type	Remarks
Scenario 1	Tankers	50 –150 m	Zone 2	Collision	Two full tanker
Scenario 2	Tankers	50 – 150 m Above 250 m	Zone 3	Collision	Full and empty tankers
Scenario 3	Tanker and Passenger	Above 250 m 50-150 m	Zone 1	Collision	Full tanker
Scenario 4	Tanker and Cargo ship	150-250 m Above 250 m	Zone 2	Collision	Full tanker
Scenario 5	Cargo and Passenger	50-150 m 150-250 m	Zone 1	Collision	
Scenario 6	Passenger	50-150 m	Zone 2	Collision	Two passenger ships
Scenario 7	Tankers	Above 250 m	Zone 2	Collision	Two full tankers
Scenario 8	Passenger	150-250 m	Zone 2	Contact	-
Scenario 9	Cargo	50-150 m	Zone 3	Contact	-
Scenario 10	Tanker	Above 250 m	Zone 2	Contact	-
Scenario 11	Passenger	150-250 m	Zone 3	Stranded	-
Scenario 12	Cargo	Above 250 m	Zone 1	Stranded	-
Scenario 13	Tanker	Above 250 m	Zone 2	Stranded	Empty tanker
Scenario 14	Tanker	150-250 m	Zone 3	Stranded	Full tanker
Scenario 15	Passenger	150-250 m	Zone 2	Stranded	

Figure 7.9 presents the probability of each consequence, given that a collision has occurred, with respect to the various values of the attributes shown in Table 7.3. In this figure the relative normalization method has been used. Thus, except the second and the seventh scenarios, the most probable consequence of the collisions is their negative impact over the Istanbul Strait waterway efficiency, (i.e. a temporary closure of the Strait). However, if one of the vessels involved in the accident is a full loaded tanker and longer than 250 meter in length, there is a high possibility of environmental damage as shown in the second and the seventh scenarios. Finally, the likelihood of consequences involving human casualties remains almost steady, at less than 10 per cent level. It is also interesting

to note that the only scenarios where this probability reaches 10 per cent are those involving passenger vessels.

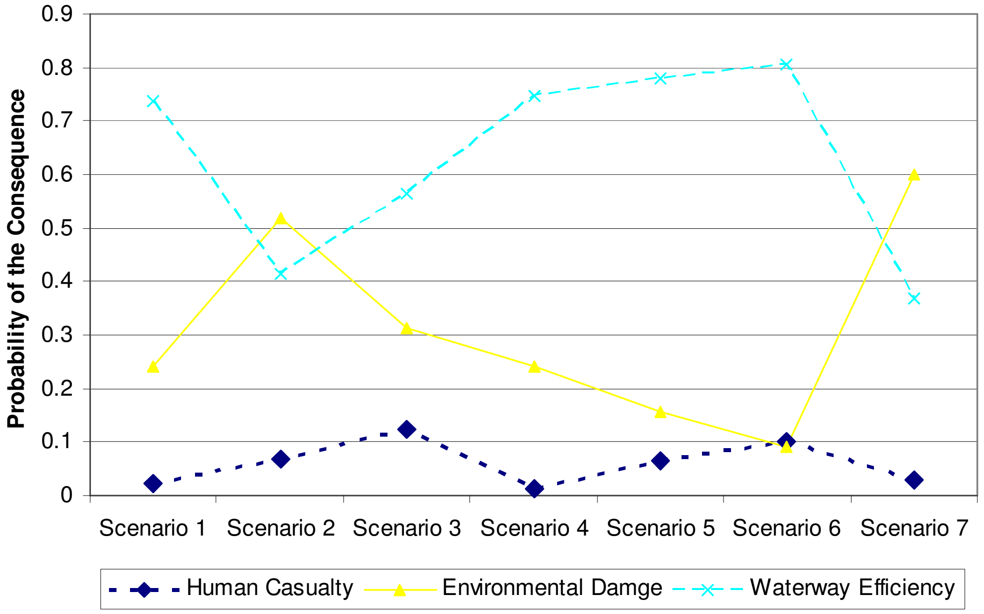


Figure 7.9. The relative probability of the consequences, given that a collision has occurred

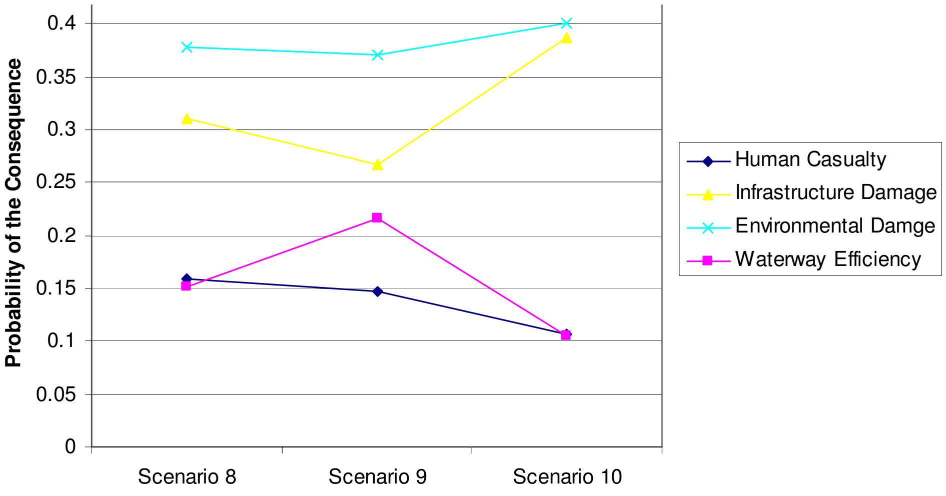


Figure 7.10. The relative probability of the consequences, given that a contact has occurred

Figure 7.10 shows the likelihood of various consequences, given that a contact accident has occurred, based on the scenarios given in Table 7.3. The most likely consequences of contact accidents are environmental and infrastructure damages, followed by their negative impact over the waterway efficiency of the Strait.

The probabilities of the consequences, given that a vessel stranding has occurred, are shown in Figure 7.11. The results show that most likely consequence of a stranding is its negative impact over the Istanbul Strait waterway efficiency. Moreover, the results (of scenarios 13 and 15) indicate that the negative effect of the second zone over waterway efficiency is very considerable (this is in line with the demanding morphologic characteristics of second zone).

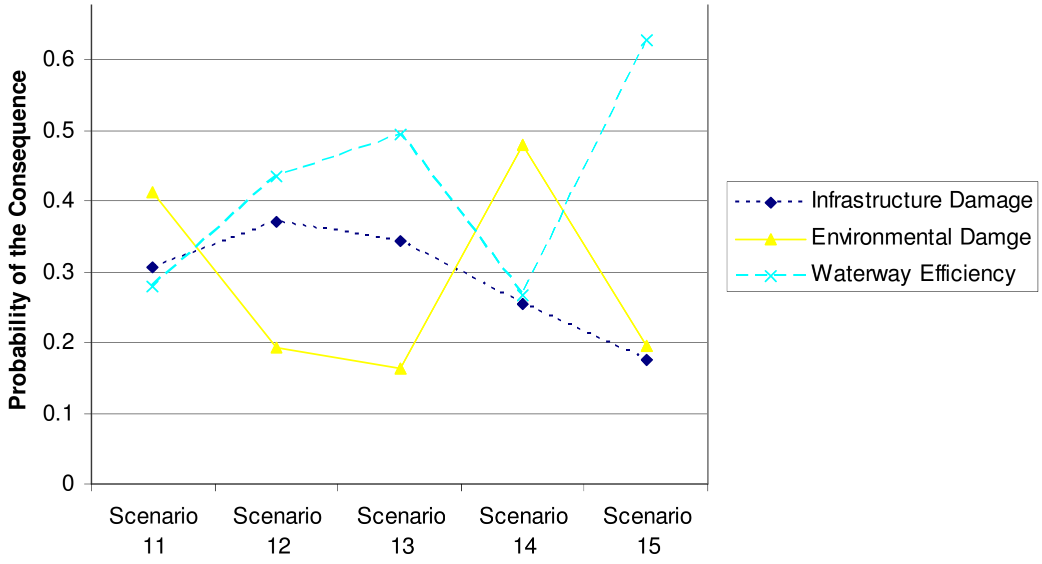


Figure 7.11. The probability of the consequences, given a stranding has occurred

Prevention is certainly preferred to clean up and mitigation, but cannot eliminate accidents. All risks of transporting hazardous cargo, facilities and vessels are required to have an action plan for accidents and conduct response actions if an accident occurs. Unfortunately when the situational factors (which affect the realization of various consequences as a result of an accident) are examined, the Turkish State has very limited influence to control them. Moreover, the actions to be taken regarding waterway efficiency are very much limited to the uncompromising morphological characteristics of the Strait. This highlights the importance of the measures and actions to be taken once an accident has occurred. Moreover, the rescue efforts and contingency plans should not be limited to reduce the impact of a given accident over environment or infrastructure. Hence, contingency plans coordinated with the Municipality of Istanbul, as well as with other governmental and non-governmental organizations, should be readied for potential high levels of consequences of maritime accidents.

In this chapter, the model outcomes associated with some of the selected scenario are compared with one another in order to enhance the understanding of factors' effects on the maritime accidents and its consequences. Based on the scenario analysis results, some risk mitigation measures are suggested in Section 8.1 with the aim of reducing the possibility of maritime accidents and thus enhance the maritime safety of the Istanbul Strait.

8. CONCLUSIONS

In this study a Risk Model for the Istanbul Strait is developed in general terms. This model addresses both the probabilities and consequences associated with the potential Strait maritime accidents, and includes the following modules;

- An econometric model, (i.e. the logit model), to estimate the conditional probability of an accident in the Istanbul Strait (given the level of various accident causing factors);
- A probabilistic consequence model to predict the probability of each type of the accident consequences after the occurrence of an accident;
- Finally, an AHP model to show the relations of the factors over the likelihood of an accident based on the experts views.

The logit model gives consideration to more than 386,000 transit passages without an accident, and 154 accident involving transits, as a representation of the 1995-2005 period. The model estimates the conditional accident probability of a specific accident type, given the status of transit time (i.e. day or night), visibility range, amount of precipitation, wind speed, local traffic intensity at time of transit, along with the information about the utilization of pilot service, and length and type of the vessel involved.

When the results of the logit model are compared with the actual accident statistics of the year 2005, the total number of accidents that has occurred in the year 2005 is slightly underestimated, (with less than seven per cent error). Moreover, the number of accidents during nighttime and the tankers involved in an accident are accurately estimated by the logit model. On the other hand, the number of contact, foundered and fire & explosions types of accidents are underestimated, while there are overestimations for the number of collision, stranded and hull & machine failure types of accidents. However, when the results of the logit model are compared with 8 years (1997-2004) statistics, the model estimations are close to the average numbers (since the number of accidents that has occurred in 2005 is approximately 15 per cent more than the 8 year annual average).

During the 1995-2004 period, no dangerous cargo carrying vessel (designated as IMO) has been involved in any accident. Similarly, no passenger ship was involved in fire accidents in this period. Hence, the logit models (the general model, the machine and hull failure model and the fire accident model) have been unable to estimate coefficients for these types of vessels and accidents. This clearly affects the estimation output of the model. Thus, the model requires to be updated with available data continuously in order to make accurate estimation.

The logit model analysis suggests the following;

- Taking pilot during a transit decreases the ratio of the probability of an accident to the probability of not having accident, by nearly 49 per cent. Since the accident probability is very low and close to zero, this result implies that pilot utilization reduces the accident probability by almost 50 per cent.
- Similarly, a daytime transit through the Istanbul Strait versus a nighttime transit, decreases the probability of accident by 28 per cent.
- Passenger ships are more prone, (about more than four times) to accidents than cargo ship and tankers, in contradiction to the widespread belief of "*passenger ships are safer*", while cargo ships and tankers have about equal likelihood of being involved in an accident.
- Wind speed and visibility also have significant effects over the accident probability. When the wind speed increases by one m/sec, the accident probability increases more than 22 per cent. Likewise, when the visibility range increases one km, the accident probability decreases nearly eight per cent.
- If the developed logit model is run only with daytime data, significant results are obtained regarding the relationship between the local traffic intensity and the accident probability. In other words, while the coefficient of the local traffic intensity is insignificant and negative (which suggest a decreasing effect on accident probability for increasing local traffic density) when all transits are considered, this coefficient becomes significant and positive for the daytime model. This is probably because the nighttime local traffic density is very low to begin with. Numerically, one additional daytime local traffic movement in the Strait causes almost one per cent increase on the accident probability. Moreover, the accident probability could increase nearly 100

per cent between most congested time of the local traffic and its average level. In other words, it is demonstrated that the local traffic during daytime is one of the key factors triggering maritime accidents in the Istanbul Strait.

The developed logit model has been used to test 20 scenarios in order to observe the joint effects of the aforementioned factors over maritime accident probability in the Istanbul Strait. The following observations can be made;

- The difference in the accident probability between a daytime transit in the Strait with pilot onboard and a nighttime transit without a pilot is more than twice.
- The accident probability of a passenger vessel without a pilot on board increases more than five times for the 10 nm and 0.5 nm of level of visibility.
- The effects of the local traffic during the daytime are very significant and could increase nearly 100 per cent between most congested time of the local traffic and its average level.
- The effects of the vessel length over accident probability are not significant.

The accidents themselves result in a range of consequences, such as human casualty, infrastructure damage, environmental damage and negative impact over the waterway efficiency. The results of interviews with various experts suggest that these consequences are directly dependent on the type of accident, vessels involved and location of the accident. To assess the likelihood of a consequence after an accident, experts are asked to compare two accident situations for three different types of accidents (collision, stranded and contact). The experts are asked to complete a set of 63 such questions, each involving the comparison of two situations, which differ from one another in one factor only. The outcome of this analysis is as follows;

- Almost 40 per cent of the potential human casualty of a collision depends on accident location, while another 40 per cent of this casualty is due to vessel type and its cargo and the rest of the human casualty is affected by the length of the vessel. Regarding environmental damage, while the effect of vessel type is still at 45 per cent level, the impact of vessel length is significantly enlarged. Finally, the likelihood of the Strait closure primarily depends on accident location and the vessel types involved in a collision.

- For contact type accidents, the major factor that determines the likelihood of the consequence is the type of the vessel and its cargo. The second important factor for the consequences of a contact is the length of the vessel involved in the accident.
- For the likelihood of the consequences of a stranded vessel, the type of the vessel and the accident location are the primary factors.

Another analysis carried out is the relative contribution of each factor to the likelihood of a consequence at its different levels. As a result of this analysis;

- For all types of accidents and their consequences, fully loaded tankers and vessels longer than 250 meters drastically affect the likelihood of the consequences. Regarding the effect of accident location, the second zone, namely the area between the line of Kurucesme–Cengelkoy and Yenikoy-Pasabahce, is the major contributor to the likelihood of a potential closure of the Strait, if a vessel is stranded in this region. (This observation is actually very intuitive since this area has the most uncompromising morphological characteristics, regarding width and the number/sharpness of turns.)
- The most likely consequences of a contact accident are environmental and infrastructure damages, followed by negative impact over the waterway efficiency of the Strait.
- Similarly, the most likely consequence of a stranding is its negative impact over the Istanbul Strait maritime traffic. Waterway efficiency becomes especially vulnerable if the accident occurs in the second zone, (this is the area between the line of Kurucesme–Cengelkoy and Yenikoy–Pasabahce) due to its morphological characteristics.

After the interviews with maritime traffic and safety experts and other stakeholders, the following risk factor groups over the accident probability are identified in the AHP model framework.

- The vessel characteristics: Type, length, draught, age and flag state of the vessel.

- Maritime traffic characteristics: The intensity of the local traffic (e.g. between two sides of the Strait) and transit traffic as well as the time of passage namely day or night.
- Environmental conditions: Wind speed, visibility, current and precipitation during the passage as well as the morphological characteristics of the Istanbul Strait.
- Organizational factors: The knowledge or competence of the crew on board, pilot service, navigational aids, Vessel Traffic System (VTS), violation of the regulation enforced and the quality of cargo handling.

The AHP model results show that the most important factor group is the organizational factors. The model results also highlight the competence of the crew as the most important sub-factor (which is in line with the efforts of the IMO to upgrade the standards of training, certification and watchkeeping for seafarers, through the STCW programme). Moreover, the accident statistics of the last decade (as displayed in Figure 6.9) show that at least 36 per cent of the accidents are caused by human error. Unfortunately, due to the lack of legal authority invested on the Turkish State, she has no legal power to verify the competence of the vessel crews due to transit the Strait.

The weights of certain accident causing factors, which are not included in the logit model, are estimated by using an AHP model, and then these factors are incorporated in the logit model. The results of this integration show that violation of the Regulation increases the accident odd by 2.44 E+68 per cent and one unit increase in the excess factor of Flag State causes approximately 22 per cent increase in the accident odd and one meter increase in the draught of the vessel results in approximately five per cent increase in the accident odd as well. These figures especially highlight the significance of the compliance with the Regulations during the Strait transit.

8.1. Suggested Risk Mitigation Measures for the Istanbul Strait

Just like many other complex, important systems involving risk, also in the Istanbul Strait maritime traffic system, it is clear that each of the individual policy instruments enhances safety, but it is not equally clear which combination of policy instruments represents the most cost-effective combination for maintaining and enhancing safety at the

Istanbul Strait. In this regard, the results of this study identify and, to a large degree, quantify the risks and their sources regarding the maritime traffic in the Strait. As such, it can be said that the obtained results can also be deployed in selecting and guiding the measure to be taken regarding the mitigation of these risks; and thus enhance the maritime safety in the Strait. Nevertheless, there is still, of course, room to improve the safety and to reduce the maritime risk stemming from potential maritime accidents in the Istanbul Strait.

According to the Montreux Convention, pilotage is optional and in general, only 42 per cent of all transit vessels took pilot in the Istanbul Strait in last decade (it should, however, be noted that in the mentioned time period around 83 per cent of the vessels that are longer than 150 meters did take pilots). As underlined by Mitropoulos [55] and also "strongly recommended" by the IMO [72], it is essential to benefit from local knowledge, skill and experience while transiting the Turkish Straits. Moreover, the International Navigation Association (PIANC) study [1] for narrow channels revealed that vessels of 155 m and above in length, proceeding reciprocally and entering a bend at the same time, are most likely to touch one another after they start rounding the bend.

In the 1994 Maritime Traffic Regulations for the Turkish Straits and the Marmara Region [77], the Turkish State had made pilotage service obligatory for transiting vessels carrying the Turkish flag and longer than 150 meters. Unfortunately, this key risk mitigation measure was later dropped in the 1998 Regulations [12]. At present there are 15 pilots available in the Istanbul Strait and Almaz [65] shows that 40 per cent increase in the number of pilot availability results 54 per cent decrease in average waiting time of the vessels at the entrance. In this study, it has been demonstrated that pilot utilization diminishes accident probability almost 50 per cent. Thus, in order to enhance the safety in the Strait, it is recommended to increase the number of pilot serving in the Strait, and then to make the pilotage service obligatory for the transit vessels, which are longer than 150 meters (starting initially with the Turkish flagged vessels). Taking the nature of the Istanbul Strait into consideration, vessels should definitely navigate with the aid of pilot through the Strait in order to prevent accidents.

As manifested in the aftermath of the Erika and Prestige accidents, marine safety is a growing concern worldwide. There are also significant outputs of the EU efforts [9] (such as the phasing-out of single hull oil tankers, tightening of the existing legislation and the distribution of an indicative black list of ships, which are banned from European ports), which may reduce the maritime risk in the Istanbul Strait, as part of Turkey's membership to EU. In line with the results of the probabilistic consequence model and also the AHP model, a similar approach to the Istanbul Strait would also enhance the maritime safety and reduce the risk stemming from "potential" maritime accidents. Considering the legal status of the Istanbul Strait, the accession negotiations on transport policy and full membership to EU certainly has the potential to have a positive effect over the efforts to enhance the maritime safety in the Istanbul Strait.

Another important outcome of this study is the importance it attaches to the effects of wind over accident probabilities. Presently, there is no direct measure taken by the TSVTS Authority with respect to the wind speed. (There is an indirect effect though, through the traffic limitations/restrictions imposed when strong southwestern winds bring about the treacherous Orkoz current). However, the results of the logit model analysis show that one m/sec increase on the wind speed causes nearly 22 per cent increase in the accident probability. This suggests that certain measures should be developed with respect to the wind speed, in order to further reduce the accident probability.

