ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

RISK ANALYSIS FOR MARINE ACCIDENTS ON THE ISTANBUL STRAIT BY UTILIZING FUZZY-ANALYTIC HIERARCHY PROCESS

M.Sc. THESIS

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Department of Maritime Transportation Engineering

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Thesis Advisor: Asst. Prof. Dr. Cemil YURTÖREN

JANUARY 2015

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

BULANIK-ANALİTİK HİYERARŞİ SÜRECİNİ KULLANARAK İSTANBUL BOĞAZI'NDA DENİZ KAZALARI RİSK ANALİZİ

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OCAK 2015

İbrahim KILIÇ, a **M.Sc.** student of ITU **Institute of Graduate School of Science Engineering and Technology** student ID 512121008, successfully defended the **thesis** entitled "**RISK ANALYSIS FOR MARINE ACCIDENTS ON THE ISTANBUL STRAIT BY UTILIZING FUZZY-ANALYTIC HIERARCHY PROCESS**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 15 December 2015
Date of Defense : 22 January 2015

To my family,

FOREWORD

The Istanbul Strait is situated between the Black Sea and the Sea of Marmara. The Black Sea is an inland sea so the Istanbul Strait is the only door which is opened to international waters for vessels which transport on the Black Sea. The Strait is one of the most intensive waterways, in addition to being the most narrowest international waterway in the whole world. Hence, several very serious collisions have occured on the Istanbul Strait. Owing to the fact that Sea of Marmara is a inland sea and the Istanbul Strait separates the city of Istanbul into two parts where approximately 15 million people live, it is required to do collision risk analysis for the Istanbul Strait. Due to the fact that sea casualties and their reasons are *sui generis* and comprehensive structures, human decision and judgement skill is also required for good risk assessment. In this study, therefore, the Fuzzy-Analitic Hierarchy Process (AHP) is used for risk analysis.

This study was finished successfully and it will not only assist in preventing collisions but also guide experts and academicians for future studies by its method and clarity.

I consider it is my duty to thank my advisor Asst. Prof. Dr. Cemil Yurtören and Phd Bekir Şahin for their gentle contributions.

January 2015

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ABBREVIATIONS

F-AHP : Fuzzy Analytic Hierarchy Process
VTS : Vessel Traffic Service
AHP : Analytic Hierarchy Process
SWOT : Strengths, Weaknesses, Opportunities, Threats
RADAR : Radio Detecting and Ranging
COLREGS : International Regulations for Preventing Collisions at Sea
GMDSS : Global Maritime Distress Safety System
MCDM : Multiple Criteria Decision Making
CI : Consistency Index
TFN : Triangular Fuzzy Number
CCI : Centric Consistency Index
GCI : Geometric Consistency Index
IMO : International Maritime Organization
POM : Princeton Ocean Model
GNOME : General NOAA (National Oceanic and Atmospheric Administration) Oil Modeling Environment

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RISK ANALYSIS FOR MARINE ACCIDENTS ON THE ISTANBUL STRAIT BY UTILIZING FUZZY-ANALYTIC HIERARCHY PROCESS

SUMMARY

Turkish Straits consist of the Istanbul Strait, Canakkale Strait and Sea of Marmara and is the only door which is opened to international waters for vessels which transport on the Black Sea. More than 90 percent of all products and raw materials are transported by maritime transportation and the Turkish Straits is very significant for international maritime transportation. The Strait has also a niche significance for the Black Sea bordering states (Ukraine, Russia, Bulgaria, Romania and Georgia). The strait is 30 km and it is the narrowest international waterway, which connects the Black Sea and Sea of Marmara thereby Canakkale, Aegean Sea and Mediterranean Sea. Its geographical position and formation, heavy population, historical buildings around it, strong currents and winds are some risks for sea transportation in this strait. There always have the possibility of unpredictable catastrophes such as a collision, grounding, explosion and etc. in this region. Reflections of such unwanted incidents might be very costly for economical, political, environmental and safety concerns. In the past, extremely serious maritime accidents and explosions have occurred on the Istanbul Strait. However, there are limited academic studies regarding to analytical and systematical risk identification and determination of risk levels. In this study, pre-defined risk factors of the Istanbul Strait are explained and numerical weights of each risk are determined by using Fuzzy Analytical Hierarchy Process (F-AHP) method after conducting an expert consultation. The novelty of this study is that we consider the expert consultations by asking pilots, academicians and VTS operators of the Istanbul Strait who know this region better than anyone else. F-AHP method including the expert prioritization and consistency check is used to analyze the data. The results and discussion are expected to guide the representatives minimizing the probable risks before they occur.

BULANIK-ANALİTİK HİYERARŞİ SÜRECİNİ KULLANARAK İSTANBUL BOĞAZI'NDA DENİZ KAZALARI RİSK ANALİZİ

ÖZET

Türk Boğazları, İstanbul ve Çanakkale Boğazları ile Marmara Denizi'ni içine alan su yolunu ifade etmektedir. Asya ve Avrupa kıtaları arasındaki doğal sınırlardan biridir. Türk Boğazları'nın jeopolitik konumu sebebiyle, tarihten bu yana pek çok savaş, anlaşma ve dahi ülke politikalarında Türk Boğazları'nın odak noktası olduğunu görmekteyiz. Bir iç deniz olan Karadeniz'in uluslararası denizlere ve okyanuslara açılan tek kapısıdır. Türk Boğazları içerisinde yer alan İstanbul Boğazı ise, tarihten bu yana çeşitli uygarlıklara başkentlik yapmış ve Türkiye Cumhuriyeti devletinin ekonomik ve nüfus açısından en büyük şehri olan İstanbul'u ikiye bölen uluslararası bir suyoludur. Deniz taşımacılığının tüm ulaştırma sistemleri içerisinde uluslararası taşımacılıkta birinci sırada olduğu günümüz dünyasında, Karadeniz ülkelerinin uluslararası deniz taşımacılığında yegane geçidi olan İstanbul Boğazı, özellikle Karadeniz'i çevreleyen ülkeler olmak üzere, tüm dünya ülkeleri tarafından sıklıkla kullanılmaktadır ve bu sebeple yüksek ticari gemi yoğunluğuna sahiptir. Ayrıca, yaklaşık 15 milyon kişinin yaşadığı İstanbul şehrinin, Anadolu ve Avrupa yakaları arasında taşımacılık yapan yerel trafik gemileri de bulunmaktadır. Üstelik, Boğaz üzerinde balıkçı barınakları da bulunmakta ve aktif olarak balıkçılık da yapılmaktadır. Bütün bunlara, İstanbul'un tarihi eserleri sebebiyle yerli ve yabancı turistler tarafından gözde turizm mekanlarından olması, çeşitli Boğaz turları yapılması ve cruise gemilerinin Boğaz'a girmesi eklenince, İstanbul Boğaz'ı trafiğinde karışıklık ve çeşitlilik görülmektedir. İstanbul Boğazı trafik yoğunluğu bölge ülkelerinin ekonomisinin gelişmesiyle her geçen zamanda ciddi seviyede artmaktadır.

İstanbul Boğazı'nda, Karadeniz ve Marmara Denizi arasındaki su seviye farkından kaynaklanan güçlü bir yüzey akıntısı mevcuttur. Ayrıca Boğaz'ın hakim rüzgarlara

bağlı olarak ortaya çıkan kendine özgü Orkoz akıntısı da bulunmaktadır. Bu duruma İstanbul Boğazı'ndaki yüksek açılı rota değişimli manevralarda eklenince, Boğaz daha da riskli bir hale gelmektedir. Geçmiş yıllarda İstanbul Boğazı'nda pek çok ciddi kaza meydana gelmiş, pek çok insan yaşamını yitirmiş ve ciddi seviyede deniz kirliliği görülmüştür. Yukarıda anlatılan tüm sebeplerden ötürü İstanbul Boğazı'nda deniz kazası risk analizi yapmak gerekli görülmüştür.

Deniz kazalarına sebep olan insan kaynaklı, gemi kaynaklı ve çevre kaynaklı pek çok etken bulunmaktadır. Üstelik bu etkenler arasında yüksek derecede ilişki (korelasyon) görülmektedir. Mesela, deniz kazalarına sebep olan etkenlerden biri olan akıntıyı ele alacak olursak, akıntının deniz kazalarına sebebiyet veren başka etkenlerden (hakim rüzgarlar, sıcaklık farkları gibi) yüksek oranda etkilendiği görülecektir. Bu sebeple, deniz kazalarına sebep olan etkenler için, sadece sayısal olasılık hesaplamalarının yüksek korelasyon sebebiyle sağlıklı bilgiler veremeyeceği söylenebilir. Bu etkenler yahut kriterler arasındaki korelasyonu kaldırmanın en iyi yolu, insan mantığına ve muhakeme etme yeteneğine başvurmak olacaktır. Bunun için de uygun metod olarak Analitik Hiyerarşi Süreci seçilmiştir. Fakat Analitik Hiyerarşi Süreci anket sisteminde, kesin değerler ile kriterler arası karşılaştırma matrisi kurulması gerekmektedir. Bu ise insan mantığına çok uygun değildir. Karşılaştırma matrisi birimlerini çok riskli, çok daha riskli ve mutlak riskli gibi her birinin üçgensel bir fuzzy sayısı karşılığı olan dilsel değerlerden oluşturmak en iyi çözüm yolu olarak düşünülmüş ve kısacası, metod olarak Bulanık Analitik Hiyerarşi Süreci seçilmiştir.

İstanbul Boğazı'nın kendine özgü yapısı ve bu yapısının tüm yönleri ile kavranmasının yüksek deneyim gerektirdiği göz önünde bulundurulmuş, uzmanlık seviyesi yüksek 10 uzmana anket yapılmıştır. Anketlerden elde edilen değerler Bulanık-Analitik Hiyerarşi Süreci'nden geçirilmiş ve İstanbul Boğazı'nda deniz kazalarına sebebiyet veren çeşitli ana kriter ve alt kriterlerin her birinin ağırlıkları bulunmuştur.

Bu çalışmanın amacı, İstanbul Boğazı'nda deniz kazalarına sebep olan bir veya birkaç kriterin etkilerini değerlendirmek değil; tüm risk kriterlerinin ağırlıklarını bularak İstanbul Boğazı'nda deniz kaza risklerini bütünüyle göstermek ve doğru değerlendirme yapılabilmesini sağlamaktadır. Boğazı çok sayıda risk kriteri açısından değerlendirmesi, bu çalışmayı daha önceki bir çok çalışmadan farklı kılmaktadır. Ayrıca, İstanbul Boğazı'nda deniz kazalarını bütünüyle analiz etmesi itibariyle, bundan sonraki birçok çalışmaya öncü bir kaynak ve çeşitli otoritelere İstanbul Boğazı'nda gemi kaza risklerini azaltmada iyi bir rehber olacaktır.

1. INTRODUCTION

Turkish Straits consist of the Istanbul Strait, the Sea of Marmara and the Canakkale Strait. They are a natural boundary between the continents of Europe and Asia. The Istanbul Strait is situated between the Black Sea and the Sea of Marmara. It has both strategic and economics importance due to its location. As part of the only passage between the Black Sea and the Mediterranean, the Istanbul Strait is the only door which is opened to international waters for vessels which transport on the Black Sea. More than 90 percent [1] of all products and raw materials are transported by maritime transportation and the Strait is very significant for international maritime transportation too. Therefore, the Strait has also a niche significance for the Black Sea bordering states (Ukraine, Russia, Bulgaria, Romania and Georgia). These countries export and import their products to other countries by maritime transportation and via the Istanbul Strait. Due to its location and significance of maritime transportation, there is traffic intensive in the Strait.

Figure 1.1 : The Istanbul Strait satellite photo.

The Istanbul Strait has a dense of marine traffic. The traffic density on the Istanbul Strait is three times more than The Suez Canal and four times more than the Panama Canal [2]. In 2013, the number of the vessels using the Strait for passage are 46.532 and gross tonnages of these vessels are 551.775.136 [3]. Moreover, there is intensive local traffic in the Strait.

The Istanbul Strait separates the city of Istanbul into two parts, where approximately 15 million people live. Everyday, approximately 265,000 people are transported to one of two parts from another part by local traffic vessels. There are also ports, fishing shelters, marinas and various barges all along the Strait. All these cause rise of the traffic density and traffic congestion in the Istanbul Strait. Furthermore, the touristic tours are made regularly on the Istanbul Strait too.

