ANALYSIS OF THE EXTREME WEATHER CONDITIONS, VESSEL ARRIVAL PROCESSES AND PRIORITIZATION IN THE STRAIT OF ISTANBUL THROUGH SIMULATION MODELING

by

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ABSTRACT

ANALYSIS OF THE EXTREME WEATHER CONDITIONS, VESSEL ARRIVAL PROCESSES AND PRIORITIZATION IN THE STRAIT OF ISTANBUL THROUGH SIMULATION MODELING

Globalization leads to a rapid increase in vessel movements in many sea ports and waterways around the world. As this trend continues to grow, many busy waterways throughout the world face various navigation and traffic problems leading to serious economic and environmental risks. Being the narrowest and one of the most hazardous and busiest waterways in the world, the Istanbul Strait maintains over many years, the character of being a high-risk waterway. The increasing number of vessels navigating through the Strait, hazardous cargo transportation, complex navigational conditions and extreme weather conditions pose serious environmental and safety hazards for the Istanbul Strait and the surrounding residential areas, which are of high strategic, historical and economical importance for Turkey. This study aims to investigate the impact of extreme weather conditions, vessel arrival processes and prioritization policies on the maritime transit traffic in the Istanbul Strait, through the deployment of an integrated simulation model, which provides a practical environment to analyze the effects of a comprehensive set of environmental and meteorological conditions, type and frequency of transit traffic demand, availability of support services and decision/policy rules applied by the Turkish Straits Vessel Traffic System (TSVTS), via scenario analysis. A long term, ultimate aim is to facilitate a simulation based risk analysis of the Istanbul Strait through the developed simulation model. Vessel arrival rates under consideration of extreme weather conditions in the Istanbul Strait and the prioritization policy of TSVTS for direct/indirect passing vessels have been analyzed and integrated into an earlier version of the Istanbul Strait Maritime Traffic Simulation Model, which also covers the Turkish Straits Vessel Traffic System Rules and Regulations (TSMTR&R), the pilotage and tugboat services, traffic lanes and overtaking conditions, as well as a stochastic modeling of visibility and current conditions in the Istanbul Strait. Scenario analyses have been developed to analyze the effects and interrelations of vessel arrival rates, pilot and tugboat availabilities, vessel transit prioritization, pursuit distances between vessels, seasons and storm occurrences on performance measures, which are determined as the number and average transit time of the vessels passed, average waiting time of vessels, maximum waiting time of vessels, number of vessels in the queues, vessel density throughout the Strait and pilot/tugboat utilization. Results indicate that most of the input factors are significant, but vessel arrival rate proves to be the most important factor affecting several responses together such as number of vessels passed, average waiting time of vessels, maximum waiting time of vessels, number of vessels in the queues and vessel density in the Strait. This result depicts the high congestion and security risk in the Istanbul Strait along with the increasing vessel traffic and thus the importance of the role of the TSVTS. Results also indicate that meteorological conditions such as fog and storm occurrences in the Istanbul Strait have a significant effect on the maritime traffic providing another reason for safety hazards in the Istanbul Strait.

ÖZET

İSTANBUL BOĞAZI'NDAKİ KÖTÜ HAVA KOŞULLARININ, GEMİ GELİŞ SÜREÇLERİ VE ÖNCELİK POLİTİKALARININ BENZETİM MODELLEME İLE İNCELENMESİ

Ticaretin küreselleşmesi, dünya üzerindeki birçok liman ve su yollarındaki gemi hareketliliğinde hızlı bir artışa yol açmaktadır. Ticaret hızı artmaya devam ettikçe, işlek denizyollarının birçoğu ekonomik, çevresel ve sefer güvenliğine ilişkin risk konuları ile yüz yüze gelmektedir. Dünya üzerindeki en dar su geçidi olan İstanbul Boğazı, dünyanın en tehlikeli ve kalabalık denizyollarından biri olması nedeniyle uzun yıllar boyunca yüksek riskli bir su yolu olma özelliğini korumaktadır. Boğazlardan seyreden gemilerin sayısındaki artış, tehlikeli kargo taşımacılığı, zorlu seyir şartları ve kötü hava koşulları, Türkiye için yüksek ekonomik, tarihi ve stratejik öneme sahip İstanbul ve İstanbul Boğazı için önemli çevresel kirlenme ve güvenlik risklerini beraberinde getirmektedir. Bu çalışma, deniz trafiği için bütünleşik bir benzetim modeli kullanarak olumsuz hava koşullarının, gemi gelişleri ve öncelik tanıma politikalarının İstanbul Boğazı deniz trafiği üzerindeki etkilerini incelemeyi ve geliştirilen benzetim modeli ile çevresel ve meteorolojik şartların, geçiş talebi tip ve sıklığının, destek hizmet imkanlarının ve Türkiye Boğazları Gemi Trafik Sistemi (TSVTS) karar/politika kurallarının içinde yer aldığı geniş bir kapsamın sistem üzerindeki etkilerini incelemek için senaryo analizi gerçekleştirmeyi amaçlamaktadır. Uzun vadeli, nihai amaç, geliştirilmiş olan benzetim modelinin kullanımıyla İstanbul Boğazı'nın benzetime dayalı risk analizine yardımcı olmaktır. Çalışma kapsamında olumsuz hava koşullarının gemi gelişlerine etkisi ile TSVTS'nin uğraklı ve uğraksız gemilere yönelik öncelik tanıma politikaları analiz edilerek İstanbul Boğazı Deniz Trafiği Benzetim Modeli'nin önceki versiyonuna entegre edilmiştir. İstanbul Boğazı Deniz Trafiği Benzetim Modeli, TSVTS trafik kuralları ve düzenlemelerini, gemi gelişleri ve özelliklerini, kılavuz kaptan ve römorkör hizmetlerini, trafik şeritleri ve sollama kurallarını, İstanbul Boğazı'ndaki görüş mesafesi ve akıntı şartlarının rassal modellemesini de içermektedir. Girdi faktörler olarak belirlenen gemi geliş sıklığının, kaptan ve römorkör sayısının, öncelik politikalarının, mevsimsel değişimlerin, gemiler arası takip mesafesinin ve fırtına oluşumlarının, başarım ölçüsü olarak belirlenen geçen gemi sayısı ve tipi, gemi geçiş süreleri ve bekleme zamanları, kuyruklardaki gemi sayıları, Boğaz boyunca gemi yoğunlukları, kılavuz kaptan ve römorkör kullanım oranları üzerindeki etkilerini incelemek için senaryo analizleri tasarlanmıştır. Çalışmanın sonuçları, girdi faktörlerinin çoğunun sonuçlar üzerinde etkili olduğunu göstermekle birlikte, gemi geçiş süreleri ve bekleme zamanları, kuyruklardaki gemi sayıları ve Boğaz boyunca gemi yoğunluğunu birlikte etkileyen gemi geliş sıklığının en önemli faktör olarak ortaya çıktığı görülmektedir. Bu sonuç artan gemi trafiğine paralel olarak İstanbul Boğazı'ndaki yüksek tıkanıklık ve güvenlik riskine işaret etmekte ve TSVTS'nin rolünün önemini ortaya koymaktadır. Ayrıca sonuçlar sis ve fırtına gibi meteorolojik şartların Boğaz trafiği üzerinde önemli etkiye sahip olduğunu güvenlik riskini artırdığını göstermektedir.

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LIST OF SYMBOLS/ABBREVIATIONS

ANOVA	Analysis of Variance
Coef_FAV	Converted Prioritization Index
CoefFD	Prioritization Coefficient
GAP	Generalized Allocation Problems
GRA	Grey Relational Analysis
HAZMAT	Hazardous Material Carrying Vessels
HPM	Hydrodynamic Prediction Model
IMO	International Maritime Organization
KOERI	Kandilli Observatory and Earthquake Resarch Institute
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
TSMTR&R	Turkish Straits' Maritime Traffic Rules and Regulations
TSS	Traffic Separation Scheme
TSVTS	Turkish Straits Vessel Traffic Services
VMM	Vessel Motions Model
VTMIS	Vessel Traffic Management and Information Systems

1. INTRODUCTION

Globalization leads to a rapid increase in vessel movements in many sea ports and waterways around the world. As this trend continues to grow, many busy waterways throughout the world face various navigation and traffic problems leading to serious economic and environmental risks. Consequently, analysis of maritime traffic, navigational safety issues and the associated accident risks are the focus of many recent studies, because of their relation to the transport safety, distribution and logistics reliability and loss prevention in these waterways and in the surrounding land mass.

Considering the maritime risks involved, some waterways in the world like the Istanbul Strait present a great challenge. Being the narrowest and one of the most hazardous, crowded and potentially dangerous waterways in the world, the Istanbul Strait maintains, over many years, the character of being a high-risk waterway.

Besides its narrow and twisted nature, this Strait forms a waterway of high strategic and economic importance, since it is the only maritime route for the five neighboring Black Sea states (Ukraine, Romania, Georgia, Bulgaria, Russia) and the Central Asian Turkish Republics. Being one of the busiest waterways in the world, the Istanbul Strait is roughly four times and three times busier than the Panama and the Suez Canals, respectively.

As the only water route between the Black Sea and the Mediterranean, it both geographically and metaphorically connects Europe to Asia, while it snakes through the heart of Istanbul, a city of over 10 million people, which is declared as a "World Heritage City" by UNESCO.

1.1. Characteristics of the Istanbul Strait

The Istanbul Strait is unique in many respects. This very narrow and winding Strait runs right across Istanbul, and it has unique physical, hydrological and oceanographic characteristics and complicated navigational conditions.

The Strait is about 32 km long. Its width is 4.7 km and 2.5 km at the northern and the southern entrances respectively. At its narrowest point (between Kandilli and Bebek) it measures a mere 700 meters (Figure 1.1). The Strait has 12 sharp turns, including a 45° turn near Kandilli and a 80° turn near Yenikoy and is therefore very difficult to navigate.

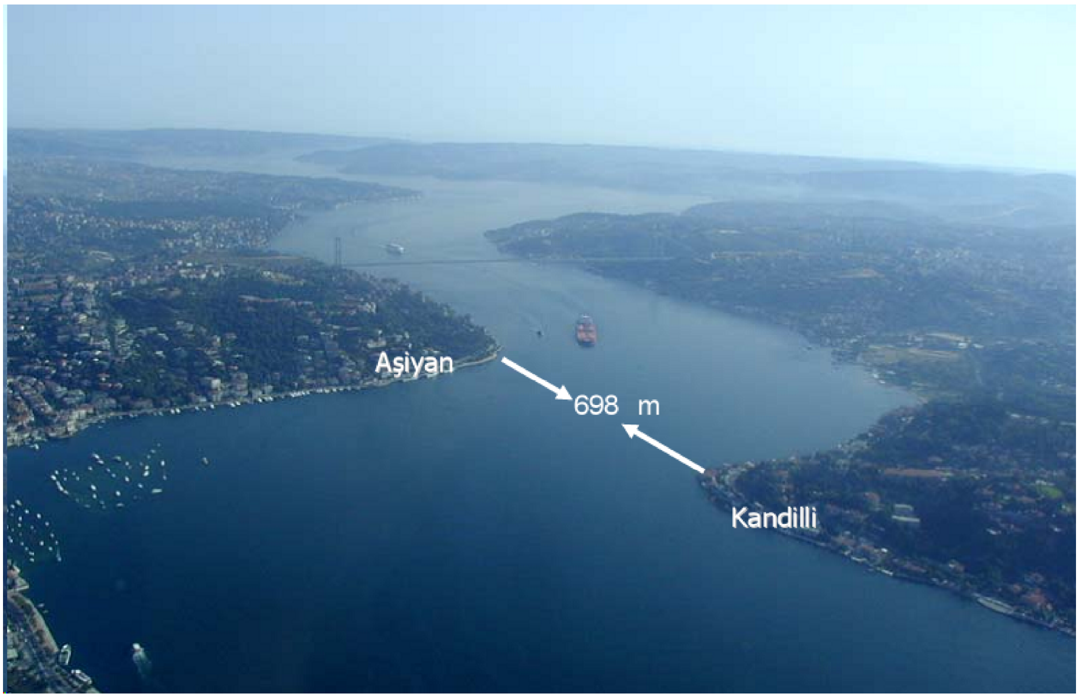


Figure 1.1. A view from the Istanbul Strait

The most important oceanographic factor affecting the Istanbul Strait is the current, which can reach up to 7-8 knots. There are four different types of currents. Whilst a surface current moves form North to South due to the height difference of the Black Sea and Marmara, a deep current flows from South to North, due to the salinity difference between the two seas. Besides, there are local currents and the orkoz current, which is created by strong southerly winds.

In addition to the transit traffic, around 1500 vessels are criss-crossing between the two shores of the Strait every day.

1.2. The Transit Traffic in the Istanbul Strait

The Istanbul Strait is one of the most crowded waterways in the world, today, about 55000 ships pass through the Strait per year (Birpınar et al, 2006). At the time the Montreaux Treaty was signed in 1936, the number of ships passing through Istanbul Strait was only 4500 per year. The Montreaux Treaty, which formally defines the unrestricted and free stature of the Istanbul Strait for all international civilian maritime traffic, without any restriction on flag and cargo type, is the primary driver behind this increasing transit demand.

The following are other contributing factors to the traffic growth in the Istanbul Strait in the past 25 years (Sarıöz and Narlı, 2003).

- The opening of the Main-Danube Canal, which linked the Rhine and Danube rivers, thereby creating a direct route between Rotterdam and Constanza and thus connecting the North Sea and the Black Sea.
- An increase in the maritime traffic originating from Volga-Baltic and Volga-Don Canals and abounds to Mediterranean and to the Turkish ports.
- The ports of the Black Sea gaining recognition and importance as major outlets for Russian and Central Asian oil exports. Actually, exports of oil and many other materials through the Istanbul Strait have significantly grown since the break up of the Soviet Union in 1991.

From 1996 to 2005, the average annual increase in the number of vessels passed through the Istanbul Strait was 1.31%. The Table 1.1 shows the growth of maritime traffic from 1995 to 2005.

Frequency distribution of all transit vessel types and lengths passed in 2005 is given Figure 1.2 and in Figure 1.3 respectively.

Table 1.1. The Number of vessel transits in the Istanbul Strait between 1995 and 2005

Year	*Total*	*Used Pilot*	*Longer than 200 meters*	*Direct Passed*	*Tankers*
1995	46954	17772	6491	24325	N/A
1996	49952	20317	7236	23755	4248
1997	50942	19752	6487	24568	4303
1998	49304	18881	1943	24561	5142
1999	47906	18424	2168	26323	4452
2000	48079	19209	2203	26858	4937
2001	42637	17767	2453	26113	6516
2002	47283	19905	3113	29398	7427
2003	46939	21175	2923	28961	6578
2004	54564	22318	N/A	34256	N/A
2005	54790	24651	3503	34072	9190

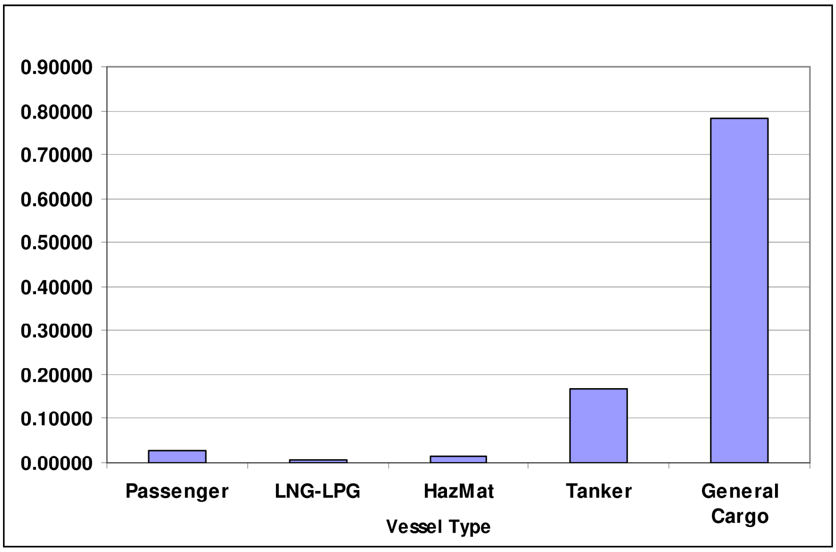


Figure 1.2. The Frequency distribution of transit vessel types in 2005

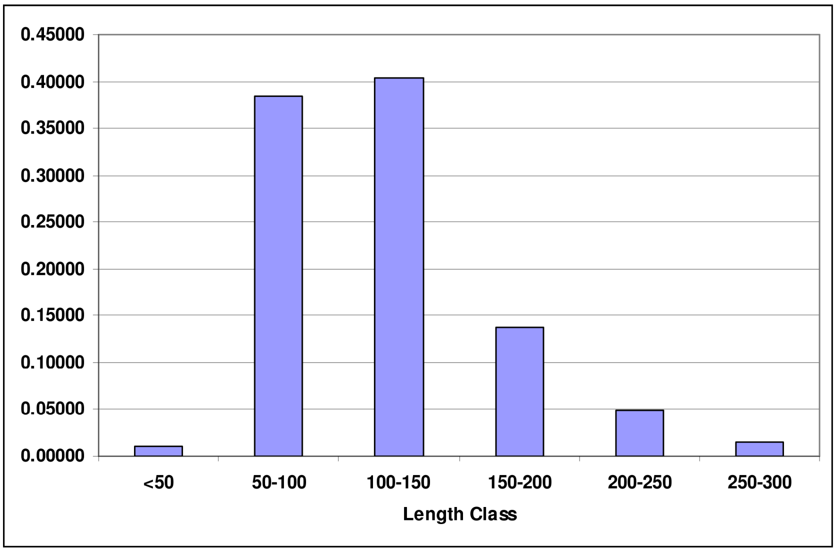


Figure 1.3. The Frequency distribution of transit vessel lengths in 2005

1.3. Traffic Risks and Accidents

The increasing number of vessels navigating through the Istanbul Strait, the dense local maritime traffic, hazardous cargo transportation, complex navigational conditions and inconvenient weather and sea conditions pose serious accident risks for the Strait and the surrounding land mass.

The number of tankers passed through the Istanbul Strait between 1996 and 2005 and the amount of hazardous cargo (especially oil and other petroleum products) carried between 2000 and 2004 are displayed in Figure 1.4 and Figure 1.5, respectively.

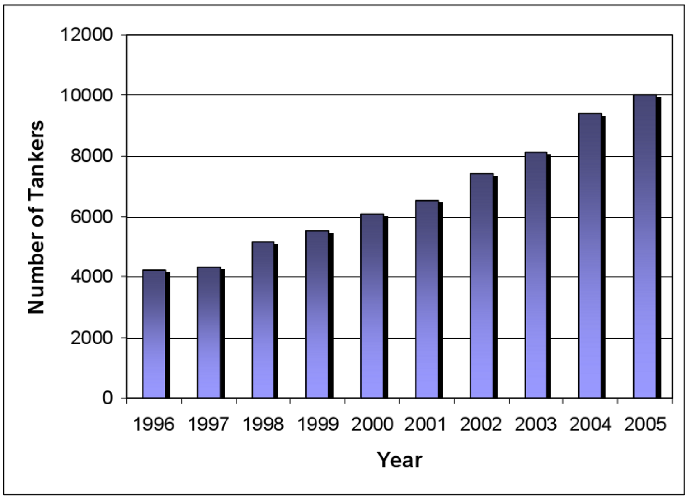


Figure 1.4. The Number of Tankers passed through the Istanbul Strait between 1996 and 2005

Potential maritime accidents pose a serious threat not only to the city of Istanbul and its residents, but also to the environment. Since 1948 the number of ship accidents are around 700 in the Istanbul Strait. Some of these accidents have been severe accidents and caused serious environmental problems , material damage and loss of life. Some of the major maritime accidents in the Istanbul Strait are listed below:

- In November 1979, 29 Million gallons of oil spilled due to a tanker accident.
- In 1998, the Romanian tanker, Independenta, collided with a Greek freighter and the collision caused a massive explosion with great consequences. Forty-three

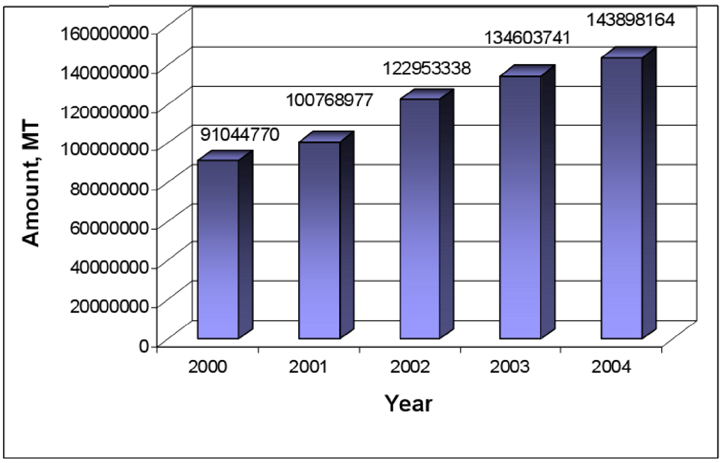


Figure 1.5. Dangerous Cargo carried through the Istanbul Strait between 2000 and 2004

sailors were burned alive, the tanker sank leaving behind a burning lake of crude oil for six weeks and a formation of black smoke over Istanbul for two months.

- Another incident occurred in March, 1994, when a Greek Cypriot oil tanker carrying 19-million gallons of crude oil collided with an empty Greek Cypriot cargo ship. This collision caused a total halt to navigation of the Strait for nine days.

1.4. Vessel Traffic Regulations

The Montreux Convention provides the main legal framework for the Turkish Straits. However, in the face of the serious and increasing risks brought about by the increasing maritime traffic, safe transportation is possible only if it is done strictly according to precise and detailed regulations. Vessel traffic control is widely recognised as an essential element in ensuring safe and efficient operation of sea transport (Köse et al., 2003)

Consequently, in 1994 the Turkish State developed and put into effect a comprehensive set of rules and regulations to govern all civilian maritime traffic in the Turkish Straits in order to ensure safe navigation. New regulations and Traffic Separation Schemes were approved by the International Maritime Organization (IMO). Then the Turkish Straits Vessel Traffic Services (TSVTS) was established in 2004 in accordance with applicable national laws and international rules and regulations, in order to better manage the flow of maritime traffic and to reduce the accident risks (Almaz, 2006). These rules and regulations define, control, and regulate all vessel movements in the Strait, including entrance, overtaking, pursuing conditions, lane structures and vessel speeds. The pilotage and tugboat deployment in the Istanbul Strait is strongly recommended by the regulations to ensure safe navigation in the Strait.

1.5. Objectives of the Study

The main objective of this study is to contribute to the risk management study conducted in the Istanbul Strait, which is (as discussed in sections 1.1, 1.2, 1.3, 1.4) one of the most challenging waterways in the world due to increasing transit traffic, high navigational difficulties, meteorological conditions and a large and complex set of rules and regulations defined by the TSVTS.

Simulation is considered to be an appropriate tool for this study; the analysis of previous studies on maritime traffic modelling and risk management in hazardous waterways (discussed in the Literature Survey, Section 2) shows that simulation modelling is an effective and preferred method for investigating the behaviour of a traffic system under specific conditions and for estimating accident probabilities with their possible impacts. This is done by developing a realistic simulation model, which mimicks the behaviour of the system analyzed and facilitates experimentation under various scenarios.

Consequently, simulation methodology is chosen and applied in this study to investigate possible effects of environmental and meteorological conditions, type and frequency of transit traffic, availability of support services and Turkish Straits' Maritime Traffic Rules and Regulations (TSMTR&R) on TSVTS performance indicators (such as, the number and waiting times of vessels passed, pilot/tugboat utilizations, vessel density etc.) A long term objective of this simulation study is to provide an appropriate platform and infrastructure for a further comprehensive risk management study.

The Istanbul Strait Maritime Traffic Simulation Model, which is used in this study, has been first designed by Özbaş (2005) and further developed by Almaz (2006). This model is further developed and expanded in this study, giving the opportunity to investigate the effects of the following factors on the vessel traffic, in integration with other factors considered in previous versions:

- An expanded and comprehensive set of vessel arrival frequencies based on vessel type, length and/or transit time and direction;
- Prioritization effect for certain group of vessels by the TSVTS;
- Storm occurrences in the vicinity of the Strait throughout the year and their effect on vessel arrivals

Moreover, due to "Marmaray", (which is a metro and railway project aiming to link the European and Asian shores of Istanbul by constructing a subway tunnel below the surface of the Strait), the TSVTS has suspended the two-way traffic in the Istanbul Strait since the beginning of 2006, so that vessels can pass the Istanbul Strait only in one direction. So, another long term objective of this study is to provide information and infrastructure for the comparison of the strengths and weaknesses between the two-way and one-way traffic protocols.

The study of simulation modeling of the maritime transit traffic in the Istanbul Strait is conducted under the research project on the comprehensive risk management and analysis of the Istanbul Strait, with cooperation of Rutgers University and Boğaziçi University, through the supports of NSF (National Science Foundation), TUBİTAK (Turkish Technological and Scientific Research Institute) and Boğaziçi University Research Fund.

1.5.1. The Simulation Model

The main simulation model and some integrated modules, including the visibility module and the current module, were developed using the simulation software Arena 9.0, whereas in this study the new modules are all developed using Arena 11.0, while the earlier modules are also updated under Arena 11.0.

The following classes of control parameters are used in the model:

- External parameters, which cannot be controlled by the TSVTS, can be summarized as, i) vessel arrival rates, ii) vessel profiles, iii) vessel speeds, iv) pilot/tugboat demands of transit vessels, v) meteorological conditions.
- Pilot and tugboat availabilities, transit vessel priorities (including prioritization level for indirect vessels) and various interpretations of the TSMTR&R, such as, overtaking criteria, pursuit distance between vessels, speed limits in the Istanbul Strait and Kandilli region encounter prevention rules, are the internal parameters of the model, which can be managed by the TSVTS. Actually, the TSMTR&R are considered unchangable, nevertheless in practice, various interpretations of some rules and regulations are quite possible and pursued.

The simulation model includes the following major components:

- Stochastic arrival processes of vessels at the North and South entrances, based on vessel types and characteristics,
- TSMTR&R
- The pilotage and tugboat services with parameterized capacities,
- Prioritization opportunities for indirect passing vessels (A direct passing vessel is a vessel planned not to call any port, berth or place within Turkish Straits, (and so reported in her Sailing Plan to the TSVTS before entering to the Straits). An indirect passing vessel is a vessel which planned to call a port, berth or place within Turkish Straits (and so reported in her Sailing Plan to the TSVTS before entering to the Straits), or a vessel whose direct passing has been cancelled or interrupted.)
- A stochastic storm model for the Istanbul Strait,
- A stochastic visibility model for the Istanbul Strait,
- A stochastic current model for the Istanbul Strait,
- Transit vessel traffic flow in the Istanbul Strait.

Many scenarios are developed and analyzed, primarily in regard to the effects and interrelations of the factors of vessel arrival rates, pilot and tugboat availabilities, vessel transit prioritization, pursuit distances between vessels, season and storm occurrence conditions, on predetermined performance measures. The effects of those factors can be observed on the following performance measures;

- Number of vessels which have completed their transit through the Channel in a given time period,
- Average transit time of vessels passed,
- Average waiting time of vessels (before entering the Strait),
- Maximum waiting time of vessels (before entering the Strait),
- Number of vessels in the queues,
- Vessel density throughout the Strait,
- Pilot utilization,
- Tugboat utilization.

2. LITERATURE SURVEY

In this section, previous studies on maritime traffic modelling and simulation is reviewed with a focus on the vessel traffic control problems and navigation safety. It should be noted, that the majority of research in this area has been devoted to the risk modeling associated with the hazards of navigating potentially dangerous waterways. Several other studies examine the maritime traffic rules and vessel traffic control systems in order to enable better design of infrastructure for waterways.

In the study of Tan and Otay (1999) a stochastic model of tanker traffic is presented to determine the probability of vessel casualties resulting from the transit traffic through a narrow waterway. A state-space representation of the waterway is developed to determine the location of vessels at given times and the study is based on modeling of physical forces and movements of individual ships. Drift probabilities together with random arrival of vessels are incorporated into a Markov chain model to evaluate the vessel casualty risks.

Inoue Kinzo (2000) proposed a quantitative model for evaluating the difficulty of ship-handling when a mariner is challenged by a restricted manoeuvring area or by traffic congestion or by a combination of both. The proposed model is called the Environmental Stress Model (ES-model), which quantitatively expresses in the degree of stress imposed by topographical and traffic environments on the mariner.

Or and Kahraman (2002) investigated the accident probabilities in the Istanbul Strait through Bayesian analysis and simulation modeling. They analyzed the potential causes for accidents and casualties and calculated estimates for conditional maritime accident probabilities, based on various accident triggering factors, through Bayesian analysis. They also developed a simulation model to integrate and keep track of the the proposed accident probabilites combined with the Strait characteristics, the traffic rules and vessel behavior in the Istanbul Strait.

Gören (2002) investigated the maritime accidents in the Istanbul Strait using logistics regression technique and simulation. In this study, accidents are categorized and probability models for each category are developed which are then integrated into a simulation model to investigate the accident probabilities throughout the Istanbul Strait.

Sarıöz and Narlı(2003) developed a real-time simulation model to investigate the manoeuvring performance of large tankers in the Istanbul Strait. In this study, they considered various combinations of environmental conditions, (i.e. wind, current and wave drift forces) and developed a mathematical model representing the behaviour of a large tanker. The study is conducted using a PC based, ship manoeuvring simulation software. The simulation results indicated that even in the ideal conditions (no wind, no current, no wave), vessels larger than a certain size can not manoeuvre the Istanbul Strait safely without violating the traffic separation lanes.

In the research of Squire (2003), the hazards to be encountered by mariners when transiting the Dover Strait, (which is among the busiest shipping lanes in the world) are investigated. Squire examined the development of the Traffic Separation Scheme (TSS) which was established for the regulation of maritime traffic in converging areas. He also analysed the vessel density in the Dover Strait together with the statistics and causes of the inter-ship collisions and hazardous incidents within the TSS.

Otay and Özkan (2003) developed a mathematical risk model to estimate the probability distribution of vessel casualties in the Istanbul Strait. In order to generate risk maps showing the expected number of accidents in different sections of the Strait, they developed a simulation model, which is based on the geographical characteristics, random distributions of surface currents, arrival of transit vessels, vessel sizes and pilotage error in the Istanbul Strait. Risk map of the Strait is generated for different vessel sizes and casualty types including collision, ramming and grounding. The model results indicate that the vessel length directly correlates with the casualty risk, when the same pilotage error is incorporated for all vessel types, regardless of vessel size or travel direction.

An example for using a Maritime Traffic Simulation Model as a decision tool for the traffic control authority is the traffic density analysis of proposed ferry service expansion in San Francisco. Merrick et al. (2003) investigated the risks associated with a dramatical increase in the frequency and coverage of ferry service in the San Francisco Bay area after it has been proposed to the California legislature. They developed a simulation model to estimate the number of vessel interactions in the current system and in the case of three alternative expansion plans. The output of the simulation model is a geographic risk map profile which shows the frequency of vessel interactions across the study area and represents the level of congestion under each alternative.

Franzese et al. (2004) developed a simulation model of the Panama Canal allowing the Panama Canal Authority to test different strategies for lock operations, as well as proposed locks and navigation channels. This simulation model, which incorporates vessel arrivals, traffic rules and vessel sequencing, is developed with the ARENA software. The results of this study indicate that the Panama Canal will face capacity problems in the next 5 to 10 years considering the Canal's current and future resources. This will have a negative impact on the Canal's long term competitiveness.

Some research is devoted to the design of vessel traffic management and information systems. İnce and Topuz (2004) outlined the design of a vessel traffic management system for the Turkish Straits and analyzed the design considerations and primary requirements of a vessel traffic system system in general. They described several models for the simulation of vessel motions, current conditions and vessel traffic flow such as Hydrodynamic Prediction Model (HPM) and Vessel Motions Model (VMM). According to the results of their study, potential maritime accident related casualties in Istanbul are expected to be reduced to levels below one fifth of the present level when a modern Vessel Traffic Management and Information Systems (VTMIS) has been implemented. They argue that modelling and simulation provides an effective means for system designers of vessel traffic services to improve their decisions about the formulations of rules and decisions necessary to minimize the probability of maritime accidents.

Filipowicz (2004) discussed several vessel traffic control decision problems belonging to NP-complete class of the generalized allocation problems (GAP), such as association of routes for particular vessels with their cost value. The study describes various metaheuristics or extended heuristics to solve these kind of vessel control problems.

Özbaş (2005) studied the maritime transit traffic in the Istanbul Strait by modeling the entrance procedures of the Strait, based on vessel types and lengths, prioritization of vessels for the entrance, pilotage and tugboat services and vessel transitions throughout the Strait. This study provided a simulation platform to analyze the effects of factors such as vessel traffic rules and regulations, number of available resources such as tugboats and pilots, vessel type and traffic density on the maritime traffic in the Istanbul Strait.

Liu et al. (2006) studied port and navigation safety issues in Taiwanese territorial waters where there have been 3428 marine accidents (with 548 deaths and 524 vessels sunk) over a 10-year period. Instead of descriptive statistical analysis or regression analysis, they have chosen the Grey Relational Analysis (GRA) as the data analysis methodology. Another study of port traffic risks, Yip T. L. (2006), applies negative binomial regression modeling to explain port accident injuries and fatalities in Hong Kong waters.

Yazıcı and Otay (2006) developed a hydrodynamics based mathematical model to simulate safe navigation of vessels in the Istanbul Strait. The model simulates possible maneuvers according to probable hydrodynamic conditions, using channel geometry, bathymetry, counter traffic and surface currents as inputs. Two different decision-making algorithms called “Grounding Only” and “Collision Combined” are used for cases with and without clear and present collision risk and for both cases, the routes with minimum casualty risk are found.

Almaz (2006) analyzed the fog occurrences and current conditions in the Istanbul Strait and developed stochastic visibility and current sub-models to improve and expand the simulation model originally developed by Özbaş (2005). He also analyzed specific traffic rules and regulations (such as overtaking and pursuit distance rules) and integrated these in the simulation model, together with the visibility and current submodels. He then performed scenario analysis to investigate the effects of vessel arrival rates, vessel profiles, pilot and tugboat availabilities, current conditions, pursuit distances between vessels, visibility and seasonal conditions on the performance measures in the Strait such as number and types of vessels passed, transit times and waiting times of vessels, number of vessels in the queues, vessel densities throughout in the Istanbul Strait and pilot and tugboat utilizations.

This simulation study expands the Istanbul Strait Maritime Traffic Simulation Model developed by Almaz (2006) to incorporate and analyze the impact of extreme weather conditions in the Marmara and/or Black Sea, vessel arrival processes and vessel prioritization (in gaining access to the Strait). This simulation model which provides a practical environment to analyse various scenarios regarding environmental and meteorological conditions, availability of support services and varied interpretations of the TSMTR&R.

3. DATA COMPILATION AND ANALYSIS

In this chapter, compilation and analysis of the data on arrival of transit vessels to the system, on storm occurrences and the effect of storm occurrences on vessel arrivals are presented and discussed. Following the analysis of data, model parameters and probability distributions are specified and the related input processes of the Istanbul Strait Maritime Traffic Simulation Model are developed.

3.1. The Arrival Processes

The arrival distributions deployed for the random generation of interarrival times of the vessels in the Istanbul Strait Maritime Traffic Simulation Model are based on the actual vessel arrivals in the Istanbul Strait in 2005. Arrival processes refer to the random generation of vessel interarrival times, vessel lengths, speeds, anchoring durations, pilot demands, tugboat demands and direct and indirect passing status based on vessel types, vessel length group and entering direction. Same vessel type and length classifications are applied as in the study of Almaz (2006).

Vessels are classified into 5 general types. The vessel types considered in the model are i) Passenger Vessels, ii) LNG-LPG Carrying Vessels, iii) Hazardous Material Carrying Vessels (HAZMAT), iv) Tankers and v) General Cargo Carrying Vessels. The vessel types are also subcategorized into 6 length groups, regarding the application of the TSMTR&R,. Table 3.1 and Table 3.2 illustrate the number of vessel arrivals in 2005 and their frequency distributions according to vessel and length type, respectively.

Table 3.1. The Number of Vessel Arrivals into Istanbul Strait in 2005

Vessel Type / Length [m]	***<50***	***50-100***	***100-150***	***150-200***	***200-250***	***250-300***	***Total in Type***
Passenger	96	1080	235	59	26	2	**1498**
LNG-LPG		127	83	71	51		**332**
HazMat	1	225	290	220	95	14	**845**
Tanker	5	2716	2038	2369	1321	712	**9161**
General Cargo	482	16905	19488	4795	1167	117	**42954**
Total in Length	**584**	**21053**	**22134**	**7514**	**2660**	**845**	**54790**

Table 3.2. Frequency Distribution of Vessel Arrivals into Istanbul Strait in 2005

Vessel Type / Length [m]	***<50***	***50-100***	***100-150***	***150-200***	***200-250***	***250-300***	***Total in Type***
Passenger	0,00175	0,01971	0,00429	0,00108	0,00047	0,00004	**0,02734**
LNG-LPG	0,00000	0,00232	0,00151	0,00130	0,00093	0,00000	**0,00606**
HazMat	0,00002	0,00411	0,00529	0,00402	0,00173	0,00026	**0,01542**
Tanker	0,00009	0,04957	0,03720	0,04324	0,02411	0,01300	**0,16720**
General Cargo	0,00880	0,30854	0,35569	0,08752	0,02130	0,00214	**0,78398**
Total in Length	**0,01066**	**0,38425**	**0,40398**	**0,13714**	**0,04855**	**0,01542**	**1,00000**

Interarrival times of vessels are separately analyzed for each vessel type, vessel length class and entrance direction. For Passenger vessels, direct/indirect passing status is taken into consideration instead of vessel length, for interarrival time analysis.

Interarrival distributions of vessels of the above mentioned classifications are fitted appropriate probability distributions through the Input Analyzer, as illustrated in Table A.1 and Table A.2.

For instance, the histogram and fitted distribution summary for interarrival times (in minutes) of 1019 northbound tankers with a length between 100-150 meters are shown in Figure 3.1 and Table 3.3, respectively. Both the histogram and the distribution summary are obtained from the Input Analyzer, where it selected the exponential distribution, with the scale parameter $\beta = 513$, as the best fitting probability distribution to represent the interarrival times of vessels in this class. The interarrival times histogram displayed in Figure 3.1 provides visual support that it is reasonable to accept the selected distribution. Furthermore, the p-value of the chi-square test for this fit is 0.405, (that is, appropriateness of the selected distribution for northbound tanker arrivals with a length between 100-150 meters is not rejected) and the square error associated with this fit is 0,000808. Hence, the exponential distribution with scale parameter $\beta = 513$ is accepted as the appropriate distribution for the northbound tanker vessel arrivals with a length between 100-150 meters.

As explained in detail for the 100-150 meters northbound tanker arrival case, in most of the cases, chi-square tests are satisfied for the selected distributions. However, in a few cases, the best fitting distributions are accepted as sufficient considering just square error terms and visual analysis of the histograms.

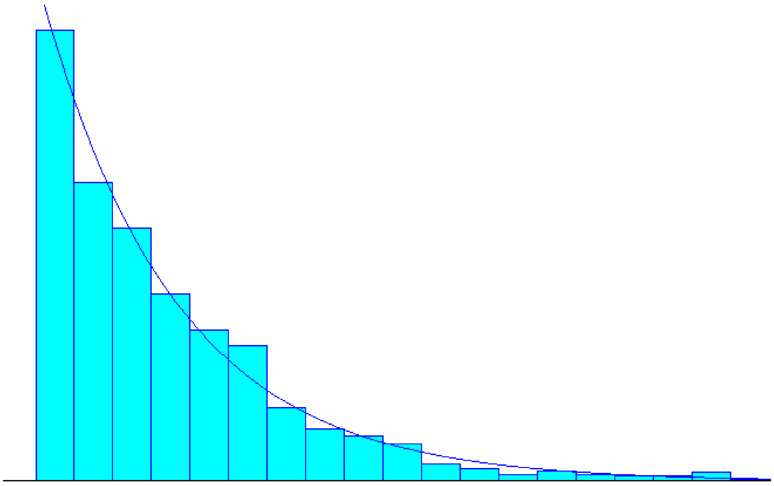


Figure 3.1. The Histogram of interarrival times of northbound tanker vessels length between 100-150 meters

Table 3.3. Distribution summary for interarrival times of northbound tanker vessels with length between 100-150 meters

Distribution:	Exponential
Expression:	EXPO(513)
Square Error:	0.000808
Chi Square Test	
Number of intervals =	14
Degrees of freedom =	12
Test Statistic =	12.7
Corresponding p-value =	0.405
Kolmogorov-Smirnov Test	
Test Statistic =	0.0221
Corresponding p-value =	> 0.15
Data Summary	
Number of Data Points =	1017
Min Data Value =	2
Max Data Value =	4.57e+003
Sample Mean =	515
Sample Std Dev =	510

For example, the histogram and the fitted distribution summary for the interarrival times of 9659 northbound general cargo vessels with length between 100 and 150 meters, is given in Figure 3.2 and Table 3.4, respectively.

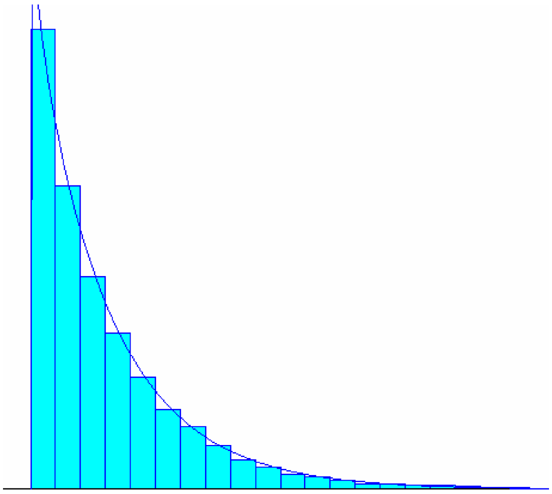
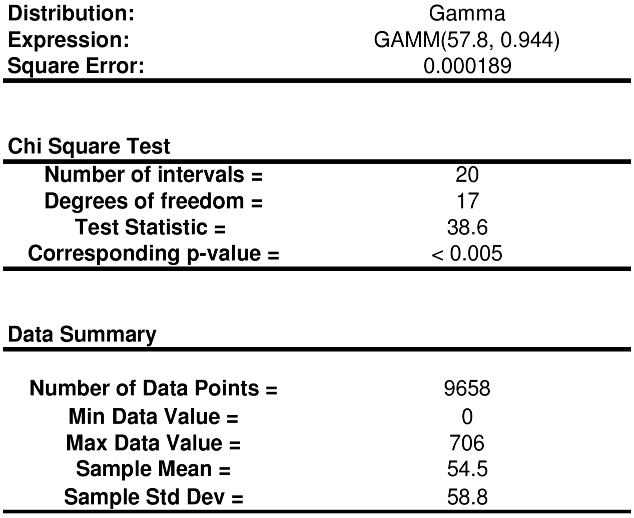


Figure 3.2. The Histogram of interarrival times of northbound general cargo vessels length between 100-150 meters

Table 3.4. Distribution summary for interarrival times of northbound general cargo vessels length between 100-150 meters



Distribution:	Gamma
Expression:	GAMM(57.8, 0.944)
Square Error:	0.000189
Chi Square Test	
Number of intervals =	20
Degrees of freedom =	17
Test Statistic =	38.6
Corresponding p-value =	< 0.005
Data Summary	
Number of Data Points =	9658
Min Data Value =	0
Max Data Value =	706
Sample Mean =	54.5
Sample Std Dev =	58.8

The best fitting distribution in this case (i.e. regarding the interarrivals of northbound general cargo vessels with a length of 100-150 meters), as selected by the Input Analyzer, is the Gamma distribution with parameters $\alpha = 57.8$ and $\beta = 0.944$.

As can be seen from Figure 3.2, even though visual observation indicates that this selection is quite reasonable, the p-value (of the chi-squared test) for this fit is below 0.005. On the other hand, the square error associated with this fit is very low and there is no better fit to this data set than the selected Gamma distribution. Therefore, the selected Gamma distribution with parameters $\alpha = 57.8$ and $\beta = 0.944$ is regarded to be sufficiently representative for the arrival process of the northbound general cargo vessels with a length between 100-150 meters (that is, appropriateness of the selected distribution for northbound general cargo vessel arrivals with a length between 100-150 meters is not rejected).

For vessel groups without sufficient data points, such as a few length groups in Tanker, Hazardous Material and LNG-LPG vessels, uniform distribution is assumed (Table A.1).

Exact lengths of all vessels are modelled according to the uniform distribution. While the arrival distributions are different for the defined vessel length groups, the exact length of vessels within their own length group is randomly determined based on a uniform distribution whose lower and upper limits are defined as the lower and upper limits of the vessel length group which the vessel belongs to.

The pilotage and tugboat usage in the Istanbul Strait is strongly recommended by the TSVTS to ensure safe navigation in the Strait. Frequency distributions of pilot requests and direct/indirect passing status of vessels for each cluster are illustrated in Table A.3 and Table A.4. The assumed probability distribution used is based on tugboat demand data for differing length classes of vessels of 1999 statistics, as no relavant data was available in the 2005 data (Table 3.5).

Average speed of all vessel types and lengths are analyzed separately and fitted appropriate probability distributions through the Input Analyzer. In most of the cases, triangular distribution is found to be the best fit (see Table A.5).

Table 3.5. Probability distribution for tugboat demand

Length (meters)	Probability
< 50	0.3
50 - 100	0.3
100 - 150	0.3
150 - 200	0.3
200 - 250	0.3
250 - 300	0.9
>300	1.0

3.2. Treatment of Storm Occurrences in the Vicinity of the Istanbul Strait

In this section, the effect of storm occurrences, in the vicinity of the Istanbul Strait, on the maritime transit traffic in the Strait is discussed. Stochastic analysis of storm occurrences and the resulting vessel arrival rate variations in the Istanbul Strait is named as the storm submodel.