Similarly a daytime transit through the Istanbul Strait versus a nighttime transit further decreases the probability of accident by 28 per cent. Thus, the vessels should be encouraged to transit the Istanbul Strait during daytime.

This study shows that local traffic during daytime is one of the key factors triggering maritime accidents in the Istanbul Strait. On the other hand, the Municipality of Istanbul is aiming to ease the city's road traffic congestion by expanding the local maritime public transportation system. Thus, local traffic intensity is expected an increase in the future and this will certainly raise the number of interactions between local traffic vessels and transit traffic vessels in the Strait. Since it is not possible to reduce the local traffic intensity during daytime, neither to avoid the future expansion plans. Measures to reduce possible interactions between transit and local traffic (such as better route separation) should be sought and situational awareness should be provided to the captains of the transit vessels by informing them about the routes of local traffic. Additionally, some strict measures should be enforced in line with the rules as set out in the International Regulations for Preventing Collision at Sea 1972 (COLREGS). In this regard, the violation of these rules should be closely monitored and sanctions should be applies if required.

The AHP model results highlight the competence of the crew as the most important sub-factor and at least 36 per cent of the accidents in the Strait are caused by human error (this statistics reaches to about 75-90 per cent worldwide [71]) Therefore, an inspection right (invested on the Turkish State) similar to port state control for verification of the vessel crew knowledge should be searched at the IMO arena.

Prevention is certainly preferred to clean up and mitigation, but cannot eliminate accidents. Unfortunately, when the situational factors of the probabilistic consequence model (these are type and length of vessel and accident location) are examined, the Turkish State has limited power to control them. Moreover, the actions to be taken regarding waterway efficiency are very much limited, due to the uncompromising morphological characteristics of the Strait. This highlights the importance of the measures and actions required to be taken once an accident has occurred. In general, the rescue efforts of the TSVTS Authority appear to be limited to reduce the impact of a given accident over environment or infrastructure. Hence, contingency plans coordinated with the Municipality of Istanbul, as well as with other governmental and non-governmental organizations, should be readied to reduce the level of adverse consequences of maritime accidents.

8.2. Further Studies

As discussed in Chapter 4, this study lacks to estimate the probability that a certain combination of accident/consequence causing factors (with each individual factor achieving a specific setting) occurs in the Istanbul Strait. As already suggested, this value could be estimated using a simulation model supplemented with meteorological conditions and unfortunately, no such comprehensive simulation model is available. Accordingly, the simulation models such as the ones developed by Özbaş [64] and Almaz [65] can be integrated with the models developed in this study.

Another further study area may be to develop an econometric model to estimate the consequences of maritime accidents in the Strait. The main difficulty for this study will be the availability and also reliability of the data. But, certainly such a model will improve this study by increasing the quality of the overall estimation, which currently relies purely upon subjective expert judgments.

As already discussed in Section 6.3.1, the basic logit model is unable to estimate the conditional accident probability with respect to various regions of the Istanbul Strait and also to incorporate certain situational factors, (such as current and navigational aids in the concerned region) into the accident probability. This could be achieved by developing similar logit models for different parts of the Istanbul Strait, by including certain regional situation factors, which vary with respect to time and location.

APPENDIX A: ARRIVAL PROCESS PROBABILITY DISTRIBUTIONS

Table A.1. Fitted distributions to vessel clusters in arrival processes

Vessel type	Length	Direction	# of data points	Expression	Square error	p value
General Cargo	0-50	N-S	245	20 + EXPO(2.11e+003)	0.002253	0.715
General Cargo	0-50	S-N	235	11 + GAMM(77.6, 2.17)	0.002971	0.341
General Cargo	50-100	N-S	8457	-0.001 + GAMM(66.6, 0.932)	0.000222	< 0.005
General Cargo	50-100	S-N	8422	-0.001 + GAMM(67, 0.931)	0.000215	0.00519
General Cargo	100-150	N-S	9820	-0.001 + WEIB(50, 0.963)	0.000220	< 0.005
General Cargo	100-150	S-N	9645	-0.001 + GAMM(57, 0.953)	0.000230	< 0.005
General Cargo	150-200	N-S	2396	-0.001 + EXPO(218)	0.000282	0.184
General Cargo	150-200	S-N	2391	-0.001 + GAMM(239, 0.919)	0.000243	0.647
General Cargo	200-250	N-S	584	2 + GAMM(956, 0.934)	0.000571	> 0.15
General Cargo	200-250	S-N	581	2 + 5.77e+003 * BETA(0.593, 2.94)	0.002578	< 0.005
General Cargo	250-300	N-S	62	39 + 2.53e+004 * BETA(0.898, 1.87)	0.011070	0.0679
General Cargo	250-300	S-N	53	88 + 3.32e+004 * BETA(0.724, 1.79)	0.002595	0.655
Tanker	0-50	N-S	2	1.25e+005 + 5.73e+004 * BETA(0.112, 0.112)	0.210537	
Tanker	50-100	N-S	1346	-0.001 + EXPO(389)	0.000326	> 0.75
Tanker	50-100	S-N	1367	-0.001 + GAMM(421, 0.912)	0.000673	0.502
Tanker	100-150	N-S	1019	0.999 + 3.08e+003 * BETA(0.735, 3.39)	0.001073	0.111
Tanker	100-150	S-N	1014	2 + EXPO(512)	0.000837	0.405
Tanker	150-200	N-S	1176	0.999 + GAMM(483, 0.917)	0.000895	0.176
Tanker	150-200	S-N	1187	-0.001 + LOGN(658, 2.84e+003)	0.009624	< 0.005
Tanker	200-250	N-S	656	-0.001 + WEIB(821, 1.04)	0.001536	0.128
Tanker	200-250	S-N	661	0.999 + LOGN(1.54e+003, 8.56e+003)	0.033848	< 0.005
Tanker	250-300	N-S	353	6 + 5.51e+003 * BETA(0.972, 2.7)	0.003417	0.196
Tanker	250-300	S-N	355	2 + 7.21e+003 * BETA(0.54, 1.9)	0.024973	< 0.005
IMO	50-100	N-S	139	6 + EXPO(3.72e+003)	0.002223	0.743
IMO	50-100	S-N	84	64 + 2.61e+004 * BETA(0.837, 2.75)	0.002529	0.596
IMO	100-150	N-S	99	191 + EXPO(5.05e+003)	0.024320	< 0.005
IMO	100-150	S-N	189	18 + WEIB(2.78e+003, 1.07)	0.005715	0.0449
IMO	150-200	N-S	129	91 + WEIB(4.07e+003, 1.1)	0.001404	0.484
IMO	150-200	S-N	88	4 + EXPO(5.84e+003)	0.002630	0.484
IMO	200-250	N-S	63	57 + WEIB(8.15e+003, 1.07)	0.005438	0.249
IMO	200-250	S-N	29	77 + 3.62e+004 * BETA(1.08, 1.38)	0.022356	0.0451

Table A.1. Fitted distributions to vessel clusters in arrival processes (continued)

Vessel type	Length	Direction	# of data points	Expression	Square error	p value
IMO	250-300	N-S	2	5.36e+004 + 3.22e+004 * BETA(0.112, 0.112)	0.210537	
IMO	250-300	S-N	10	7.02e+003 + EXPO(4e+004)	0.021432	
LNG-LPG	50-100	N-S	29	1.24e+003 + 6.2e+004 * BETA(0.854, 2.49)	0.008498	< 0.005
LNG-LPG	50-100	S-N	96	4 + WEIB(5.43e+003, 1.01)	0.002596	0.128
LNG-LPG	100-150	N-S	12	4.42e+003 + WEIB(2.13e+004, 0.458)	0.058492	
LNG-LPG	100-150	S-N	69	3 + 2.83e+004 * BETA(0.934, 2.71)	0.012308	0.0861
LNG-LPG	150-200	S-N	68	71 + 2.47e+004 * BETA(0.836, 1.95)	0.002199	0.644
LNG-LPG	200-250	N-S	3	UNIF(2.1e+004, 1.4e+005)	0.133333	
LNG-LPG	200-250	S-N	46	45 + 4.01e+004 * BETA(0.579, 1.56)	0.003829	0.401
Passenger	Direct	N-S	410	0.999 + EXPO(1.26e+003)	0.005190	0.00623
Passenger	Direct	S-N	451	-0.001 + 9.51e+003 * BETA(0.408, 3.03)	0.005768	< 0.005
Passenger	Indirect	N-S	243	0.999 + EXPO(2.11e+003)	0.003640	0.453
Passenger	Indirect	S-N	205	0.999 + EXPO(2.49e+003)	0.002049	0.244

Table A.2. Pilot demand frequencies of vessel clusters in arrival processes

Type of vessel	Length	Entrance Direction	Pilot Demand Probability
General Cargo			
	0-50	NS	0.252
		SN	0.157
	50-100	NS	0.248
		SN	0.279
	100-150	NS	0.352
		SN	0.387
	150-200	NS	0.764
		SN	0.769
	200-250	NS	0.921
		SN	0.912
	250-300	NS	0.937
		SN	0.981
IMO			
	0-50	NS	0.000
		SN	0.000
	50-100	NS	0.443
		SN	0.600
	100-150	NS	0.560
		SN	0.568
	150-200	NS	0.908
		SN	0.787
	200-250	NS	1.000
		SN	0.968
	250-300	NS	1.000
		SN	1.000
LNG-LPG			
	0-50	NS	
		SN	
	50-100	NS	0.433
		SN	0.423
	100-150	NS	0.692
		SN	0.671
	150-200	NS	0.500
		SN	0.971
	200-250	NS	1.000
		SN	1.000

Table A.2. Pilot demand frequencies of vessel clusters in arrival processes (continued)

Type of vessel	Length	Entrance Direction	Pilot Demand Probability
Tanker			
	0-50	NS	0.000
		SN	0.000
	50-100	NS	0.268
		SN	0.291
	100-150	NS	0.483
		SN	0.494
	150-200	NS	0.913
		SN	0.939
	200-250	NS	0.959
		SN	0.979
	250-300	NS	0.975
		SN	0.975
Passenger			
	direct	NS	1.000
			0.969
		SN	0.962
			0.991
	indirect	NS	0.990
			0.958
		SN	0.904
			0.974

APPENDIX B: SIGN CHECK FOR THE ACCIDENT TYPES COEFFICIENTS ESTIMATED BY LOGIT MODEL

Table B.1. Sign check for the contact type accident

Variable	Coefficient	Sign Check	Significance
Constant	-29.7066	Not available	
Transit Time	-0.31063	As expected	
Wind Speed	0.026278	As expected	
Precipitation	-0.32335	Not expected	
Visibility	-0.07937	As expected	Significant
Pilotage	-0.49123	As expected	
Vessel Length	-0.00398	Not expected	
Local Traffic	-0.0054	Not expected	
Cargo	22.18075	As expected	
Tanker	21.87873	As expected	
Passenger	23.09193	As expected	

Table B.2. Sign check for the stranded type accident

Variable	Coefficient	Sign Check	Significance
Constant	-29.3432	Not available	
Transit Time	-0.55499	As expected	Significant
Wind Speed	0.231208	As expected	Significant
Precipitation	-0.01837	Not expected	
Visibility	-0.05686	As expected	Significant
Pilotage	-1.16028	As expected	Significant
Vessel Length	-0.00293	Not expected	
Local Traffic	-0.0009	As expected	
Cargo	21.6525	As expected	
Tanker	21.55182	As expected	
Passenger	22.97274	As expected	

Table B.3. Sign check for the hull and machine failure type accident

Variable	Coefficient	Sign Check	Significance
Constant	-32.0614	Not available	
Transit Time	0.206373	Not expected	
Wind Speed	0.379379	As expected	Significant
Precipitation	0.040625	As expected	
Visibility	-0.10008	As expected	Significant
Pilotage	-0.13368	As expected	
Vessel Length	0.007384	As expected	Significant
Local Traffic	0.00255	As expected	
Cargo	22.05767	As expected	
Tanker	21.88823	As expected	
Passenger	23.53841	As expected	

Table B.4. Sign check for the fire type accident[1]

Variable	Coefficient	Sign Check	Significance
Constant	-53.8788	Not available	
Transit Time	0.266189	Not expected	
Wind Speed	0.194452	As expected	
Precipitation	-0.05196	As expected	
Visibility	0.926822	Not expected	
Pilotage	-1.17758	As expected	
Vessel Length	0.008003	As expected	
Local Traffic	0.00171	As expected	
Cargo	23.62199	As expected	

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[1] Neither passenger ship nor tanker is involved in any fire in 1995-2004.

Table B.5. Sign check for the foundered type accident [2]

Variable	Coefficient	Sign Check	Significance
Constant	-30.2516	Not available	
Transit Time	0.815571	Not expected	
Wind Speed	0.782889	As expected	Significant
Precipitation	-0.47335	Not expected	
Visibility	-0.19164	As expected	Significant
Pilotage	-0.37439	As expected	
Vessel Length	-0.01231	Not expected	
Local Traffic	-0.0261	Not expected	
Cargo	20.18987	As expected	
Tanker	22.73581	As expected	

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[2] No passenger ship has been foundered in 1995-2004.

APPENDIX C: THE CORRELATION COEFFICIENTS OF THE LOGIT MODEL VARIABLES

Table C.1. The correlation coefficient of the variables in the logit model

	Vessel Length	Local Traffic	Wind Speed	Visibility	Tanker	Precipitation	Passenger	Transit Time	Cargo	Pilot
Vessel Length	1	0.003	0.007	0.003	0.296	0.003	-0.099	0.017	-0.252	0.401
Local Traffic	0.003	1	0.012	-0.010	0.002	0.005	-0.011	0.077	0.005	-0.008
Wind Speed	0.007	0.012	1	0.087	0.005	0.057	-0.003	0.034	-0.003	0.006
Visibility	0.003	-0.010	0.087	1	-0.003	-0.286	-0.001	0.049	0.003	-0.002
Tanker	0.296	0.002	0.005	-0.003	1	0.004	-0.071	0.009	-0.862	0.178
Precipitation	0.003	0.005	0.057	-0.286	0.004	1	-0.001	-0.011	-0.003	0.002
Passenger	-0.099	-0.011	-0.003	-0.001	-0.071	-0.001	1	-0.004	-0.303	0.165
Transit Time	0.017	0.077	0.034	0.049	0.009	-0.011	-0.004	1	-0.006	0.000
Cargo	-0.252	0.005	-0.003	0.003	-0.862	-0.003	-0.303	-0.006	1	-0.249
Pilot	0.401	-0.008	0.006	-0.002	0.178	0.002	0.165	0.000	-0.249	1

APPENDIX D: THE TYPE DESIGNATION OF THE MARITIME VESSELS IN THE MODEL AND THEIR FREQUENCIES

Table D.1. The type designation of the maritime vessels in the logit model and their frequencies

Type of the Vessel	Number of Vessels	Carrying Hazardous Material (IMO)	New Type Designation
Barge	65		5
Barge Carrier	2		5
Bulk Barge	2		5
Bulk Carrier	5290	6	5
Cable-Layer	2		5
Cement Carrier	32		5
Chemical Tanker	1887	10	4
Container Ship	2285	364	5
Dredger	2		5
Factory Fishing	11		5
Fish Carrier	10		5
Fishing	4		5
General Cargo	33987	83	5
General Cargo Barge	2		5
Heavy-Load Carrier	10		5
Heavy-Load Carrier, Semi-Sub	2		5
Hopper	1		5
Hopper Barge	1		5
Liquefied Gas Tanker	6	3	2
Liquefied Gas/Chemical Tanker	2		2
Livestock Carrier	72		5
LPG Barge	674	356	2
Naval	157		1
Open Hatch Bulk Carrier	3		5
Open-Hatch Bulk Carrier	4		5
Ore/Bulk/Oil Carrier	70		5
Ore/Oil Carrier	29		5
Passenger	1172		1
Passenger/General Cargo	75		1
Passenger/Research	10		1
Passenger/Roro Cargo	13		1
Passenger/Roro Cargo/Ferry	113		1
Refrigerated Cargo	776	1	5
Refrigerated Cgo/Fish Carrier	7		5
Refrigerated Cgo/Pallets Ca.	2		5
Research	37		5

Table D.1. The type designation of the maritime vessels in the logit model and their frequencies (continued)

Type of the Vessel	Number of Vessels	Carrying Hazardous Material (IMO)	New Type Designation
RoRo Cargo	330	14	5
RoRo Cargo/Ferry	62		5
Sailing Ship (Museum)	1		5
Submarine	10		1
Supply Launch	1		5
Supply Ship	1		5
Supply Ship (O.R.S.V.)	2		5
Support Ship	2		5
Tank Barge	2		4
Tanker	7239	8	4
Tanker/Oil-Reclamation Vessel	62		4
Training Ship, Sailing	6		1
Tug	223		5
Tug/Supply Ship (O.R.S.V.)	8		5
Vehicles Carrier	4		5
Wood-Chip Carrier	2		5
Yacht	18		1
Grand Total	54790	845	

Table D.2. The designation number of vessel types

Type of vessel	Designated Number
Passenger	1
LNG-LPG	2
IMO	3
Tanker	4
General Cargo	5

APPENDIX E: THE FREQUENCIES OF ACCIDENTS OVER THE REGIONS OF THE ISTANBUL STRAIT

Table E.1. The frequencies of the accidents with respect to their locations

	Collision	Contact	Stranded	Fire	Foundered	Hull & Machine Failure	Total
Zone 0	8	0	1	1	2	2	12
Zone 1	0	0	0	0	0	1	1
Zone 2	2	2	0	0	0	0	4
Zone 3	7	0	15	0	0	4	26
Zone 4	5	5	11	0	1	10	32
Zone 5	8	9	7	1	0	1	23
Zone 6	6	1	4	1	0	8	20
Zone 7	10	1	2	0	0	1	14
Zone 8	11	1	3	2	0	0	17
Total	57	19	43	5	3	27	154

APPENDIX F: DATA FOR 1995-2005 IN THE ISTANBUL STRAIT

Table F.1. The accident data for 1995-2005 in the Istanbul Strait

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length[3]	Type of Vessel	Reason of the Accident	Pilot
1	25-Mar-95	2345	Collision	Ahirkapi	Quanhai	China	20382	***182.56***	B/C	Improper Navigation	Yes
					Barbaros Oktay	Turkey	6284	***123.20***	B/C		No
2	23-Apr-95	2350	Contact	Akinti Burnu	Al Mehyar	Egypt	2350	***104.72***	G/C	Strong Current	No
3	24-May-95	340	Collision	Kavak Br	Huasheng	Liberia	1141	***75.00***	B/C	Improper Navigation	No
					Suphan Allah	Honduras	8404	***143.16***	B/C		No
4	21-Jun-95	1346	HM	Pasabahce	Salih Kaptan	Turkey	1127	***75.00***	B/C	Machine Failure	No
					Rio Cuyamel	Bahamas	3313	***90.65***	B/C		Yes
					Kremnica	Czech	1969	***83.00***	B/C		Yes
5	26-Jul-95	N/A	Stranded	Salacak	Beylerbeyi	Turkey			Ferry	Improper Navigation	No
6	27-Jul-95	1650	Stranded	Yenikoy	Marwan	Ukraine	N/A		G/C	Not known	No
7	21-Dec-95	2000	Stranded	Umuryeri	Evdokia K	India	1473	***70.63***	G/C	Improper Navigation	No
8	17-Jan-96	2215	Stranded	Sait Halim Pasa Yalisi	Arwad	Syria	2242	80.5	B/C	Improper Navigation	No
9	18-Jan-96	430	Stranded	Yenikoy	Nikolay Kantemir	Russia	3672	97	B/C	Improper Navigation	No
10	13-Mar-96	1405	Stranded	Bebek	Airstotleles	S.Cyprus	8902	***136.30***	B/C	Improper Navigation	Yes
11	21-Mar-96	1045	Stranded	Rumeli Feneri	Mahran	Syria	375	65	B/C	Personal Fault	No
12	15-Apr-96	1436	HM	Kanlica	Sunny Sarah	Bahamas	1178	73	B/C	Machine Failure	Yes
13	30-Jun-96		Stranded	Umuryeri	Maria	Russia	236	***28.50***	G/C	Improper Navigation	No

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[3] The italic bold figures are generated via regression analysis based on the given tonnage of the vessels due to the absence of the vessel length involved in the subject accident.

