ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A MODEL FOR ANALYSING SHIP EMERGENCY PREPAREDNESS LEVEL

Ph.D. THESIS

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Department of Maritime Transportation Engineering

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MAY 2019

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

GEMİLERDE ACİL DURUM HAZIRLIK SEVİYESİNİN ANALİZİ ÜZERİNE BİR MODEL

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MAYIS 2019

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Date of Submission : 26 April 2019
Date of Defence : 20 May 2019

To Tuna & Ekin,

FOREWORD

First of all, I would like to thank to my supervisor Assoc. Prof. Dr. Metin ÇELİK for his valuable guiding and effort during this PhD. study. Also, I would like to express my gratitute to Assoc. Prof. Dr. Emre AKYÜZ due to his encouragements in this dissertation both academic and supportive. This study will not be as it is now without his suggestions. In addition, I would like to thank to Prof. Dr. Leyla TAVACIOĞLU for her constructive comments to research as the esteemed member of the thesis monitoring committee.

On the other hand, the research content necessitates achieving a high level of interactions with the shipping companies which provided technical support during my PhD research. Therefore, I would like to express my gratitude to all managers of Yasa Tanker Management S.A. both for their technical support and encouragement during this PhD. study. Also, I would like to thank Gözde TURAN and Ali ÖZDEMİR from Ince Shipping Group, Kubilay SARI from Fleet Management Limited and Hakan GÖRGÜN from Yasa Shipmanagement and Trading S.A.

I want to thank my friends who supported me and tried to reduce my stress level during the study especially Gözde TURAN, Didem KABADAYI, Gizem ÇEVİK and all my friends who I could not spare time due to study. My deepest thanks are for my huge and lovely family. I could not even start my thesis without their help and cooperation. Finally, I am very appreciatory to my husband Umut TAÇ for his valuable help, support and encouragement in the course of the thesis.

April 2019

Burcu ÖZTÜRK TAÇ
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ABBREVIATIONS

AHP : Analytical Hierarchy Process
BN : Bayesian Network
CBT : Computer Based Training
ENSI : Enhanced Navigation Support Information
FEMA : Federal Emergency Management Agency
FMEA : Failure Mode and Effects Analysis
FSA : Formal Safety Assessment
HSEQ : Health, Safety, Environment and Quality
IMO : International Maritime Organization
ISM : International Safety Management
ISO : International Organization for Standardization
ISPS : International Ship and Port Facility Security
IMO : International Maritime Organization
MEPC : Marine Environment Protection Committee
MCDM : Multi Criteria Decision Making
MOU : Memorandum of Understanding
MSC : Maritime Safety Committee
NCN : Non-conformity
OBS : Observation
OPRC : International Convention on Oil Pollution Preparedness Response and Cooperation
PMS : Planned Maintenance System
SD : System Dynamics
SMS : Safety Management System
STCW : International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
SOLAS : The Convention for the Safety of Life at Sea
TMSA : Tanker Management Self-Assessment

SYMBOLS

N_m	**:** Number of replications
s(m)	**:** Data standard deviation
t	**:** Test statistics
m	**:** Initial replications
α	**:** Confidence interval
€	**:** Allowable percentage error
µA	**:** Membership function of a triangular fuzzy number
%	**:** Percentage value

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A MODEL FOR ANALYSING SHIP EMERGENCY PREPAREDNESS LEVEL

SUMMARY

Although there are sufficent number of rules which have been brought into force by authorities such as IMO, European Union, flag states, etc. regarding enchancement of safety on board, there are implementation deficiencies on operational level and resultant accidents indicated weakness at emergency situations. Henceforth, academic and industrial institutions concentrated on improving enchancement of safety. Emergency preparedness is still unsolved problem for the maritime industry since its structure prevents external help, heavy weather conditions, and having long distances with closest emergency teams such as fireman, hospital, etc. Despite this, there is not any consistent and applicable measurement way and companies determine their fleet vessels emergency preparedness level through inspection/audit results, incident, accident, near miss analyses and drill performances. It is an indisputable fact that, establishing strict procedures including drill and exercise programs is the best way to analyse current emergency preparedness level.

During the study, systematic literature review has been conducted and found that existing literature on emergency preparedness in maritime domain is not so extensive and focuses particularly on oil spill and prevention, supply chain, personnel transfer from offshore facilities and hazard identification. Current emergency preparation methods do not ensure a consistent approach and they are impractical to implement on board. Considering the literature and industrial gaps and expectations; the primary aim of the thesis is to evaluate operational drill for analysing ship emergency preparedness level by conducting theoretical research. To achieve this purpose, Fuzzy Dematel method integrated with Arena software has been proposed. To simulate operational drill in order to achieve emergency response time, to determine generic factors which influences emergency situation directly, to show how emergency situations on board and their affected factors can be easily simulated in Arena software, to research throughly the effectiveness of the present system by analysing the interested data gathered from the simulation and lastly to establish a marine-specific methodology to evaluate emergency preparedness level are the sub goals of the thesis.

Fire has been chosen as a case study in this thesis due to high likelihood of occurrence and severe consequences among other types. First, steps of an operational firefighting drill were determined. Then, most significant factors, affecting predefined steps of an operational firefighting drill, are revealed and evaluated for each drill step by Fuzzy Dematel method. While the conditions which have no generic factor represented ideal conditions, that have all generic factors represented worst-case condition. 45 real shipboard firefighting drills are applied in Arena to demonstrate the model in ideal conditions and drill duration found 27.47 minutes. When factor analysis received from Fuzzy Dematel methodology integrated to simulation, we have received worst case condition and whole drill duration reached up 51.49 minutes which is unacceptable for operational firefighting drill on board. Findings clearly showed that the effect of generic factors should be decreased, and corrective/preventive actions should be established in order to be prepared for real fire on board. Therefore, suggested actions have been proposed for all generic factors which have adverse effect on drill steps. Finally, to test the effectiveness of the model two different case studies have been analyzed and compared with their real drill durations and results found proper. This study enables ship owners/managers to evaluate their fleet vessels status and to improve their performance in drills by remedying the deficiencies and reducing the risk factors to minimum in the defined factors. Also, the study indicates how a comprehensive insight into the ship emergency preparedness level can be gained by maritime safety managers and professionals.

GEMİLERDE ACİL DURUM HAZIRLIK SEVİYESİNİN ANALİZİ ÜZERİNE BİR MODEL

ÖZET

Deniz taşımacılığı, diğer taşıma modları arasında en düşük maliyete sahip olması, güvenilir olması, tek seferde büyük miktardaki yüklerin taşınmasına imkan tanıması, mal kaybının minimum olması gibi bir çok avantaja sahip olması nedeniyle dünyada en çok tercih edilen ulaşım türüdür. Deniz ticaretinin yapı taşını oluşturan gemiler can ve mal emniyeti açısından büyük riskler taşımaktadır. Gemilerin emniyet önlemlerinin etkinliği konusu deniz taşımacılığı endüstrisinin son yıllarda üzerinde çalıştığı ve geliştirmeye çalıştırdığı konulardan biridir. Fakat artan emniyet standartlarına ve ilgili kuralların yeterli bir sayıya ulaşmasına karşın yakın zamanda yayımlanan raporlar hala gemilerde operasyonel seviyede uygulama eksikliklerini işaret etmektedir. Ulusal/uluslararası sularda meydana gelen yangın, çatışma, su alma, vb. gibi acil durumlarda yaşanan zaafiyetlerden dolayı can ve mal kayıpları meydana gelmektedir. Özellikle yolcu gemilerinde yaşanılan acil durumlara hazırlıksız yakalanıldığı ve cevap verilemediği takdirde, olayın etkileri felaket boyutuna ulaşmaktadır.

Acil durum yönetimi tehlikelere karşı hazırlıklı olma, müdahale etme, zararın etkilerini azaltma ve iyileştirme safhalarından oluşan ve bu amaçlarla planlama, karar verme, değerlendirme, mevcut kaynakların ve insan gücünün organize edilmesi süreçlerini kapsayan yönetim şeklidir. Acil durum yönetiminin en önemli basamaklarından biri olan acil durum hazırlığı safhası, olası acil durumlara karşı eksikliklerin giderildiği, tatbikat ve düzenlemelerin güncel tutulduğu sürekli bir hazır olma durumudur. Birçok endüstri için önem arz eden acil durum hazırlığı; kötü hava koşulları sebebiyle dışarıdan gelecek yardımın engellenmesi ve gecikmesi, çalışma ortamının hastane, itfaiye gibi yardım noktalarına uzaklığı, tahliye bölgesinin yine tehlikeli bölge içinde yer alması gibi sebeplerden dolayı deniz taşımacılığı endüstrisinde çok daha kritik öneme sahiptir. Gemilerde meydana gelen ve gelebilecek olan yaygın kazalar çatma/çatışma, karaya oturma, yangın, su alma, vb.'dir. Acil durum hazırlık ise olaylara ve zamana bağlı olarak değişen bir konsept olup, her olay farklı bir yaklaşım gerekmektedir (Wang, 2006). Kwesi-Buor vd. (2016) yapmış olduğu çalışmasında denizcilik endüstrisinde Formal Emniyet Değerlendirme (FSA) gibi yaklaşımlarının veri yetersizliği ve girdi belirsizliklerinden dolayı yetersiz kaldığını savunmaktadır.

Bu çalışmada deniz taşımacılığı endüstrisinde acil durum hazırlık seviyesi ile ilgili çalışmalar Kitchenham (2004) ile Kitchenham ve Charters (2007) makalelerinde tanımlanan sistematik literatür tekniği ile taranmış ve yapılan çalışmaların sayısı, çalışmaların hangi tip acil durum üzerinde yoğunlaştığı, çalışmaların önemi araştırılmış ve sonuçlarının analizi yapılmıştır. Yapılan çalışmaların büyük kısmını petrol tankerlerinden kaynaklanan deniz kirliliği, özel deniz alanlarında oluşan deniz kirlilikleri, mevcut konvansiyonların bu kirliliklerle mücadele yönteminde etkili olup

olmadığı gibi konular üzerinde yoğunlaşmıştır. Petrol ve doğalgaz platformlarında acil durum hazırlıkları çalışmaları, toplam çalışmalar göz önüne alındığında deniz kirliliği çalışmalarını takip etmiş ve daha çok platformlar ve kıyı arasında personel taşımacılığı konuları üzerinde durulmuştur. Çalışmalar tedarik zinciri üzerinde devam etmiştir. Bu alanda özellikle limanlarda mevcut uygulamaların yetersizliğinden, politika üretmenin ve değiştirmenin önemi ve risklerinden bahsedilmiştir. Sistematik literatür taraması sonucunda, var olan acil durum yönetimi hazırlık safhası çalışmalarının çok kısıtlı olduğu, yapılan çalışmaların gemi platformunda olası kazalara adapte edilemeyeceği, deniz taşımacılığı endüstrisinin beklentilerine cevap verebilecek nitelikte bir bilimsel yaklaşımın bulunmadığı görülmüştür. Ayrıca çalışmaya başlamadan önce denizcilik firmaları ile filo gemilerindeki acil durum hazırlık seviyesini nasıl belirledikleri hakkında görüşülmüş olup sistematik ve düzenli bir yöntemlerinin olmadığı ve iç/dış denetim, kaza raporları, talim değerlendirmelerine göre karar verdikleri sonucuna ulaşılmıştır.

Denizcilik endüstrisi ve literatürdeki acil durum hazırlık yönetimi safhasındaki boşluklar ve beklentiler çalışmanın ana motivasyon kaynağını oluşturmuştur ve gemilerin acil durum hazırlık seviyesinin belirlenmesi üzerine model geliştirilmesi hedeflenmiştir. Bu amaçla kesikli olay simulasyonu olan Arena yazılımı ile bütünleşik faktör analizi (Fuzzy Dematel) yaklaşımı önerilmiştir. Bunun için talim değerlendirmesi yapılmasına karar verilmiştir. Acil durum olarak sonucu ve meydana geliş sıklığı dikkate alındığında en tehlikeli kaza türlerinden biri olan yangın seçilmiş ve dolayısıyla yangın talimi analizi yapılması kararlaştırılmıştır. Öncelikle yangın taliminin alt basamakları belirlenmiştir. Literatür taraması, uzman görüşleri ve ilgili kural/regülasyonlar dikkate alınarak talim performansını olumsuz etkileyecek dolayısıyla gemi acil durum etkinliğini zaafiyete uğratabilecek faktörler belirlenmiştir. 20 faktörden oluşan faktör havuzu oluşturulmuştur. Elde edilen faktörlerin her bir talim adımını ne kadar etkilediği, hangilerinin etkileyen hangilerinin etkilenen faktörler arasında olduğunun analizi için Fuzzy Dematel metodu kullanılmıştır. Analiz yapılırken gemi tecrübesi bulunan, daha önce yangın talimlerine liderlik yapan ve en az enspektör/müdür seviyesinde 5 homojen uzman görüşüne danışılmıştır. Her bir talim adımını etkileyen faktörler birbirinden farklı olsa da genel olarak kayıp/etkisiz takım lideri ve mürettebat, yetersiz eğitim ve talim, yangın koruyucu ekipmanların kullanımında disiplinsizlik ve emniyet kültürü eksikliği, bilgi eksikliği ve eğitim seviyesi düşüklüğü, gemi adamlarının yorgunluğu, ekipman arızası yangın talimini olumsuz etkileyen en önemli faktörlerdendir.

Çalışmada faktör havuzunda yer alan hiç bir faktörü içermeyen gemiler ideal koşul şartlarını temsil etmektedir. Tüm faktörlerin tek bir gemide toplandığı durum ise en kötü senaryoyu temsil etmektedir. Belirlenen talim adımları ve oluşturulan faktör havuzu örneklem alınacak gemi işletmeciliği firmalarına bildirilmiştir. Firma yöneticilerinden ideal koşullarda bulunan filo gemilerinde gerçekleşen yangın talimindeki her bir adım için sürenin bildirilmesi istenilmiştir. Senaryosu baş tarafta olan bir yangın talimi, talim süresini uzattığı düşünülerek sisteme eklenmemiştir.

Öncelikle gerçek talim akışı düşünülerek Arena yazılım programında kullanılması gereken modüller belirlenmiştir. Program çalıştırma süresi ve sayısı belirlenmiştir. Toplam 45 gemiden ölçüm alınmıştır. Talim süreleri toplandıktan sonra olası sapmaları tespit etmek ve engellemek için aykırı (outlier) analizi gerçekleştirilmiştir. Outlier analizi sonrası olasılık dağılımlarının bulunması için Arena yazılım programında yer alan Input Analiz aracı kullanılmıştır. Model ideal koşullarda çalıştırıldığında toplam talim süresi 27.47 dakika olarak bulunmuştur.