The storm submodel is based on the following data of the last 26 years obtained from Kandilli Observatory and Earthquake Research Institute (KOERI):

- Historical daily wind direction statistics between 1981-2006 reported in cardinal and intercardinal directions
- Historical daily max. wind speed statistics between 1981-2006 reported in m/s

3.2.1. Analysis of Wind Speed and Wind Direction Data

The KOERI wind direction data is recorded according to the compass rose including the intercardinal directions (Figure 3.3).

In this study, this data is reclassified into the four cardinal directions, in order to analyse the main effect of the prevailing primary winds separately. Table 3.6 displays the conversion principles deployed in the reclassification of wind data into four main cardinal directions.

A strict meteorological definition of a terrestrial storm is a wind with a speed of 24.5 m/s (89 km/h, 55 mph) or more; however, this classification is not restrictive.

On the other hand, the Beaufort scale (displayed in Table 3.7) is an empirical measure for describing wind intensity, based mainly on observed sea conditions.According to the Beuafort Wind Force scale obtained from Turkish State Meterological Service, the term storm is used for winds measuring 8 or higher on the Beaufort Scala, which is also accepted in this study.

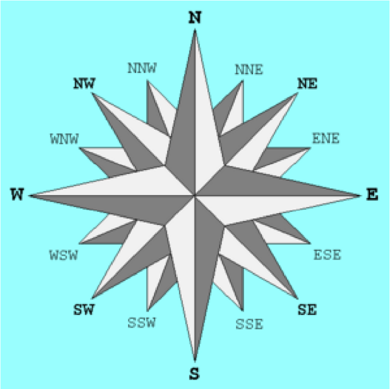


Figure 3.3. Compass Rose

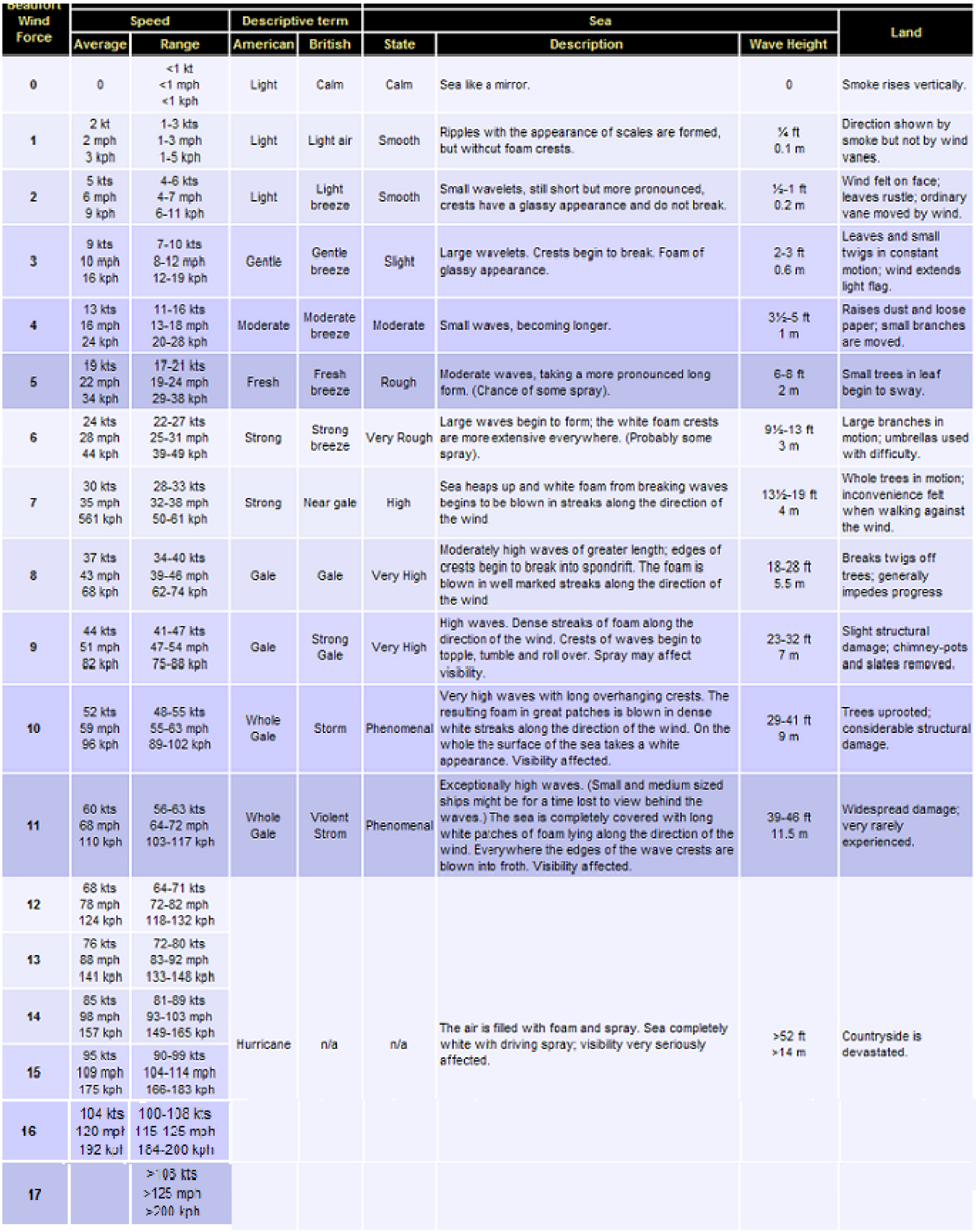
Table 3.6. Wind Directions in Data Set and Their Reclassification into four Cardinal Directions

Wind Direction(s)	Categorized Wind Direction	Wind Direction(s)	Categorized Wind Direction
S	**3**	**N**	**1**
SW	3	**NW**	1
SE	3	**NE**	1
SSW	3	**NNW**	1
SSE	3	**NNE**	1
S-N	3	**N-NNW**	1
SWW	3	**N-NE**	1
SEW	3	**NNW-N**	1
E	**2**	**NNW-S**	1
ESE	2	**NW-S**	1
ENE	2	**NSW**	1
E-NW	2	**NS**	1
W	**4**	**NN**	1
WSW	4	**NEN**	1
WNW	4	**NEE**	1
W-NW	4		

Accordingly, The KOERI wind speed data is analysed and recategorized into two classes:

- '0' corresponding to "no storm case", for wind occurrences having daily max. speed less than 17.2 m/s, (equivalent to the Beuafort number less than 8)

Table 3.7. Beuafort Wind Force scale



Beaufort Wind Force	Speed		Descriptive term		Sea			Land
	Average	Range	American	British	State	Description	Wave Height	
0	0	<1 kt <1 mph <1 kph	Light	Calm	Calm	Sea like a mirror.	0	Smoke rises vertically.
1	2 kt 2 mph 3 kph	1-3 kts 1-3 mph 1-5 kph	Light	Light air	Smooth	Ripples with the appearance of scales are formed, but withcut foam crests.	¼ ft 0.1 m	Direction shown by smoke but not by wind vanes.
2	5 kts 6 mph 9 kph	4-6 kts 4-7 mph 6-11 kph	Light	Light breeze	Smooth	Small wavelets, still short but more pronounced, crests have a glassy appearance and do not break.	½-1 ft 0.2 m	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3	9 kts 10 mph 16 kph	7-10 kts 8-12 mph 12-19 kph	Gentle	Gentle breeze	Slight	Large wavelets. Crests begin to break. Foam of glassy appearance.	2-3 ft 0.6 m	Leaves and small twigs in constant motion; wind extends light flag.
4	13 kts 16 mph 24 kph	11-16 kts 13-18 mph 20-28 kph	Moderate	Moderate breeze	Moderate	Small waves, becoming longer.	3½-5 ft 1 m	Raises dust and loose paper; small branches are moved.
5	19 kts 22 mph 34 kph	17-21 kts 19-24 mph 29-38 kph	Fresh	Fresh breeze	Rough	Moderate waves, taking a more pronounced long form. (Chance of some spray).	6-8 ft 2 m	Small trees in leaf begin to sway.
6	24 kts 28 mph 44 kph	22-27 kts 25-31 mph 39-49 kph	Strong	Strong breeze	Very Rough	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray).	9½-13 ft 3 m	Large branches in motion; umbrellas used with difficulty.
7	30 kts 35 mph 561 kph	28-33 kts 32-38 mph 50-61 kph	Strong	Near gale	High	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	13½-19 ft 4 m	Whole trees in motion; inconvenience felt when walking against the wind.
8	37 kts 43 mph 68 kph	34-40 kts 39-46 mph 62-74 kph	Gale	Gale	Very High	Moderately high waves of greater length; edges of crests begin to break into spondrift. The foam is blown in well marked streaks along the direction of the wind	18-28 ft 5.5 m	Breaks twigs off trees; generally impedes progress
9	44 kts 51 mph 82 kph	41-47 kts 47-54 mph 75-88 kph	Gale	Strong Gale	Very High	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility.	23-32 ft 7 m	Slight structural damage; chimney-pots and slates removed.
10	52 kts 59 mph 96 kph	48-55 kts 55-63 mph 89-102 kph	Whole Gale	Storm	Phenomenal	Very high waves with long overhanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. Visibility affected.	29-41 ft 9 m	Trees uprooted; considerable structural damage.
11	60 kts 68 mph 110 kph	56-63 kts 64-72 mph 103-117 kph	Whole Gale	Violent Strom	Phenomenal	Exceptionally high waves. (Small and medium sized ships might be for a time lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	39-46 ft 11.5 m	Widespread damage; very rarely experienced.
12	68 kts 78 mph 124 kph	64-71 kts 72-82 mph 118-132 kph	Hurricane	n/a	n/a	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	>52 ft >14 m	Countryside is devastated.
13	76 kts 88 mph 141 kph	72-80 kts 83-92 mph 133-148 kph						
14	85 kts 98 mph 157 kph	81-89 kts 93-103 mph 149-165 kph						
15	95 kts 109 mph 175 kph	90-99 kts 104-114 mph 166-183 kph						
16	104 kts 120 mph 192 kph	100-108 kts 115-125 mph 184-200 kph						
17		>108 kts >125 mph >200 kph						

- '1' corresponding to "storm occurrence" for wind occurances having a daily speed equal to or higher than 17.2 m/s, (equivalent to the Beuafort number equal to or more than 8).

Combining the storm occurrences based on the wind speed data with the recategorized wind directions data, the daily and weekly storm occurrence and direction analysis for the last 26 years could be made.

The daily/weekly storm occurrence analysis is first accomplished for all directions in order to assess a general storm frequency in the Istanbul region. Then, the storm frequencies in different directions are analyzed. The resulting count of storm occurrences on a weekly basis is displayed in Table 3.8, Table 3.9, Table 3.10 and Table 3.11 for each of the four cardinal directions.

Table 3.8. Weekly Storm Occurrence Frequency for Storms from North Direction

Week	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0,19
2	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0,27
3	0	0	0	1	0	1	0	0	1	0	1	0	0	0	2	2	0	0	0	0	0	0	0	0	1	0	0,35
4	0	0	0	0	0	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	0	0	0	3	0	3	0,50
5	0	3	0	0	2	1	0	2	0	0	1	0	0	2	1	0	0	0	0	0	0	0	1	0	1	0	0,54
6	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	2	0	0,31
7	0	0	1	0	2	1	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	1	0	0	0,35
8	0	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	3	0	0	0	0,38
9	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0,19
10	0	0	0	2	0	0	2	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0,27
11	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,12
12	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	1	0	0	0	0	0,23
13	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	1	0	0	1	0	0,23
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0,12
15	0	0	0	0	0	0	1	1	0	0	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0,23
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
17	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,04
18	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
20	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0,04
22	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0,15
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0,08
24	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,04
25	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
26	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
27	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0,12
28	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
29	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0,08
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0,04
31	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0,04
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
33	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0,19
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0,12
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0,08
36	0	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0,23
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
38	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	0	0,15
40	0	0	0	0	0	2	0	1	2	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0,31
41	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
42	0	1	0	0	4	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0,31
43	0	0	0	0	1	1	1	2	0	1	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0,35
44	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0,19
45	0	3	0	0	1	0	0	1	0	3	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0,38
46	0	0	1	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0,31
47	0	0	0	0	0	0	0	0	1	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	1	0	0,23
48	0	0	0	0	1	1	0	0	1	0	0	0	0	1	0	0	0	0	0	2	0	0	0	1	0	0	0,27
49	0	0	0	0	0	0	2	1	0	0	3	0	0	1	0	0	2	0	0	0	5	1	1	0	0	0	0,62
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0,12
51	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	2	2	2	0	0	0	0,38
52	1	0	0	0	0	1	0	1	0	1	2	0	0	0	0	2	0	1	1	0	0	0	1	0	0	0	0,42
53	0	2	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0,15
Grand Total	**1**	**15**	**4**	**5**	**25**	**14**	**12**	**14**	**16**	**11**	**11**	**7**	**3**	**12**	**12**	**8**	**9**	**9**	**6**	**10**	**15**	**8**	**15**	**10**	**10**	**4**	**10,23**

Table 3.9. Weekly Storm Occurrence Frequency for Storms from South Direction

Week	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
1	0	1	0	0	4	4	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	1	0	0	0	0,54
2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0,15
3	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0,19
4	0	0	0	1	2	2	2	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	1	0	0,46
5	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0,19
6	0	0	0	1	2	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0	0	0	2	0	0	0	0,38
7	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	0,38
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	0,19
9	0	0	0	0	0	0	0	2	4	2	0	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0,46
10	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0,15
11	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0,12
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0,12
13	0	1	0	0	0	0	0	0	0	0	0	3	0	0	2	0	1	0	0	1	0	0	0	1	0	0	0,35
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0,04
15	0	0	0	0	3	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0,27
16	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0,15
17	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0,12
18	0	1	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,15
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0,04
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0,04
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
23	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0,08
24	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,04
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
30	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,04
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0,04
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0,04
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0,04
41	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0,12
42	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0,08
44	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,08
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0,04
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0,08
47	0	0	0	0	0	0	1	3	1	2	0	0	0	0	1	1	0	0	1	0	1	0	0	2	0	0	0,50
48	0	0	2	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0,23
49	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0	0,23
50	4	1	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0,35
51	1	3	0	0	0	1	0	0	0	0	0	0	2	0	0	0	1	0	1	1	0	0	0	0	1	0	0,42
52	0	0	0	0	1	0	0	0	0	0	0	0	3	0	4	1	0	0	3	2	0	1	0	0	0	0	0,58
53	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0,19
Grand Total	**7**	**8**	**3**	**3**	**18**	**10**	**6**	**9**	**10**	**11**	**3**	**5**	**7**	**2**	**18**	**3**	**9**	**6**	**15**	**8**	**11**	**2**	**10**	**8**	**6**	**3**	7,73

Table 3.10. Weekly Storm Occurrence Frequency for Storms from East Direction

Week	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**0,04**
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**0,04**
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**0,04**
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	**0,04**
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
46	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,12**
47	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,08**
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
Grand Total	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	0,35

Table 3.11. Weekly Storm Occurrence Frequency for Storms from West Direction

Week	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**0,04**
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**0,04**
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**0,04**
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	**0,08**
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
19	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,04**
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	**0,04**
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,00**
Grand Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**2**	**0**	**0**	**2**	**0**	**1**	0,27

Tables 3.8, Table 3.9, Table 3.10 and Table 3.11 clearly highlight the strong storm occurrence variation among different directions. It can be seen that the winds from the North and South directions lead to far more storm occurrences in the Istanbul region than those from the East or West directions.

As there is not sufficient data for the storms from East and West directions, and since such storm occurences are indeed quite rare, seasonal analysis is made only for the storms from cardinal directions North and South.

3.2.2. Modeling of Storm Occurrences in Different Seasons

Besides the variation due to different directions, a seasonal variation is also foreseen and analysed.

To analyze the seasonal variation of storm occurrences and to smooth out the seasonality effect, moving average of 31 days are calculated for each day in the year. The resulting storm occurrence frequency distribution of days is displayed in Figure

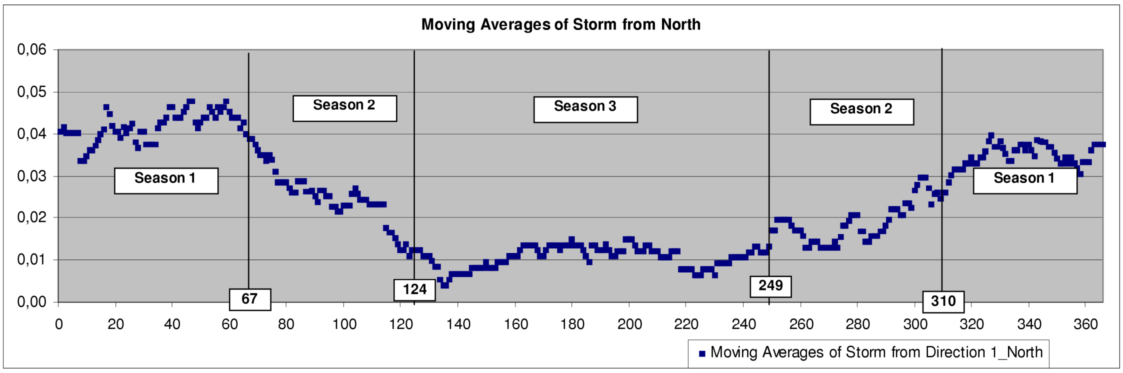


Figure 3.4. Moving Averages for Storm Occurrences from North Direction

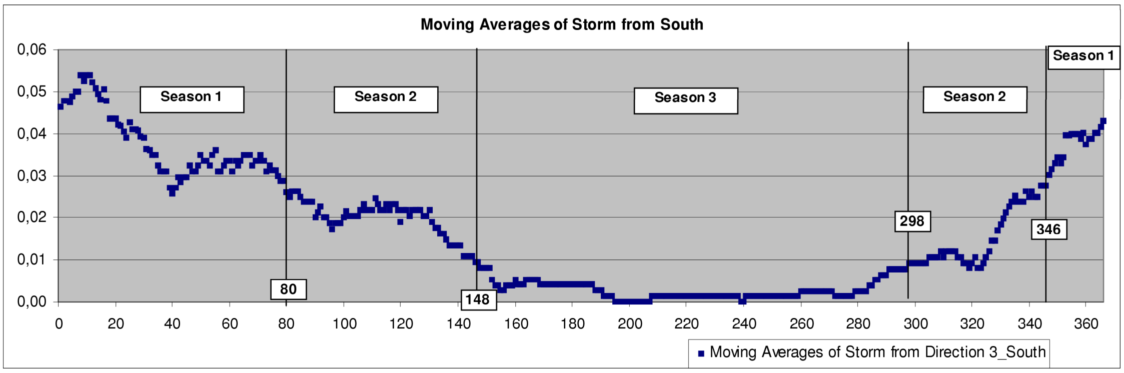


Figure 3.5. Moving Averages for Storm Occurrences from South Direction

3.4 and Figure 3.5, respectively, for the two cardinal directions North and South. The storm occurrence frequency distribution of days is based on the number of storms observed in the last 26 years.

Based on the graphs displayed in Figures 3.4 and 3.5, a year is classified into 3 seasons. These seasons are (1) winter, (2) fall/spring and (3) summer. The days that fall in these seasons are shown in Table 3.12.

Table 3.12. Seasonal Periods for Storm Occurrences from North and South Directions

Season / Storm Direction	NORTH	SOUTH
Season -1	Day 1 - Day 67	Day 1 - Day 80
	Day 310 - Day 365	Day 346 - Day 365
Season - 2	Day 68 - Day 124	Day 81 - Day 148
	Day 249 - Day 309	Day 298 - Day 345
Season - 3	Day 125 - Day 248	Day 149 - Day 297

Interarrival times of storms in such determined seasons are independently analyzed for the cardinal directions North and South. For each season, for both directions, interarrival distributions are fitted appropriate probability distributions (see Table 3.13) through the Input Analyzer.

Table 3.13. Fitted Distributions to Storm Interarrivals from North and South Directions for 3 Seasons

Season / Storm Direction	**NORTH**	**SOUTH**
Season -1	2.88e+003 + EXPO(3.12e+004)	1.44e+003+EXPO(3.06e+004)
Season - 2	2.88e+003 + EXPO(7.14e+004)	1.44e+003+EXPO(5.33e+004)
Season - 3	1.44e+003 + EXPO(8.99e+004)	NORM(5.21e+005,2.37e+005)

For instance, the histogram and the fitted exponential probability distribution for the interarrival times of 118 storm occurrences from the North direction in Season 1 are shown in Figure 3.6 and Table 3.14, respectively. Both the histogram and the distribution summary are obtained from the Input Analyzer, where it selected the exponential distribution with scale parameter $\beta = 31200$ as the best fit for the interarrival data. The histogram displayed in Figure 3.6 also visually supports that it is reasonable to accept the selected distribution. Furthermore, the p-value of the chi-square test for this test equals 0.321, while square error term is 0.002598. Hence, exponential distribution with scale parameter $\beta = 31200$ is accepted as the appropriate interarrival distribution for the storm occurrences from North direction in Season 1 (that is, appropriateness of the selected distribution for Northerly storm occurrences in Season 1 is not rejected).

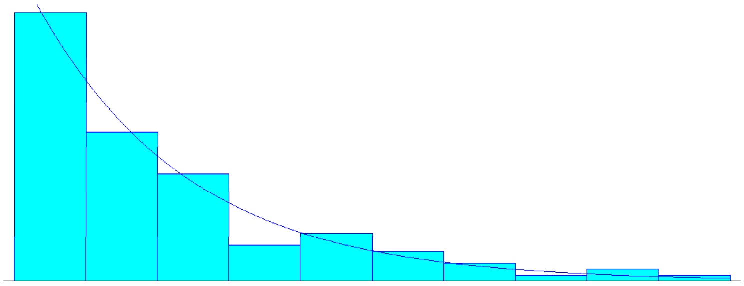


Figure 3.6. The Histogram of Interarrival Times of Storm Occurrences in Season 1 from North Direction

Table 3.14. Distribution Summary for Interarrival Times of Storm Occurrences in Season 1 from North Direction

Distribution:	Exponential
Expression:	2.88e+003 + EXPO(3.12e+004)
Square Error:	0.002598

Chi Square Test	
Number of intervals =	5
Degrees of freedom =	3
Test Statistic =	3.61
Corresponding p-value =	0.321

Kolmogorov-Smirnov Test	
Test Statistic =	0.0587
Corresponding p-value =	> 0.15

Data Summary	
Number of Data Points =	114
Min Data Value =	2.88e+003
Max Data Value =	1.5e+005
Sample Mean =	3.4e+004
Sample Std Dev =	3.08e+004

3.2.3. Modeling of Storm Durations

In modeling storm durations, the duration of each storm in three seasons and both from North and South directions are seperately analyzed with the Input Analyzer, to determine their best fitting probability distributions. Since wind speed data was available only on a daily basis showing the maximum wind speed observed during the given date, without any indication regarding its beginning and ending time, each data point indicating a wind speed greater than 17.2 m/s is assumed to be a storm occurrence with a duration of one whole day. In this respect, two (or more) consecutive days with recorded wind speeds greater than 17.2 m/s, are regarded as one storm with a duration of two (or more) days. By conducting a further analysis together with experts from the Turkish State Meteorological Services, storm durations can be estimated more realistically and more flexibly than the assumption of this study that an observation of a wind speed greater than 17.2 m/s indicates a storm occurrence of one whole day.

Graphs on Figure 3.7. display the so compiled histograms of storm occurrences according to storm duration, season and direction.

Then it is attempted to fit appropriate proability distributions to the storm duration data through the Input Analyzer (for each season and storm direction). However, Chi-Squared tests were unsatisfied and squared errors were too high in many cases (Table 3.15).

On the other hand, as illustrated in Figure 3.8, the great majority of storm durations in Season 1 from North Direction are observed to be 1 day long (as observed in all seasons); so, considering that the error involved would not be greatly significant, uniform distribution has been accepted as the random representation of storm durations. Probability distributions of storm durations such determined are displayed in Table 3.16.

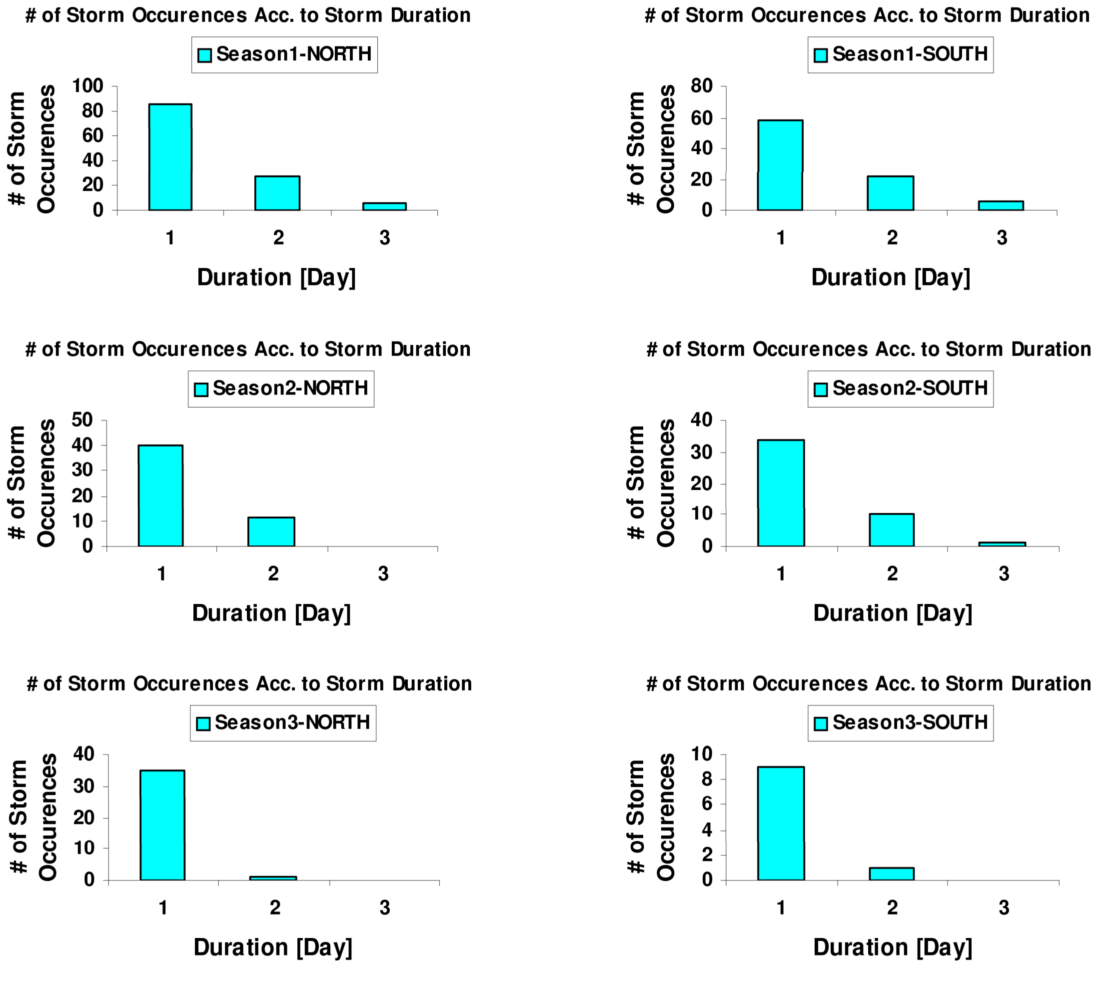


Figure 3.7. The Histogram of Number of Storm Occurrences with Different Durations from North and South Directions in 3 Seasons

Table 3.15. Distribution Summary for Storm Durations in Season 1 from North Direction

Distribution:	Exponential
Expression:	0.05+EXPO(0.828)
Square Error:	0.00091

Chi Square Test	
Number of intervals =	2
Degrees of freedom =	0
Test Statistic =	0.262
Corresponding p-value =	<0.005

Kolmogorov-Smirnov Test	
Test Statistic =	0.0545
Corresponding p-value =	> 0.15

Data Summary	
Number of Data Points =	119
Min Data Value =	1
Max Data Value =	3
Sample Mean =	1.33
Sample Std Dev =	0.569

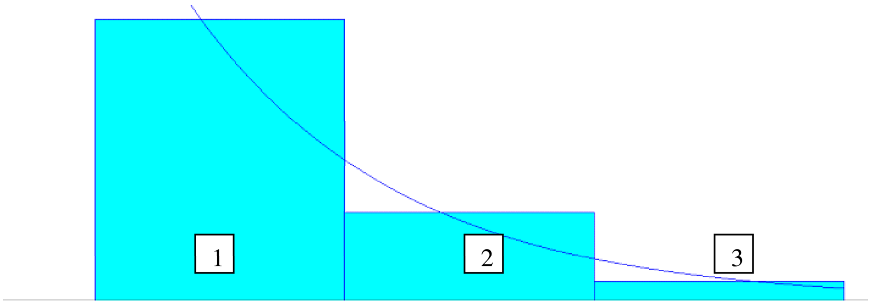


Figure 3.8. The Histogram of Number of Storm Occurrences with given Durations in Season 1 from North Direction

Table 3.16. Fitted Distributions for Storm Durations from North and South Directions in 3 Seasons

Season / Storm Direction	NORTH	SOUTH
Season -1	DISC(0.72,1,0.95,2,1,3)	DISC(0.67,1,0.93,2,1,3)
Season - 2	DISC(0.78,1,1,2)	DISC(0.76,1,0.98,2,1,3)
Season - 3	DISC(0.97,1,1,2)	DISC(0.90,1,1,2)

3.2.4. Analyzing the Effect of Storm Occurrences on Vessel Arrival Rates

In this subsection, the effect of storm occurrences on vessel arrival rates is discussed. In order to identify the effect of storm occurrences on vessel arrivals, vessel arrival dates are classified into 15 day classes according to the presence of a storm occurrence on the given vessel arrival date or up to 3 days before/after this. This classification has been done for storm occurences from two cardinal directions North and South separately (Table 3.17).

Table 3.17. Day Classification according to Storm Occurrences from North and South Directions

NoStorm	Day without any Storm Occurence
3DaysBeforeStormDir-1	3 Days Before a Storm Occurence from North
2DaysBeforeStormDir-1	2 Days Before a Storm Occurence from North
1DayBeforeStormDir-1	1 Day Before a Storm Occurence from North
StormDayDir-1	Stormy Day
1DayAfterStormDir-1	1 Day After a Storm Occurence from North
2DaysAfterStormDir-1	2 Days After a Storm Occurence from North
3DaysAfterStormDir-1	3 Days After a Storm Occurence from North
3DaysBeforeStormDir-3	3 Days Before a Storm Occurence from South
2DaysBeforeStormDir-3	2 Days Before a Storm Occurence from South
3DayBeforeStormDir-3	1 Day Before a Storm Occurence from South
StormDayDir-3	Stormy Day
3DayAfterStormDir-3	1 Day After a Storm Occurence from South
2DaysAfterStormDir-3	2 Days After a Storm Occurence from South
3DaysAfterStormDir-3	3 Days After a Storm Occurence from South

Vessel arrivals are further classified into six length groups, (same as those previously determined for analysing the arrival process), to investigate whether the effect of storm occurrence on vessel arrivals differs with length of vessels.

Additionally, northbound and southbound arrivals are analyzed separately, as the effect of storm occurrences on vessel arrivals may differ according to the direction of the storm and the travel direction of the vessel.

As an example, Table 3.18 illustrates the number of northbound general cargo vessels in 2005, for each length group separately, according to the day and direction classification of the storm occurrences with respect to their arrival date, together with the number of days that fall into the determined day classes.

Table 3.18. The Annual Number of Northbound General Cargo Vessel Arrivals according to the presence of / closeness to Storm Occurrences

Ship Type-GENERAL CARGO	S-N						
NUMBER OF SHIPS/LENGTH		Length 0 (<50)	Length 1 (50-100)	Length 2 (100-150)	Length 3 (150-200)	Length 4 (200-250)	Length 5 (250-300)
# of Days Acc to Storm Occurence		# of Ships Arrived on the Given Day Classification					
NoStorm	271	184	6601	7317	1801	413	40
3DaysBeforeStormDir-NORTH	7	4	122	173	41	11	0
2DaysBeforeStormDir-NORTH	7	2	122	151	40	12	1
1DayBeforeStormDir-NORTH	8	5	84	133	53	13	3
StormDayDir-NORTH	10	**2**	**103**	**144**	**53**	**23**	**1**
1DayAfterStormDir-NORTH	7	1	163	209	41	10	1
2DaysAfterStormDir-NORTH	7	2	230	210	55	19	1
3DaysAfterStormDir-NORTH	7	7	187	249	59	14	0
3DaysBeforeStormDir-SOUTH	6	3	129	180	34	6	3
2DaysBeforeStormDir-SOUTH	6	5	146	185	35	5	0
1DayBeforeStormDir-SOUTH	6	6	126	161	39	8	0
StormDayDir-SOUTH	6	**3**	**110**	**130**	**25**	**9**	**2**
1DayAfterStormDir-SOUTH	6	3	119	150	52	16	2
2DaysAfterStormDir-SOUTH	6	5	85	135	29	11	0
3DaysAfterStormDir-SOUTH	6	4	112	132	37	12	0

The same classification of storm occurrences, as in the Table 3.18, is made for each vessel type and for northbound and southbound vessels, respectively. These tables obtained are then converted into interarrival time tables by dividing the number of days that fall into a specific day class (according to the storm occurrence, closeness and direction) by the number of vessels arrived in these days. To obtain the arrival rates of vessels for each day group and vessel length, this calculation is made for each length group separately.

As an example, Table 3.19 illustrates the interarrival times such obtained for each day and direction combination of the storm occurrence, for different vessel length groups of northbound general cargo vessels.

For each vessel type and direction (northbound or southbound) these tables are converted into unitless “adjustment coefficients”, by dividing the interarrival time of a specific day class and vessel length, to the interarrival time of the same vessel length in the day class “No Storm”.

As an example, Table 3.20 illustrates the interarrival time adjustment coefficients for differing length groups of northbound general cargo vessels. In this context, an adjustment coefficient larger than 1 means a decrease in the rate of vessel arrivals in the associated storm related days (i.e. pre, after and/or storm occurrence days) with respect to “no storm” days, whereas an adjustment coefficient smaller than 1 means an increase in the rate of vessel arrivals (again in the associated storm related days, with respect to “no storm” days).

Table 3.19. The Average Interarrival Times of Northbound General Cargo Vessels according to the presence of / closeness to Storm Occurrences

Ship Type-GENERAL CARGO	S-N						
NUMBER OF SHIPS/LENGTH		Length 0 (<50)	Length 1 (50-100)	Length 2 (100-150)	Length 3 (150-200)	Length 4 (200-250)	Length 5 (250-300)
# of Days Acc to Storm Occurence		Interrrival Times of Vessels on the Given Day Classification					
NoStorm	271	1.47	0.04	0.04	0.15	0.66	6.78
3DaysBeforeStormDir-NORTH	7	1.75	0.06	0.04	0.17	0.64	n/a
2DaysBeforeStormDir-NORTH	7	3.50	0.06	0.05	0.18	0.58	7.00
1DayBeforeStormDir-NORTH	8	1.60	0.10	0.06	0.15	0.62	2.67
StormDayDir-NORTH	10	**5.00**	**0.10**	**0.07**	**0.19**	**0.43**	**10.00**
1DayAfterStormDir-NORTH	7	7.00	0.04	0.03	0.17	0.70	7.00
2DaysAfterStormDir-NORTH	7	3.50	0.03	0.03	0.13	0.37	7.00
3DaysAfterStormDir-NORTH	7	1.00	0.04	0.03	0.12	0.50	n/a
3DaysBeforeStormDir-SOUTH	6	2.00	0.05	0.03	0.18	1.00	2.00
2DaysBeforeStormDir-SOUTH	6	1.20	0.04	0.03	0.17	1.20	n/a
1DayBeforeStormDir-SOUTH	6	1.00	0.05	0.04	0.15	0.75	n/a
StormDayDir-SOUTH	6	**2.00**	**0.05**	**0.05**	**0.24**	**0.67**	**3.00**
1DayAfterStormDir-SOUTH	6	2.00	0.05	0.04	0.12	0.38	3.00
2DaysAfterStormDir-SOUTH	6	1.20	0.07	0.04	0.21	0.55	n/a
3DaysAfterStormDir-SOUTH	6	1.50	0.05	0.05	0.16	0.50	n/a

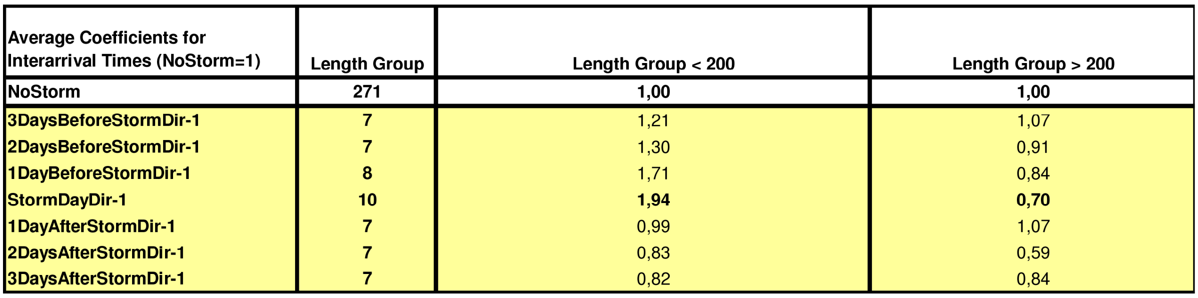
Table 3.20. Interarrival Time Adjustment Coefficients of Northbound General Cargo Vessels according to the presence of / closeness to Storm Occurrences

Ship Type-GENERAL CARGO	S-N						
NUMBER OF SHIPS/LENGTH		Length 0 (<50)	Length 1 (50-100)	Length 2 (100-150)	Length 3 (150-200)	Length 4 (200-250)	Length 5 (250-300)
# of Days Acc to Storm Occurence		Interarrival Time Ratios of Vessels on the Given Day Classification					
NoStorm	271	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
3DaysBeforeStormDir-NORTH	7	1.19	1.40	1.09	1.13	0.97	n/a
2DaysBeforeStormDir-NORTH	7	2.38	1.40	1.25	1.16	0.89	1.03
1DayBeforeStormDir-NORTH	8	1.09	2.32	1.62	1.00	0.94	0.39
StormDayDir-NORTH	10	**3.39**	**2.36**	**1.88**	**1.25**	**0.66**	**1.48**
1DayAfterStormDir-NORTH	7	4.75	1.05	0.90	1.13	1.07	1.03
2DaysAfterStormDir-NORTH	7	2.38	0.74	0.90	0.85	0.56	1.03
3DaysAfterStormDir-NORTH	7	0.68	0.91	0.76	0.79	0.76	n/a
3DaysBeforeStormDir-SOUTH	6	1.36	1.13	0.90	1.17	1.52	0.30
2DaysBeforeStormDir-SOUTH	6	0.81	1.00	0.88	1.14	1.83	n/a
1DayBeforeStormDir-SOUTH	6	0.68	1.16	1.01	1.02	1.14	n/a
StormDayDir-SOUTH	6	**1.36**	**1.33**	**1.25**	**1.59**	**1.02**	**0.44**
1DayAfterStormDir-SOUTH	6	1.36	1.23	1.08	0.77	0.57	0.44
2DaysAfterStormDir-SOUTH	6	0.81	1.72	1.20	1.37	0.83	n/a
3DaysAfterStormDir-SOUTH	6	1.02	1.30	1.23	1.08	0.76	n/a

Further analysis of such vessel interarrival changes (due to storm) reveals that, in general, storm occurences have a similar effect on the arrival frequency of all vessels with a length less than 200 meters, so the given six different length groups are aggregated into just two length groups.

Furthermore, it is observed that effect of storms on vessel interarrival times are considerably larger for Northerly storms than as those from the South. Hence, the effect of storms from South direction are not included in the analysis any further.

Table 3.21. Interarrival Time Adjustment Coefficients of Northbound General Cargo Vessels according to the presence of / closeness to Northerly Storm Occurrences



Average Coefficients for Interarrival Times (NoStorm=1)	**Length Group**	**Length Group < 200**	**Length Group > 200**
NoStorm	**271**	**1,00**	**1,00**
3DaysBeforeStormDir-1	**7**	1,21	1,07
2DaysBeforeStormDir-1	**7**	1,30	0,91
1DayBeforeStormDir-1	**8**	1,71	0,84
StormDayDir-1	**10**	**1,94**	**0,70**
1DayAfterStormDir-1	**7**	0,99	1,07
2DaysAfterStormDir-1	**7**	0,83	0,59
3DaysAfterStormDir-1	**7**	0,82	0,84

As an example, Table 3.21 displays the interarrival time adjustment coefficients for day classes related to Northerly storm occurrences, with respect to the day class "no storm", for northbound general cargo vessels aggregated into two length groups.

Possible interarrival time changes for all northbound and southbound vessels, under northerly storm occurrences, are incorporated into the vessel arrival distributions by adjusting the mean arrival rate of the associated interarrival time distribution (which was obtained for the "no storm" case) to reflect the determined rate increase/decrease (i.e. by multiplying the mean arrival parameter with the appropriate adjustment coefficients displayed in Table 3.21) for northbound general cargo vessels. Thus, in simulation runs, vessel interarrival rates will be changing dynamically, according to the presence of / closeness to storm. On time-windows without any storm occurrence, all adjustment coefficients are set to "1". When the storm submodel signals a storm, the interarrival time distribution governing vessel generations falling to the storm time-window are individually adjusted with respect to vessel length, vessel type, direction of transit and presence of / closeness to storm, in order to increase / decrease vessel arrival rates appropriately.

Furthermore, before integrating the interarrival time adjustment coefficients into the arrival distributions, all adjustment coefficients are carefully analyzed for their applicability. For the cases, where there were not sufficient data points to enable a conclusion that the calculated interarrival time adjustment coefficients may reflect a general behaviour, the coefficient is set simply to 1 throughout the whole simulation run regardless of the storm occurrences, (i.e. not changing the interarrival times). For the cases, where such determined interarrival time adjustment coefficients along days preceeding, on, and following storm occurences reflected a random behaviour, not providing any reasonable pattern, the corresponding adjustment coefficients are also set to 1, (reflecting the belief that adjustment coefficient differences are purely caused by the random behaviour of the underlying distributions).

The coefficients highlighted in yellow in Table 3.22 indicate the interarrival time adjustments incorporated into the model. Those highlighted in black are found not to indicate a meaningful behaviour, so that they are not incorporated into the model, and for the corresponding cases, adjustment coefficients are set to "1" through the whole simulation.

Table 3.22. Differentiation of Interarrival Time Adjustment Coefficients of Northbound General Cargo Vessels to be incorporated into the Simulation Model

Average Coefficients for Interarrival Times (NoStorm=1)	Length Group	Length Group < 200	Length Group > 200
NoStorm	**271**	**1.00**	**1.00**
3DaysBeforeStormDir-1	**7**	1.21	**1.07**
2DaysBeforeStormDir-1	**7**	1.30	**0.91**
1DayBeforeStormDir-1	**8**	1.71	0.84
StormDayDir-1	**10**	**1.94**	**0.70**
1DayAfterStormDir-1	**7**	**0.99**	**1.07**
2DaysAfterStormDir-1	**7**	0.83	0.59
3DaysAfterStormDir-1	**7**	0.82	0.84

Table 3.22 indicates an increase in the interarrival times of northbound general cargo vessels having lengths less than 200 m, up to three days before and during the storm occurrence, (hence a decrease in the number of arrivals). For these vessel types,

after the storm, the interarrival times decrease, indicating an increase in vessel arrivals. This behaviour can be explained as follows: small to medium size northbound general cargo vessels do not prefer to sail in stormy weather conditions, so they tend to postpone their arrival after the storm. On the other hand, for large size vessels (those longer than 200 m), stormy weather conditions do not cause problems, and the decrease in the arrival rate of the other vessels may actually encourage them to prefer and adjust their arrivals in such weather conditions. Alternatively, the speeding up of vessel arrivals of large size vessels on stormy days can be traced back to our assumption that a wind speed larger than 17.2 m/s indicates a storm occurrence of a whole day on the given date. Large size vessels might have come in the morning hours of a stormy day, when the storm occurrence took place in the later hours of that day, so that our assumption of storm duration causes to observe an accelaration in the large size vessel arrivals on the stormy days, even though they might have arrived just before the storm.

Another possibility is that, general cargo vessels with a length greater than 200 m may not be able to postpone their sailing schedules and with the stormy conditions in the sea posing a danger on such vessels, they prefer to live out the storm in calmer conditions of the Strait. Thus they speed to arrive at the Strait before and during the storm more often than usual.

For the case of LNG-LPG vessels, the arrival frequency of the vessels are very low, so that any generalization of the vessel arrivals according to the storm occurrence is hardly possible. In this case, all the defined interarrival adjustment coefficients are set to “1”, so that no changes are made to the arrival rates. Table 3.23. and Table 3.24. display the number of vessel arrivals under storm occurrences and interarrival time adjustment coefficients for northbound LNG-LPG vessels, respectively.