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
14	20-Jul-96	1915	Contact	Buyuk Liman	Minamar	India	499	70	G/C	Not known	No
15	17-Sep-96	2140	Collision	Kizkulesi	Doganay	Turkey	1442	81	B/C	Improper Navigation	No
					Selcuk - K	Turkey	3739	105	RO RO		No
16	03-Oct-96	620	Collision	Yenikoy	Maria 1	Malta	2457	***112.50***	B/C	Improper Navigation	Yes
					Celik Trans	Turkey	789	***65.40***	B/C		No
17	20-Nov-96		Contact	Haydarpaşa	Volgobal	Russia	2547	***112.50***	B/C	Not known	Yok
18	09-Dec-96	2200	Stranded	Bebek	Lady Ooti G	Belaruz	4909	***121.00***	G/C	Strong Current	Yok
19	12-Dec-96	1230	HM	İstinye	Friendly	Malta	15548	182	B/C	Machine Failure	Yes
20	04-Jan-97	51	Collision	Arnavutkoy	Osmangazi	Turkey	6878	129	B/C	Poor visibility	No
					Porto Margagera	Italy			B/C		No
21	16-Jan-97	720	Collision	Haydarpaşa	Kuzguncuk	Turkey	780		Passenger Ship	Not known	
					Varna	Bulgaria	7455	***134.56***	Container		
22	23-Jan-97	1020	Contact	Buyuk Liman	Rifki Bey	Turkey	15373	160	B/C	Improper Navigation	No
23	25-Jan-97	125	Collision	Umuryeri	Hagieni	Romania	5931	131	B/C	Improper Navigation	No
					Barbarossa	Italy	12927	157	Tanker		Yes
24	10-Mar-97	1940	Stranded	Umuryeri	Alexandr	Greece	497	65	Tanker	Improper Navigation	No
25	02-Apr-97	150	Stranded	Umuryeri	Faisal	Syria	2060	89	B/C	Improper Navigation	No
26	18-May-97	400	HM	Umuryeri	Kaptan Zaman	Turkey	4012	87	Ferry	Machine Failure	No
27	01-Aug-97	615	Stranded	Tarabya	Vityaz	Russia	5291	111	Ferry	Improper Navigation	Yes
28	01-Aug-97	1500	HM	Yenikoy	Truva	Turkey	4300	91	Ferry	Machine Failure	No
29	11-Oct-97	510	Collision	Kavak Y.Mahalle	Salih Unlu	Turkey	659	68	B/C	Not known	No
					Ilyas Reis	Turkey	49		Fishing Boat		No
30	17-Dec-97	720	Stranded	Yenikoy	Orange Star	Norway	18302	171	Tanker	Improper Navigation	Yes
31	23-Dec-97	1610	Collision	Turkeli	Leenaneft - 251	Russia	2071	***90.90***	Tanker	Poor visibility	No
					Baris B	Malta	999	***69.12***	B/C		No
32	06-Jan-98	730	Collision	Separation Buoys	Enis – S	Turkey	1943	91	Tanker	Poor visibility	No
					Tahsin Reis	Turkey	49		Fishing Boat		No
33	07-Jan-98	600	Stranded	Umuryeri	Pasa Limani	Turkey	109		Tug Boat	Improper Navigation	No
34	15-Jan-98	2220	Stranded	Sutluce	Anafarta	Turkey	954	70	B/C	Poor visibility	No

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
35	16-Jan-98	1905	HM	Kurucesme	Hadil	Syria	1999	98	B/C	Machine Failure	Yes
36	01-Feb-98	1905	HM	Kireçburnu	Kuban	Russia	2583	104	Ferry	Machine Failure	No
37	13-Feb-98	1155	Stranded	Rumelihisari	Mina 1	Turkey	1244	78	B/C	Strong Current	No
38	26-Feb-98	1940	Collision	Kizkulesi	Pletsetsk	Russia	4903	121	B/C	Not known	Yes
					Vilademir Filkov	Russia		132	B/C		No
39	01-Mar-98	25	Stranded	Sariyer	Fadel 1	Syria	4244	114	B/C	Improper Navigation	No
40	14-Mar-98	2020	Collision	Uskudar	Continental	Malta	3019	95	Container	Improper Navigation	No
					Suadiye	Turkey	1808	185	Passenger Ship		No
41	15-Apr-98	1530	Collision	Moda	Fahri Eksioglu	Turkey	1238	***72.40***	Coster	Not known	
					Aksemseddin	Turkey	187		Passenger Ship		
42	31-May-98	630	Collision	Kireçburnu	Binga Orkid Tigra	Malesia	25498	***184.00***	B/C	Poor visibility	Yes
					KARGEM	Turkey	2374	81	Ferry		No
43	09-Jun-98	1400	Fire	Istanbul Strait	Marina	Greece	15976	***176.00***	B/C	Fire	
44	29-Jun-98	1215	Collision	Umuryeri	Haidar	Syria	1366	***72.50***	B/C	Not known	No
					Fishing Boat	Turkey		6	Fishing Boat		No
45	09-Jul-98	2025	Stranded	Haydarpaşa	Sea Salvia	Malta	52852	247	Tanker	Improper Navigation	Yes
46	23-Jul-98	1454	Collision	Ahirkapi	Bayram Abi	Turkey	9853	***147.00***	B/C	Not known	
					Bukovina	Panama	3435	***110.60***	Passenger Ship		
47	14-Aug-98	515	HM	Yenikoy	Caldiran	Turkey	1594	81	B/C	Machine Failure	No
48	22-Aug-98	2100	HM	Kurucesme	Asia Pearl	St.Vincent	30078	218	B/C	Machine Failure	No
49	25-Aug-98	915	HM	Haydarpaşa	Crude Gulf	Greece	149803	274	Tanker	Machine Failure	Yes
50	25-Sep-98	215	HM	Umuryeri	Leonid Bykov	Russia	4096	138	B/C	Machine Failure	No
51	26-Sep-98	1230	Collision	Umuryeri	Haydar 6	Syria	1366	***72.50***	B/C	Not known	No
					Fishing Boat	Turkey			Fishing Boat		No
52	12-Oct-98	745	Collision	Bebek	Mamamia	Romania	12219	158	B/C	Improper Navigation	No
					Bogazici 81	Turkey			Passenger Ship		No

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
53	25-Oct-98	220	Collision	Pasalimani	Kaptan Osman Bahri	Turkey	14800	171	Tanker	Machine Failure	Yes
					Omerli	Turkey	450	***59.70***	Tanker		Yes
54	03-Dec-98		HM	Baltalimani	Birdy		7069		Tanker	Machine Failure	No
55	18-Dec-98	225	Collision	Akinti Burnu	Grace 1	Belize	1798	75	B/C	Machine Failure	No
					Kemal Levent	Turkey					No
					Buyuk Camlica	Turkey					No
56	21-Dec-98	500	Stranded	Umuryeri	Good Dream	Panama	1908	84	B/C	Improper Navigation	No
57	28-Jan-99	1910	Stranded	Yenikoy	Dutch Navigator	Holland	2994	99	Container	Improper Navigation	No
58	23-Feb-99		Stranded	Burunbahce	Steptes	Greece			Tanker	Not known	
59	28-Aug-99	1250	Collision	Turkeli	Harmony	Malta	14386	172	BBU	Poor visibility	No
					Kaptan Hilmi	Turkey	359	42	B/C		No
60	07-Sep-99	300	Contact	Yenikoy	Karabacak – 1	Turkey	995	***70.90***	B/C	Not known	No
61	28-Oct-99	2040	HM	Kandilli	Lenaneft– 2047	Russian	2871	***122.60***	Tanker	Machine Failure	Yes
62	07-Nov-99	1230	Collision	Ahirkapi	Semele	Belize	5945	120	B/C	Not known	No
					Shipka	Bulgaria	16166	***183.40***	B/C		No
63	10-Nov-99	2115	Stranded	Umuryeri	Omodos	Malta	2332	122	Tanker	Not known	No
64	01-Dec-99	1655	HM	İstinye	Euro Bulker 4	Cambodia	16038	***169.55***	B/C	Machine Failure	No
65	06-Dec-99	1415	Stranded	Ahirkapi	Historia Sea Tide	Malta	45752	***219.30***	Tanker	Improper Navigation	No
66	10-Dec-99	2005	Collision	Kizkulesi	Nadezha	Russia	2488	***100.07***	B/C	Not known	No
					Ferryboat	Turkey			Ferry		No
67	11-Jan-00	2030	Collision	Beykoz	Zafer-15	Turkey	188	39	Tanker	Not known	No
					Cayeli	Turkey	8		Passenger Boat		No
68	26-Jan-00	1800	Collision	Uskudar	Ilker Karter	Turkey	456	58	Ferry	Improper Navigation	No
					Alexasdir Arzhavkin	Ukraine	2060	***89.00***	B/C		No
69	28-Mar-00	637	Collision	Sarayburnu	Turan Emeksiz	Turkey	780	70	Ferry	Not known	No
					Fishing Boat	Turkey	292		Fishing Boat		No
70	07-Apr-00	130	Contact	Yenikoy	Ten Clipper	Denmark	548	***40.30***	B/C	Improper Navigation	No
71	09-Apr-00	2050	HM	Bebek	Jessilena	Antigua	9068	131	Container	Machine Failure	No

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
72	22-Apr-00	855	Contact	South of F.S.M. Bridge	Conti Roze	Ukraine	6911	135	B/C	Poor visibility	No
73	07-May-00	1530	Collision	Sarayburnu	Burak Han	Turkey	1231	65	B/C	Not known	No
					Oguz	Turkey			Fishing Boat		No
74	31-Jul-00	1835	Fire	Cengelkoy	Valsim	Holland	3433	80	B/C	Fire	No
75	04-Nov-00	2235	Contact	Akinti Burnu	Anna-Lk	Greece	22080	**187.11**	B/C	Improper Navigation	***Yes***[4]
76	18-Jan-01	628	Collision	Ahirkapi	Marika	Cambodia	1945	96	B/C	Not known	No
					Victoria 3		4034	***80.00***	River		No
77	21-Jan-01	633	Collision	Turkeli	Kaptan Cavit	Turkey	654	***64.20***	B/C	Not known	***Yes***
					Nadya	Turkey	487	41.5	B/C		No
78	08-Feb-01	715	Collision	Istanbul Strait	Akaylar-2	Turkey	2558	90	B/C	Not known	No
					Med Glory	Cambodia	6660	125	B/C		***Yes***
79	18-Feb-01	525	Collision	Istanbul Strait	Robel	Sao Tome	2478	114	B/C	Improper Navigation	No
					Bunga Melor Satu	Malaysia	24550	184	B/C		***Yes***
80	19-Feb-01	230	Collision	Istanbul Strait	Spar Eight	Norway	22300	190	B/C	Improper Navigation	***Yes***
					Khaleda	Malta	12212	156	B/C		***Yes***
81	28-Feb-01	1905	HM	Istanbul Strait	Edmando	Turkey	1854	80	B/C	Machine Failure	No
82	23-Mar-01	2100	HM	Istanbul Strait	Akado	St.Vincent	5863	123	B/C	Machine Failure	No
83	30-Apr-01	2245	Stranded	Yenikoy	National Star	Egypt	6160	130	B/C	Improper Navigation	No
84	12-May-01	2320	Fire	Ahirkapi	Selin S	Honduras	4289	***109.75***	B/C	Fire	No
85	26-Aug-01	1340	Stranded	Galatasaray Island	Tania	Cambodia	96	***22.50***	B/C	Improper Navigation	No
86	03-Sep-01	2310	Collision	Kizkulesi	Rumeli Kavagi	Turkey	1350	***79.00***	B/C	Improper Navigation	No
					Olimp	Bulgaria		82	B/C		No

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[4] The italic bold values of the pilot variable are randomly generated based on Table A.2 pilot demand frequencies of vessel clusters in arrival processes.

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
87	04-Nov-01	2000	Stranded	Yenikoy	Mechanic Chereko	Ukraine	2842	***103.00***	B/C	Improper Navigation	No
88	13-Nov-01	1822	Stranded	Umurbanki	Alexandar Karastoyanov	Ukraine	1866	100	B/C	Improper Navigation	No
89	02-Dec-01	1005	HM	Beylerbeyi	West Virginia	Malta	49526	236	Tanker	Machine Failure	***Yes***
90	08-Dec-01	110	HM	Northern Ent.	Altair	Cambodia	5654	***125.38***	B/C	Adverse Weather Conditions	No
91	04-Jan-02	415	HM	Sarayburnu	Sismanoglu	Turkey			Pleasure Boat	Machine Failure	No
92	05-Jan-02	2300	HM	Yenikoy	Haci Emin Ana	Turkey	4923	118	B/C	Machine Failure	No
93	05-Jan-02	500	HM	Northern Ent.	Nestor	St.Vincent	183	29	Tug Boat	Adverse Weather Conditions	No
94	08-Jan-02	335	Stranded	Umuryeri	Sunrise	Honduras	2938	***99.11***	B/C	Improper Navigation	No
95	23-Jan-02	810	Stranded	Ahirkapi	Mustafa Bey	Turkey	1823	***80.30***	B/C	Improper Navigation	No
96	28-Feb-02	2340	Stranded	Umuryeri	Volgobalts-35	Russia	2406	***110.30***	B/C	Improper Navigation	***Yes***
97	11-Apr-02	755	HM	Uskudar	Alexandropolis	Malta	41342	***226.75***	B/C	Machine Failure	***Yes***
98	19-Apr-02	635	HM	Kurucesme	Gerani	Malta	53974	243	Tanker	Machine Failure	***Yes***
99	01-May-02	400	Contact	Northern Ent.	Edo	Cambodia	3689	115	B/C	Poor visibility	***Yes***
100	06-Jun-02	1620	Foundered	Kiz Kulesi	Ata-2	Turkey	14		Pleasure Boat	Improper Navigation	No
101	16-Jun-02	10	Collision	Kurucesme	Modiks - 3	Cambodia	1694	***82.00***	B/C	Improper Navigation	***Yes***
					Yeni Besiktas	Turkey	705		Pleasure Boat		No
102	29-Jun-02	230	HM	Umuryeri	Lotus	Gina	1741	86	B/C	Machine Failure	No
103	31-Jul-02	1630	HM	Yalikoy	Tentor	Antigua	3119	103	B/C	Machine Failure	No
104	08-Aug-02	930	HM	Ortakoy	Remo-2	Malta	6459	***136.05***	B/C	Machine Failure	No
105	24-Aug-02	1715	Stranded	Tarabya	Nasuhi	Cambodia	1891	***103.00***	B/C	Not known	No
106	25-Aug-02	1700	Collision	Ahirkapi	Istanbul - 8	Turkey	47		Pleasure Boat	Improper Navigation	No
					Canpinar	Turkey			Fishing Boat		No
107	26-Aug-02	1645	HM	Yenikoy	Atanin	Turkey	914	52	B/C	Machine Failure	No

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
108	02-Sep-02	935	HM	Umuryeri	Atar	Cambodia	2550	92	B/C	Machine Failure	No
109	06-Oct-02	1930	Contact	Emirgan	Gotia	Malta	7159	116	B/C	Not known	***Yes***
110	16-Nov-02	2130	Stranded	Umuryeri	Comanche	Malta	4989	139	B/C	Improper Navigation	No
111	02-Dec-02	400	Collision	Kandilli	Selay 5	Turkey	993	***79.90***	Bunker	Improper Navigation	No
					Eleftroria	S.Cyprus	6442	***136.00***	Tanker		No
112	20-Dec-02	1520	Foundered	Yenikoy	Mekin K	Turkey	1544	***79.80***	Tanker	Strong Current	***Yes***
113	01-Jan-03	1900	Stranded	Turkeli	Med General 4	Cambodia	860	***66.40***	B/C	Adverse Weather Conditions	No
114	07-Feb-03	2050	HM	Buyukdere	Diana	Bolivia	1639	***81.30***	B/C	Machine Failure	No
115	17-Feb-03	2100	Stranded	Bebek	Sea Patron	Malta	10230	145	B/C	Improper Navigation	No
116	27-Feb-03	940	Fire	Istanbul Strait	Capitannisa Parma	Cambodia	1696	***81.50***	B/C	Fire	No
117	08-Mar-03	1500	HM	Yenikoy	Jakop	St.Vincent	92	***19.00***	B/C	Machine Failure	***Yes***
118	14-Mar-03	1715	HM	Istanbul Strait	Ruya	Turkey	1993	***85.88***	B/C	Adverse Weather Conditions	No
119	23-Apr-03	540	Collision	Turkeli	Meryem	Turkey	746	73	B/C	Improper Navigation	***Yes***
					Pontokratis	S.Cyprus	1612	170	B/C		***Yes***
120	27-May-03	2200	Contact	Bebek	Polixeni 1	Greece	14513	***172.50***	Tanker	Improper Navigation	***Yes***
121	07-Jun-03	2340	Stranded	Umuryeri	Arial	N.Korea	843	66.90	B/C	Not known	No
122	03-Jul-03	540	Collision	Sarayburnu	Baris Manco	Turkey	12	84	Passenger Boat	Not known	No
					D.Kardesler	Turkey	10		Pleasure Boat		No
123	12-Aug-03	30	Fire	Kurucesme	Yasemin	Turkey	16.52		Yacht	Fire	
124	01-Sep-03	1800	HM	Kurucesme	Sea Tide	Ukraine	3451	***97.96***	B/C	Machine Failure	No
125	11-Sep-03	215	Foundered	Turkeli	Bulut	Turkey	2067	***90.90***	Tanker	Not known	No
126	27-Sep-03	1140	Stranded	Istanbul Strait	Lady S	N.Korea	1344	***75.50***	B/C	Not known	
127	18-Oct-03	620	Stranded	Yenikoy	Khazar Star 2	Russia	2426	108	B/C	Improper Navigation	No
128	10-Nov-03	2010	HM	Turkeli	Svyatov Panteleymon	Georgia	16216	***183.51***	B/C	Adverse Weather Conditions	***Yes***
129	23-Nov-03	1215	Contact	Uskudar	Ivoli Sprint	Italy	3703	***101.00***	B/C	Improper Navigation	No

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
130	02-Dec-03	2320	Fire	Istanbul Strait	Turan - C	Turkey	9145	***143.40***	B/C	Fire	***Yes***
131	09-Jan-04	1845	Stranded	Ahirkapi	Marilia	Liberia	20885	183	B/C	Improper Navigation	No
132	11-Jan-04	749	HM	Yenikoy	Magis K	Panama	3422	***80.30***	B/C	Machine Failure	No
133	11-Jan-04	1205	Collision	Ahirkapi	Nina	Comoros	39997	231	B/C	Improper Navigation	***Yes***
					A.Akif	Cambodia	3269	104	B/C		***Yes***
134	11-Feb-04	432	HM	Yenikoy	Rovenbek	Antigua	2690	***91.80***	Tanker	Machine Failure	***Yes***
135	12-Feb-04		Stranded	Turkeli Aslan Burnu	Stronsy	Russia			B/C	Not known	No
136	13-Feb-04		Stranded	Turkeli Dalyan Burnu	Lujin – 1	N.Korea			B/C	Not known	No
137	13-Feb-04	1240	Foundered	Turkeli	Hera	Cambodia	7871	139	B/C	Adverse Weather Conditions	No
138	29-Mar-04	259	HM	Garipce	Mario	Marshall Islands	17825	178	Tanker	Machine Failure	No
139	11-Jun-04	1855	Stranded	Yenikoy	Amina	Lebanon	26	***24.50***	B/C	Not known	No
140	13-Jun-04	2330	HM	Ahirkapi	Ulku	Turkey			Pleasure Boat	Machine Failure	No
141	24-Jun-04	1352	Stranded	Yenikoy	Tulune	Turkey	3982	***91.80***	B/C	Strong Current	No
142	21-Jul-04	2040	HM	Bebek	Samur	Turkey	1846	***88.70***	B/C	Machine Failure	No
143	02-Sep-04	245	HM	Kurucesme	Antwerb	Malta	6316	***103.25***	B/C	Machine Failure	***Yes***
144	03-Oct-04	1540	HM	Cengelkoy	Odin Bey	Turkey	8239	***133.00***	B/C	Machine Failure	No
145	12-Nov-04	2234	HM	Kanlica	Xufc – 7	Cambodia	2802	***95.59***	B/C	Machine Failure	No
146	20-Nov-04	500	Contact	Kandilli	Arados H	Syria	5306	***116.40***	B/C	Improper Navigation	No
147	03-Dec-04	10	Collision	Ahirkapi	Chem Prince	Turkey	2780	***103.00***	Tanker	Not known	***Yes***
					ZZ San Chon Nyon	N.Korea	9003	103	B/C		No
148	06-Jan-05	1942	Contact	Yeniköy	Asari	S.Cyprus	18526	179	Tanker	Improper navigation	Yes
149	20-Jan-05	2215	Collision	Kiz Kulesi	Ravan River	Liberia	23100	170	Tanker	Low visibility	No
					Cadebostan	Turkey	456		Passenger Ship	Low visibility	No