İkinci adım olarak, Fuzzy Dematel metoduyla gerçekleştirilen faktör analizi ideal koşullarda elde edilen verilere entegre edilmiş ve en kötü senaryo sonuçlarına ulaşılmak istenilmiştir. 45 en kötü senaryo Arena simülasyonunda çalıştırıldığında toplam talim süresinin 51.49 dakikaya ulaştığı görülmüştür. Gerçek bir yangın durumunda bu sürenin kabul edilebilir olduğu düşünülmemektedir ve acil duruma hazırlıksız olunduğunun göstergesidir. Dolayısıyla belirlenen faktörlerin ortadan kaldırılması ve risklerinin minimuma indirilmesi gerekmektedir. Eğer bu mümkün değilse her bir faktör için düzeltici faaliyet planlanması gerekmektedir. Çalışmamızda her bir faktör için önleyici/düzeltici faaliyetler belirlenmiştir.

Son olarak modelinin etkinliğini değerlendirmek için ideal koşullarda olmayan ve en az bir faktör içeren 2 örnek olay incelenmiştir. Örnek olayların toplandığı gemilerdeki faktörler Arena simülasyon programına entegre edilmiş ve tahmini talim sonucu modellenmiştir. Simulasyon ile elde edilen sonuç ve gemilerden alınan gerçek sonuçlar karşılaştırılmış ve sonuçların birbiriyle uyumlu olduğu görülmüştür. Böylelikle modelin doğruluğu sağlanmıştır.

Bu çalışma acil durumu etkileyen faktörlerin önem derecelerinin Fuzzy Dematel yaklaşımıyla bulunabileceği, gemilerde gerçekleştirilen operasyonel talimlerin acil durum cevap verme süresinin Arena programında kolaylıkla simüle edilebileceği ve Fuzzy Dematel metoduyla kesikli olay simülasyonunun kolaylıkla entegre edilebileceğini göstermiştir.Ayrıca çalışmanın çıktılarının denizcilik platformuna emniyet farkındalığını artırması ve olası acil durum koşullarında hazırlık aksiyonlarına katkı verebileceği düşünülmektedir. Oluşturulan model sayesinde şirket yöneticileri acil durumlarda filo gemilerinin aksiyonlarını öncesinde analiz edebileceklerdir. Modelin sadece yangın durumunda değil tüm acil durumlar için uyarlanabilmesi, pratik olması ve kolay uygulanabilirliği sayesinde gemi platformları haricinde liman, terminal, tersane gibi diğer denizcilik platformlarına da uygulanabilmesi hem sektörler hem de akademik boşluğu gidermektedir.

1. INTRODUCTION

In the global world trade, maritime transportation has an important share (Hu and Zhu, 2009). However, the environmental conditions of the sea hold all hazards regarding cargo loss and damage, injuries and fatalities (Lu and Tsai, 2008). Emergency preparedness is being ready to the undesirable event when unforeseen accident occurs by taking necessary and correct actions. Emergency preparedness also contains readiness to commence appropriate mitigating behaviours in which incidents turn into major accidents affecting people, property and environment (Kristiansen, 2005). Since emergency situations can be encountered in every industry, emergency preparedness has an importance for most of industries. However, due to the reasons such as the remoteness and the need to be fully self-sufficient, harsh weather conditions which prevent external help, etc. emergency preparedness has a crucial importance in maritime industry (Vinnem, 2011).

The International Maritime Organization (IMO) as a leading worldwide regulatory authority has developed regulations aiming risk reduction in ship operations (Karahalios, 2018). However, even though the increasing regulatory control and innovative trend of marine technology, the number of shipping accidents has not reached to the intended standards and prevention of these accidents is still a focused subject of maritime interests (Celik et al. 2010). According to Buor et al. (2016), implementation of quantitative risk assessment techniques such as Formal Safety Assessment (FSA) of IMO are inappropriate because of the data insufficiency and input uncertainties. Authors also pointed out that, changes in emergency preparedness and risk status depends on emergency/disaster type, place, time, resource availability, etc. Common accidents in the shipping industry include: contact/collision, explosion, external hazards, fire, and flooding, grounding/stranding, hazardous substance related failure, loss of hull integrity, machinery failure, etc. Wang (2006) states that each event affected by emergencies is unique, therefore needs a unique approach to successfully respond.

Good management need to eliminate a good deal of risks and uncertainties in their business thus organisation's destiny can be controlled, and the uncertainty can be removed or at least be lowered through risk assessment and emergency preparedness (Fink, 1986). However, in the lights of interviews with shipping companies, companies determine their fleet vessels emergency preparedness level through inspection/audit results, incident, accident, near miss analyses and drill performances (Tac et al., 2018).

The evaluation of emergency, disaster and crisis management exercises supports both individual and organizational learning, enables the enhancement of response capabilities, and assists to determine the current level of preparedness (Beerens and Tehler, 2016). Wu et al. (2014) highlighted that; as an important part of ship management, effectiveness evaluation of drills should be carried on board to determine current level of emergency preparedness. According to O'Brien (2003), companies with well thought-out emergency preparedness that hold regular training drills are better equipped to handle large-scale emergencies than those that are not prepared.

1.1 Objectives

It is one of the significant dilemmas in maritime transportation industry to enhance utility of ship safety implementations. The various reports published by International Maritime Organization (IMO) have pointed that; although there has been sufficient number of rules; there are implementation deficiencies in operation level. Specifically, the recent maritime cases have addressed the loss of life and property occurred due to weakness at emergency situations (abandon ship, fire, collision, grounding, and other critical situations) at international waters. Therefore, academic and industrial organizations have focused on improving ship safety management at emergency situations. Considering the literature and industrial gaps & expectations; the primary aim of the thesis is to evaluate operational drill for analysing ship emergency preparedness level by conducting theoretical research. To achieve this purpose, Fuzzy Dematel method integrated with Arena software has been proposed.

The objectives of this paper are defined as follows:

- To simulate operational fire fighting drill in order to achieve emergency response time
- To determine generic factors which influences emergency situation directly
- To show emergency situations on board and their affected factors can be easily simulated in Arena software
- To examine the effectiveness of the current system by obtaining and analysing the related data obtained from the simulation
- To establish a marine-specific methodology to evaluate emergency preparedness level

This study enables ship owners/managers to evaluate their fleet vessel status and to improve their performance in fire drills by remedying the deficiencies and reducing the risk factors to minimum in defined factors. Also, the study contributes in several ways to the current literature and provide a basis to examine the effectiveness of the current system.

1.2 Scope, Limitations and Assumptions

The most frequently encountered emergency situations on board are fire, collision, explosion, flooding, grounding, etc. While this study contributes to specifying current level of preparedness for various emergency situations, the scope of the study is limited with fire.

One source of weakness in this study which may affect the measurement of emergency preparedness level in case of fire is that, all drills are performed in morning and noon times. After working hours especially at nights all ship crew is on rest except watch keepers and personnel on duty. Due to decreased alertness, emergency response time may increase.

An issue that is not touched in this study is unplanned drills. All drills are performed in planned time and all crew informed regarding drill and its scenario before implementation. Unannounced drills may reflect more realistic results in case of emergencies.

The last limitation of the study is that, only Turkish seafarers participated in drills. Further research should be carried out with multi national crew.

Despite its limitations, the study certainly adds to our understanding of how emergency situations on board and their affected factors can be easily simulated.

This study has been carried out on the assumption of that; all experts evaluated the generic factors properly and drills are performed by seafarers according to rules and regulations.

1.3 Thesis Organization

At the first glance, this section provides a short introduction about the emergency preparedness on board ships. Motivating factor behind the needs of this study is given in first section. Moreover, the scope, limitations and assumptions of the study is settled. Section 2 provides detailed literature review and technical knowledge of emergency preparedness on maritime domain. Section 3 introduces methodologies utilized in the paper. Model development of a case study regarding the firefighting drill on-board ship is illustrated in Section 4 and the final section gives conclusive comments, contributions of the thesis, and further proposals. The conceptual skeleton of the study is given in figure 1.1.

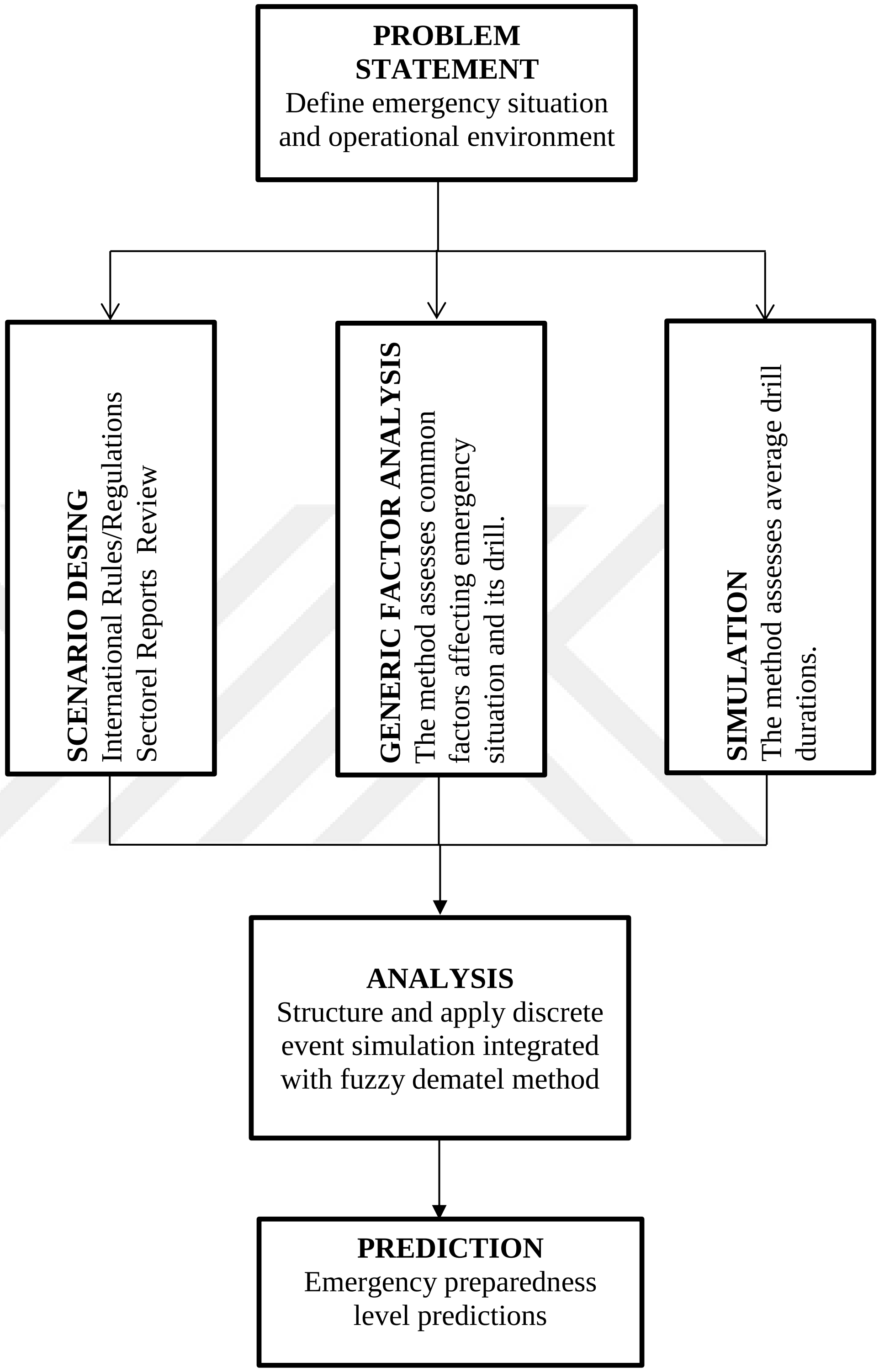

Figure 1.1 : Conceptual skeleton of the study.

2. LITERATURE REVIEW AND INDUSTRIAL FEEDBACKS

The differences of the terms “emergency management” and “disaster management” had caused many debates so far. Some authors define emergency management that is applied to events which needs no external assistance and may be managed by the own resources. However, disaster management may not be managed by local resources and needs external assistance. Another opinion of the differences of terms is while emergency management is associated with a specific geographical area such as city; disaster management effects larger geographic areas. In the contrast, some authors think that terms refer to same meaning but while emergency management is being used in United States, the term disaster management is being used in Asia.

According to Quarantelli (2005), these are emergencies, disasters, and catastrophes. According to author, emergencies are predictable but unforeseen events in which narrow scope incidents may occur. In 2000, author defined disaster as sudden onset occasions which critically clutter up social routines and they are rarer than emergencies with many human causalities, serious property damages and severe social disruptions. A catastrophe has larger impact which affects multiple communities with highest damage and social disruption. The term emergency described by Johnson (2000) as a diversion form aforethought and scheduled action which affects enviroment, people and propery adversely. According to Johnson (2000), the scope of emergency characterizes the disasters and disasters are mostly result in severe damages. Disaster occurs when capability of the own and local resources is not enough to manage emergencies.

In broad terms, emergency management can be identified as a range of activites to keep emergency situation in contol and to constitute a skeleton to protect people in order to avoid and recover the impacts of emergency situation (Souza & Kushchu, 2005). Also, another definition of the term is given by Eraslan et al. (2004) as coordination of organisations to lower and prevent the effect of emergency situation by using all available sources.

McEntire (2007) states the purpose of emergency management as to prevent injury and save lives, to protect environment and property enchancing the competencies of the organisations and third parties involved in Emergency Management. According to Eralp 2016, emergency management tries to deal with emergencies from the smallest incidents to largest ones by decreasing vulnerability to hazards.

Considering the fire on board vessels and its consequences and in the light of above opinions discussed by the several authors, the term “emergency management” will be used during dissertation.

Traditionally, an emergency management is assumed as comprising four phases (Leduc et al. 2009; Mushkatel and Weschler, 1985; Waugh and Streib, 2006; Fogli et al. 2017; Eralp, 2016):

- Mitigation
- Preparedness
- Response
- Recovery

The preparedness phase of emergency management comprises an integrated assembly of exercises, planning, training, personnel competencies and qualification, acquisition of equipment’s etc. in order to cope with an emergency situation (FEMA, 2010) which also consists of assessment of preventive and corrective actions to make certain of coordination during emergency response (Arora and Arora,2013). The mitigation phase of emergency management aims to prevent potential future emergency situations and decrease their effect to minimum which needs to be considered before emergency occurred (FEMA, 2010). The response phase of emergency consists of necessary behaviours to respond safely to an emergency such as saving lives and preventing more equipment/property damages (FEMA, 2010). According to Eralp (2016), the success in response phase depends on preparedness phase. The recovery phase of emergency management which happens after an emergency aims to return to normal and safer situation in which also future actions should be considered to mitigate the next emergency situations unwanted affects (FEMA, 2010). According to Annelli (2006), effective emergency management begins with well-established preparedness activities based on a ‘steady-state’ basis ahead of any possible emergency situation.