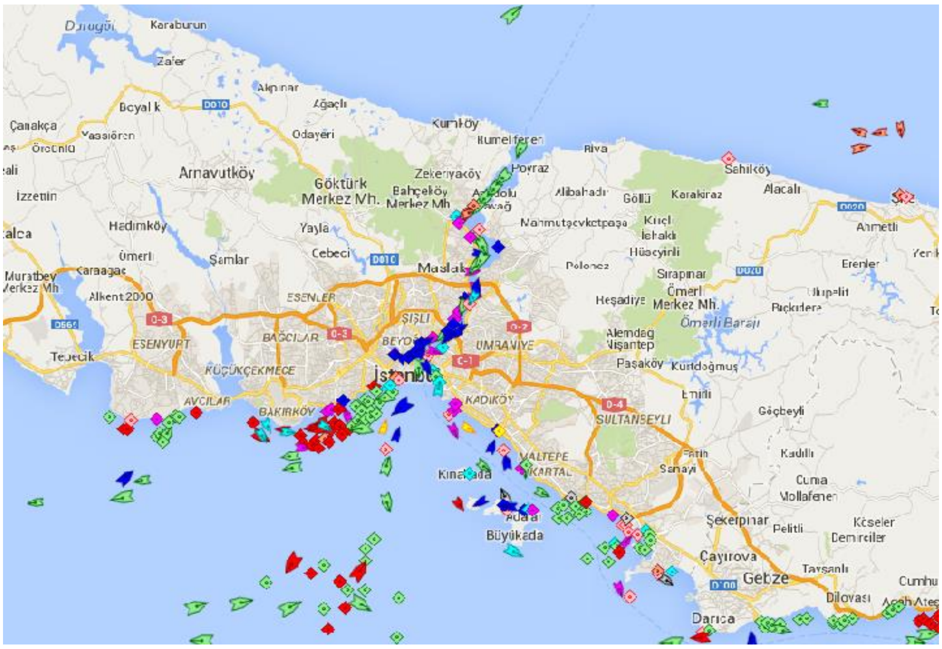

Figure1.2: Marine Traffic in the Istanbul Strait [4].

Istanbul is one of the most famous tourism cities of the world and it became the European Capital of Culture in 2010. There are thousands of historical places in Istanbul. These historical places such as Dolmabahce Palace, Beylerbeyi Palace, Ortakoy Mosque, Ciragan Palace are also situated on the Istanbul Strait coastline.

Because of its history and natural structure and the touristic strait tours are made on the Strait and increase traffic density.

Figure 1.3. : The Istanbul Strait, Ortakoy Mosque

The Istanbul Strait is 17 nautical miles, the narrowest international waterway. The narrowest distance of the Strait is 698 meters. Furthermore it has a curved shape and there are sharp turns. Above all the Strait has a distinctive and a very strong current system due to sea level and salinity differences between the Black Sea and Sea of Marmara. All of these have caused a lot of collision.

In the past, extremely serious maritime accidents and explosions have occurred in the Istanbul Strait. For instance, the collision occurred between M/Tanker Zoranic, M/Tanker World Harmony in 1960. 20 people lost their lives and 22.000 tonnes of oil were spilled into the sea. As another collision example, M/Tanker Independenta and M/Tanker Evriyali collided in 1979, 43 people died and 95.000 tonnes of oil were spilled into the sea [5]. Despite of these serious collisions, the number of commercial vessels dense has rapidly increased, due to the fact that the global economics have increased recently.

Russia had increased oil production between the years 2001-2007 thus became the second most oil-producer after Saudi Arabia [6]. Commerce of not only Russia but also other the Black sea bordering states increased at the same time. As a result of all these, the Istanbul Strait become more risky area than before.

For all reasons given above, it is accepted that the Istanbul Strait is very risky area and it is one of the most difficult-to-navigate waterways in the world. a comprehensive risk analysis for the Istanbul Strait is very important for the area of maritime transportation.

1.1. The Risk Analysis For The Istanbul Strait

A comprehensive risk analysis requires adequate criteria and correct method. There are so many criteria in maritime risk analysis and also there might be the high correlation between criteria.

In order to explain high correlation,

As a regression equation [7], the risk is:

$$\mathbf{Y = e + a_1.X_1 + a_2.X_2 + a_3.X_3 + \ldots + a_i.X_i + \ldots + a_n.X_n} \qquad (1)$$

Y = dependent variable, risk value

X_i = independent variables, i = 1,2,3,…,n

e = fixed number, a_i = the effect coefficient of i th criterion

For instance, Let's assume,

X_1 is the value of current

X_2 is the value of wind

X_3 is season

X_2 (wind) an X_3 (season) can effect the strength of current. Like that, in maritime risk analysis, there might be strong correlation values between risk criteria (X_1, X_2, X_3, … X_n). It can be claimed that the strong correlation values in maritime risk analysis between risk criteria is a remarkable problem. For the right risk analysis, it is required to eliminate the correlation problem. In this study, the human judgement skills are used to cope with the correlation problem. A questionnaire is conducted to experts who work as a pilot or VTS operator or academician who know this region better than anyone else.

In this study, pre-defined risk factors of the Istanbul Strait are explained and numerical weights of each risk are determined by using Fuzzy-Analytical Hierarchy Process (F-AHP) method after conducting an expert consultation. The experts make hierarchical ranking between criteria and it is assessed by AHP. Triangular fuzzy numbers are utilized due to the fact that the hierarchical ranking between criteria is increasingly difficult. The human thinking system is combined with risk analysis thanks to Fuzzy–Analitic Hierarchy Process Method (F-AHP), so that the correlation is eliminated and the right risk analysis for the Istanbul Strait is done.

The study does not indicate risk scores of only few criteria which are more important than the others. It aims to indicate risk scores for all or many criteria. So that this study risk represents a comprehensive risk map for many criteria in the Istanbul Strait and it differs from a lot of previous studies. This study provides researchers and authorities to assess and to eliminate the reasons of casualties in the Istanbul Strait correctly. Moreover, this study will become one of prior sources for next researchers and provide a sophisticated guide in descreasing accidents for the Istanbul Strait.

1.2. Literature Review

Maritime risk assessment studies are categorized in three main groups. Firstly, they are categorized in two groups in terms of used methods: risk analysis methods which are based on either probability or simulation frame. Secondly, risk assessment studies are investigated in two groups according to the number of risk factors: Some studies present effects of several risk factors in detail, other studies present impact level of all risk factors. Finally, they are also categorized in two groups according to the sources of data: data which are from experts or from historical statistics.

1.2.1. Literature review on maritime risk analysis

There are many studies in literature about maritime risk analysis, some of which are given below. They have contributed to the safety of the maritime transportation.

Harrald et al. [8] focuses on the modeling of human error related accident events. The risk analysis is made for maritime oil transportation in Prince William Sound, Alaska. Human error frame and the conditional probabilities are obtained from system experts who are tanker masters, mates, engineers, and state pilots via a dynamic simulation. This study aims at reducing human error. In the result of this study, it is proposed interventions at reducing human and organizational error.

Van Dorp et al. [9] focuses on the Washington State Ferries risk assessment by using a modeling approach combines system simulation, data and expert judgement. This model is used to estimate the contribution of each risk factors to accident risk. In the result of this study, potential risk reduction measures are evaluated and detailed risk management recommendations are maked.

Trucco et al. [10] uses the Bayesian Belief Network approach to integrate human factor into risk analysis. The Bayesian Belief Network is developed to model the maritime transportation, by taking into account its different maritime actors such as ship owner, ship-yard. It focuses on a collision in open sea. In the result of this study, configuration is suggested to reduce accident probability during the operation of the high speed craft.

Kujala et al. [11] analyses the safety of the marine traffic in the Gulf of Finland. In this study, theoretical modelling is used and this model is based on probabilistic risk analysis and probability safety analysis. The risk of ship collision is studied by theoretical modelling thanks to detail accident statistics for the last 10 years. Finally, the results of theoretical models are compared with actual statistics. This paper presents that grounding is the dominant accident type, the highest risks for collision which the passenger ship traffic causes.

Montewka et al. [12] presents a new approach for the geometrical probability on collision estimation. The geometrical model takes into account registered vessel traffic data and advanced statistical and optimisation methods (Monte Carlo and genetic algorithms) are used. In this model, three main types of vessel encounters are analized: head-on, overtaking and crossing. The results which are obtained from this model, are controlled by using data for maritime traffic in the Gulf of Finland and agreement between registered data and results are quite good.

1.2.2. Literature review on risk analysis for the Istanbul Strait

Sarioz et al. [13] presents a real-time simulation study investigating the manoeuvring performance of large tankers in the Istanbul Strait. Its results show that when realistic environmental conditions are taken into account, the size of ships that can navigate safely with the traffic separation lanes is limited.

Or and Kahraman [14] presents possible factors contributing to collisions in the Istanbul Strait via Bayesian analysis and also simulation modelling. Firstly, the Bayesian method is used to estimate conditional maritime accident probabilities of the Istanbul Strait. Then, this accident probabilities are combined with the geographical characteristics of the Istanbul Strait and traffic regulations by utilizing the simulation model. The result of simulation indicates impacts of local traffic density, traffic arrivals and meteorological conditions.

The simulation of the Istanbul Strait is done under traffic conditions by Kose et al. [15] and the effects of probable increase in marine traffic due to new oil pipelines, are discussed. The model is developed to simulate the traffic in the Istanbul Strait, investigates behaviour of traffic for the different scenarios, different ship arrival and waiting times, gives information about future traffic for different situations. In the result of this study, it is claimed that new pipelines of Russia will increase the traffic at the Turkish Straits.

In Otay and Ozkan [16], a physics based mathematical model is developed. Thus, the random maritime traffic through the Istanbul Strait is simulated. This model estimates the probability distribution of vessel accidents by using the geographical characteristics of the Istanbul Strait. The expected number of accidents in the different sections of the Istanbul Strait is shown in the risk maps.

Akten [17] considers some factors which cause shipping casualties in the Istanbul Strait by using statistic and historical data. This study shows that the major casualty types are grounding and stranding. Furthermore, in this study, it is showed that the major risk factors are current, sharp turn and darkness. But there is insufficient information about how the major risk factors were obtained.

Yurtoren and Aydogdu [18] investigates navigational risks of local traffic. This study exposes to transit passing vessels through Istanbul Strait. Risk analysis was applied at the south entrance area of the Istanbul Strait, where the local traffic is the most congested. Ship handling simulator is used for risk area and the simulation can be integrated with the effects of topographic features and meteorological conditions. The results of the simulation are analyzed that using the Environmental Stress Model provides an opportunity to analyze vessel traffic risks quantitatively. In the result of this study, effects of the local traffic and the most dangerous spots in the Istanbul Strait are presented.

Uluscu et al. [19] develops a mathematical risk model which is based on probabilistic arguments regarding situations, accidents, consequences and historical data. It is presented that local traffic density and pilotage turned out to be two main factors affecting the risks at the Strait of Istanbul. As the results of this study, scheduling changes that allow more vessels into the Strait will increase risks to extreme levels. Contrarily, scheduling policy changes that are opted to reduce risks may cause major increases in average vessel waiting times.

In Arslan and Turan [20], factors which affect marine casualties examine and determine by using SWOT (strengths, weaknesses, opportunities and threats) analysis method. After that, weights of the factors are determined with the AHP (analytic hierarchy process) method. By SWOT-AHP approach, strategic action plans are developed for minimizing shipping casualties at the Strait of Istanbul, taking into account the weighting factors and previously marine accidents. In the result of this study, several factors such as human-related and meteorological factors cause accidents despite latest navigational technologies and established VTS or pilotage systems, at the Strait of Istanbul.

Table 1.1: Literature review.

ARTICLE	STUDY TYPE	METHOD IS BASED ON	AREA	THE NUMBER OF FACTORS	SOURCE OF DATA
Harrald et al. (1998) [8]	Risk Assessment	Probability	Alaska	Human Factor	Experts
Akhtar And Utne (2014) [21]	Risk Assessment	Probability (Bayesian)	General	Human Fatique	Historical Data
Montewka et al. (2013) [22]	Method	Probability (Bayesian)	General	All Collision Factors	Historical Data
Van Dorp et al. (2001) [9]	Risk Assessment	Simulation	Washington State Ferries	All Factors	Historical Data And Experts
Trucco et al. (2008) [10]	Method	Probability (Bayesian)	General	Human Factor	Experts
Kujala et al. (2008) [11]	Risk Assessment	Probability	Gulf Of Finland	All Factors	Historical Data
Montewka et all. (2010) [12]	Method	Geometric Modelling (Collision Probability)	General	NA	Vessel Particulars And Statistics Of Area
PAWSA (US COASTGUARD) [23]	Risk Assessment Method	Probability (AHP)	General	All Factors	Experts
Merrick and Van Dorp (2006) [24]	Risk Assessment	Probability (Bayesian)	San Francisco Bay, Washington Ferries	All Factors	Historical Data And Experts

Kuroda et al. (1982) [25]	Risk Assessment	Probability	Japan Channels and Straits	Some Factors	Area Structure And Statistical Data
Amrozowicz (1996) [26], Amrozowicz et.al. (1997) [27]	Risk Assessment	Probability (Several methods)	General	All Factors	Statistical Data
Sarioz et al. (1999) [13]	Risk Assessment	Simulation	The Istanbul Strait	Some Factors	Historical Data And Experts
Or and Kahraman (2002) [14]	Risk Assessment	Probability (Bayesian)	The Istanbul Strait	Some Factors	Statistical Data
Kose et al. (2003) [15]	Risk Assessment	Simulation	The Istanbul Strait	Some Factors	Different Senarios
Otay and Ozkan (2003) [16]	Risk Assessment	Simulation	The Istanbul Strait	Traffic Simulation	Statistical Data
Akten (2004) [17]	Risk Assessment	Statistical	The Istanbul Strait	Some Factors	Historical Data
Yurtoren and Aydogdu (2009) [18]	Risk Assessment	Simulation (Environmental Stress Model)	The Istanbul Strait	The Local Traffic	Statistical Data
Uluscu et al. (2009) [19]	Risk Assessment	Statistical	The Istanbul Strait	Some Factors	Historical Data
Arslan and Turan (2009) [20]	Risk Assessment	Probability (SWOT-AHP)	The Istanbul Strait	All Factors	Experts

1.2.3. The theses about the Istanbul Strait

Turker (2008) [28] assesses risk for the Istanbul Strait. The risk model of this thesis consists of the econometric, probabilistic consequence and Analytic Hierarchy Process (AHP) models. The econometric model predicts the conditional probability of an accident for various factors in the Istanbul Strait. The probabilistic consequence model estimates the probability of each type of the accident consequences after the occurrence of an accident. The AHP model indicates relations of other factors by experts' views. In the result of this thesis, there are various recommendations in order to limit the effects of the factors.