Table F.1. The accident data for 1995-2005 in the Istanbul Strait (continued)

Serial #	Date	Time	Type of Accident	Accident Location	Ships Involved	Flag State	GRT	Length	Type of Vessel	Reason of the Accident	Pilot
150	02-Feb-05	1400	Contact	Karaburun	Akkoç-1	Turkey	498	60	B/C	Not known	Yes
151	19-Feb-05	1455	Collision	Türkeli	Cassiope	Cambodia	2406	110	B/C	Human error	No
					Spetses	Greece	80637	280	B/C	Human error	Yes
152	12-Mar-05	2238	Foundered	Türkeli	Jm-2	N.Korea	1387	75	B/C	Improper cargo handling	No
153	13-Mar-05	0200	Stranded	Harem	Zim Novorossis	Malta	15560	186	Container	Not known	Yes
154	22-Mar-05	2335	Contact	Yeniköy	Fauna	Rusia	1772	88	B/C	Improper navigation	No
155	10-May-05	2347	Contact	Rumeli önleri	Ivon Nazarov	Rusia	1768	88	B/C	Improper navigation	No
156	17-May-05	2136	Stranded	Kandilli burnu	Aura	Cambodia	1995	90	Passenger Ship	Rudder failure	Yes
157	18-May-05	2138	Fire	Rumeli feneri	Yaşar Kaptan	Georgia	3493	135	B/C	Not known	No
158	20-Jun-05	0342	Stranded	Umuryeri	Arbitraje	N.Korea	885	73	B/C	Improper navigation	No
159	03-Jul-05	2320	Contact	Istanbul Strait	Eurocarrier	Cambodia	15627	160	B/C	Improper navigation	Yes
160	18-Jul-05	2345	Collision	Rumeli feneri	Tegucigalpa	Belize	7468	135	B/C	Adverse weather conditions	No
					Pakistanli-3	Turkey	77		B/C	Adverse weather conditions	No
161	29-Jul-05	1930	Contact	Yeniköy	Tosunlar-1	Turkey	126	32	B/C	Not known	Yes
162	31-Jul-05	0137	HM	Kavak	Rez Hpdk	Panama	1805	90	IMO	Electrical system failure	No
163	04-Aug-05	1758	Contact	Saray burnu	Merton	Moldova	2592	114	B/C	Not known	No
164	16-Aug-05	1925	HM	Istanbul Strait	Turanlar	Turkey	1144	71	B/C	Rudder failure	No
165	02-Oct-05	0840	Stranded	Istanbul Strait	Aytak	Turkey	7831	145	Tug boat	Engine failure	No
166	21-Oct-05	0310	Fire	Rumeli feneri	Svir	Russia	2794	105	B/C	Not known	No
167	07-Nov-05	1500	Collision	Türkeli	Mobbydick	Honduras	451.89	60	B/C	Improper navigation	No
					Karadeniz-5	Turkey	1700	82	B/C	Improper navigation	No
168	16-Dec-05	0440	Stranded	Umuryeri	Nader-Ii	N.Korea	1285	25	B/C	Improper navigation	No

Table F.2. Sample data set of the logit model

i	Y_i	X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	X_{7i}	X_{8i}	X_{9i}	X_{10i}	X_{11i}	X_{12i}	A_{1i}	A_{2i}	A_{3i}	A_{4i}	A_{5i}	A_{6i}
1	1	0	0	20	1.7	1	182.56	9.58	0	1	0	0	0	1	0	0	0	0	0
2	1	0	0	20	1.7	0	123.2	9.58	0	1	0	0	0	1	0	0	0	0	0
3	1	0	0	8	1.8	0	104.72	9.58	0	1	0	0	0	0	1	0	0	0	0
4	1	0	0	20	0	0	75	0.24	0	1	0	0	0	1	0	0	0	0	0
5	1	0	0	20	0	0	143.16	0.24	0	1	0	0	0	1	0	0	0	0	0
6	1	1	0	20	4.2	0	75	25.50	0	1	0	0	0	0	0	0	0	0	1
7	1	1	0	20	4.2	1	90.65	25.50	0	1	0	0	0	0	0	0	0	0	1
8	1	1	0	20	4.2	1	83	25.50	0	1	0	0	0	0	0	0	0	0	1
9	1	0	0	20	4.7	0	70.63	15.75	0	1	0	0	0	0	0	1	0	0	0
10	1	0	0	10	5.5	0	80.5	9.58	0	1	0	0	0	0	0	1	0	0	0
11	1	0	0.3	20	5.3	0	97	0.24	0	1	0	0	0	0	0	1	0	0	0
12	1	1	0	15	3.5	1	136.3	29.08	0	1	0	0	0	0	0	1	0	0	0
13	1	1	0	20	3.5	0	65	28.92	0	1	0	0	0	0	0	1	0	0	0
14	1	1	1.6	10	2.3	1	73	29.08	0	1	0	0	0	0	1	0	0	0	0
15	1	1	0	20	2.13	0	28.5	29.08	0	1	0	0	0	0	0	1	0	0	0
16	1	1	0	20	3.8	0	70	88.56	0	1	0	0	0	0	1	0	0	0	0
17	1	0	0	20	0	0	81	15.75	0	1	0	0	0	1	0	0	0	0	0
18	1	0	0	20	0	0	105	15.75	1	0	0	0	0	1	0	0	0	0	0
19	1	0	0	4	0	1	112.5	83.14	0	1	0	0	0	1	0	0	0	0	0
20	1	0	0	4	0	0	65.4	83.14	0	1	0	0	0	1	0	0	0	0	0
21	1	0	3.56	18.33	1.56	0	112.5	83.14	0	1	0	0	0	0	1	0	0	0	0
22	1	0	0.1	10	3.3	0	121	15.75	0	1	0	0	0	0	0	1	0	0	0
23	1	1	0.6	6	2.7	1	182	25.50	0	1	0	0	0	0	0	0	0	0	1
24	1	0	0	10	0	0	129	0.24	0	1	0	0	0	1	0	0	0	0	0
25	1	1	0	20	1.8	0	134.56	0.24	1	0	0	0	0	1	0	0	0	0	0
26	1	1	0	20	0	0	160	28.92	0	1	0	0	0	0	1	0	0	0	0
27	1	0	0	20	4	0	131	0.24	0	1	0	0	0	1	0	0	0	0	0
28	1	0	0	20	4	1	157	0.24	0	0	0	0	1	1	0	0	0	0	0

Table F.2. Sample data set of the logit model (continued)

i	Y_i	X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	X_{7i}	X_{8i}	X_{9i}	X_{10i}	X_{11i}	X_{12i}	A_{1i}	A_{2i}	A_{3i}	A_{4i}	A_{5i}	A_{6i}
29	1	0	2.1	20	4.2	0	65	88.56	0	0	0	0	1	0	0	1	0	0	0
30	1	0	0	15	1.5	0	89	0.24	0	1	0	0	0	0	0	1	0	0	0
31	1	0	0	20	2	0	87	0.24	1	0	0	0	0	0	0	0	0	0	1
32	1	1	0.9	20	4.7	1	111	83.14	1	0	0	0	0	0	0	1	0	0	0
33	1	1	0	20	4.2	0	91	29.08	1	0	0	0	0	0	1	0	0	0	0
34	1	0	0	20	0	0	68	0.24	0	1	0	0	0	1	0	0	0	0	0
35	1	1	0.3	10	4.2	1	171	83.14	0	0	0	0	1	0	0	1	0	0	0
36	1	1	0	5	0.7	0	90.9	70.27	0	0	0	0	1	1	0	0	0	0	0
37	1	1	0	5	0.7	0	69.12	70.27	0	1	0	0	0	1	0	0	0	0	0
38	1	1	0	10	0.3	0	91	83.14	0	0	0	0	1	1	0	0	0	0	0
39	1	0	0	15	0.8	0	70	9.58	0	1	0	0	0	0	0	1	0	0	0
40	1	0	0	0.2	0.8	1	98	88.56	0	1	0	0	0	0	0	0	0	0	1
41	1	0	0	20	5	0	104	88.56	1	0	0	0	0	0	0	0	0	0	1
42	1	1	0	8	1.3	0	78	28.92	0	1	0	0	0	0	0	1	0	0	0
43	1	0	0	20	3.8	1	121	88.56	0	1	0	0	0	1	0	0	0	0	0
44	1	0	0	20	3.8	0	132	88.56	0	1	0	0	0	1	0	0	0	0	0
45	1	0	0	15	0	0	114	0.24	0	1	0	0	0	0	0	1	0	0	0
46	1	0	0	15	1.7	0	95	15.75	1	0	0	0	0	1	0	0	0	0	0
47	1	1	0	20	4	0	72.4	29.08	0	1	0	0	0	1	0	0	0	0	0
48	1	1	0	5	0	1	81	83.14	0	1	0	0	0	1	0	0	0	0	0
49	1	1	0	5	0	0	81	83.14	1	0	0	0	0	1	0	0	0	0	0
50	1	1	0	20	3.8	0	176	29.08	0	1	0	0	0	0	0	0	1	0	0
51	1	1	0	20	4.5	0	72.5	25.50	0	1	0	0	0	1	0	0	0	0	0
52	1	1	8.8	12	0.5	1	247	15.75	0	0	0	0	1	0	0	1	0	0	0
53	1	1	0	20	6.3	0	147.02	29.08	0	1	0	0	0	1	0	0	0	0	0
54	1	1	0	20	6.3	0	110.6	29.08	1	0	0	0	0	1	0	0	0	0	0
55	1	0	0	20	5.3	0	81	0.24	0	1	0	0	0	0	1	0	0	0	0
56	1	0	0	15	0	0	218	15.75	0	1	0	0	0	0	0	0	0	0	1

Table F.2. Sample data set of the logit model (continued)

i	Y_i	X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	X_{7i}	X_{8i}	X_{9i}	X_{10i}	X_{11i}	X_{12i}	A_{1i}	A_{2i}	A_{3i}	A_{4i}	A_{5i}	A_{6i}
57	1	1	0	15	1.3	1	274	47.48	0	0	0	0	1	0	0	0	0	0	1
58	1	0	0.5	20	0.2	0	138	0.24	0	1	0	0	0	0	0	0	0	0	1
59	1	1	0	20	3.7	0	72.5	25.50	0	1	0	0	0	1	0	0	0	0	0
60	1	1	0	0.6	0.5	0	158	83.14	0	1	0	0	0	1	0	0	0	0	0
61	1	0	0	5	0	1	171	0.24	0	0	0	0	1	1	0	0	0	0	0
62	1	0	0	5	0	0	59.7	0.24	0	0	0	0	1	1	0	0	0	0	0
63	1	0	0.2	10	4.2	0	75	0.24	0	1	0	0	0	1	0	0	0	0	0
64	1	0	0	20	0	0	84	0.24	0	1	0	0	0	0	0	1	0	0	0
65	1	0	0	10	0	0	99	88.56	1	0	0	0	0	0	0	1	0	0	0
66	1	1	0	20	4	0	172	25.50	0	1	0	0	0	1	0	0	0	0	0
67	1	1	0	20	4	0	42	25.50	0	1	0	0	0	1	0	0	0	0	0
68	1	0	0	20	0	0	70.9	0.24	0	1	0	0	0	0	1	0	0	0	0
69	1	0	0	15	0	1	122.6	15.75	0	0	0	0	1	0	1	0	0	0	0
70	1	1	0	20	4.7	0	120	25.50	0	1	0	0	0	1	0	0	0	0	0
71	1	1	0	20	4.7	1	183.4	25.50	0	1	0	0	0	1	0	0	0	0	0
72	1	0	0	20	5.5	1	122	15.75	0	0	0	0	1	0	0	1	0	0	0
73	1	1	0	20	2	1	169.55	70.27	0	1	0	0	0	0	0	0	0	0	1
74	1	1	0	10	3.8	1	219.3	29.08	0	0	0	0	1	0	0	1	0	0	0
75	1	0	0	20	0.5	0	100.07	15.75	0	1	0	0	0	1	0	0	0	0	0
76	1	0	1	15	1.8	0	35.4	15.75	0	0	0	0	1	1	0	0	0	0	0
77	1	0	0	20	1.3	0	40.3	0.24	0	1	0	0	0	0	1	0	0	0	0
78	1	0	0	20	0	0	131	15.75	0	1	0	0	0	0	0	1	0	0	0
79	1	1	0	5	0	0	135	47.48	0	1	0	0	0	0	1	0	0	0	0
80	1	1	0	20	1	0	65	29.08	0	1	0	0	0	1	0	0	0	0	0
81	1	1	0	20	2.8	0	80	88.56	0	1	0	0	0	0	0	0	1	0	0
82	1	0	0	6	0	1	187.11	9.58	0	1	0	0	0	0	1	0	0	0	0
83	1	0	0	15	4	0	96	83.14	0	1	0	0	0	1	0	0	0	0	0
84	1	0	0	20	4.7	1	64.2	83.14	0	1	0	0	0	1	0	0	0	0	0

Table F.2. Sample data set of the logit model (continued)

i	Y_i	X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	X_{7i}	X_{8i}	X_{9i}	X_{10i}	X_{11i}	X_{12i}	A_{1i}	A_{2i}	A_{3i}	A_{4i}	A_{5i}	A_{6i}
85	1	0	0	20	4.7	0	41.5	83.14	0	1	0	0	0	1	0	0	0	0	0
86	1	1	0	12	0	0	90	83.14	0	1	0	0	0	1	0	0	0	0	0
87	1	1	0	12	0	1	125	83.14	0	1	0	0	0	1	0	0	0	0	0
88	1	0	0	15	1.7	0	114	0.24	0	1	0	0	0	1	0	0	0	0	0
89	1	0	0	15	1.7	1	184	0.24	0	1	0	0	0	1	0	0	0	0	0
90	1	0	3.1	10	1.2	1	190	0.24	0	1	0	0	0	1	0	0	0	0	0
91	1	0	3.1	10	1.2	1	156	0.24	0	1	0	0	0	1	0	0	0	0	0
92	1	0	0	20	3.5	0	80	88.56	0	1	0	0	0	0	0	1	0	0	0
93	1	0	0	20	2	0	123	15.75	0	1	0	0	0	0	0	1	0	0	0
94	1	0	0	12	3.8	0	130	9.58	0	1	0	0	0	0	0	1	0	0	0
95	1	0	0	20	2.8	0	109.75	9.58	0	1	0	0	0	0	0	0	1	0	0
96	1	1	0	20	4.5	0	22.5	25.50	0	1	0	0	0	0	0	1	0	0	0
97	1	0	0	20	0.2	0	79	9.58	0	1	0	0	0	1	0	0	0	0	0
98	1	0	0	20	0.2	0	82	9.58	0	1	0	0	0	1	0	0	0	0	0
99	1	0	1.4	5	5.2	0	103	15.75	0	1	0	0	0	0	0	1	0	0	0
100	1	0	0	20	1.3	0	100	88.56	0	1	0	0	0	0	0	1	0	0	0
101	1	1	11.6	10	8.3	1	236	28.92	0	0	0	0	1	0	0	0	0	0	1
102	1	0	3.8	5	10.5	0	125.38	0.24	0	1	0	0	0	0	0	0	0	0	1
103	1	0	2.3	15	4.5	0	118	9.58	0	1	0	0	0	0	0	1	0	0	0
104	1	0	2.1	5	3	0	99.11	0.24	0	1	0	0	0	0	0	1	0	0	0
105	1	1	0	15	0.5	0	80.3	47.48	0	1	0	0	0	0	0	1	0	0	0
106	1	0	0	20	2.5	1	110.3	9.58	0	1	0	0	0	0	0	1	0	0	0
107	1	1	0	15	3.3	1	226.75	83.14	0	1	0	0	0	0	0	0	0	0	1
108	1	1	0	15	2.3	1	243	83.14	0	0	0	0	1	0	0	0	0	0	1
109	1	0	0	15	1.8	1	115	0.24	0	1	0	0	0	0	1	0	0	0	0
110	1	0	0	20	0.7	1	82	0.24	0	1	0	0	0	1	0	0	0	0	0
111	1	0	0	20	0.3	0	86	0.24	0	1	0	0	0	0	0	1	0	0	0
112	1	1	0	20	3.7	0	82	70.27	0	1	0	0	0	0	0	0	0	0	1

Table F.2. Sample data set of the logit model (continued)

i	Y_i	X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	X_{7i}	X_{8i}	X_{9i}	X_{10i}	X_{11i}	X_{12i}	A_{1i}	A_{2i}	A_{3i}	A_{4i}	A_{5i}	A_{6i}
113	1	1	11.1	20	0	0	136.05	47.48	0	1	0	0	0	0	0	1	0	0	0
114	1	1	0	15	3	0	103	70.27	0	1	0	0	0	0	0	1	0	0	0
115	1	1	0	20	4.8	0	52	70.27	0	1	0	0	0	0	1	0	0	0	0
116	1	1	1.2	20	0.3	0	92	47.48	0	1	0	0	0	0	0	1	0	0	0
117	1	0	0	20	0.3	1	116	88.56	0	1	0	0	0	0	1	0	0	0	0
118	1	0	0	20	0	0	139	15.75	0	1	0	0	0	0	0	1	0	0	0
119	1	0	0	20	0	0	70.9	0.24	0	1	0	0	0	1	0	0	0	0	0
120	1	0	0	20	0	0	136	0.24	0	0	0	0	1	1	0	0	0	0	0
121	1	1	0.8	20	4.5	1	79.8	29.08	0	0	0	0	1	0	0	0	0	1	0
122	1	0	7.6	8	3	0	66.4	88.56	0	1	0	0	0	0	0	1	0	0	0
123	1	0	10.7	8	5.7	0	81.3	15.75	0	1	0	0	0	0	0	0	0	0	1
124	1	0	0	20	7	0	145	15.75	0	1	0	0	0	0	0	1	0	0	0
125	1	1	0	20	0	0	81.5	47.48	0	1	0	0	0	0	0	0	1	0	0
126	1	1	0	20	3.7	1	19	29.08	0	1	0	0	0	0	0	0	0	0	1
127	1	1	6.7	4	1.7	0	85.88	70.27	0	1	0	0	0	0	0	0	0	0	1
128	1	0	0	20	1.3	1	73	0.24	0	1	0	0	0	1	0	0	0	0	0
129	1	0	0	20	1.3	1	170	0.24	0	1	0	0	0	1	0	0	0	0	0
130	1	0	0	15	1.3	1	172.5	15.75	0	0	0	0	1	0	1	0	0	0	0
131	1	0	0	20	1.2	0	66.9	9.58	0	1	0	0	0	0	0	1	0	0	0
132	1	1	0	20	1.7	0	97.96	88.56	0	1	0	0	0	0	0	0	0	0	1
133	1	0	0	20	0	0	90.9	0.24	0	0	0	0	1	0	0	0	0	1	0
134	1	1	0	20	4.5	0	75.5	28.92	0	1	0	0	0	0	0	1	0	0	0
135	1	0	0.1	15	0	0	108	15.75	0	1	0	0	0	0	0	1	0	0	0
136	1	0	6	10	6.8	1	183.51	15.75	0	1	0	0	0	0	0	0	0	0	1
137	1	1	0	15	1.3	0	101	25.50	0	1	0	0	0	0	1	0	0	0	0
138	1	0	0.9	20	3.3	1	143.4	9.58	0	1	0	0	0	0	0	0	1	0	0
139	1	0	0	20	0.2	0	183	88.56	0	1	0	0	0	0	0	1	0	0	0
140	1	1	0	15	1.8	0	80.3	83.14	0	1	0	0	0	0	0	0	0	0	1