2.1 Emergency Preparedness Studies in Other Disciplines

Publications that concentrate on emergency management more frequently focuses on mitigation phases by 44%. It is followed by response phase by 23.9%. In research productivity, preparedness and recovery phases have the almost lowest ratio in whole studies respectively 21.1% and 11.0% (Altay and Green, 2006). Most of the preparedness studies focus on health, nuclear disasters, flood, hurricanes and earthquake and latest studies regarding these chapters are given in the table 2.1.

While evaluation tools, survey and questionnaire design, interviews and exercise evaluations are mostly used techniques on health related studies; optimizing, location capabilities of the distribution and rescue centers and factor determination are mostly used techniques in other studies.

Table 2.1 : Studies on emergency preparedness in other disciplines.

Study Area	Articles
Health	Shabanikiya et al. (2019); Rizqillah and Suna (2018); Samsuddin et al. (2018); Skryabina et al. (2017); Lapčević et al. (2018); Baduge et al. (2017); Valdmanis et al.(2010); Martono et al. (2018); Rajiah et al. (2016); Liu et al. (2018); Hui et al. (2007); Whetzel et al. (2013); Rebmann et al. (2009); Adini et al. (2009); Lee et al.(2018); Sangkala and Gerdtz (2018); Osman (2016); Manley et al. (2006).
Earthquake	Battara et al. (2018); Kirschenbaum et al. (2017); Shapira et al. (2017); Becker et al. (2017); Paul and Wang (2019); Zang et al. (2018); Manandhar (2016); Wu et al. (2013); Sharma (2015).
Flood	Arrighi et al. (2019); Rattanakanlaya et al. (2018); Coates et al. (2019); Mabuku et al. (2018); Rattanakanlaya et al. (2016); Fox-Rogers et al. (2016); Kerstholt et al. (2017); Rodríguez-Espíndola et al. (2018); Tantanee et al. (2018); Altarawneh et al. (2018); Deen (2015); Ejeta et al. (2016); Miceli et al. (2008); Cools et al. (2016).
Nuclear and Explosion	Andersson et al. (2018); Park et al. (2017); CastroSilva and Medeiros (2015); Baklanov et al. (2006); Schwartz (2004); Lu et al. (2010); Ritzman (2013); Scalzo et al. (2008); Ishigami et al. (2004); Kostadinov (2011); Mavhura (2019); Hamalainen et al. (2000).
Hurricane	Baker (2011); Rincon et al. (2001); Howe (2011); Hernández et al. (2018); Cahyanto et al. (2016).

2.2 Emergency Preparedness in Maritime Domain

During dissertation study, systematic literature review have been conducted for the analyses of the studies on emergency preparedness in maritime domain. Since all the information about the researches regarding specific subject are involved in literature reviews, they are very useful and facilitator for the researchers. Therefore, a good few of literature review studies have been carried out in recent times in different sciences such as physical sciences, economics and others (Sponos and Angelis, 2016). In maritime domain, examples include the field of emergency logistics, supply chain performance measurement (Akyuz and Erkan, 2009), freight transportation planning (SteadieSeifi et al. 2014), stress and strain in seafaring (Olderburg et al. 2013), container terminal operations (Stennken et al. 2004) and many others.

During our research, we have followed systematic literature review which stated in Kitchenham (2004) and Kitchenham and Charters (2007). According to Kitchenham and Charters (2007); systematic literature review consist of three stages: The Planning Stage, the Conducting Stage and the Reporting Stage whose steps are shown in Figure 2.1.

1) Planning the Review

- Identification of the need for a review
- Specifying the research question(s)
- Developing a review protocol

2) Conducting the Review

- Identification of Studies
- Selection of Studies
- Data extraction
- Data synthesis

3) Reporting the Review

- Specifying dissemination mechanisms
- Formatting the main report

Search methods includes extensive automated searches in digital libraries, conference proceedings, manual searches in specific journals, backward or forward snowball techniques or combination of the mentioned methods (Sponos and Angelis,2006). According to authors, first step of the research starts with selecting search strategy. Its importance is also highligthed in Kitchenham and Charters's (2007) guidelines. Online database can be used for the initial searches however the nature of different interface for different database prevents a standardized search. Snowball technique may be used to prevent missing studies (Wohlin and Prikladnicki, 2013). For the studies which could not found in the first method, the backward snowball technique may be used since it is review of references of papers found in first method. During dissertation, we have used a combination of the extensive automated search and the backward snowball technique. We have looked at the references from each selected paper (backward snowballing). In addition, we also have looked on the Google Scholar to find out who have cited their papers (forward snowballing) and listed out the titles that look relevant to our study. Selected papers from both citation-based searches (backward and forward snowballing) were analyzed and any duplicate studies were removed.

Our research questions of the systematic literature review in emergency preparedness studies in maritime domain are listed below:

- How many research studies exist, having as subject the emergency/disaster preparedness on maritime domain?
- What types of emergency/disaster preparedness events on maritime domain are analyzed in the existing literature?
- What are the results and significance of the studies?

In this regard, we have considered the set of papers which were published before 30 March of 2019 and perform at least one study that analyzes the emergency preparedness on maritime domain, using the event study methodology as inclusion criterion. Exclusion criterion used for studies those are related to the emergency preparedness studies in other disciplines, recurrent studies in maritime domain.

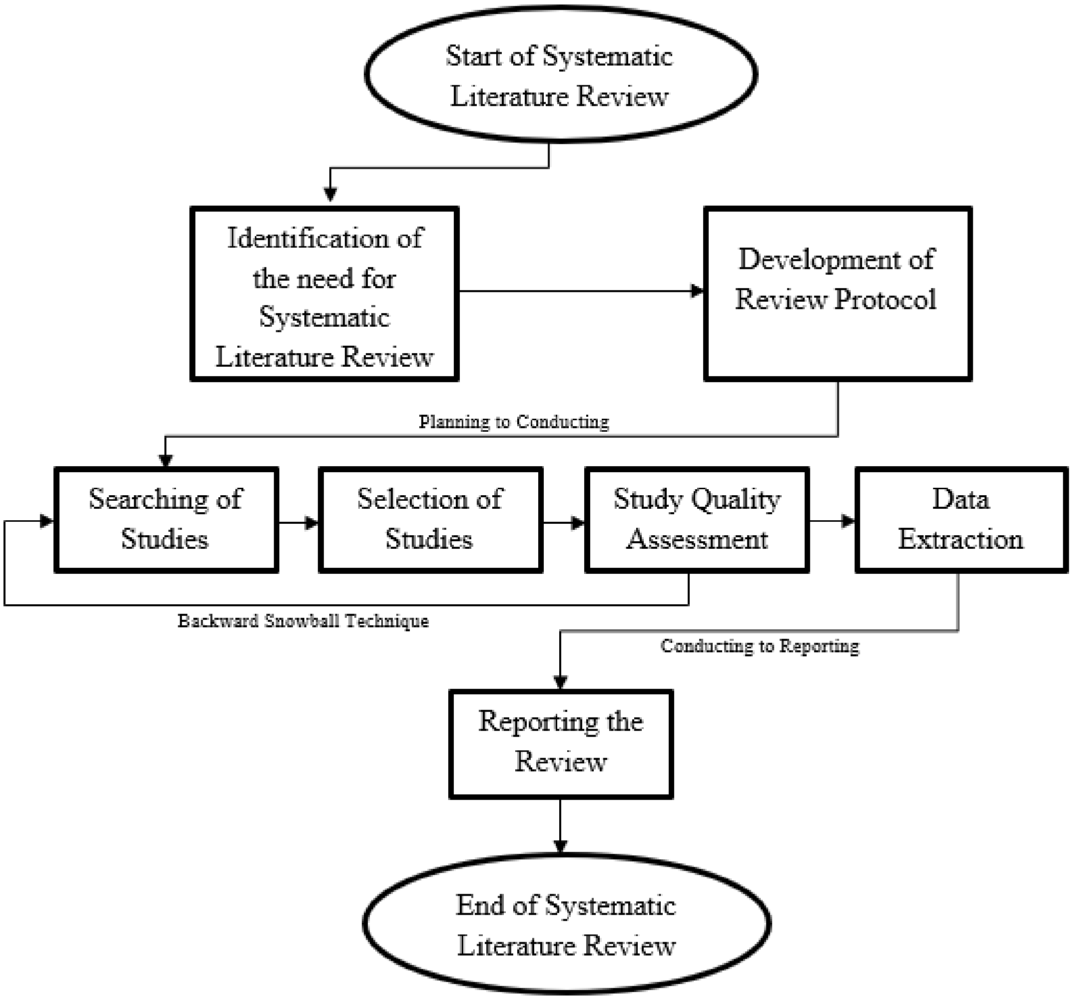

Figure 2.1 : The systematic literature review procedure steps (Spanos and Angelis, 2016).

We have determined different search terms which enables to reach papers belong to research field. The procedure of determining search terms conclude when the initial set of papers by a majority is found by the search. The search string that was used in the present literature review is shown in Figure 2.1. All the papers are selected as per title, abstract and keywords for avoiding massive number of irrelevant papers as search results.

In our thesis study; accessibility and the specification of the data, the specification of the used methodologies and the representment of the results have been chosen as criteria for an article to be included into the study. All the predefined steps of the systematic literature review are executed after the development of the review protocol.

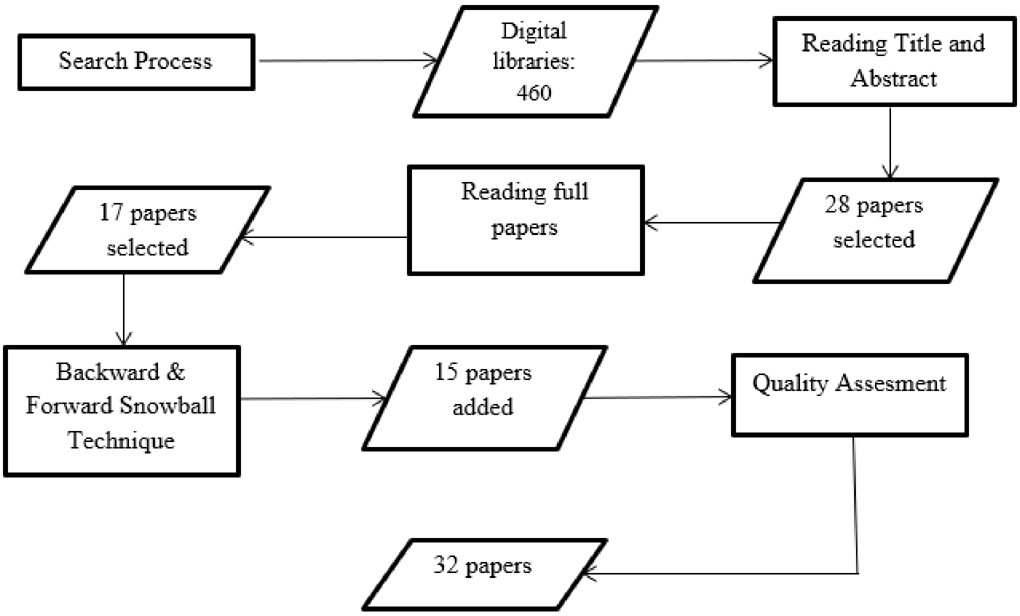

Figure 2.2 : The steps to find the number of inserted papers.

Research conducted with below search time using and/or interventions:

"“Emergency management” or ”disaster management” and “maritime””; "“Emergency management” or ”disaster management” and “marine””; "“Emergency management” or ”disaster management” and “port””; "“Emergency management” or ”disaster management” and “sea””; "“Emergency management” or ”disaster management” and “offshore””; "“Emergency management” or ”disaster management” and “ship””; "“Emergency management” or ”disaster management” and “ferry””; "“Emergency management” or ”disaster management” and “supply chain””; "“Emergency management” or ”disaster management” and “sea transportation””; "“Emergency management” or ”disaster management” and “accident””; "“Emergency management” or ”disaster management” and “incident””;

With the selected keywords, 841 papers have been found and it is filtered to 460 when the repetitive articles on different databases were removed.

In Figure 2.2, the steps leading to the final number of the selected papers of the present review for maritime emergency preparedness are depicted. Specifically, after the initial search process, 460 papers were found. After the reading of titles and abstracts of the candidate papers, aiming to find irrelevant papers or duplicates, most of the papers were removed and the number of remaining papers became 28. Next, after the reading of full papers, 11 more papers were removed as irrelevant based on the inclusion/exclusion criteria. Hence, the final number of selected papers resulting from the broad automated search was 17. The backward snowball technique was subsequently applied and from the reading of the references, 8 more papers were added. Thus, the number of the papers after the entire study selection process was 25. With the forward snowballing method, 7 more papers were added. Finally, these 32 papers cover either partially or completely the four quality assessment criteria described above and therefore, the concluding number of selected papers for our literature review for emergency preparedness in maritime domain is 32.

2.2.1 Supply chain related studies

Paramount fractures like the piracy attacks off shore Somalia, Hurricane Katrina, global financial crisis, flooding's and tsunami indicated a lack of preparedness of supply chain actors. The industry of supply chain has got to know from the fractures and need to reach increased level to improve preparedness (World Economic Forum, 2011). Stopford (2007) stated that since the port/maritime logistics industry is very complex; their structure is very difficult to evaluate since their functions are incomprehensible and their behaviors are unpredictable. According to authors, there are lots of risk management models for decision making in ports/maritime industry however they are not perceptible to the user. Increasing needs to improve safety; both quantitative-qualitative safety analysis techniques have been used by industry actors. Transportation infrastructures such as ports and harbors are imposed upon variable natural hazards such as earthquakes, landslides and tsunamis (Pitilakis et al. 2016). According to authors, improvement of emergency preparedness, strengthening of present structures and enchancement of the recovery planning are very important in terms of safety of life, business disruption, etc. Markmann et al. (2013) performed a Delphi-based risk analysis in order to identify and estimate man made risks for the semipermanent future of supply chain security. They applied the method for determining a concrete assesment of the Delphi technique's adaptedness for emergency preparedness. Heckman et al. (2015) pointed out that time aspects should be considered when appertaining to the preparedness of the supply chain activities. Kwesi-Buor et al. (2016) used a hybrid modeling technique (the SD model) in order to investigate effects of the policy change on managers preparedness to decrease risks on supply chain network. According to authors; industry actors' level of "DP", "Attitude to risk prevention", "Technology change" and "Maritime activities" are significantly sensitive to ‘Forecast accuracy’and ‘Extent of damage’, but not very dependent on increases in ‘Resource availability’. Asgari et al. (2015) provided a general framework, a number of criteria & sub-criteria to study port sustainability performance considering five major ports in the Uniyed Kingdom via Analytical hierarchy process and Multi Criteria Decision Making methods. Sustainability dimensions were chosen as environmental, economic and social dimensions. Emergency preparedness and emergency response were the criterias of the seven criteria assigned to the environmental dimensions. According to Wood et al. (2002), catastrophic earthquakes and tsunamis are expected in the future at the Pacific Northwest that poses a crucial threat to harbors and ports in the coastside. Authors highlighted that vulnerability of harbors and ports against tsunami and earthquake hazards need to be decreased. According to Hale and Moberg (2005), supply chain confusion caused by external man made or natural events such as earthquakes or terrorism can have crucial financial and operational impacts on affected parties. Therefore, enchancing emergency preparedness in supply chain is very important. Especially warehousing of emergency and vital documents should given utmost attention. Therefore, authors proposed a decision continuum for constructing smooth system of secure warehousing facilities.