In Viran (2014) [29], a risk map for the southern entrance of the Istanbul Strait which is known with an intensive traffic, is formed by using Environmental Stress Model. Automatic Identification System data are used in this model.

In Talay (2012) [30], a risk analysis for factors which cause the accidents in the Haydarpaşa Port, is made. The Fault Tree Analysis metod is utilized for analysis.

Bayar (2010) [31] consists of a study over the marine accidents which were occured in the Istanbul Strait. The F-AHP method is used to determine the factors which causes accidents in the Istanbul Strait. A hierarchical ranking is also made between accidents types. All these are assessed via the FMEA (Failure Mode and Effect Analysis). In the result of this study, the problem types is presented clearly and the various aspects for solving this problems are suggested.

In Kececi (2010) [32], an analysis over the vessel length factor for the Istanbul Strait is made by utilizing AHP metod. According to the result of this study, all vessels which have length to 200 from 151, are defined as a large vessel.

In Aydoğdu (2006) [33] and Atasoy (2008) [34], ES Model (Environmental Stress Model) is used and the most risky areas for the south region of the Istanbul Strait are identified. In the result, the various recommendations and some routes are proposed.

ECE (2005) [35] uses various statistical methods for analysing the accidents which were occurred in the Istanbul Strait. This study presents analysis, assessment and accident maps for different accident types, reasons, areas and different years, months and hours. Ther are also some suggestions in this study to decrease the effects of various factors.

In Başar (2003) [36] analysis oil spreading for the possible marine accidents in the Istanbul Strait. POM (Princeton Ocean Model) is utilized to analysis the current of the Istanbul Strait and then, oil spreading is analysed by a simulation model based on GNOME (General NOAA Oil Modeling Environment) model.

The next chapter consists of the structure of the Istanbul Strait such as currents, restricted visibility conditions and geographic structure, the navigation challenges and some important marine accidents occurred in the Istanbul Strait. After this chapter, that main and sub-criteria consist which accident factors is explained. Then, methodology will be given for AHP and F-AHP. Finally, the results of analysis and conclusion is given.

2. THE CHARACTERISTICS OF THE ISTANBUL STRAIT

It is the information about the Istanbul Strait is based on Istanbul Port Authority[37] and Undersecretariat for Maritime Affairs[38] reports.

2.1. Structure of the Istanbul Strait

The fundamental characteristic of the strait is being one of the narrowest waterways in the world. The distance from the separation line is approximately 17 nautical miles (nm). Coast length is 19 nm in Anatolian side and 30 nm in European side because of its curved structure. In the north, the widest place of the Strait is between Anatolian and Turkeli lighthouses with being 3600 meters. Similarly, in the south, the widest place of the Strait is between Ahirkapi and Inciburnu with being 3220 meters. The narrowest place of the strait is 698 meters and it is between Anadoluhisari and Rumeli hisari. Accordingly, the entrances of both sides are wider than the middle side.

2.2. Depth of the Istanbul Strait

The depth of the Strait is varying between 30 and 110 meters alongside the strait. The deepest point is 110 meters at the Kandilli offshore. However, the depth is generally between 30 to 60 meters. Besides, there are even some places less than 30 meters.

2.3. Islands at the Istanbul Strait

There is an island close to the south entrance of the Istanbul strait called Kizkulesi which is 250 meters to the Salacak offshore. Rocks and a bank surround the island. The bank is connected by shallowness to the coast at east of the island. The second island is Kurucesme lighthouse which is at the 880 meter north of Defterdar Cape. The depth over the banks is less than 10 m, its length is 400 m and width is 120 m.

Another island is located at the center of Bebek Bay and there exists Bebek lighthouse. Aprroximate length of the Bebek bank is 450 m and width is 120 m. Water depth of over the bank is varying between 2.7 and 10 m. The distance to the land is 165 m. At the Rumelikavagi offshore, there is Dikilikaya island which has approximately 180 m length and 120 m width.

2.4. Banks at the Istanbul Strait

In the strait, other than Kurucesme, Dimi, Bebek and Dikilikaya banks, there are many other dangerous banks which are called as islands because of their structures alike islands and isles.

The water depth for the Sarayburnu banks is between 1 to 10 m. Ortakoy bank reaches to the 80 m offshore of the Ortakoy Burnu. Yenikoy bank (Koybasi sigligi) reaches through Istinye and Yenikoy Cape. There has 350 m more extension through northwest after Yenikoy Cape. Distance to land is 100 to 350 m. Buyukliman bank reaches through Garipce Cape after Karatas Cape as a bow. The bank is 250 m far from the land and the water depth varies 3 to 5 m.

The first bank from the south to north of the Anatolian-side coasts is Kizkulesi Bank. To the upwards, there exists Goksu and Anadoluhisari Bank. Macar bank is 400 m away to north east of Macar Cape which has 270 m length and 120 m width with 3.7-1.5 m water depth. Moreover, there exist Poyraz Bank 700 m away to Poyrakoy, Incirkoy bank 480 m away to Incirkoy, Pasabahce bank 190 m away to Pasabahce, Baltalimani bank 140 m away to Baltalimani brook and Sariyer bank 120 m away to Mezar Cape.

2.5. Bays

Starting from the south, there exist a recess in Dolmabahce, Cenkelkoy bay and Pasabahce bay. However, the numbers of bays and capes are not similar for both sides of strait. The bays in the strait are refuge for fishing vessels and private yatchs. There are approximately 1653 vessels in diverse bays and ports of Anatolian side and 1781 vessels in European Side and there are total 3434 vessels in the Istanbul Strait. The majority of the vessels are fishing vessels and they commonly take place at the north of the Strait. The general locations of these vessels; 74 vessels around Rumelikavagi, 30 are around Sariyer, 20 are around Istinye in the European Side. 91

vessels locate around Anadolukavagi, 8 are around Yalikoy and 27 vessels are around Anadoluhisari in the Anatolian Side.

2.6. Climate Characteristics of the Istanbul Strait

The prevailing climate is Mediterranean. In the summers, it is dry and hot because of the prevailing tropical air mass. However, drought is not as strong as the south and west of Turkey. Duration is shorter comparing to those regions. Winters are warm and cold. There might be even observed snowy and icy weather due to polar air mass.

It is a dynamic environment in terms of circulation. The prevailing air motion is towards northeast-southwest. It occurs alongside and parallel to the Istanbul Strait axis. The circulation reaches its the strongest situation through the strait. Moreover, topography affects the circulation in respect to direction and force and there occur some deviations through the valleys.

2.7. Yearly Wind Conditions of the Istanbul Strait

Storms in the Istanbul Strait occur more on January than other months. Storms start early September and then the number of occurrences increases. Water motions and currents enormously affect the navigation.

2.8. Fog and Restricted Visibility

Precipitations affect the navigation in the strait. For example, since there is a dense snowfall, navigation safety decreases because of low visibility. Fog is observed mostly in March. It is rare in summer months. The best visibility is evening times of November, December and January, and for other months noon is the best time for visibility. There is always a possibility of being off-the-record that the occurrence of fog in low level fog because of 114 m higher position of Kandilli observatory station.

2.9. Current System of the Istanbul Strait

Reasons of current:

- heat differences
- entrance of new water mass
- the motion of water due to tides
- it occurs when the wave length is higher than the sea depth.

The currents observed in the Istanbul Strait can be categorized into four items.

1. Surface current
2. Deep current
3. Counter current
4. Orkoz current

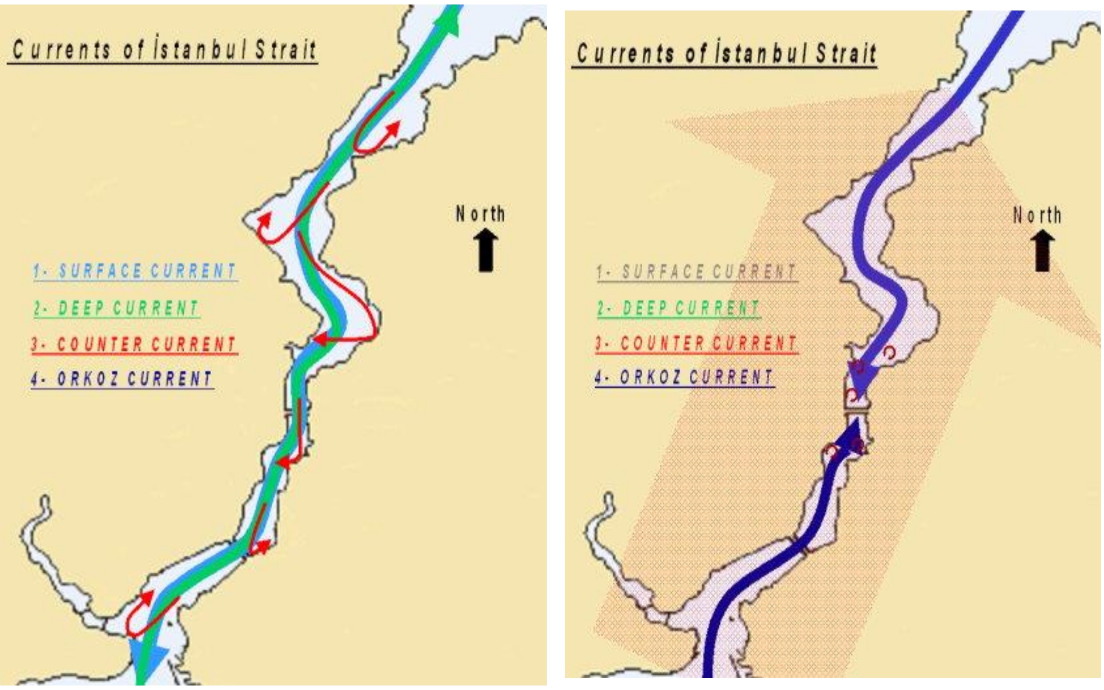

Figure 2.1 : The currents of the Istanbul Strait

The double current system (bottom and top) which move opposite to each other is observed in the region called as Turkish Straits. The less salty waters move from top of Marmara Sea via Canakkale Strait to Ege Sea. The more salty waters of Marmara sea flow to Black Sea. The difference between Marmara and Black Sea is 25 m and Black Sea is higher. The depth of separation level for surface current and bottom current varies depends on especially wind condition and meteorological and regional changes. Since the direction of surface current is through Black Sea, Istanbul Strait, Marmara Sea and Canakkale Strait and Ege Sea, bottom currents move to opposite direction, through Black Sea.

2.9.1. Surface current

Water level of Blacksea is 40 cm higher than Marmara Sea. The reason why the direction of current from Blacksea through Marmara is the difference of water level. The higher water levels of Blacksea flows through the lower water levels of Marmara Sea. This current is more than the middle of the Strait and exceeds increasingly especially from Kandilli Cape through south.

2.9.2. Deep current

The direction of deep current is opposite to surface current because of the difference of salinity. The reason of lower salinity of Blacaksea is it is always fed by fresh water salt water is carried by surface current. Marmara Sea is almost two times saltier than Black Sea. This also means that buoyancy of Black Sea is lower than Marmara Sea. Due to the difference of salinity between these two seas, the deep current flows from 15 to 45 m depth.

2.9.3. Gulf current

There exists a counter current against the main current in the Istanbul strait. This type of current follows the curves and forms eddies and whirlpools at the curves. Direction and power of the currents are directly related to the weather and especially wind and thus it may have a huge number of changes. When the winds directed to south is too strong, the main current in the strait tends to north.

2.9.4. Orkoz current

South winds and especially southwester affect the local traffic event greatly and it may even cancel the lines. These winds accumulate the waters of Marmara through north and it increases the water level of Istanbul strait about an half meter. In this case, the current regime changes and there occurs “orkoz” at the surface. It sometimes reaches the speed of north current. It means that orkoz current reaches to 6 to 7 knots.

2.10. The effect of the Geographic Structure over the Navigation

In the Istanbul Strait, there are at least 12 waypoints. Some of these require altering the course more widely than 45 degrees.

Figure 2.2 : The narrowest point of the Istanbul Strait (The Turkish Straits Vessel Traffic Service) [39].