Table 3.23. The Annual Number of Northbound LNG-LPG Vessel Arrivals according to the presence of / closeness to Northerly Storm Occurences

Ship Type-LPG-LNG	S-N						
NUMBER OF SHIPS/LENGTH		Length 0	Length 1	Length 2	Length 3	Length 4	Length 5
# of Days Acc to Storm Occurence		# of Ships Arrived on the Given Day Classification					
NoStorm	271	n/a	70	48	51	35	n/a
3DaysBeforeStormDir-NORTH	7	n/a	4	2	1	0	n/a
2DaysBeforeStormDir-NORTH	7	n/a	0	1	1	0	n/a
1DayBeforeStormDir-NORTH	8	n/a	0	3	3	1	n/a
StormDayDir-NORTH	10	**n/a**	**2**	**2**	**1**	**2**	**n/a**
1DayAfterStormDir-NORTH	7	n/a	2	1	1	0	n/a
2DaysAfterStormDir-NORTH	7	n/a	4	1	1	1	n/a
3DaysAfterStormDir-NORTH	7	n/a	3	2	3	1	n/a

Table 3.24. Interarrival Time Adjustment Coefficients of Northbound LNG-LPG Vessels according to the presence of / closeness to Northerly Storm Occurrences

Average Coefficients for Interarrival Times (NoStorm=1)	Boy Sınıfı	Boy < 200	Boy > 200
NoStorm	271	1,00	1,00
3DaysBeforeStormDir-North	7	0,62	n/a
2DaysBeforeStormDir-North	7	2,18	n/a
NorthDayBeforeStormDir-North	8	0,83	1,03
StormDayDir-North	10	1,25	0,65
NorthDayAfterStormDir-North	7	1,09	n/a
2DaysAfterStormDir-North	7	0,73	0,90
3DaysAfterStormDir-North	7	0,55	0,90

3.2.5. The Storm Submodel in Arena

The results of the statistical analysis are incorporated into the main Maritime Traffic Simulation Model through an appropriate Arena submodel containing and implementing the discussed probability distributions for the storm durations and storm interarrival times.

The interarrival time adjustment coefficients for each vessel type, entrance direction and length group are defined and incorporated into the model. Their values change during simulation runs according to randomized storm occurrences. Accordingly, the vessel arrival rates are changed by multiplying the mean arrival parameter of the vessel arrival distributions with the corresponding interarrival time adjustment coefficient, as discussed in section 3.2.4. The submodel structure is given in Figure 3.9.

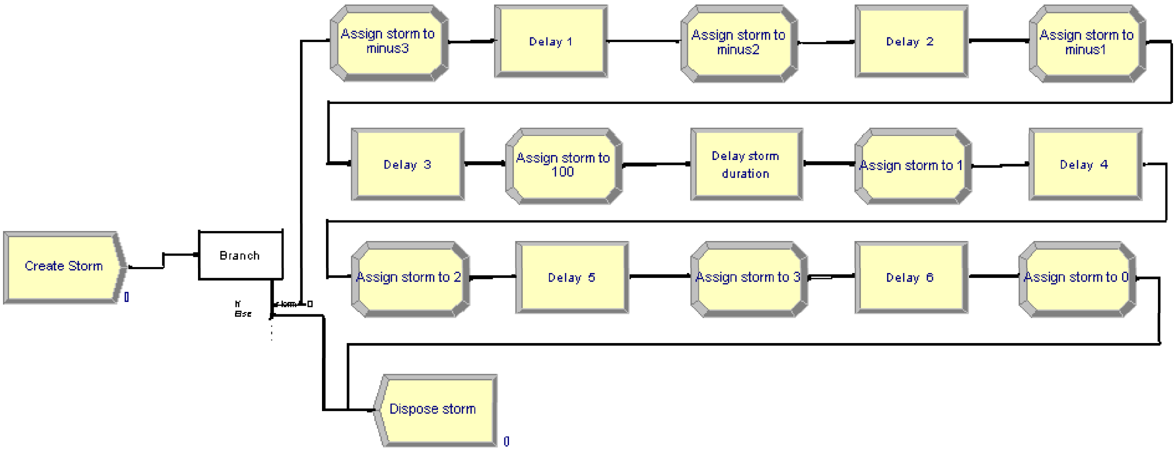


Figure 3.9. The Storm Submodel in Arena 11.0

3.2.6. Verification and Validation of the Storm Submodel

Before integrating the storm submodel into the Istanbul Strait Maritime Traffic Simulation Model however, various verification and validation considerations are accomplished. Since actual storm duration data was not available, the assumption “the occurrence of a wind speed greater than 17.2 m/s indicates a storm whole day long” is made, and hence an overall validity is not possible. Furthermore, the storm arrival distributions are based on a data set of 26 years long, whereas the vessel arrival data is based on a single year. This data discrepency, naturally, does not help the overall validity of the model.

However, some outputs of the model can be compared with the available relevant data.Figure 3.10. illustrates the average daily occurrence of Northerly storms for the three defined seasons, over 50 replications of the storm submodel. The graph shows the frequency of a storm occurrence in a specific day over a year period. This frequency is around 0.04 for Winter Season days, whereas it is around 0.02 for Summer Season days.

Both the graphical profile and the average values are similar to that of Figure 3.4, which illlustrates the frequency distribution of actual storm occurrences. The only major difference is the peak in Season 3, where the number of storm occurrences were quite low and hence any two or more storms coinciding the same date cause this peak.

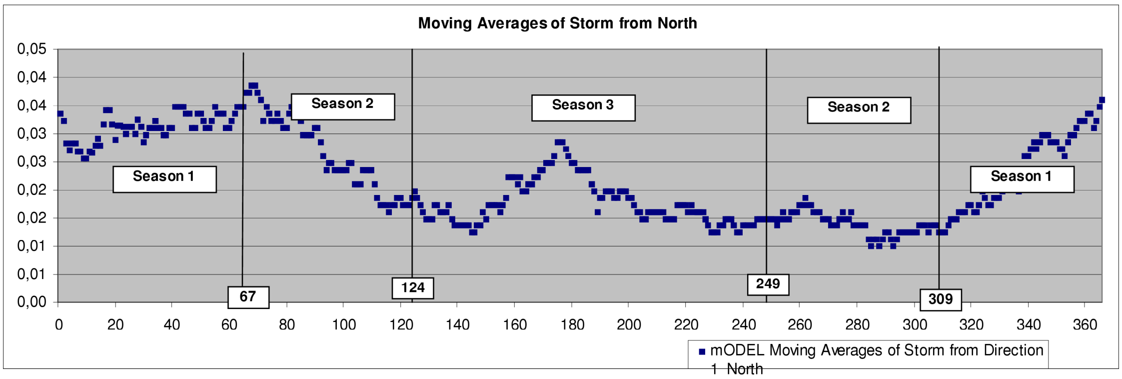


Figure 3.10. The Average Daily Storm Occurrence Frequency (in Moving Averages of 31 days)

Seasonality can also be detected in Figure 3.11, which displays the average number of monthly storm occurrences, (over 50 replications), through 1 year period.

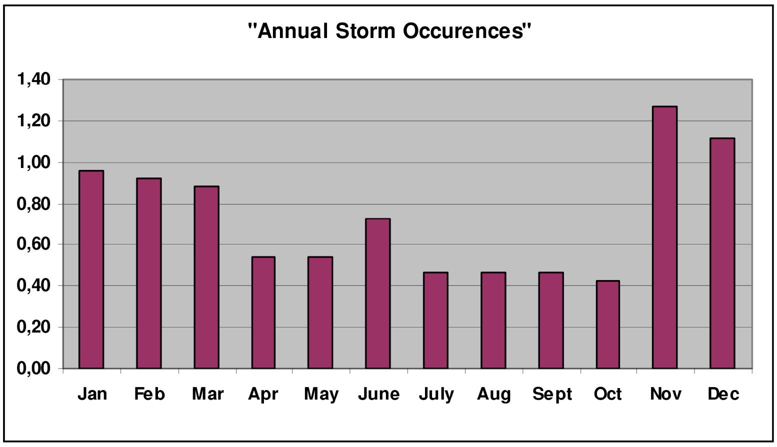


Figure 3.11. The Average Number of Monthly Storm Occurrences

The storm durations cannot be checked for validity, since no storm duration data was available, and any day where a wind speed greater than 17.2 m/s was observed, is assumed to be a stormy day.

The representativeness and appropriateness of interarrival time adjustment coefficients are first verified by tracing the effect of a single storm occurrence on arrivals of different vessel types. For each tracing, the interarrival time adjustment coefficients of a certain type of vessel is analyzed before-during-after storm and under no storm.

In each case, intearrival times are found to be increased / decreased exactly by the coefficient calculated based on the actual data set.

At the second step, average interarrival times of simulation outputs and actual data are compared for each vessel type. Table 3.25. displays the simulation generated interarrival times for northbound general cargo vessels (over 10 replications) for 1 year, while Table 3.26 displays the actual interarrival times for northbound general cargo vessels in the 2005 data.

Table 3.25. The Annual Average Number and Interarrival Times of Northbound General Cargo Vessels

Simulation with 10 replications for 1 year (GENERAL CARGO; S-N)		# of Vessels <200	# of Vessels >=200	Interarrival Time for Vessel Length <200	Interarrival Time for Vessel Length >=200
NoStorm	**328**	19007	560	0.017	0.587
3DaysBeforeStormDir-1	**5**	217	6	0.023	0.789
2DaysBeforeStormDir-1	**5**	216	12	0.023	0.405
1DayBeforeStormDir-1	**5**	151	9	0.033	0.556
StormDayDir-1	**7**	180	19	0.037	0.345
1DayAfterStormDir-1	**5**	213	10	0.024	0.484
2DaysAfterStormDir-1	**5**	300	11	0.017	0.441
3DaysAfterStormDir-1	**5**	323	9	0.015	0.556
Average # of Daily Vessels	**58.2**				

Table 3.26. The Actual Annual Average Number and Interarrival Times of Northbound General Cargo Vessels

Original Data (GENERAL CARGO; S-N)		# of Vessels <200	# of Vessels >=200	Interarrival Time for Vessel Length <200	Interarrival Time for Vessel Length >=200
NoStorm	**313**	18.083	530	0.017	0.591
3DaysBeforeStormDir-1	**7**	340	11	0.021	0.636
2DaysBeforeStormDir-1	**7**	315	13	0.022	0.538
1DayBeforeStormDir-1	**8**	275	16	0.029	0.500
StormDayDir-1	**10**	302	24	0.033	0.417
1DayAfterStormDir-1	**7**	414	11	0.017	0.636
2DaysAfterStormDir-1	**7**	497	20	0.014	0.350
3DaysAfterStormDir-1	**7**	502	14	0.014	0.500
Average # of Daily Vessels	**58.4**				

When simulation outputs are compared with the actual data, average interarrival times are quite consistent for vessels less than 200 m long. Regarding vessels greater than 200 m, the number of such vessel arrivals during the whole year is quite lower, when compared with vessels less than 200 m length. Thus, the arrival distributions are based on far fewer data points, so that variance in the probability distributions and hence in arrivals are much higher.

For the cases of HAZMAT, the number of vessel arrivals were very low (Table 3.27 and Table 3.28), so that no conclusion could be made regarding the effect of storms on such vessel arrivals. Therefore, all related interarrival time adjustment coefficients are not deployed and the original interarrival time rates of the associated arrival distributions are kept intact regardless of storm occurrences.

Table 3.27. The Actual Annual Average Number and Interarrival Times of Northbound HAZMAT Vessels

Original Data (HAZMAT; S-N)		**# of Vessels <200**	**# of Vessels >=200**	**Interarrival Time for Vessel Length <200**	**Interarrival Time for Vessel Length >=200**
NoStorm	**313**	308	33	1.016	9.485
3DaysBeforeStormDir-1	**7**	10	2	0.700	3.500
2DaysBeforeStormDir-1	**7**	5	1	1.400	7.000
1DayBeforeStormDir-1	**8**	7	1	1.143	8.000
StormDayDir-1	**10**	5	1	2.000	10.000
1DayAfterStormDir-1	**7**	10	1	0.700	7.000
2DaysAfterStormDir-1	**7**	9	2	0.778	3.500
3DaysAfterStormDir-1	**7**	10	1	0.700	7.000
Average # of Daily Vessels	**1.1**				

Table 3.28. The Annual Average Number and Interarrival Times of Northbound HAZMAT Vessels

Simulation with 10 replications for 1 year (HAZMAT; S-N)		**# of Vessels <200**	**# of Vessels >=200**	**Interarrival Time for Vessel Length <200**	**Interarrival Time for Vessel Length >=200**
NoStorm	**328**	358	52	0.918	6.314
3DaysBeforeStormDir-1	**5**	5	0	1.000	15.000
2DaysBeforeStormDir-1	**5**	4	1	1.154	7.500
1DayBeforeStormDir-1	**5**	8	1	0.652	5.000
StormDayDir-1	**7**	8	1	0.833	5.000
1DayAfterStormDir-1	**5**	4	2	1.250	2.500
2DaysAfterStormDir-1	**5**	5	0	1.071	15.000
3DaysAfterStormDir-1	**5**	2	1	2.500	5.000
Average # of Daily Vessels	**1.2**				

Even though the simulation generated average daily number of overall vessel arrivals for northbound HAZMAT vessels are quite similar to the actual daily average of northbound HAZMAT vessels, disaggregation of the average daily number of vessel arrivals into day classes exhibits variances between simulation generated results and actual values. This is mainly caused by the low number of vessel arrivals, hence small differences between the simulation generated and actual number of annual vessel arrivals can cause a high difference when divided by the number of days falling into a day class.

4. THE ISTANBUL STRAIT MARITIME TRAFFIC SIMULATION MODEL

The Istanbul Strait Maritime Traffic Simulation Model is based on the TSMTR&R, while giving due consideration to geographic, meteorological conditions in the Strait, as well as vessel characteristics and pilot/tugboat availabilities. It is designed to provide different stakeholders and decision-makers an effective tool that mimics the real system behavior close enough to be used for experimentation purposes. Therefore, various experiences to affect the maritime traffic, such as anchoring, waiting (due to nighttime, visibility conditions, adverse current conditions or due to pilot / tugboat unavailabilities or rule restrictions, extreme weather conditions and prioritization) and transit conditions (such as overtaking possibilities, current effects and pursuit distances), are incorporated into and analyzed through the model.

The Istanbul Strait Maritime Traffic Simulation Model also includes a real time animation of vessel movements through the Istanbul Strait during a simulation run. The main functions of the animation are to communicate the essence of the simulation model and debugging of the simulation program. (Almaz, 2006)

The main simulation model and some integrated submodels, including the visibility module and the current module, are developed using simulation software Arena 9.0, whereas new modules, such as, the Storm and Prioritization Submodels are integrated into the main simulation model using Arena 11.0, the recent update version of the simulation software. Some earlier modules are also updated using Arena 11.0.

All primary input factors (such as vessel arrivals and storm occurrences) are randomly generated internally in the model, based on probability distributions obtained from historical data using Input Analyzer 11.0.

Additionally, the input data can also be read from external text files, if so desired. This feature facilitates debugging in the design phase and is also used in the validation of the model with actual data input.The current viewscreen of the simulation model is displayed in Figure 4.1.

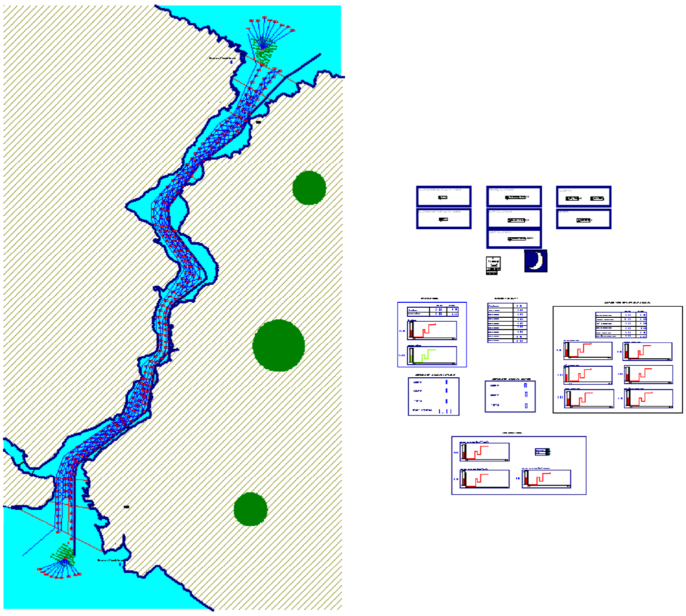
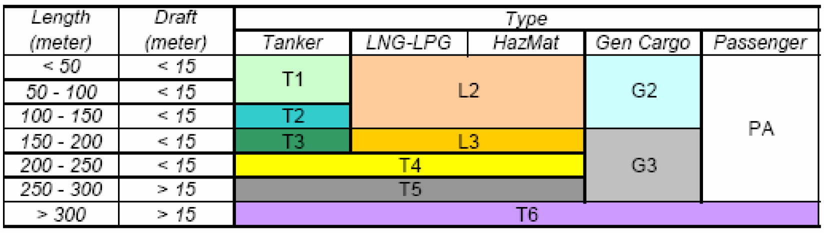


Figure 4.1. A viewscreen from the Istanbul Strait Maritime Traffic Simulation Model

4.1. Vessel Classes

The vessel types considered in the Istanbul Strait Maritime Traffic Simulation Model are Passenger Vessels, LNG-LPG Carrying Vessels, HAZMAT, Tankers and General Cargo Carrying Vessels. On the other hand, according to the TSMTR&R, all vessels are classified into 11 treatment classes, based on their types, lengths and drafts, the associated transition rules and restrictions. These vessel classes are displayed in Table 4.1. This vessel classification is deployed in the Istanbul Strait Maritime Traffic Simulation Model, primarily in regard to vessel entrance criteria.

Table 4.1. Vessel treatment classes



Length (meter)	Draft (meter)	Type				
		Tanker	LNG-LPG	HazMat	Gen Cargo	Passenger
< 50	< 15	T1	L2		G2	PA
50 - 100	< 15					
100 - 150	< 15	T2				
150 - 200	< 15	T3	L3		G3	
200 - 250	< 15	T4				
250 - 300	> 15	T5				
> 300	> 15	T6				

The arriving vessels can enter the anchoring area first, according to their preference, and can stay there during their anchoring durations. Vessels that do not anchor or are due to leave anchoring area are to enter the Strait.

During the simulation, each vessel, which is ready to enter the Strait, first checks whether its entry is restricted by any other vessel already in the Strait, according to the TSMTR&R (and as summarized in Figure 4.2). Similarly, if a vessel enters the Strait, it then restricts the entrance of other vessels into the Strait, within the framework of the TSMTR&R.

According to the "Kandilli Rule" displayed in Figure 4.2, the indicated vessel classes are not allowed to encounter one another in the Kanlıca - Vaniköy region (of the Strait), when traveling at opposite directions. (Almaz, 2006)

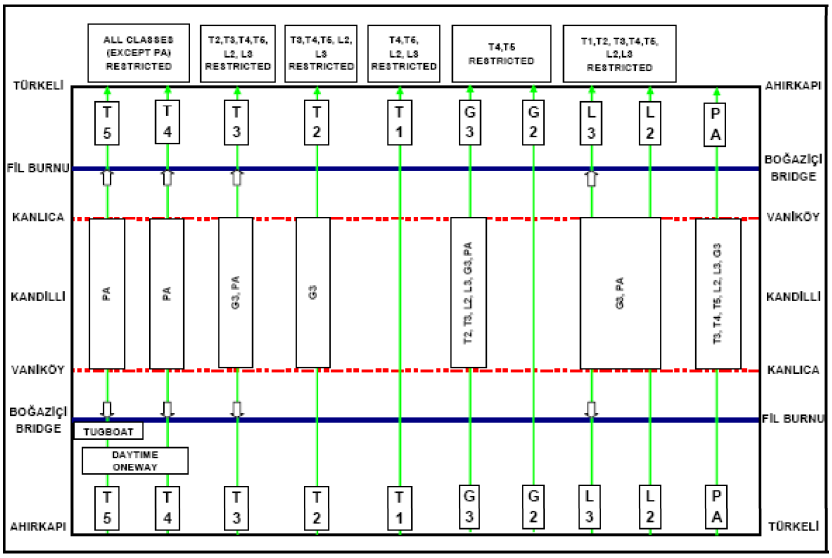


Figure 4.2. Vessel treatment classes

Similar to Almaz (2006), the 'Common Queue' in the revised model is designed to hold the already arrived, ready and waiting vessels. For the vessels in the common queue, a continuous check is made to keep track on whether the Strait is available and safe for their transit. A new check is triggered whenever a condition (such as location of a vessel in transit, busy / idle condition of a pilot / tugboat occurrence or termination of fog, change in current conditions, change in day / night status) changes in the Strait.

Unlike Almaz (2006), the ranking order of the common queue is determined according to the decreasing order of the ‘Time_Elapsed’ attribute, which refers to the time passed between a vessel’s ‘Ready_Time’ and current (clock) time in the simulation run.

Each vessel in the common queue checks for the satisfaction of the TSMTR&R, with respect to the existing conditions in the Strait. If there is no restriction regarding the traffic rules, environmental conditions and availability of tugboat/pilot services, then the vessel enters the Strait.

4.2. Modeling Prioritization Policies For Indirect Passing Vessels

The TSVTS is inclined to show some preference to indirect passing vessels over direct passing vessels. The TSVTS experts indicated that they would like to give transit priority to southbound indirect passing vessels, with the level of priority differing among different vessel types, length and destination ports. (The reason for such a prioritization could be, i) not delaying the delivery of key strategic/economic goods important for the Turkish market and economy, ii) promotion of some port facilities, iii) promotion of the Turkish maritime industry or services.) Such prioritization policies are modeled and integrated into the Istanbul Strait Maritime Traffic Simulation Model in order to observe and investigate their effect on the overall maritime traffic as well as on individual vessel types.

4.2.1. The Prioritization Policies for Indirect Passing Vessels

The TSVTS reported that the following prioritization policies, regarding the transit of indirect passing vessels, are possible and should be considered in the model:

1. Different priorities to be given to indirect vessels, according to destination ports, vessel types and lengths,
2. Priority to be given only to southbound indirect vessels,
3. Higher prioritization to be applied for certain vessel types in the following desti-

nation ports:

  - "Haydarpaşa" and "Ambarlı" ports for General Cargo vessels
  - "Tütünçiftlik" port for the Tankers/LNG-LPG vessels (only vessels over 200 m use this port)

4. Lesser prioritization to be applied to longer vessels. There are three exceptions:
    - For Tankers/LNG-LPG vessels with the destination Tütünçiftlik port, higher prioritization is to be applied regardless of their lenghts.
    - For General Cargo vessels with the destination Haydarpaşa port, higher prioritization is to be applied regardless of their lenghts.
    - Prioritization is to be applied to all passenger vessels. However, for Passenger vessels having lengths greater than 200 m, higher prioritization level to be applied than those with shorter lengths.
5. Vessel type is to be the most significant factor in identifying the relative prioritization level of indirect passing vessels. (For example, the prioritization level to be applied to Passenger vessels is to be higher than those applied to any other vessel type.) Similarly, the prioritization level applied to General Cargo vessels should be higher than that applied to Tankers/LNG-LPG/HAZMAT vessels.

In the Istanbul Strait Maritime Traffic Simulation Model, vessels waiting to enter the Strait are basically ordered with respect to their "Ready_time" (i.e. the "Ready_time" refers to the time when the ship is ready to be evaluated to enter the Strait). In the revised model, this ordering is done with respect to their elapsed time (i.e. "Time_Elapsed" refers to the time passed between a vessel's "Ready_Time" and the time it enters the common queue). This change (from ready time to elapsed time) facilitated a simple and straightforward implementation of giving different priorities to different vessel classes/destinations/lengths. This prioritization is achieved as follows: Any vessel which is to be assigned a priority, simply gets its "Time_Elapsed" attribute multiplied by a prioritization index $\lambda > 1$. This way, its elapsed time is artificially increased, thereby assuring the vessel a better standing in the waiting queue.

In order to quantify the relative importance of the prioritization needs/conditions, all main factors to affect the priority level (e.g. vessel type, vessel length and destination port) are relatively questioned through an appropriate questionnaire filled out by experts in the TSVTS.

For the determination of the prioritization indices, the experts are first asked to quantify their prioritization preferences by defining the relative importance of the main factors vessel type, length and transit destination, in applying a prioritization.

In the second phase the interaction among these main factors are questioned. Thus, the results of this analysis could be used to construct a Prioritization Index Matrice, which includes all the priority indices in accordance with their relative importances. The Basic Prioritization Index Matrice is displayed in Table 4.2.

Table 4.2. The Basic Prioritization Index Matrice

	SHIP TYPE	PASSENGER INDIRECT		GENERAL CARGO INDIRECT			TANKER/LNGLPG INDIRECT		HAZMAT INDIRECT
	LENGTH	Seeport	Salıpazarı	Haydarpaşa	Ambarlı	Diğer	Tütünçiftlik	Diğer	
I	50-100	20,00	20,00	18,00	6,40	3,40		1,40	1,40
	100-150	20,00	20,00	18,00	6,30	3,30		1,30	1,30
	150-200	20,00	20,00	18,00	6,20	3,20		1,20	1,20
	200-250	26,00	26,00	18,00	6,10	3,10	8,00	1,10	1,10
	250-300	26,00	26,00	18,00	6,00	3,00	8,00	1,00	1,00

As displayed in Table 4.2, the priority index for direct passing HAZMAT vessels longer than 250 m is set to 1.0 and other priority indices are adjusted accordingly. However, the differences between factor levels turned out to be very large to be deployed as adjustment coefficients of “elapsed time”. (For example, multiplying the “elapsed time” attribute of passenger vessels larger than 200 m by 26 would be increasing the “elapsed time” to an unrealistically high level.)

In order to scale down the priority level differences, a conversion equation is applied to define the converted priority index of the vessel of type i, with the destinaton port j and with the length k:

$$\text{Converted Priority Index}_{ijk} = 1 + (\lambda - 1) * \text{Prioritization Index}_{ijk} \quad (4.1)$$

i: Vessel Type: (Passenger Indirect, General Cargo Indirect, Tanker/LNG-LPG Indirect, HAZMAT Indirect)
j: Port: (Seeport, “Haydarpaşa”,“Ambarlı”,“Tütünçiftlik”, “Salıpazarı”)
k: Length: (50-100, 100-150, 150-200, 200-250, 250-300)

The driving idea behind this equation is the application of the expert determined adjustment factors (prioritization indices) to the elapsed time changes (i.e. $(\lambda - 1)$) rather than the elapsed time itself (i.e. λ). This is accomplished by multiplying the prioritization indices with the base increment in the prioritization coefficient (i.e. $(\lambda - 1)$).

The priority indices in the Converted Prioritization Index Matrice, are then deployed in the simulation model to prioritize different type/length/destination port classes of indirect vessels by artificially increasing their ”elapsed time”. Different levels of λ (between 1 - 3), are deployed as different priority scenarios. (The higher the λ, the higher are the priorities extended to various classes of indirect vessels) The Converted Prioritization Index Matrice for $\lambda = 1,3$ is given in Table 4.3.

Table 4.3. The Converted Prioritization Index Matrice

SHIP TYPE	PASSENGER INDIRECT		GENERAL CARGO INDIRECT			TANKER/LNGLPG INDIRECT		HAZMAT INDIRECT
LENGTH	Seeport	Salıpazarı	Haydarpaşa	Ambarlı	Diğer	Tütünçiftlik	Diğer	
50-100	7,00	7,00	6,40	2,92	2,02		1,42	1,42
100-150	7,00	7,00	6,40	2,89	1,99		1,39	1,39
150-200	7,00	7,00	6,40	2,86	1,96		1,36	1,36
200-250	8,80	8,80	6,40	2,83	1,93	3,40	1,33	1,33
250-300	8,80	8,80	6,40	2,80	1,90	3,40	1,30	1,30

4.2.2. The Integration of Prioritization Policies into the Simulation Model

The Converted Prioritization Index Matrice is incorporated into the model through the variable CoefFD, which refers to the prioritization coefficient (λ) in the Conversion Equation 4.1. This prioritization coefficient is assigned a value (between 1 - 3) according to the desired level of prioritization. With the parameterized priority coefficient and the Conversion Equation, specific prioritization indices for all vessel types/lengths/destination ports are calculated and stored as an attribute (Coef_FAV) for each vessel.

4.2.3. Verification and Validation of the Prioritization Policies

Before the integration of the prioritization policies, the verification and validation of the submodel is checked. The prioritization submodel is based on expert opinion in the TSVTS and there is no actual data for the applied level of prioritization throughout the year to compare with the simulation outputs. Hence, an overall validity of the model is not possible. However, the correct integration of the prioritization policies into the model can be verified by comparing the simulation statistics for different levels of the prioritization coefficient.

At the first step, the prioritization coefficient (λ) is set to 1.0, so no priority is given to indirect passing vessels. The proper integration is ensured by having the same simulation statistics with prioritization coefficient (λ) value equal to “1” as those without the integration of the prioritization policies.

Then, the prioritization coefficient is increased to 1.1, 1.2, 1.3 ,1.4 and 1.5 and simulation runs are obtained for each setting for 20 replications over 8 months. Figure 4.3 and Table 4.4 display the average waiting time for all, direct and indirect passing vessels.

As expected, Figure 4.3 and Table 4.4 show that the average waiting time of all indirect passing vessels decrease along with the increasing value of the prioritization coefficient, while the average waiting time of all direct vessels increase. Additionally, it can be observed that the level of increase of the average waiting time of direct passing vessels is far fewer than the level of decrease in the average waiting time of indirect passing vessels. The reason behind this difference is that the number of indirect southbound vessels corresponds to only a smaller proportion of all vessels so that the prioritization applied has more influence on the behaviour of the average waiting time of indirect passing vessels. It can also be observed, based on the same reason, that the total average waiting time slightly increases along with the increase of the average waiting time of direct passing vessels.

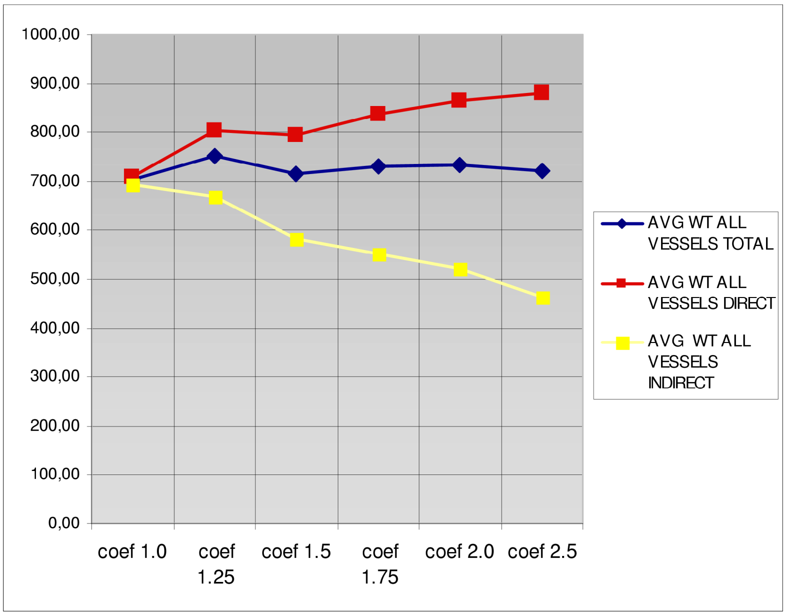
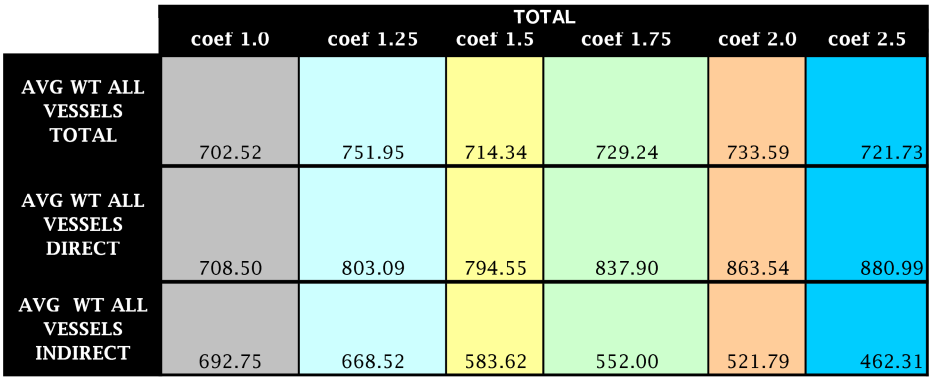


Figure 4.3. The Average Waiting Times of All/Direct/Indirect Passing Vessels for varying CoefFD levels

Table 4.4. The Average Waiting Times of All/Direct/Indirect Passing Vessels for varying CoefFD levels



			TOTAL			
	coef 1.0	coef 1.25	coef 1.5	coef 1.75	coef 2.0	coef 2.5
AVG WT ALL VESSELS TOTAL	702.52	751.95	714.34	729.24	733.59	721.73
AVG WT ALL VESSELS DIRECT	708.50	803.09	794.55	837.90	863.54	880.99
AVG WT ALL VESSELS INDIRECT	692.75	668.52	583.62	552.00	521.79	462.31

The average waiting time statistics are also analyzed for each vessel type separately, in order to better understand the changes in waiting times of direct/indirect passing vessels (Figures 4.4 - 4.8 and Tables 4.5 - 4.9).

Figure 4.4 and Table 4.5 show the change in the average waiting time of Passenger vessels according to the different levels of the prioritization coefficient. As mentioned in 4.2.1., the prioritization level to be applied to Passenger vessels is to be higher than those applied to any other vessel type. This is the reason for the sharp decrease in the average waiting time of indirect passing Passenger vessels. Additionally, the experts in the TSVTS indicated that they show some preference to direct passing Passenger vessels over other direct passing vessels. This is the reason that the average waiting times of direct passing Passenger vessels (together with the average waiting time of all Passenger vessels) show an unregular pattern with up and downs.

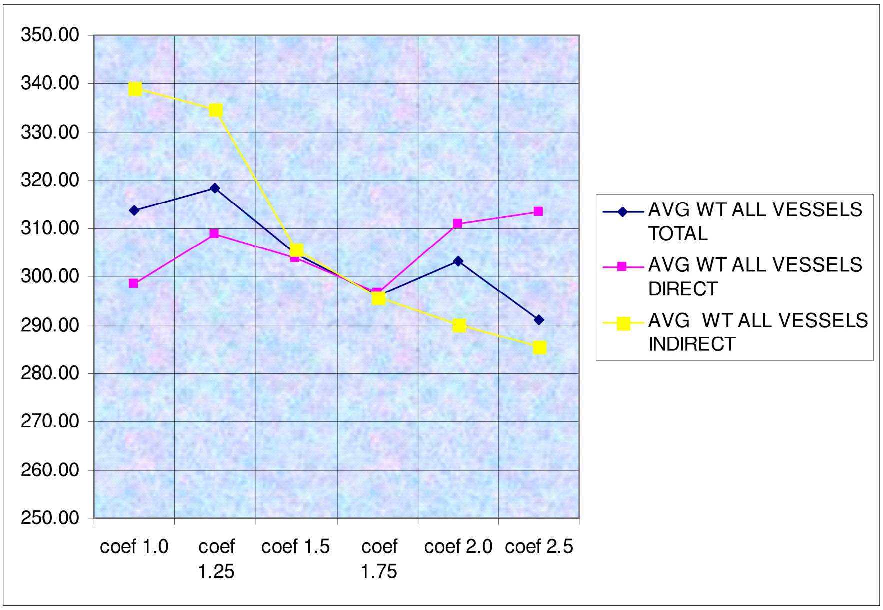


Figure 4.4. The Average Waiting Times of All/Direct/Indirect Passing Passenger Vessels for varying CoefFD levels

Table 4.5. The Average Waiting Times of All/Direct/Indirect Passing Passenger Vessels for varying CoefFD levels

	PASSENGER					
	coef 1.0	coef 1.25	coef 1.5	coef 1.75	coef 2.0	coef 2.5
AVG WT ALL VESSELS TOTAL	313.84	318.55	304.65	296.28	303.27	291.05
AVG WT ALL VESSELS DIRECT	298.67	308.83	303.93	296.63	311.12	313.45
AVG WT ALL VESSELS INDIRECT	339.12	334.74	305.85	295.70	290.19	285.65

Figure 4.5 and Table 4.6 show that the average waiting time of all LNG-LPG vessels closely follows the changes in the average waiting time of direct passing LNG-LPG vessels, while the average waiting time of indirect passing vessels decreases, reaching a lower limit at around 810 min. at the prioritization coefficient level 2 or more.

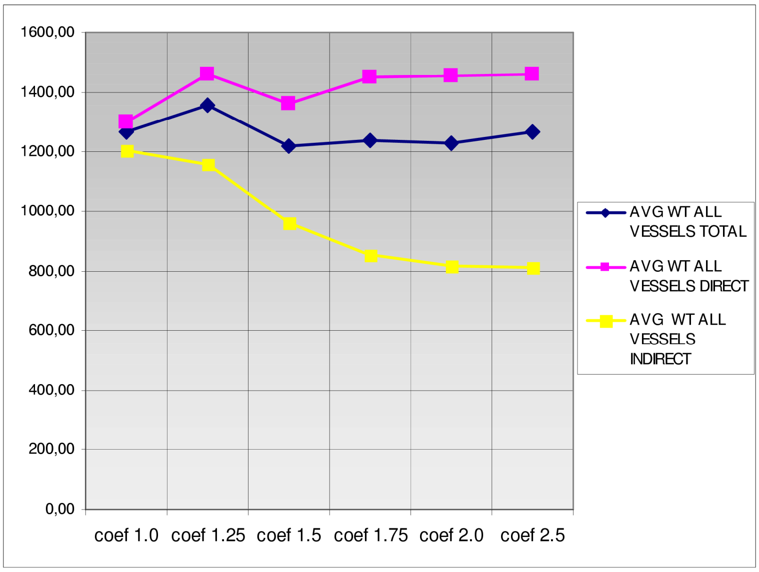


Figure 4.5. The Average Waiting Times of All/Direct/Indirect Passing LNG-LPG Vessels for varying CoefFD levels

Table 4.6. The Average Waiting Times of All/Direct/Indirect Passing LNG-LPG Vessels for varying CoefFD levels

	LNGLPG					
	coef 1.0	coef 1.25	coef 1.5	coef 1.75	coef 2.0	coef 2.5
AVG WT ALL VESSELS TOTAL	1264.98	1354.45	1218.38	1238.22	1227.71	1266.02
AVG WT ALL VESSELS DIRECT	1298.52	1461.04	1358.91	1449.29	1452.62	1458.93
AVG WT ALL VESSELS INDIRECT	1203.86	1160.25	962.31	853.63	818.06	810.27

It can be observed in Figures 4.6 - 4.7 and Tables 4.7 - 4.8, that the behavior of all/direct/indirect passing Tankers and HAZMAT carrying vessels show a similar behavior, where the average waiting time of direct vessels increases sharply along with a sharp decrease in the average waiting time of indirect passing vessels. Accordingly, the average waiting time of all Tankers and HAZMAT carrying vessels slightly increase compared to the base level (i.e.when no prioritization is applied)

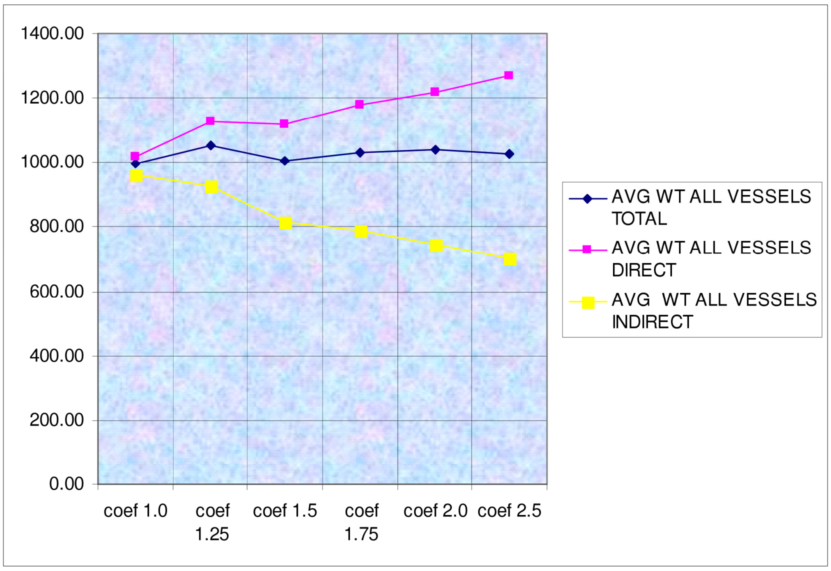


Figure 4.6. The Average Waiting Times of All/Direct/Indirect Passing HAZMAT Vessels for varying CoefFD levels

Table 4.7. The Average Waiting Times of All/Direct/Indirect Passing HAZMAT Vessels for varying CoefFD levels

			HAZMAT			
	coef 1.0	**coef 1.25**	**coef 1.5**	**coef 1.75**	**coef 2.0**	**coef 2.5**
AVG WT ALL VESSELS TOTAL	995.92	1051.77	1004.19	1030.92	1039.72	1028.24
AVG WT ALL VESSELS DIRECT	1016.81	1128.10	1120.23	1178.73	1218.96	1270.31
AVG WT ALL VESSELS INDIRECT	961.56	926.61	813.64	788.09	744.82	702.21

Analysis of Figure 4.8 and Table 4.9 show the fact that General Cargo vessels are considerably affected by the application of prioritization policies, since the average waiting time of indirect passing General Cargo vessels decrease form 526 min. to 370 min., when the prioritization coefficient is increased from 1.0 to 2.5. The level of this decrease is less than the level of increase in the average waiting time of direct passing General Cargo vessels so that the average waiting time of all General Cargo vessels slightly decreases at the prioritization level of 2.5, compared to the base level.

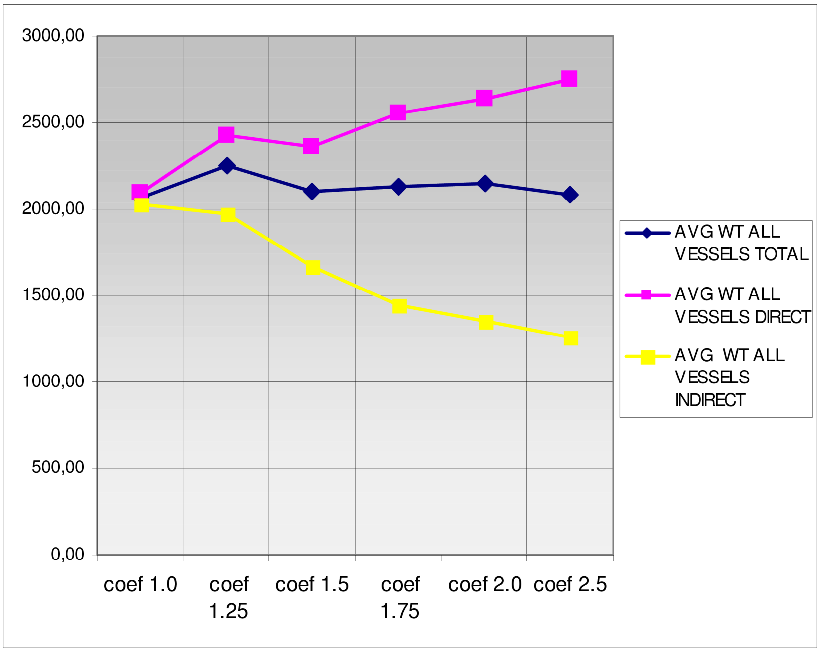


Figure 4.7. The Average Waiting Times of All/Direct/Indirect Passing Tanker Vessels for varying CoefFD levels

Table 4.8. The Average Waiting Times of All/Direct/Indirect Passing Tanker Vessels for varying CoefFD levels

	TANKER					
	coef 1.0	coef 1.25	coef 1.5	coef 1.75	coef 2.0	coef 2.5
AVG WT ALL VESSELS TOTAL	2067.21	2250.95	2100.79	2133.87	2149.85	2085.27
AVG WT ALL VESSELS DIRECT	2089.81	2423.61	2365.60	2555.68	2639.03	2751.66
AVG WT ALL VESSELS INDIRECT	2030.29	1968.68	1667.99	1444.56	1351.04	1259.98

Table 4.9. The Average Waiting Times of All/Direct/Indirect Passing General Cargo Vessels for varying CoefFD levels

	GENERAL CARGO					
	coef 1.0	coef 1.25	coef 1.5	coef 1.75	coef 2.0	coef 2.5
AVG WT ALL VESSELS TOTAL	525.14	549.40	515.32	512.80	528.04	513.82
AVG WT ALL VESSELS DIRECT	524.43	582.79	568.59	585.32	617.90	632.14
AVG WT ALL VESSELS INDIRECT	526.31	494.92	428.43	394.51	381.54	370.01

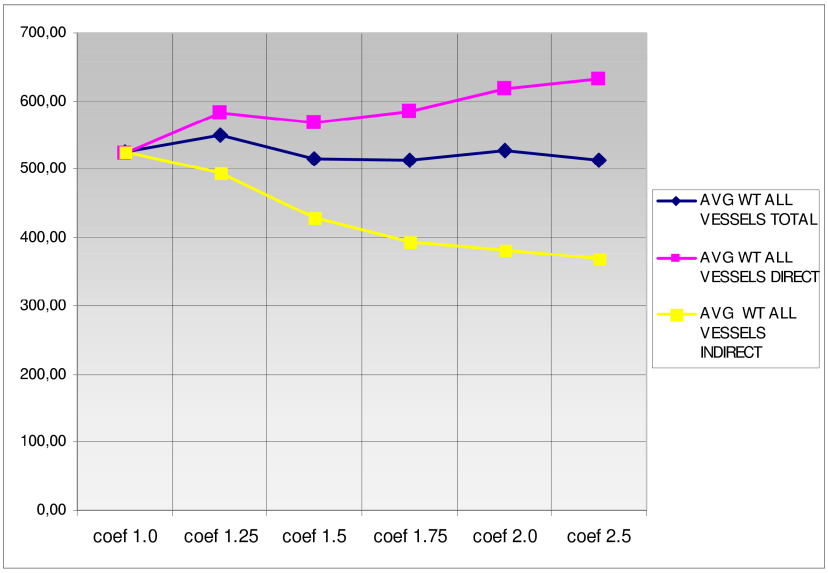


Figure 4.8. The Average Waiting Times of All/Direct/Indirect Passing General Cargo Vessels for varying CoefFD levels

The general behaviour of the average waiting times of the vessel types separately show a similar pattern to the behaviour of the total average waiting time, with some different behaviour patterns corresponding to the different levels of the prioritization coefficient.