2.2.2 Offshore related studies

Offshore industry should improve risk management to reduce the risk of hazardous material releases during future hurricanes. Against severe storms in the future, the offshore industry will need to work on improved loss-prevention mechanisms, and disaster preparedness planning through post-storm response and recovery (Cruz and Krausmann, 2009). Bracher and Hvattum (2016) proposed a mathematical model for personnel transfer among offshore facilities and onshore bases which is usually carried out by helicopters. They aim to answer unsolved emergency preparedness system in the High North region due to long distance and adverse environmental conditions. Brachner and Hvattum (2017) proposed a mathematical combined routing and covering problem (CRCP) to plan the offshore personnel transportation system and the offshore preparedness system in Arctic region. Vinnem (2011) performed a comprehensive assessment of adequacy of emergency preparedness activites recently performed on offshore installations. Authors recommend that;

emergency preparedness level should not be decreased but superiority should be given on preventive measures.

2.2.3 Oil pollution related studies

The oil spills through oil tankers have interested especially coastal countries and forced them to have taken a series of precautions to prevent and handle such pollutions (Lin, 2013; Santos et al. 2013). The IMO has issued an array of rules such as the MARPOL73/78, and the OPRC 1990. Parallel to the increasing petroleum activities, there is an augmenting attention about the effectiveness of the systems for emergency preparedness in case of oil spill (The Pew Charitable Trusts Arctic Standards, 2013). While the Arctic Council has developed pioneers for offshore gas and oil activities in the Arctic that includes how to manage emergencies successfully, the growing accessibility puts emergency preparedness in focus. Knol and Arbo (2014), focused on the characteristics and the challenges ahead of oil spill emergency preparedness networks in the Arctic. Although new partnerships and networks are formed in the north, and technology is under continuous development, there are many challenges for a well-functioning emergency preparedness network in the north. Huntinghon et al. (2015) evaluated vessel traffic in the Bering Strait. Authors thought that; as well as vessel traffic increases, it poses several risks in the Bering Strait and they evaluated which regulatory and other measures can help reduce the risks. Salvage, oil spill prevention and preparedness are one of the risks identified by authors in their paper. According to authors, there is only one Alaska-based U.S. Coast Guard classified OSRO for the Bering Sea, and it does not meet the current time frame or equipment requirements, leaving a significant gap in emergency preparedness. In 2010, two catastrophic oil spills in history of the world occurred: the “Deepwater Horizon” incident at Mexico Gulf, USA and “Dalian 7.16” in China which inspired public concerns regarding oil spill on marine and questions on the current preparedness competence to combating oil spill at sea (Zhang et al. 2015). Liao et al. (2012) proposed integration of methodologies including Case-Based Reasoning, Artificial neural Network and Genetic Algorithm for determining emergency preparedness for oil spill accidents by analysing 32 oil spill incidents. Afenyo et al. (2017) presented a model which can assess the ecological risk threaten to the Artic marine ecosystem in case of accidental oil release. According to Liu et al. (2012), one of the major contributing factor to oil spill in Chinese Bohai Sea is ship related accidents. Aiming to provide guidelines in order to prevent local oil spill, authors developed a three-dimensional oil transformation and transport model. Ivanova (2011) states that regional response system to oil spill at Murmansk in Russian Artic has not been fully developed due to the shortfall funding that reduce their preparedness level to handle spill of oil. Castanedo et al. (2016), developed forecasting system to help against 2002 Prestige oil spill in Cantabria by providing forecast wind currents & tidal currents and wave climate aiming to provide technical assessment.

2.2.4 Accident investigation and policy related studies

Mileski et al. (2014) investigated cruise vessel mishaps, failures via two stage measurement design draws on the ability for analyzing two questions of what happened, and what was the cause. They believed that knowing the factors that contribute to cruise vessel failures may provide a base of preparedness which enables to prevent future disasters in the cruise vessels. Marchenko et al. (2018), investigated accident risks in Atlantic Artic by analyzing experienced ship accidents and maritime activity changes. However due to accident numbers are very small to investigate in detail, authors offered a qualitative analysis and an expert based risk assessment and lastly, they discussed the implication of the study for the emergency preparedness system. According to Alyami et al. (2016), it is possible to reduce and eliminate the effects of accidents and/or disasters in terminal operations by effective risk forecasting mechanism. Authors proposed a method to allow for the application of Failure Mode and Effects Analysis to assess the safety performance of a Container Terminal Operational System by including a Fuzzy Rule-Based Bayesian Network along with Evidential Reasoning which enables to measure and predict system safety performance.

According to Haapasaari et al. (2015) regional policy making may develop particularly sensitive sea area type regulatory safety measures and proposed a governance framework for the GoF (Gulf of Finland).

2.2.5 Others

Cwilewicz and Tomczek (2004) mentioned that CBT (Computer Based Training) simulation possibilities play crucial role on auxiliary machinery interactive programs, where perfect knowledge of various operational modes are needed in order to achieve desired level of emergency preparedness. A high level of emergency preparedness can only be obtained by repeating such emergency procedures many times until the trainee shows proper operational behavior according to authors.

Lu and Yang (2011) assessed safety behaviour and climate in the passenger vessel. According to their studies results, emergency preparedness and safety training influence self-reported safety behaviors in positive with respect to safety participation and safety compliance in positive.

Akbar et al. (2013), presented multi-scale integrated simulation for emergency preparedness in case of hurricane, infrastructure assessment, flood forecasting and emergency planning. Authors proposed emergency management tool to be used for helping decision makers in preparation of hurricane disasters in Gulf of Mexico.

Pristrom et al. (2016) investigated various maritime piracy and robbery issues and then presented a novel model in order to predict the likelihood of a piracy attack by analysing the vessels characteristics, environment situations and the maritime security measures via Bayesian Network (BN) approach.

2.2.6 Summary of the systematic literature review

In the light of above literature review conducted till 30 March 2019 for emergency preparedness in maritime domain, following significant points are revealed;

- There are limited studies undertaken through emergency preparedness in maritime domain.
- Most of the studies regarding emergency preparedness in maritime industry has investigated oil spill and prevention, supply chain, personnel transfer from offshore facilities and hazard identification.
- Current emergency preparedness evaluation methods do not provide a consistent approach and impractical to implement on board ships.
- It would be substantial advantage in establishing a marine-specific methodology to evaluate emergency preparedness on board ships.

With the proposed approach in the dissertation, it is aimed to fill the gap in literature.

2.3 Technical Knowledge Support to Thesis

The various reports published by International Maritime Organization (IMO) have pointed that; although there has been sufficient number of rules; there are implementation deficiencies in operation level. Specifically, the recent maritime cases have addressed the loss of life and property occurred due to weakness at emergency situations (abandon ship, fire, collision, grounding, and other critical situations) at international waters.

The ISM Code presentes proactive safety management pursuant to emergency preparedness. Shipboard emergency preparedness will be evaluated under the paragraphs 8 of the (International Safety Management) ISM Code. According to paragraph;

- The company should identify potential emergency shipboard situations, and establish procedures to respond to them,
- The company should establish programmes for drills and exercises to prepare for emergency actions
- The SMS should provide for measures ensuring that the Company's organization can respond at any time to hazards, accidents and emergency situations involving its ships.

The ISM Code requires that emergency preparedness should be established based on the estimation of risks, identification of hazards, and introduction of safety measures.

According to Kristiansen (2013), the main critism of SOLAS has focused on the following aspects regarding emergency and life-saving regulations; while too much interest regarding technical details of life saving appliance system, very little focus on overall performance of them and their testing conditions especially in calm weather are unrealistic. As an answer to these situations, IMO has presented regulations that address simulation trainings in the evaluation of life-saving effectiveness.

Chapter VI of the STCW Code clearly expresses “standards regarding emergency, occupational safety, medical care and survival functions” for crewmembers (IMO, 2002a). Familiarization training, minimum and basic trainings for crewmembers for their duties and crew competence requirements are key elements in emergency preparedness.

Emergency Preparedness and Contingency Planning is also 11th element of TMSA (Tanker Management Self Assessment) among 13 elements which aims to prepare for and regularly test the ability of the company to respond to and effectively manage incidents.

3. RESEARCH METHODOLOGY

This chapter focuses on improving a scientific research background to enable measuring ship emergency preparedness level on board ships. To achieve this purpose, Fuzzy Dematel method integrated with Discrete Event Simulation in Arena software has been proposed. While theoretical background of both methodologies given in this chapter, integration and the implementation of the proposed methods are provided in Chapter 4.

3.1 Simulation Technique

Several definitions of simulation have been proposed. While Cantot and Luzeaux (2013), defined the term simulation as "*a broad collection of methods and applications to initate the action of real systems, usually on a computer with appropriate software*"; Chung (2003) defined simulation as "*process of creating and experimenting with a computerized mathematical model of a physical system*". According to Bank et al. (2004); simulation is "*the imitation of a real system in a virtual world without making any changes in the real-world system.*"

Simulators are the modelling of existing or proposed systems which is either actual or planned (Chung, 2003). Simulation's popularities main reason is its ability to cope with complex models of correspondingly complicated systems. This makes it a versatile and powerful tool. The primary goal of the simulation modelling and analysis is to understand how the system works. Other general purposes of simulation modelling and analysis can be listed as follows (Pedgen et al., 1995):

- To find out the how the system operates
- To enchance policies to increase system performance
- To test systems or proposed actions before implementation
- To gain information without deforming the real system

Simulation has become an essential tool in many systems since World War II and it has been applied to predict performances, to respond "what if" questions and to train the trainees in use of new systems and equipment's such as predicting productivity measures in inventory systems, evaluating maritime port operations, materials handling, logistic operations, etc. (Altıok and Melamed, 2010).

According to Cantot and Luzeaux (2013), sometimes it is possible to experiment with the actual system which has an advantage for model constructer that do not need to worry if a model for the system reflects its purposes. However, sometimes it is impossible to experiment with the real system. In these circumstances, a model should be built by underlying the questions of what would happen in the system if you did planned actions or develop policy, etc. The advantages of second situation is to prevent somebody get hurt, to lost money, and/or to give wrong decisions before implementation. In this dissertation, both possibilities mentioned by Cantot and Luzeaux (2013) have been applied in the name of ideal conditions and worst-case scenario which detailed in Chapter 4.

Types of simulation may be divided into three main dimensions which are given in the following (Kelton, 2002):

1. Static versus Dynamic: While time is very important in dynamic simulations, it is not important in static models. While static models are mostly used in statistical outcome by generating random samples, models develop in time in dynamic models (Yılmaz, 2018).
2. Continuous versus Discrete: While the system state may change continuously by the time of progress in continuous models, variables of the state change only at a determined number of points in discrete models. In this dissertation our focus will be on discrete models.
3. Deterministic versus Stochastic: Initial conditions are identified, and the result is achieved by equation solving in deterministic systems (Runciman, 1997). In stochastic models, minimum one input contains random variables (Yılmaz, 2018). While initial conditions and parameter values may fully determine output of the model in deterministic models, same will lead to ensemble of different outputs in stochastic models.

3.1.1 General information about discrete event simulation

(DES) Discrete Event Simulation enables to model the system operation like a discrete seqeuence of the events in a timely manner and simulation may directly leap from one to other event since no change occurs between consecutive events (Sharma, 2015). In the beginning, general-purpose programming languages Forthan, Phyton, C, Basic, Pascal, Java were used however parallel to the increasing computer technologies, languages of simulation like, GPSS, GPSS/H, SIMSCRIPT, SIMAN, and SLAM were developed to create simulation models more easily. After then, several software packages (simulators), which have more visual and easy interfaces to use, have been developed (Yılmaz, 2018). Arena Simulation Software is among the most used software package through discrete event simulators. Also in this dissertation, Arena ® simulation software is used whose details are given in Chapter 4. Basic terminologies and concepts in Discrete Event Simulation are given in the following in order to comprehend the simulation technique (Yılmaz, 2018).

"System is the collection of entities, machines that interact with each other in logic."

"System state is the condition of the system and it is described by information from collection of variables."

"Entity is an observed component of the system. Entity can be a permanent component that remains in the system like cycling systems or it can be a temporary component that flows through the system, and then leaves the system."

"Resource is a part of the system that entities utilize."

"Attribute is a type of data that the entity stores. Attributes are not global. They are only entity-related properties."

"Variable is a type of data that describes the system. Variables can also be defined as "global variables". Any entity in the system can change property of the variables and as a result property of the system."

"Event is the incident that changes the system state such as, entering of an entity to the system."

"Activity is the time duration of events with a specified length such as, service time of a resource. Activity can be defined by either statistical distributions or a constant value."

3.1.2 Advantages & disadvantages of simulation modeling

The simulation modeling contains many benefits comparing with statistical analysis and other mathematical programming techniques. The advantages of the simulation modeling can be listed as follows (Chung, 2003; Sharma, 2015):

- Testing in restricted time
- Less analytic requirements
- Demonstrated models with ease
- Flexibility
- Modification to configure the environmental variations of real situations.
- Ability to foresee difficulties and restrictions before real system implementation such as new equipment supply, etc which eliminates unnecessary investments.

In addition to advantages of simulation modelling, also it has some disadvantages. Some disadvantages can be listed as follows (Chung, 2003):

- When input data is wrong, simulation cannot give right results
- It may take time to answer complex problems
- It provides a way to obtain a solution; it does not provide solution technique. The modeler need to develop the solution.
- All situations cannot be addresses by simulations.

In addition to advantages and disadvantages of the simulation, according to Yılmaz (2018), impressive use of simulation is very essential, and it should not be used if below items exists in systems:

- For the problems which may be solved easily by analytical solution
- If real system is more appropriate than virtual world for changes and experiment
- If profit is lower than simulation cost
- If there are unadequate sources
- If validation and verification of the model is impossible

3.1.3 Simulation model in Arena

Arena was developed by C. Dennis Pegden who is institutor of System Modeling Association and introduced at the Winter Simulation Conference in 1992 which is part of Rockwell Software (Pegden and Davis, 1992).

Arena provides capability to the user in order to model easily and rapidly with a tool and so user may combine constructs up to several application-focused templates by SIMAN modeling language. Since it is fill in the blanks style, drag and drop and object-oriented system, it does not require programming and enables user with a tool that pairs closely with the real system. So, the user who know their system very well but not technically oriented can use Arena as well (Hammann and Markovitch, 1995). Authors also thought that, simulation will be used as a decision support and planning instrument by means of increasing number of user.