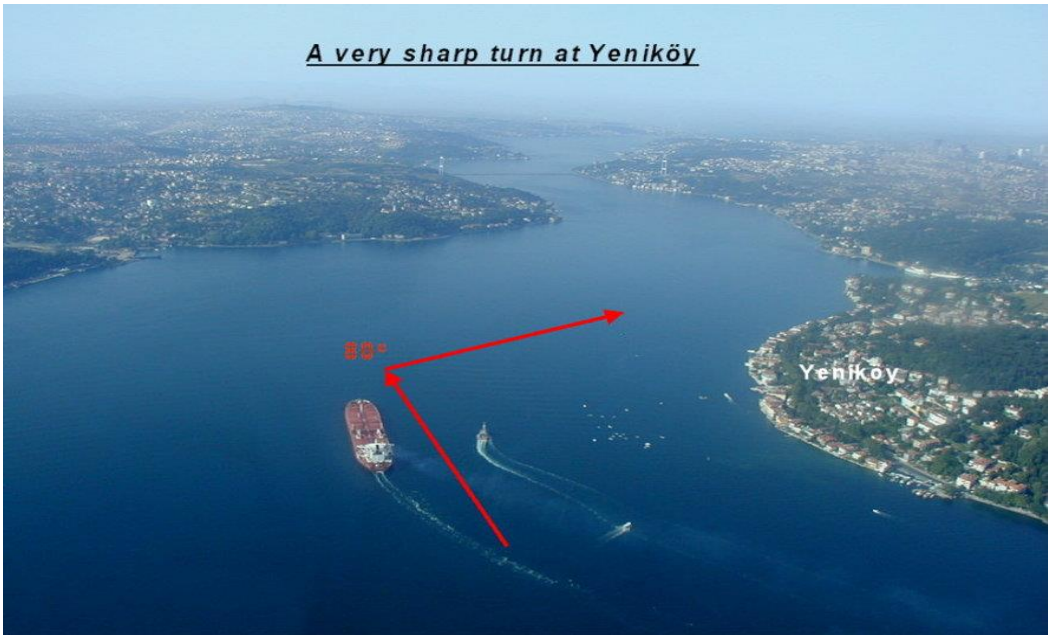

Figure 2.3 : A very sharp point of the Istanbul Strait [39]

2.11. The effect of the Current System over the Navigation

In the Istanbul Strait, currents generally flows through south from north except some currents which are formed by strong winds such as Orkoz. Therefore, The vessels which enter the Istanbul Strait from northern usually are under the effect of a northern current until entering Sea of Marmara. At the point of altering course, head and stern of the vessels are under effect of currents which come from different directions and it cause same direction of moment. Thus, speed of vessel and danger of grounding increase seriously. Therefore, it is very difficult to maneuver appropriately.

2.12. The Other Negative Situations in the Istanbul Strait

In the Istanbul Strait, two energy transmission lines located between Bebek and Kandilli, Rumelikavagi and Anadolu Kavagi. The high voltage energy is transmitted by these lines but they affect the RADAR echoes and cause a false echo on RADAR monitor.

2.13. The Statistics for the Istanbul Strait about Commercial Vessel Passages

There are a serious dense of gross tonnages of the vessels which uses the Istanbul Strait. A comparative data on Table 2.1 is given for the annual passages of some main canals of the world over the period 2012-2014.

Table 2.1: Annual passages of some main canals of the world

Annual Passages	2012	2013	2014
Istanbul Strait [3]	48.329	46.532	38.155*
Çanakkale Strait [3]	44.613	43.889	36.589*
Panama Canal [40]	14.544	13.660	13.482
Suez Canal [41]	17.225	16.596	

* only for the first ten months

In spite of this intensive transportation, the use of a pilot is not compulsory in the Istanbul Strait due to the Montreux Convention. There is a rise in the use of a pilot in the Istanbul Strait, Table 2.2, but it is inadequate.

Table 2.2: The statistics of the passages with pilot [3]

Year	Total Passages	Passages With Pilot	%
2000	48.078	19.209	39%
2005	54.794	24.449	45%
2010	50.871	26.035	51%
2011	49.798	26.011	52%
2012	48.329	24.792	51%
2013	46.532	24.022	52%
2014 (10 months)	38.155	20.397	53%

The Turkish Straits are the primary oil export routes for Russia and other Eurasian countries, including the Caspian Sea Region (Azerbaijan and Kazakhstan) [42] .

The Figure 2.4. indicates the most significant routes used for the transportation of crude oil and petroleum products of the whole world.

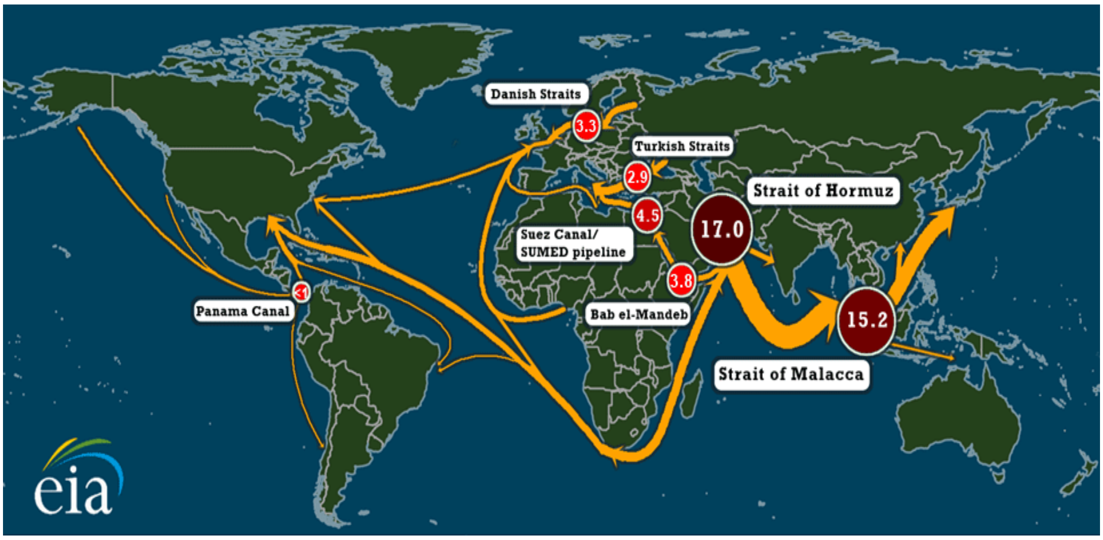

Figure 2.4: The routes of crude oil and petroleum products as percentage [42].

2.14. The Local Traffic in the Istanbul Strait

The Istanbul Strait separates the city of Istanbul into two parts, where approximately 15 million people live. Everyday, approximately 265,000 people are transported to one of two parts from another part by local traffic vessels. There are also ports, fishing shelters, marinas and various barges all along the Strait. All these cause rise of the traffic density and traffic congestion in the Istanbul Strait. Furthermore, the touristic tours are made regularly on the Istanbul Strait too. There are some statistics on Table 2.3 for the local traffic in the Strait.

Table 2.3: The passanger capacities of the local traffic vessels [43].

	Passangers	%
The Istanbul Water Bus	20.610	7,8
The Istanbul Lines	106.357	40,2
Private Vessels	137.285	52
Total	**264.252**	**100**

2.15. The Some Significant Marine Accidents in the Istanbul Strait

In the Istanbul Strait, so many serious accidents have occured until now and have caused environmental disasters, life and economic losses. Some of these is given below clearly by a table.

Table 2.4 : Significant marine accidents in the Istanbul Strait

Date	Vessels-Flags	Incidents and Results
14 December 1960	M/T Peter Verovitz (Yugoslavia) and M/T World Harmony (Greek)	After the collision, a fire broke out. 20 people lost their lives and 22.000 tonnes of oil were spilled into the sea. The fire continued for 52 days [44].
15 September 1964	The ship Norhom registered to Norway	She collided the wreck of the Zoranic. Thousands more tons of oil were spilled into the sea [45].
1 Mart 1966	Two Soviet-flagged vessels, M/T Lutsk and M/T Kransky Oktiabr	1,850 tons of oil which were spilled, caught fire and caused a passenger ferryboat and the ferry boat terminal of Karaköy to burn entirely [30].
3 July 1966	Passenger ferryboat Yeni Galatasaray and Turkish coaster Aksaray	13 people died due to fire [46].
18 November 1966	Passenger ferryboat Bereket and the Romanian-flagged Ploeşti	M/T Ploeşti hit a fishing boat called Bereket and 8 people lost their lives [44].
1 July 1970	Italian vessel Agip Ancona	She ran ashore due to steering failure, caused the collapse of a building and 5 people lost their lives [45].
21 April 1979	The Romanian-fagged M/V Karpat The Turkish-fagged M/V Kefeli	Both of the vessels sank and 11 people died [45].

15 November 1979	M/T Independenta (Romenian) M/T Evriyali (Greek)	Largest marine accident in the Istanbul Strait: M/Tanker Independenta and M/Tanker Evriyali collided in 1979, 43 people died and 95.000 tonnes of oil were spilled into the sea. The fire continued for 2 months [46].
2 April 1980	Greek ship M/V Elsa (Greek) and M/V Moskovosky (Soviet)	5 people lost their lives because of collision [46].
24 September 1985	Turkish Navy fast attack boat TCG Meltem and Soviet Navy warship	TCG Meltem sank and 5 Turkish marines died [45].
29 October 1988	Ammonia carrier M/T Blue Star (Panama) and M/T Gaziantep (Turkish)	1,000 tons of ammonia spilled into the Marmara Sea [44].
29 March 1990	M/T Jampur (Iraq) And M/V Da Tung Shang (Chinese)	2,600 tons of oil spilled from M/T Jampur [45].
14 December 1991	M/V Madonna Lily (Philippines) And livestock carrier M/V Rabunion XVIII (Lebanese)	M/V Rabunion XVIII sank with her 3 crew and 20,000 sheep drowned in the sunk [46].
14 March 1994	M/T Nasia and M/V Shipbroker (Both Greek Cypriot Administration of Southern Cyprus)	27 people lost their lives, 9,000 tons of oil spilled and 20,000 tons burnt over four days, caused severe pollution. M/V Shipbroker burnt totally [45].
7 November 1999	M/V Semele (Belize) and M/V Shipka (Bulgaria)	M/V Semele sank [44].

7 October 2002	Maltese vessel M/V Gotia	stranded at Bebek Point. 22 tons of oil spilled [45].
10 November 2003	Georgian flagged cargo ship GGC Svyatoy Panteleymon	ran aground off Anadolufeneri and broke into two pieces and 500 tons of oil spilled [47].

3. THE ISTANBUL STRAIT RISK CRITERIA

When the risk criteria are determined, primarily experts' opinion has been used . Then PAWSA [23] and other articles have been benefited from.

Table 3.1 : The Istanbul Strait risk criteria.

	Main Criteria	Sub-Criteria
The Istanbul Strait Risk Criteria	A.Vessel Factor	A1. Local Traffic Vessel
		A2. Commercial Vessel
		A3. Barges & Others
	B. Traffic Conditions	B1. Traffic Variety & Congestion
		B2. Local Traffic
		B3. International Vessel Traffic
	C. Waterway Structure	C1. Size of Waterway
		C2. Sharpness Course Alteration
		C3. Obstacles & Bench
	D. Meteorology & Oceanography	D1. Currents
		D2. Wind
		D3. Restricted Visibility
	E. Human Factor	E1. Lack of Knowledge on Nav. Area
		E2. Lack of General Maritime Knowledge
		E3. Factors Reduces The Perception
		E4. Poor Communication & Organization

3.1. Vessel Factor

- Sub-Criterion A1 (local traffic vessel) consists all risks arising from:
    - Vessel hull fitness
    - Machine failure
    - Steering failure
    - Equipment failure
    - Deficient equipment etc. of local traffic vessels
- Sub-Criterion A2 (commercial vessel) consists all risks arising from:
    - Vessel hull fitness
    - Machine failure
    - Steering failure
    - Equipment failure
    - Deficient equipment etc. of commercial traffic vessels
- Sub-Criterion A3 (barges & others) consists all risks arising from:
    - Vessel hull fitness
    - Machine failure
    - Steering failure
    - Equipment failure
    - Deficient equipment etc. of barges, fishing vessels, yachts, sailing vessels, tour boat, tug boats etc.

3.2. Traffic Condition

- Sub-Criterion B1 (Traffic Congestion) covers:
    - The density of barges, fishing vessels, yachts, sailing vessels, tour boat, tug boats.
    - The diversity of traffic
    - The congestion of traffic
    - The confusion of traffic

- Sub-Criterion B2 (Local Traffic) consists of:
    - The density of local traffic vessels
- Sub-Criterion B3 (International Vessel Traffic) consists of:
    - The density of international vessels

3.3. Waterway Structure

- Sub-Criterion C1 (Size of Waterway) symbolizes all risks based on:
    - The waterway width
    - The length of the waterway
    - Depth effect, squat
    - Bank effect
- Sub-Criterion C2 (Sharpness Course Alteration) symbolizes all risks based on:
    - Effect of course alteration by wide angle over the manoeuvring
    - Effect of frequency of sharpness course alteration
- Sub-Criterion C3 (Obstacles & Bench) is based on:
    - Effect of benches over the navigation
    - Effect of islands over the navigation
    - Effect of other obstacles bridges, platforms, piers and jetties.