According to the analysis of the simulation model outputs, it can be observed that the general trend of the average waiting time is well represented for all vessels as well as for the different vessel types. Consequently, the simulation model is regarded to be sufficiently valid to represent the general behaviour of the system according to the applied prioritization policies.

4.3. Pilotage and Tugboat Services

Pilotage and tugboat deployment in the Istanbul Strait is strongly recommended by the TSVTS to ensure safe navigation in the Strait. Pilot captains and tugboats are defined as limited resources in the simulation model. (There are 15 pilot captains and 6 tugboats in service in the base scenario of the simulation model.)

Pilot embarking / disembarking stations are included in the model and a certain amount of time is allocated to cover the slowing down and speeding up of vessels while the embarking or disembarking activity is accomplished.(Almaz, 2006)

At any Strait entrance, while the pilot or tugboat is released, if the number of idle pilots or tugboats at that station is higher than or equal to a predefined limit, the excess pilot or tugboat is transferred to the opposite side station in 30 minutes and in 90 minutes respectively. This limit parameter is determined as three for pilots and three for tugboats in this study. Additionally, when a vessel seizes a pilot or tugboat, number of remaining pilots or tugboats in that station is checked. If the value is zero and the station on the opposite side has more than two idle units of the same resource, the excess units are sent to the demanding side. During the transfer of excess pilots and tugboats, simultaneous transfers are avoided. (Almaz, 2006)

4.4. Navigation in the Strait and Pursuit Distances

In the Strait, a vessel moves through eight different zones. Each zone is divided into a sequence of "stations", which are set at a distance of eight cables (0.8 nautical miles $\approx$ 1.482 km) away from one another (Table 4.10). Accordingly, the Strait is represented on 21 stations to cover a distance of 16.8 nautical miles. Also, each station is comprised of four 'substations', which are set at a distance of two cables from one another. This structure is designed to satisfy and experiment with the regulation that vessels in transit in the Strait shall maintain a certain pursuit distance between each other. (In different scenarios of the simulation model the minimum possible pursuit distance is inputted as different number of in between stations.)(Almaz 2006)

Table 4.10. Zone lengths and number of stations

Zone no	No of Stations	Length (nautical Miles)
1	2	1.6
2	3	2.4
3	2	1.6
4	3	2.4
5	4	3.2
6	5	4
7	1	0.8
8	1	0.8

4.5. The Visibility

The visibility submodel is developed as an independent module and integrated to the simulation model. The random generation of fog initiations in summer and in transition seasons are based on empirical distributions, whereas the winter season (based on an on/off process) is modeled through a phase type distribution. The duration of fog events (namely the off-period) is also modeled through phase type distributions (Almaz, 2006).

The primary rules applied in the simulation model (based on the TSMTR&R) is given below.

- When visibility is less than one nautical mile in the Strait, only one-way traffic is permitted and dangerous cargo carrying vessels (Tanker, LNG-LPG, HAZMAT type vessels) and vessels longer than 200 meters are not allowed to enter the Strait.
- When visibility is less than 0.5 nautical miles in the Strait, all traffic is seized until more favorable visibility conditions.

4.6. The Current

The following conditions based on the TSMTR&R are taken into consideration in the current submodel within the main simulation model.

- If the current is less than 4 knots, vessels with speeds less than four knots are restricted or assigned a tugboat to oversee their safe passage through the Strait.
- If the current is more than 4 knots or orkoz occurs, dangerous cargo carrying vessels (Tanker, LNG-LPG and HAZMAT type vessels) with a speed less than 10 knots and vessels longer than 200 meters with speeds less than 10 knots are restricted to enter the Strait.
- When the current is more than 6 knots or strong orkoz occurs, dangerous cargo carrying vessels and vessels longer than 200 meters are restricted to enter the

Strait, until the current conditions change to safe levels.

The current has a strong influence on the Strait entrance rules. The maximum current magnitude observed at any point of the Strait directly affects the permission of vessels to the Strait. Since the station at which the maximum current is realized is predetermined in the current model, the maximum current value is calculated along with the generation of daily base current value Almaz, 2006).

4.7. Extreme Weather Conditions

The Istanbul Strait is regularly exposed to extreme weather conditions, which have an important effect on the maritime transit traffic. Especially the storms in the Strait area hinder, postpone or speed up the arrival and/or transit through the Strait of many vessels. The effect of storm occurrences in the Istanbul region and the variations in the storm occurrence frequency among seasons are analyzed and integrated into the model. Stochastic analysis of storm occurrences and the effect of storm occurrences on vessel arrival rates at the Istanbul Strait is named as the storm submodel. The storm submodel is based on the statistical analysis of historical wind speed and duration data, between 1981-2006. The results of the statistical analysis are incorporated into the main Maritime Traffic Simulation Model through an appropriate Arena submodel containing and implementing the discussed probability distributions for the storm durations and storm interarrival times (as discussed in section 3.2).

4.8. The Seasons

Based on the strong variation in storm occurrences throughout the year, a year is classified into 3 seasons. Interarrival times of storms in such determined seasons are independently analyzed for the cardinal directions North and South. These seasons are (1) winter, (2) fall/spring and (3) summer. The year days that fall into these season classes are shown in Table 4.11.

Table 4.11. Seasonal Periods for Storm Occurrences from North and South Directions

Season / Storm Direction	NORTH	SOUTH
Season -1	Day 1 - Day 67	Day 1 - Day 80
	Day 310 - Day 365	Day 346 - Day 365
Season - 2	Day 68 - Day 124	Day 81 - Day 148
	Day 249 - Day 309	Day 298 - Day 345
Season - 3	Day 125 - Day 248	Day 149 - Day 297

Besides the variation in storm occurrence frequencies, storm duration frequencies also differ for the given seasons. The storm durations in each of the three seasons are seperately analyzed and fitted appropriate probability distributions through the Input Analyzer.

4.9. Outputs of the Model

The output elements of Arena 11.0 are utilized to keep track of the entities in different run-time periods during the simulation.

The statistics have been kept on a monthly basis and it is assumed that one month is 30 days and a year is 360 days to facilitate statistics collection.

The major output file is for statistics collection on transit vessels with respect to North and South entrances, total entrances based on aggregate of all vessels and each vessel type. The statistical values include maximum, minimum, average values, standard deviations and 95 percent confidence intervals of the following output variables;

- Number of vessels that have completed their Strait transit;
- Transit time of vessels that have completed their Strait transit (aggregate of all vessels and by vessel type at each direction);
- Waiting time of vessels that have completed their Strait transit (aggregate of all vessels and by vessel type at each direction);
- Number of vessels in queue (still waiting for transit) at end of each month;
- Number of vessels in the Strait (still in transit) at the end of each month;
- Waiting time of vessels in queue at end of each month;

- Vessel densities (number of transit vessels per nautical mile) in each zone and for the entire Strait (aggregate of all vessels and by vessel type);
- Pilot captain and tugboat utilization (ratio of total busy time to total available time)

Moreover, the following outputs are traced and analyzed separately to keep track of the effect of the extreme weather conditions and prioritization:

- Day classification statistics with respect to storm occurrences indicating the number of storm occurrence, the season of the storm, storm duration and interarrival time ratios for each vessel type on the given year day
- Prioritization indices for each vessel cluster based on the vessel type, length and destination port and prioritization coefficient

5. VERIFICATION, VALIDATION AND OUTPUT COMPARISONS

Verification addresses the correctness of the implementation of the conceptual model into the computer. Furthermore, it questions the correct representation of the input parameters and logical structure of the model. (Banks et al., 2001)

Validation is concerned with the question whether a model is an accurate representation of the real system. Validation is an iterative process of comparing the model to the actual system behavior, defining and using discrepancies and the insights gained to improve the model. This process is repeated until model accuracy reaches an acceptable level. (Banks et al., 2001)

Validation process has two main goals:

1. To produce a model representing the actual system behavior closely enough for experimentation purposes with the model
2. To increase the credibility of the model to be used by managers and decision-makers

As mentioned before, the objective of this study is to expand the simulation model developed by Almaz (2006) to investigate the impacts of extreme weather conditions, vessel arrival processes and prioritization through a functional simulation model. The simulation model incorporates some simplifications and assumptions to facilitate its development and utilization. Therefore, the simulation model should not be regarded as a representative of the total system, but it takes major system components into account to test the effects of defined factors on the system behavior through scenario analysis.

5.1. The Verification of the Istanbul Strait Maritime Traffic Simulation Model

The development of the Istanbul Strait Maritime Traffic Simulation Model is accomplished in stages and each stage proceeded with discussions and controls on each item to be added into the model through a structured walk-through with TSVTS. The several components, such as storm submodel and prioritization rules, are each individually debugged and tested before being integrated into the model developed by Almaz. The same procedure is followed by restating the arrival process.

As indicated in the study of Almaz (2006), one of the objectives of the simulation model is to keep track of every movement of vessels from arrival to departure. Thus, for identifying possible errors in vessel movements, and the dependency of the considerable increases and decreases in waiting times of the vessels on the existing conditions within the simulation model, records of the generated vessel movements are kept, observed and closely analyzed. Besides these algebraic and tabular checks, animation capability and features of the model also enabled us to visually track the model behavior and to verify the model.

Tracing of the detailed outputs of simulation runs are effectively used for questioning the correct implementation of the input parameters and logical structure of the model, and to identify sources of errors for debugging, while building, testing and implementing prioritization and storm submodels. Trace feature is also used for detecting unexpected changes in variables or movements in entities as well.

In order to further test the model behaviour, the model is also run under some simplifying assumptions, by isolating the recently integrated prioritization rules and the storm submodel. A complete run by setting all prioritization and storm coefficients to “1” is analyzed and compared with a complete run of the basic model without the prioritization and storm submodels, for detecting any possible differences and errors. Another test is tracing all values of the input parameters of the prioritization and storm submodels with the aim of verifying correct representation in the model. All those tests gave reasonable results and there was no indication of incorrect transformation of the conceptual model into the computerized model.

5.2. Validation and Output Comparisons

Throughout the development of the arrival, prioritization and storm submodels, the outputs of the simulation model are critically studied and discussed with the TSVTS experts in workshops, to obtain their feedback regarding the face validity of the overall model.

The data used as model inputs in output comparisons with actual vessel arrivals and storm occurrences, are collected through authorized sources. During the analyses phases, the deficiencies detected in the data are tried to be reduced by expert opinion and classification. Also, arrival distributions in the vessel arrival process and storm submodel are fitted the appropriate probability distributions, using the Input Analyzer, by checking through graphical plots or goodness of fit tests.

As indicated in the study of Almaz, the Istanbul Strait Maritime Traffic Simulation Model has many simplifying assumptions on the actual system. The enchanced model aims to incorporate changes in the vessel arrivals due to extreme weather conditions and prioritization levels of vessels. Even though the TSMTR&R and above mentioned prioritization policies are applied in the simulation model, it should be stated that not all precise Strait entrance procedures and all specific directions of controllers are aimed to be represented in the system, as it is very difficult to model all of the subjective, instinct-based and instantaneous decisions of the controllers and their interpretations of the TSMTR&R. The TSMTR&R relaxations, as in the case of modeling the transition prioritization policies, are possible, and their correct representation in the simulation model can only be tested by fine-tuning of the parameters between successive simulation runs, by comparing the simulation outputs with the actual system behavior, and hence making the necessary calibrations in the model as an iterative and time-consuming process.

5.2.1. The Comparison of 2005 Statistics and the Simulation Model Outputs with External Input

In order to eliminate the random effects in the input stream, historical data can directly be used as input data to enable a basic comparison of the essential model representations of the Strait entrance rules and vessel transitions in the Strait, with the actual system.

The set of historical data used as input data to the model is the actual vessel arrivals data (first contact time) in the year 2005. This vessel arrivals data include actual vessel arrival times, vessel types, lengths, speeds, anchoring durations and pilot demands. Wind speed and wind direction data sets, combined into a storm occurrence data set during the development of storm submodel, is not externally inputted to the model, since the storm submodel only covers the increasing or decreasing effect of storm occurrences on vessel interarrival times. Accordingly, when the vessel arrivals are externally inputted, since the storm occurrences are not taken into account directly, the storm submodel does not have any other impact on any other variable. The other inputs of the simulation model, such as daily peak current value and tugboat demands, are randomly generated through the appropriate probability distributions (as explained in section 3.1 and 3.3), since historical input data on these inputs could not be obtained.

The simulation model is run for the 9 month period (April-December) over 10 replications with a 3 months warmup period (January-March).The actual vessel arrival data of January-March 2005 is designated as the input data for the warmup period, in order to represent the conditions more realistically. The number of vessels passed, the average transit times and the average waiting times of vessels are the basic performance measures, where historical data is available and hence could be used for comparison purposes. The vessel density in the Strait, the number of vessels in the queues, pilot and tugboat utilizations are also presented, but could not be compared, since historical data regarding these measures are not available.

Lower and upper confidence levels are presented in order to evaluate the difference between the performance measures of the system and the simulation model. The confidence intervals based on the t-distribution (even if sample size is too small) are larger than the confidence intervals based on the normal distribution and generally have coverage closer to the desired level of (1- α). Thus, the 95 per cent confidence levels for the simulation outputs are calculated through the t-confidence interval.

The actual total number of vessels passed in the first nine months of 2005 and the total number of vessels passed in the simulation runs are displayed in Table 5.1. Also, the plot of the total number of vessels passed in the selected nine months period is in Figure 5.1. The numbers of total, southbound and northbound vessels passed in the actual data and in the simulation results are very close. Besides, the plot of the total number of vessels passed in the simulation outputs closely resemble the actual realization of the given period.

Table 5.1. The actual number of vessels passed in the March-December 2005 data and in the simulation runs

	The 2005 Data	**The Simulation Model**			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	42.256	42.171.00	27.38	23.774.08	60.737.92
NS	21.150	21.099.00	24.39	11.903.13	30.396.87
SN	21.106	21.072.00	11.68	11.870.96	30.341.04

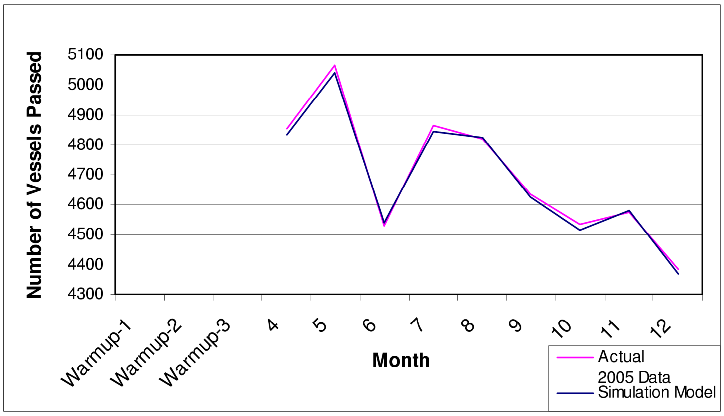


Figure 5.1. The comparison of the number of vessels passed in the March-December 2005 period of the actual data and in the simulation runs

The mean and standard deviation of transit times of vessels both in the actual 2005 data and in the 10 replication simulation runs are displayed in Table 5.2 and in Table 5.3. As can be seen from these tables, the mean transit times of total, southbound and northbound vessels (for the simulation runs versus the actual situation) do not differ too much and are very close to the upper confidence limits; standard deviations, on the other hand, differ slightly.

Table 5.2. Average transit times in the March-December 2005 period of the actual data and in the simulation runs

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	103.26	102.57	0.29	102.39	102.75
NS	93.26	92.38	0.33	92.17	92.59
SN	113.31	112.98	0.50	112.67	113.29

Table 5.3. The standard deviation of transit times in the March-December 2005 period of the actual data and in the simulation runs

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	21.59	19.99	0.29	19.81	20.17
NS	13.65	12.89	0.33	12.68	13.10
SN	23.36	21.35	0.50	21.04	21.66

The average waiting time of the vessels and its standard deviation for the last nine months of 2005 are displayed in Table 5.4.

Table 5.4. The actual average waiting times in the March-December 2005 data and in the simulation runs

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	836.92	798.00	78.23	749.51	885.41
NS	769.48	714.22	123.38	637.75	845.95
SN	904.23	979.44	84.17	927.27	956.40

As depicted in Figure 5.2, Figure 5.3 and Figure 5.4, the average waiting times of southbound vessels regarding the difference between the actual data and the simulation outputs, are higher than that of the northbound vessels for the first five months. After that period, the simulation-generated average cumulative waiting times of both northbound and southbound vessels are quite close to the actual 2005 data.

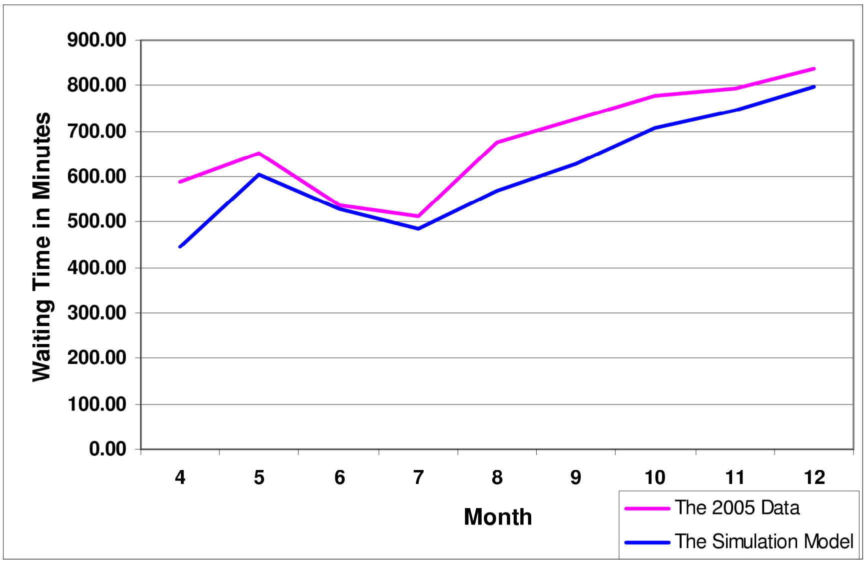


Figure 5.2. The comparison of the average waiting times of total vessels in the March-December 2005 period of the actual data and in the simulation runs

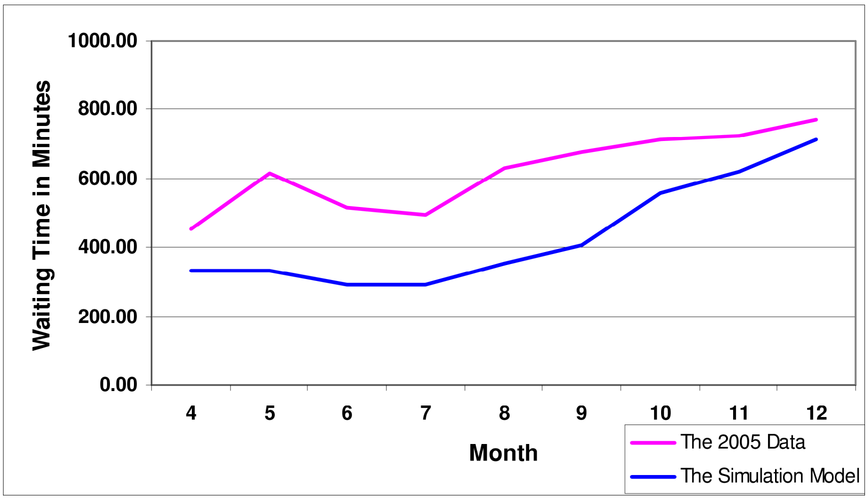


Figure 5.3. The comparison of the average waiting times of southbound vessels in the March-December 2005 period of the actual data and in the simulation runs

The cumulative average of the number of vessels in queues in the mentioned last nine months, as determined by the 10 replication simulation runs, is displayed in Figure 5.5. The average taken is weighted to take into consideration the queue length as a function of time. As can be seen from this figure, the average queue length is between

40 and 50 vessels throughout the seven months. Unfortunately, there is no information in the actual data of this period to compare this output with. Nevertheless, these attained queue lengths seem reasonable for the system.

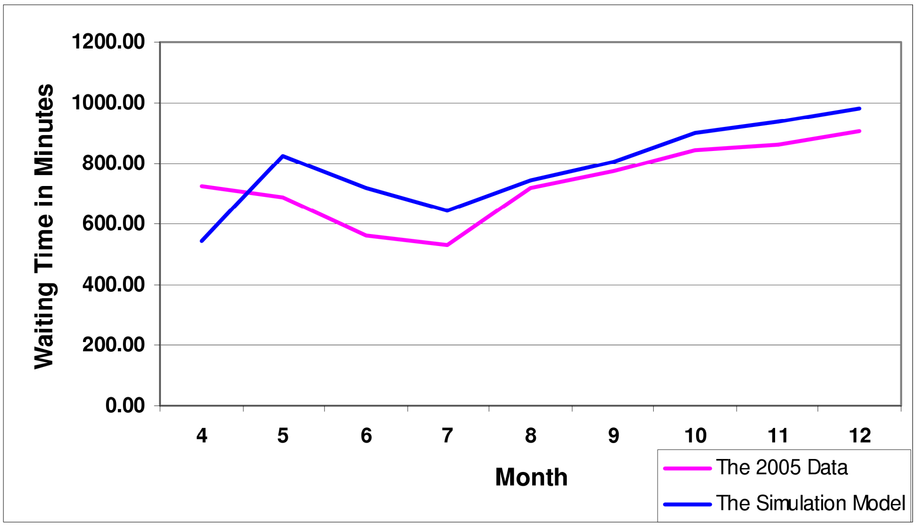


Figure 5.4. The comparison of the average waiting times of northbound vessels in the March-December 2005 period of the actual data and in the simulation runs

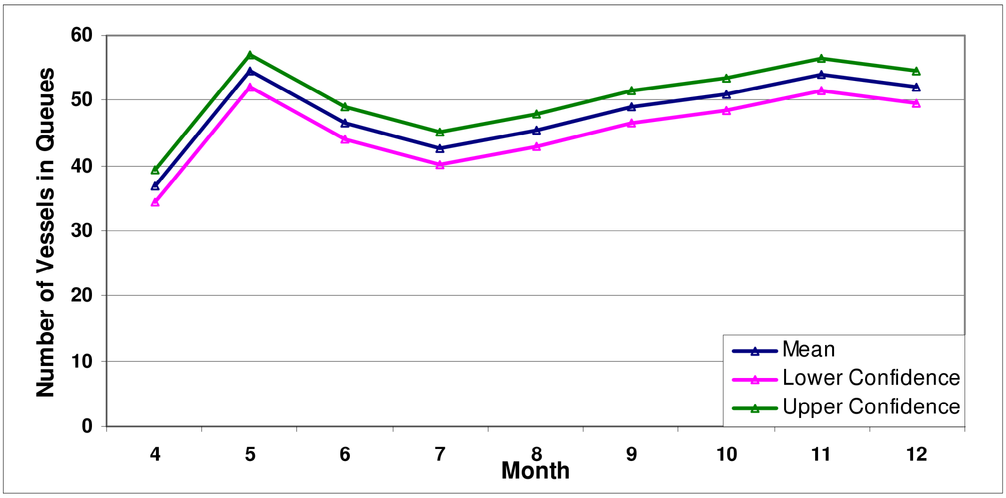


Figure 5.5. The cumulative average number of vessels in queues, according to the simulation run of the base scenario

The vessel density in the Strait, as determined by the 10 replication simulation runs, is displayed in Table 5.5. These statistics (which are weighted with respect to time) indicate that, on the average, there are about 11 vessels in the Strait at any time.

Although there is no real data to compare this statistic with, it seems quite reasonable.

Table 5.5. Average vessel density in the Strait according to the simulation run of the base scenario

	The Simulation Model			
	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Vessel Density in the Channel	0.6092	0.0080	0.6043	0.6142

The simulation outputs of the 10 replications, regarding pilot and tugboat utilizations in the Strait are displayed in Table 5.6. The average number of pilots in use at any time is estimated to be 4.56 of the 15 pilots (for the base scenario) and the average number of tugboats at any time is estimated to be 3 out of the 6 tugboats. Even though there is no relevant data to compare with, the results regarding pilot and tugboat utilization seem to be quite reasonable.

Table 5.6. Average pilot and the tugboat utilizations, according to the simulation run of the base scenario

	Mean	Standard Deviation	Lower Confidence	Upper Confidence
Pilot Utilization	0.3043	0.0011	0.3036	0.3050
Average Number of Pilots in Use	4.56	0.0165	4.5543	4.5747
Tugboat Utilization	0.5087	0.0038	0.5063	0.5111
Average Number of Tugboats in Use	3.05	0.0228	3.0381	3.0663

According to the comparisons of the simulation model outputs with the 2005 actual data, it seems that the simulation model developed is deficient to explain higher average waiting time of southbound vessels for the first couple of months. However, the general trend of the average waiting time is well represented for the period under investigation. Besides, the other output variables are quite satisfactory to explain the transit times and total vessels passed as well. Lastly, the average number of vessels in queues, the vessel density in the Strait, the pilot and the tugboat utilizations seem quite reasonable, even though there are no relevant historical data to compare with. Consequently, the simulation model is regarded to be sufficiently valid to represent the general behavior and trends of the actual system and also to approximate the values of major performance measures of the actual system.

5.2.2. The Comparison of 2005 Statistics and the Outputs of the Simulation Model under Randomized Arrivals without the Storm submodel

The comparisons performed with external inputting of actual data to the simulation model, enabled the validation of the Strait entrance and vessel transit procedures followed in the simulation model, whereas the scenario analyses are to be performed through the random generation of inputs. Thus, the performance of the simulation model with appropriately randomized inputs should also be compared with the actual system as well.

Three runs with the following features are taken in this regard with two months warm-up period, (the statistics of these months are excluded). In the first run, in order to obtain similar behaviors under the same external conditions and to perform a meaningful comparison with the actual realizations regarding the validation of the arrival process, both the interarrival coefficients of the storm submodel and the prioritization coefficients of prioritization model are set to “1”. Then, in order to test which prioritization coefficient is more likely to represent the actual system behavior, the prioritization coefficient is set to 1.3 and 1.5, in the second and third runs, respectively.

The models are run for a twelve months period, with 10 replications. Then, the outputs of the simulation model are compared with the year 2005 statistics. The statistics collection is accomplished on a monthly basis and it is assumed that one month is 30 days and a year is 360 days, in order to simplify statistics collection and comparisons in the simulation model.

The actual total number of vessels passed in 2005 and the mean of total number of vessels passed in the 10 replication simulation runs for CoefFD values 1.0, 1.3 and 1.5 are displayed in Table 5.7 , Table 5.8 and Table 5.9, respectively.

Table 5.7. The number of vessels passed in the actual data and in the simulation runs for CoefFD = 1.0

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standart Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	54.790	53.930.10	289.07	53.750.94	54.109.26
NS	27.388	27.414.20	362.64	27.189.44	27.638.96
SN	27.402	26.515.90	387.64	26.275.64	26.756.16

Table 5.8. The number of vessels passed in the actual data and in the simulation runs for CoefFD = 1.3

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standart Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	54.790	53.938.10	290.61	53.810.74	54.065.46
NS	27.388	27.413.50	356.90	27.257.09	27.569.91
SN	27.402	26.524.60	395.49	26.351.27	26.697.93

Table 5.9. The number of vessels passed in the 2005 data and in the simulation runs for CoefFD = 1.5

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standart Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	54.790	53.927.80	387.63	53.757.92	54.097.68
NS	27.388	27.411.80	293.83	27.283.03	27.540.57
SN	27.402	26.516.00	359.13	26.358.61	26.673.39

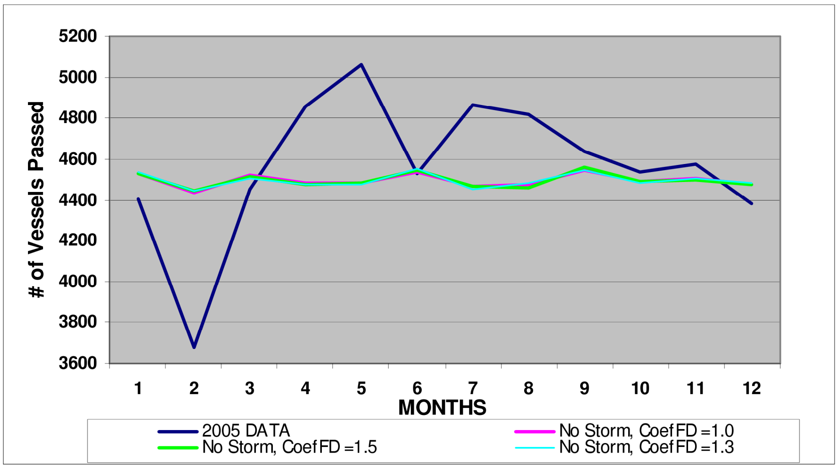


Figure 5.6. The plot of the total number of vessels passed in the three simulation runs and in the actual data

The plot of the total vessels passed on a monthly basis is displayed in Figure 5.6. As can be seen in Table 5.7, Table 5.8 and Table 5.9, the number of southbound and northbound vessels passed in the actual 2005 data and in the simulation results are very close. Since the simulation duration of one year consists of 360 days, it is quite reasonable that the total number of vessels passed is slightly below the 2005 actual data corresponding to 365 days. Furthermore, there is a high fluctuation in the number of vessels passed in each month of the actual 2005 data, whereas the simulation outputs show a stationary trend. The reason behind this could be the arrival processes, where arrivals are generated through the assumed stationary probability distributions. Another possible explanation may be the non-inclusion of extreme weather (storm) conditions, as yet. The effect of extreme weather conditions on vessel arrivals is analyzed in section 5.2.3.

Table 5.10, Table 5.11 and Table 5.12 display the average transit times of vessels in the actual 2005 data and in the 10 replication simulation runs, for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, respectively. The tables show that mean of the transit time for all, northbound and southbound vessels are quite similar and do not differ for varying CoefFD rates.

Table 5.10. Average transit times in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	103.26	102.67	0.29	102.49	102.85
NS	93.26	92.93	0.35	92.72	93.15
SN	113.31	112.73	0.49	112.43	113.04

Table 5.11. Average transit times in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	103.26	102.68	0.28	102.51	102.85
NS	93.26	92.94	0.36	92.72	93.17
SN	113.31	112.74	0.47	112.45	113.04

Table 5.12. Average transit times in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	103.26	102.68	0.28	102.51	102.85
NS	93.26	92.90	0.32	92.71	93.10
SN	113.31	112.78	0.48	112.48	113.08

Table 5.13, Table 5.14 and Table 5.15 illustrate the standard deviation in the transit times of vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, respectively. The tables show that standard deviation of the transit times for all, northbound and southbound vessels are quite similar and do not differ for varying CoefFD rates.

Table 5.13. The standard deviation of the transit times in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	21.59	19.91	0.23	19.77	20.06
NS	13.65	12.70	0.16	12.61	12.80
SN	23.36	20.98	0.26	20.82	21.14

Table 5.14. The standard deviation of the transit times in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	21.59	19.93	0.24	19.79	20.08
NS	13.65	12.73	0.15	12.63	12.82
SN	23.36	21.01	0.25	20.85	21.16

Table 5.15. The standard deviation of the transit times in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	21.59	19.94	0.20	19.82	20.07
NS	13.65	12.71	0.14	12.62	12.80
SN	23.36	20.99	0.16	20.89	21.09

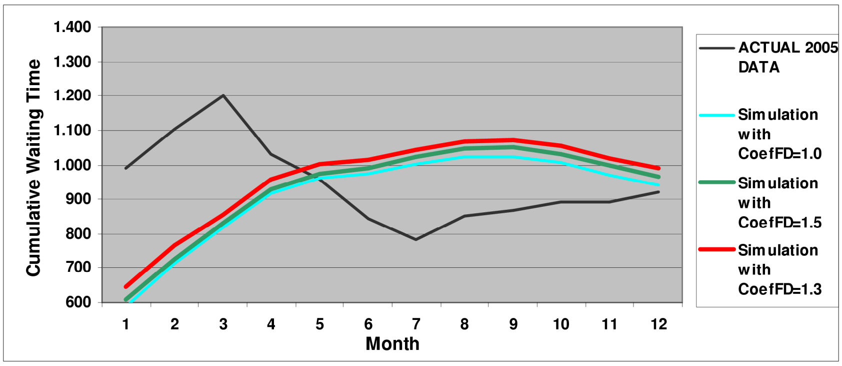


Figure 5.7. The comparison of the average waiting times of total vessels in the actual data and in the simulation runs

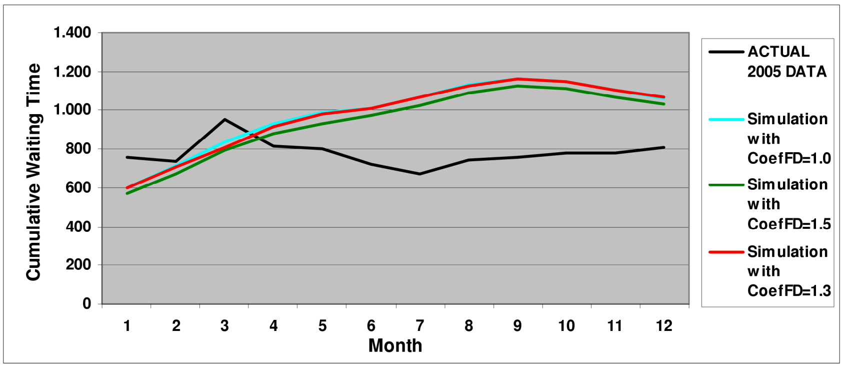


Figure 5.8. The comparison of the average waiting times of southbound vessels in the actual data and in the simulation runs

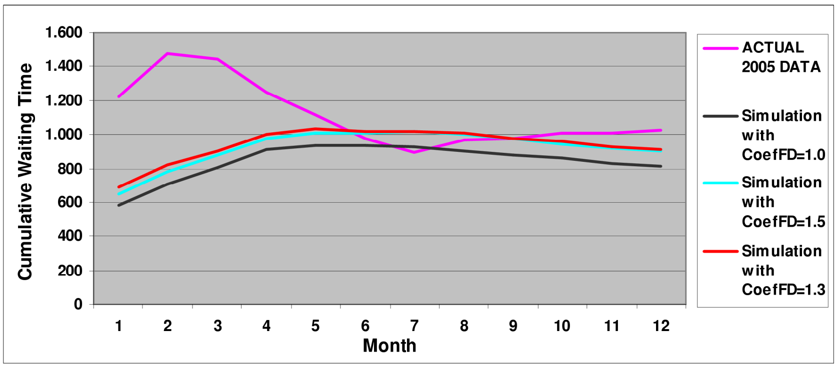


Figure 5.9. The comparison of the average waiting times of northbound vessels in the actual data and in the simulation runs

The comparison of the average waiting times of total, southbound and northbound vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period for CoefFD values of 1.0, 1.3 and 1.5 are displayed in Figure 5.7, Figure 5.8 and Figure 5.9, respectively.

The average waiting times of total, southbound and northbound vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period for CoefFD values of 1.0, 1.3 and 1.5 are displayed in Table 5.16, Table 5.17 and Table 5.18, respectively. As can be seen in the tables, for all values of CoefFD, the average waiting times of total vessels in the simulation outputs is very close to the actual system behavior, whereas the average waiting times of southbound and northbound vessels slightly differ. The average waiting times of total vessels only slightly increase for CoefFD values greater than 1, where this increase is mainly caused by the increase in the average waiting times of northbound vessels. Besides, there is a slight decrease in the average waiting times of southbound vessels for CoefFD value "1.5". These results are quite consistent with the prioritization policy incorporated into the model that transit priority is only given to soutbound indirect vessels. Thus, a slight decrease is observed in the average waiting times of southbound vessels for the higher prioritization level (for the CoefFD value "1.5"), as a result of the transit priority applied to some of the indirect soutbound vessels. Consequently, the average waiting times of northbound vessels increase causing a slight increase in the overall average waiting time of the system for values of CoefFD greater than 1. (The change in the average waiting times of southbound vessels is a combined effect of prioritization level, where the average waiting times of the indirect vessels given a transit priority decreases, whereas the average waiting times of other vessels increase consequently. Thus, a similar decrease in the average waiting times of southbound vessels could not be observed for the lower prioritization level with the CoefFD value "1.3".) The changes observed in the average waiting times of total, northbound and southbound vessels are quite consistent with the prioritization policies modeled and incorporated into the simulation model.

Table 5.16. The average waiting times in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	**The Simulation Model**			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	941.33	255.10	783.22	1.099.44
NS	811.27	1.063.28	342.28	851.14	1.275.42
SN	1.028.30	814.89	177.38	704.95	924.83

Table 5.17. The average waiting times in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	**The Simulation Model**			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	990.87	197.79	868.28	1.113.46
NS	811.27	1.069.07	260.28	907.75	1.230.39
SN	1.028.30	909.52	154.71	813.63	1.005.41

Table 5.18. The average waiting times in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	**The Simulation Model**			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	966.77	234.19	821.62	1.111.92
NS	811.27	1.030.20	288.40	851.45	1.208.95
SN	1.028.30	900.49	199.23	777.01	1.023.97

The comparison of the average waiting times of direct and indirect passing vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period for CoefFD values of 1.0, 1.3 and 1.5 are displayed in Figure 5.10 and Figure 5.11, respectively.

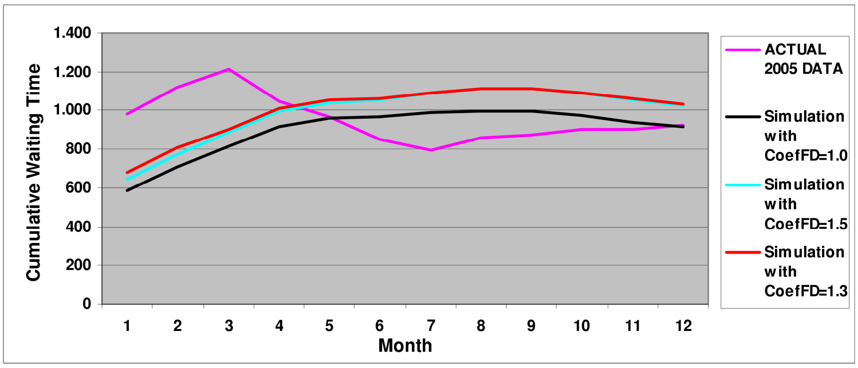


Figure 5.10. The comparison of the average waiting times of direct passing vessels in the actual data and in the simulation runs

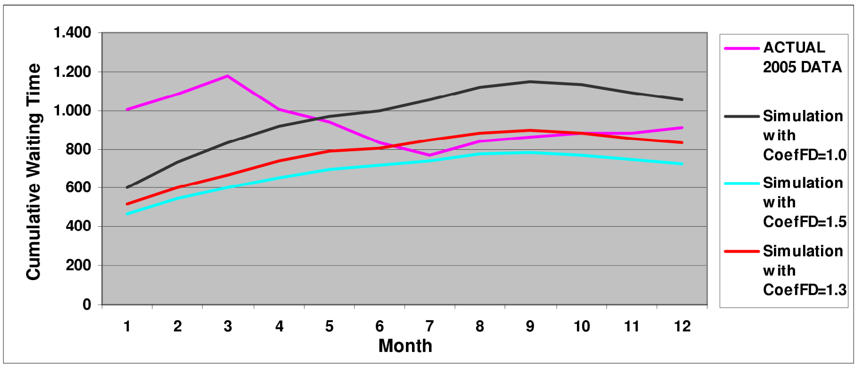


Figure 5.11. The comparison of the average waiting times of indirect passing vessels in the actual data and in the simulation runs

The average waiting times of direct and indirect passing vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period for CoefFD values of 1.0, 1.3 and 1.5 are displayed in Table 5.19, Table 5.20 and Table 5.21, respectively. As can be seen in the tables, the average waiting times of indirect passing vessels in the simulation outputs is very close to the actual system behavior for CoefFD=1.3, whereas the average waiting times of direct passing vessels slightly increase. The effects of the prioritization policy favoring only to indirect passing vessels can be cleary observed from these tables. Due to the transit priority applied to some of the indirect passing vessels, their average waiting times decrease, whereas the average waiting times of direct passing vessels increase consequently, causing a slight increase in the average waiting times of total vessels. The changes observed in the average waiting times of total, direct and indirect passing vessels are quite consistent with the prioritization policies modeled and incorporated into the simulation model.

Table 5.19. The average waiting times of total/direct/indirect passing vessels in the 2005 data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919,81	941,33	255,10	783,22	1.099,44
Direct	914,04	914,10	238,03	766,57	1.061,63
Indirect	923,32	1.054,45	331,97	848,70	1.260,20

Table 5.20. The average waiting times of total/direct/indirect passing vessels in the 2005 data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919,81	990,87	197,79	868,28	1.113,46
Direct	914,04	1.028,91	201,88	903,79	1.154,03
Indirect	923,32	831,30	184,63	716,87	945,73

Table 5.21. The average waiting times of total/direct/indirect passing vessels in the 2005 data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919,81	966,77	234,19	821,62	1.111,92
Direct	914,04	1.025,04	247,98	871,34	1.178,74
Indirect	923,32	722,53	180,66	610,56	834,50

The cumulative average of number of vessels in queues in the 10 replication simulation runs, for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5 are displayed in Figure 5.12. The average queue length is between 75 and 85 throughout the twelve months. This value increases with the increase in the value of CoefFD, as an increase in CoefFD is associated with a slight increase in the total waiting time of the system, hence increasing the number of vessels in queues.

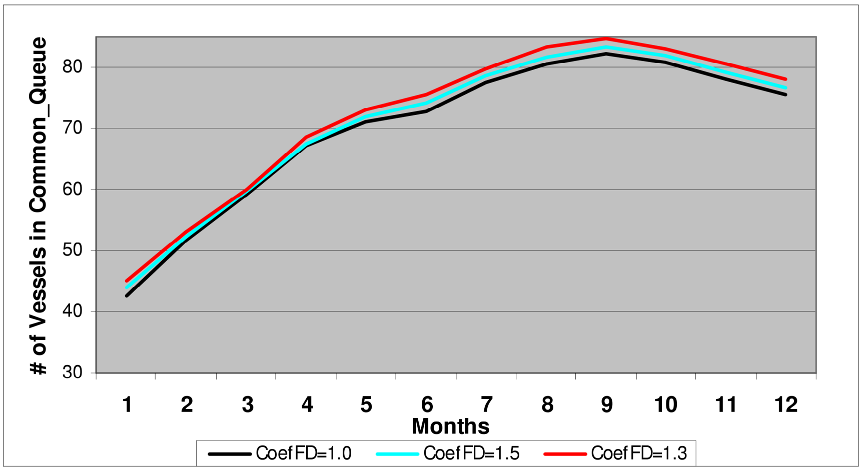


Figure 5.12. Cumulative average number of vessels in the queues in months for varying CoefFD

Table 5.22, Table 5.23 and Table 5.24 display the vessel density in the Strait in the actual 2005 data and in the 10 replication simulation runs, for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, respectively. The figures in the tables indicate that the vessel density in the Strait does not change for different values of CoefFD. In all the three cases, the simulation output values are very close to the actual values in the 2005 data, regarding vessel densities.

Table 5.22. The vessel density in the Strait in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	0.6380	0.6374	0.0017	0.6364	0.6384
N	0.2913	0.2926	0.0006	0.2922	0.2929
S	0.3467	0.3448	0.0012	0.3441	0.3456

Table 5.23. The vessel density in the Strait in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	0.6380	0.6385	0.0017	0.6375	0.6396
N	0.2913	0.2927	0.0007	0.2923	0.2931
S	0.3467	0.3458	0.0012	0.3450	0.3466

Table 5.24. The vessel density in the Strait in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	0.6380	0.6382	0.0016	0.6372	0.6391
N	0.2913	0.2929	0.0006	0.2925	0.2932
S	0.3467	0.3453	0.0012	0.3445	0.3460

The simulation outputs of the 10 replications regarding pilot and tugboat utilizations in the Strait are displayed in Table 5.25, Table 5.26 and Table 5.27 for CoefFD values of 1.0, 1.3 and 1.5, respectively. The average number of pilots in use at any time is projected to be 4.45 of the 15 pilots (of the base scenario) and the average number of tugboats at any time is projected to be 2.98 of the 6 tugboats. These values are consistent with the results of the simulation model with external inputting.

Table 5.25. Tugboat and pilot utilization in the Strait in the simulation runs for CoefFD=1.0

	The Simulation Model			
Utilization of	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Tugboat	0.4970	0.0044	0.4943	0.4997
# of Tugboats in Use	2.9820	0.0265	2.9656	2.9984
Pilot	0.2964	0.0036	0.2942	0.2987
# of Pilots in Use	4.4463	0.0543	4.4127	4.4800

Table 5.26. Tugboat and pilot utilization in the Strait in the simulation runs for CoefFD=1.3

	The Simulation Model			
Utilization of	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Tugboat	0.4975	0.0046	0.4946	0.5003
# of Tugboats in Use	2.9847	0.0277	2.9675	3.0019
Pilot	0.2964	0.0036	0.2942	0.2987
# of Pilots in Use	4.4463	0.0542	4.4127	4.4799

Table 5.27. Tugboat and pilot utilization in the Strait in the simulation runs for CoefFD=1.5

	The Simulation Model			
Utilization of	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Tugboat	0.4972	0.0044	0.4944	0.4999
# of Tugboats in Use	2.9829	0.0265	2.9665	2.9993
Pilot	0.2964	0.0038	0.2941	0.2988
# of Pilots in Use	4.4467	0.0571	4.4113	4.4821

The comparison of the simulation outputs with randomized arrivals and the actual data of 2005 reveal that the general vessel arrival behavior of the system are well represented under randomized arrival processes. As the arrival distributions are assumed to remain stationary throughout a year, the actual vessel arrival data and the generated arrivals differ for the first couple of months in the year.