Arena simulation software has been applied by several researches in maritime disciplines. Almaz and Altiok (2012), studied simulation modeling of the vessel traffic in Delaware River in order to investigate effects of deepening on port performance measures. Lin et al. (2014) focused on port investment planning problem and aimed to minimize the investment cost under a required service level via Arena Software. Cortés et al. (2007) simulated freight transport in Seville inland port of which process begins with the movement through the whole estuary of the river and finishes with the vessels arriving to the port dependencies. Iannone et al. (2016) aimed to assess the impact of managers' decisions on planning and operational efficiency with a particular focus on vehicle handling in a Ro/Ro Terminal. They developed a model in Arena Rockwell by describing terminal operations, operation decisions and costs involved. Rahimikelarijani et al. (2018) focused on simulation and analysis of the Houston Ship Channel vessel traffic and operation, through a discrete event model in Arena in order to mitigate the consequences of the channel closure for constructing a new bridge over the water-way. Table 3.1 shows the recent studies gathered from literature research for Arena in all industries.

Table 3.1 : Studies on Arena software.

Author(s)	Year	Industry/Area	Aim	Combined Methods
Wang et al.	2013	Health	To reveal the physician behaviours in emergency department	-
Eskandari et al.	2011	Health	To analyse improving scenarios for reducing waiting times of patients	AHP TOPSIS
Medeiros et al.	2008	Health	To model patient flow of an emergency department	-
Teilans et al.	2008	Management	To assess UML models using ARENA	UML modelling
Nagarajan et al.	2002	Network Systems	To simulate SNMPv3 traffic flow meter MIB using ARENA	-
Cartenì, and De Luca	2009	Port Industry	To evaluate the impacts of different approaches on estimating terminal performance	DES models
Snowdon et al.	2000	Aviation	To develop a model for airlines to use advanced technology	-
Yang et al.	2015	Railway	To analyse the level of service in railway station	-
Li et al.	2018	Management	To evaluate performance in production lines	-
Yuniawan et al.	2018	Land Transportation	To develop a model for solution of the traffic queue problem	-

Arena is a high-powered simulation tool with a visual front-end which compose of object templates (modules) and transactions that go through entities. Modules are internally built of SIMAN blocks and/or elements and template panel is used in order to select Arena modules (Altıok and Melamed, 2010). Home screen of Arena is given in the figure 3.1.

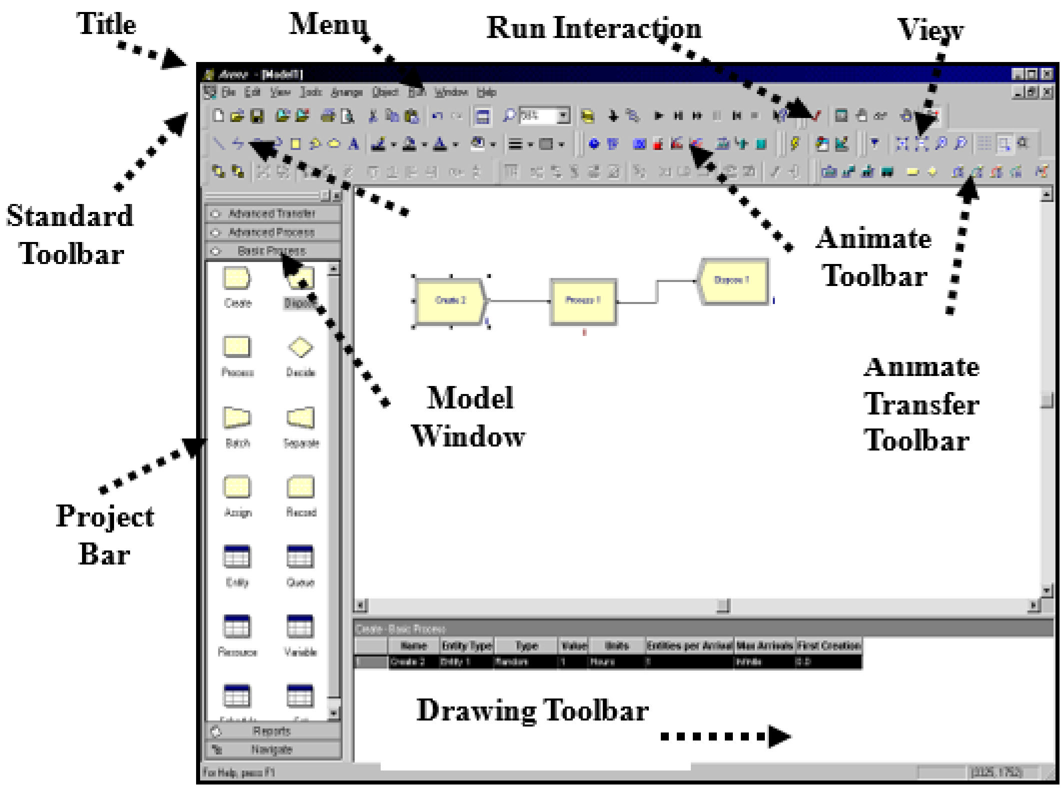

Figure 3.1 : Home screen of Arena (Altıok and Melamed, 2010).

Arena modules can be classified into flowchart and data which specify any continuum to be simulated. Flowchart modules describe the simulation process and located in the model window. First eight shape of the flowcharts modules are given in the Table 3.2 (Rockwell Automation, 2012).

Table 3.2 : The Arena flowchart modules.

Module	**Aim of the Module**
Create	*"The beginning of process flow where entities go into simulation. Entities are constituted using a schedule or based on a time between arrivals. Name, entity type, expression, units, entities per arrival, max arrival and first creations are the fields in dialog box of create modules"* *Following options are offered in Time Between Arrivals:* - *Random (exponential inter-arrival times with mean given in the Value field)* - *Schedule (allows the user to create arrival schedules using the Schedule module from the Basic Process template panel* - *Constant (specifies fixed inter arrival times)* - *Expression (any type of inter-arrival time pattern specified by an Arena expression, including Arena distributions)*

Table 3.2 (continued) : The Arena Flowchart Modules.

Module	Aim of the Module
Dispose	*"The expiration of process flow where entities are got out from the simulation".*
Process	*"An activity, usually carried out by one or more resources and needs some time to complete. Fields on the dialog box of process module are: name, type, action, priority, resources, delay type, units, allocation and expression."* *The Action field option is Seize Delay Release, which add up to a sequence of SEIZE, DELAY and RELEASE SIMAN blocks* - *SEIZE and RELEASE blocks are used to model contention for a resource possessing a capacity when resource capacity is exhausted, the entities contending for the resource must wait until the resource is released thus, the SEIZE block operates like a gate between entities and a resource the processing time of a resource by an entity is specified via a DELAY block within the Process module.*
Decide	*"A branch in process flow where just one branch can be retrieved."*
Batch	*"Gather a number of entities before they can go on processing."*
Separate	*"Duplicate entities for concurrent or parallel process, or separate a previously constrcted batch of entities."*
Assign	*"Change the value of some parameter (during the simulation), something like the entity's type or a model variable."*
Record	*"Gather a statistic, like an entity count or cycle time."*

In this dissertation, in order to simulate the drill, all mentioned modules expect batch and separate have been used as flowchart modules.

Data modules specify the characteristics of different process elements such as queues and resources at the model. Main elements of the data modules are given in the Table 3.3 (Rockwell Automation, 2012).

Attribute, entity and variable are the frequently used data modules in this dissertation.

Table 3.3 : The Arena Data Modules.

Module	Aim of the module
Attribute	*"It is used to specify an attribute's datatype, dimension and initial value(s). An attribute is a characteristic of all entities, but with a specific value that may change at each entity. Attributes may be referenced in other modules may be assigned again to a new value with the Assign module, and may be used in any expression."*
Entity	*"It identifies the different entity types and initial picture values of them in a simulation."*
Queue	*"It can be utilized to switch the ranking rule for a determined queue. The default ranking rule for all queues is First In, First Out unless otherwise specified."*
Resource	*"It describes the resources in the simulation system, including resource availability and costing information. Resources can have a constant capacity that does not change over the simulation run or can operate based on a schedule."*
Variable	*"It is used to describe a variable's dimension and initial value(s). Variables may be taken reference in other modules (e.g., the Decide module), may be assigned again a new value with the Assign module, and may be used in any expression."*
Schedule	*"It can be used together with the Resource module to describe an operating schedule for a resource or with the Create module to describe an arrival schedule."*
Set	*"It describes different types of sets, including resource, entity picture, tally, entity type, and counter."*

3.1.3.1 Data collection and distribution fitting

Input data which needed to run simulation involves the analysis, collection and use of data respectively in the simulation model (Ungureanu et al. 2005). Through entire simulation project, when considering time consumption and model reliability, input data management is the foremost task since it takes approxiametly 40% of discrete event simulation projects (Trybula, 1994). This idea has been also supported by Skoogh and Johansson (2011). According to authors, imput data phase is the most consuming time parameter with 42% through project. Remaining percentages consists of problem definition, model verification and validation and analysis of the results.

The input data can be gained by previous records or can be gained in real time. Theoretical distribution diagnosis which presents the input data is one of most important task when analysing input data. However, fitting a considerable amount data to theoretical distributions may be difficult sometimes. Therefore, users put the good use of sort of data fitting software. Arena input analyzer and expert fit are the commonly available programs to carry out this function (Ungureanu et al. 2005).

Chi-square, Kolmogorov Smirnov test, graphic & square error methods are the some of the comparison methods to select best theoretical distribution for the input data. However, in some cases it is impossible to obtain satisfactory fit. In these circumtances user should collect additional data and should try again (Ungureanu et al. 2005). System design of the Arena Input Analyser is given in the figure 3.2.

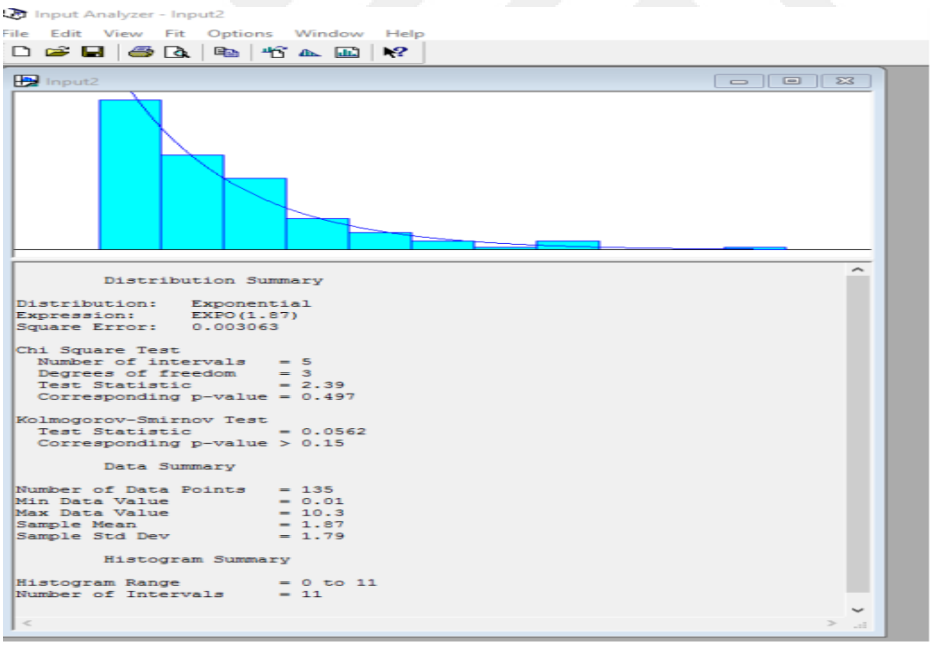

Figure 3.2 : System design of Arena input analyser.

Arena involves a group of built-in functions in order to constitute random variates by the mostly used probability distributions which matches the distributions at the Arena Input Analyzer (Kelton, 2002). Common distributions and their parameter values are given in Table 3.4.

Table 3.4 : Common distributions in Arena.

Distribution			Parameter Values
-Beta	-BETA	-BE	-Beta, Alpha
-Continuous	-CONT	-CP	-CumP$_1$, Val$_1$, CumPn, Valn
-Discrete	-DISC	-DP	-CumP$_1$, Val$_1$, CumPn, Valn
-Erlang	-ERLA	-ER	-ExpoMean, k
-Exponential	-EXPO	-EX	-Mean
-Gamma	-GAMM	-GA	-Beta, Alpha
-Johnson	-JOHN	-JO	-Gamma, Lambda, Delta, Xi
-Lognormal	-LOGN	-RL	- LogStd LogMean
-Normal	-NORM	-RN	- StdDev Mean
-Poisson	-POIS	-PO	-Mean
-Triangular	-TRIA	-TR	-Min, Mode, Max
-Uniform	-UNIF	-UN	-Min, Max
-Weibull	-WEIB	-WE	-Beta, Alpha

3.1.3.2 Number of replications

Simulations may be classified as terminating and non-terminating. While terminating (finite) simulations have a definite end such as generation of random events, non-terminating (steady state) simulations have no defined end event in which determination of steady state behavior of the model is very important (Currie and Cheng,2016). Terminating simulations are easier than non-terminating simulations since it is not needed to determine warm up duration. The simulation will end as per assigned specific rule or condition.

In this dissertation, we have constructed terminating simulation. In terminating simulations, due to the probabilistic variables used in simulation modeling, each simulation experiment will give different results. Therefore, each simulation result can actually be considered as a sample drawn from all possible set of results and the outputs of the simulation process need to be repeated at least for a certain number in order to achieve statistically significant results. To calculate the sufficient number of replications, the below formula (Toledo et al. 2003) is used:

$$Nm=\left(\frac{s(m)\ x\ t_{m-1,1-\frac{\alpha}{2}}}{\bar{x}(m)£}\right) \tag{3.1}$$

where Nm is the replication number, s(m) is the deviation of data standard, test statistic obtained from t-table is the t, m is the number of initial replications that was supposed to be 10, α is the confidence interval as 90%, x(m) is the data mean and £ is the allowable percentage error.

3.1.3.3 Verification & validation of model

Kelton (2012) uses term ‘verification’ to refer to “the continuum of confirming that the model acts in the way it was intended as per the modeling assumptions made”. The author also uses term “validation” as “the task of confirming that the model acts the same as the real system”.

According to Sargent (2015), the paramount factor affecting both verification and validation is observable modelled problem entity and meaningful data to be collected. Authors also highlights the importance that validation and verification of the model should be fulfilled for each use via identification of interest of models’ output variables and specification of their acceptable range since the model may be valid in some experiments and invalid in other experiments.