Table F.2. Sample data set of the logit model (continued)

i	Y_i	X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	X_{7i}	X_{8i}	X_{9i}	X_{10i}	X_{11i}	X_{12i}	A_{1i}	A_{2i}	A_{3i}	A_{4i}	A_{5i}	A_{6i}
141	1	1	1.9	20	8	1	231	25.50	0	1	0	0	0	1	0	0	0	0	0
142	1	1	1.9	20	8	1	104	25.50	0	1	0	0	0	1	0	0	0	0	0
143	1	0	0	20	0	1	91.8	0.24	0	0	0	0	1	0	0	0	0	0	1
144	1	1	1.2	0.6	8	0	139	25.50	0	1	0	0	0	0	0	0	0	1	0
145	1	0	10.4	8	3.7	1	178	0.24	0	0	0	0	1	0	0	0	0	0	1
146	1	1	0	20	1.2	1	24.5	88.56	0	1	0	0	0	0	0	1	0	0	0
147	1	1	0	20	1.7	1	91.8	25.50	0	1	0	0	0	0	0	1	0	0	0
148	1	1	0	20	2.3	0	88.7	15.75	0	1	0	0	0	0	1	0	0	0	0
149	1	0	0	15	0	1	103.25	0.24	0	1	0	0	0	0	0	0	0	0	1
150	1	1	0	20	2.8	0	133	29.08	0	1	0	0	0	0	0	0	0	0	1
151	1	0	0	20	0	0	95.59	9.58	0	1	0	0	0	0	0	0	0	0	1
152	1	0	0	20	4	0	116.4	0.24	0	1	0	0	0	0	1	0	0	0	0
153	1	0	0	20	2	1	103	0.24	0	0	0	0	1	1	0	0	0	0	0
154	1	0	0	20	2	1	154.2	0.24	0	1	0	0	0	1	0	0	0	0	0
155	0	1	1	20	1.2	1	177	0.24	0	1	0	0	0	0	0	0	0	0	0
156	0	0	0.1	20	3	0	56	0.24	0	0	0	0	1	0	0	0	0	0	0
157	0	1	0	20	1.7	0	158.7	0.24	0	1	0	0	0	0	0	0	0	0	0
158	0	1	1.6	10	0.7	0	79.5	0.24	0	1	0	0	0	0	0	0	0	0	0
159	0	1	0.7	20	0.3	0	72	0.24	0	1	0	0	0	0	0	0	0	0	0
160	0	1	0	20	0	1	289	83.14	0	1	0	0	0	0	0	0	0	0	0
161	0	0	0	0.8	0.3	1	114.02	83.14	0	1	0	0	0	0	0	0	0	0	0
162	0	0	0	15	1.7	0	114	83.14	0	1	0	0	0	0	0	0	0	0	0
163	0	0	0	15	1	0	88.9	83.14	0	1	0	0	0	0	0	0	0	0	0
164	0	1	4.5	8	4	1	138	83.14	0	1	0	0	0	0	0	0	0	0	0
165	0	1	2.2	20	1.7	0	50.4	47.48	0	1	0	0	0	0	0	0	0	0	0
166	0	0	2.2	20	1.7	1	76.35	47.48	0	1	0	0	0	0	0	0	0	0	0
167	0	1	0	15	0.7	1	82	47.48	0	1	0	0	0	0	0	0	0	0	0
168	0	0	0	15	0.8	1	274.5	47.48	0	0	0	0	1	0	0	0	0	0	0

APPENDIX G: THE MARGINAL EFFECTS OF THE VARIABLES IN THE LOGIT MODEL

Table G.1. The marginal effects of the independent variables on accident probabilities when a cargo ship is involved in an accident

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	0.000192517	0.000379631	0.00026833	0.000529096
Transit Time	-6.39265E-05	-0.000126035	-8.909E-05	-0.00017563
Wind Speed	3.9055E-05	7.69994E-05	5.4431E-05	0.000107299
Precipitation	-1.44008E-05	-2.83921E-05	-2.007E-05	-3.95644E-05
Visibility	-1.52573E-05	-3.00808E-05	-2.126E-05	-4.19177E-05
Pilot	-0.000130733	-0.000257748	-0.0001822	-0.000359172
Vessel Length	6.00538E-08	1.184E-07	8.3697E-08	1.64991E-07
Local Traffic	-5.07763E-07	-1.00109E-06	-7.077E-07	-1.39502E-06
Cargo	0.00425643	0.008391821	0.00593222	0.01169403

Table G.2. The marginal effects of the independent variables on accident probabilities when a tanker ship is involved in an accident

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	0.000190934	0.000376509	0.00026613	0.000524746
Transit Time	-6.34008E-05	-0.000124999	-8.836E-05	-0.000174187
Wind Speed	3.87338E-05	7.63664E-05	5.3984E-05	0.000106417
Precipitation	-1.42824E-05	-2.81587E-05	-1.991E-05	-3.92393E-05
Visibility	-1.51319E-05	-2.98335E-05	-2.109E-05	-4.15732E-05
Pilot	-0.000129658	-0.000255629	-0.0001807	-0.000356221
Vessel Length	5.956E-08	1.17427E-07	8.3009E-08	1.63635E-07
Local Traffic	-5.03587E-07	-9.92857E-07	-7.019E-07	-1.38355E-06
Tanker	0.004219853	0.008319733	0.00588125	0.011593604

Table G.3. The marginal effects of the independent variables on accident probabilities when a passenger ship is involved in a collision

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	0.000274002	0.00054219	0.000471246	0.000932312
P(1-P)	0.000273927	0.000541896	0.000471024	0.000931443
Transit Time	-0.000148589	-0.000293947	-0.000255503	-0.000505253
Wind Speed	3.56716E-05	7.05674E-05	6.13381E-05	0.000121295
Precipitation	-0.000145682	-0.000288196	-0.000250504	-0.000495368
Visibility	-2.711E-05	-5.36304E-05	-4.66163E-05	-9.2183E-05
Pilot	-0.000187024	-0.000369979	-0.000321591	-0.000635942
Vessel Length	-1.34224E-07	-2.65529E-07	-2.30802E-07	-4.56407E-07
Local Traffic	-1.40579E-06	-2.78101E-06	-2.41729E-06	-4.78016E-06
Passenger Vessel	0.006513043	0.012884425	0.011199322	0.022146499

Table G.4. The marginal effects of the independent variables on accident probabilities when a cargo ship is involved in a collision

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	5.01882E-05	9.93332E-05	8.63307E-05	0.000170861
P(1-P)	5.01857E-05	9.93234E-05	8.63232E-05	0.000170832
Transit Time	-2.72228E-05	-5.38771E-05	-4.68253E-05	-9.26661E-05
Wind Speed	6.53533E-06	1.29342E-05	1.12413E-05	2.22462E-05
Precipitation	-2.66902E-05	-5.2823E-05	-4.59092E-05	-9.08532E-05
Visibility	-4.96678E-06	-9.82983E-06	-8.54324E-06	-1.69069E-05
Pilot	-3.42642E-05	-6.78129E-05	-5.89371E-05	-0.000116635
Vessel Length	-2.4591E-08	-4.86684E-08	-4.22984E-08	-8.37075E-08
Local Traffic	-2.57553E-07	-5.09727E-07	-4.43011E-07	-8.76708E-07
Cargo	0.001108048	0.002192957	0.001905928	0.003771787

Table G.5. The marginal effects of the independent variables on accident probabilities when a tanker is involved in a collision

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	0.000274002	0.00054219	0.000471246	0.000932312
P(1-P)	0.000273927	0.000541896	0.000471024	0.000931443
Transit Time	-0.000148589	-0.000293947	-0.000255503	-0.000505253
Wind Speed	3.56716E-05	7.05674E-05	6.13381E-05	0.000121295
Precipitation	-0.000145682	-0.000288196	-0.000250504	-0.000495368
Visibility	-2.711E-05	-5.36304E-05	-4.66163E-05	-9.2183E-05
Pilot	-0.000187024	-0.000369979	-0.000321591	-0.000635942
Vessel Length	-1.34224E-07	-2.65529E-07	-2.30802E-07	-4.56407E-07
Local Traffic	-1.40579E-06	-2.78101E-06	-2.41729E-06	-4.78016E-06
Tanker	0.006056426	0.011981122	0.010414158	0.020593849

Table G.6. The marginal effects of the independent variables on accident probabilities when a passenger ship is involved in a contact

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	6.54377E-05	0.000106942	8.92736E-05	0.00014589
P(1-P)	6.54334E-05	0.000106931	8.92657E-05	0.00014587
Transit Time	-2.03257E-05	-3.32161E-05	-2.77288E-05	-4.5313E-05
Wind Speed	1.71946E-06	2.80992E-06	2.34572E-06	3.8332E-06
Precipitation	-2.11579E-05	-3.4576E-05	-2.88641E-05	-4.7168E-05
Visibility	-5.19332E-06	-8.48686E-06	-7.08484E-06	-1.1578E-05
Pilot	-3.21428E-05	-5.25275E-05	-4.385E-05	-7.1657E-05
Vessel Length	-2.6049E-07	-4.25691E-07	-3.55367E-07	-5.8072E-07
Local Traffic	-3.51574E-07	-5.74538E-07	-4.79624E-07	-7.8377E-07
Passenger	0.001510983	0.002469233	0.002061316	0.00336848

Table G.7. The marginal effects of the independent variables on accident probabilities when a cargo ship is involved in a contact

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	2.63102E-05	4.29987E-05	3.58943E-05	5.8662E-05
P(1-P)	2.63095E-05	4.29969E-05	3.5893E-05	5.8658E-05
Transit Time	-8.17258E-06	-1.33562E-05	-1.11495E-05	-1.8221E-05
Wind Speed	6.91362E-07	1.12987E-06	9.43198E-07	1.5414E-06
Precipitation	-8.50718E-06	-1.3903E-05	-1.1606E-05	-1.8967E-05
Visibility	-2.08813E-06	-3.41258E-06	-2.84876E-06	-4.6556E-06
Pilot	-1.2924E-05	-2.11214E-05	-1.76317E-05	-2.8815E-05
Vessel Length	-1.04738E-07	-1.71171E-07	-1.4289E-07	-2.3352E-07
Local Traffic	-1.41361E-07	-2.31022E-07	-1.92853E-07	-3.1517E-07
Cargo	0.000583565	0.000953703	0.000796135	0.00130108

Table G.8. The marginal effects of the independent variables on accident probabilities when a tanker is involved in a contact

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	6.54377E-05	0.000106942	8.92736E-05	0.00014589
P(1-P)	6.54334E-05	0.000106931	8.92657E-05	0.00014587
Transit Time	-2.03257E-05	-3.32161E-05	-2.77288E-05	-4.5313E-05
Wind Speed	1.71946E-06	2.80992E-06	2.34572E-06	3.8332E-06
Precipitation	-2.11579E-05	-3.4576E-05	-2.88641E-05	-4.7168E-05
Visibility	-5.19332E-06	-8.48686E-06	-7.08484E-06	-1.1578E-05
Pilot	-3.21428E-05	-5.25275E-05	-4.385E-05	-7.1657E-05
Vessel Length	-2.6049E-07	-4.25691E-07	-3.55367E-07	-5.8072E-07
Local Traffic	-3.51574E-07	-5.74538E-07	-4.79624E-07	-7.8377E-07
Tanker	0.001431599	0.002339505	0.001953019	0.00319151

Table G.9. The marginal effects of the independent variables on accident probabilities when a passenger ship is involved in a stranded

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	0.000122775	0.000391648	0.00021	0.00068202
P(1-P)	0.00012276	0.000391495	0.00021	0.000681555
Transit Time	-6.813E-05	-0.000217274	-0.00012	-0.000378253
Wind Speed	2.8383E-05	9.05167E-05	4.9E-05	0.000157581
Precipitation	-2.2545E-06	-7.1898E-06	-3.9E-06	-1.25168E-05
Visibility	-6.9799E-06	-2.22596E-05	-1.2E-05	-3.87518E-05
Pilot	-0.00014244	-0.000454244	-0.00025	-0.000790796
Vessel Length	-3.6018E-07	-1.14865E-06	-6.3E-07	-1.99968E-06
Local Traffic	-1.1159E-07	-3.55869E-07	-1.9E-07	-6.19533E-07
Passenger Vessel	0.002820123	0.008993703	0.00491	0.01565718

Table G.10. The marginal effects of the independent variables on accident probabilities when a cargo ship is involved in a stranded

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	3.27925E-05	0.000104628	5.7E-05	0.000182239
P(1-P)	3.27914E-05	0.000104617	5.7E-05	0.000182206
Transit Time	-1.8199E-05	-5.8061E-05	-3.2E-05	-0.000101122
Wind Speed	7.58164E-06	2.41883E-05	1.3E-05	4.21274E-05
Precipitation	-6.0221E-07	-1.92129E-06	-1E-06	-3.34621E-06
Visibility	-1.8645E-06	-5.94831E-06	-3.2E-06	-1.03599E-05
Pilot	-3.8047E-05	-0.000121385	-6.6E-05	-0.00021141
Vessel Length	-9.621E-08	-3.06946E-07	-1.7E-07	-5.34592E-07
Local Traffic	-2.9807E-08	-9.50968E-08	-5.2E-08	-1.65625E-07
Cargo	0.000710017	0.002265219	0.00124	0.00394521

Table G.11. The marginal effects of the independent variables on accident probabilities when a tanker is involved in a stranded

	Day		Night	
	Pilot	No Pilot	Pilot	No Pilot
P	0.000122775	0.000391648	0.00021	0.00068202
P(1-P)	0.00012276	0.000391495	0.00021	0.000681555
Transit Time	-6.813E-05	-0.000217274	-0.00012	-0.000378253
Wind Speed	2.8383E-05	9.05167E-05	4.9E-05	0.000157581
Precipitation	-2.2545E-06	-7.1898E-06	-3.9E-06	-1.25168E-05
Visibility	-6.9799E-06	-2.22596E-05	-1.2E-05	-3.87518E-05
Pilot	-0.00014244	-0.000454244	-0.00025	-0.000790796
Vessel Length	-3.6018E-07	-1.14865E-06	-6.3E-07	-1.99968E-06
Local Traffic	-1.1159E-07	-3.55869E-07	-1.9E-07	-6.19533E-07
Tanker	0.002645692	0.00843742	0.00461	0.014688745

APPENDIX H: FACTOR LEVELS AND THE RESULTS OF SCENARIO ANALYSIS OF THE LOGIT MODEL

Table H.1. Factor levels and the results of the scenario analysis

Scenario 1 (Best)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	0				
Precipitation	-0.074817	0				
Visibility	-0.079267	20.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	88.56				
Passenger Ship	23.52085		0.00038921	0.000542438	0.00076734	0.001069288
Cargo Ship	22.11361		9.5313E-05	0.000132853	0.000187968	0.000261993
Tanker	22.10535		9.4529E-05	0.00013176	0.000186422	0.000259838
Scenario 2 (Worst)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	10.00				
Precipitation	-0.074817	34.00				
Visibility	-0.079267	0.93				
Pilot	-0.679201					
Vessel Length	0.000312	300.00				
Local Traffic	-0.002638	0.24				
Passenger Ship	23.52085		0.00140779	0.001961264	0.002772797	0.00386084
Cargo Ship	22.11361		0.00034502	0.000480865	0.000680255	0.000947967
Tanker	22.10535		0.00034218	0.000476911	0.000674663	0.000940177

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 3 (Average)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot – Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00137875	0.001920827	0.002715674	0.003781388
Cargo Ship	22.11361		0.0003379	0.000470936	0.000666212	0.000928403
Tanker	22.10535		0.00033512	0.000467064	0.000660736	0.000920773

Scenario 4 (Visibility 2 nm)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	3.75				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00226079	0.003148556	0.004449178	0.006190948
Cargo Ship	22.11361		0.00055443	0.00077266	0.001092911	0.001522775
Tanker	22.10535		0.00054987	0.000766309	0.001083931	0.001510268

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 5 (Visibility 1 nm)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	1.85				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00262688	0.003657872	0.005167794	0.007188858
Cargo Ship	22.11361		0.00064439	0.000897994	0.001270126	0.001769569
Tanker	22.10535		0.00063909	0.000890613	0.001259691	0.001755038

Scenario 6 (Visibility 0.5 nm)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	0.93				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00282638	0.003935368	0.005559197	0.007732144
Cargo Ship	22.11361		0.00069343	0.000966321	0.00136673	0.001904087
Tanker	22.10535		0.00068773	0.00095838	0.001355502	0.001888453

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 7 (Wind Min)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	0.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00091928	0.001280933	0.00181147	0.002523244
Cargo Ship	22.11361		0.00022521	0.000313899	0.000444088	0.000618915
Tanker	22.10535		0.00022336	0.000311318	0.000440437	0.000613827

Scenario 8 (Wind Max)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	10.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00695052	0.00966201	0.013616491	0.018879037
Cargo Ship	22.11361		0.00171059	0.002382821	0.003368198	0.004688777
Tanker	22.10535		0.00169654	0.002363266	0.003340583	0.004650387

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 9 (Precipitation 10mm)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	10.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00070363	0.000980537	0.001386828	0.001932071
Cargo Ship	22.11361		0.00017235	0.000240231	0.000339876	0.000473697
Tanker	22.10535		0.00017094	0.000238255	0.000337082	0.000469802

Scenario 10 (Precipitation 20mm)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	20.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00033311	0.000464261	0.000656771	0.000915249
Cargo Ship	22.11361		8.1571E-05	0.000113699	0.000160869	0.000224224
Tanker	22.10535		8.09E-05	0.000112764	0.000159546	0.00022238

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 11 (Precipitation Min)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	0.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.0014857	0.002069742	0.002926029	0.004073955
Cargo Ship	22.11361		0.00036414	0.000507503	0.000717931	0.001000456
Tanker	22.10535		0.00036114	0.000503331	0.00071203	0.000992234

Scenario 12 (Precipitation Max)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	35.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00010846	0.000151185	0.000213903	0.000298139
Cargo Ship	22.11361		2.6556E-05	3.70171E-05	5.23758E-05	7.30062E-05
Tanker	22.10535		2.6338E-05	3.67126E-05	5.1945E-05	7.24057E-05

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 13 (Local Traffic 06:00)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	0.24				
Passenger Ship	23.52085		0.00150966	0.002103098	0.002973145	0.004139479
Cargo Ship	22.11361		0.00037001	0.000515695	0.000729518	0.001016597
Tanker	22.10535		0.00036697	0.000511456	0.000723521	0.001008243

Scenario 14 (Local Traffic 08:00)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	83.14				
Passenger Ship	23.52085		0.00121346	0.001690662	0.002390493	0.003329022
Cargo Ship	22.11361		0.00029735	0.000414434	0.000586294	0.000817059
Tanker	22.10535		0.0002949	0.000411026	0.000581474	0.000810343

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 15 (Local Traffic 12:00)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817					
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	28.92				
Passenger Ship	23.52085		0.00139981	0.001950149	0.002757096	0.003839002
Cargo Ship	22.11361		0.00034306	0.000478136	0.000676395	0.00094259
Tanker	22.10535		0.00034024	0.000474205	0.000670835	0.000934843

Scenario 16 (Local Traffic 16:00)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	29.08				
Passenger Ship	23.52085		0.0013992	0.001949293	0.002755887	0.003837321
Cargo Ship	22.11361		0.00034291	0.000477926	0.000676098	0.000942176
Tanker	22.10535		0.00034009	0.000473996	0.00067054	0.000934433

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 17 (Local Traffic 20:00)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	118.93				
Local Traffic	-0.002638	88.56				
Passenger Ship	23.52085		0.00119627	0.001666715	0.002356658	0.003281946
Cargo Ship	22.11361		0.00029313	0.000408556	0.000577981	0.000805476
Tanker	22.10535		0.00029072	0.000405197	0.000573229	0.000798856

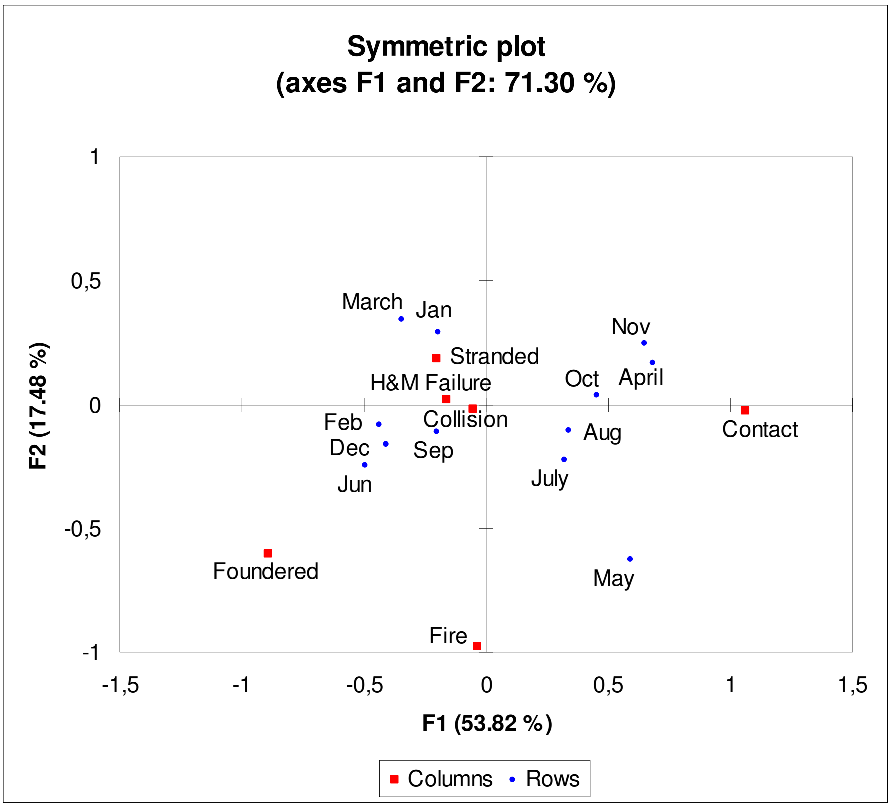
Scenario 18 (V_Length 300 m)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	300.00				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00145877	0.002032242	0.002873061	0.00400029
Cargo Ship	22.11361		0.00035753	0.000498294	0.000704907	0.000982311
Tanker	22.10535		0.00035459	0.000494197	0.000699112	0.000974238