The simulation outputs for the average waiting time of vessels are consistent with the behaviour of the actual system. Its increasing trend for vessels with the increasing CoefFD values is reasonable, since the prioritization policies decrease the average waiting time of some indirect vessels, while increasing the average waiting time of many other vessels, thus causing a slight increase in the average waiting time of overall vessels. Other output measures, such as the average number of vessels in queues, the vessel density in the Strait, the pilot and tugboat utilizations, are reasonable and consistent with the simulation outputs of the model with external inputting structure.

5.2.3. The Comparison of 2005 Statistics and the Outputs of the Simulation Model under Randomized Arrivals with the Storm submodel

Both comparisons (the comparison of the actual data with the simulation outputs of the model with external inputting structure and the comparison of the actual data with the simulation outputs of the model with stochastic vessel arrival process and prioritization) enabled to check the validation of the Strait entrance and vessel transit procedures followed in the simulation model, and the correct implementation of prioritization policies. However, scenario analyses are to be performed under the random generation of inputs regarding storm occurrences. Thus, the simulation model with randomized arrivals for both vessels and storm occurrences, and with changing interarrival time coefficients due to the storm occurrences should be compared with the actual data as well.

Three runs where prioritization coefficients are set to values “1.0”, “1.3”, and “1.5”, as in section 5.2.2, are used to enable the fine-tuning of the parameters for the selection of the base scenario.

All models are run for a twelve months period with 10 replications, with two months warm-up period. (The statistics of these months are excluded.) Then, the outputs of the simulation model are compared with the year 2005 statistics. Again, the statistics are collected on monthly basis and it is assumed that one month is 30 days and a year is 360 days to simplify statistics collection and comparisons in the simulation model.

The actual total number of vessels passed in 2005 and the mean of the total number of vessels passed in 10 replication simulation runs are displayed in Table 5.28, Table 5.29 and Table 5.30 for CoefFD values of 1.0, 1.3 and 1.5, respectively.

Table 5.28. The number of vessels passed in the actual data and in the simulation runs for CoefFD = 1.0

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	54.790	53.503.40	642.54	53.105.16	53.901.64
NS	27.388	27.372.70	267.24	27.207.06	27.538.34
SN	27.402	26.130.70	438.75	25.858.77	26.402.63

Table 5.29. The number of vessels passed in the actual data and in the simulation runs for CoefFD = 1.3

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	54.790	53.513.40	639.13	53.233.29	53.793.51
NS	27.388	27.380.40	268.61	27.262.68	27.498.12
SN	27.402	26.133.00	443.08	25.938.82	26.327.18

Table 5.30. The number of vessels passed in the actual data and in the simulation runs for CoefFD = 1.5

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	54.790	53.504.80	639.09	53.224.71	53.784.89
NS	27.388	27.378.30	259.75	27.264.46	27.492.14
SN	27.402	26.126.50	440.06	25.933.64	26.319.36

The plot of the total vessels passed on a monthly basis is displayed in Figure 5.13. As can be seen in Table 5.28, Table 5.29 and Table 5.30, the number of southbound and northbound vessels passed in the actual data and in the simulation results are very close. Thus, the number of vessels passed does not change with the incorporation of the storm submodel. Besides that, there is a high fluctuation in the number of vessels passed between the months in the actual 2005 data, whereas the simulation outputs show a stationary trend.

Table 5.31, Table 5.32 and Table 5.33 display the average transit times of vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, respectively. The tables show that mean of the transit time for all, northbound and southbound vessels are quite similar and do not change for different CoefFD values.

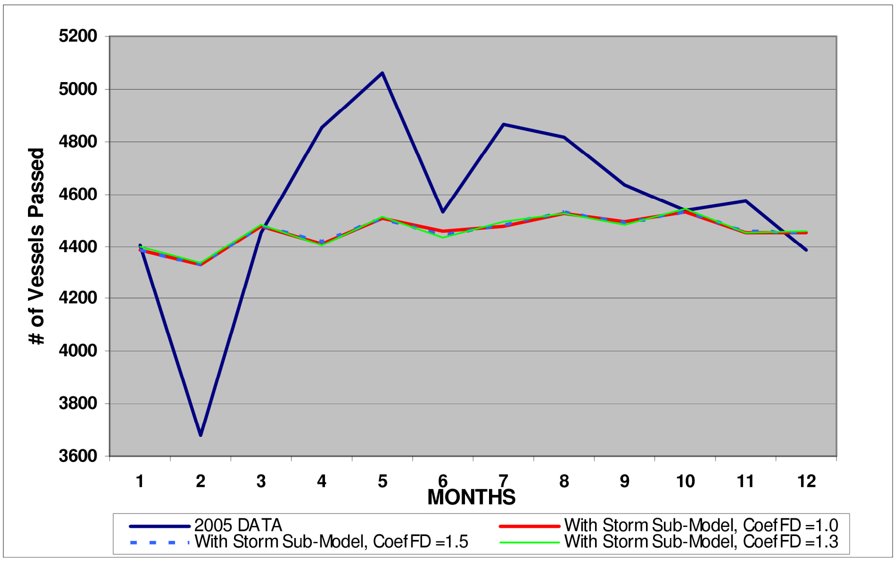


Figure 5.13. The plot of the total number of vessels passed in the three simulation runs and in the actual data

Table 5.31. Average transit times in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	103.26	102.49	0.25	102.33	102.64
NS	93.26	92.77	0.35	92.55	92.98
SN	113.31	112.66	0.55	112.32	113.00

Table 5.32. Average transit times in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	103.26	102.50	0.25	102.34	102.65
NS	93.26	92.82	0.37	92.59	93.04
SN	113.31	112.64	0.48	112.34	112.94

Table 5.33. Average transit times in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	Mean	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	103.26	102.51	0.28	102.34	102.68
NS	93.26	92.83	0.33	92.62	93.03
SN	113.31	112.66	0.50	112.35	112.97

Table 5.34, Table 5.35 and Table 5.36 illustrate the standard deviation in the transit times of vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, respectively. The tables show that standard deviation of the transit times for all, northbound and southbound vessels are quite similar and do not differ for varying CoefFD rates.

Table 5.34. The standard deviation of the transit times in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	**Total**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	21.59	19.96	0.24	19.81	20.11
NS	13.65	12.67	0.15	12.58	12.76
SN	23.36	21.09	0.25	20.94	21.25

Table 5.35. The standard deviation of the transit times in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	**Total**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	21.59	19.94	0.22	19.80	20.08
NS	13.65	12.71	0.14	12.62	12.79
SN	23.36	21.07	0.21	20.94	21.19

Table 5.36. The standard deviation of the transit times in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	**Total**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	21.59	19.96	0.19	19.84	20.07
NS	13.65	12.70	0.16	12.60	12.80
SN	23.36	21.10	0.21	20.97	21.23

The comparison of the average waiting times of total, southbound and northbound vessels in the actual 2005 data and in the 10 replication simulation runs for the selected twelve month period for CoefFD values of 1.0, 1.3 and 1.5 are displayed in Figure 5.14, Figure 5.15 and Figure 5.16, respectively.

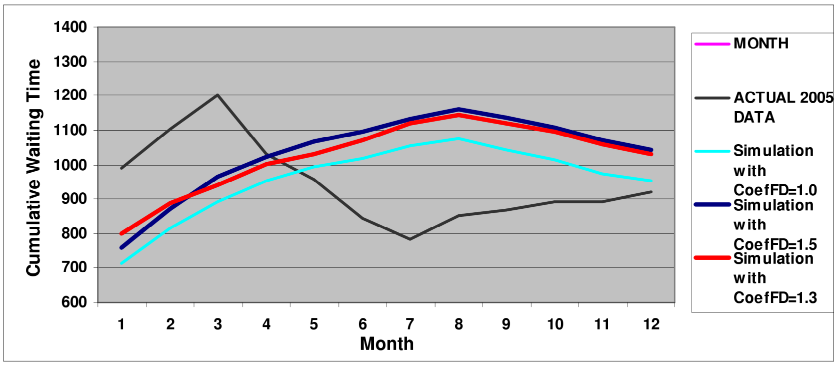


Figure 5.14. The comparison of the average waiting times of all vessels in the actual data and in the simulation runs

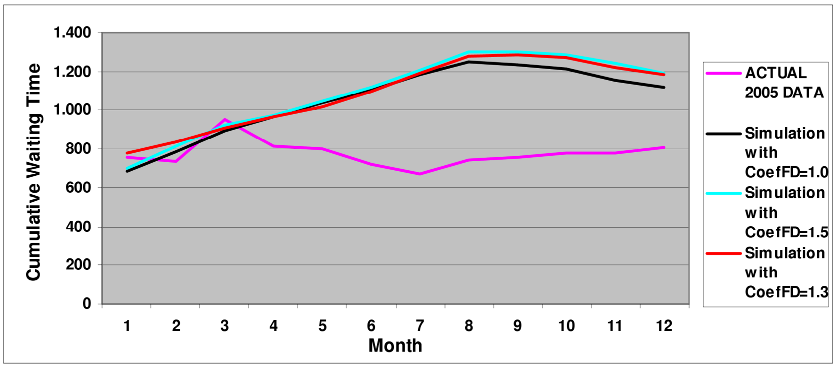


Figure 5.15. The comparison of the average waiting times of southbound vessels in the actual data and in the simulation runs

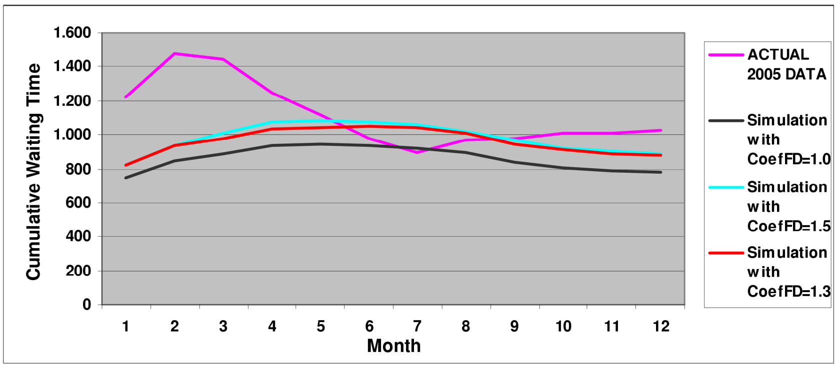


Figure 5.16. The comparison of the average waiting times of northbound vessels in the actual data and in the simulation runs

The average waiting times of total, southbound and northbound vessels in the actual 2005 data and in the 10 replication simulation runs, for the selected twelve month period, are displayed in Table 5.37, Table 5.38 and Table 5.39, for CoefFD values of 1.0, 1.3 and 1.5, respectively. As can be seen in the tables, the average waiting times of total vessels in the simulation outputs is very close to the actual system behavior, whereas the average waiting times of southbound and northbound vessels slightly differ.When compared with Table 5.16, Table 5.17 and Table 5.18 (section 5.2.2), the average waiting times of northbound vessels decrease with the incorporation of storm submodel. The reason for this decrease is mainly caused by the decrease in arrival rate of the general cargo vessels before 3 days and during a storm occurrence. Among varying CoefFD levels, average waiting times of total, northbound and southbound vessels are found to be more representative for the CoefFD value “1.3”, since for higher CoefFD values, the actual average waiting time of the simulation model exceeds the actual average waiting time of the system even more.

Table 5.37. The actual average waiting times in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	951.91	427.85	686.73	1.217.09
NS	811.27	1.117.45	646.77	716.59	1.518.31
SN	1.028.30	777.74	232.56	633.60	921.88

Table 5.38. The actual average waiting times in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	1.032.32	537.06	699.45	1.365.19
NS	811.27	1.180.57	777.25	698.83	1.662.31
SN	1.028.30	875.92	307.24	685.49	1.066.35

The comparison of the average waiting times of direct and indirect passing vessels in the actual 2005 data and in the 10 replication simulation runs, for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, are displayed in Figure 5.17 and Figure 5.18, respectively.

Table 5.39. The actual average waiting times in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	1.043.30	471.98	750.77	1.335.83
NS	811.27	1.191.39	682.69	768.26	1.614.52
SN	1.028.30	887.24	274.76	716.94	1.057.54

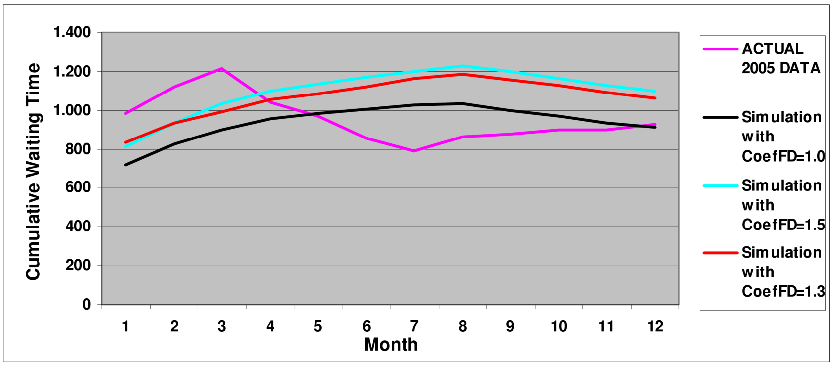


Figure 5.17. The comparison of the average waiting times of direct passing vessels in the 2005 data and in the simulation runs

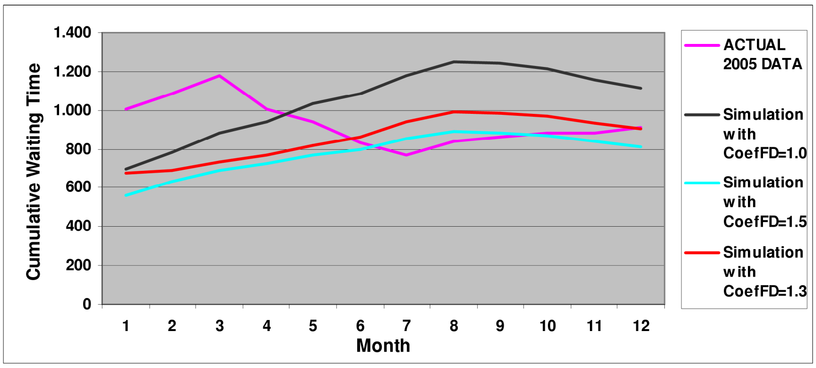


Figure 5.18. The comparison of the average waiting times of indirect passing vessels in the 2005 data and in the simulation runs

The average waiting times of direct and indirect passing vessels in the actual 2005 data and in the 10 replication simulation runs, for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, are displayed in Table 5.40, Table 5.41 and Table 5.42, respectively. As can be seen in these tables, the average waiting times of total vessels in the simulation outputs is very close to the actual system behavior for CoefFD=1.3, whereas the average waiting times of direct and indirect passing vessels slightly differ. These tables illustrate the effect of CoefFD on the average waiting time for direct and indirect passing vessels under the existence of storm submodel, so they clearly highlight that average waiting times of total, direct and indirect passing vessels mimic the actual system behavior for CoefFD level “1.3”.

Table 5.40. The average waiting times of total/direct/indirect passing vessels in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	**The Simulation Model**			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	951.91	427.85	686.73	1.217.09
Direct	923.32	912.27	376.14	679.14	1.145.40
Indirect	914.04	1.115.90	655.42	709.67	1.522.13

Table 5.41. The average waiting times of total/direct/indirect passing vessels in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	**The Simulation Model**			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	1.032.32	537.06	699.45	1.365.19
Direct	923.32	1.063.60	534.78	732.15	1.395.05
Indirect	914.04	902.32	551.25	560.66	1.243.98

Table 5.42. The average waiting times of total/direct/indirect passing vessels in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	**The Simulation Model**			
Direction	**Mean**	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Total	919.81	1.043.30	471.98	750.77	1.335.83
Direct	923.32	1.099.62	488.27	796.99	1.402.25
Indirect	914.04	809.66	407.79	556.91	1.062.41

The cumulative average of number of vessels in the queues in the 10 replication simulation runs, for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, are displayed in Figure 5.19. The average queue length is between 75 and 85 throughout the twelve months. This value increases with the increase in the value of CoefFD, as an increase in CoefFD is associated with a slight increase in the total waiting time of the system, hence increasing the number of vessels in queues.

Table 5.43, Table 5.44 and Table 5.45 display the vessel density in the Strait in the 2005 data and in the 10 replication simulation runs, for the selected twelve month period, for CoefFD values of 1.0, 1.3 and 1.5, respectively. Similar to the results obtained in section 5.2.2, these tables indicate that the vessel density in the Strait does not change for different values of CoefFD. In all the three cases, the simulation output values for vessel density are very close to the actual vessel density values in the 2005 data.

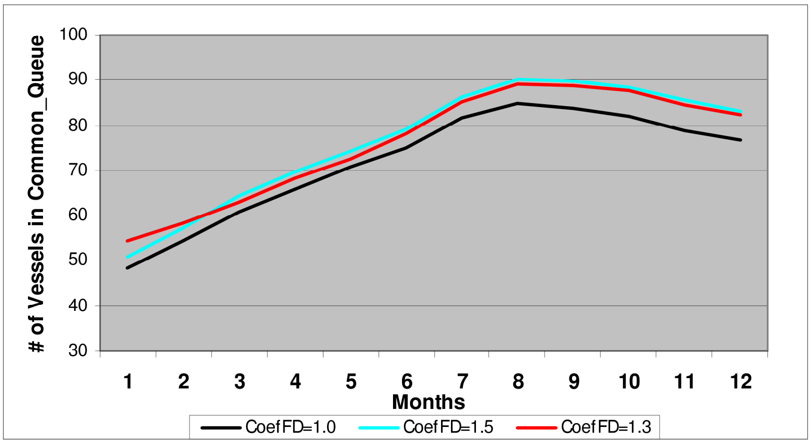


Figure 5.19. The cumulative average number of vessels in the queues for different values of CoefFD

Table 5.43. The vessel density in the Strait in the actual data and in the simulation runs for CoefFD=1.0

	The 2005 Data	The Simulation Model			
Direction	Total	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	0.6380	0.6245	0.0060	0.6208	0.6282
N	0.2913	0.2898	0.0023	0.2884	0.2913
S	0.3467	0.3347	0.0038	0.3323	0.3370

Table 5.44. The vessel density in the Strait in the actual data and in the simulation runs for CoefFD=1.3

	The 2005 Data	The Simulation Model			
Direction	Total	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	0.6380	0.6248	0.0055	0.6214	0.6282
N	0.2913	0.2902	0.0020	0.2889	0.2914
S	0.3467	0.3346	0.0036	0.3324	0.3369

Table 5.45. The vessel density in the Strait in the actual data and in the simulation runs for CoefFD=1.5

	The 2005 Data	The Simulation Model			
Direction	Total	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Total	0.6380	0.6243	0.0060	0.6206	0.6281
N	0.2913	0.2898	0.0024	0.2884	0.2913
S	0.3467	0.3345	0.0038	0.3322	0.3368

The simulation outputs of the 10 replications regarding pilot and tugboat utilizations in the Strait are displayed in Table 5.46, Table 5.47 and Table 5.48 for CoefFD values of 1.0, 1.3 and 1.5, respectively. The average number of pilots in use at any time is estimated to be 4.45 of the 15 pilots (of the base scenario) and the average number of tugboats at any time is estimated to be 2.98 of the 6 tugboats. These values are consistent with the results of the simulation model with external inputting.

Table 5.46. Tugboat and pilot utilizations in the Strait in the simulation runs for CoefFD=1.0

	The Simulation Model			
Utilization of	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Tugboat	0.4907	0.0085	0.4855	0.4960
# of Tugboats in Use	2.9445	0.0512	2.9127	2.9762
Pilot	0.2911	0.0054	0.2878	0.2945
# of Pilots in Use	4.3671	0.0815	4.3165	4.4176

Table 5.47. Tugboat and pilot utilizations in the Strait in the simulation runs for CoefFD=1.3

	The Simulation Model			
Utilization of	Mean	Standard Deviation	Lower Confidence Limit	Upper Confidence Limit
Tugboat	0.4914	0.0083	0.4862	0.4965
# of Tugboats in Use	2.9481	0.0495	2.9174	2.9788
Pilot	0.2913	0.0056	0.2878	0.2947
# of Pilots in Use	4.3689	0.0835	4.3171	4.4206

The comparisons of the simulation model with randomized arrivals with the actual data of 2005 reveal that the general behavior of the system and trends are well represented. As arrival distributions remain stationary throughout a year, the actual vessel arrival data and the generated arrivals differ for the first couple of months in the year.

Table 5.48. Tugboat and pilot utilizations in the Strait in the simulation runs for CoefFD=1.5

	The Simulation Model			
Utilization of	**Mean**	**Standard Deviation**	**Lower Confidence Limit**	**Upper Confidence Limit**
Tugboat	0.4905	0.0082	0.4855	0.4956
# of Tugboats in Use	2.9432	0.0490	2.9128	2.9736
Pilot	0.2909	0.0055	0.2876	0.2943
# of Pilots in Use	4.3641	0.0818	4.3134	4.4148

On the other hand, the comparisons of the simulation model outputs before and after the integration of the storm submodel indicates that integration of the storm submodel enables to mimic the actual system behavior more closely. As depicted in Table 5.49. and Table 5.50, the simulation model better represents the actual system behavior for the cumulative average waiting time of indirect vessels with the CoefFD value "1.3" and with the integration of the storm submodel. Furthermore, a comparison of the cumulative average waiting times of overall vessels before and after the integration of the storm submodel (Table 5.51. and Table 5.52) reveals that the simulation model better represents the actual system behavior after the integration of the storm submodel by increasing the cumulative average waiting time for the first couple of months, where the the simulation-generated average waiting time before the integration of the storm submodel is much lower than that of the actual system.

Even though the cumulative average waiting times of overall vessels in the simulation outputs increase with the CoefFD value "1.3" and with the integration of the storm submodel, these statistics are still quite close to those in the actual data.

As depicted in Table 5.53. and Table 5.54. the cumulative average waiting times of the northbound and southbound vessels reveal that the actual cumulative average waiting times of northbound vessels are higher than those in the simulation outputs, whereas the cumulative average waiting times of southbound vessels in the actual data are lower than those in the simulation outputs.

Table 5.49. The average waiting times of indirect passing vessels before the integration of the storm submodel

OVERALL INDIRECT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Actual 2005	983,9	1117,7	1211,4	1043,3	969,9	855,0	791,3	861,2	875,7	899,5	898,8	923,3
Without Storm Sub-Model Coef FD=1.0	603,9	732,9	835,8	915,5	968,5	999,2	1057,8	1121,6	1147,7	1133,5	1091,2	1054,5
Without Storm Sub-Model Storm Coef FD=1.3	**515,1**	**599,6**	**665,6**	**737,8**	**786,7**	**807,4**	**844,3**	**880,8**	**897,6**	**883,4**	**857,0**	**831,3**
Without Storm Sub-Model Storm Coef FD=1.5	464,3	542,8	604,4	653,5	694,7	714,4	741,1	773,7	785,4	770,4	746,5	722,5

Table 5.50. The average waiting times of indirect passing vessels after the integration of the storm submodel

OVERALL INDIRECT VESSELS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Actual 2005	983,9	1117,7	1211,4	1043,3	969,9	855,0	791,3	861,2	875,7	899,5	898,8	923,3
With Storm Sub-Model Coef FD=1.0	697,7	779,3	881,9	939,2	1030,4	1085,2	1175,2	1250,6	1238,6	1209,8	1156,5	1115,9
With Storm Sub-Model Storm Coef FD=1.3	**676,9**	**692,3**	**733,5**	**769,4**	**819,5**	**861,7**	**939,3**	**988,3**	**985,4**	**969,3**	**933,7**	**902,3**
With Storm Sub-Model Storm Coef FD=1.5	556,5	628,7	686,5	722,4	769,8	797,8	853,6	892,0	886,6	869,0	838,6	809,7

Table 5.51. The average waiting times of overall vessels before the integration of the storm submodel

OVERALL	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Actual 2005	991,5	1104,5	1199,3	1028,8	958,0	845,6	783,3	853,2	869,8	893,9	893,5	919,8
Without Storm Sub-Model Coef FD=1.0	589,5	712,3	821,1	918,4	962,5	972,1	1001,2	1021,9	1022,8	1004,6	969,0	941,3
Without Storm Sub-Model Storm Coef FD=1.3	**646,1**	**765,2**	**857,6**	**958,9**	**1003,8**	**1013,5**	**1043,2**	**1068,9**	**1071,8**	**1052,8**	**1019,1**	**990,9**
Without Storm Sub-Model Storm Coef FD=1.5	609,4	725,2	833,2	929,0	972,7	990,1	1021,3	1046,6	1050,1	1029,0	995,9	966,8

Table 5.52. The average waiting times of overall vessels after the integration of the storm submodel

OVERALL VESSELS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Actual 2005	991,5	1104,5	1199,3	1028,8	958,0	845,6	783,3	853,2	869,8	893,9	893,5	919,8
With Storm Sub-Model Coef FD=1.0	714,9	814,8	892,8	952,6	993,6	1018,2	1053,3	1073,4	1043,4	1013,3	974,9	951,9
With Storm Sub-Model Storm Coef FD=1.3	**799,1**	**886,7**	**940,5**	**1000,4**	**1031,9**	**1071,3**	**1119,1**	**1143,5**	**1120,2**	**1095,1**	**1058,0**	**1032,3**
With Storm Sub-Model Storm Coef FD=1.5	759,2	873,6	964,6	1023,1	1065,7	1096,5	1132,1	1160,5	1136,9	1108,3	1072,7	1043,3

Table 5.53. The average waiting times of northbound vessels after the integration of the storm submodel

OVERALL (S-N) NORTHBOUND VESSELS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Actual 2005	1221,4	1473,8	1448,0	1245,1	1112,0	972,8	893,0	966,6	978,0	1009,0	1006,5	1028,3
With Storm Sub-Model Coef FD=1.0	742,7	847,1	887,6	937,2	943,4	931,5	921,1	890,4	840,8	807,3	784,8	777,7
With Storm Sub-Model Storm Coef FD=1.3	**817,6**	**935,4**	**974,5**	**1036,2**	**1044,0**	**1047,6**	**1041,5**	**1005,4**	**947,2**	**908,9**	**885,4**	**875,9**
With Storm Sub-Model Storm Coef FD=1.5	820,0	936,1	1009,9	1072,0	1086,8	1077,9	1057,4	1020,6	964,9	922,6	899,1	887,2

Table 5.54. The average waiting times of southbound vessels after the integration of the storm submodel

OVERALL (N-S) SOUTHBOUND VESSELS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Actual 2005	754,5	737,4	951,7	813,0	804,0	718,1	673,9	739,8	761,1	778,4	780,3	811,3
With Storm Sub-Model Coef FD=1.0	688,0	783,1	897,5	967,4	1041,9	1102,1	1180,5	1249,1	1237,4	1209,5	1155,6	1117,5
With Storm Sub-Model Storm Coef FD=1.3	**778,8**	**838,4**	**907,5**	**966,7**	**1020,9**	**1095,0**	**1194,1**	**1276,9**	**1286,6**	**1272,7**	**1222,0**	**1180,6**
With Storm Sub-Model Storm Coef FD=1.5	701,0	814,7	922,0	977,4	1046,4	1115,4	1204,4	1295,7	1302,4	1285,6	1237,7	1191,4

Detailed analysis of the actual 2005 data reveals that the cumulative average waiting times of northbound general cargo vessels are considerably high for the first three months, even though the number of vessels arrivals are significantly lower than the number of vessel arrivals in the following months, as indicated in Figure 5.20. Furthermore, Figure 5.21. shows that such an increase in the cumulative average waiting time of southbound general cargo vessels is not observed within the same period. One possible explanation could be that the TSVTS applied a temporary policy by delaying the entrance of the northbound general cargo vessels due to extreme weather conditions at the Black Sea. Consequently, the cumulative waiting time of the northbound vessels increased due to the delay in their transit, whereas the transit of the southbound vessels are facilitated causing a decrease in their average waiting times. However, since no standard TSMTR&R are defined by the TSVTS, regarding a possible change in the transit policies applied under the existence of extreme weather conditions, such policies are not modeled and not integrated into the simulation model. Consequently, the simulation model could not reflect the increase in the average waiting times of northbound vessels.

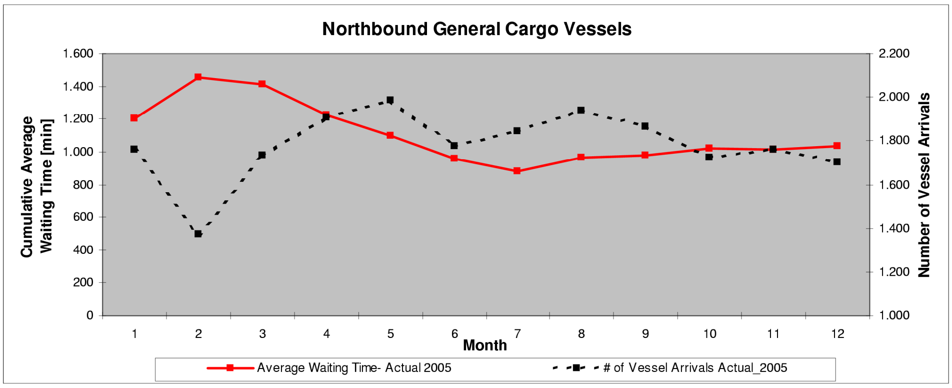


Figure 5.20. The average waiting times and the number of vessels passed for northbound general cargo vessels in the 2005 data

The simulation outputs for the average waiting time of vessels are consistent with the behaviour of the actual system. Its slightly increasing trend with the increasing CoefFD values is reasonable, as the prioritization level decreases the average waiting time of some indirect vessels, thereby increasing the average waiting time of other

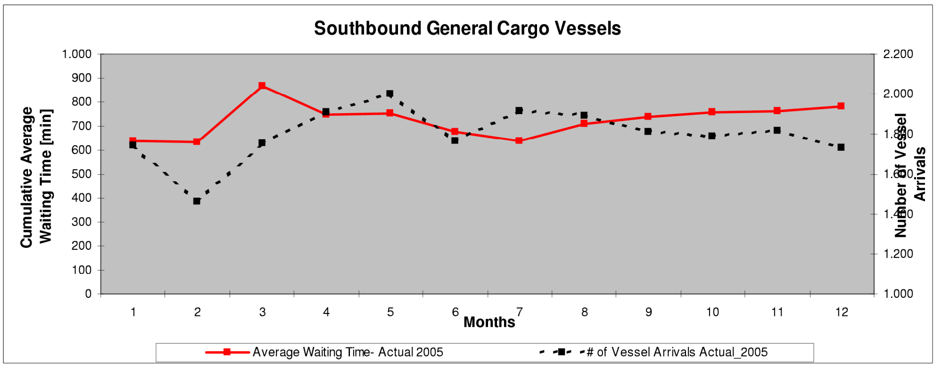


Figure 5.21. The average waiting times and the number of vessels passed for southbound general cargo vessels in the 2005 data

vessels, which also causes a slight increase in the average waiting time of overall vessels. Other output measures, such as average number of vessels in the queues, the vessel density in the Strait, the pilot and tugboat utilizations are reasonable and consistent with the simulation outputs of the model with external inputting structure.

6. SCENARIO ANALYSIS AND RESULTS

Simulation experiments are conducted to enable a better understanding of the effect of multiple factors on various output performance measures. Furhtermore, scenario analysis enables better and more accurate estimation of the performance of the system under some predefined projected set of conditions.

6.1. Design of Simulation Experiments

Simulation experiments with multiple factors aim to identify each factor's effect on performance measures and possible interactions between factors.

The six input factors chosen for the revised Maritime Traffic Simulation Model are as follows:

- Arrival rates of transit vessels
- Pilot and tugboat availabilities
- Prioritization level
- Pursuit distance between vessels
- Seasonal conditions
- Storm level

During the simulation experiments, the effects of these factors on performance measures and their interactions are analyzed. Factorial designs enable to conduct simulation experiments efficiently, while setting the multiple factors at different levels. When only two levels of factors are to be considered, 2^k observations are required and then it is called 2^k factorial design (Montgomery, 2001).

If all factors in the experiment are fixed, hypotheses about the main effects and interactions can be easily formulated and tested. For a fixed effects model, test statistics for each main effect and interaction may be constructed by dividing the corresponding mean square for the effect or interaction by the mean square error. All of these F tests are upper-tail, one tail tests. The number of degrees of freedom for any of the main effects is the number of levels of the factor minus one and the number of degrees of freedom for an interaction is the product of the number of degrees of freedom associated with the individual components of the interaction. (Montgomery, 2001)

The full factorial design for six factors, each tested on two levels, forms 64 scenarios. Additionally, 10 replications are taken for each scenario, in order to better observe and investigate the effects on performance measures of the randomized (according to the selected probability distributions) input factors. Hence, in total 640 simulation runs are accomplished.

6.1.1. The Factors and Levels

Pre-experimental planning for designing an experiment involves the following three basic steps (Montgomery, 2001):

6.1.1.1. Recognition and Statement of the Problem. It is usually helpful to prepare a list of specific problems or questions that are to be addressed by the experiment. A clear statement of the problem often contributes substantially to better understanding of the phenomenon being studied and the final solution of the problem. The problems considered in this scenario analysis address how environmental and meteorological conditions, type and frequency of transit traffic, availability of support services and the TSMTR&R affect the TSVTS performance indicators (such as, the number and waiting times of vessels passed, pilot/tugboat utilization, vessel density etc.)

6.1.1.2. Choice of Factors, Levels and Ranges. When considering the factors that may influence the performance of a process or a system, the experimenter usually discovers that these factors can be classified as either potential design factors or nuisance factors. The potential design factors are those factors that the experimenter may wish to vary in the experiment. After the selection of the design factors, both the ranges over which these factors will vary, and the specific factor levels at which simulation runs will be made are to be determined. The design factors are determined for this study as the critical factors which are expected to have a significant effect on various outputs of the system (such as, storm occurrences, vessel arrival rates, pilot and tugboat availabilities, etc.)

There is no general prescription regarding factor level selection. Generally, the levels should not be very far apart from each other. These levels can be determined in a way so as to balance the output values. However, if the response is highly variable, the closeness between the levels of design variables may bring about a misleading conclusion that estimated factor effect is close to zero. Thus, intuitive feel for the system under study and the model are considered to specify reasonable values for the quantitative factors and meaningful options for the qualitative factors (Law and Kelton, 2000; Montgomery, 2001) The levels of the design variables in this study are determined either through multiplication by a certain percent degree (such as in the arrival rate and storm occurrences in the High level) or through specifying meaningful options. The six factors and their levels deployed in 64 scenarios are displayed in Table 6.1.

Table 6.1. Factors and Levels Employed in the Scenario Analysis

FACTOR	**Name**	**Low**	**High**
A	Arrival Rate	Normal	High
B	Pilot/Tugboat Availability	20/9	15/6
C	Prioritization	Low	High
D	Pursuit Distance	4 Cables	8 Cables
E	Season	Summer	Winter
F	Storm Level	Normal	High

The arrival rate defines the arrival frequency of transit vessels and therefore the total number of vessels arriving at the Istanbul Strait. The ‘Normal’ setting refers to the interarrival rate level (for each cluster of transit vessels used in the model), based on actual 2005 data. In the ‘High’ setting of the arrival rate, the total number of transit vessels is increased by 15 percent, by dividing the interarrival time parameter of the fitted interarrival distributions of each cluster by 1.15.

Regarding the pilot/tugboat level, ‘High’ term refers to the current situation of 15 pilot captains and 6 tugboats availability, whereas the 'Low' setting refers to prospective levels of 20 pilot captains and 9 tugboats.

Regarding the prioritization level, 'Low' and 'High' terms refer to the values 1.3 and 1.5 of the prioritization coefficient respectively, where level 1.3 is the level closely resembling the actual system behaviour (as discussed in section 5.2.3.).

According to the TSMTR&R, the vessels in transit have to maintain a pursuit distance of at least eight cables, while passing the Strait. However, in the simulation model this pursuit distance is allowed to vary, in order to better observe the effect of pursuit distance on performance measures. In reality, the TSVTS does actually adjust higher and lower pursuit distances, as they see fit depending on the environment. In the scenario analysis, four and eight cables are used as the low and the high settings, respectively.

Seasons deployed in the scenario analysis are the winter and the summer seasons. The winter season includes September and October, as its warm-up period, and the months from November to February as the normal simulation period of four months length. The summer season includes March and April as its warm-up period and months between May and August is the normal simulation period. In simulation outputs of both seasons, statistics associated with the warm-up period are excluded. Seasons are expected to have an effect on vessel transits due to their different fog and storm interarrival frequencies, and daytime periods.

In the experimental design, the storm level is also included as an additional factor to enable the observation of any direct effects of more or less frequent storm occurrences in different seasons. The 'Normal' setting refers to the fitted probability distributions of interarrival times of storm occurrences, based on meteorological data between 1981-2006, while for the 'High' setting of the interarrival rate of storm occurrences, the rate parameters of the interarrival distributions are increased by 50%. This 50% increase value is determined as follows: The maximum and minimum arrival realizations (25 per year in 1985 and 1 per year in 1981, respectively) are excluded as outliers. Then, the remaining maximum number of storm occurrence value of 16 storms is divided by the yearly average of storm occurrences of 10,5 storm per year , which makes around 50% more storm occurrences than the annual average. Thus, the high storm level setting is determined to be ‘50% more’ storm occurrences. Accordingly, for the ‘High’ setting of this factor, the interarrival time component of the corresponding interarrival time distribution for each vessel cluster is divided by 0.67 (1/1.5).

6.1.1.3. Selection of the Response Variables. Response variables should provide useful information about the process under study. Most often, the average or standard deviation (or both) of the measured characteristics will be the response variables. It is usually critically important to identify issues related to defining the responses of interest and how they are to be measured before conducting the experiment.

The effect of factors is investigated on the following output performance measures through scenario analysis:

- Number of vessels passed (completed their transit),
- Average transit time of vessels (that have completed their transit),
- Average waiting time of vessels (that have completed their transit),
- Maximum waiting time of vessels (that have completed their transit),
- Number of vessels in the queues (still waiting for transit),
- Vessel density in the Strait (number of transit vessels per mile),
- Pilot utilization (ratio of total busy time to total available time),
- Tugboat utilization (ratio of total busy time to total available time).

6.2. Results of the Scenario Analysis

The 10 replications of the 64 scenarios are run for a six month period where two months are used as warm-up period (with their statistics being excluded.) The outputs for each scenario are collected and analyzed through Design Expert 7.0 software in order to evaluate the effects of the determined factors on the selected response variables (Table B.1 and Table B.2).

The significant factors and factor interactions are determined through an iterative process which includes transformation selection (if needed), choosing significant effects and analyzing the model through ANOVA tables, evaluating model fit and assumptions and interpreting results in the Design Expert software.

In analyzing the model through ANOVA tables, factors are added to the model according to normal plots of standardized effects and Pareto charts, unless there are nonsignificant terms. The ANOVA tables for all defined responses are displayed in Appendix C and model graphs on each significant main factor and two-way factor interactions are displayed in Appendix D. Detailed results are discussed in the following sections.

The overall results for the percent contributions of the significant main factors and significant factor interactions to explain the variance of the responses among scenario runs are displayed in Table 6.2 and Table 6.3 respectively, where positive effects are denoted with a (+) sign and negative effects denoted with a (-) sign.

Table 6.2 and Table 6.3 show the significance of factors on the increase or decrease of the associated output performance measure. For example, Table 6.2 shows that 94.61 percent of the variation in the number of vessels passed is caused by the change in the arrival rate. That is, 15 percent increase of the arrival rate (which is the case in the 'High' setting) positively effects number of vessels passed. Besides, the Table 6.3 shows that the seasons and interarrival rate interaction have little but significant influence on the number of vessels passed.

Table 6.2. Percent contributions of the significant factors on the variance of responses

Responses/Factors	**A** ***ArrivalRate***	**B** ***Pilot/ Tugboat Availability***	**C** ***Prioritization***	**D** ***Pursuit Distance***	**E** ***Season***	**F** ***Storm Level***
No of Vessels Passed	(+)94.61				(-)0.03	
Avg Transit Times of Vessels	(+)4.57			(+)75.16	(-)3.70	
Avg Waiting Time of Vessels	(+)53.53	(+)5.05			(-)8.08	
Max Waiting Time of Vessels	(+)41.24	(+)6.04			(+)20.50	
No Vessels in the Queues	(+)57.26				(-)10.18	
Vessel Density	(+)91.98			(+)0.30		(+)0.14
Pilot_Utilization	(+)20.42	(+)76.96		(+)0.08	(-)0.05	
Tugboat_Utilization	(+)10.53	(+)87.80		(+)0.05	(+)0.02	

Table 6.3. Percent contributions of the significant factor interactions on the variance of responses

Responses/Factors	**AB** *ArrivalRate Pilot/Tugboat*	**AC** *ArrivalRate Prioritization*	**AE** *ArrivalRate Season*	**BE** Pilot/Tugboat Availability Season	**DE** Pursuit Distance Season	**ABE** *ArrivalRate Pilot/Tugboat Season*	**AEF** ArrivalRate *Season Storm Level*
No of Vessels Passed			(+)0.27				
Avg Transit Times of Vessels					(-)1.61		
Avg Waiting Time of Vessels	(+)1.42		(-)10.43				
Max Waiting Time of Vessels	(+)1.30	(+)0.15	(+)5.07	(+)1.10		(+)0.35	(-)0.40
No Vessels in the Queues			(-)8.14				
Vessel Density			(+)0.09				
Pilot_Utilization	(+)0.42						
Tugboat_Utilization	(+)0.42		(+)0.13				

6.2.1. The Number of Vessels Passed

The significant factors affecting the number of vessels passed are selected through the normal probability plot of the standardized effects depicted in Figure 6.1.

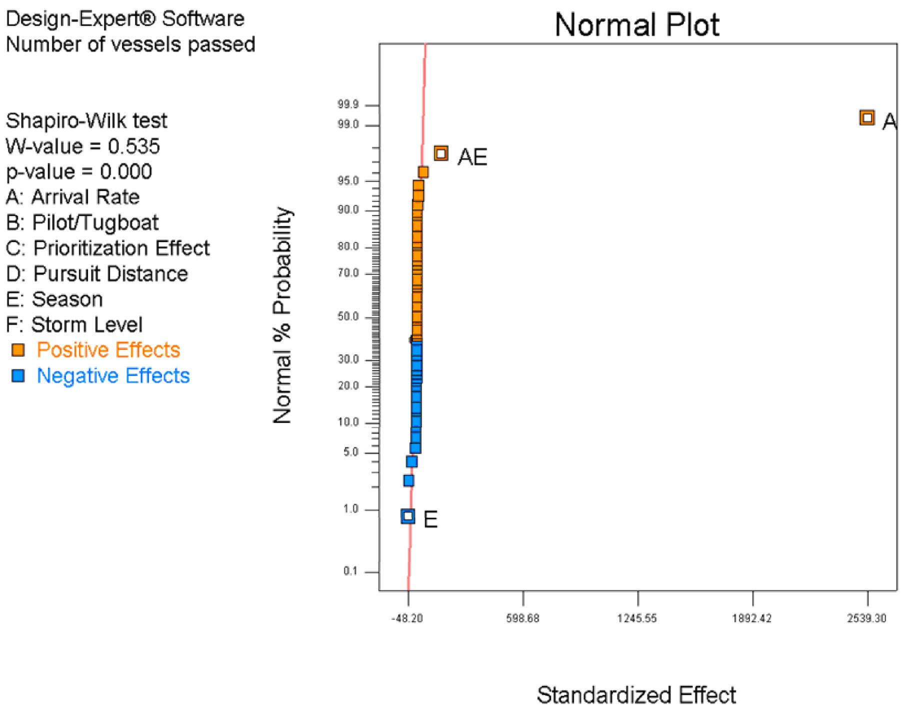


Figure 6.1. The normal probability plot of the effects for number of vessels passed

The selected factors are evaluated in the ANOVA table displayed in Table C.1. The Model F-value of 3960.79 implies that the model is significant. Values of 'Prob > F' less than 0.0500 indicate model terms are significant. In this case A, E, AE are significant model terms.

The 'Lack of Fit F-value' of 0.12 implies that the Lack of Fit is not significant relative to the pure error. Besides, the 'Pred R-Squared' of 0.9486 is in reasonable agreement with the 'Adj R-Squared' of 0.9490.

In order to check assumptions of the model, the normal probability plot of residuals and residuals versus predicted response values graphs are checked. These graphs do not indicate great distortions from normality (of residuals) and constant variance assumptions.

Table 6.4 displays the significant factors' standardized effects and their percent contributions. The ANOVA table for the number of vessels passed is shown in Appendix C.1. Furthermore, Figure D.1, Figure D.2 and Figure D.3 in Appendix D illustrate the model graphs for factor and factor interaction plots for the number of vessels passed.

Table 6.4. Standardized effects and their percent contributions for number of vessels passed

		Standardized Effect	**Per cent contribution**
A	**Arrival Rate**	2539,3	94.61
E	**Season**	-48,2	0.03
AE	**Arrival Rate-Season**	136,58	0.27

As evidenced in Figure 6.1, the most important factor on the number of vessels passed is obviously the arrival rate. Additionally, season has a negative influence on the number of vessels passed. This can be explained as follows: There is a strong variation in the number of storm occurrences between the winter and summer seasons. Since storm occurrences can change the arrival rate within the related time window (of 3 days before, during and 3 days after any storm occurrence), and the number of vessel arrivals considerably decrease during these periods for general cargo and passenger vessels, (which account for 81% of all vessels), the overall impact of season could well be negative. In other words, even though a storm occurrence can affect the number of vessel arrivals both positively and negatively, considering the results, it turns out that for the 'High' setting of season, (namely, the winter season with much more storm occurrences than the summer) the number of vessel arrivals decreases (upon the combined aggregate effect of all arrival rate increases and decreases, within the time windows of the realized storm occurrences).