Sargent (2015) defines three decision making approaches in order to decide validity of the model. Model development team is required to perform verification and validation in all approaches. First one is that, model development team it selves decide whether the model is valid. Their decision based on the results of multiple tests and evaluations. Second approach is the decision of the model by users of simulation. In this approach, users determine satisfaction of validation and verification in every phase of the model. The final approach is the independent verification and validation which decides validation of the model by using third party who are independent from both simulation developers and potential commercial users. In this dissertation, both first and second approaches have been used.

3.2 Fuzzy Dematel Method

A fuzzy DEMATEL method is beneficial in finding out the relationships among the factors and ordering the criteria based on the type of relationships and severity of their effects on each other factors (Akyuz and Celik, 2015; Wu and Lee, 2007). In order to handle with flexibly with fuzziness, use of fuzzy sets integrated DEMATEL has many advantages (Wu, 2012). Theoretical background of botth fuzzy and DEMATEL are presented in the next section.

Table 3.5 shows the elaborative list of recent studies gathered from literature research for Fuzzy Dematel in all industries. As per table 3.5, method mostly used in the area of supply chain and management. While the method was used alone in most of studies, it has supported by other methods such as Fuzzy ANP, Fuzzy TOPSIS in remaining.

Table 3.5 : Eloborative list of Fuzzy Dematel studies.

Author(s)	**Year**	**Industry/Area**	**Aim**	**Combined Methods**
Jeng, D. J. F.	2015	Supply Chain	To investigate the relationships among supply chain collaboration dimensions in manufacturing industry	-
Uygun, Ö et al	2015	Communication	To assess and determinate outsourcing provider for a telecommunication company	Fuzzy ANP
Zhou, Q et al	2011	Emergency Management	To indicate critical success factors in emergency management	-
Mentes, A et al	2015	Maritime	To assess cause factors of fatality for commercial vessels	FSA - FST - OWGA
Akyuz, E., & Celik, E.	2015	Maritime	To determine critical operational hazards when gas freeing process	-
Jassbi, J et al	2011	Management	To model strategy map’s cause and effect relationships	-

Table 3.5 (continued) : Eloborative list of Fuzzy Dematel studies.

Author(s)	Year	Industry/Area	Aim	Combined Methods
Baykasoğlu et al	2013	Land Transportation	To model and solve truck selection problem of a land transportation	Fuzzy TOPSIS
Abdullah, L., & Zulkifli, N.	2015	Management	To integrate fuzzy AHP and fuzzy DEMATEL	Fuzzy AHP
Govindan et al	2015	Supply Chain	To assess causal relationships between GSCM practices and performances	-
Acuña-Carvajal et al	2019	Management	To develop a method that supports the overall process of planning, structuring and validating for businesses	Balanced Scorecard (BSC)
George-Ufot, G et al	2017	Electric Industries	To examine the electricity consumption pattern and their influencing factors	-
Tooranloo et al	2017	Management	To analyse factors for sustainable human resource management	Fuzzy AHP
Mavi, R. K., & Standing, C.	2018	Construction Industry	To investigate factors for sustainable project management	Fuzzy ANP
Liu, Z et al	2019	Logistics	To determine and assess cocreative value propositions for smart PSS	IVHF-DEMATEL
Fu, X. M et al	2019	Marine Biology	To identify factors on the international cooperative exploitation for deep-sea bioresources	-
Luthra, S et al	2016	Energy	To assess the enablers in solar power developments	-
Ocampo et al	2018	Tourism	To identify the antecedents of organizational citizenship behaviour	-
Wu, W. W.	2012	Management	To segment critical factors of knowledge management	-

Table 3.5 (continued) : Eloborative list of Fuzzy Dematel studies.

Author(s)	Year	Industry/Area	Aim	Combined Methods
Mirmousa, S., & Dehnavi, H. D.	2016	Supply Chain	To develop criteria for selection of the supplier	-
Muhammad, M. N., & Cavus, N.	2017	Education	To identify LMS evaluation criteria	-
Ashtarinezhad, E et al	2018	Oil and Gas Industry	To evaluate and categorize the suppliers	-
Galehdar et al	2018	Automotive Industry	To model for selection of quality management system	Analytic Network Process
Başhan, V., & Demirel, H.	2019	Maritime	To assess most common critical operational faults of marine boilers	-
Haghighat, N.	2017	Aviation	To evaluate airline service quality	Fuzzy ANP
Gao et all	2018	Management	To identify the key factors affecting promotion.	-
Chirra, S., & Kumar, D.	2018	Automobile Industry	To evaluate the supply chain flexibility	-
Rafiee et al	2019	Mining	To assess the rock mass cavability	Fuzzy RES
Keskin, G. A.	2015	Supply Chain	To determine the selection of the supplier	Fuzzy C
Toosi, S. R., & Samani, J. M. V.	2017	Geography	To evaluate watersheds with respect to different development strategies	Fuzzy ANP Fuzzy VIKOR
Ebrahimi, E., & Fathi, M. R.	2017	Management	to propose a model for human capital performance	Fuzzy Similarity

3.2.1 Fuzzy sets

In order to cope with the vagueness, ambiguity and uncertainty of judgement and assessment in decision-making, Fuzzy logic is a practical approach (Akyuz et al. 2016; Akyuz, 2016). Conceptually, decision-making problems contains faulty measurements since goals, constraints, and possible actions are not known precisely (Zadeh, 1965). Linguistic statements of experts are converted in to fuzzy numbers in fuzzy logic. A triangular fuzzy number may be described as a triplet $\tilde{A} = (l, m, u)$ where *l*, *m* and *u* denote lower, medium and upper numbers of the fuzzy sets

$(x \le y \le z)$. The membership function of a triangular fuzzy number can be defined as follows (Zadeh, 1965).

$$\mu_{\tilde{A}} = \begin{cases} 0, & x<l \\ (x-l)/(m-l), & l\le x\le m \\ (u-x)/(u-m), & m\le x\le u \\ 0 & x\ge u \end{cases} \tag{3.2}$$

Accordingly, Figure 3.3 illustrates a triangular fuzzy number. The relationship among the linguistic terms and triangular fuzzy numbers are determined with respect to the Table 3.6. Fuzzy rating and their membership function are given in figure 3.4 respectively.

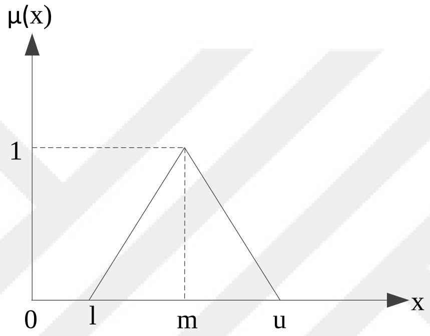

Figure 3.3 : Triangular fuzzy number.

Table 3.6 : Relationship among the linguistic terms and triangular fuzzy numbers.

Linguistic terms	Triangular fuzzy numbers
No influence (No)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1)
Very high influence (VH)	(0.75, 1, 1)

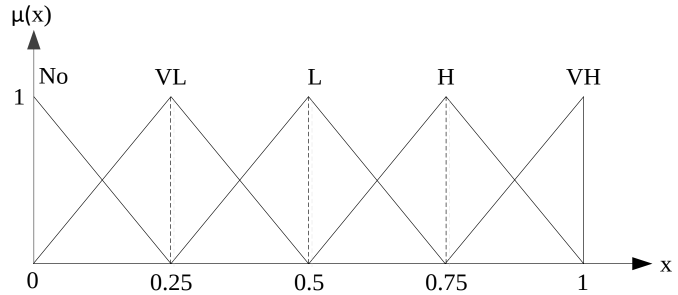

Figure 3.4 : Fuzzy rating and their membership function.

For any of two triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, the mathematical calculation of the them are summarized as follows:

The aggregation between the triangular fuzzy numbers;

$$\tilde{A}_1+\tilde{A}_2=(l_1+l_2,m_1+m_2,u_1+u_2) \tag{3.3}$$

The subtraction between the triangular fuzzy numbers;

$$\tilde{A}_1-\tilde{A}_2=(l_1-u_2,m_1-m_2,u_1-l_2) \tag{3.4}$$

The multiplication between the triangular fuzzy numbers;

$$\tilde{A}_1 \text{ x } \tilde{A}_2=(l_1 x l_2,m_1 x m_2,u_1 x u_2) \tag{3.5}$$

The arithmetic means of the triangular fuzzy numbers;

$$kx\tilde{A}_1=(kxl_1,kxm_1,kxu_1),\ (k>0) \tag{3.6}$$

$$\frac{\tilde{A}_1}{k}=\left(\frac{l_1}{k},\frac{am_1}{k},\frac{u_1}{k}\right),\ (k>0) \tag{3.7}$$

3.2.2 DEMATEL technique

The DEMATEL is one of the useful multi-criteria decision-making model generally used to negotiate complex and comprehensive decision-making problems (Gabus and Fontela, 1972). To find out cause and effect relationship among the criteria is the aim of the method (Lin and Tzeng, 2009). Conceptually, the technique is based on the graph theory which allows analysing and explaining problems by visualization (Lin et al. 2013). It provides the interdependence relationship among the factors as well as values of influential effect (Akyuz and Celik, 2015). This method is preeminent to conventional techniques due to exposing the relationships between criteria, ranking the criteria relating to the type of relationships and revealing intensity of their effects on each criterion (Seker and Zavadskas, 2017). The main steps of the DEMATEL are defined as follows (Celik and Akyuz, 2017).

Step 1: In the first step, an initial direct-relation matrix is built for pair wise comparison. A group of experts with high experience and knowledge about the problem is specified. Then experts are asked to evaluate affect among each factor pairs. After linguistic assessment of experts is converted to real values, the direct-relation matrix is constituded. Accordingly, $A = [a_{ij}]$, where A is a nxn non negative matrix, a_{ij} states the direct impact of factor i on factor$j$; and when $i = j$, the diagonal elements $a_{ij} = 0$.

Step 2: The initial direct-relation matrix is normalized to compare the factors. A normalized direct-relation matrix, $D = [d_{ij}]$, is found by using equation (3.8) and (3.9). All elements in matrix D are harmonized with $0 \leq d_{ij} \leq 1$.

$$s=\frac{1}{\max\limits_{1\leq i\leq n}\sum_{j=1}^{n} a_{ij}} \qquad i,j=1,2,\ldots,n. \tag{3.8}$$

$$D=s.\ A \tag{3.9}$$

Step 3: A total-relation matrix (T) is figured out by means of the equation (3.10) where I gives nxn identity matrix in the third step. The element t_{ij} represents the indirect effects that criterion i have on criterion$j$, so that the matrix T states the total relationship among each pair of factors.

$$T=D(I-D)^{-1} \tag{3.10}$$

Step 4: In this step, the total of rows and columns of matrix T are found. r_i and c_j are calculated as per equation (3.11) and (3.12) respectively. In the equation, while r_i states all direct and indirect influence given by criterion i to all other factors, c_j gives the degree of influenced impact.

$$r_i=\sum_{1\leq j\leq n} t_{ij} \tag{3.11}$$

$$c_j=\sum_{1\leq i\leq n} t_{ij} \tag{3.12}$$

When $i = j$, $r_i + c_j$ presents all effects that are given and received by criterion i. That is, $r_i + c_j$ indicates both criterion$i$'s impact on the entire system and other system factors impact upon factor$i$. Thus, the indicator $r_i + c_j$ implies the degree of importance that criterion i in the total system. On the other hands, the difference of the two, $r_i - c_j$, denotes the net effect that criterion i has on the system. Particularly, if the value of $r_i - c_j$is positive, the factor i will be a net cause. When $r_i - c_j$ is negative, the factor will be a net result clustered into effect group (Akyuz and Celik, 2015; Yang et al. 2008).

Step 5: In the last step, a cause and effect relationship diagram is established with respect to the $r_i + c_j$ and $r_i - c_j$. Accordingly, the complex interrelationship among factors is visualized easily.

3.2.3 Fuzzy DEMATEL approach

In this section, fuzzy sets and DEMATEL method are combined to determine and quantify influence factors on firefighting drill which affects emergency preparedness. Integration of fuzzy sets and DEMATEL methods are expressed step by step (Akyuz and Celik, 2015). The steps of the proposed approach are depicted in Figure 3.5.

Step 1 - A group of experts: Expert judgements may be an answer in decision-making problem since data inadequacy is a common problem in maritime industry. Particularly, the linguistic assessment of experts is practical when dealing with situations which specified in quantitative. The linguistic judgements of marine experts are used for transforming idea of decision makers into valuable data. At this point, the fuzzy logic tackles with the vagueness, ambiguity and uncertainty of judgment and assessment in decision-making.

Step 2 - Determine factors and construct fuzzy scale: Significant factors are specified in order to carry out evaluation. Then, linguistic variable is used in accordance with five fuzzy scales (no influence, very low influence, low influence, high influence, and very high influence). Thereafter, corresponding triangular fuzzy members are determined.

Step 3 - Obtain evaluation of the group decision-makers: The pair wise comparison is constructed in terms of linguistics variables. Then, the fuzzy assessments are transformed into defuzzified and aggregated as a crisp value. As a result, initial direct-relation fuzzy matrix $\tilde{E}$ is constructed. Following equations are used respectively.

$$\tilde{E}=\begin{bmatrix} 0 & \cdots & \tilde{E}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{E}_{n1} & \cdots & 0 \end{bmatrix} \tag{3.13}$$

$$\tilde{e}_{ij}=\left(l_{ij},m_{ij},u_{ij}\right) \tag{3.14}$$

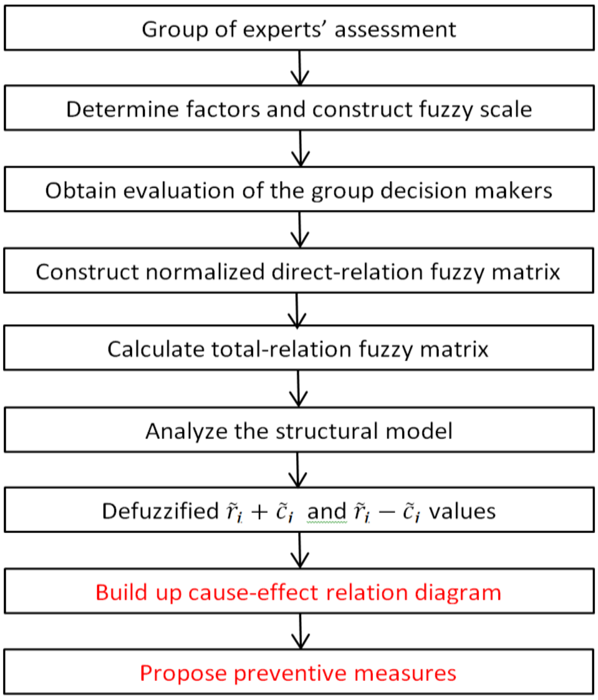

Figure 3.5 : Steps of the proposed approach.