3.4. Meteorology & Oceanography

- Sub-Criterion D1 (Currents) includes all risks of:
    - Effect of currents over the vessel safe speed
    - Effect of currents over the maneuverability
    - Effect of currents over the vessel turning circle
- Sub-Criterion D2 (Winds) includes all risks of:
    - Effect of prevailing winds over the vessel safe speed
    - Effect of prevailing winds over the maneuvrability

- > Effect of prevailing winds over the vessel turning circle
  - > The annual number of stormy days
- Sub-Criterion D3 (Restricted Visibility) covers all risks of:
  - > The annual number of foggy days
  - > Effect of restricted visibility over the look-out

3.5. Human Factor

- Sub-Criterion E1 (Lack of Knowledge about the Istanbul Strait) consists all risks deriving from:
  - > Lack of knowledge about characteristics of the Istanbul Strait
  - > Lack of knowledge about management system (rules, VTS, working on the sea) of the Istanbul Strait
- Sub-Criterion E2 (Lack of General Maritime Knowledge) consists all risks deriving from:
  - > Lack of Crew knowledge level about general maritime rules
  - > Faulty maneuvering
  - > Faulty ship management
  - > Lack of look-out
  - > Misinterpreting other vessels actions
  - > Not the consider the safe speed
  - > Wrong avoiding action from collision
  - > Violating all COLREGS
  - > Insufficient knowledge about the use of GMDSS equipments
- Sub-Criterion E3 (Factors Reduces the Perception) consists all risks deriving from:
  - > Weak perception due to working conditions
  - > Weak perception due to the use of alcohol or drug
  - > Weak perception due to psychological problems

- Sub-Criterion E4 (Poor Communication & Organization) consists all risks deriving from:
    - Poor comminication between vessel and VTS operator
    - Poor comminication between vessel and pilot
    - Poor comminication between VTS operator and pilot
    - Poor comminication with other vessels
    - Poor communication within the vessel
    - Weak organization within the vessel
    - Insufficiency of English level
    - Insufficiency of the use of radio communication equipments

4. METHODOLOGY

4.1. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process is a way of multiple criteria decision making (MCDM), Arbel and Orgler [48]. This method is introduced and developed by Saaty [49] and [50]. Initially, Analytic Hierarchy Process was developed to allocate scarce resources efficiently in the military. Then, it has become a essential tool for academic researchers and managers Cheng et al. [51]. It aids on eliminating the problems of decision-making. Analytic Hierarchy Process involves a questionnaire to collect information about hierarchical comparisions between decision points, this information is obtained from experts or decision makers. Finally, the weight for each decision point is found by using AHP method. Analytic Hierarchy Process is presented in main four steps Saaty [52], Saaty [53] :

$$\left[AW = \lambda_{\max} W\right] \tag{2}$$

W is the Eigenvector, $\lambda_{\max}$ is the Eigenvalue and A is the comparison matrix

Step1: The values of pairwise comparisions obtained by a questionnare, are variable between 1 and 9. Each element a_{ij} of A represents the relative importance of criterion i to criterion j:

1. If a_{ij} = 1, i and j are equally important,
2. If a_{ij} > 1, i is more important than j,
3. If a_{ij} < 1, i is less important than j,

The number of subjective values can be increased such as more important, much more important, extremely important. Each sujective value refers a exact value.

A basic assumption for comparing criteria:

$$a_{ji} = \frac{1}{a_{ij}} \qquad a_{ji} \cdot a_{ij} = 1 \tag{3}$$

For instance, if C_1 is extremely more important than C_2 and is rated at 9, then C_2 must be extremely less important than C_1 and is graded as 1/9.

Pairwise comparision matrix is a square matrix with dimension of [nxn].

Criteria	C_1	C_2	C_3	. . .	C_n
C_1	a_{11}	a_{12}	a_{13}	. . .	a_{1n}
C_2	a_{21}	a_{22}	a_{23}	. . .	a_{2n}
C_3	a_{31}	a_{32}	a_{33}	. . .	a_{3n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$
C_n	a_{n1}	a_{n2}	a_{n3}	. . .	a_{n3}

Figure 4.1 : Comparisions Table

As a pairwise comparison matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

It is also called the priority matrix.

Step 2: to the normalize pairwise comparision matrix, divide each column entry by the sum of the column. So that, the sum of all entries of each column is equal to 1.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (4)$$

$$A_{norm} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & & & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix}$$

Step 3: Take the all row averages

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \quad (5)$$

Then, the Eigenvector of size n×1, also called the priority vector is obtained.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$ w_i is the weight of each criterion.

Step 4: to calculate $\lambda_{\max}$ so as to obtain the Consistency Index,

$$AW = \lambda_{\max} W = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{bmatrix}$$

$$E_I = \frac{d_i}{w_i} \quad (6)$$

$$E_I = \begin{bmatrix} d_1 / w_1 \\ d_2 / w_2 \\ \vdots \\ d_n / w_n \end{bmatrix} \quad (7)$$

$$\lambda_{\max} = \frac{\sum_{i=1}^{n} E_i}{n} \quad (8)$$

$$CI = \frac{\lambda - n}{n-1} \quad (9)$$

Analytic Hierarchy Process is widely used by researchers, has been applied to many fields such as selection, evalation, planning, forecasting Vaidya and Kumar [54].

However, it doesn't reflect the human thinking system Chang [55] due to used exact values for comparing between criteria.

4.2. Fuzzy Logic and Triangular Fuzzy Number (TFN)

In mathematics, numerical values are utilized to define anything. There are also linguistic variables in human thinking system such as young or old for age, warm or cold for temperature. There may be even more complex linguistic variables on comparing of two things such as moderately important, more important, strongly important, extremely important. Human can not always explain his/her thought directly by using exact value. Therefore, fuzzy logic which introduced by Zadeh [56]. It can be represent human subjective judgements and express linguistic values of natural language, Khashei et al. [57]. Fuzzy set theory is applied succesfully on numerous fields of business, engineering and natural sciences Guiffrida [58]. Over 7000 books and research papers which use fuzzy set theory are reported in Kaufmann and Gupta [59].

4.2.1. Definitions

Definitions below briefly denote fuzzy sets and triangular fuzzy number Zadeh [56], Zimmermann [60], Van Laarhoven and Pedrycz [61], Chang[55] Pedrycz and Gomide [62].

Definition 1: If X is a collection of objects (x_i), a fuzzy set Ã is in X defined by

Ã = [x, μ_A(x)] and x $\in X$

$\mu_{\tilde{A}}(x) \in [0,1]$

sup $\mu_{\tilde{A}}(x) = 1$ $\mu_{\tilde{A}}(x)$ is called the membership function.

Definition 2: Convexity of a fuzzy number

If $\mu_{\tilde{A}}[\lambda x_1 + (1-\lambda)x_2] \geq \min\{\mu_{\tilde{A}}(X_1), \mu_{\tilde{A}}(X_2)\}$, the fuzzy number is convex.

$x_1, x_2 \in X$, $\lambda \in [0,1]$

Definition 3: Triangular Fuzzy Number (TFN) is defined by its membership $\mu_{\tilde{A}}$ (x):R$\rightarrow$[0,1] is equal to

$$\mu_{\tilde{A}}(x)=\begin{cases}0 & \text{for } x< l\\ (x-l)/(m-l) & \text{for } x\in[l\ ,m]\\ (u-x)/(u-m) & \\ 0 & \text{for } x\in[m,u]\end{cases} \qquad (10)$$

for $x>u$

l is the lower value of Ã, u is the upper value of Ã

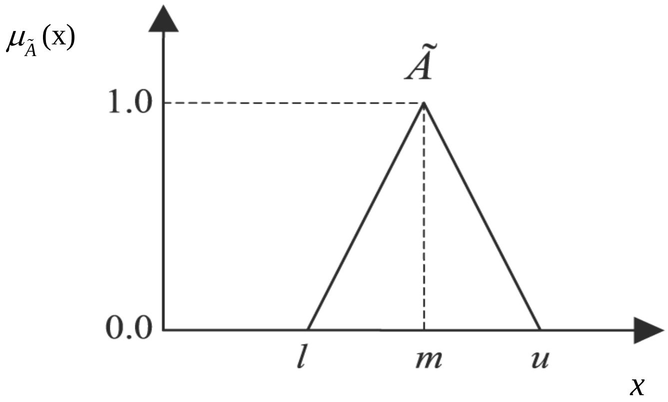

Figure 6.2 : Triangular Fuzzy Number.

Hence, Triangular Fuzzy Number is defined as $\tilde{A}=(l,m,u)$. $l,m,u\in\left\{R-R^{-}\right\}$

4.2.2. Algebraic operations with triangular fuzzy number (Kaufmann and Gupta, [63])

Consider two triangular fuzzy numbers $\tilde{A}_1=(l_1,m_1,u_1)$ and $\tilde{A}_2=(l_2,m_2,u_2)$.

1. Addition of two triangular fuzzy numbers

$$\tilde{A}_1\oplus\tilde{A}_2=(l_1,m_1,u_1)\oplus(l_2,m_2,u_2)=(l_1+l_2,m_1+m_2,u_1+u_2) \qquad (11)$$

2. Subtraction of two triangular fuzzy numbers

$$\tilde{A}_1 - \tilde{A}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (12)$$

3. Multiplication of two triangular fuzzy numbers

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \quad (13)$$

4. Division of two triangular fuzzy numbers

$$\tilde{A}_1 \div \tilde{A}_2 = (l_1, m_1, u_1) \div (l_2, m_2, u_2) = (l_1 \div l_2, m_1 \div m_2, u_1 \div u_2) \quad (14)$$

5. Inverse of a triangular fuzzy number

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = (\frac{1}{l_1}, \frac{1}{m_1}, \frac{1}{u_1}) \quad (15)$$

6. Multiplication of a triangular fuzzy number with a fixed number

$$a \in R \qquad a \otimes \tilde{A}_1 = a \otimes (l_1, m_1, u_1) = (a \times l_1, a \times m_1, a \times u_1)$$

(16)

7. Division of a triangular fuzzy number with a fixed number

$$a \in R \text{ and } a \neq 0 \qquad \frac{\tilde{A}_1}{a} = (\frac{l_1}{a}, \frac{m_1}{a}, \frac{u_1}{a})$$

(17)

8. Exponent of a triangular fuzzy number

$$a \in R \quad (\tilde{A}_1)^a = (l_1, m_1, u_1)^a = (l_1{}^a, m_1{}^a, u_1{}^a) \quad (18)$$

4.3. Fuzzy-Analytic Hierarchy Process (F-AHP)

F-AHP method is firstly proposed by Van Laarhoven and Pedrycz [64], triangular fuzzy numbers (TFN) is used in the pairwise comparison matrix of the AHP. Buckley [65] utilizes trapezoidal fuzzy numbers to evluate the alternatives based on each criterion. Furthermore, there is a wide variety of F-AHP approaches such as Chang [55], Leung and Cao [66], Kahraman et al. [67], Duru et al. [68].

In this paper, the weight of each collision risk criterion is found by using the extent analysis method of Chang [69]. Chang [55] uses the extent analysis method to obtain synthetic extent values of the pairwise comparison matrix which is based on triangular fuzzy number.

4.3.1. Introduction to Fuzzy-AHP

According to the principles of Chang's [69] extent analysis,

1. Initial assumptions:

the object set is defined as $X = \{x_1, x_2, x_3, ..., x_n\}$, the goal set is $G = \{u_1, u_2, u_3, ..., u_n\}$

for $\forall x$; $M_{g_i}^{j} : X \rightarrow G$ and

$M_{g_i}^{j}\,(j = 1, 2, 3, ..., n) \in$[Triangular Fuzzy Numbers] $\Rightarrow$ to obtain the values of extent analysis is possible.