6.2.2. The Average Transit Times of Vessels

The significant factors affecting the average transit times of vessels are selected through the normal probability plot of the standardized effects depicted in Figure 6.2.

As displayed in the ANOVA table Table C.2, the model F-value of 902.07 implies that the model is significant. Values of "Prob > F' less than 0.0500 indicate model terms are significant. In this case A, D, E are significant model terms. The 'Pred R-Squared' of 0.8480 is in reasonable agreement with the 'Adj R-Squared' of 0.8494.

Table 6.5 displays the significant factors' standardized effects and their percent contributions. The ANOVA table for average transit times of vessels is shown in Appendix C.2. Furthermore, Figure D.4, Figure D.5, Figure D.6 and Figure D.7 in Appendix D illustrate the model graphs for factor and factor interaction plots for the number of average transit times of vessels.

The most important factor affecting the transit time is pursuit distance between vessels. The reason behind is that high speed vessels can overtake lower speed vessels more easily in lower pursuit distances and thus affecting a decrease in the average transit times of vessels.

Table 6.5. Standardized effects and their percent contributions for average transit time

		Standardized Effect	**Per cent contribution**
A	**Arrival Rate**	1.678	4.57
D	**Pursuit Distance**	6.807	75.16
E	**Season**	-1.51	3.70
DE	**Pursuit Distance-Season**	-1.00	1.61

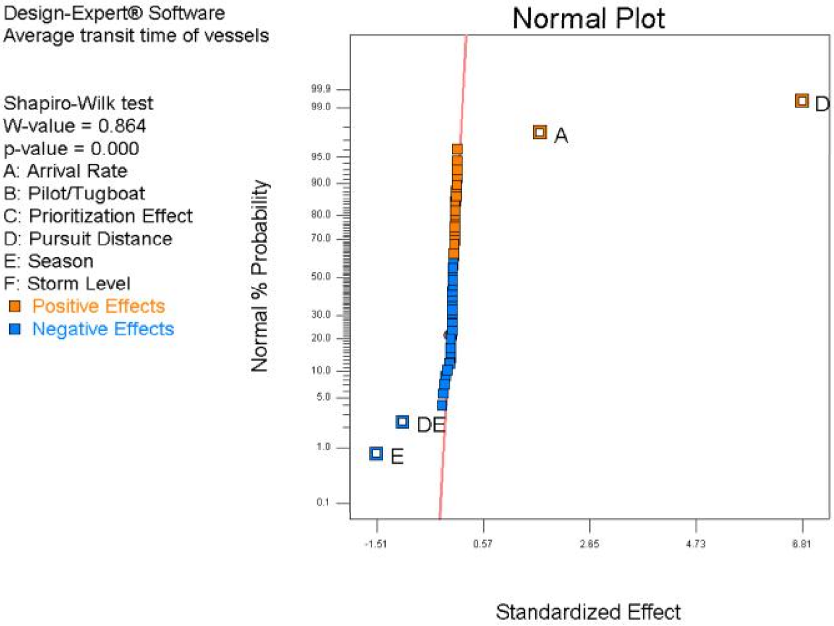


Figure 6.2. The Normal probability plot of the effects for average transit times

6.2.3. The Average Waiting Times of Vessels

The normal probability plot of standardized effects of the significant factors are displayed in Figure 6.3.

As displayed in the ANOVA table in Table C.3 , the Model F-value of 462.83 implies the model is significant. Values of ‘Prob > F’ less than 0.0500 indicate model terms are significant. In this case A, B, E, AB, AE are the significant model terms. The ‘Pred R-Squared’ of 0.7809 is in reasonable agreement with the ‘Adj R-Squared’ of 0.7833.

Table 6.6 displays the significant factors’ standardized effects and their percent contributions. The ANOVA table for average waiting times of vessels passed is shown in Appendix C.3. Furthermore, Figure D.8, Figure D.9, Figure D.10, Figure D.11 and Figure D.12 in Appendix D illustrate the model graphs for factor and factor interaction plots for the average waiting times of vessels.

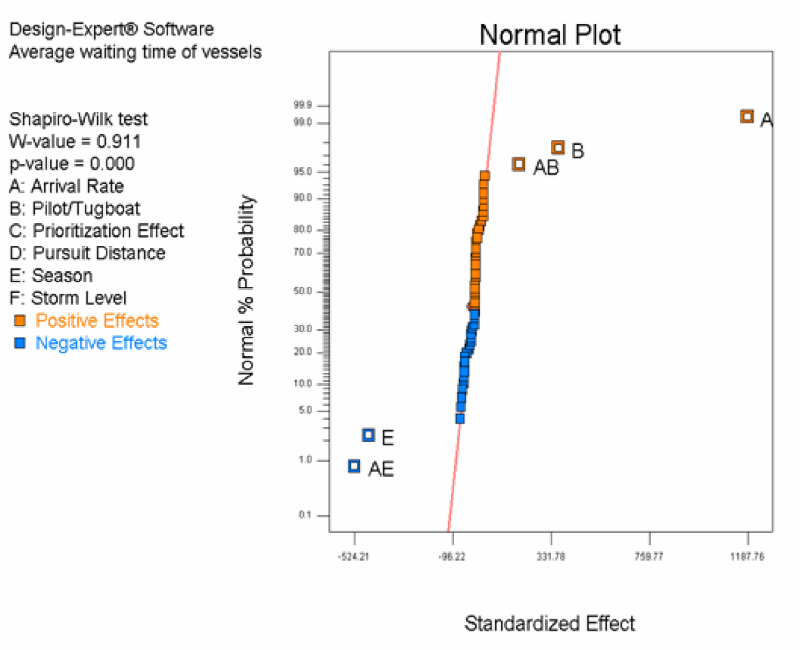


Figure 6.3. The normal probability plot of the effects for average waiting times

Table 6.6. Standardized effects and their percent contributions for average waiting time

		Standardized Effect	**Per cent contribution**
A	**Arrival Rate**	1187,76	53.53
B	**Pilot/Tugboat Availability**	364,66	5.05
E	**Season**	-461,43	8.08
AB	**Arrival Rate-Pilot/Tugboat**	193,27	1.42
AE	**Arrival Rate-Season**	-524,21	10.43

According to Table 6.6, the most important factors affecting average waiting times of vessels are arrival rate, season and pilot / tugboat availability. Arrival rate has an increasing effect on average waiting time (increasing the number of vessel arrivals cause an increase in the number of vessels in queues, which in turn results in an increase of the average waiting time of vessels.) On the other hand, season has a negative influence on the average waiting time, since it decreases the number of vessel arrivals for the 'High' setting winter period (as discussed in section 6.2.1), which in turn decreases the congestion in the queues and thus decreasing the average waiting time. The interaction of arrival rate and season also has a negative effect on the average waiting time, while the factor pilot/tugboat availability has a positive effect on the average waiting time, (as waiting times increase when the service resources are scarce). Since an increase in the level of both arrival rate and tugboat/pilot availability increases the average waiting time, expectedly, their interaction shows a similar effect on the response variable average waiting time.

6.2.4. Maximum Waiting Time of Vessels

The normal probability plot of standardized effects of the significant factors are displayed in Figure 6.4.

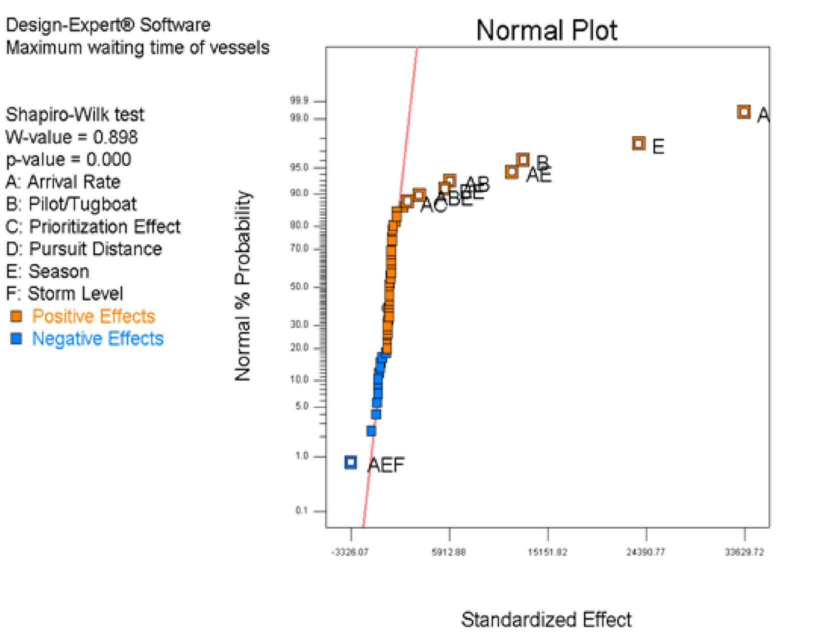


Figure 6.4. The normal probability plot of the effects for maximum waiting times

As displayed in the ANOVA table in Table C.4, the Model F-value of 223.35 implies the model is significant. Values of ‘Prob > F’ less than 0.0500 indicate model terms are significant. In this case A, B, E, AB, AE, BE, ABE, AEF are the significant model terms. The ‘Pred R-Squared’ of 0.7537 is in reasonable agreement with the ‘Adj R-Squared’ of 0.7580.

Table 6.7 displays the significant factors’ standardized effects and their percent contributions. The ANOVA table for maximum waiting times of vessels passed is shown in Appendix C.4. Furthermore, Figure D.13, Figure D.14, Figure D.15, Figure D.16, Figure D.17, Figure D.18 and Figure D.19 in Appendix D illustrate model graphs for factor and factor interaction plots for maximum waiting times of vessels.

Table 6.7. Standardized effects and their percent contributions for maximum waiting time

		Standardized Effect	Per cent contribution
A	**Arrival Rate**	33629.72	41.24
B	**Pilot/Tugboat Availability**	12871.23	6.04
E	**Season**	23712.18	20.50
AB	**Arrival Rate-Pilot/Tugboat**	5962.99	1.30
AC	**Arrival Rate-Prioritization Level**	2000.33	0.15
AE	**Arrival Rate-Season**	11783.93	5.06
BE	**Pilot/Tugboat-Season**	5496.47	1.10
ABE	**Arrival Rate-Pilot/Tugboat-Season**	3112.23	0.35
AEF	**Arrival Rate-Season-Storm Level**	-3332.32	0.40

The factors affecting the maximum waiting time performance measure are similar to those affecting the average waiting time. However, the importance and direction of the effect of factors are changed. The most important factors affecting maximum waiting time are arrival rate and season, as in the case of the average waiting time. However, season has an increasing effect on the maximum waiting time, which is possibly caused by the visibility conditions and shorter daylight periods during the winter season. This increasing effect of season could not be observed in the case of the average waiting time, since the decrease in the number of vessel arrivals probably exposed a stronger decreasing effect on the average waiting on the overall time, compensating for the increase due to the visibility conditions. Besides, pilot/tugboat availability also has an important effect. Furthermore, the effect of interaction effects between main factors become more significant.

6.2.5. The Number of Vessels in Queues

The normal probability plot of standardized effects of the significant factors are displayed in Figure 6.5.

As displayed in the ANOVA table in Table C.5, the Model F-value of 656.37 implies the model is significant. Values of 'Prob $>$ F' less than 0.0500 indicate model terms are significant. In this case A, E, AE are the significant model terms. The 'Pred R-Squared' of 0.7528 is in reasonable agreement with the 'Adj R-Squared' of 0.7547.

Table 6.8 displays the significant factors' standardized effects and their percent contributions. The ANOVA table for the number of vessels in queues is shown in Appendix C.5. Furthermore, Figure D.20, Figure D.21 and Figure D.22 in Appendix D illustrate the model graphs for factor and factor interaction plots for the number of vessels in queues.

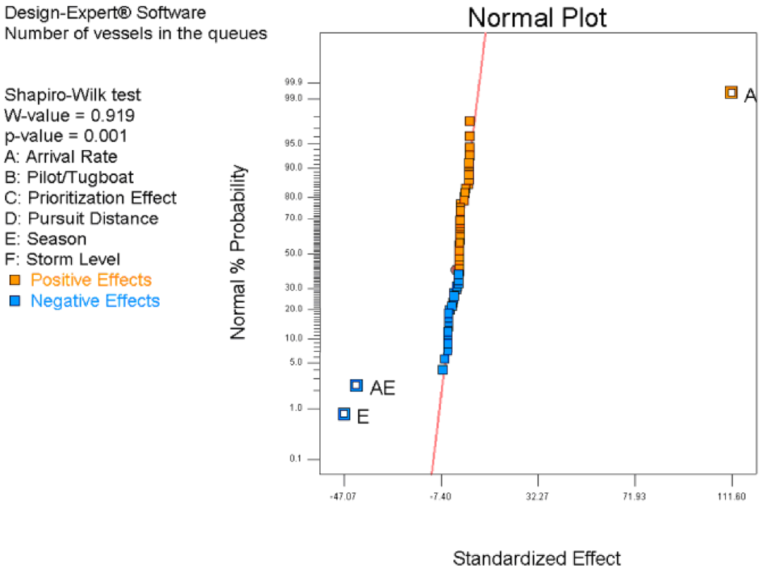


Figure 6.5. The normal probability plot of the effects for number of vessels in queues

Table 6.8. Standardized effects and their percent contributions for number of vessels in queues

		Standardized Effect	**Per cent contribution**
A	**Arrival Rate**	111.6	57.26
E	**Season**	-47.066	10.18
AE	**Arrival Rate-Season**	-42.077	8.14

The factors affecting the number of vessels in queues are the same as those affecting the number of vessels passed. The most significant factor turns out to be the arrival rate, which directly affects the number of vessels present in the queues at any given time period. Season and its interaction with arrival rate also have significant effects on number of vessels in queues, since season affects the daylight period length and the arrival rate through the number of storm.

6.2.6. Vessel Density in the Strait

The normal probability plot of standardized effects of the significant factors are displayed in Figure 6.6.

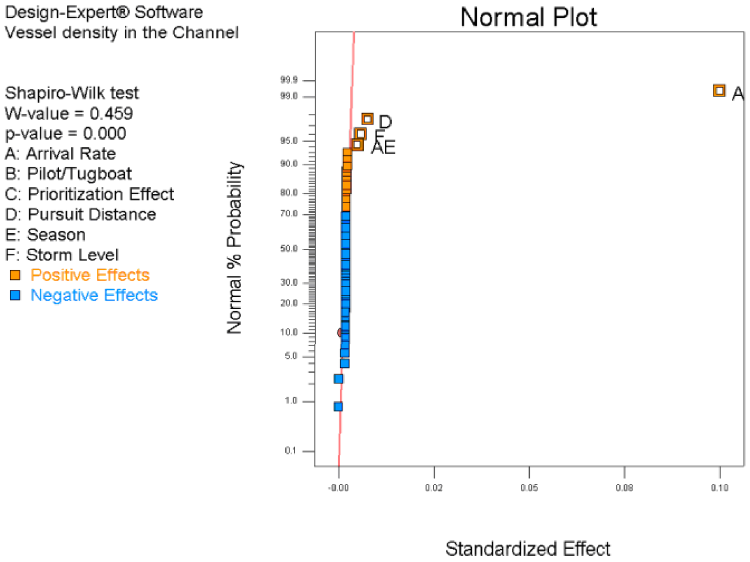


Figure 6.6. The normal probability plot of the effects for vessel density in the Strait

As displayed in the ANOVA table in Table C.6, the Model F-value of 1961.50 implies the model is significant. Values of ‘Prob > F’ less than 0.0500 indicate model terms are significant. In this case A, D, F, AE are the significant model terms. The ‘Pred R-Squared’ of 0.9239 is in reasonable agreement with the ‘Adj R-Squared’ of 0.9247.

Table 6.9 displays the significant factors’ standardized effects and their percent contributions. The ANOVA table for the vessel density in the Strait is shown in Appendix C.6. Furthermore, Figure D.23, Figure D.24,, Figure D.25 and Figure D.26 in Appendix D illustrate the model graphs for factor and factor interaction plots for the vessel density in the Strait.

The most significat factor affecting vessel density in the Strait is the arrival rate. Pursuit distance also has a significant but a small effect on vessel density as well, as lower pursuit distance favors the overtaking conditions, hence decreasing the transit time and the vessel density in the Strait. Storm level also has a very slight increasing effect on vessel density, since storm occurences change the vessel arrival rates for a period between 3 days before and 3 days after storm.

Table 6.9. Standardized effects and their percent contributions for vessel density

		Standardized Effect	**Per cent contribution**
A	**Arrival Rate**	0.102	91.98
D	**Pursuit Distance**	0.006	0.30
F	**Storm Level**	0.004	0.14
AE	**Arrival Rate-Season**	0.003	0.08

6.2.7. Pilot Utilization

The normal probability plot of standardized effects of the significant factors are displayed in Figure 6.7.

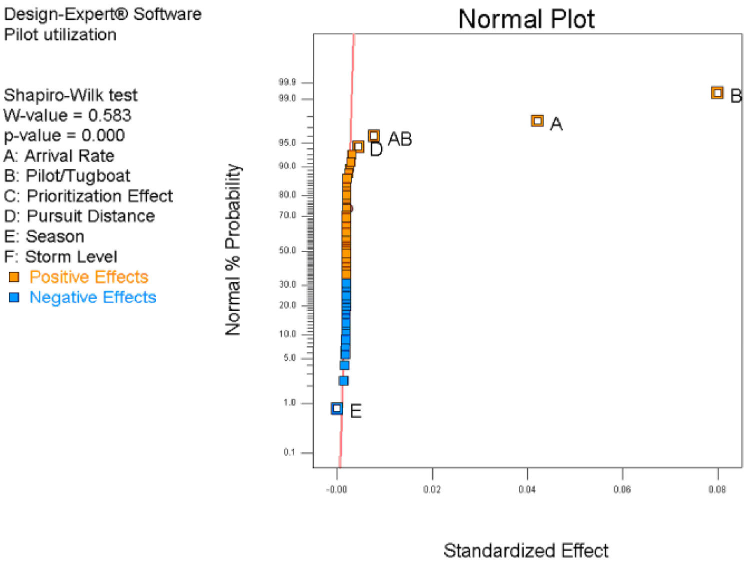


Figure 6.7. The Normal probability plot of the effects for pilot utilization

As displayed in the ANOVA table in Table C.7, the Model F-value of 6014.64 implies the model is significant. Values of 'Prob > F' less than 0.0500 indicate model terms are significant. In this case A, B, D, E, AB are the significant model terms. The 'Pred R-Squared' of 0.9790 is in reasonable agreement with the 'Adj R-Squared' of 0.9792.

Table 6.10 displays the significant factors' standardized effects and their percent contributions. The ANOVA table for the pilot utilization is shown in Appendix C.7. Furthermore, Figure D.27, Figure D.28, Figure D.29, Figure D.30 and Figure D.31 in Appendix D illustrate the model graphs for factor and factor interaction plots for the pilot utilization.

Table 6.10. Standardized effects and their percent contributions for pilot utilization

		Standardized Effect	Per cent contribution
A	**Arrival Rate**	0.041	20.42
B	**Pilot/Tugboat Availability**	0.079	76.96
D	**Pursuit Distance**	0.003	0.08
E	**Season**	-0.002	0.05
AB	**Arrival Rate-Pilot/Tugboat**	0.006	0.42

Pilot / tugboat availability and arrival rate have the most important effects on pilot utilization. Pursuit distance also has a significant but relatively lower effect on pilot utilization, since the higher the pursuit distance, the longer is the transit time and therefore the higher is the pilot utilization.

6.2.8. Tugboat Utilization

The normal probability plot of standardized effects of the significant factors are displayed in Figure 6.8.

As displayed in the ANOVA table in Table C.8, the Model F-value of 9856.34 implies the model is significant. Values of 'Prob $>$ F' less than 0.0500 indicate model terms are significant. In this case A, B, D, E, AB, AE are the significant model terms. The 'Pred R-Squared' of 0.9892 is in reasonable agreement with the 'Adj R-Squared' of 0.9893.

Table 6.11 displays the significant factors' standardized effects and their percent contributions. The ANOVA table for the tugboat utilization is shown in Appendix C.8. Furthermore, Figure D.32, Figure D.33, Figure D.34, Figure D.35, Figure D.36 and Figure D.37 in Appendix D illustrate the model graphs factor and factor interaction plots for the tugboat utilization.

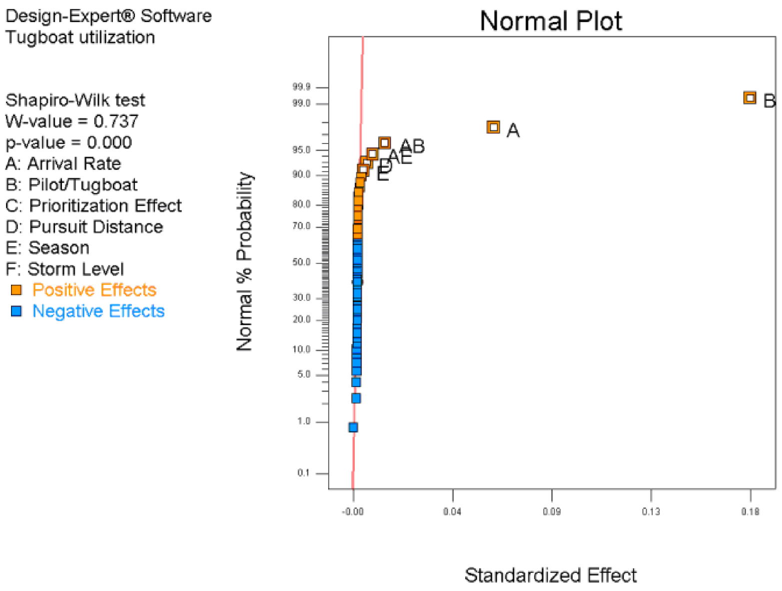


Figure 6.8. The Normal probability plot of the effects for tugboat utilization

Table 6.11. Standardized effects and their percent contributions for tugboat utilization

		Standardized Effect	**Per cent contribution**
A	**Arrival Rate**	0.061	10.53
B	**Pilot/Tugboat Availability**	0.176	87.80
D	**Pursuit Distance**	0.042	0.05
E	**Season**	0.003	0.02
AB	**Arrival Rate-Pilot/Tugboat**	0.012	0.42
AE	**Arrival Rate-Season**	0.007	0.13

The pilot / tugboat availability and the arrival rate have the most important effects on tugboat utilization (similar to that of the pilot utilization).

6.3. Summary of Factor Effects

Simulation experiment results show that all input factors have some impact on various simulation output variables. The arrival rate and season turn out to be the most common and important factors affecting the response variables.

The arrival rate determines the number of vessels arriving at the entrances of the Strait. Therefore, it has a great impact on the number of vessels passed, the average and the maximum waiting times of all vessels. Furthermore, since increasing the number of vessel arrivals increases the number of vessels in queues and the vessel density in the Strait, arrival rate is also a very important variable affecting these response variables. Additionally, as the number of vessels requiring tugboat and pilot services have a positive effect on their utilization, arrival rate is a significant variable in affecting pilot/tugboat utilization.

Season is another important significant variable affecting most of the response variables, as it can change the vessel arrival rate during a period of three days before, three days after and during a storm occurrence both positively and negatively depending on the type and length of the vessels. Considering the experimentation results, it turns out that the combined effect of increases and decreases in the arrival rate due to a storm occurrence has in total a decreasing effect on the number of vessel arrivals, since 3 days before and during the storm occurrences the arrival rate of general cargo vessels and passenger vessels decrease considerably, where these two type of vessels count for the 81% of overall vessels. Thus, for the ‘High’ setting (the winter season) the average waiting time of overall system decreases upon the delivery of fewer vessels, which also decreases the number of vessels in queues and the average waiting time of the vessels. On the contrary, season shows a slightly increasing effect on the maximum waiting time of vessels, which may be caused by the change in the visibility conditions and shorter daylight, that may increase the maximum waiting time of a few vessels. In overall, this effect is easily covered by the decrease in the average waiting time of most of the vessels, hence still enabling a decrease in the overall average waiting time of the system.

Comparison of the effects of the storm and fog related season factor of this study with the just fog related season factor in the study of Almaz (2006), shows that the effects of season on average waiting times and number of vessels in queues are in opposite directions in these studies. In the study of Almaz (2006), fog related season level was used to define the different fog occurrence frequencies throughout a year, whereas in this study, fog and storm related seasons are mainly determined according to the storm occurrence frequency changes throughout a year. Thus, the summer months with very low fog occurrences coincide with the summer months with low storm occurrences in this study (the four month period between May and August).

On the other hand, the winter season with more frequent fog occurrences was defined in the study of Almaz (2006) as the four month period between January and April, whereas the winter season in this study with more frequent fog and storm occurrences covers the four month period between November and February. So, when comparing the experimentation results, regarding the effect of the season factor on the response variables, between the two studies, it must be considered that the time frame used for the winter setting differs between the two studies. Even though both studies indicate that winter season causes a slight decrease in the number of vessel arrivals, the results of this study show that the integration of the storm submodel actually covered the slight increase in the average waiting time in the winter season due to the fog occurrences, as previously indicated in the study of Almaz (2006). This can be explained as follows: The changes in the vessel arrival rates due to the increase in the number of storm occurrences in the winter season has in the overall a decreasing effect on the number of vessels in queues, so that the average waiting time of the vessels decreases consequently. Moreover, even though fog occurrences cause a slight increase in the average waiting time of vessels (by affecting visibility conditions), this slight increase in the average waiting time due to the fog occurrences could be easily covered by the decrease in the average waiting times due to the decrease in the number of vessels in queues.

Close investigation of the 64 scenarios (see Table B.1. and Table B.2) revealed an interesting finding. For the 'Normal' setting of the vessel arrival rate, the average waiting time of the system for 'Summer' season is slightly lower than that of the 'Winter' season. However, for the 'High' setting of the vessel arrival rate, the average waiting time of the system is lower for the winter season than that of the summer. Detailed analysis of the simulation outputs for all scenarios indicated that for the 'High' setting of the arrival rate, the increase in the average waiting time of the vessels for 'Summer' season is quite high for all type of vessels. However, for the 'Winter' case (where the storm occurrences are much higher than the 'Summer') the arrival rate for general cargo vessels and passenger vessels decreases considerably at the storm periods (i.e. the period 3 days before, three days after and during a storm occurrence). Since these two types of vessels count for the 81% of the total vessel arrivals into the system, the number of vessels in the queues considerably decrease within these days, thereby causing this remarkable decrease in the average waiting time of all vessels (when the vessel arrival rate of the total system is increased by 15%). The reason, why a lower average waiting time of vessels in the 'Winter' season than that of the 'Summer' season can not be observed for the 'Normal' arrival rate setting as well, can be explained as follows: For the 'Normal' arrival rate setting, the increase in the average waiting time of vessels due to the fog occurrences can not be covered by the decrease in the average waiting time of vessels caused by the decrease in the number of vessel arrivals due to storm occurrences, hence resulting in a slight increase in the average waiting time of vessel from 'Summer' to 'Winter' season. However, for the 'High' arrival rate setting, the primary cause of the very high increase in the average waiting time of vessels is the higher number of vessel arrivals, so that the decrease in the number of vessel arrivals due to the storm occurrences could be more effective and overcame the increase in the average waiting time due to the fog occurrences, resulting in a lower average waiting time for the 'Winter' season.

Another significant variable influential on the average transit times of vessels is the pursuit distance, as it is an important parameter defining the overtaking conditions. Since lower pursuit distance facilitates easier overtaking of lower speed vessels, the average transit time of the system decreases accordingly. It also has a significant but low effect on vessel density in the Strait, and on pilot and tugboat utilizations as well.

Pilot / tugboat availability is the major significant variable affecting pilot/tugboat utilization. Furthermore, wider availability of these services has a significant effect on the average and the maximum waiting times of all vessels.

The storm level has a significant but very slight effect on the vessel density in the Strait. However, it does not have any significant effect on any other response variables. This might be explained as follows: a change in the season status is a more representative factor in explaining the effect of storm occurrences on various response variables, since there is a considerable difference in the number of storm occurrences between the summer and winter seasons. The 1981-2006 data shows that the average number of storm occurrences within a year is 10,5 storm occurrences, (where this number is distributed between the winter and summer seasons as 8,5 and 2,0 respectively; that is the winter arrival rate is more than four times of the summer's rate). Therefore, deploying factor level of 1.5 in the high setting of the storm factor could not make a significant difference in the levels of the response variables, in the "High storm" scenarios.

Prioritization level does not have a significant effect on any of the response variables. This result is quite consistent with and foreseen at the validation stage of the prioritization submodel, since different prioritization coefficients do not change the overall waiting time of the system remarkably. The prioritization coefficient is primarily effective in differentiating the waiting times of direct and indirect vessels. Prioritization level simply decreases the waiting time of the indirect passing vessels, as a result of the prioritization applied, and hence increases the waiting time of the direct vessels, but the overall waiting time of the overall system hardly changes.

Interaction of the arrival rate and season (AE) also proved to be a significant factor for most of the response variables, (especially for the average waiting time, the maximum waiting time and the number of vessels in the queues).

The interaction of the arrival rate and tugboat/pilot availability (AB) has a significant but quite low effect on the response variables, such as average waiting time of vessels, the maximum waiting time of vessels, pilot and tugboat utilizations.

6.4. Comparison of Scenario Outputs

Even though the effects of the input variables on the selected response variables are discussed in the previous section, a comparison of the base, best and worst case scenarios would enhance the understanding of their relationship.

The Table 6.12. illustrates the selected base, best and worst case scenarios for the levels of the input factors.

Table 6.12. Scenarios with base, best and worst settings

Factor	Name	Base	Best	Worst
A	Arrival Rate	Normal	Normal	High
B	Pilot/Tugboat	15/6	20/9	15/6
C	Prioritization	1.3	1.3	1.5
D	Pursuit Distance	8 cables	4 cables	8 cables
E	Season	Winter	Summer	Summer
F	Storm Level	Normal	Normal	High

The results of the simulation runs with the given scenario settings are displayed in Table 6.13.

According to the simulation results, the number of vessels passed varies between 17539 and 20154. The number of vessels passed changes mainly with the change in the arrival rate, hence the number of vessels passed does only slightly change between base and best case scenarios.

The average transit time basically changes with the pursuit distance, so that it ranges between 102 mins and 112 mins between best and worst case scenarios respectively. The slight change between the transit times of the base and worst case scenarios is caused by the change in the level of arrival rate from 'Normal' to 'High' setting, since arrival rate has a significant effect on the average transit time.

The average waiting time ranges between 302 mins and 2623 mins. Since arrival rate has the most significant effect on the average waiting time, the average waiting time between best and worst case scenarios equals 302 mins and 2623 mins respectively. Since it changes also with tugboat/pilot availability and season level as well, the average waiting time of the system changes between 302 mins and 539 mins for best and base case scenarios respectively.

The maximum waiting time of the system depends highly on the arrival rate, and hence it ranges between 26489 and 44962 for base and worst case scenarios respectively. The second major significant factor on this response variable is the season, hence it equals 9378 and 26489 for the summer and the winter settings for normal arrival rate.

Table 6.13. Comparison of scenarios with base, best and worst settings

Scenario	Number of Vessels Passed	Average Transit Time	Average Waiting Time	Maximum Waiting Time	Number of Vessels in Queues	Vessel Density in the Channel	Pilot Utilization	Tugboat Utilization
Base	17539	107,82	539	26489	32	0,6205	0,2898	0,4895
Best	17697	102,19	302	9378	34	0,6199	0,2178	0,3255
Worst	20154	111,98	2623	44962	191	0,7282	0,3396	0,5614

The number of vessels in queues is mainly affected by the arrival rate, hence it increases upto 191 vessels from 32 vessels, between worst and base case scenarios respectively.

Vessel density in the Strait changes mainly with the arrival rate, hence it equals 0.6205 and 0.7282 for base and worst case scenarios respectively. Pursuit distance has also a significant effect on the vessel density in the Strait. Therefore it decreases from 0.6205 to 0.6199 for the base and best cases respectively.

Pilot utilization is primarily affected by the number of pilots available. Hence, it decreases from 0.2898 to 0.2178 between base and best case scenarios. Since the vessel arrival rate is another important factor in the utilization rate of this service, it increases from 0.2898 upto 0.3396 between base and worst case scenarios.

Similar to the case of pilot utilization, tugboat utilization is primarily affected by the number of tugboats available. Hence, it decreases from 0.4895 to 0.3255 between base and best case scenarios. Since the vessel arrival rate is another important parameter in the utilization rate of this service, it increases from 0.4895 upto 0.5614 between base and worst case scenarios.

Furthermore, tracking the effects of factors on performance measures is easier when the scenarios with single factor level change with respect to the base scenario are investigated. Table 6.14. illustrates the response variables for the scenarios with only a single factor change on the base scenario.

The 15% increase in arrival rates increases the average waiting time of the total system by 175%, whereas the maximum waiting time is increased by 218%. Number of vessels in queues are increased nearly up to 5 times of that of the setting value in the base scenario. Higher vessel arrival rate also increases the vessel density in the Strait, tugboat and pilot utilizations as expectedly.

Table 6.14 Comparison of selected scenarios through single factor change

Scenario No	Scenario	Number of Vessels Passed	Average Transit Time	Average Waiting Time	Maximum Waiting Time	Number of Vessels in Queues	Vessel Density in the Channel	Pilot Utilization	Tugboat Utilization
Base	Base	17539	107,82	539	26489	32	0,6205	0,2898	0,4895
8	Arrival Rate	20267	109,29	1476	84443	115	0,7276	0,3385	0,5731
56	Pilot/Tugboat	17539	107,82	359	17659	32	0,6205	0,2160	0,3253
48	Favor Level	17543	107,69	546	24042	33	0,6210	0,2901	0,4899
36	Pursuit Distance	17539	101,95	521	26278	31	0,6149	0,2862	0,4840
38	Season	17697	102,19	453	14067	34	0,6199	0,2904	0,4883
39	Storm Level	17590	108,18	567	30312	32	0,6264	0,2919	0,4930

Higher pilot/tugboat availability causes a decrease both in the average waiting time of overall vessels and in the maximum waiting time of the vessels by around 30%.

Setting prioritization level to 1.5 slightly decreases the maximum waiting time of the vessels.

Decreasing the pursuit distance (to 4 cables) primarily effects the average transit time (a decrease of 5%).

Changing the season status from 'Winter' to 'Summer' decreases the average waiting time by 16% and the maximum waiting time by 47%, while increasing in the storm level increases the average waiting time by 5% and the maximum waiting time by 14%.

Furthermore, as discussed in Section 6.3., an interesting finding reveals when the average waiting times of vessels are investigated for 'Winter' and 'Summer' seasons, where the vessel arrival rate changes from 'Normal' to 'High' setting. For the 'Normal' vessel arrival rate setting, the average waiting times of vessels is slightly higher for the 'Winter' season than that of the 'Summer' season, whereas for the 'High' vessel arrival rate setting, the average waiting time of vessels in 'Summer' season increases considerably (from 473 mins in Scenario 8 to 2481 mins in Scenario 6), so that it exceeds the average waiting time of vessels in 'Winter' season remarkably. This can be observed more easily, when the scenario 8 (the high arrival rate setting version of the base scenario) is compared with other scenarios for factor level changes on season and storm level variables (Table 6.15).

Furthermore, as discussed in section 6.3., storm interarrival frequency does not prove to be a significant factor, especially for the summer season (when storm occurrences are so low that and dividing the interarrival time parameter by 1.5 does not lead to a meaningful increase in the number of storm occurrences). Therefore, the slight increase in the average waiting time between scenarios 6 and 5 (with 'Normal' and 'High' storm level respectively) in the summer season are caused by the random behaviour of the storm and vessel arrivals, not by the increase in the number of storm occurrences.

The simulation experiment outputs of the 64 scenarios with 10 replications are displayed in detail in Appendix B.

Table 6.15. Comparison of selected 'High' arrival rate scenarios through single factor change

Scenario No	E:Season	F:Storm Level	Number of Vessels Passed	Average Transit Time	Average Waiting Time	Maximum Waiting Time	Number of Vessels in Queues	Vessel Density in the Channel	Pilot Utilization	Tugboat Utilization
8	Winter	Normal	20267	109,29	1476	84443	115	0,7276	0,3385	0,5731
7	Winter	High	20228	109,73	1286	78928	95	0,7304	0,3393	0,5724
6	Summer	Normal	20129	112,42	2481	34233	190	0,7266	0,3400	0,5599
5	Summer	High	20167	111,93	2616	39826	192	0,7277	0,3397	0,5615

7. CONCLUSION

In this study, a comprehensive Maritime Traffic Simulation Model is developed, which is based on the model of Almaz (2006), but also includes an extended set of vessel interarrival distributions, a new storm submodel and a new prioritization policy submodel. This Maritime Traffic Simulation Model facilitates the investigation and analysis of the major factors affecting the maritime traffic in the Istanbul Strait, by providing a realistic representation of the traffic system in the Strait. The model is equipped with type, length and direction based arrival processes of transit vessels. (including the effects of storm occurrences on vessel arrivals), stochastic treatment of the visibility issues associated with fog occurrences, stochastic treatment of the current issues and the stochastic treatment of storm occurrences. The TSMTR&R, the available pilotage and tugboat services, traffic lanes and overtaking conditions are covered in the model as well.

In order to realistically represent the storm occurrences in the Strait, the wind data and wind direction data of the last 26 years are compiled and analyzed leading to a season-based storm arrival and duration submodel.

A wide range of scenarios (64 in total), concerning the effects of changes in the arrival rates of transit vessels, availability of support services, prioritization level settings, pursuit distance and environmental and meteorological conditions, are developed and run (with 10 replications) in the model.

Simulation experiments used for the analysis of these scenarios are conducted using full fractional design. They are especially designed to investigate the effects of vessel arrival rate, tugboat/pilot availability, prioritization level, pursuit distance, season and storm level on the response variables, number of vessels passed, average transit time, average waiting time, maximum waiting time, number of vessel in queues, vessel density in the Strait, pilot and tugboat utilizations. Furthermore, selected scenarios are compared and discussed.

The results of the simulation experiments show the importance of the input factors on different response variables, for the selected levels. The study reveals that most of the factors are significant, but vessel arrival rate proves to be the most important factor affecting the responses. Its importance is especially high for number of vessels passed, average waiting time of vessels, maximum waiting time of vessels, number of vessels in the queues and vessel density in the Strait.

Season proves to be the second important factor on most of the response variables. It is the second major factor for the response variables, average waiting time and maximum waiting time of the vessels and number of vessels in the queues. One interesting finding about seasonality effects is that the increase in the average waiting time of all vessels is remarkably lower for the 'Winter' season than the increase in the 'Summer' season, when the vessel arrival rate is increased by 15%. This is mainly caused by the decrease in the vessel arrival rates of passenger and general cargo vessels before, after and during storm occurrences.

Pilot/tugboat availability is the major factor affecting the pilot and tugboat utilizations. It is also significant for the average waiting time and maximum waiting time of overall vessels. On the other hand, pursuit distance is the major factor affecting the average transit time.

Prioritization level does not affect the aggreagate response variables significantly. This result shows that it is not a meaningful parameter affecting the overall system behavior, but it is an important parameter in reflecting the performance of southbound indirect passing vessels (especially in comparison to the other vessels).

The storm level in itself is not significant for any of the response variables. However, its three-way interaction with the arrival rate and the season has a significant but low effect on the maximum waiting time of vessels. This "non performance" of the storm level is mainly caused by the fact that the 'High' setting of 1.5 for the storm level is not sufficiently high to generate significant differences, since the average annual number of storm occurrences for the winter and the summer seasons differ by fourfold (8.5 and 2.0 respectively) anyway. (That is, increasing their arrival rates by 50% does not generate a remarkable increase in the number of storm occurrences especially in the summer season) Accordingly, the winter and the summer scenarios are more meaningful for investigating the effect of number of storm occurrences.

8. FURTHER STUDIES

This study investigated the impact of extreme weather conditions, vessel arrival processes and prioritization policies of the TSVTS on the maritime traffic in the Istanbul Strait. The simulation model deployed in this study is an integrated simulation model, including the current traffic rules and regulations, transit vessel arrivals and characteristics, pilotage and tugboat services, overtaking rules, as well as meteorological, geographical and seasonal conditions, to provide a realistic representation of the system analyzed.

Besides these factors which have been integrated to the simulation model through various studies, there are some other factors which have been held beyond the scope of this study. One example is the effects of local traffic. The local traffic (which includes around 1500 vessels criss-crossing between the two shores of the Istanbul Strait, daily) can be modeled and integrated into the Istanbul Strait Maritime Traffic Simulation Model. Another possible extension would be the integration of accident probabilities into the simulation model. Analyzing the 700 maritime accidents that have occurred since 1948, the risk map of the Istanbul Strait can be developed and integrated into the model with appropriate accident probabilities, types and outcomes in a further study.

This study has been designed according to the two-way traffic system in the Istanbul Strait which was in effect for many years. However, at the beginning of 2006, the TSVTS suspended the two-way traffic in the Istanbul Strait due to the metro construction project “Marmaray” (in effect implementing a major but temporary change in the vessel traffic). The TSVTS is considering to make this change permanent. So, in the future, a new simulation model based on the one-way traffic can be designed and developed, through which the same response factors may be investigated using the same inputs. This will facilitate the comparison of these two different strategic policies.

The storm submodel designed in this study is based on the historical wind direction and wind speed statistics between 1981 and 2006; but the analysis of the effects of storm occurrences on vessel interarrival times has been based on the vessel arrivals in 2005. A further study could expand the simulation model by considering all vessel arrivals between 1981 and 2006. Moreover, as mentioned in Section 3.2.3, a further analysis together with experts from the Turkish State Meteorological Services could enable to estimate storm durations more realistically and more flexibly than the assumption of this study that an observation of a wind speed greater than 17.2 m/s indicates a storm occurrence of one whole day.