Step 4- Constructed normalized direct-relation fuzzy matrix: In the presence of the initial direct-relation matrix, a normalized direct-relation fuzzy matrix is established. In order to achieve this purpose, the following equations are adopted. In the equations, $\tilde{\beta}_i$ and γ denote triangular fuzzy numbers.

$$\tilde{\beta}_i = \sum \tilde{e}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right) \quad (3.15)$$

$$\gamma = \max \left(\sum_{j=1}^{n} u_{ij} \right) \quad (3.16)$$

The linear scale transformation is applied to convert the factors into comparable scales. The normalized direct-relation fuzzy matrix $\tilde{F}$ of experts is determined as follows.

$$\tilde{F} = \begin{bmatrix} \tilde{\tilde{F}}_{11} & \cdots & \tilde{F}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{F}_{n1} & \cdots & \tilde{F}_{nn} \end{bmatrix}$$

Where $$\tilde{f}_{ij} = \frac{\tilde{e}_{ij}}{\gamma} = \left(\frac{\tilde{e}_{ij}}{\gamma}, \frac{\tilde{e}_{ij}}{\gamma}, \frac{\tilde{e}_{ij}}{\gamma} \right) \quad 3.17)$$

Step 5- Calculate total-relation fuzzy matrix: After constructed normalized direct-relation fuzzy matrix, a total-relation fuzzy matrix is determined by ensuring of $\lim_{\omega \to \infty} F^{\omega} = 0$. The crisp case of the total-relation fuzzy matrix is expressed as follows.

$$\tilde{T} = \lim_{\omega \to \infty} \left(\tilde{F} + \tilde{F}^2 + \ldots + \tilde{F}^{\omega} \right) \tag{3.18}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \ldots & \tilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \ldots & \tilde{t}_{nn} \end{bmatrix}$$

$$\text{where } \tilde{t}_{ij=} = (l''_{ij}, m''_{ij}, u''_{ij}) \tag{3.19}$$

$$\text{Matrix}\left[l''_{ij}\right] = F_l \text{ x } (I - F_l)^{-1} \tag{3.20}$$

$$\text{Matrix}\left[m''_{ij}\right] = F_m \text{ x } (I - F_m)^{-1} \tag{3.21}$$

$$\text{Matrix}\left[u''_{ij}\right] = F_u \text{ x } (I - F_u)^{-1} \tag{3.22}$$

Step 6- Analyse the structural model: After calculated matrix$\tilde{T}$, $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$ are determined. In the formula, $\tilde{r}_i$ and $\tilde{c}_j$ gives the sum of the rows and columns of matrix $\tilde{T}$. Since the $\tilde{r}_i + \tilde{c}_j$ presents the importance of factor i, $\tilde{r}_i - \tilde{c}_j$ states the net effect of factor i.

Step 7- Defuzzified $\tilde{\mathbf{r}}_{\mathbf{i}} + \tilde{\mathbf{c}}_{\mathbf{j}}$ and $\tilde{\mathbf{r}}_{\mathbf{i}} - \tilde{\mathbf{c}}_{\mathbf{j}}$: The $\tilde{r}_i + \tilde{c}_j$ + and $\tilde{r}_i - \tilde{c}_j$ are defuzzified by adopting COA (centre of area) defuzzification method presented by Ross (1995) to determine BNP (best non-fuzzy performance) values. For a convex fuzzy number $\tilde{\delta}$, a real number z^* corresponding to its centre of area, can be estimated with following equation (Akyuz and Celik, 2015; Gumus et al. 2013).

$$z^* = \frac{\int \mu_{\tilde{\delta}}(z) z dz}{\int \mu_{\tilde{\delta}}(z) dz} \tag{3.23}$$

The BNP value of a fuzzy number $\tilde{G} = (l_{ij}, m_{ij}, u_{ij})$ is calculated according to following equation.

$$\text{BNP}_{ij} = \frac{u_{ij} - l_{ij} + m_{ij} - l_{ij}}{3} + l_{ij} \tag{3.24}$$

Step 8- Build up cause-effect relation diagram: In the last step, the cause and effect relation diagram is depicted by mapping the dataset of $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$. The calculation can be done according to the step 6.

Considering the integrated approach, the application stages of the proposed methodology is given in Figure 3.6.

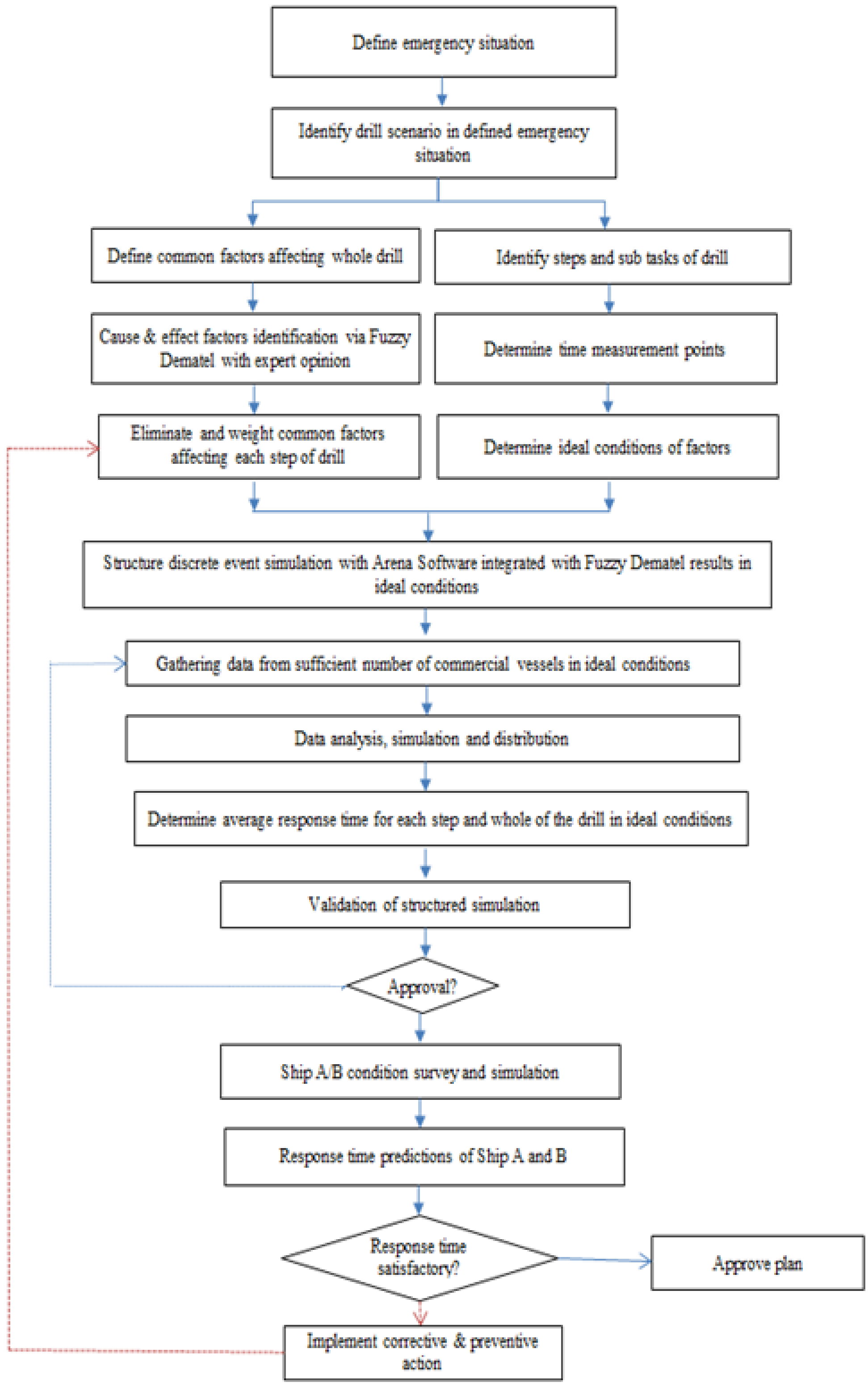

Figure 3.6 : Application stages of the proposed methodology.

4. PRACTICAL STUDY

The focus of this chapter is to integrate Fuzzy Dematel approach with Arena simulation in order to measure emergency preparedness level on board ships. To achieve this purpose, first of all, emergency situation was decided. Then drill was chosen as performance evaluation technique in case of emergencies. Generic factors which affect drill performances were determined and lastly integration of Fuzzy Dematel with Arena simulation has been proposed.

4.1 Emergency Situations on Board

Various kinds of emergency situations may occur on board at any time since its environment is very complex and changeable. Emergency situations refer to the cases where the ship and marine environment, safety of life are in danger and in need of rescue and assistance (Cheng and Miao, 2009). According to Wang (2006), common emergency situations in the shipping industry include: contact/collision, explosion, external hazards, fire, and flooding, grounding/stranding, hazardous substance related failure, loss of hull integrity, machinery failure and handling equipment failure. The author also mentioned that; emergency preparedness is a fluid, dynamic concept that keeps changing over time, dependent on a particular event and the specific hazards encountered. The success or failure of emergency preparedness is the direct index to evaluate loss and damage of lives, property and the marine environment (Cheng and Miao, 2009).

4.2 Problem Statement

Fire on-board ship is one of the most challenging and fatal events at sea (Soner et al. 2015) since it can lead to loss of cargo and the ship, environment pollution, injuries and death (Akyuz et al. 2017; Akyuz, 2015). Fire accident is an important type of maritime accidents and has a relatively high likelihood of occurrence among all types of maritime accidents besides collision and grounding (Wu et al., 2018).

PSC survey results clearly demonstrate the vulnerability of the fire safety measures on board ships. It is shown that fire safety measures, safety of navigation and life-saving appliances are at the top three categories of deficiencies discovered on ships as per annual report of Tokyo MOU PSC (Tokyo MoU, 2017). Paris MOU statistics about fire safety related deficiencies show approximately 13.1 % (Paris MoU, 2017), and Black Sea MOU statistics show approximately 12.5% (Black Sea MoU, 2017) of total deficiencies constituted by fire safety. Also, fire safety issues as the most common area for detainable deficiencies. Therefore, fire has been chosen as an emergency situation in this study.

The existing literature on fire focuses particularly on hazard identification and root cause analysis. Baalisampang et al. (2018) reviewed fire and explosion accidents that occurred in maritime transportation between 1990 and 2015 and tried to identify causal and underlying causes of these accidents. According to authors, causal factors of fire and explosion accidents are identified and categorized as human error, thermal reaction, electrical fault, mechanical failures and unknown. Authors also discussed potential preventative measures to prevent such accidents. Soner et al. (2015) proposed HFACS and FCM model to analyze the fire related deficiency database in order to identify and prioritize the consistent root causes of fire on board. Schröder-Hinrichs et al. (2011) investigated accident investigation reports related to fires and explosions in machinery space in order to find out what safety problems were addressed and whether organizational factors are determined when investigating maritime accident. Author used HFACS-MSS method in their study and important data & information gaps with regard to organizational factors were identified. Sarvari et al. (2017) studied emergency evacuations in case of engine room fires by evaluating evacuation factors which integrated into simulation results. According to Ikeagwuani and John (2013); failures and uncertainties that can lead to machinery fires can be tackled using hazard identification and risk techniques and also proposing control options for reducing their likelihood.

As an important part of ship management, effectiveness evaluation of drills should be carried on board in order to determine current level of emergency preparedness (Wu et al., 2014). Drill is a coordinated, supervised activity usually employed to test a single operation or function in a single agency which aims to provide training in the use of new equipment, to develop or test new policies or procedures and to practice and maintain current skills (US HSEEP, 2007). According to O'Brien (2003), companies with well thought-out emergency preparedness that hold regular training drills are better equipped to handle large-scale emergencies than those that are not prepared. In order to prevent fire risk on board ships, the ship managers and professionals should ensure effective implementation of a safety management system in accordance with the International Safety Management (ISM) Code (Soner et al. 2015; Akyuz and Celik, 2014).The fire drill, in this context, provides the opportunity to plan and exercise command and control techniques, and to allow fire team members the opportunity to see, feel, and use equipment they need to extinguish a real fire (Veenstra et al. 2015). Thus, in this study it is decided to proceed with assessment of operational firefighting drill in order to evaluate emergency preparedness level on board in case of fire.

Subsequent to determining fire as an emergency situation, steps of firefighting drill on board have been determined as follows:

1. Sounding the fire alarm
2. Announcing the fire via public addressor system
3. Mustering
4. Enumeration
5. Donning a fire suit
6. Putting on breathing apparatus
7. Starting fire pumps
8. Preparing/pressurizing fire hoses
9. Isolation of electrical supply
10. Closing down of fans, ventilations and watertight doors
11. Getting in fire zone in logical and safe way and successfully extinguishing fire
12. Starting cooling process with sea water
13. Putting back the equipment's used in drill

4.3 Generic Factors Affecting Firefigting Drill

In ideal shipboard conditions, it is accepted that all personnel are fit to work, have sufficient training and exercise, have safety awareness and all equipment's are proper and ready to use. Also, drills are accepted as well designed and performed. However, in some cases ideal conditions cannot be met by vessels and therefore drills cannot be performed as successful as accepted. The factors which could affect drill performance in negative and increase drill duration are called generic factors in this dissertation.

Generic factors have been selected by interview with marine experts, investigating ship management companies drill record forms, and literature review on disaster exercise evaluation, preparedness and response performances of other sectors such as hospitals and nuclear plants. While determining generic factors; factors such as personnel competence, training needs, drill structure and equipment conditions, etc. have been included in order to perform exact evaluation. After generic factors have been determined, they were argued with marine experts and accepted.

Table 4.1 : Generic factors affecting firefighting drills on-board ship.

Code	Factor
F1	Un pre-defined scenario and scenario realism
F2	Lack of knowledge and education level of officers/engineers
F3	Insufficient firefighting training and practice
F4	Missing crew
F5	Missing supervisor
F6	Experience of crew
F7	Insufficient supervisor experience in rank
F8	No learning objectives defined in previous drills
F9	External factors (weather, sea state, wind, etc.)
F10	Unclearly pre-defined crew’s task in muster list
F11	Lack of safety culture and discipline about the use of personal protective/firefighting equipment and firefighting
F12	Fatigues of crews on board
F13	Insufficient physical capability (age, weight)
F14	Illness and health problems of crew
F15	Being under the influence of alcohol and drug
F16	Crew reliability
F17	Failure on firefighting/communication equipment.
F18	Neglected items in firefighting equipment routine inspection check list
F19	Incorrect placement of portable tools, equipment or material in firefighting system
F20	Wrong IMO labeling of firefighting equipment.

While Table 4.1 shows generic factors affecting fire-fighting drills on-board ship, table 4.2 shows recent studies regarding determined generic factors.

Table 4.2 : Studies related generic factors.