Table H.1. Factor levels and the results of the scenario analysis (continued)

Scenario 19 (V_Length 100 m)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	100.00				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00137065	0.001909541	0.00269973	0.00375921
Cargo Ship	22.11361		0.00033591	0.000468165	0.000662293	0.000922943
Tanker	22.10535		0.00033314	0.000464316	0.000656848	0.000915357

Scenario 20 (V_Length 200 m)	Coefficients	Value	Accident Probability (P)			
Constant	-28.57869		Pilot - Day	Pilot-Night	No Pilot-Day	No Pilot-Night
Transit Time	-0.33212					
Wind Speed	0.202904	2.00				
Precipitation	-0.074817	1.00				
Visibility	-0.079267	10.00				
Pilot	-0.679201					
Vessel Length	0.000312	200.00				
Local Traffic	-0.002638	34.67				
Passenger Ship	23.52085		0.00141402	0.001969938	0.002785051	0.003877884
Cargo Ship	22.11361		0.00034655	0.000482995	0.000683268	0.000952164
Tanker	22.10535		0.0003437	0.000479024	0.000677651	0.000944339

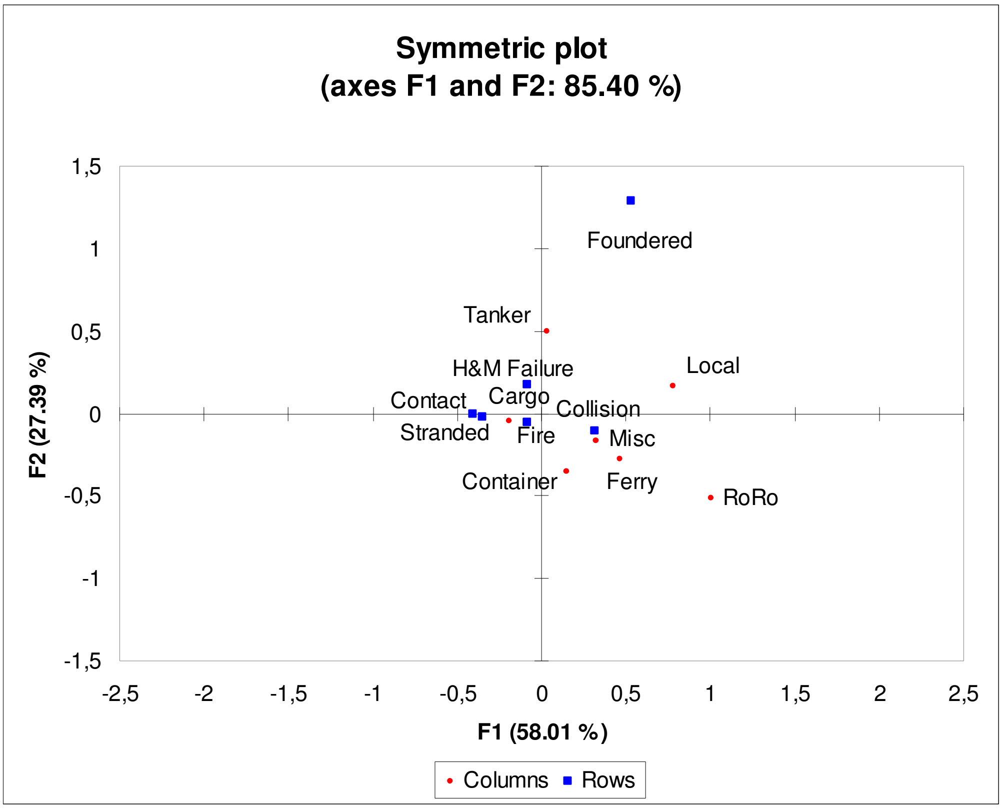
APPENDIX I: THE RESULTS OF THE CORRESPONDENCE ANALYSIS



Chi-square (Observed value)	50.947
Chi-square (Critical value)	73.311
DF	55
p-value	0.630
H0: The rows and the columns of the table are independent.	
Ha: There is a link between the rows and the columns of the table.	
As the computed p-value is greater than the significance level alpha=0.05, one should accept the null hypothesis H0.	

	F1	F2	F3	F4	F5
Eigenvalue	0.185	0.060	0.052	0.038	0.009
Rows depend on columns (%)	53.817	17.484	15.076	11.048	2.575
Cumulative %	53.817	71.301	86.377	97.425	100.000

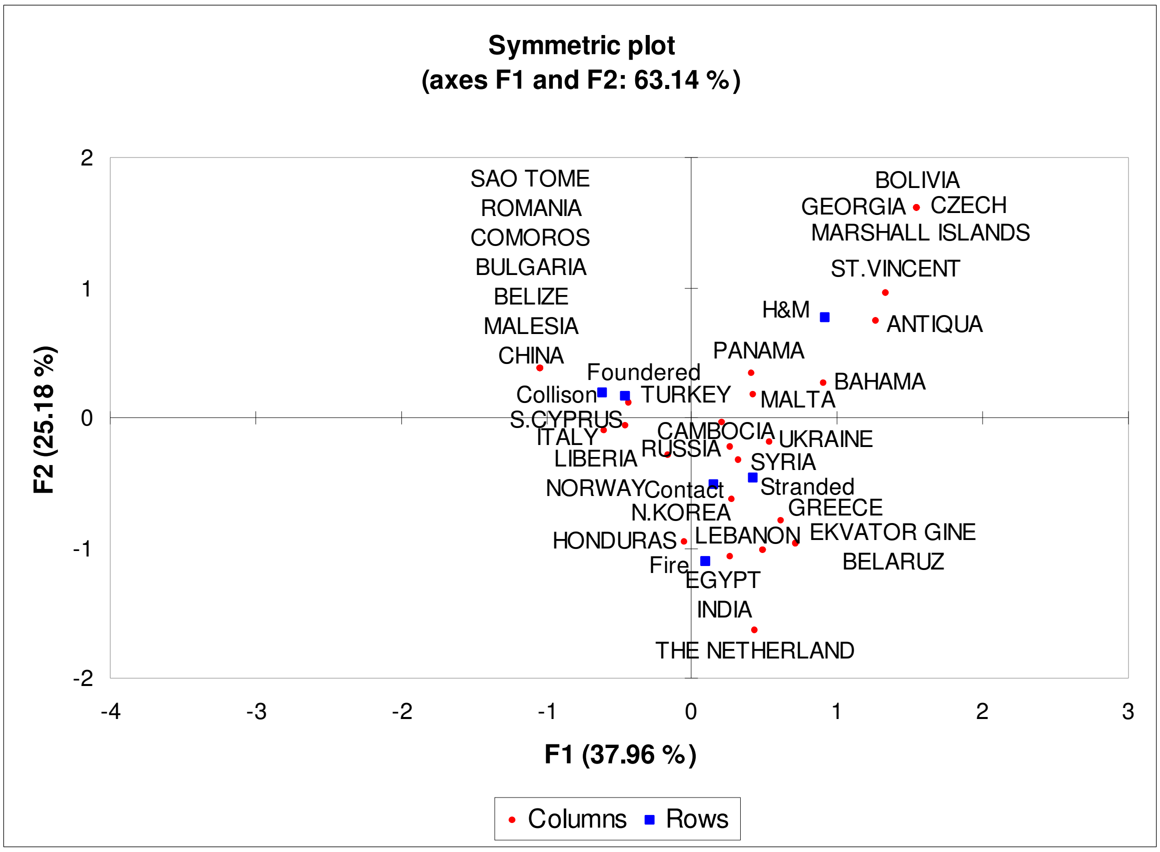
Figure I. 1. The correspondence analysis between accident month and accident type



Test of independence between the rows and the columns:	
Chi-square (Observed value)	31.459
Chi-square (Critical value)	43.773
DF	30
p-value	0.393
Test interpretation:	
H0: The rows and the columns of the table are independent.	
Ha: There is a link between the rows and the columns of the table.	
As the computed p-value is greater than the significance level alpha=0.05, one should accept the null hypothesis H0.	
The risk to reject the null hypothesis H0 while it is true is 41.91%.	

	F1	F2	F3	F4	F5
Eigenvalue	0.097	0.046	0.016	0.007	0.002
Rows depend on columns (%)	58.013	27.390	9.387	3.935	1.275
Cumulative %	58.013	85.403	94.790	98.725	100.000

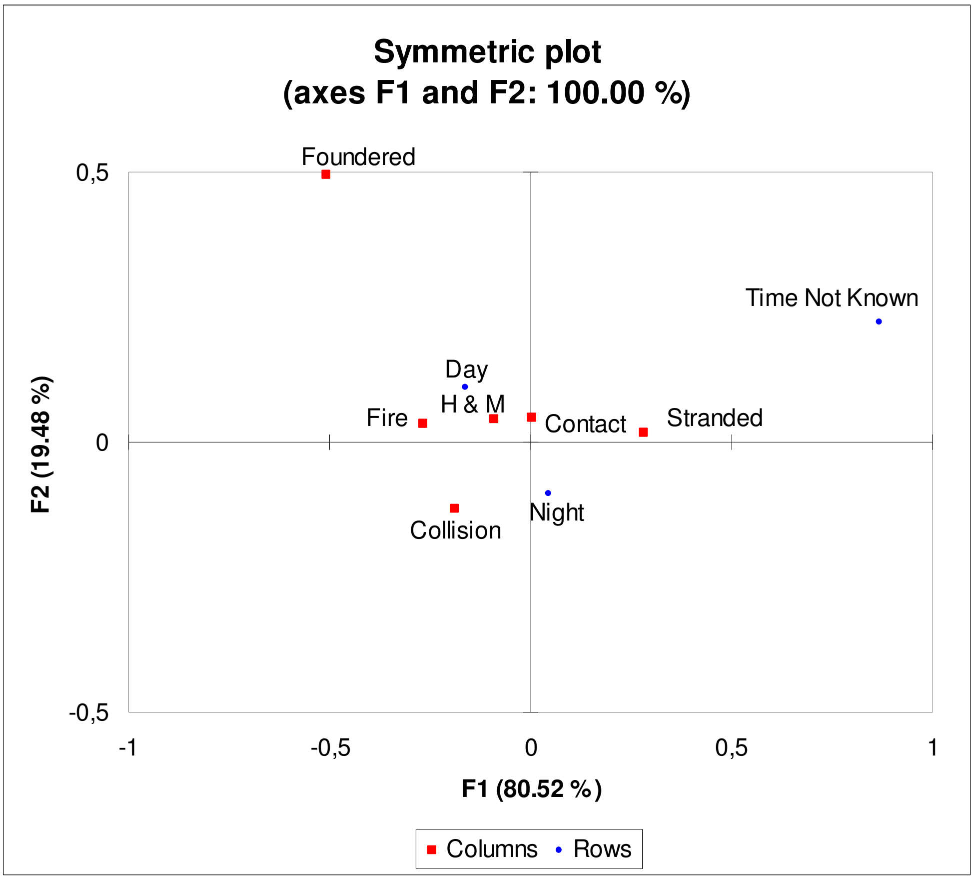
Figure I.2. The correspondence analysis between vessel type and accident type



Chi-square (Observed value)	172.728
Chi-square (Critical value)	206.867
DF	175
p-value	0.534
Test interpretation:	
H0: The rows and the columns of the table are independent.	
Ha: There is a link between the rows and the columns of the table.	
As the computed p-value is greater than the significance level alpha=0.05, one should accept the null hypothesis H0.	
The risk to reject the null hypothesis H0 while it is true is 53.44%.	

	F1	F2	F3	F4	F5
Eigenvalue	0.349	0.231	0.166	0.148	0.024
Rows depend on columns (%)	37.965	25.180	18.117	16.129	2.609
Cumulative %	37.965	63.144	81.262	97.391	100.000

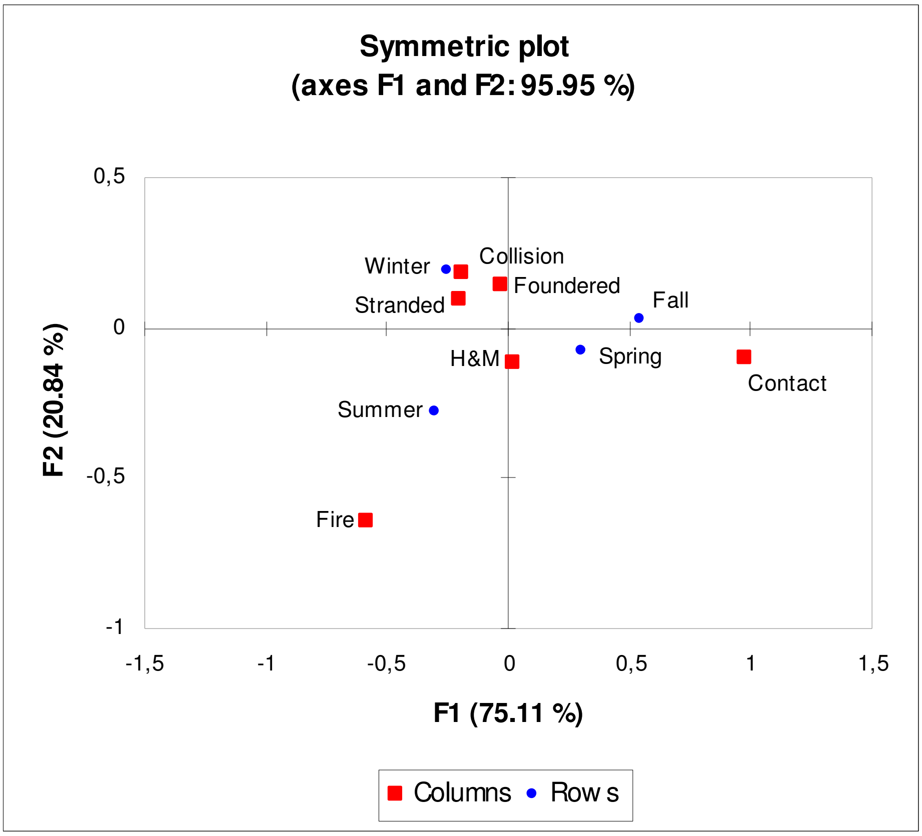
Figure I.3. The correspondence analysis between vessel flag state and accident type



Test of independence between the rows and the columns:	
Chi-square (Observed value)	8.731
Chi-square (Critical value)	18.307
DF	10
p-value	0.558
H0: The rows and the columns of the table are independent.	
Ha: There is a link between the rows and the columns of the table.	
As the computed p-value is greater than the significance level alpha=0.05, one should accept the null hypothesis H0.	
The risk to reject the null hypothesis H0 while it is true is 55.8%.	

	F1	F2
Eigenvalue	0.048	0.011
Rows depend on columns (%)	80.521	19.479
Cumulative %	80.521	100.000

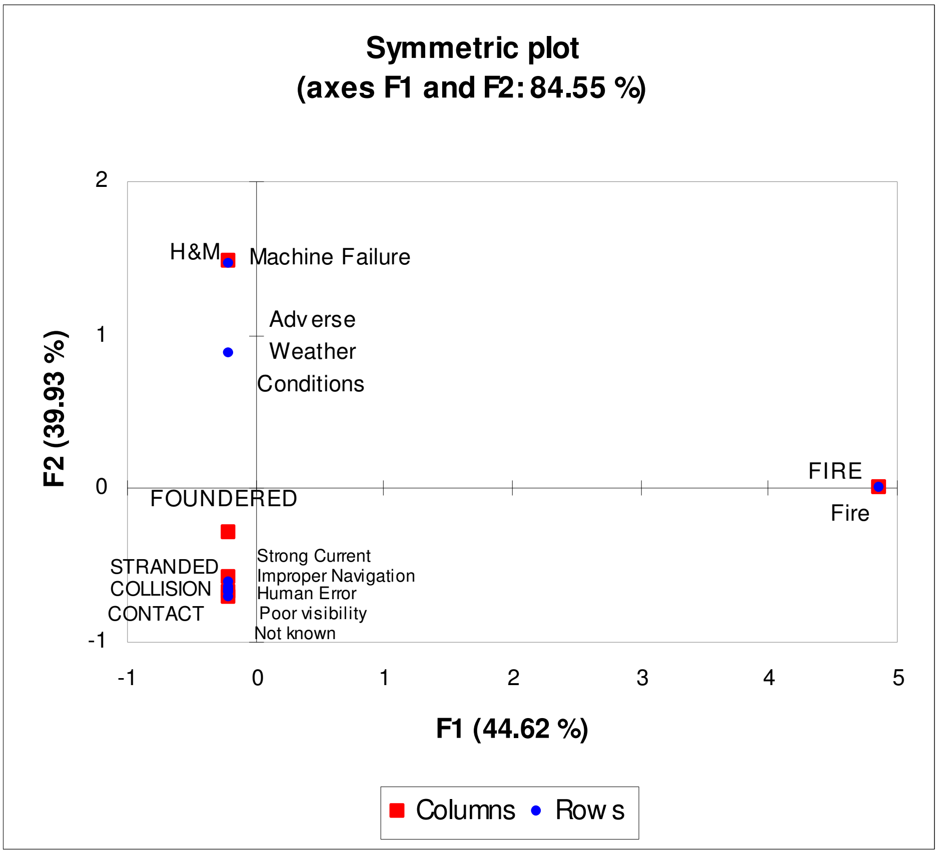
Figure I.4. The correspondence analysis between accident time and accident type



Test of independence between the rows and the columns:	
Chi-square (Observed value)	23.653
Chi-square (Critical value)	24.996
DF	15
p-value	0.071
H0: The rows and the columns of the table are independent.	
Ha: There is a link between the rows and the columns of the table.	
As the computed p-value is greater than the significance level alpha=0.05, one should accept the null hypothesis H0.	
The risk to reject the null hypothesis H0 while it is true is 7.1%.	

	F1	F2	F3
Eigenvalue	0.119	0.033	0.006
Rows depend on columns (%)	75.115	20.836	4.049
Cumulative %	75.115	95.951	100.000

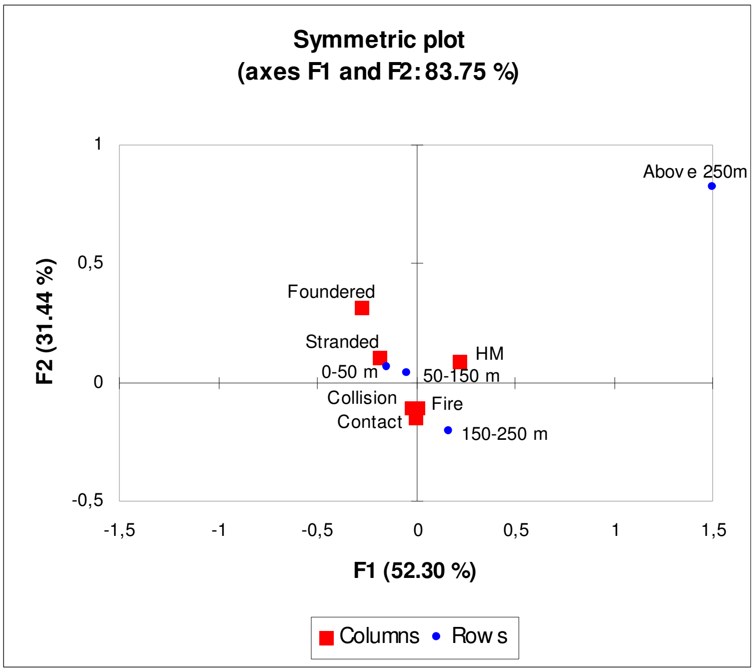
Figure I.5. The correspondence analysis between accident season and accident type



Test of independence between the rows and the columns:	
Chi-square (Observed value)	331.699
Chi-square (Critical value)	55.758
DF	40
p-value	< 0.0001
H0: The rows and the columns of the table are independent.	
Ha: There is a link between the rows and the columns of the table.	
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.	
The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.	