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APPENDIX A:

Table A.1. Arrival Distributions of General Cargo/HAZMAT/LNG-LPG/Tanker Vessels

Number of Data Points	Vessel Type	Length	Direction	Distribution Expression	Square Error	Chi-Square P-value
246	Gen Cargo	0-50	N-S	20 + EXPO(2.11e+003)	0.002252	0.715
236	Gen Cargo	0-50	S-N	0.999 + WEIB(2.24e+003, 1.03)	0.002259	0.639
8461	Gen Cargo	50-100	N-S	-0.001 + GAMM(67.5, 0.919)	0.000193	< 0.005
8439	Gen Cargo	50-100	S-N	-0.001 + GAMM(68, 0.92)	0.000201	0.00792
9829	Gen Cargo	100-150	N-S	-0.001 + WEIB(49.8, 0.942)	0.000117	0.00936
9659	Gen Cargo	100-150	S-N	-0.001 + GAMM(57.8, 0.944)	0.000189	< 0.005
2401	Gen Cargo	150-200	N-S	-0.001 + EXPO(218)	0.000296	0.214
2394	Gen Cargo	150-200	S-N	-0.001 + GAMM(239, 0.916)	0.000258	0.632
585	Gen Cargo	200-250	N-S	2 + GAMM(971, 0.919)	0.000498	0.636
582	Gen Cargo	200-250	S-N	2 + 5.77e+003 * BETA(0.586, 2.91)	0.002504	< 0.005
63	Gen Cargo	250-300	N-S	38 + 2.53e+004 * BETA(0.899, 1.87)	0.011061	0.068
54	Gen Cargo	250-300	S-N	89 + 3.32e+004 * BETA(0.724, 1.79)	0.002603	0.654
3	Tanker	0-50	N-S	UNIF(1.25e+005, 1.82e+005)	-	-
2	Tanker	0-50	S-N	UNIF(1.2e+005, 2.32e+005)	-	-
1347	Tanker	50-100	N-S	-0.001 + EXPO(389)	0.000314	> 0.75
1369	Tanker	50-100	S-N	0.999 + GAMM(441, 0.868)	0.000556	> 0.15
1020	Tanker	100-150	N-S	0.999 + 3.08e+003 * BETA(0.735, 3.39)	0.000974	0.173
1018	Tanker	100-150	S-N	2 + EXPO(513)	0.000808	0.405
1179	Tanker	150-200	N-S	-0.001 + GAMM(469, 0.945)	0.000728	0.296
1190	Tanker	150-200	S-N	-0.001 + LOGN(633, 2.6e+003)	0.010025	< 0.005
659	Tanker	200-250	N-S	-0.001 + WEIB(816, 1.03)	0.001570	0.113
662	Tanker	200-250	S-N	0.999 + LOGN(1.42e+003, 7.13e+003)	0.034716	< 0.005
356	Tanker	250-300	N-S	7 + 5.5e+003 * BETA(0.97, 2.69)	0.003468	0.191
356	Tanker	250-300	S-N	2 + 7.21e+003 * BETA(0.54, 1.9)	0.024969	< 0.005
0	HazMat	0-50	N-S	-	-	-
0	HazMat	0-50	S-N	-	-	-
140	HazMat	50-100	N-S	6 + EXPO(3.72e+003)	0.002222	0.743
85	HazMat	50-100	S-N	64 + 2.61e+004 * BETA(0.837, 2.75)	0.002530	0.596
100	HazMat	100-150	N-S	191 + EXPO(5.05e+003)	0.024400	< 0.005
190	HazMat	100-150	S-N	17 + WEIB(2.78e+003, 1.07)	0.005690	0.0457
131	HazMat	150-200	N-S	92 + WEIB(4.05e+003, 1.1)	0.001465	0.481
89	HazMat	150-200	S-N	4 + EXPO(5.84e+003)	0.002630	> 0.75
64	HazMat	200-250	N-S	57 + WEIB(8.15e+003, 1.07)	0.005437	0.249
31	HazMat	200-250	S-N	76 + 3.62e+004 * BETA(0.983, 1.32)	0.020448	0.0439
3	HazMat	250-300	N-S	UNIF(5.36e+004, 8.57e+004)		
11	HazMat	250-300	S-N	7.02e+003 + EXPO(4e+004)	0.021432	> 0.15
0	LNG-LPG	0-50	N-S	-	-	-
0	LNG-LPG	0-50	S-N	-	-	-
30	LNG-LPG	50-100	N-S	1.23e+003 + 6.2e+004 * BETA(0.854, 2.49)	0.008496	< 0.005
97	LNG-LPG	50-100	S-N	4 + WEIB(5.43e+003, 1.01)	0.002596	0.128
13	LNG-LPG	100-150	N-S	4.42e+003 + WEIB(2.13e+004, 0.458)	0.058489	> 0.15
70	LNG-LPG	100-150	S-N	3 + 2.83e+004 * BETA(0.934, 2.71)	0.012308	0.086
2	LNG-LPG	150-200	N-S	UNIF(1.23e+005, 1.59e+005)	-	-
69	LNG-LPG	150-200	S-N	70 + 2.47e+004 * BETA(0.837, 1.95)	0.002200	0.644
4	LNG-LPG	200-250	N-S	UNIF(2.1e+004, 1.4e+005)	-	-
47	LNG-LPG	200-250	S-N	44 + 4.01e+004 * BETA(0.579, 1.56)	0.003826	0.401
0	LNG-LPG	250-300	N-S	-	-	-
0	LNG-LPG	250-300	S-N	-	-	-

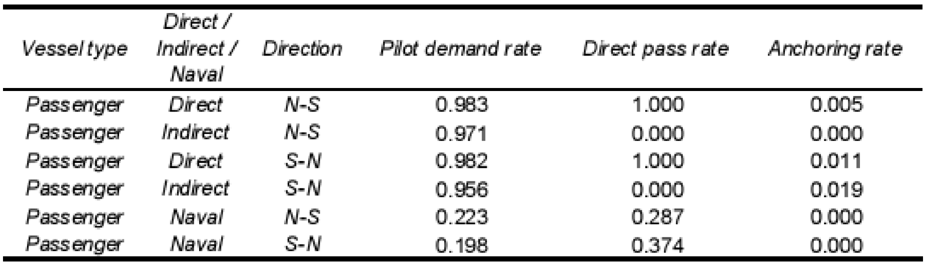
Table A.2. Arrival Distributions of Passenger Vessels

Number of Data Points	Vessel Type	Direct/Indirect	Direction	Distribution Expression	Square Error	Chi-Square P-value
410	Passenger	Direct	N-S	-0.001 + GAMM(1.74e+003, 0.725)	0.004836	< 0.005
243	Passenger	Direct	S-N	-0.001 + 9.51e+003 * BETA(0.426, 2.62)	0.007759	< 0.005
451	Passenger	Indirect	N-S	-0.001 + EXPO(2.13e+003)	0.002091	0.673
205	Passenger	Indirect	S-N	-0.001 + EXPO(2.49e+003)	0.002053	0.244
93	Passenger	Other(Naval)	N-S	-0.001 + WEIB(2.57e+003, 0.439)	0.004505	< 0.005
90	Passenger	Other(Naval)	S-N	-0.001 + WEIB(2.68e+003, 0.455)	0.003000	< 0.005

Table A.3. Pilot demand, Direct and Indirect status and Anchoring frequencies of arriving vessel clusters of General Cargo/HAZMAT/LNG-LPG/Tanker Vessels

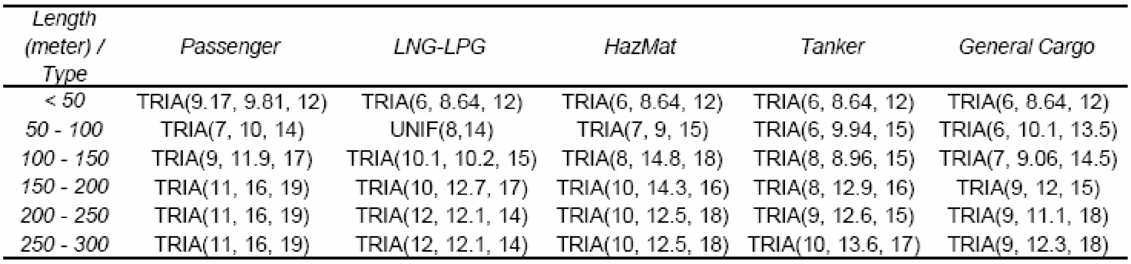
Vessel type	*Length*	*Direction*	*Pilot demand rate*	*Direct pass rate*	*Anchoring rate*
Gen Cargo	*0-50*	*N-S*	0.252	0.354	0.028
Gen Cargo	*0-50*	*S-N*	0.157	0.419	0.178
Gen Cargo	*50-100*	*N-S*	0.248	0.385	0.013
Gen Cargo	*50-100*	*S-N*	0.279	0.380	0.381
Gen Cargo	*100-150*	*N-S*	0.352	0.372	0.005
Gen Cargo	*100-150*	*S-N*	0.387	0.383	0.398
Gen Cargo	*150-200*	*N-S*	0.764	0.386	0.002
Gen Cargo	*150-200*	*S-N*	0.769	0.366	0.161
Gen Cargo	*200-250*	*N-S*	0.921	0.391	0.002
Gen Cargo	*200-250*	*S-N*	0.912	0.381	0.088
Gen Cargo	*250-300*	*N-S*	0.937	0.444	0.000
Gen Cargo	*250-300*	*S-N*	0.981	0.426	0.037
Tanker	*0-50*	*N-S*	0.000	0.667	0.000
Tanker	*0-50*	*S-N*	0.000	0.000	0.000
Tanker	*50-100*	*N-S*	0.268	0.391	0.005
Tanker	*50-100*	*S-N*	0.291	0.395	0.364
Tanker	*100-150*	*N-S*	0.483	0.338	0.001
Tanker	*100-150*	*S-N*	0.494	0.383	0.414
Tanker	*150-200*	*N-S*	0.913	0.366	0.001
Tanker	*150-200*	*S-N*	0.939	0.393	0.192
Tanker	*200-250*	*N-S*	0.959	0.392	0.002
Tanker	*200-250*	*S-N*	0.979	0.384	0.097
Tanker	*250-300*	*N-S*	0.975	0.346	0.003
Tanker	*250-300*	*S-N*	0.975	0.351	0.087
HazMat	*0-50*	*N-S*	0.000	0.000	0.000
HazMat	*0-50*	*S-N*	-	-	-
HazMat	*50-100*	*N-S*	0.443	0.343	0.007
HazMat	*50-100*	*S-N*	0.600	0.329	0.353
HazMat	*100-150*	*N-S*	0.560	0.320	0.010
HazMat	*100-150*	*S-N*	0.568	0.389	0.105
HazMat	*150-200*	*N-S*	0.908	0.374	0.000
HazMat	*150-200*	*S-N*	0.787	0.348	0.022
HazMat	*200-250*	*N-S*	1.000	0.375	0.000
HazMat	*200-250*	*S-N*	0.968	0.419	0.032
HazMat	*250-300*	*N-S*	1.000	0.333	0.000
HazMat	*250-300*	*S-N*	1.000	0.364	0.091
LNG-LPG	*0-50*	*N-S*	-	-	-
LNG-LPG	*0-50*	*S-N*	-	-	-
LNG-LPG	*50-100*	*N-S*	0.433	0.433	0.033
LNG-LPG	*50-100*	*S-N*	0.423	0.340	0.454
LNG-LPG	*100-150*	*N-S*	0.692	0.308	0.000
LNG-LPG	*100-150*	*S-N*	0.671	0.300	0.171
LNG-LPG	*150-200*	*N-S*	0.500	1.000	0.000
LNG-LPG	*150-200*	*S-N*	0.971	0.362	0.203
LNG-LPG	*200-250*	*N-S*	1.000	0.250	0.000
LNG-LPG	*200-250*	*S-N*	1.000	0.404	0.085
LNG-LPG	*250-300*	*N-S*	-	-	-
LNG-LPG	*250-300*	*S-N*	-	-	-

Table A.4. Pilot demand, Direct and Indirect status and Anchoring frequencies of arriving vessel clusters of Passenger Vessels



Vessel type	*Direct / Indirect / Naval*	*Direction*	*Pilot demand rate*	*Direct pass rate*	*Anchoring rate*
Passenger	*Direct*	*N-S*	0.983	1.000	0.005
Passenger	*Indirect*	*N-S*	0.971	0.000	0.000
Passenger	*Direct*	*S-N*	0.982	1.000	0.011
Passenger	*Indirect*	*S-N*	0.956	0.000	0.019
Passenger	*Naval*	*N-S*	0.223	0.287	0.000
Passenger	*Naval*	*S-N*	0.198	0.374	0.000

Table A.5. Declared Speeds of Arriving Vessels



Length (meter) / Type	*Passenger*	*LNG-LPG*	*HazMat*	*Tanker*	*General Cargo*
< 50	TRIA(9.17, 9.81, 12)	TRIA(6, 8.64, 12)	TRIA(6, 8.64, 12)	TRIA(6, 8.64, 12)	TRIA(6, 8.64, 12)
50 - 100	TRIA(7, 10, 14)	UNIF(8,14)	TRIA(7, 9, 15)	TRIA(6, 9.94, 15)	TRIA(6, 10.1, 13.5)
100 - 150	TRIA(9, 11.9, 17)	TRIA(10.1, 10.2, 15)	TRIA(8, 14.8, 18)	TRIA(8, 8.96, 15)	TRIA(7, 9.06, 14.5)
150 - 200	TRIA(11, 16, 19)	TRIA(10, 12.7, 17)	TRIA(10, 14.3, 16)	TRIA(8, 12.9, 16)	TRIA(9, 12, 15)
200 - 250	TRIA(11, 16, 19)	TRIA(12, 12.1, 14)	TRIA(10, 12.5, 18)	TRIA(9, 12.6, 15)	TRIA(9, 11.1, 18)
250 - 300	TRIA(11, 16, 19)	TRIA(12, 12.1, 14)	TRIA(10, 12.5, 18)	TRIA(10, 13.6, 17)	TRIA(9, 12.3, 18)

APPENDIX B:

Table B.1. Scenario Results 1-32

ArrivalRate	Tugboat	FavorLevel	Pursuit	Season	Storm_Level	No of Vessels Passed	Avg Transit Times of Vessels	Avg Waiting Time of Vessels Minutes	Max Waiting Time of Vessels Minutes	No Vessels in the Queues	Vessel Density	Pilot_Utilization	Tugboat_ Utilization
High	**15/6**	**1.3**	**4**	**Summer**	**High**	20167	104,21	2500	39477	184	0,7218	0,3360	0,5560
High	**15/6**	**1.3**	**4**	**Summer**	**Normal**	20129	104,12	2372	33971	181	0,7203	0,3364	0,5544
High	**15/6**	**1.3**	**4**	**Winter**	**High**	20228	103,45	1247	78294	92	0,7239	0,3357	0,5669
High	**15/6**	**1.3**	**4**	**Winter**	**Normal**	20267	103,33	1425	83688	110	0,7210	0,3349	0,5677
High	**15/6**	**1.3**	**8**	**Summer**	**High**	20167	111,93	2616	39826	192	0,7277	0,3397	0,5615
High	**15/6**	**1.3**	**8**	**Summer**	**Normal**	20129	112,42	2481	34233	190	0,7266	0,3400	0,5599
High	**15/6**	**1.3**	**8**	**Winter**	**High**	20228	109,73	1286	78928	95	0,7304	0,3393	0,5724
High	**15/6**	**1.3**	**8**	**Winter**	**Normal**	20267	109,29	1476	84443	115	0,7276	0,3385	0,5731
High	**15/6**	**1.5**	**4**	**Summer**	**High**	20154	104,17	2507	44544	183	0,7222	0,3359	0,5560
High	**15/6**	**1.5**	**4**	**Summer**	**Normal**	20143	104,03	2172	34432	163	0,7213	0,3368	0,5577
High	**15/6**	**1.5**	**4**	**Winter**	**High**	20210	103,96	1165	77028	85	0,7244	0,3357	0,5684
High	**15/6**	**1.5**	**4**	**Winter**	**Normal**	20244	103,36	1420	84704	108	0,7208	0,3347	0,5673
High	**15/6**	**1.5**	**8**	**Summer**	**High**	20154	111,98	2623	44962	191	0,7282	0,3396	0,5614
High	**15/6**	**1.5**	**8**	**Summer**	**Normal**	20143	111,40	2267	34698	170	0,7276	0,3406	0,5632
High	**15/6**	**1.5**	**8**	**Winter**	**High**	20244	108,81	1309	87375	96	0,7293	0,3397	0,5705
High	**15/6**	**1.5**	**8**	**Winter**	**Normal**	20244	109,11	1471	85505	112	0,7274	0,3384	0,5727
High	**20/9**	**1.3**	**4**	**Summer**	**High**	20167	104,21	1667	26318	184	0,7218	0,2520	0,3707
High	**20/9**	**1.3**	**4**	**Summer**	**Normal**	20129	104,12	1582	22647	181	0,7203	0,2523	0,3696
High	**20/9**	**1.3**	**4**	**Winter**	**High**	20228	103,45	831	52196	92	0,7239	0,2518	0,3779
High	**20/9**	**1.3**	**4**	**Winter**	**Normal**	20267	103,33	950	55792	110	0,7210	0,2512	0,3784
High	**20/9**	**1.3**	**8**	**Summer**	**High**	20167	111,93	1744	26550	192	0,7277	0,2537	0,3743
High	**20/9**	**1.3**	**8**	**Summer**	**Normal**	20129	112,42	1654	22822	190	0,7266	0,2539	0,3731
High	**20/9**	**1.3**	**8**	**Winter**	**High**	20213	109,77	822	49883	91	0,7307	0,2531	0,3819
High	**20/9**	**1.3**	**8**	**Winter**	**Normal**	20267	109,29	984	56296	115	0,7276	0,2527	0,3815
High	**20/9**	**1.5**	**4**	**Summer**	**High**	20154	104,17	1672	29696	183	0,7222	0,2520	0,3707
High	**20/9**	**1.5**	**4**	**Summer**	**Normal**	20180	104,18	2022	32961	231	0,7199	0,2514	0,3712
High	**20/9**	**1.5**	**4**	**Winter**	**High**	20226	103,35	808	54235	88	0,7234	0,2518	0,3778
High	**20/9**	**1.5**	**4**	**Winter**	**Normal**	20244	103,36	947	56469	108	0,7208	0,2511	0,3782
High	**20/9**	**1.5**	**8**	**Summer**	**High**	20154	111,98	1748	29974	191	0,7282	0,2537	0,3743
High	**20/9**	**1.5**	**8**	**Summer**	**Normal**	20180	112,19	2118	33269	241	0,7261	0,2531	0,3747
High	**20/9**	**1.5**	**8**	**Winter**	**High**	20244	108,81	873	58250	96	0,7293	0,2536	0,3799
High	**20/9**	**1.5**	**8**	**Winter**	**Normal**	20244	109,11	980	57003	112	0,7274	0,2526	0,3813

Table B.2. Scenario Results 33-64

ArrivalRate	Tugboat	FavorLevel	Pursuit	Season	Storm_Level	No of Vessels Passed	Avg Transit Times of Vessels	Avg Waiting Time of Vessels Minutes	Max Waiting Time of Vessels Minutes	No Vessels in the Queues	Vessel Density	Pilot_Utilization	Tugboat_ Utilization
Normal	**15/6**	**1.3**	**4**	**Summer**	**High**	17806	102,42	453	12971	36	0,6263	0,2911	0,4932
Normal	**15/6**	**1.3**	**4**	**Summer**	**Normal**	17697	102,19	453	14067	34	0,6199	0,2904	0,4883
Normal	**15/6**	**1.3**	**4**	**Winter**	**High**	17590	101,99	551	30084	30	0,6209	0,2883	0,4875
Normal	**15/6**	**1.3**	**4**	**Winter**	**Normal**	17539	101,95	521	26278	31	0,6149	0,2862	0,4840
Normal	**15/6**	**1.3**	**8**	**Summer**	**High**	17806	110,00	473	13072	38	0,6315	0,2947	0,4987
Normal	**15/6**	**1.3**	**8**	**Summer**	**Normal**	17697	110,34	473	14160	36	0,6253	0,2940	0,4938
Normal	**15/6**	**1.3**	**8**	**Winter**	**High**	17590	108,18	567	30312	32	0,6264	0,2919	0,4930
Normal	**15/6**	**1.3**	**8**	**Winter**	**Normal**	17539	107,82	539	26489	32	0,6205	0,2898	0,4895
Normal	**15/6**	**1.5**	**4**	**Summer**	**High**	17803	102,36	470	12792	38	0,6261	0,2912	0,4936
Normal	**15/6**	**1.5**	**4**	**Summer**	**Normal**	17695	102,32	489	14261	36	0,6205	0,2907	0,4884
Normal	**15/6**	**1.5**	**4**	**Winter**	**High**	17590	102,05	574	30875	32	0,6214	0,2884	0,4881
Normal	**15/6**	**1.5**	**4**	**Winter**	**Normal**	17543	102,02	528	23834	32	0,6154	0,2865	0,4845
Normal	**15/6**	**1.5**	**8**	**Summer**	**High**	17803	110,02	491	12895	39	0,6313	0,2948	0,4991
Normal	**15/6**	**1.5**	**8**	**Summer**	**Normal**	17695	109,56	510	14352	38	0,6259	0,2944	0,4938
Normal	**15/6**	**1.5**	**8**	**Winter**	**High**	17590	107,56	589	31105	33	0,6268	0,2920	0,4936
Normal	**15/6**	**1.5**	**8**	**Winter**	**Normal**	17543	107,69	546	24042	33	0,6210	0,2901	0,4899
Normal	**20/9**	**1.3**	**4**	**Summer**	**High**	17806	102,42	302	8647	36	0,6263	0,2183	0,3288
Normal	**20/9**	**1.3**	**4**	**Summer**	**Normal**	17697	102,19	302	9378	34	0,6199	0,2178	0,3255
Normal	**20/9**	**1.3**	**4**	**Winter**	**High**	17590	101,99	367	20056	30	0,6209	0,2162	0,3250
Normal	**20/9**	**1.3**	**4**	**Winter**	**Normal**	17539	101,95	347	17519	31	0,6149	0,2146	0,3227
Normal	**20/9**	**1.3**	**8**	**Summer**	**High**	17806	110,00	315	8715	38	0,6315	0,2198	0,3320
Normal	**20/9**	**1.3**	**8**	**Summer**	**Normal**	17697	110,34	316	9440	36	0,6253	0,2192	0,3287
Normal	**20/9**	**1.3**	**8**	**Winter**	**High**	17590	108,18	378	20208	32	0,6264	0,2176	0,3277
Normal	**20/9**	**1.3**	**8**	**Winter**	**Normal**	17539	107,82	359	17659	32	0,6205	0,2160	0,3253
Normal	**20/9**	**1.5**	**4**	**Summer**	**High**	17803	102,36	313	8528	38	0,6261	0,2184	0,3291
Normal	**20/9**	**1.5**	**4**	**Summer**	**Normal**	17695	102,32	326	9507	36	0,6205	0,2181	0,3256
Normal	**20/9**	**1.5**	**4**	**Winter**	**High**	17590	102,05	382	20584	32	0,6214	0,2163	0,3254
Normal	**20/9**	**1.5**	**4**	**Winter**	**Normal**	17543	102,02	352	15890	32	0,6154	0,2148	0,3230
Normal	**20/9**	**1.5**	**8**	**Summer**	**High**	17803	110,02	327	8597	39	0,6313	0,2199	0,3323
Normal	**20/9**	**1.5**	**8**	**Summer**	**Normal**	17695	110,16	340	9566	38	0,6258	0,2196	0,3286
Normal	**20/9**	**1.5**	**8**	**Winter**	**High**	17590	107,56	393	20736	33	0,6268	0,2177	0,3282
Normal	**20/9**	**1.5**	**8**	**Winter**	**Normal**	17543	107,69	364	16028	33	0,6210	0,2162	0,3256

APPENDIX C:

Table C.1. The ANOVA table for Number of Vessels Passed

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	1.035.039.788	3	345.013.263	3960.78575	< 0.0001	significant
A-Arrival Rate	1.031.683.507	1	1.031.683.507	11843.8268	< 0.0001	
E-Season	371.650	1	371.650	4.26657633	0.0393	
AE	2.984.631	1	2.984.631	34.2638554	< 0.0001	
Residual	55.400.228	636	87.107			
Lack of Fit	665.797	60	11.097	0.11677575	1.0000	not significant
Pure Error	54.734.431	576	95.025			
Cor Total	1.090.440.016	639				
Std. Dev.	295		R-Squared	0.9492		
Mean	18.927		Adj R-Squared	0.9490		
C.V. %	1.5593		Pred R-Squared	0.9486		
PRESS	56.099.278		Adeq Precision	114.6829		

Table C.2. The ANOVA table for Average Transit Times

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	8.387	4	2.097	902.07467	< 0.0001	significant
A-Arrival Rate	451	1	451	193.816903	< 0.0001	
D-Pursuit Distance	7.414	1	7.414	3189.35315	< 0.0001	
E-Season	365	1	365	157.020967	< 0.0001	
DE	159	1	159	68.4471136	< 0.0001	
Residual	1.476	635	2			
Lack of Fit	38	59	1	0.25975932	1.0000	not significant
Pure Error	1.438	576	2			
Cor Total	9.863	639				
Std. Dev.	2		R-Squared	0.8504		
Mean	106		Adj R-Squared	0.8494		
C.V. %	1.4332		Pred R-Squared	0.8480		
PRESS	1.499		Adeq Precision	74.1731		

Table C.3. The ANOVA table for Average Waiting Times

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	331.011.178	5	66.202.236	462.833454	< 0.0001	significant
A-Arrival Rate	225.725.197	1	225.725.197	1578.09131	< 0.0001	
B-Pilot/Tugboat	21.275.968	1	21.275.968	148.744672	< 0.0001	
E-Season	34.066.240	1	34.066.240	238.164093	< 0.0001	
AB	5.976.501	1	5.976.501	41.7829466	< 0.0001	
AE	43.967.272	1	43.967.272	307.38425	< 0.0001	
Residual	90.685.358	634	143.037			
Lack of Fit	6.741.446	58	116.232	0.79755082	0.8580	not significant
Pure Error	83.943.912	576	145.736			
Cor Total	421.696.536	639				
Std. Dev.	378		R-Squared	0.7850		
Mean	1.022		Adj R-Squared	0.7833		
C.V. %	36.9916		Pred R-Squared	0.7809		
PRESS	92409922.01		Adeq Precision	56.7087		

Table C.4. The ANOVA table for Maximum Waiting Times

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	334.053.393.423	9	37.117.043.714	223.346319	< 0.0001	significant
A-Arrival Rate	180.951.473.012	1	180.951.473.012	1088.84872	< 0.0001	
B-Pilot/Tugboat	26.506.715.065	1	26.506.715.065	159.500236	< 0.0001	
E-Season	89.961.912.970	1	89.961.912.970	541.332501	< 0.0001	
AB	5.689.111.741	1	5.689.111.741	34.2333881	< 0.0001	
AC	640.210.417	1	640.210.417	3.85237146	0.0501	
AE	22.241.130.557	1	22.241.130.557	133.832712	< 0.0001	
BE	4.822.756.260	1	4.822.756.260	29.0202222	< 0.0001	
ABE	1.543.525.549	1	1.543.525.549	9.28793661	0.0024	
AEF	1.770.017.996	1	1.770.017.996	10.6508214	0.0012	
Residual	104.697.214.949	630	166.186.055			
Lack of Fit	2.868.261.710	54	53.115.958	0.30045278	1.0000	not significant
Pure Error	101.828.953.239	576	176.786.377			
Cor Total	438.750.608.372	639				
Std. Dev.	12891.31706		R-Squared	0.7614		
Mean	34081.9212		Adj R-Squared	0.7580		
C.V. %	37.8245		Pred R-Squared	0.7537		
PRESS	108.047.265.704		Adeq Precision	48.8053		

Table C.5. The ANOVA table for Number of Vessels in Queues

Source	Squares	df	Square	Value	Prob > F	
Model	2.630.517	3	876.839	656.367665	< 0.0001	significant
A-Arrival Rate	1.992.805	1	1.992.805	1491.73672	< 0.0001	
E-Season	354.439	1	354.439	265.319279	< 0.0001	
AE	283.273	1	283.273	212.047001	< 0.0001	
Residual	849.630	636	1.336			
Lack of Fit	74.476	60	1.241	0.92236349	0.6421	not significant
Pure Error	775.154	576	1.346			
Cor Total	3.480.147	639				
Std. Dev.	37		R-Squared	0.7559		
Mean	90		Adj R-Squared	0.7547		
C.V. %	40.5146		Pred R-Squared	0.7528		
PRESS	860.351		Adeq Precision	54.9116		

Table C.6. The ANOVA table for Vessel Density

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2	4	0	1961.49651	< 0.0001	significant
A-Arrival Rate	2	1	2	7803.7595	< 0.0001	
D-Pursuit Distance	0	1	0	25.7005477	< 0.0001	
F-Storm Level	0	1	0	12.1205694	0.0005	
AE	0	1	0	7.32339819	0.0070	
Residual	0	635	0			
Lack of Fit	0	59	0	0.09242501	1.0000	not significant
Pure Error	0	576	0			
Cor Total	2	639				
Std. Dev.	0.0145		R-Squared	0.9251		
Mean	0.6741		Adj R-Squared	0.9247		
C.V. %	2.1567		Pred R-Squared	0.9239		
PRESS	0.1364		Adeq Precision	89.0820		

Table C.7. The ANOVA table for Pilot Utilization

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1	5	0	6014.63995	< 0.0001	significant
A-Arrival Rate	0	1	0	6273.12977	< 0.0001	
B-Pilot/Tugboat	1	1	1	23638.0969	< 0.0001	
D-Pursuit Distance	0	1	0	25.3300446	< 0.0001	
E-Season	0	1	0	14.1495142	0.0002	
AB	0	1	0	129.766845	< 0.0001	
Residual	0	634	0			
Lack of Fit	0	58	0	0.23176604	1.0000	not significant
Pure Error	0	576	0			
Cor Total	1	639				
Std. Dev.	0.0065		R-Squared	0.9794		
Mean	0.2746		Adj R-Squared	0.9792		
C.V. %	2.3743		Pred R-Squared	0.9790		
PRESS	0.0275		Adeq Precision	197.3845		

Table C.8. The ANOVA table for Tugboat Utilization

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	6	6	1	9856.33651	< 0.0001	significant
A-Arrival Rate	1	1	1	6293.29823	< 0.0001	
B-Pilot/Tugboat	5	1	5	52490.2491	< 0.0001	
D-Pursuit Distance	0	1	0	29.7503804	< 0.0001	
E-Season	0	1	0	10.8682118	0.0010	
AB	0	1	0	248.965595	< 0.0001	
AE	0	1	0	75.7707424	< 0.0001	
Residual	0	633	0			
Lack of Fit	0	57	0	0.32632133	1.0000	not significant
Pure Error	0	576	0			
Cor Total	6	639				
Std. Dev.	0.0097		R-Squared	0.9894		
Mean	0.4396		Adj R-Squared	0.9893		
C.V. %	2.2130		Pred R-Squared	0.9892		
PRESS	0.0613		Adeq Precision	243.8616		

APPENDIX D:

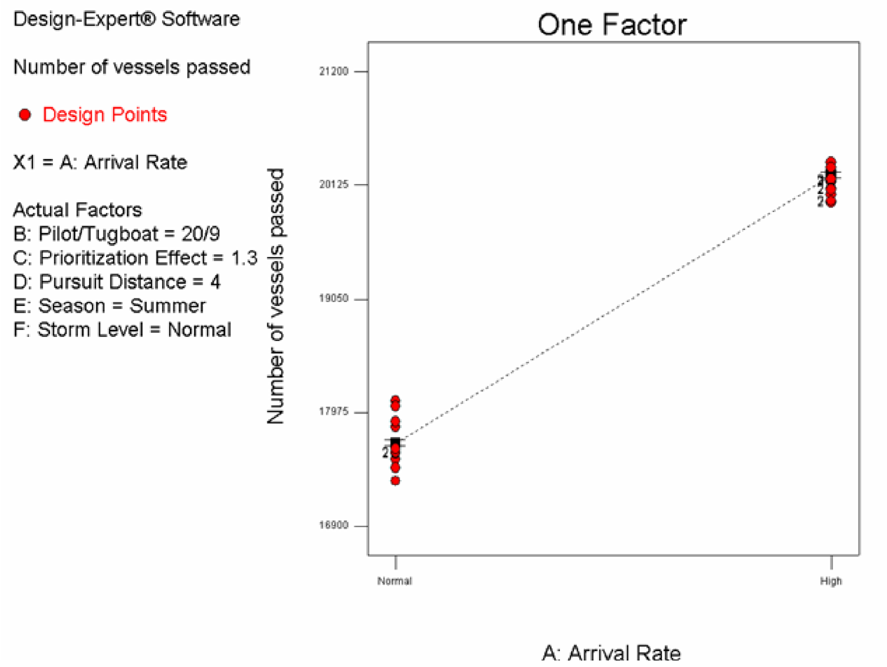


Figure D.1. The Effect of Arrival Rate on Number of Vessels Passed

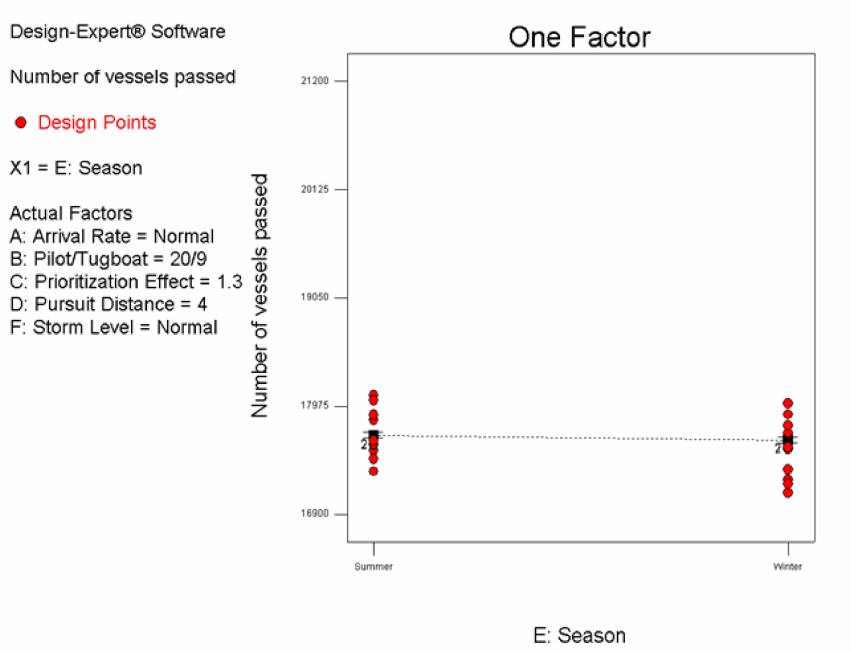


Figure D.2. The Effect of Season on Number of Vessels Passed

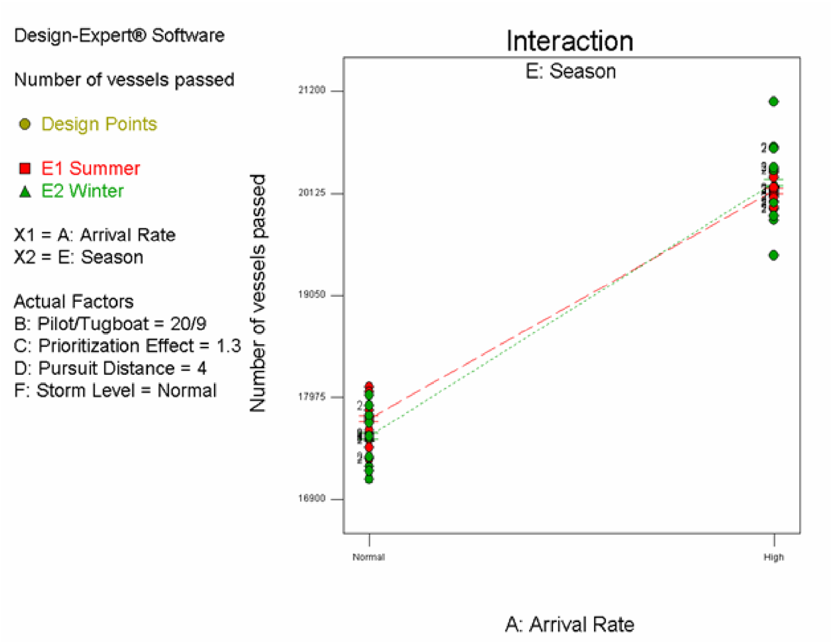


Figure D.3. The Effect of Arrival Rate - Season Interaction on Number of Vessels Passed

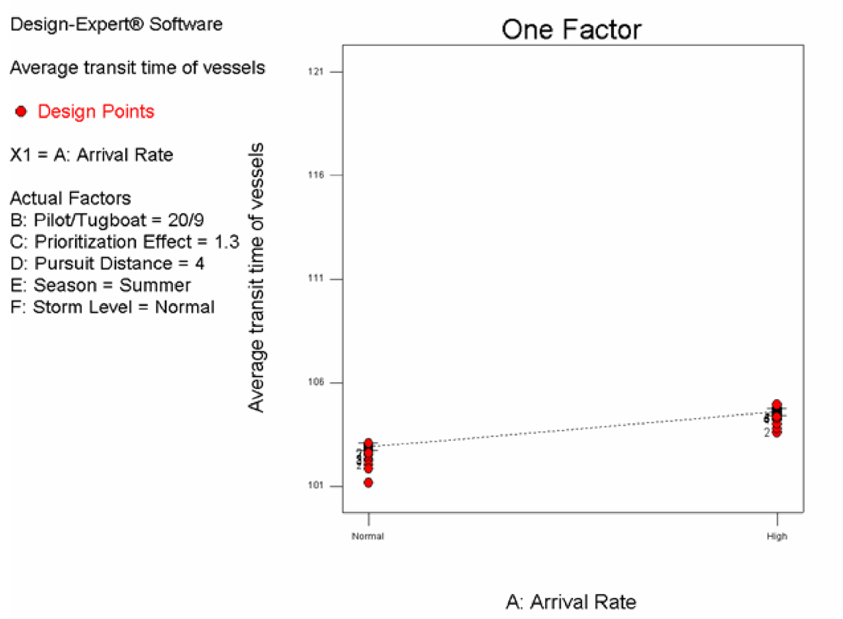


Figure D.4. The Effect of Arrival Rate on Average Transit Times

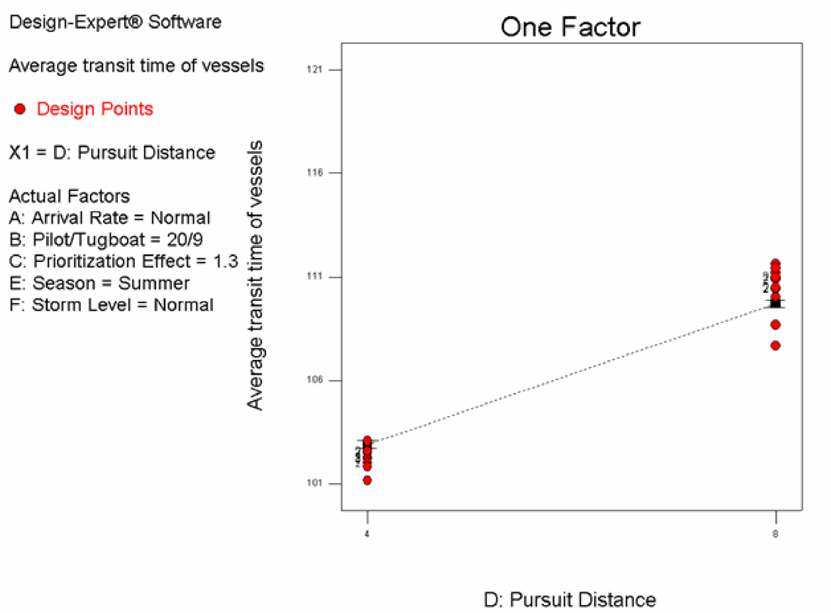


Figure D.5. The Effect of Pursuit Distance on Average Transit Times

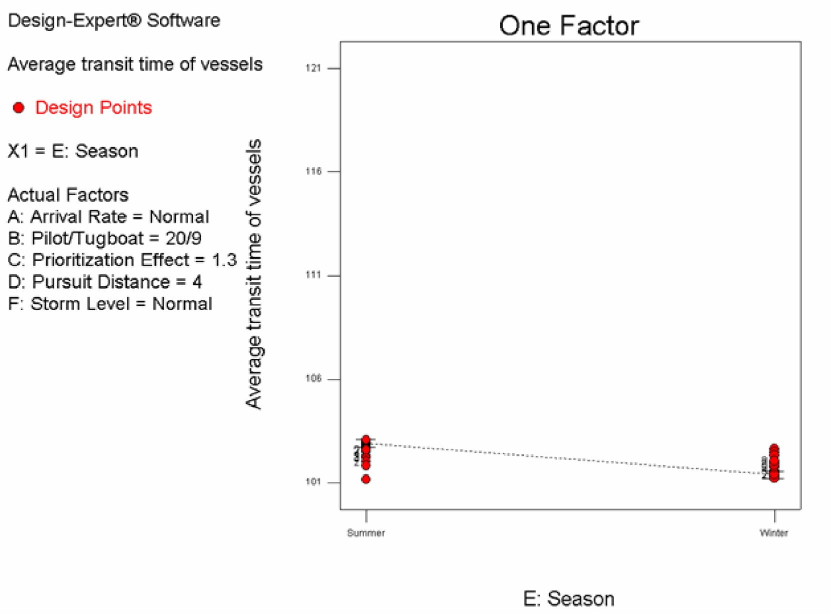


Figure D.6. The Effect of Season on Average Transit Times

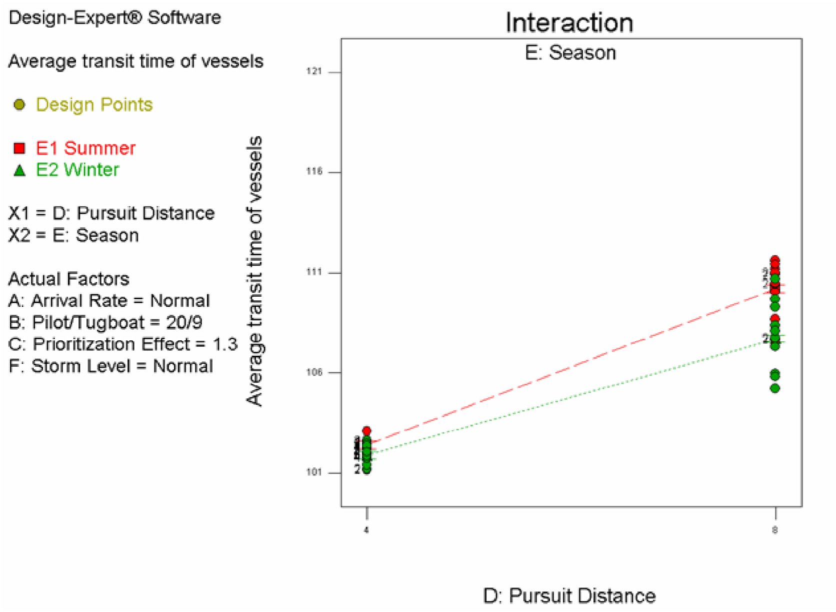


Figure D.7. The Effect of Pursuit Distance - Season Interaction on Average Transit Times

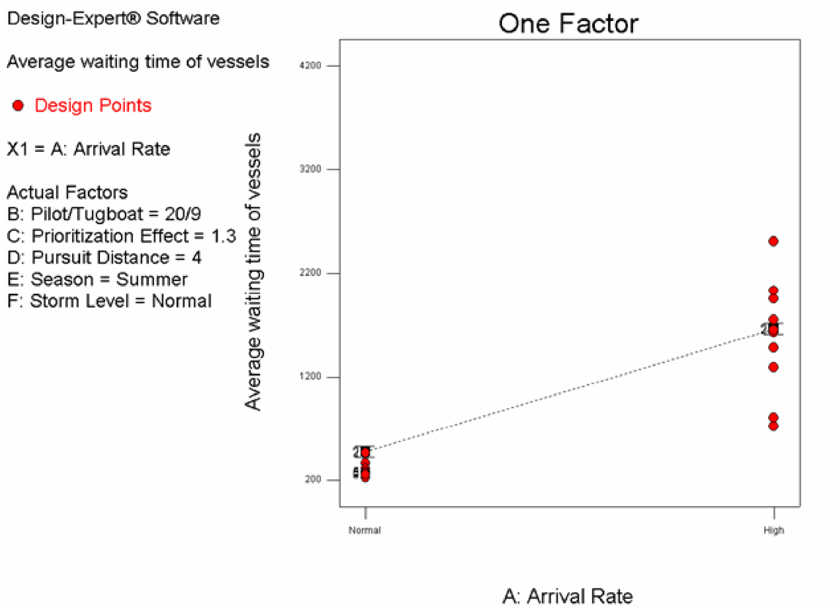


Figure D.8. The Effect of Arrival Rate on Average Waiting Times

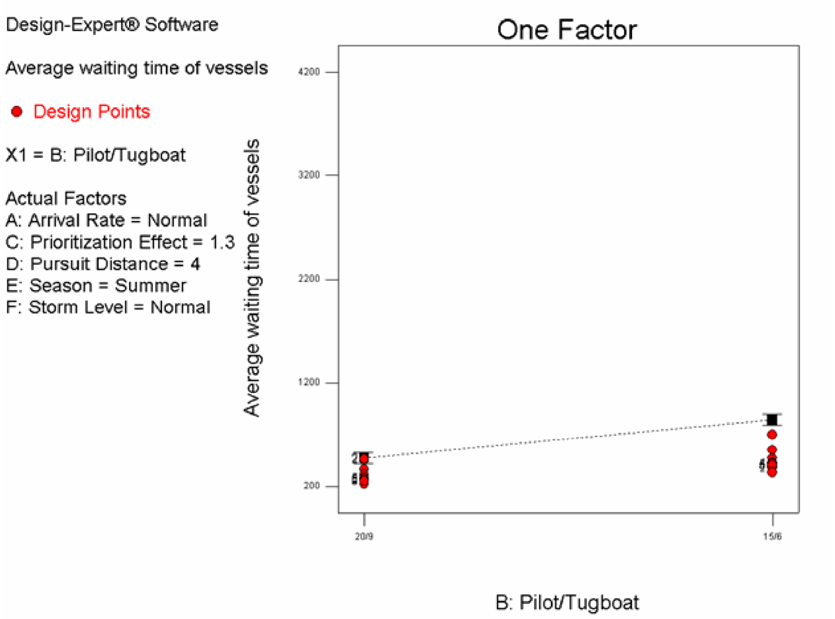


Figure D.9. The Effect of Pilot/Tugboat Availability on Average Waiting Times

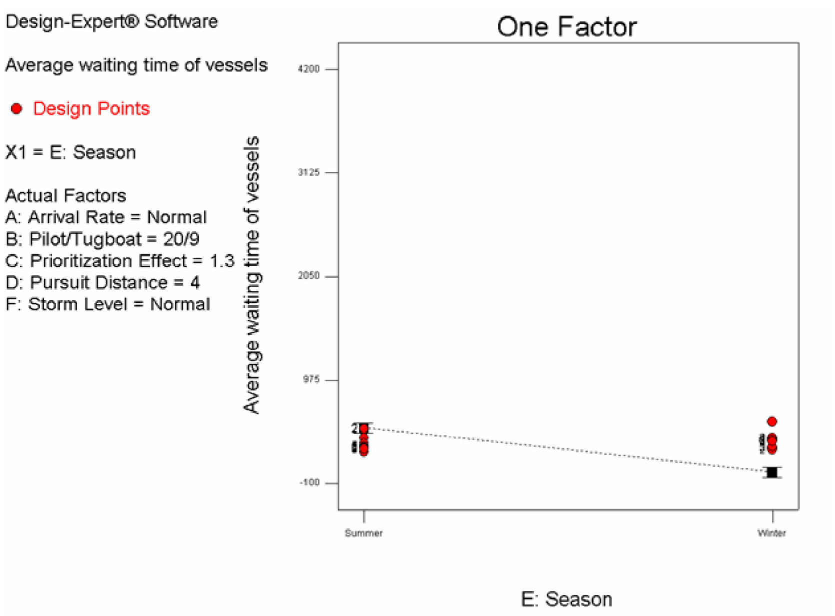


Figure D.10. The Effect of Season on Average Waiting Times

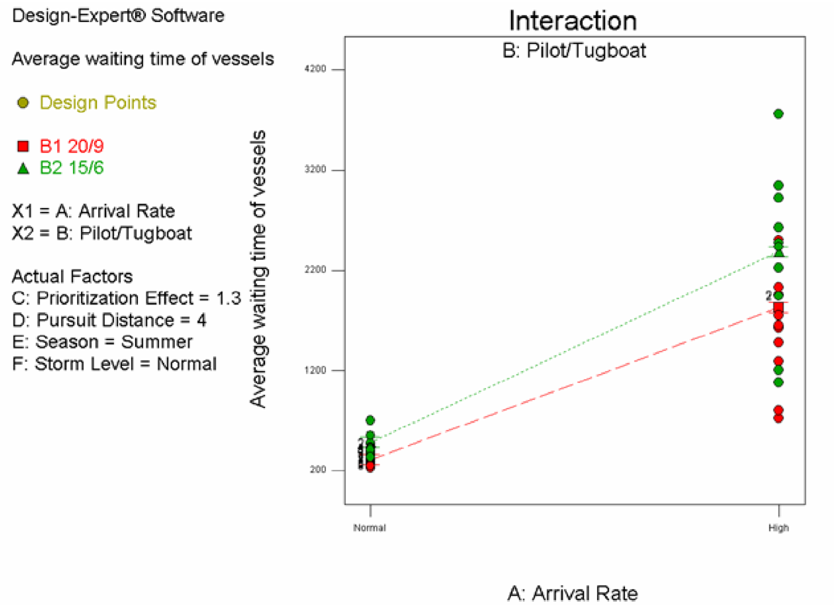


Figure D.11. The Effect of Arrival Rate - Pilot/Tugboat Interaction on Average Waiting Times