2. General information

$V(M_1 \geq M_2) = 1$ if and only if $m_1 \geq m_2$

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_1}(d) . \quad (19)$$

The weight vectors:

$$d(A_i) = \min V(M_i \geq M_k) , \quad \text{k=1,2,3,…,n} \quad k \neq i. \quad (20)$$

4.3.2. **The value of fuzzy synthetic extent** for i th object is defined as:

$$S_I = \sum_{J=1}^{M} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} \quad (21)$$

Step 1: In order to obtaine $\sum_{j=1}^{m} M_{g_i}^{j}$ the fuzzy addition operation of extent analysis values for a particular matrix such that,

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \tag{22}$$

Step 2: $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1}$ is performed such as:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \tag{23}$$

The inverse of the vector is:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i} , \frac{1}{\sum_{i=1}^{n} m_i} , \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{24}$$

Step 3:

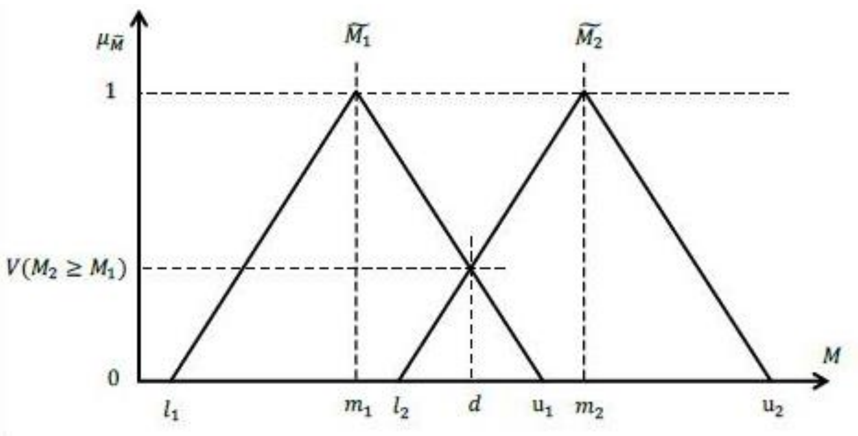

Figure 4.3 : The intersection point between M1 and M2 (Buyukozkan et al. [70])

Where d is the ordinate value of the highest intersection point D between $\mu_{M_1}(d)$ and $\mu_{M_2}(d)$, the degree of possibility of $M_2(m_2, l_2, u_2) \geq M_1(m_1, l_1, u_1)$:

is defined as $V(M_2 \geq M_1) = \sup_{y \geq x} \left\lfloor \min(\mu_{M_1}(x), \mu_{M_2}(x)) \right\rfloor$

can be expressed as follows :

$$V\left(M_2 \geq M_1\right) = hgt\left(M_1 \cap M_2\right) = \mu_{M_2}(d)$$

iff $m_1 \geq m_2$, $\mu_{M_2}(d) = 1$

iff $l_1 \geq u_2$, $\mu_{M_2}(d) = 0$

if otherwise, $$\mu_{M_2}(d) = \frac{u_2 - l_1}{(m_1 - l_1) + (u_2 - m_2)} \quad (25)$$

Step 4: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i (i = 1, 2, 3, ..., k)$ can be defined by

$$V(M \geq M_1, M_2, ..., M_K)$$

$$= V\left[(M \geq M_1) and (M \geq M_2) and ... and (M \geq M_k)\right]$$

$$= \min V(M \geq M_i), \quad i=1,2,3,\ldots,k. \quad (26)$$

Assume that, $d'(A_i) = \min V(S_i \geq S_k)$, k=1,2,…,n; k≠i

The weight vector is given by

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T, \quad A_i (i = 1, 2, 3, ..., n) \quad (27)$$

Step 5: Normalization of the weight vector

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \quad (28)$$

where W is a nonfuzzy number.

4.3.3. Centric consistency index (CCI)

Centric Consistency Index (CCI) which is proposed by Bulut et al. [71], is based on the geometric consistency index (GCI), Crawford and Williams [72]. CCI calculates the consistency of aggregated matrix. The procedure of the CCI is as follows, Duru et al. [68]:

$$CCI(A) = \frac{2}{(n-1)(n-2)} \sum_{i<j} (\log(\frac{a_{L_{ij}} + a_{M_{ij}} + a_{U_{ij}}}{3})$$

$$-\log(\frac{w_{L_i}+w_{M_i}+w_{U_i}}{3})+\log(\frac{w_{L_j}+w_{M_j}+w_{U_j}}{3})\ )^{2} \qquad (29)$$

CCI=0 refers a perfectly consistent situation, however smaller inconsistencies than a given threshold are tolerated.

The thresholds of ($\overline{GCI}$), Aguarón and Moreno-Jimenez, [73]:

= 0.31, for n=3

= 0.35, for n=4

= 0.37, for n>4

When CCI<GCI that means this matrix is sufficiently consistent.

5. THE RESULTS OF ANALYSIS

As a first step in the application of the F-AHP approach, for the each criteria weights are compared pairwise via Saaty's 1–9 scale.

Table 5.1 : Fuzzy number sets of the scale.

Linguistic terms	Fuzzy sets
Equally Risky	(1,1,1)
Moderately Risky	(1,1,3)
More Risky	(1,3,5)
Strong Risky	(3,5,7)
Extremely Risky	(5,7,9)

Secondly, to calculate experts weights. Questionnaires are carried out to pilots, academicians and VTS operators. It is accepted that professional weights of them are equal and 3.

Table 5.2 : Expert weighting determining criteria.

Parameters	Classification	Score
Professional Position	Academician	3
	Pilot	3
	VTS Operator	3
Sea service time	≥10	3
	3-10	2
	≤3	1
Educational Level	PhD	3
	Master	2
	Bachelor	1

Thirdly, The weighted product model (WPM) is a popular multi-criteria decision analysis Triantaphyllou, E. [74], Triantaphyllou, E.; S.H. Mann [75] is used for aggregated weights:

$$P(M_g)=\prod_{j=1}^{n}(M_{kj})^{w_j},\ \text{for k}=1,2,3,\ldots,n. \qquad (30)$$

Table 5.3 : Expert weights.

No of experts	Professional position	Sea service time (year)	Educational level	Weighting factor	w
1	Academician	3-10	PhD	8	0,11
2	Academician	≤3	MSc	6	0,08
3	Academician	3-10	PhD	8	0,11
4	Academician	3-10	PhD	8	0,11
5	Academician	≤3	MSc	6	0,08
6	Academician	≤3	MSc	6	0,08
7	Pilot	≥10	PhD	9	0,13
8	Pilot	≥10	MSc	8	0,11
9	Pilot	3-10	Bachelor	6	0,08
10	VTS Operator	3-10	Bachelor	6	0,08

Table 5.4 : The individual fuzzy judgment matrix for main criteria

DM_1		**A**	**B**	**C**	**D**	**E**
	A	(1,1,1)	(1/5,1/3,1)	(1,1,1)	(1,1,3)	(1,1,1)
	B	(1,3,5)	(1,1,1)	(1,1,3)	(1,1,3)	(1/3,1,1)
	C	(1,1,1)	(1/3,1,1)	(1,1,1)	(1,1,3)	(1/5,1/3,1)
	D	(1/3,1,1)	(1/3,1,1)	(1/3,1,1)	(1,1,1)	(1/5,1/3,1)
	E	(1,1,1)	(1,1,3)	(1,3,5)	(1,3,5)	(1,1,1)
DM_2	**A**	(1,1,1)	(1/3,1,1)	(1/3,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)
	B	(1,1,3)	(1,1,1)	(1,1,3)	(1/3,1,1)	(1/5,1/3,1)
	C	(1,1,3)	(1/3,1,1)	(1,1,1)	(1/3,1,1)	(1/5,1/3,1)
	D	(1,3,5)	(1,1,3)	(1,1,3)	(1,1,1)	(1/3,1,1)
	E	(3,5,7)	(1,3,5)	(1,3,5)	(1,1,3)	(1,1,1)
DM_3	**A**	(1,1,1)	(1,3,5)	(1,1,3)	(3,5,7)	(1/5,1/3,1)
	B	(1/5,1/3,1)	(1,1,1)	(1,3,5)	(1,1,1)	(1/5,1/3,1)
	C	(1/3,1,1)	(1/5,1/3,1)	(1,1,1)	(1,1,1)	(1/7,1/5,1/3)
	D	(1/7,1/5,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	(1/7,1/5,1/3)
	E	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(1,1,1)

DM_4	**A**	(1,1,1)	(1,3,5)	(1/3,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)
	B	(1/5,1/3,1)	(1,1,1)	(1/3,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)
	C	(1,1,3)	(1,1,3)	(1,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)
	D	(3,5,7)	(1,3,5)	(1,3,5)	(1,1,1)	(1/5,1/3,1)
	E	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,1,1)
DM_5	**A**	(1,1,1)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/5,1/3,1)	(1/3,1,1)
	B	(3,5,7)	(1,1,1)	(1,1,3)	(1,3,5)	(1,3,5)
	C	(1,3,5)	(1/3,1,1)	(1,1,1)	(1/3,1,1)	(1/3,1,1)
	D	(1,3,5)	(1/5,1/3,1)	(1,1,3)	(1,1,1)	(1,1,3)
	E	(1,1,3)	(1/5,1/3,1)	(1,1,3)	(1/3,1,1)	(1,1,1)
DM_6	**A**	(1,1,1)	(1,3,5)	(1,1,1)	(1,3,5)	(1/5,1/3,1)
	B	(1/5,1/3,1)	(1,1,1)	(1/5,1/3,1)	(1/3,1,1)	(1/5,1/3,1)
	C	(1,1,1)	(1,3,5)	(1,1,1)	(1/3,1,1)	(1/7,1/5,1/3)
	D	(1/5,1/3,1)	(1,1,3)	(1,1,3)	(1,1,1)	(1/7,1/5,1/3)
	E	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(1,1,1)
DM_7	**A**	(1,1,1)	(1/5,1/3,1)	(1/3,1,1)	(1/3,1,1)	(1/3,1,1)
	B	(1,3,5)	(1,1,1)	(1/3,1,1)	(1,1,3)	(1/5,1/3,1)
	C	(1,1,3)	(1/5,1/3,1)	(1,1,1)	(1/3,1,1)	(1/5,1/3,1)
	D	(1,1,3)	(1/3,1,1)	(1,1,3)	(1,1,1)	(1/5,1/3,1)
	E	(1,1,3)	(1,3,5)	(1,3,5)	(1,3,5)	(1,1,1)
DM_8	**A**	(1,1,1)	(1/5,1/3,1)	(1/5,1/3,1)	(1/5,1/3,1)	(1/5,1/3,1)
	B	(1,3,5)	(1,1,1)	(1,1,1)	(1,1,3)	(1/7,1/5,1/3)
	C	(1,3,5)	(1,1,1)	(1,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)
	D	(1,3,5)	(1/3,1,1)	(1,3,5)	(1,1,1)	(1/7,1/5,1/3)
	E	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,1)
DM_9	**A**	(1,1,1)	(1,3,5)	(1,1,1)	(3,5,7)	(1/5,1/3,1)
	B	(1/5,1/3,1)	(1,1,1)	(1,3,5)	(1,3,5)	(1/5,1/3,1)
	C	(1,1,1)	(1/5,1/3,1)	(1,1,1)	(1,1,1)	(1/7,1/5,1/3)
	D	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(1,1,1)	(1/7,1/5,1/3)
	E	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(1,1,1)
DM_{10}	**A**	(1,1,1)	(1/3,1,1)	(1,1,3)	(1,1,3)	(1,1,1)
	B	(1,1,3)	(1,1,1)	(1,1,3)	(1,1,3)	(1/3,1,1)
	C	(1/3,1,1)	(1/3,1,1)	(1,1,1)	(1,1,3)	(1/5,1/3,1)
	D	(1/3,1,1)	(1/3,1,1)	(1/3,1,1)	(1,1,1)	(1/7,1/5,1/3)
	E	(1,1,1)	(1,1,3)	(1,3,5)	(3,5,7)	(1,1,1)

Table 5.5 : The aggregated matrix consisted of experts' weights for main criteria.

CCI=0.03	A	B	C	D	E
A	(1,1,1)	(0.34, 0.91, 1.72)	(0.51, 0.80, 1.24)	(0.55, 0.92, 1.84)	(0.29, 0.47, 0.80)
B	(0.58, 1.09, 2.50)	(1,1,1)	(0.77, 1.30, 2.52)	(0.69, 1.06, 2.12)	(0.23, 0.44, 0.89)
C	(0.80, 1.24, 1.96)	(0.39, 0.77, 1.29)	(1,1,1)	(0.46, 0.78, 1.24)	(0.18, 0.28, 0.57)
D	(0.54, 1.08, 1.81)	(0.47, 0.94, 1.44)	(0.80, 1.28, 2.18)	(1,1,1)	(0.20, 0.31, 0.65)
E	(1.24, 2.12, 3.49)	(1.12, 2.25, 4.26)	(1.75, 3.54, 5.68)	(1.54, 3.18, 4.91)	(1,1,1)

The weight vector for main criteria W_{MC} =(0.15, 0.20, 0.14, 0.17, 0.34) ^{T}

Table 5.6 : The aggregated matrix of sub-criteria of vesel factor.

CCI=0.08	A1	A2	A3
A1	(1,1,1)	(1.13, 2.15, 3.52)	(0.63, 0.91, 1.32)
A2	(0.28, 0.46, 0.88)	(1,1,1)	(0.57, 1.03, 1.45)
A3	(0.76, 1.10, 1.58)	(0.69, 0.97, 1.74)	(1,1,1)

The weight vector for sub-criteria of vesel factor W_A = (0.41, 0.26, 0.33) ^{T}

Table 5.7 : The aggregated matrix of sub-criteria of traffic condition.

CCI=0.08	B1	B2	B3
B1	(1,1,1)	(1,00, 1,36, 1,98)	(1.36, 2.16, 3.20)
B2	(0.50, 0.73, 1.00)	(1,1,1)	(1.13, 1.71, 2.79)
B3	(0.31, 0.46, 0.73)	(0.36, 0.59, 0.88)	(1,1,1)

The weight vector for sub-criteria of traffic condition $W_B =$ (0.49, 0.38, 0.13) ^{T}

Table 5.8 : The aggregated matrix of sub-criteria of waterway structure.

CCI=0.14	C1	C2	C3
C1	(1,1,1)	(0.38, 0.58, 0.97)	(0.88, 1.49, 2.29)
C2	(1.03, 1.73, 2.64)	(1,1,1)	(1.98, 2.63, 3.97)
C3	(0.44, 0.67, 1.14)	(0.25, 0.38, 0.50)	(1,1,1)

The weight vector for sub-criteria of waterway structure $W_C =$(0.25, 0.46, 0.29) ^{T}

Table 5.9 : The aggregated matrix of sub-criteria of meteorology and oceanography.