	F1	F2	F3	F4	F5
Eigenvalue	1.000	0.895	0.253	0.060	0.033
Rows depend on columns (%)	44.619	39.933	11.278	2.681	1.489
Cumulative %	44.619	84.552	95.830	98.511	100.000

Figure I.6. The correspondence analysis between accident reason and accident type



Test of independence between the rows and the columns:	
Chi-square (Observed value)	6.530
Chi-square (Critical value)	24.996
DF	15
p-value	0.969
H0: The rows and the columns of the table are independent.	
Ha: There is a link between the rows and the columns of the table.	
As the computed p-value is greater than the significance level alpha=0.05, one should accept the null hypothesis H0.	
The risk to reject the null hypothesis H0 while it is true is 96.9 %.	

	F1	F2	F3
Eigenvalue	0.021	0.013	0.007
Rows depend on columns (%)	52.304	31.444	16.251
Cumulative %	52.304	83.749	100.000

Figure I.7. The correspondence analysis between vessel length and accident type

APPENDIX J: THE CONSEQUENCE ANALYSIS QUESTIONNAIRE AND RESULTS OF THE INTERVIEWS

Table J.1. The attribute levels in the consequence analysis questionnaire (for collision type accidents) and the responses given by the experts

Type of Accident	Scenario 1 Levels					Different from 1st Scenario	Questionnaire Results (Geometric Mean)			
	Type of 1st Vessel	Type of 2nd Vessel	Length of 1st Vessel	Length of 2nd Vessel	Accident Region		Human Casualty	Infrastructure Damage	Env. Damage	Waterway Efficiency
Collision	**Full Tanker**	F. Tanker	50-150 m	50-150 m	1st	Empty Tanker	4.42	-	6.44	4.03
	F. Tanker	F. Tanker	50-150 m	50-150 m	1st	Passenger	0.21	-	6.20	3.15
	F. Tanker	E. Tanker	50-150 m	50-150 m	1st	General Cargo	2.91	-	5.20	1.84
	F. Tanker	F. Tanker	**50-150 m**	50-150 m	1st	150-250 m	0.42		0.22	0.33
	F. Tanker	F. Tanker	**50-150 m**	50-150 m	1st	Above 250 m	0.19	-	0.16	0.25
	F. Tanker	F. Tanker	50-150 m	50-150 m	**1st**	2nd Region	0.72	-	0.64	0.36
	F. Tanker	F. Tanker	50-150 m	50-150 m	**1st**	3rd Region	1.86	-	0.77	1.79

Table J.2. The attribute levels in the consequence analysis questionnaire (for stranded and contact types accidents) and the responses given by the experts

	Type of 1st Vessel	Length of 1st Vessel	Accident Region					
Stranded	**Full Tanker**	50-150 m	1st Region	Empty Tanker	-	4.19	6.28	1.96
	Full Tanker	50-150 m	1st Region	General Cargo	-	2.21	5.64	1.5
	Empty Tanker	**50-150 m**	1st Region	Above 250 m	-	0.32	0.46	0.29
	General Cargo	**50-150 m**	1st Region	150-250 m	-	0.36	0.47	0.32
	Full Tanker	50-150 m	**1st Region**	3rd Region	-	1.65	1.18	1.13
	Full Tanker	50-150 m	**2nd Region**	3rd Region	-	1.84	1.17	3.18
Contact	**Full Tanker**	50-150 m	1st Region	Empty Tanker	3.24	3.26	3.71	1.83
	General Cargo	50-150 m	1st Region	Empty Tanker	1.20	1.55	1.49	1.16
	Full Tanker	**50-150 m**	1st Region	150-250 m	0.37	0.31	0.36	0.36
	General Cargo	**50-150 m**	1st Region	Above 250 m	0.26	0.22	0.25	0.23
	Full Tanker	50-150 m	**1st Region**	2nd Region	0.77	0.77	0.80	0.49
	Full Tanker	50-150 m	**3rd Region**	2nd Region	0.42	0.42	0.42	0.37

APPENDIX K: THE RESULTS OF THE CONSEQUENCE ANALYSIS

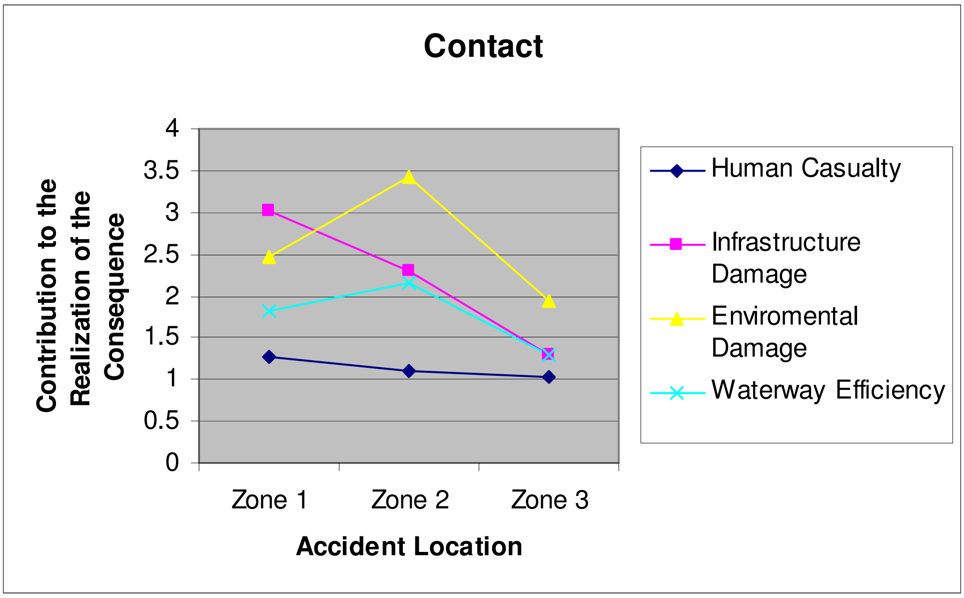


Figure K.1. The contribution of the accident location to the realization of the various consequences given a contact has occurred

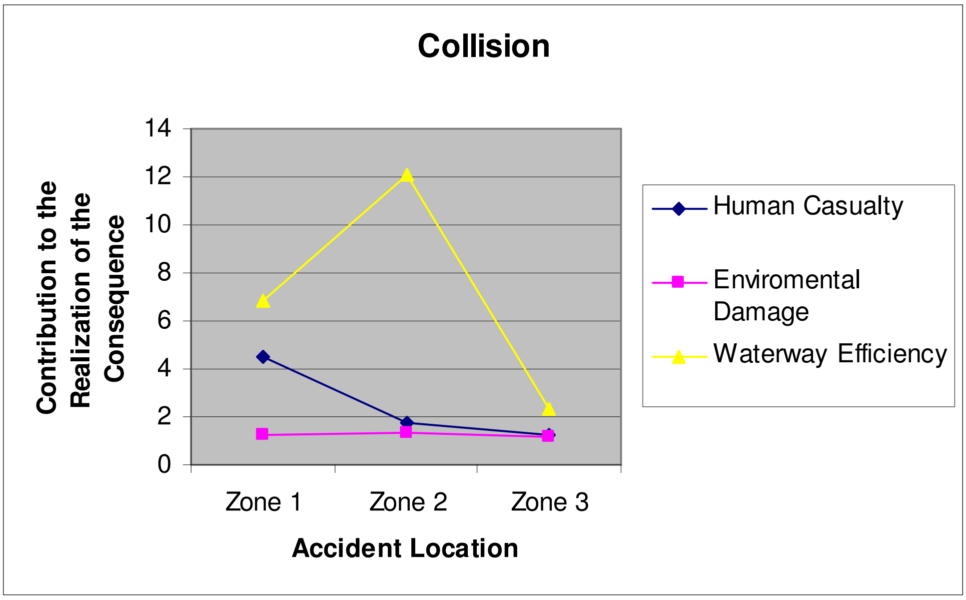


Figure K.2. The contribution of the accident location to the realization of the various consequences given a collision has occurred

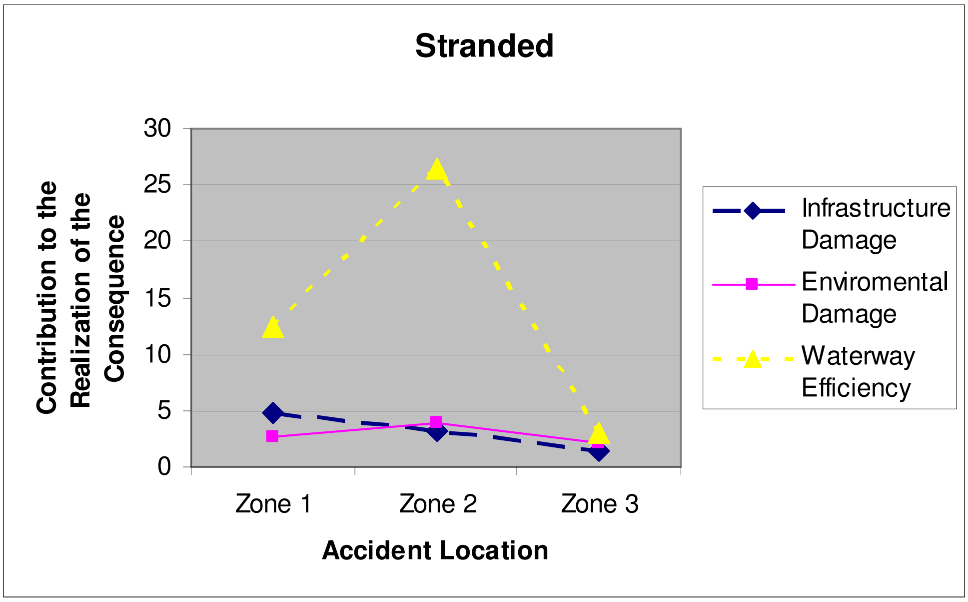


Figure K.3. The contribution of the accident location to the realization of the various consequences given a vessel has stranded

Table K.1. The computational results of the contribution of accident location to the realization of various consequences given an accident has occurred

Accident Type	Consequence Type	Zone 1	Zone 2	Zone 3
Collision	Human Casualty	4.479864188	1.756995629	1.286093744
	Environmental Damage	1.231361855	1.325936824	1.164884438
	Waterway Efficiency	6.806491883	12.06746587	2.307652242
Contact	Human Casualty	1.271047426	1.094329338	1.041062504
	Infrastructure Damage	3.026595014	2.304817158	1.299295841
	Environmental Damage	2.4764379	3.418652651	1.944494821
	Waterway Efficiency	1.809599816	2.160185643	1.29512257
Stranded	Infrastructure Damage	4.744727723	3.234886115	1.445010627
	Environmental Damage	2.726024062	3.893899013	2.086356099
	Waterway Efficiency	12.42447517	26.36365517	3.00003261

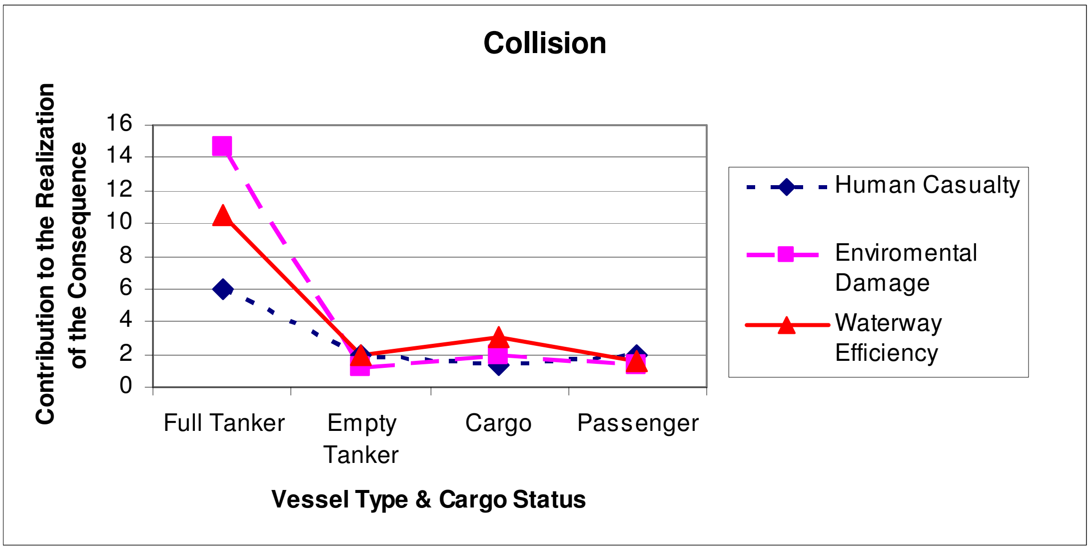


Figure K.4. The contribution of the vessel type and its cargo status to the realization of the various consequences given a collision has occurred

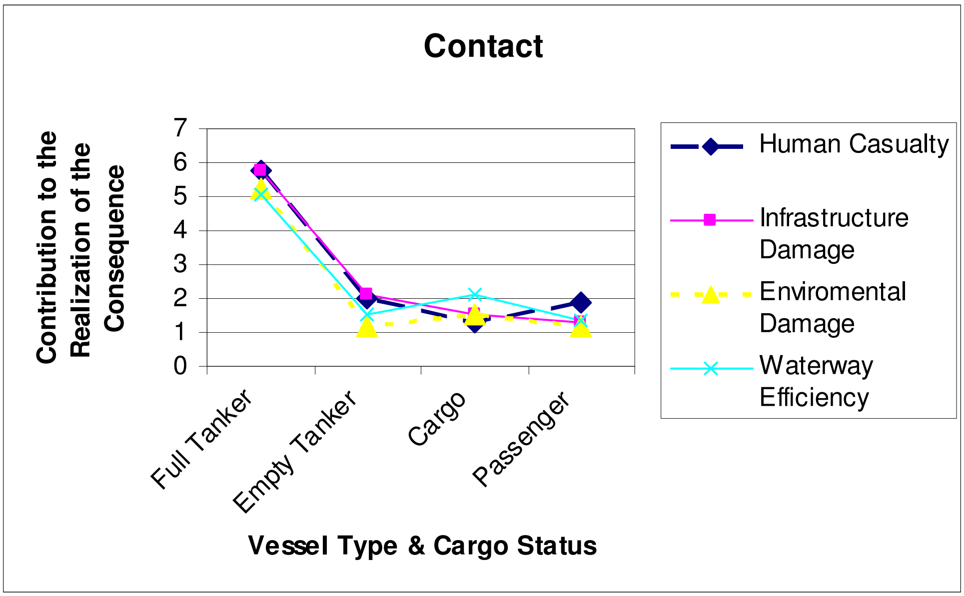


Figure K.5. The contribution of the vessel type and its cargo status to the realization of the various consequences given a contact has occurred

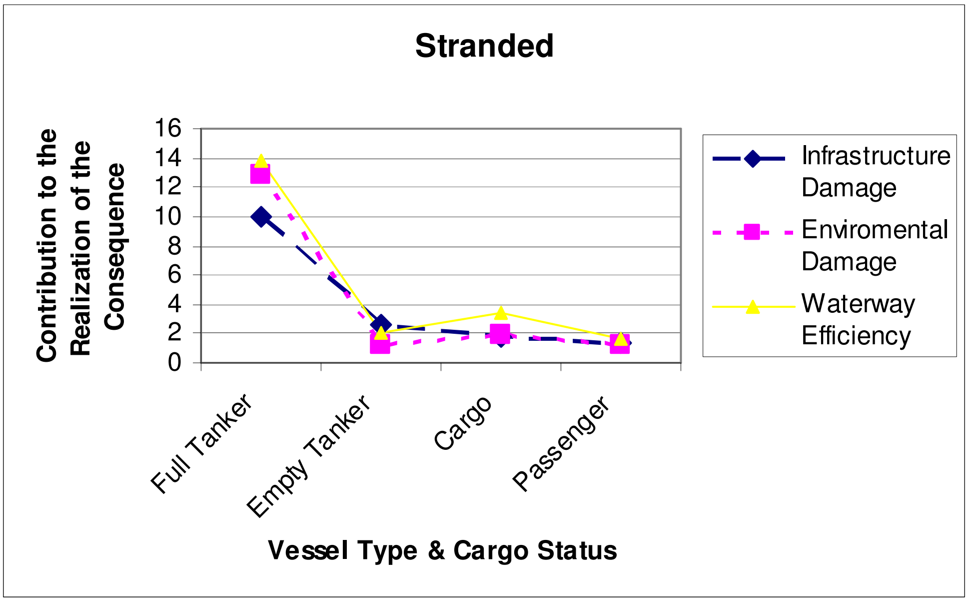


Figure K.6. The contribution of the vessel type and its cargo status to the realization of the various consequences given a vessel has stranded

Table K.2. The computational results of the contribution of vessel type and cargo status to the realization of various consequences given an accident has occurred

Accident Type	Consequence Type	Full Tanker	Empty Tanker	Cargo	Passenger
Collision	Human Casualty	6.007183	2.0046100	1.312141	1.898601
	Environmental Damage	14.61869	1.2641194	1.968133	1.297472
	Waterway Efficiency	10.55276	1.9015155	3.024628	1.590641
Contact	Human Casualty	5.769993	1.9735300	1.304156	1.871448
	Infrastructure Damage	5.750296	2.0960777	1.531273	1.279781
	Environmental Damage	5.237358	1.1556732	1.51888	1.174402
	Waterway Efficiency	5.03313	1.5538547	2.136246	1.374804
Stranded	Infrastructure Damage	9.958372	2.6442983	1.750445	1.382834
	Environmental Damage	12.9214	1.2505605	1.907765	1.282018
	Waterway Efficiency	13.81179	2.0463373	3.432195	1.677238

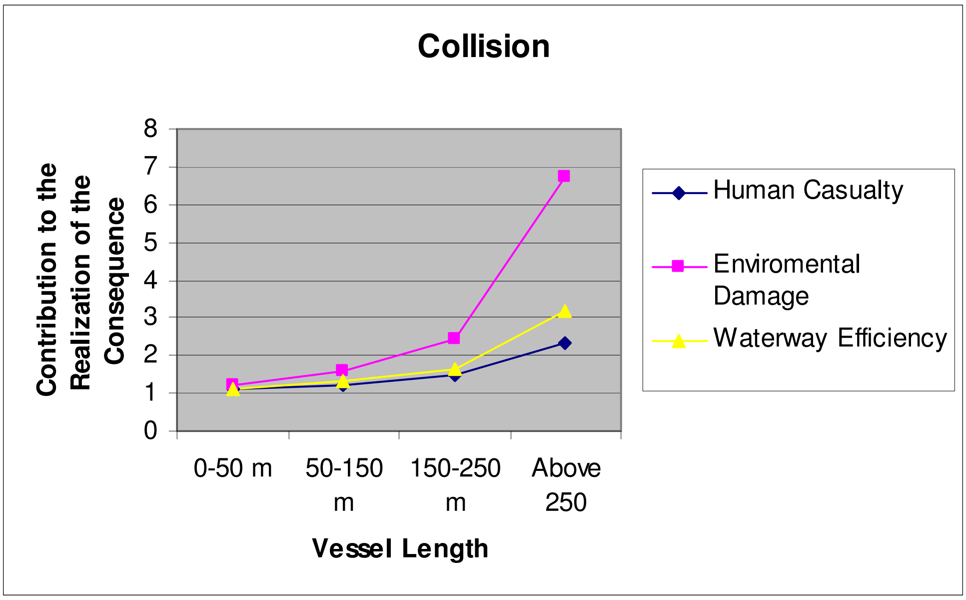


Figure K.7. The contribution of the vessel length to the realization of the various consequences given a collision has occurred