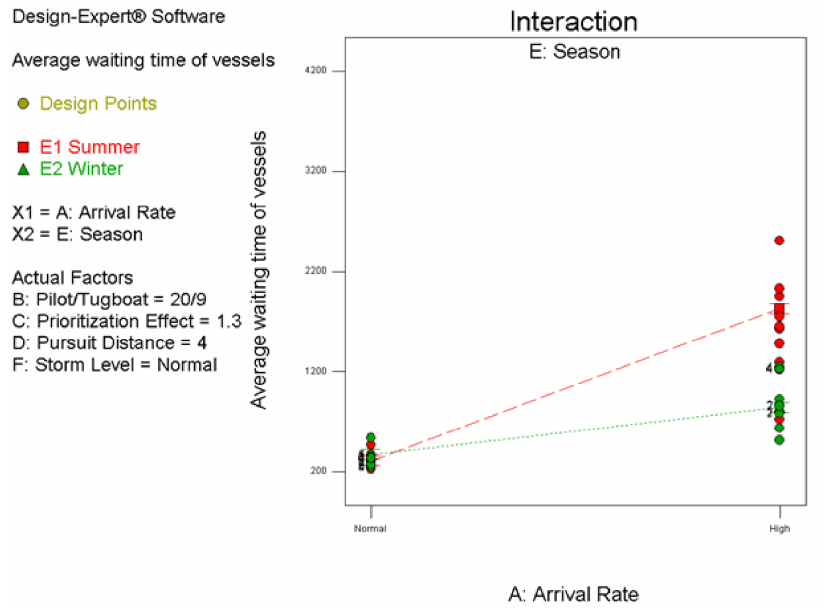


Figure D.12. The Effect of Arrival Rate - Season Interaction on Average Waiting Times

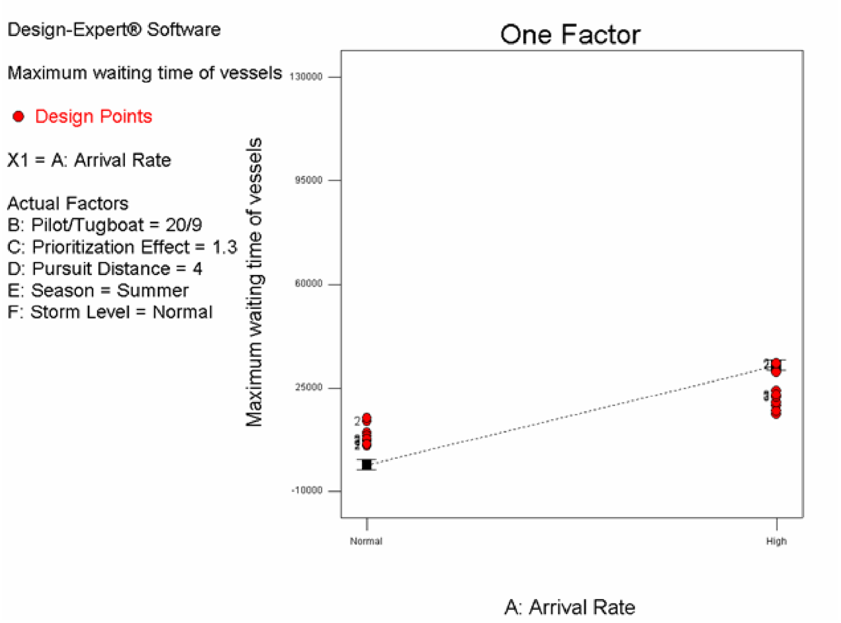


Figure D.13. The Effect of Arrival Rate on Maximum Waiting Times

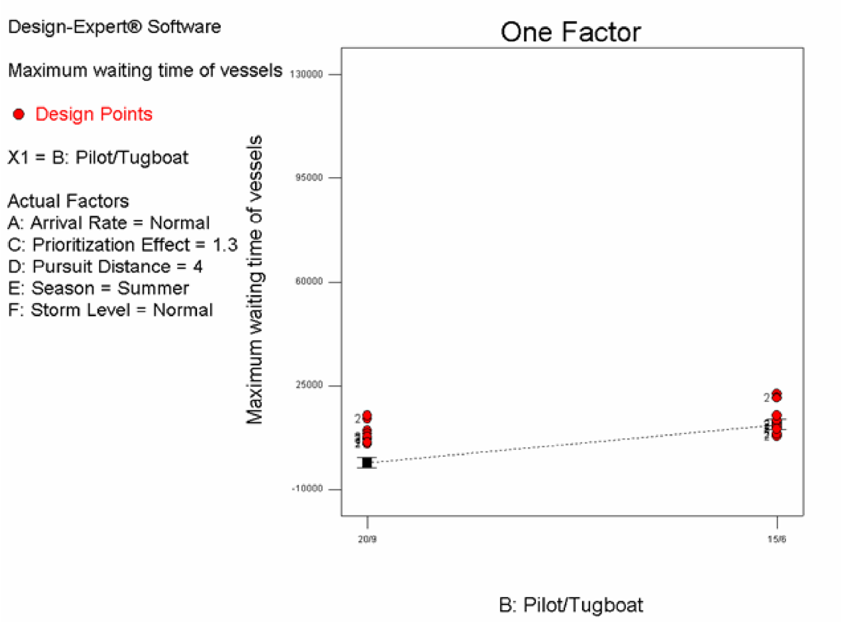


Figure D.14. The Effect of Pilot/Tugboat Availability on Maximum Waiting Times

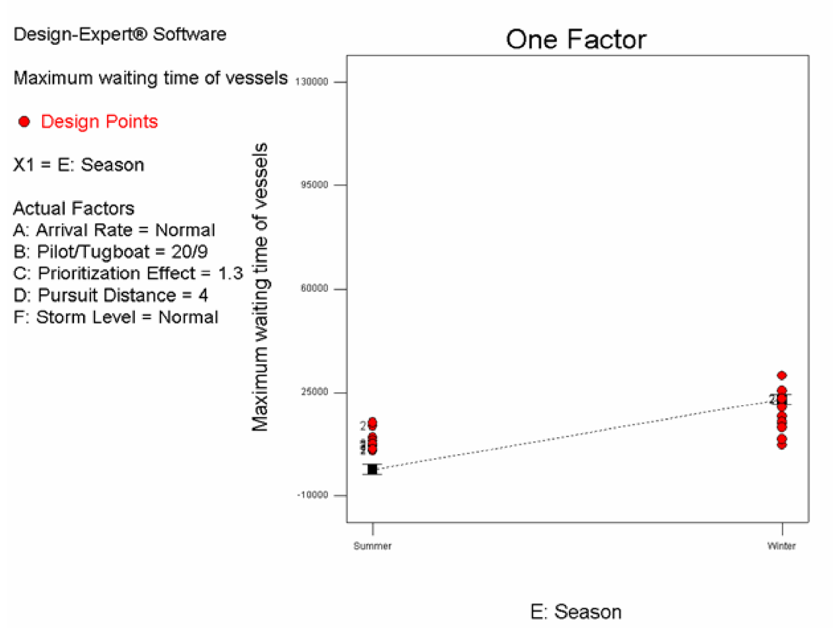


Figure D.15. The Effect of Season on Maximum Waiting Times

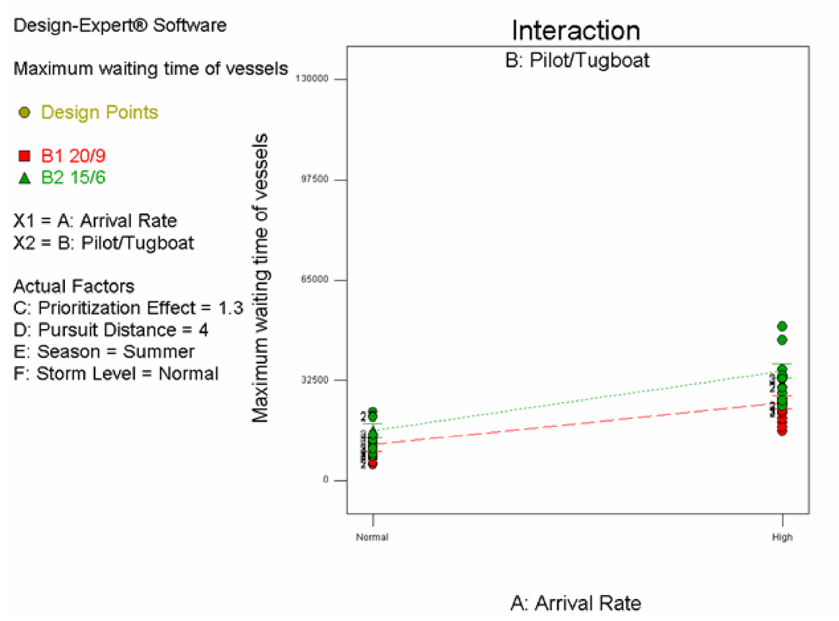


Figure D.16. The Effect of Arrival Rate - Pilot/Tugboat Availability Interaction on Maximum Waiting Times

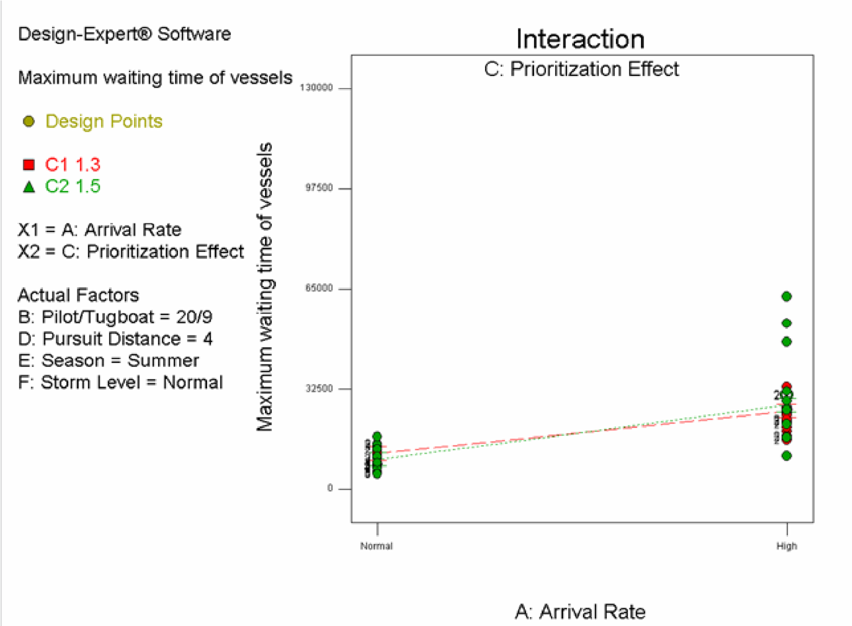


Figure D.17. The Effect of Arrival Rate - Prioritization Interaction on Maximum Waiting Times

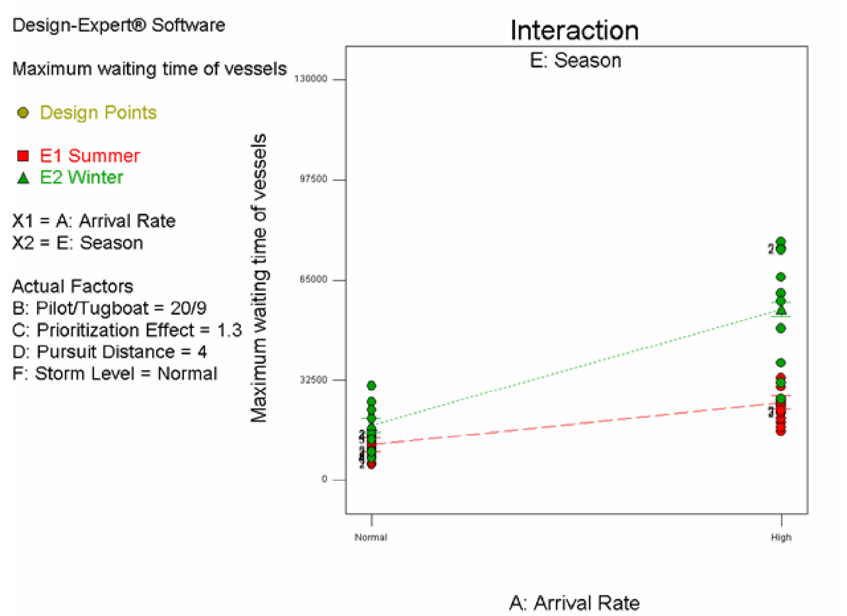


Figure D.18. The Effect of Arrival Rate - Season Interaction on Maximum Waiting Times

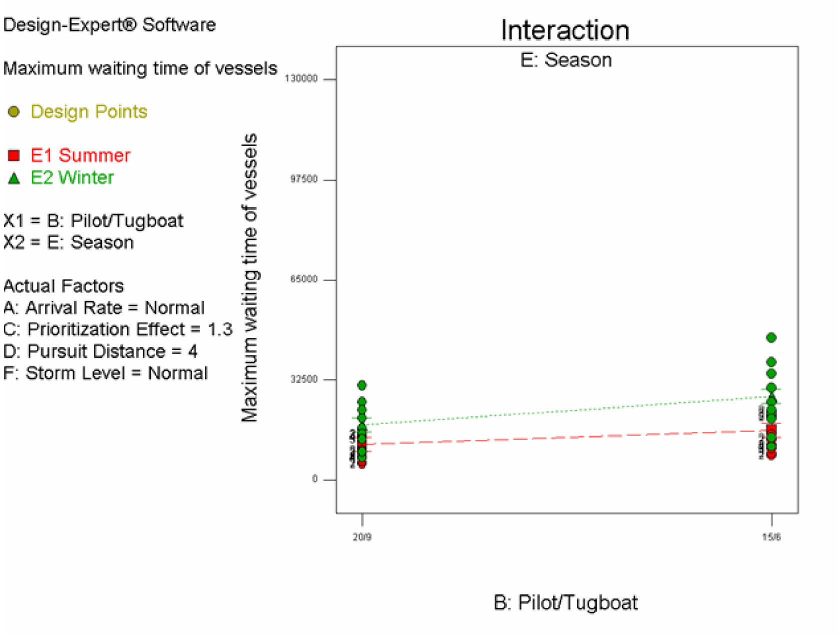


Figure D.19. The Effect of Season - Pilot/Tugboat Availability Interaction on Maximum Waiting Times

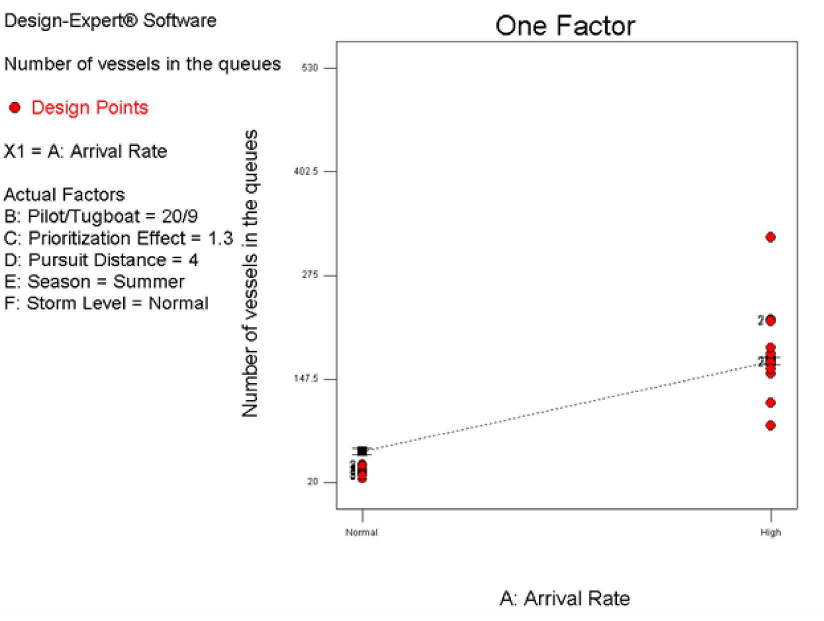


Figure D.20. The Effect of Arrival Rate on Number of Vessels in Queues

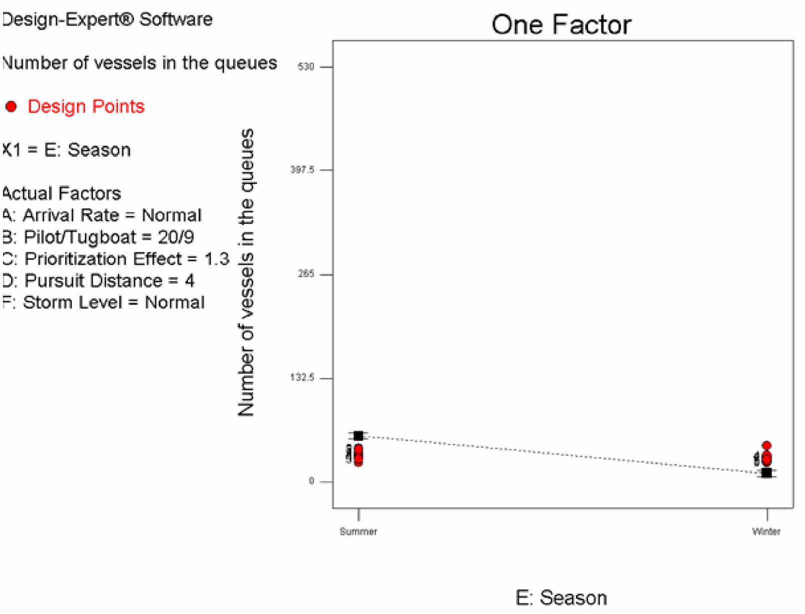


Figure D.21. The Effect of Season on Number of Vessels in Queues

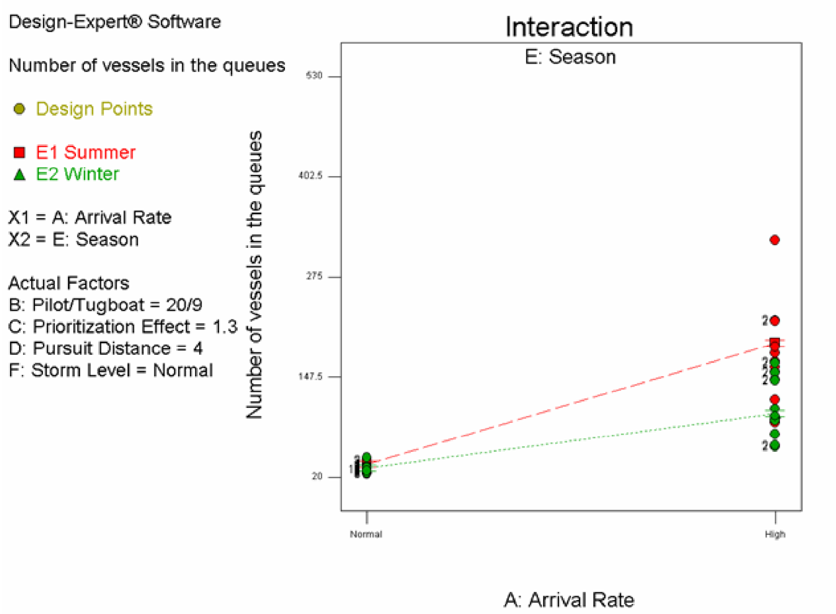


Figure D.22. The Effect of Arrival Rate - Season Interaction on Number of Vessels in Queues

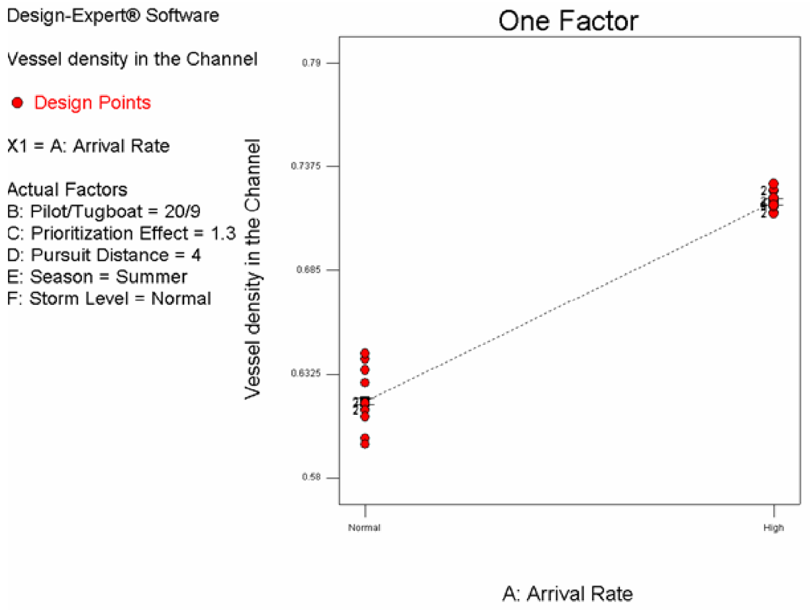


Figure D.23. The Effect of Arrival Rate on Vessel Density

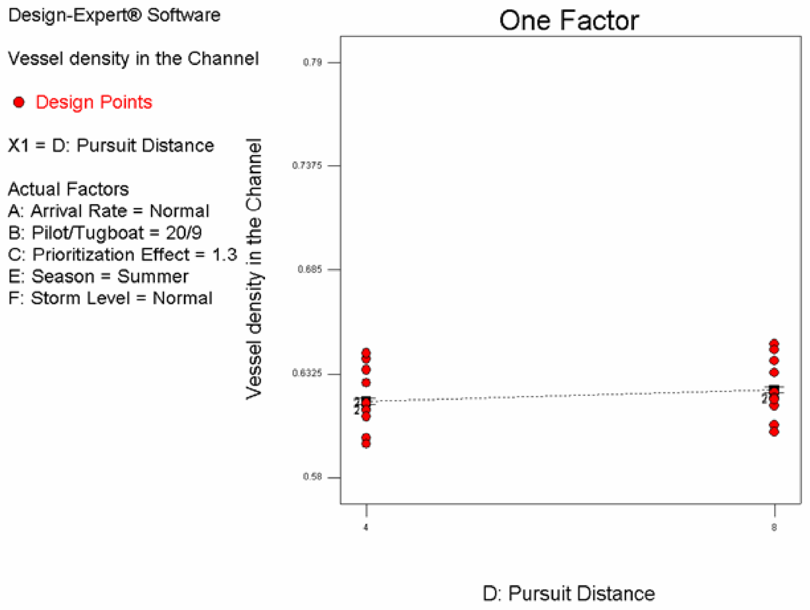


Figure D.24. The Effect of Pursuit Distance on Vessel Density

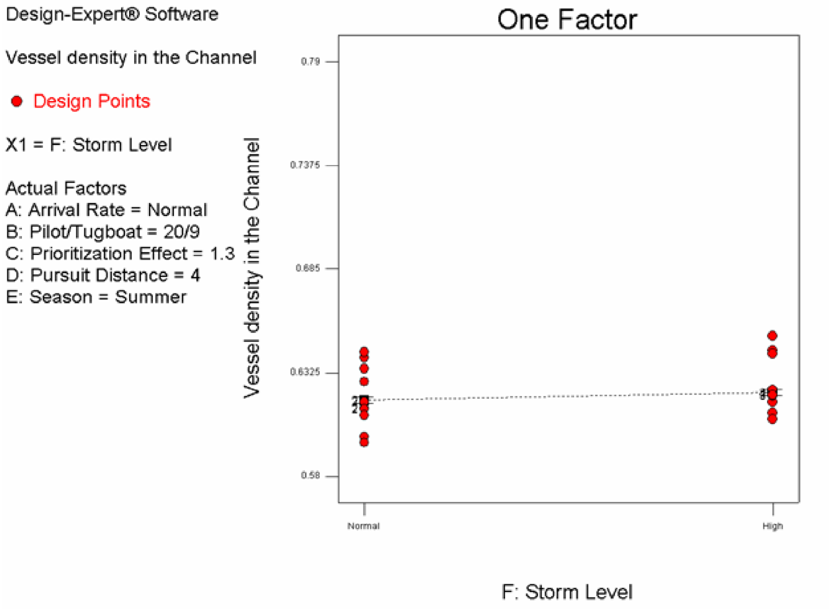


Figure D.25. The Effect of Storm Level on Vessel Density

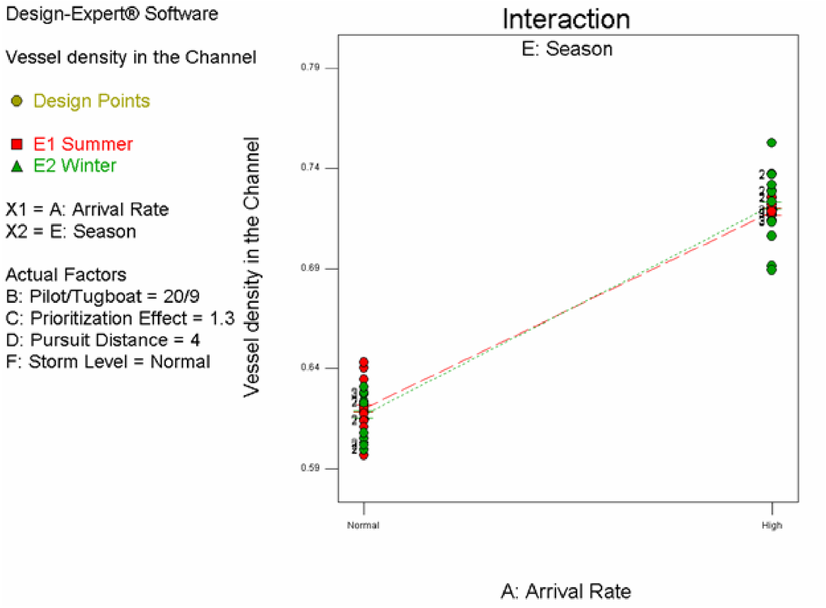


Figure D.26. The Effect of Arrival Rate - Season Interaction on Vessel Density

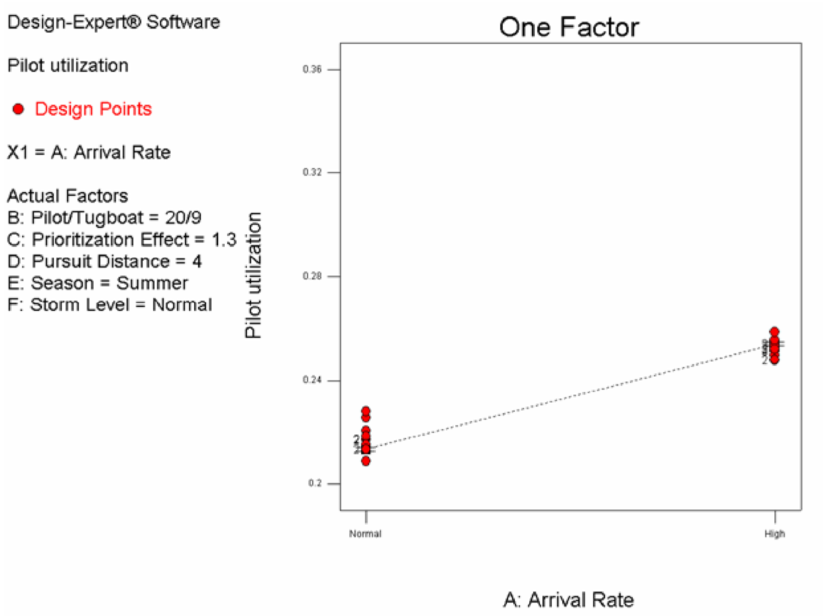


Figure D.27. The Effect of Arrival Rate on Pilot Utilization

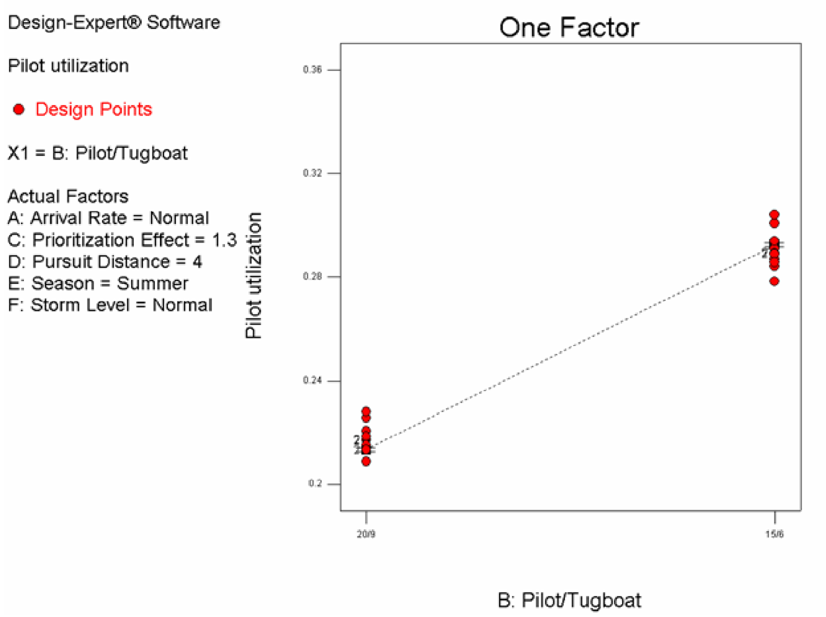


Figure D.28. The Effect of Pilot/Tugboat Availability on Pilot Utilization

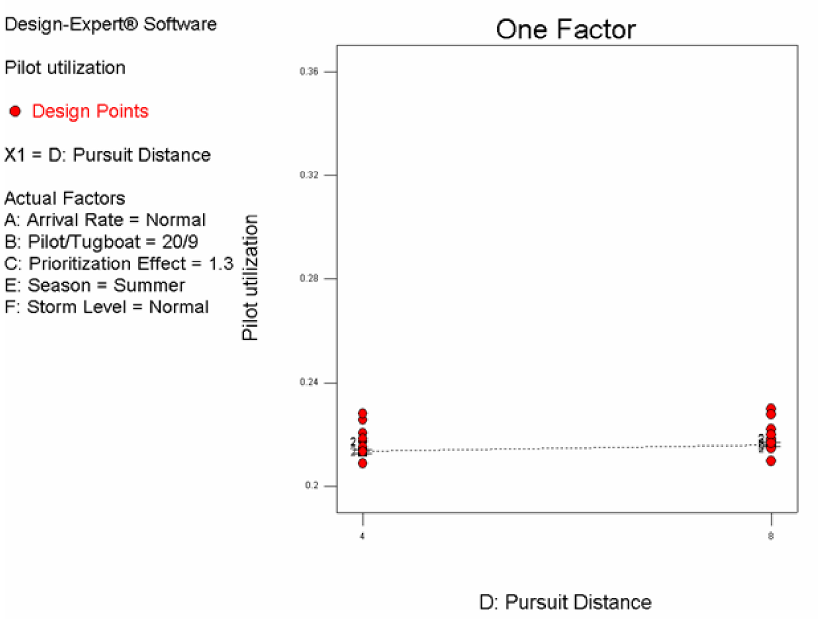


Figure D.29. The Effect of Pursuit Distance on Pilot Utilization

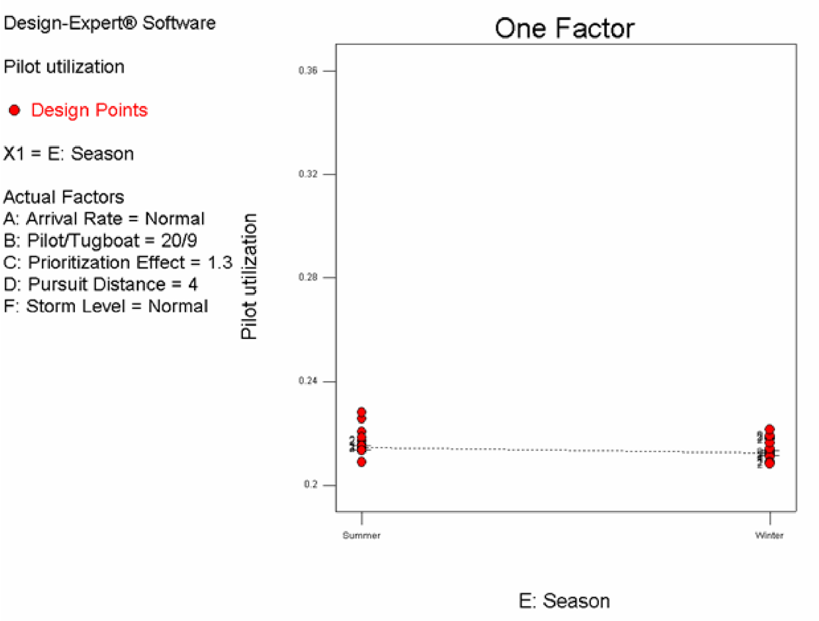


Figure D.30. The Effect of Season on Pilot Utilization

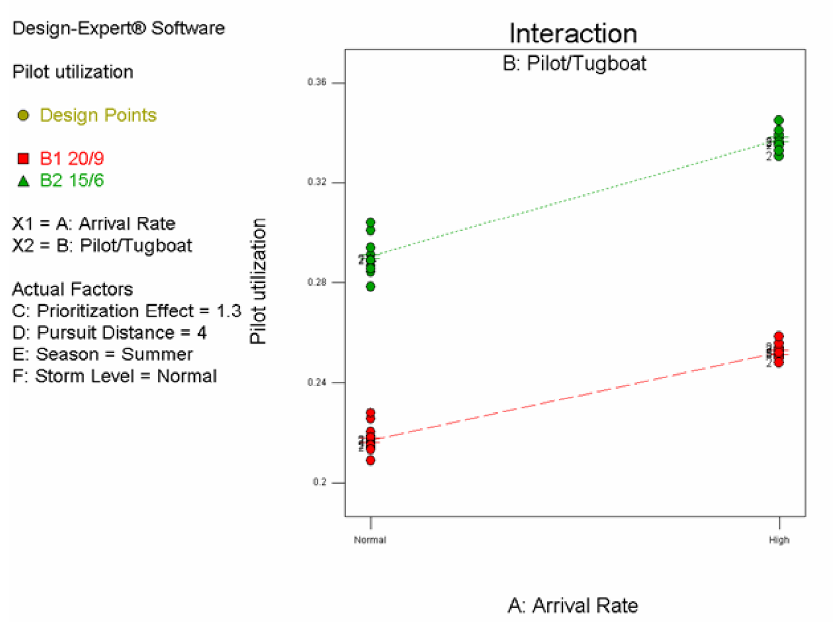


Figure D.31. The Effect of Arrival Rate - Pilot Tugboat Availability Interaction on Pilot Utilization

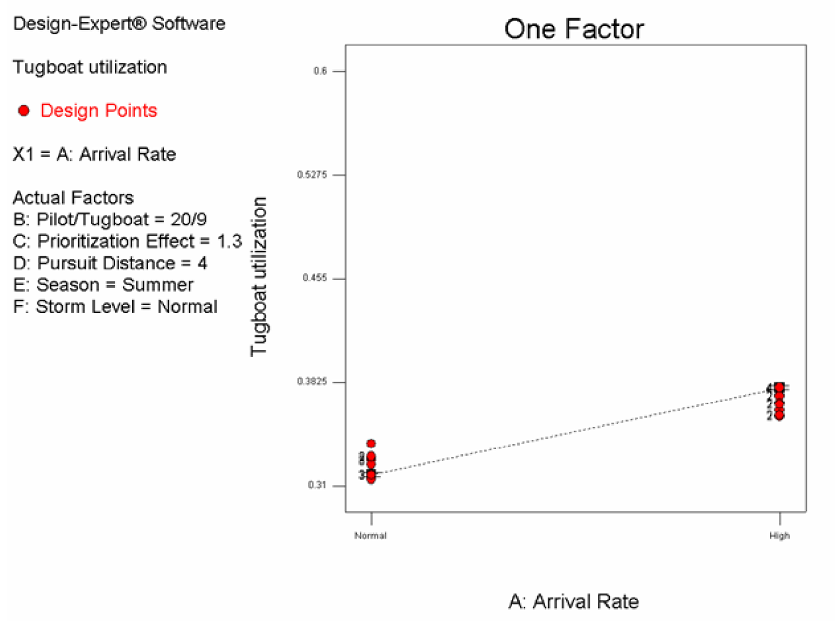


Figure D.32. The Effect of Arrival Rate on Tugboat Utilization

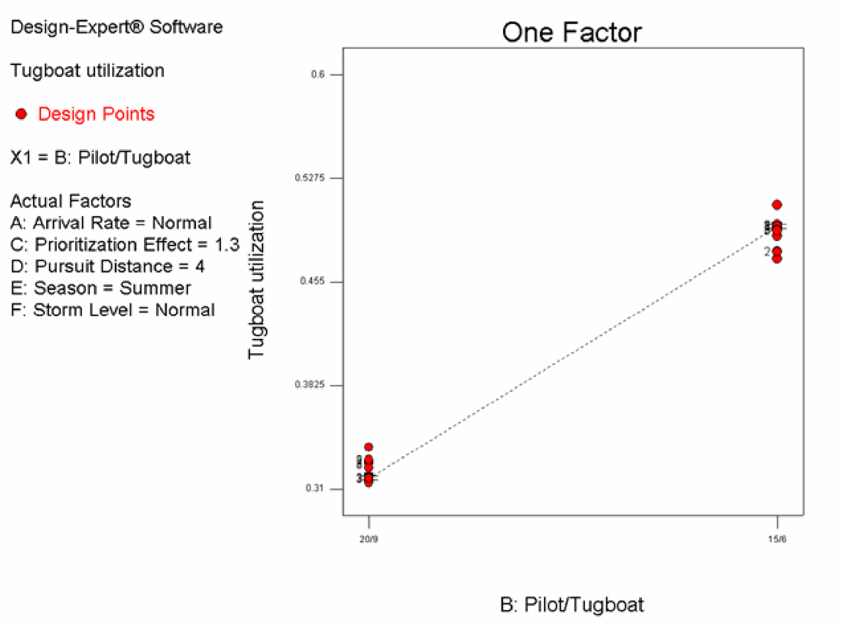


Figure D.33. The Effect of Pilot/Tugboat Availability on Tugboat Utilization

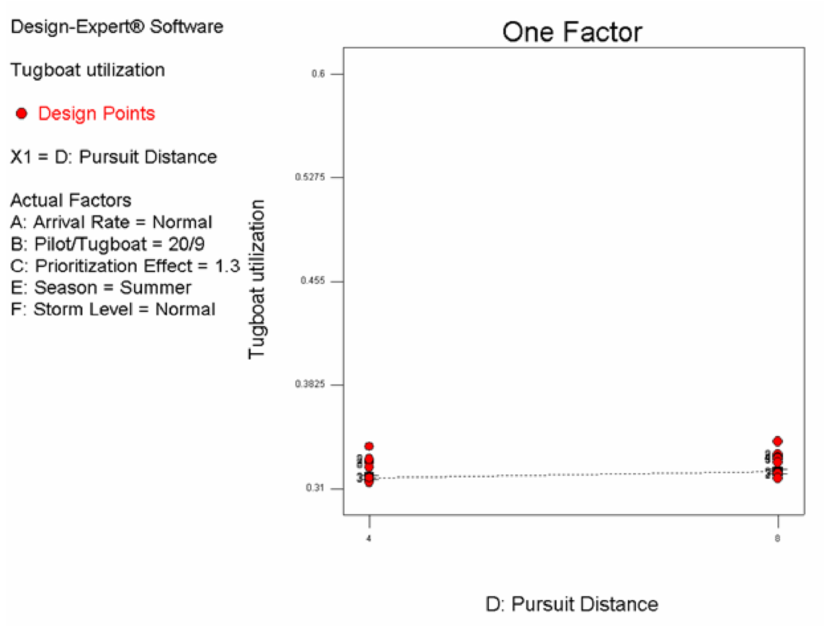


Figure D.34. The Effect of Pursuit Distance on Tugboat Utilization

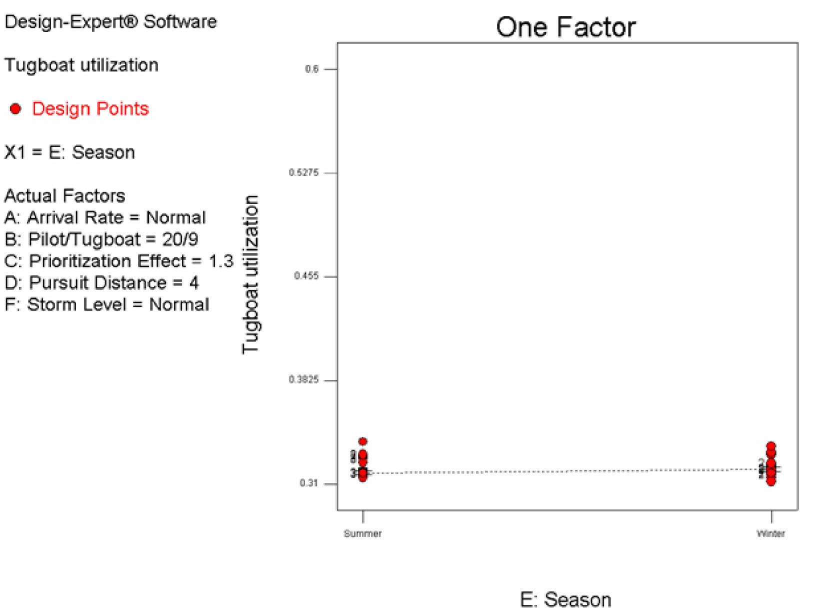


Figure D.35. The Effect of Season on Tugboat Utilization

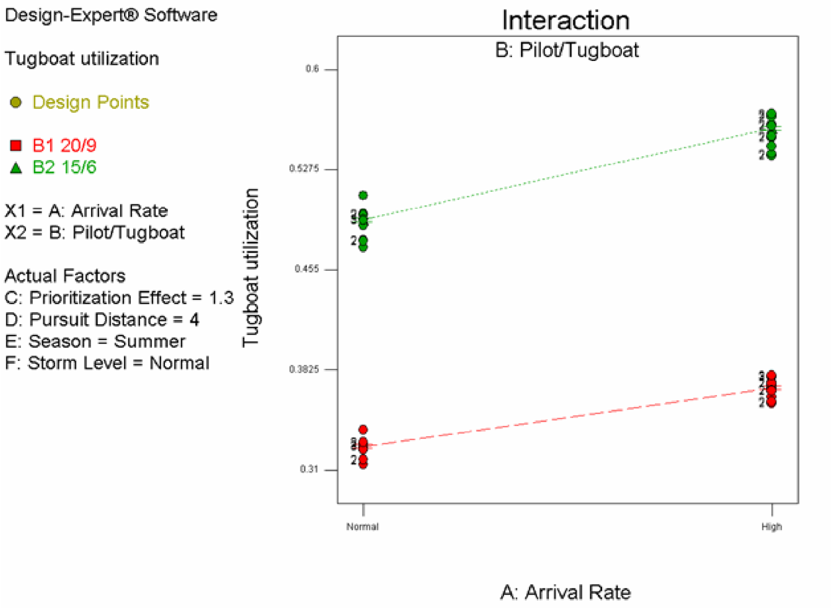


Figure D.36. The Effect of Arrival Rate - Pilot/Tugboat Availability Interaction on Tugboat Utilization

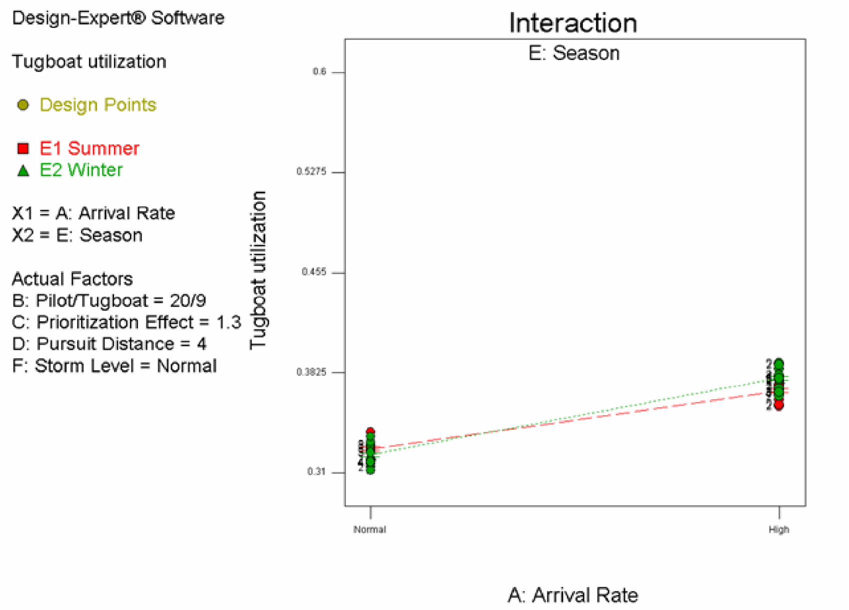


Figure D.37. The Effect of Arrival Rate - Season Interaction on Tugboat Utilization

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