CCI=0,13	D1	D2	D3
D1	(1,1,1)	(1.36, 3.06, 4.59)	(0.61, 0.95, 1.96)
D2	(0.22, 0.33, 0.73)	(1,1,1)	(0.31, 0.56, 1.06)
D3	(0.51, 1.05, 1.64)	(0.94, 1.79, 3.23)	(1,1,1)

The weight vector for sub-criteria of meteorology and oceanography

$W_D =$ (0.44, 0.19, 0.37) ^{T}

Table 5.10 : The aggregated matrix of sub-criteria of human factor.

CCI=0,01	E1	E2	E3	E4
E1	(1,1,1)	(0.78, 1.32, 2.28)	(1.14, 1.92, 3.91)	(0.56, 1.14, 1.67)
E2	(0.44, 0.76, 1.28)	(1,1,1)	(1.00, 1.49, 2.68)	(0.66, 1.32, 1.77)
E3	(0.26, 0.52, 0.88)	(0.37, 0.67, 1.00)	(1,1,1)	(0.35, 0.55, 1.00)
E4	(0.60, 0.88, 1.78)	(0.56, 0.76, 1.52)	(1.00, 1.82, 2.85)	(1,1,1)

The weight vector for sub-criteria of meteorology and oceanography

$W_E =$ (0.29, 0.27, 0.17, 0.27) ^{T}

Table 5.11 : The final weights of each sub-criteria in the results of analysis.

	Main Criteria	Sub-Criteria	w
The Istanbul Strait Risk Criteria	A.Vessel Factor	A1. Local Traffic Vessel	0.063
	0.153	A2. Commercial Vessel	0.039
		A3. Barges & Others	0.051
	B. Traffic Conditions	B1. Traffic Variety & Congestion	0.098
	0.201	B2. Local Traffic	0.076
		B3. International Vessel Traffic	0.027
	C. Waterway Structure	C1. Size of Waterway	0.035
	0.140	C2. Sharpness Course Alteration	0.064
		C3. Obstacles & Bench	0.041
	D. Meteorology & Oceanography	D1. Currents	0.073
	0.167	D2. Wind	0.031
		D3. Restricted Visibility	0.063
	E. Human Factor	E1. Lack of Knowledge on Nav. Area	0.101
	0.339	E2. Lack of General Maritime Knowledge	0.091
		E3. Factors Reduces The Perception	0.057
		E4. Poor Communication & Organization	0.090

6. CONCLUSION

The risk analysis of marine accidents requires a very comprehensive research and accurate method. F-AHP method which is a way of multiple criteria decision making (MCDM) enables to solve some problems between risk criteria such as correlation. In this study, Fuzzy Analitic Hierarchy Process is utilized and the weights of each risk criteria which is effective over the marine accidents on the Istanbul Strait.

In the result of this study, a beneficial and comprehensive risk analysis of marine accidents for the Istanbul Strait is made and the weights of different main and sub risk criteria is obtained. According to result of risk weights, "The human factor" is the most forceful risk criterion in all the main criteria with 0.339. The second forceful main criterion is "the traffic condition" for the Istanbul Strait with 0.201. The third is "the meteorologic & oceanographic conditions" with 0.167, the forth is "the vessel factor" with 0.153. Finally, the weight of "the waterway structure" is 0.140.

Firstly, the human factor is the strongest criterion in the entire main criteria. Interestingly, the most effective criterion among sub-criteria of human factor is " the lack of knowledge on navigation area" with 0.101. It indicates that characteristics of the Istanbul Strait is different and incomprehensible. Furthermore, it shows importance of getting a pilot to vessel. Because, the best way of overcoming the problems of lack of knowledge on navigation area is to get a pilot into vessel. On the Istanbul Strait, to get the pilot is not compulsory due to the Montreux Convention but we claim that all international vessels should get a pilot to their vessels as a advisor and IMO should support that. With 0.091, "the lack of general maritime knowledge" is the second strongest factor among human factor criteria. It consists of faulty maneuvering, violating all COLREGS. Education level and some countries' eduducation quality affect that especially. With 0.090, the factor of "the poor communication & organization" is the third strongest factor among human factor criteria. Its risk level is dramatically high and it especially indicates importance of insufficiency of English level and weak organization within the vessel.

Secondly, the factor of “traffic variety & congestion” is the most forceful among sub-criteria of the factor of traffic conditions and also the second strong risk criterion among all sub-criteria with 0.098. It is increasingly crucial risk factor for the Istanbul Strait. Apart from the factor of traffic variety & congestion, the local traffic has very high risk weight with 0.076. one of the Turkish authorities’ duties to arrange local traffic lines and they have major roles about solving the problem of traffic congestion. In order to prevent from several faults, the Istanbul Strait Vessel Traffic System (VTS) was established and assists vessels to avoid collision. The authorities should be also interested in solving the other traffic issues in the Istanbul Strait.

Finally, the “currents” is quiet significant risk factor in the Istanbul Strait. The Istanbul Strait current system is very characteristic. During sharpness course alteration, bow and stern of the vessel is under the effect of reverse currents and it is an important reason of grounding in the Istanbul Strait. It is an oceanographic factor and it can not be eliminated. However the risk level of currents can be descreased by assistance of pilots and VTS operators. Other important risk factor is restricted visibility. But, the passages of vessels from the Istanbul Strait are cancelled in the days when are restricted visibility.

The Istanbul Strait is an increasingly significant waterway for the maritime transportation. It is also one of the most intensive waterway in the entire world. Therefore, we have prefered to make a comprehensive risk analysis for the Istanbul Strait. The most property of this study is that it indicates the accident risk levels for all factor and it will assist academicians, researchers and authorities to prevent from maritime accidents. Briefly, this study will broaden future researhcers’ horizons and be beneficial for future study.

REFERENCES

[1] **R. Asariotis, H. Benamara,** (2012), Maritime Transport and the Climate Change Challenge. 1st Ed. USA and Canada, Chapter 10, 209, ISBN:978-1-84971-238-5.

[2] Grand National Assembly of Turkey, Minutes of the General Assembly, 21. period 3. Legislative Year, 30th Reunion (2000).

[3] Republic of Turkey, Ministry of Transport, Maritime Affairs and Communications, General Directorate of Maritime Trade, The 2013 Statistics of Vessel Passage from the Turkish Straits.

[4] Maritime Traffic System, < http://www.marinetraffic.com/tr/>, date retrieved 10.11.2014

[5] Turkish Maritime Pilots' Association. Some of the major casualties in the Strait of Istanbul during the past years, 2004.

[6] **Enache, Irina, and Sabina Zăgan**, (2009), Risk Assessment of Oil Marine Pollution. Exposure and Risk Assessment of Chemical Pollution—Contemporary Methodology. Springer Netherlands, 325-334, DOI: 10.1007/978-90-481-2335-3_23.

[7] **Damodar N. Gujarati and Dawn C. Porter**, (2009), "Basic Econometrics", 5st Ed., New York, Chapter 7 188, ISBN: 978-0-07-337577-9

[8] **J.R. Harrald, T.A. Mazzuchi, J. Spahn, R. Van Dorp, J. Merrick, S. Shrestha, Martha Grabowski**, **(1998).** Using System Simulation to Model the Impact of Human Error in a Maritime System. Safety Science, Elsevier, Volume 30(1), Pages 235-247.

[9] **Van Dorp, J. R., Merrick, J. R., Harrald, J. R., Mazzuchi, T. A., & Grabowski, M**. **(2001).** A risk management procedure for the Washington state ferries. Risk Analysis, 21(1), 127-142.

[10] **Trucco, P., Cagno, E., Ruggeri, F., & Grande, O. (2008).** A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation. Reliability Engineering & System Safety, 93(6), 845-856.

[11] **Kujala, P., Hänninen, M., Arola, T., & Ylitalo, J. (2009**). Analysis of the marine traffic safety in the Gulf of Finland. Reliability Engineering & System Safety, 94(8), 1349-1357.

[12] **Montewka, J., Hinz, T., Kujala, P., & Matusiak, J. (2010).** Probability modelling of vessel collisions. Reliability Engineering & System Safety, 95(5), 573-589.

[13] **Sariöz, K., Kükner, A., & Narli, E. (1999).** A real-time ship manoeuvring simulation study for the Strait of Istanbul (Bosporus). Journal of Navigation, 52(03), 394-410.

[14] **Or, I., & Kahraman, I. (2002).** A simulation study of the accident risk in the Istanbul Channel. International Journal of Emergency Management, 1(2), 110-124.

[15] **Köse, E., Başar, E., Demirci, E., Güneroğlu, A., & Erkebay, Ş. (2003).** Simulation of marine traffic in Istanbul Strait. Simulation Modelling Practice and Theory, 11(7), 597-608.

[16] **Otay NE., Özkan S. (2003).** Stochastic prediction of maritime accidents in the Strait of Istanbul. 3rd International conference on oil spills in the Mediterranean and Black Sea Regions, Istanbul, pp 55-64.

[17] **Akten, N. (2004).** Analysis of shipping casualties in the Bosphorus. Journal of Navigation, 57(03), 345-356.

[18] **Yurtoren, C., & Aydogdu, V. (2009, May).** Risk analysis of congested areas of Istanbul strait via ship handling simulator. In N. A. Baykara, & N. E. Mastorakis (Eds.), WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering (No. 11). World Scientific and Engineering Academy and Society.

[19] **Ulusçu, Ö. S., Özbaş, B., Altıok, T., & Or, İ. (2009).** Risk analysis of the vessel traffic in the strait of Istanbul. Risk analysis, 29(10), 1454-1472.

[20] **Arslan, O., & Turan, O. (2009).** Analytical investigation of marine casualties at the Strait of Istanbul with SWOT–AHP method. Maritime Policy & Management, 36(2), 131-145.

[21] **Akhtar, M. J., & Utne, I. B. (2014).** Human fatigue's effect on the risk of maritime groundings–A Bayesian Network modeling approach. Safety science, 62, 427-440.

[22] **Montewka, J., Weckström, M., & Kujala, P. (2013).** A probabilistic model estimating oil spill clean-up costs–A case study for the Gulf of Finland. Marine pollution bulletin, 76(1), 61-71.

[23] United States Coast Guard Navigation Center, Ports and Waterways Safety Assessment, http://www.navcen.uscg.gov/?pageName=pawsaMain

[24] **Merrick, J. R., & Van Dorp, R. (2006).** Speaking the truth in maritime risk assessment. Risk Analysis, 26(1), 223-237.

[25] **Kuroda, K., Kita, H. and Kono, S. (1982),** Mathematical Model of Ship Collision Probability, Memoirs of the Faculty of Engineering, Kyoto University, 44, no. 1, 135-157.

[26] **Amrozowicz, M. D. (1996).** The Quantitative Risk of Oil Tanker Groundings. Massachusetts Inst of Tech Cambridge.

[27] **Amrozowicz, M. D., Brown, A., & Golay, M. (1997, May).** A probabilistic analysis of tanker groundings. In 7th international offshore and polar engineering conference (pp. 1-19).

[28] **Türker, A. Y., (2008).** The Risk Assessment and Management of the Istanbul Strait, Ph.D. Thesis, Boğaziçi University.

[29] **Viran, A., (2014).** İstanbul Boğazı Yoğun Trafik Bölgesinin (Güney Bölgesi) Otomatik Tanımlama Sistemi Tabanlı Risk Haritasının Çıkarılması, M.Sc. Thesis, İstanbul Technical University.

[30] **Talay, A. A., (2012),** Liman Bölgelerindeki Seyir Güvenliğini Arttırmak İçin Oluşturulan Bir Karar Destek Modelinin Haydarpaşa Liman Bölgesine Uygulanması, Ph.D. Thesis, İstanbul Technical University.

[31] **Bayar, N., (2010).** İstanbul Boğazı'nda Deniz Trafik Güvenliğinin Risk Tabanlı Bulanık-AHP ve FMEA Yöntemleri ile İncelenmesi, Ph.D. Thesis, Yıldız Technical University.

[32] **Keçeci, T., (2010).** İstanbul Boğazı'nda Gemi Boyu Faktörünün Güvenli Seyre Etkisinin AHP Metodu Kullanılarak Analiz Edilmesi, M.Sc. Thesis, İstanbul Technical University.

[33] **Aydoğdu, Y. V., (2006).** İstanbul Boğazı Yoğun Trafik Bölgesinde Risk Analizi, M.Sc. Thesis, İstanbul Technical University.

[34] **Atasoy, C., (2008).** İstanbul Boğazı'nda Yerel Trafiğin İncelenmesi, M.Sc. Thesis, İstanbul Technical University.

[35] **Ece, N. J., (2005),** İstanbul Boğazı'ndaki Deniz Kazalarının Seyir ve Çevre Güvenliği Açısından Analizi ve Zararsız Geçiş Koşullarında Değerlendirilmesi, Ph.D. Thesis, Gazi University.

[36] **Başar, E., (2003),** İstanbul Boğazı'nda Tanker Kazaları ile Oluşabilecek Petrol Dağılımının Simülasyonu, Ph.D. Thesis, Karadeniz Technical University.