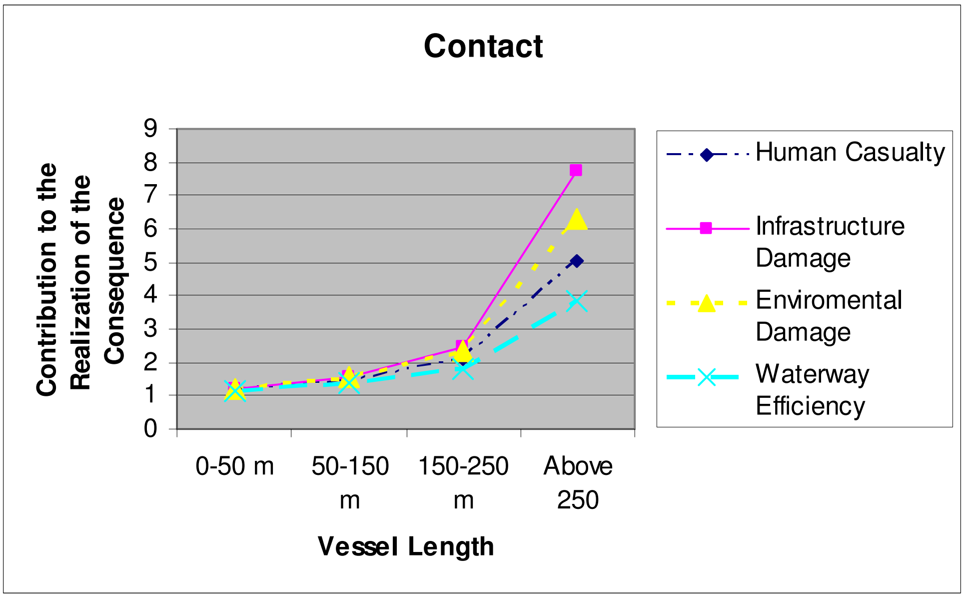


Figure K.8. The contribution of the vessel length to the realization of the various consequences given a contact has occurred

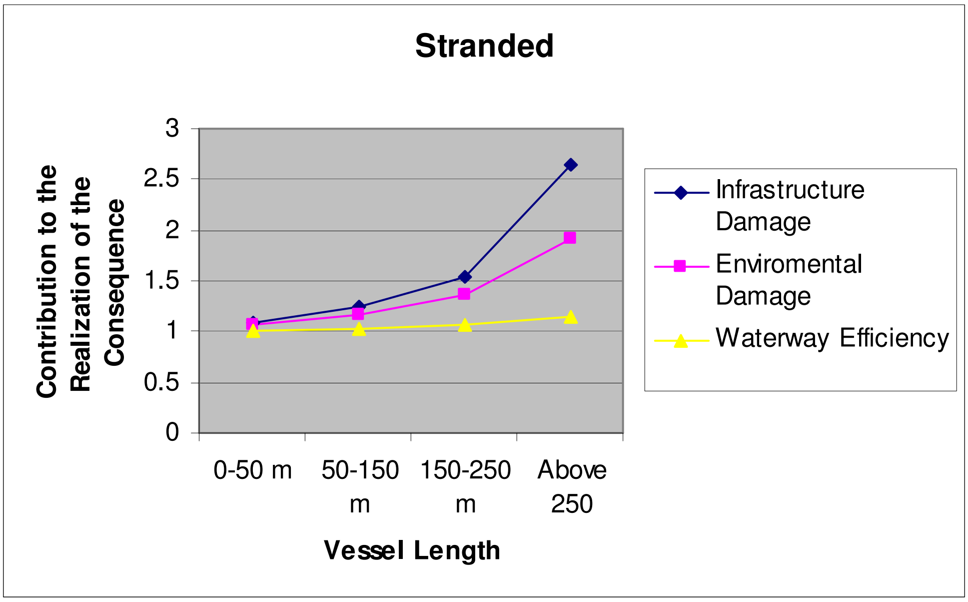


Figure K.9. The contribution of the vessel length to the realization of the various consequences given a vessel has stranded

Table K.3. The computational results of the contribution of vessel type and cargo status to the realization of various consequences given an accident has occurred

Accident Type	Consequence Type	0-50 m	50-150 m	150-250 m	Above 250
Collision	Human Casualty	1.08657069	1.205398006	1.468142414	2.34204
	Environmental Damage	1.229216486	1.590976799	2.43513124	6.746251
	Waterway Efficiency	1.115311461	1.304752543	1.656560352	3.188484
Contact	Human Casualty	1.170376261	1.424729394	2.070167359	5.015756
	Infrastructure Damage	1.208989792	1.576936922	2.486730057	7.765411
	Environmental Damage	1.220357629	1.565294362	2.3603462	6.309659
	Waterway Efficiency	1.13486899	1.361225936	1.795246127	3.835291
Stranded	Infrastructure Damage	1.093951546	1.240496112	1.538830604	2.63742
	Environmental Damage	1.072733797	1.171134887	1.353619473	1.914479
	Waterway Efficiency	1.012295275	1.030235057	1.058146611	1.138647

APPENDIX L: THE RESULTS OF THE LOGIT MODEL

Table L.1. Estimated coefficients of the logit model for collision type accident through the MLE method

Method: ML - Binary Logit (Newton-Raphson)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-28.6741	62260.89	-0.00046	0.9996
Transit Time	-0.54244	0.276224	-1.96377	0.0496
Wind Speed	0.130223	0.091027	1.430608	0.1525
Precipitation	-0.53183	0.224782	-2.36598	0.018
Visibility	-0.09897	0.026461	-3.74022	0.0002
Pilot	-0.68275	0.3374	-2.02356	0.043
Vessel Length	-0.00049	0.003624	-0.13526	0.8924
Local Traffic	-0.0051	0.00447	-1.1478	0.2511
Cargo	22.07897	62260.89	0.000355	0.9997
Tanker	22.10962	62260.89	0.000355	0.9997
Passenger	23.77655	62260.89	0.000382	0.9997
Mean dependent var	0.000147	S.D. dependent var		0.01214
S.E. of regression	0.012139	Akaike info criterion		0.002853
Sum squared resid	56.98157	Schwarz criterion		0.003162
Log likelihood	-540.73	Hannan-Quinn criter.		0.002942
Restr. log likelihood	-559.874	Avg. log likelihood		-0.0014
LR statistic (10 df)	38.28763	McFadden R-squared		0.034193
Probability(LR stat)	3.38E-05			
Obs with Dep=0	386575	Obs with Dep=1		57

Table L.2. Estimated coefficients of the logit model for contact type accident through the MLE method

Method: ML - Binary Logit (Newton-Raphson)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-29.70655	109259.6	-0.00027	0.9998
Transit Time	-0.310632	0.467658	-0.66423	0.5065
Wind Speed	0.026278	0.165247	0.15902	0.8737
Precipitation	-0.32335	0.287411	-1.12505	0.2606
Visibility	-0.079368	0.047986	-1.654	0.0981
Pilot	-0.49123	0.559229	-0.87841	0.3797
Vessel Length	-0.003981	0.006493	-0.61307	0.5398
Local Traffic	-0.005373	0.00777	-0.6914	0.4893
Cargo	22.18075	109259.6	0.000203	0.9998
Tanker	21.87873	109259.6	0.0002	0.9998
Passenger	23.09193	109259.6	0.000211	0.9998
Mean dependent var	4.91E-05	S.D. dependent var		0.007009
S.E. of regression	0.007009	Akaike info criterion		0.001108
Sum squared resid	18.99867	Schwarz criterion		0.001417
Log likelihood	-203.2286	Hannan-Quinn criter.		0.001196
Restr. log likelihood	-207.4993	Avg. log likelihood		-0.00053
LR statistic (10 df)	8.541451	McFadden R-squared		0.020582
Probability(LR stat)	0.576102			
Obs with Dep=0	386575	Obs with Dep=1		19

Table L.3. Estimated coefficients of the logit model for stranding type accident through the MLE method

Method: ML - Binary Logit (Newton-Raphson)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-29.3432	61299.77	-0.00048	0.9996
Transit Time	-0.55499	0.316937	-1.75109	0.0799
Wind Speed	0.231208	0.091242	2.534001	0.0113
Precipitation	-0.01837	0.068581	-0.26778	0.7889
Visibility	-0.05686	0.033682	-1.6881	0.0914
Pilot	-1.16028	0.433191	-2.67845	0.0074
Vessel Length	-0.00293	0.004463	-0.65728	0.511
Local Traffic	-0.0009	0.00491	-0.1853	0.853
Cargo	21.6525	61299.77	0.000353	0.9997
Tanker	21.55182	61299.77	0.000352	0.9997
Passenger	22.97274	61299.77	0.000375	0.9997
Mean dependent var	0.000111	S.D. dependent var		0.010544
S.E. of regression	0.010544	Akaike info criterion		0.002234
Sum squared resid	42.98978	Schwarz criterion		0.002543
Log likelihood	-420.966	Hannan-Quinn criter.		0.002322
Restr. log likelihood	-434.482	Avg. log likelihood		-0.00109
LR statistic (10 df)	27.03109	McFadden R-squared		0.031107
Probability(LR stat)	0.002575			
Obs with Dep=0	386575	Obs with Dep=1		43

Table L.4. Estimated coefficients of the logit model for machine and hull failure type accident through the MLE method

Method: ML - Binary Logit (Newton-Raphson)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-32.0614	77943.46	-0.000411	0.9997
Transit Time	0.206373	0.389094	0.530393	0.5958
Wind Speed	0.379379	0.102316	3.707908	0.0002
Precipitation	0.040625	0.047869	0.848682	0.3961
Visibility	-0.10008	0.038107	-2.626153	0.0086
Pilot	-0.13368	0.459559	-0.290882	0.7711
Vessel Length	0.007384	0.00447	1.651659	0.0986
Local Traffic	0.00255	0.00609	0.418414	0.6756
Cargo	22.05767	77943.46	0.000283	0.9998
Tanker	21.88823	77943.46	0.000281	0.9998
Passenger	23.53841	77943.46	0.000302	0.9998
Mean dependent var	6.98E-05	S.D. dependent var		0.008355
S.E. of regression	0.008353	Akaike info criterion		0.001461
Sum squared resid	26.98233	Schwarz criterion		0.00177
Log likelihood	-271.488	Hannan-Quinn criter.		0.001549
Restr. log likelihood	-285.379	Avg. log likelihood		-0.0007
LR statistic (10 df)	27.78208	McFadden R-squared		0.048676
Probability(LR stat)	0.001956			
Obs with Dep=0	386575	Obs with Dep=1		27

Table L.5. Estimated coefficients of the logit model for fire type type accident through the MLE method

Method: ML - Binary Logit (Newton-Raphson)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-53.8788	121584.4	-0.00044	0.9996
Transit Time	0.266189	0.918532	0.289798	0.772
Wind Speed	0.194452	0.309859	0.627549	0.5303
Precipitation	-0.05196	0.558774	-0.09299	0.9259
Visibility	0.926822	0.596088	1.554841	0.12
Pilot	-1.17758	1.206827	-0.97577	0.3292
Vessel Length	0.008003	0.012166	0.657822	0.5107
Local Traffic	0.00171	0.01424	0.12012	0.9044
Cargo	23.62199	121584.4	0.000194	0.9998
Mean dependent var	1.29E-05	S.D. dependent var		0.003596
S.E. of regression	0.003596	Akaike info criterion		0.000339
Sum squared resid	4.999981	Schwarz criterion		0.000592
Log likelihood	-56.5161	Hannan-Quinn criter.		0.000411
Restr. log likelihood	-61.2802	Avg. log likelihood		-0.00015
LR statistic (10 df)	9.528144	McFadden R-squared		0.077742
Probability(LR stat)	0.299717			
Obs with Dep=0	386575	Obs with Dep=1		5

Table L.6. Estimated coefficients of the logit model for foundered type accident through the MLE method

Method: ML - Binary Logit (Newton-Raphson)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-30.2516	98599.51	-0.00031	0.9998
Transit Time	0.815571	1.233216	0.661336	0.5084
Wind Speed	0.782889	0.314748	2.487352	0.0129
Precipitation	-0.47335	0.595858	-0.7944	0.427
Visibility	-0.19164	0.102136	-1.87629	0.0606
Pilot	-0.37439	1.389803	-0.26938	0.7876
Vessel Length	-0.01231	0.015542	-0.79174	0.4285
Local Traffic	-0.0261	0.02672	-0.9762	0.329
Cargo	20.18987	98599.51	0.000205	0.9998
Tanker	22.73581	98599.51	0.000231	0.9998
Mean dependent var	7.76E-06	S.D. dependent var		0.002785
S.E. of regression	0.002784	Akaike info criterion		0.000212
Sum squared resid	2.997293	Schwarz criterion		0.000493
Log likelihood	-31.0194	Hannan-Quinn criter.		0.000293
Restr. log likelihood	-38.3006	Avg. log likelihood		-8.02E-05
LR statistic (10 df)	14.56231	McFadden R-squared		0.190106
Probability(LR stat)	0.103682			
Obs with Dep=0	386575	Obs with Dep=1		3

APPENDIX M: THE AHP MODEL QUESTIONNAIRES

The key issue during the data collection phase of the AHP methodology is how to phrase the questions, so that the interviewee will correctly comprehend and focus on the comparison indicated. Each question is consisting of two parts: In the first part, the interviewees are requested to make a comparison, in the second part they are requested to scale the importance of one factor (in AHP criteria or sub-criteria) over other from 1 (equal) to 9 (extremely more important). The results of these pairwise comparisons constitute the data set. Below are the questionnaires being used during the interviews:

Which of the following factor groups contribute more to the realization of a maritime accident (or probability of accident) in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

To determine/measure the likelihood of each maritime accident

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL <

Circle one number per row below using the scale:

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	VESSCHAR	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	TRAFFIC
2	VESSCHAR	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ORGFACTO
3	VESSCHAR	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ENVCOND
4	TRAFFIC	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ORGFACTO
5	TRAFFIC	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ENVCOND
6	ORGFACTO	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ENVCOND

Abbreviation	Definition
VESSCHAR	The characteristics of the vessel VTS
TRAFFIC	Traffic conditions that influence the likelihood of the accidents
ORGFACTO	Crew knowledge, availablity of pilot, navigational aids and VTC
ENVCOND	Meteorological conditons during the transit

Figure M.1. The AHP model questionnaire for estimating the likelihood of a maritime accident (at first level)

Which one of the following maritime vessel characteristics is contributing more to the realization of a maritime accident (or probability of accident) in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

To determine/measure the likelihood of each maritime accident

Node: 10000

Compare the relative IMPORTANCE with respect to: VESSCHAR < GOAL

Circle one number per row below using the scale:

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	TYPE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	AGE
2	TYPE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LENGTH
3	TYPE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	DRAFT
4	TYPE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FLAGSTAT
5	AGE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LENGTH
6	AGE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	DRAFT
7	AGE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FLAGSTAT
8	LENGTH	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	DRAFT
9	LENGTH	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FLAGSTAT
10	DRAFT	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FLAGSTAT

Abbreviation	Definition
TYPE	Type of the vessel involved with accident
AGE	Age of the accident involved with accident
LENGTH	Length of the vessel involved with accident
DRAFT	Draft of the vessel involved with the accident
FLAGSTAT	The flag state of the vessel

Figure M.2. The AHP model questionnaire for estimating the likelihood of a maritime accident (vessel characteristics)

Which one of the following maritime traffic characteristics is contributing more to the realization of a maritime accident (or probability of accident) in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

To determine/measure the likelihood of each maritime accident

Node: 20000

Compare the relative IMPORTANCE with respect to: TRAFFIC < GOAL

Circle one number per row below using the scale:

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	LOCAL TR	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	TRANSIT
2	LOCAL TR	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	TRANTIME
3	TRANSIT	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	TRANTIME

Abbreviation	Definition
LOCAL TR	Local traffic (between both sidec of the Strait)
TRANSIT	Transit traffic at Istanbul Strait
TRANTIME	Time of the transit (e.g. day or night)

Figure M.3. The AHP model questionnaire for estimating the likelihood of a maritime accident (traffic conditions)

Which of the following environmental condition is contributing more to the realization of a maritime accident (or probability of accident) in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

To determine/measure the likelihood of each maritime accident

Node: 40000

Compare the relative IMPORTANCE with respect to: ENVCOND < GOAL

Circle one number per row below using the scale:

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	WIND SPD	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	VISIBILI
2	WIND SPD	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CURRENT
3	WIND SPD	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PRECIPTI
4	WIND SPD	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MORPCOND
5	VISIBILI	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CURRENT
6	VISIBILI	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PRECIPTI
7	VISIBILI	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MORPCOND
8	CURRENT	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PRECIPTI
9	CURRENT	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MORPCOND
10	PRECIPTI	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MORPCOND

Abbreviation	Definition
WIND SPD	Wind speed at Istanbul Strait
VISIBILI	Visibility range at Istanbul Strait
CURRENT	Current speed
PRECIPTI	Precipitation (rain, snow etc.)
MORPCOND	Morphological Conditions at the Strait

Figure M.4. The AHP model questionnaire for estimating the likelihood of a maritime accident (environmental conditions)

Which of the following environmental condition is contributing more to the realization of a maritime accident (or probability of accident) in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

To determine/measure the likelihood of each maritime accident

Node: 30000

Compare the relative IMPORTANCE with respect to: ORGFACTO < GOAL

Circle one number per row below using the scale:

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	CREWKNOW	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PILOTAGE
2	CREWKNOW	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	VTS
3	CREWKNOW	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	NAV AIDS
4	CREWKNOW	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CARGOHAN
5	CREWKNOW	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	REGVIOLA
6	PILOTAGE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	VTS
7	PILOTAGE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	NAV AIDS
8	PILOTAGE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CARGOHAN
9	PILOTAGE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	REGVIOLA
10	VTS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	NAV AIDS
11	VTS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CARGOHAN
12	VTS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	REGVIOLA
13	NAV AIDS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CARGOHAN
14	NAV AIDS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	REGVIOLA
15	CARGOHAN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	REGVIOLA

Abbreviation	Definition
CREWKNOW	Crew knowledge and experience regarding Istanbul Strait
PILOTAGE	Employment of the maritime pilotage service
VTS	VTS Service
NAV AIDS	The availability of the navigational aids
CARGOHAN	Cargo handling mistakes that cause an accident
REGVIOLA	Violation of the enforced regulation

Figure M.5. The AHP model questionnaire for estimating the likelihood of a maritime accident (organizational factors)

Which of the following factor groups affect more to the realization of a consequence after the occurrence of a maritime accident in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

Factors affecting the consequence of an accident

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL <

Circle one number per row below using the scale:
1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	CARGO_TY	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LENGTH
2	CARGO_TY	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LOCATION
3	LENGTH	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LOCATION

Abbreviation	Definition
CARGO_TY	Cargo and the type of the vessel involved in an accident
LENGTH	Length of the vessel invloved in an accident
LOCATION	Location of the accident

Figure M.6. The AHP model questionnaire for estimating the situational factors' values of the probabilistic consequence model (at first level)

Which of the following vessel type (and its cargo status) affects more to the realization of a consequence after the occurrence of a maritime accident in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

Factors affecting the consequence of an accident

Node: 10000

Compare the relative IMPORTANCE with respect to: CARGO_TY < GOAL

Circle one number per row below using the scale:
1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	FULLTNK	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	EMPTNK
2	FULLTNK	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CARGO
3	FULLTNK	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PASSENGE
4	EMPTNK	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CARGO
5	EMPTNK	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PASSENGE
6	CARGO	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PASSENGE

Abbreviation	Definition
FULLTNK	Fully loaded tanker
EMPTNK	Empty tanker
CARGO	Cargo ships
PASSENGE	Passenger ships

Figure M.7. The AHP model questionnaire for estimating the situational factors' values of the probabilistic consequence model (vessel type)

Which of the following vessel length category affects more to the realization of a consequence after the occurrence of a maritime accident in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

Factors affecting the consequence of an accident

Node: 20000

Compare the relative IMPORTANCE with respect to: LENGTH < GOAL

Circle one number per row below using the scale:
1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	LNGTH1	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LNGTH2
2	LNGTH1	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LNGTH3
3	LNGTH1	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LNGTH4
4	LNGTH2	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LNGTH3
5	LNGTH2	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LNGTH4
6	LNGTH3	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	LNGTH4

Abbreviation	Definition
LNGTH1	0-50 mt
LNGTH2	50-150 mt
LNGTH3	150-250 mt
LNGTH4	More than 250 mt

Figure M.8. The AHP model questionnaire for estimating the situational factors' values of the probabilistic consequence model (vessel length)

Which of the following region in the Istanbul Strait (See Figure) affects more to the realization of a consequence after the occurrence of a maritime accident in the Istanbul Strait than the other? Scale the dominance of one over other from 1 to 9.

Factors affecting the consequence of an accident

Node: 30000

Compare the relative IMPORTANCE with respect to: LOCATION < GOAL

Circle one number per row below using the scale:
1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	ZONE1	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ZONE2
2	ZONE1	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ZONE3
3	ZONE2	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ZONE3

Abbreviation	Definition
ZONE1	First zone in the picture
ZONE2	Second zone in the picture
ZONE3	Third zone in the picture

Figure M.9. The AHP model questionnaire for estimating the situational factors' values of the probabilistic consequence model (accident location)

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