[37] Republic of Turkey, Ministry of Transport, Maritime Affairs and Communications, Istanbul Port Authority, Local Marine Traffic Guide.

[38] Republic of Turkey, Undersecretariat for Maritime Affairs, 2nd National the Council of Maritime,The Reports of Safety of Navigation for Turkish Straits, Istanbul, 2000.

[39] The Turkish Straits Vessel Traffic Service, < http://www.afcan.org/dossiers_techniques/tsvts_gb.html>, date retrieved 10.12.2014.

[40] Panama Canal Authority <http://www.pancanal.com/eng/>, date retrieved 17.01.2015.

[41] Suez Canal Authority, <http://www.suezcanal.gov.eg/>, date retrieved 17.01.2015.

[42] U.S. Energy Information Administration, <http://www.eia.gov/>, date retrieved 17.01.2015.

[43] İstanbul Elektrik Tramvay ve Tünel (İETT), < http://www.iett.gov.tr/tr/main/pages/istanbulda-toplu-tasima/95>, date retrieved 17.01.2015.

[44] <http://www.yeniaktuel.com.tr/tur105,222@2100.html>, date retrieved 10.11.2014.

[45]<http://en.wikipedia.org/wiki/List_of_maritime_incidents_in_the_Turkish_Straits>, date retrieved 12.11.2014.

[46] <http://www.denizcigunlugu.com/1054-istanbul-canakkale-bogazlarinda-en-butuk-deniz-gemi-kazalari-independenta.html>, date retrieved 12.11.2014.

[47] http://www.seanews.com.tr/article/TURKISHSTRAITS/48901/Maritime-accidents-Bosporus-Accidents-in-Bosporus-Turkish-Straits-Strait-of-Istanbul/, date retrieved 02.11.2014.

[48] **Arbel, A., Orgler, Y.E. (1990).** An Application of the AHP to Bank Strategic Planning: The Mergers and Acquistions Process. European Journal of Operational Research, Vol. 48 (1990), pp. 27–37

[49] **Saaty, T. L. (1977).** A scaling method for priorities in hierarchical structures. Journal of mathematical psychology, 15(3), 234-281.

[50] **Satty, T. L. (1980).** The analytic hierarchy process.

[51] **Cheng, E. W., Li, H., & Ho, D. C. (2002).** Analytic hierarchy process (AHP): A defective tool when used improperly. Measuring Business Excellence, 6(4), 33-37.

[52] **Saaty, T. L., & Shang, J. S. (2011).** An innovative orders-of-magnitude approach to AHP-based mutli-criteria decision making: Prioritizing divergent intangible humane acts. European Journal of Operational Research, 214(3), 703-715.

[53] **Saaty, T. L., & Vargas, L. G. (2001).** The seven pillars of the analytic hierarchy process. In Models, methods, concepts & applications of the analytic hierarchy process (pp. 27-46). Springer US.

[54] **Vaidya, O. S., & Kumar, S. (2006).** Analytic hierarchy process: An overview of applications. European Journal of operational research, 169(1), 1-29.

[55] **Chang, D. Y. (1996).** Applications of the extent analysis method on fuzzy AHP. European journal of operational research, 95(3), 649-655.

[56] **Zadeh, L. A. (1965).** Fuzzy sets. Information and control, 8(3), 338-353.

[57] **Khashei, M., Rezvan, M. T., Hamadani, A. Z., & Bijari, M. (2013).** A bi-level neural-based fuzzy classification approach for credit scoring problems. Complexity, 18(6), 46-57.

[58] **Guiffrida, A. L., & Nagi, R. (1998).** Fuzzy set theory applications in production management research: a literature survey. Journal of intelligent manufacturing, 9(1), 39-56.

[59] **Kaufmann, A., & Gupta, M. M. (1988).** Fuzzy mathematical models in engineering and management science. Elsevier Science Inc.. Kaufmann, A., & Gupta, M. M. (1985). Introduction to fuzzy arithmetic: Theory and applications. New York: Van Nostrand Reinhold.

[60] **Zimmermann, H. J. (1992).** Fuzzy Set Theory and Its Applications Second, Revised Edition. Kluwer academic publishers.

[61] **Van Laarhoven, P. J. M., & Pedrycz, W. (1983).** A fuzzy extension of Saaty's priority theory. Fuzzy sets and Systems, 11(1), 199-227.

[62] **Pedrycz, W., & Gomide, F. (2007).** Fuzzy systems engineering: toward human-centric computing. John Wiley & Sons.

[63] **Kaufmann, A., & Gupta, M. M. (1985).** Introduction to fuzzy arithmetic: Theory and applications. New York: Van Nostrand Reinhold.

[64] **Van Laarhoven, P. J. M., & Pedrycz, W. (1983).** A fuzzy extension of Saaty's priority theory. Fuzzy sets and Systems, 11(1), 199-227.

[65] **Buckley, J. J. (1985).** Fuzzy hierarchical analysis. Fuzzy sets and systems, 17(3), 233-247.

[66] **Leung, L. C., & Cao, D. (2000).** On consistency and ranking of alternatives in fuzzy AHP. European Journal of Operational Research, 124(1), 102-113.

[67] **Kahraman, C., Cebeci, U., & Ruan, D. (2004).** Multi-attribute comparison of catering service companies using fuzzy AHP: the case of Turkey. International Journal of Production Economics, 87(2), 171-184.

[68] **Duru, O., Bulut, E., & Yoshida, S. (2012).** Regime switching fuzzy AHP model for choice-varying priorities problem and expert consistency prioritization: A cubic fuzzy-priority matrix design. Expert Systems with Applications, 39(5), 4954-4964.

[69] **Chang, D. Y. (1992).** Extent Analysis and Synthetic Decision, Optimization Techniques and Applications, Volume 1World Scientific, Singapore p. 352.

[70] **Büyüközkan, G., Kahraman, C., & Ruan, D. (2004).** A fuzzy multi-criteria decision approach for software development strategy selection. International Journal of General Systems, 33(2-3), 259-280.

[71] **Bulut, E., Duru, O., Keçeci, T., & Yoshida, S. (2012).** Use of consistency index, expert prioritization and direct numerical inputs for generic fuzzy-AHP modeling: A process model for shipping asset management. Expert Systems with Applications, 39(2), 1911-1923.

[72] **Crawford, G., & Williams, C. (1985).** A note on the analysis of subjective judgment matrices. Journal of mathematical psychology, 29(4), 387-405.

[73] **Aguaron, J., & Moreno-Jiménez, J. M. (2003).** The geometric consistency index: Approximated thresholds. European Journal of Operational Research, 147(1), 137-145.

[74] **Triantaphyllou, E. (2000).** Multi-criteria decision making methods a comparative study. Springer.

[75] **Triantaphyllou, E., & Mann, S. H. (1989).** An examination of the effectiveness of multi-dimensional decision-making methods: A decision-making paradox. Decision Support Systems, 5(3), 303-312.

APPENDIX

RISK ANALYSIS FOR MARINE ACCIDENTS ON THE ISTANBUL STRAIT BY UTILIZING FUZZY-ANALYTIC HIERARCHY PROCESS

Name - Surname	

Please select the most suitable situations given below.

Professional Position	
Academician	
VTS Operator	
Pilots	

Sea Service Time	
≥10	
3 - 10	
≤ 3	

Education Level	
PhD	
Master	
Bachelor	

First page of questionnaire.

1. **Pairwise comparison between sub-criteria of Vessel Factor:**

- **Local Traffic (A1)** consists all risks arising from:
  - > Vessel hull fitness
  - > Machine failure
  - > Steering failure
  - > Equipment failure
  - > Deficient equipment etc. of local traffic vessels
- **Commercial Traffic (A2)** consists all risks arising from:
  - > Vessel hull fitness
  - > Steering failure
  - > Equipment failure
  - > Deficient equipment etc. of commercial traffic vessels
- **Barges & Others (A3)** consists all risks arising from:
  - > Vessel hull fitness
  - > Steering failure
  - > Equipment failure
  - > Deficient equipment etc. of barges, fishing vessels, yachts, sailing vessels, tour boat, tug boats etc.

✓ Please compare criteria

The First Criterion	Extremely Risky	Strongly Risky	More Risky	Moderately Risky	Equally Risky	Moderately Risky	More Risky	Strong Risky	Extremely Risky	The Second Criterion
A1										**A2**
A1										**A3**
A2										**A3**

2. Pairwise comparison between sub-criteria of Traffic Conditions:

- **Traffic Congestion (B1)** covers:
  - The diversity of traffic
  - The congestion of traffic
  - The confusion of traffic
- **Local Traffic (B2)** consists of:
  - The density of local traffic vessels
- **International Vessel Traffic (B3)** consists of:
  - The density of commercial vessels

✓ Please compare criteria

The First Criterion	Extremely Risky	Strongly Risky	More Risky	Moderately Risky	Equally Risky	Moderately Risky	More Risky	Strong Risky	Extremely Risky	The Second Criterion
B1										**B2**
B1										**B3**
B2										**B3**

3. **Pairwise comparison between sub-criteria of Waterway Structure:**

- **Size of Waterway (C1)** symbolizes all risks based on:
  - > The waterway width
  - > The length of the waterway
  - > Depth effect, squat
  - > Bank effect
- **Sharpness Course Alteration (C2)** symbolizes all risks based on:
  - > Effect of course alteration by wide angle over the manoeuvring
  - > Effect of frequency of sharpness course alteration
- **Obstacles & Bench (C3)** is based on:
  - > Effect of benches over the navigation
  - > Effect of islands over the navigation
  - > Effect of other obstacles bridges, platforms, piers and jetties.

✓ Please compare criteria

The First Criterion	Extremely Risky	Strongly Risky	More Risky	Moderately Risky	Equally Risky	Moderately Risky	More Risky	Strong Risky	Extremely Risky	The Second Criterion
C1										C2
C1										C3
C2										C3

4. Pairwise comparison between sub-criteria of Meteorology & Oceanography:

- **Currents (D1)** includes all risks of:
  - > Effect of currents over the vessel safe speed
  - > Effect of currents over the maneuverability
  - > Effect of currents over the vessel turning circle
- **Winds (D2)** includes all risks of:
  - > Effect of prevailing winds over the vessel safe speed
  - > Effect of prevailing winds over the maneuvrability
  - > Effect of prevailing winds over the vessel turning circle
  - > The annual number of stormy days
- **Restricted Visibility (D3)** covers all risks of:
  - > The annual number of foggy days
  - > Effect of restricted visibility over the look-out

✓ Please compare criteria

The First Criterion	Extremely Risky	Strongly Risky	More Risky	Moderately Risky	Equally Risky	Moderately Risky	More Risky	Strong Risky	Extremely Risky	The Second Criterion
D1										D2
D1										D3
D2										D3

5. **Pairwise comparison between sub-criteria of Human Factor:**

- **Lack of Knowledge about the Istanbul Strait (E1)** consists all risks deriving from:
  - Lack of knowledge about characteristics of the Istanbul Strait
  - Lack of knowledge about management system (rules, VTS, working on the sea) of the Istanbul Strait
- **Lack of General Maritime Knowledge (E2)** consists all risks deriving from:
  - Lack of Crew knowledge level about general maritime rules
  - Faulty maneuvering
  - Faulty ship management
  - Lack of look-out
  - Misinterpreting other vessels actions
  - Not the consider the safe speed
  - Wrong avoiding action from collision
  - Violating all COLREGS
  - Insufficient knowledge about the use of GMDSS equipments
- **Factors Reduces the Perception (E3)** consists all risks deriving from:
  - Weak perception due to working conditions
  - Weak perception due to the use of alcohol or drug
  - Weak perception due to psychological problems
- **Poor Communication & Organization (E4)** consists all risks deriving from:
  - Poor comminication between vessel and VTS operator
  - Poor comminication between vessel and pilot
  - Poor comminication between VTS operator and pilot

> Poor comminication with other vessels
> Poor communication within the vessel
> Weak organization within the vessel
> Insufficiency of English level
> Insufficiency of the use of radio communication equipments

✓ Please compare criteria

- Lack of Knowledge about the Istanbul Strait (E1)
- Lack of General Maritime Knowledge (E2)
- Factors Reduces the Perception (E3)
- Poor Communication & Organization (E4)

The First Criterion	Extremely Risky	Strongly Risky	More Risky	Moderately Risky	Equally Risky	Moderately Risky	More Risky	Strong Risky	Extremely Risky	The Second Criterion
E1										E2
E1										E3
E1										E4
E2										E3
E2										E4
E3										E4

6. Pairwise Comparison Between Main-Criteria

A. Vessel Factor

B. Traffic Conditions

C. Waterway Structure

D. Meteorology & Oceanography

E. Human Factor

In previous parts, You have already seen the contents of all main criteria

✓ Finally, please compare criteria

The First Criterion	Extremely Risky	Strongly Risky	More Risky	Moderately Risky	Equally Risky	Moderately Risky	More Risky	Strong Risky	Extremely Risky	The Second Criterion
A										B
A										C
A										D
A										E
B										C
B										D
B										E
C										D
C										E
D										E

Thank You For Participating To My Questionnaire

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