Factor No	Generic Factor	Author(s)	Year
1	Un pre-defined scenario and scenario realism	Gillett et al. Klein et al. Meesters and Walle Savonia et al.	2008 2005 2013 2009
2	Lack of knowledge and education level of officers /engineers	Desai et al. Ismail et al. Kim, H Mattila et al. Wu et al.	2005 2012 2013 1994 2008
3	Insufficient firefighting training and practice	Chang and Yang Choudhry and Fang Cross R. Desai et al. IMO, STCW Ismail et al. Puisa et al. Vederhus et al.	2011 2008 2010 2005 2002 2012 2018 2018
4 5	Missing crew Missing supervisor	Lawrence, R. A. Meltzer, A. Toubia and Browning	1991 2005 2001
6 7	Experience of crew Insufficient supervisor experience in rank	Becker et al. Desai et al. Soliman, H. Wu et al.	2017 2005 2013 2008
8	No learning objectives defined in previous drills	Klein et al.	2005
9	External factors (weather, sea state, wind, etc.)	Cruz and Krausmann De Girolamo et al. Knol and Arbo	2009 2017 2014
10	Unclearly pre-defined crew's task in muster list	Horita et al.	2016
11	Lack of safety culture and discipline about the use of personal protective/firefighting equipment and firefighting	Choudhry and Fang Gershon et al. Soner et al. Wu et al.	2008 2000 2015 2008
12	Fatigues of crews on board	Hystad and Eid Hystad and Eid Strauch, B.	2016 2017 2015
13	Insufficient physical capability (age, weight)	Lamb et al. Soner et al.	2008 2015
14	Illness and health problems of crew	Lowe et al. Soner et al.	2013 2015

Table 4.2 (continued) : Studies related generic factors.

Factor No	Generic Factor	Author(s)	Year
15	Being under the influence of alcohol and drug	Jonkman and Kelman Sekizawa, A. Soner et al.	2005 1991 2015
16	Crew reliability	Akyuz, E. Cwilewicz and Tomczak Hsieh et al.	2016 2004 2018
17	Failure on firefighting/communication equipment.	Karahalios, H. Mattila et al Nordström et al. Okumura et al. Soner et al.	2018 1994 2016 1998 2015
18 19 20	Neglected items in firefighting equipment routine inspection check list / Incorrect placement of portable tools, equipment or material in firefighting system/ Wrong IMO labeling of firefighting equipment.	Chang and Yang Chi and Han Gershon et al. Soner et al. Wu et al.	2011 2013 2000 2015 2008

4.4 Simulation Analysis

In this section, operational fire fighting drill is constructed in Arena software. Layout of the model is given in the Figure 4.1.

4.4.1 Assumptions of the simulation model

The model has been constructed based on the following assumptions:

- No interruption occurs during the drill
- No steps should be skipped

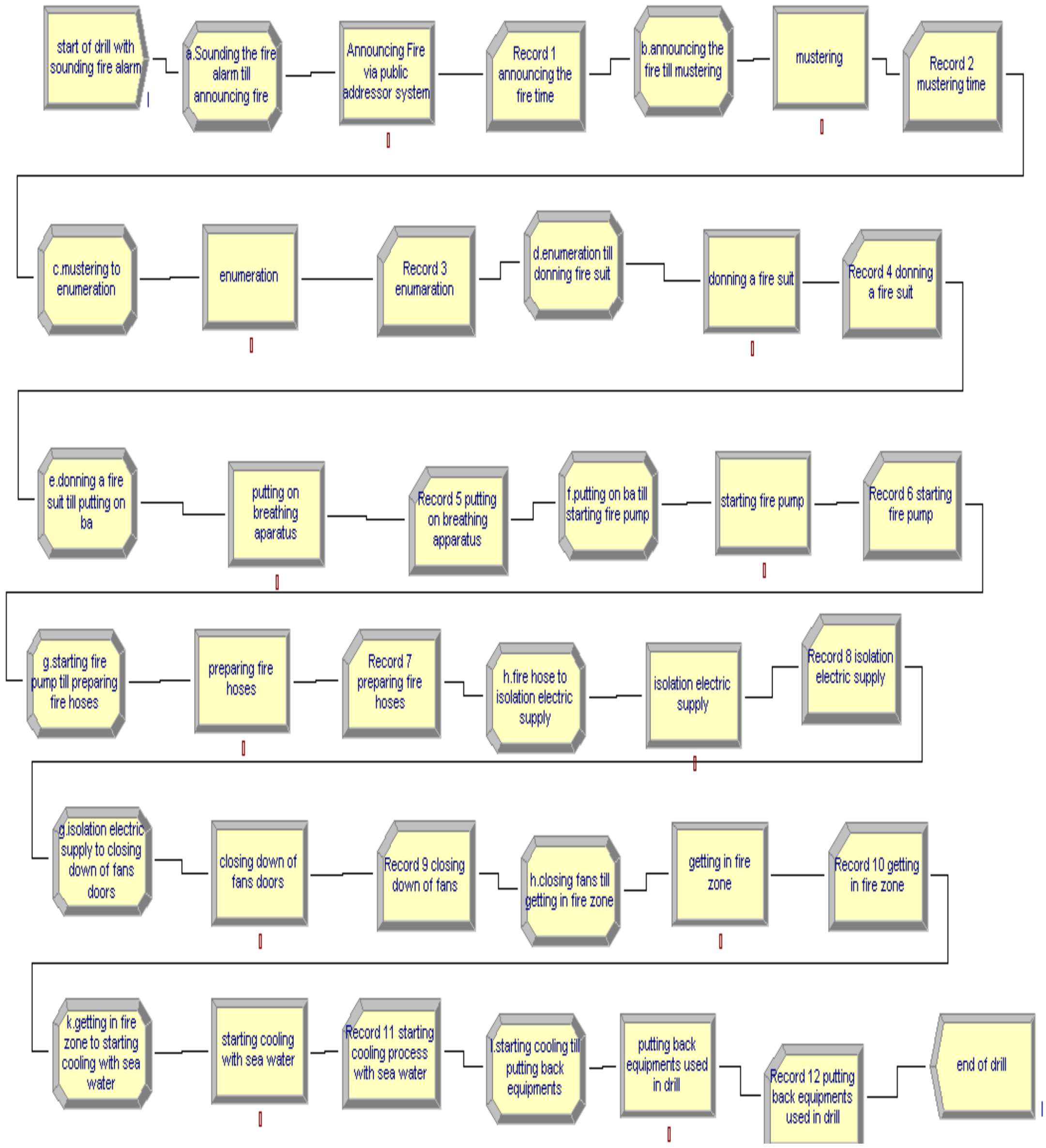

Figure 4.1 : Simulation model constructed by Arena.

4.4.2 The proposed model and its elements

There is one entry in the system. CREATE module was used to simulate the drill starting with sounding the fire alarm. In this study, time from realizing the fire till sounding the fire alarm has been ignored. Then, each step of fire drill has been simulated by using PROCESS modules. In Table 4.3, extended information on process module is provided. Finally, DISPOSE module was assigned when the equipment's used in drill has been put back which denotes that drill has been completed.

4.4.3 Data collection and distribution fitting

The next step was collecting required data for the model. Four ship management companies have been asked for their fleet vessels time measurements for the above-mentioned steps during fire drill. All data were collected from 45 commercial vessels. 15 of 45 vessels were bulk carrier and remaining 30 vessels were oil product tanker vessels. Vessels requested to send durations for each defined fire fighting drill step during real fire drill by their ship managers. Most of the drills have been carried out on galley(N=9) and manifold area(N=8). Following this, paint store (N=5), engine room(N=5), pump room (N=5), and officers mess rooms (4) are the widely used places for fire fighting drill. Other places were bridge, garbage station, mast riser and laundry room. One of the drill carried out at fore deck has been ignored in order not to undermine analysis due to different lenght of the vessels which can affect time measurements. Gathered dr.ill durations from 45 commercial vessels have given in Table 4.4. It is seen that; all drills have been carried out at morning, noon and afternoon times. Widely used fire drill locations from 45 commercial vessels are given in Figure 4.2 and drill durations of the vessels are given in Figure 4.4

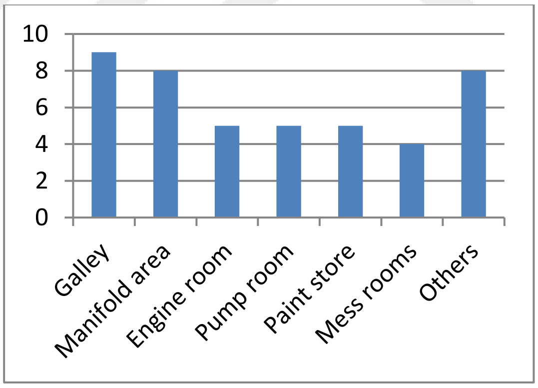

Figure 4.2 : Fire drill location.

Tablo 4.3 : List of process.

Name	Distribution	Distribution Main Parameters	Arena Name	Action	Delay Type	Arena Expression
Announcing the fire via public addressor system	Gamma	Beta:2.16 Alpha:0.247	GAMM	-Delay	-Expression	-0.001 + GAMM (2.16,0.247)
Mustering	Triangular	Min:0.999 Mode:2.81 Max:4	TRIA	-Delay	-Expression	TRIA(0.999, 2.81, 4)
Enumeration	Normal	Mean:3.23 StdDev:1.28	NORM	-Delay	-Expression	NORM(3.23, 1.28)
Donning a fire suit	Normal	Mean:7.07 StdDev:1.79	NORM	-Delay	-Expression	NORM(7.07, 1.79)
Putting on breathing apparatus	Triangular	Min:4 Mode:6.25 Max:13	TRIA	-Delay	-Expression	TRIA(4, 6.25, 13)
Starting fire pump	Triangular	Min:0.999 Mode:1.92 Max:12	TRIA	-Delay	-Expression	TRIA(0.999, 1.92, 12)
Preparing fire hoses	Beta	Beta:1.39 Alpha:1.32	BETA	-Delay	-Expression	4 + 7 * BETA(1.39,1.65)
Isolation of electrical supply	Triangular	Min:2 Mode:5.33 Max:10	TRIA	-Delay	-Expression	TRIA(2, 5.33, 10)
Closing down of fans	Triangular	Min:3 Mode:4.75 Max:10	TRIA	-Delay	-Expression	TRIA(3, 4.75, 10)
Getting in fire zone	Triangular	Min:6 Mode:23.3 Max:29	TRIA	-Delay	-Expression	TRIA(6, 23.3, 29)
Starting cooling process with sea water	Weibull	Beta:8.85 Alpha:1.32	WEIB	-Delay	-Expression	5 + WEIB(8.85, 1.32)
Putting back equipments used in drill	Triangular	Min:15 Mode:29.1 Max:35	TRIA	-Delay	-Expression	TRIA(15, 29.1, 35)

Table 4.4 : Drill durations of the vessels.

Process	Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6	Vessel 7	Vessel 8	Vessel 9	Vessel 10	Vessel 11	Vessel 12	Vessel 13	Vessel 14	Vessel 15
1.Time of sounding the fire alarm	08:42	09:36	11:00	11:15	11:00	15:36	15:40	13:00	13:00	15:32	15:42	13:49	16:10	15:30	13:00
2.Time of announcing the fire via public addressor system	08:42	09:36	11:00	11:17	11:01	15:37	15:41	13:00	13:02	15:33	15:42	13:50	16:10	15:31	13:01
3. Time of mustering	08:43	09:37	11:02	11:18	11:04	15:40	15:42	13:04	13:08	15:35	15:44	13:51	16:13	15:33	13:03
4.Time of enumeration	08:44	09:37	11:03	11:19	11:05	15:42	15:42	13:06	13:10	15:35	15:45	13:52	16:15	15:34	13:04
5.Time of donning a fire suit	08:46	09:42	11:07	11:24	11:08	15:45	15:43	13:08	13:14	15:38	15:49	13:55	16:18	15:38	13:09
6.Time of putting on breathing apparatus	08:46	09:42	11:07	11:25	11:09	15:46	15:44	13:09	13:15	15:39	15:50	13:55	16:19	15:38	13:10
7.Time of starting fire pums	08:44	09:38	11:03	11:22	11:10	15:48	15:44	13:08	13:16	15:37	15:47	13:57	16:17	15:37	13:09
8.Time of preparing/pressurizing fire hoses	08:47	09:44	11:07	11:22	11:10	15:46	15:45	13:08	13:17	15:36	15:47	13:56	16:17	15:37	13:07
9.Time of isolation of electrical supply	08:44	09:38	11:03	11:22	11:10	15:45	15:45	13:08	13:15	15:38	15:48	13:54	16:18	15:37	13:06
10.Time of closing down of fans ventilations and watertight doors	08:47	09:45	11:07	11:25	11:10	15:45	15:47	13:07	13:15	15:38	15:48	13:54	16:18	15:37	13:07
11.Time of getting in fire zone in logical and safe way and successfully extinguishing fire	08:48	09:45	11:10	11:27	11:24	15:50	15:49	13:10	13:18	15:44	15:57	14:05	16:22	15:38	13:15
12.Time of starting cooling process with sea water	08:52	09:53	11:15	11:27	11:24	15:50	15:50	13:09	13:17	15:39	15:47	14:06	16:18	15:37	13:09
13.Time of putting back the equipments used in drill	09:02	10:06	11:28	11:40	11:30	15:55	16:10	13:30	13:30	16:00	16:08	14:30	16:25	16:05	13:30

Table 4.4 (continued) : Drill durations of the vessels.

Process	**Vessel 16**	**Vessel 17**	**Vessel 18**	**Vessel 19**	**Vessel 20**	**Vessel 21**	**Vessel 22**	**Vessel 23**	**Vessel 24**	**Vessel 25**	**Vessel 26**	**Vessel 27**	**Vessel 27**	**Vessel 29**	**Vessel 30**
1.Time of sounding the fire alarm	13:45	09:38	15:31	14:30	16:07	13:45	13:13	12:02	15:30	13:02	13:37	13:02	15:03	13:05	09:30
2.Time of announcing the fire via public addressor system	13:46	09:38	15:31	14:30	16:07	13:46	13:13	12:02	15:31	13:02	13:37	13:02	15:03	13:06	09:31
3. Time of mustering	13:47	09:41	15:33	14:32	16:08	13:48	13:20	12:05	15:33	13:05	13:38	13:06	15:05	13:09	09:34
4.Time of enumeration	13:49	09:41	15:34	14:33	16:08	13:48	13:20	12:05	15:34	13:05	13:38	13:06	15:05	13:09	09:34
5.Time of donning a fire suit	13:53	09:44	15:37	14:37	16:18	13:51	13:26	12:10	15:40	13:10	13:48	13:10	15:13	13:11	09:36
6.Time of putting on breathing apparatus	13:54	09:44	15:39	14:37	16:18	13:51	13:26	12:10	15:41	13:10	13:48	13:10	15:13	13:11	09:36
7.Time of starting fire pums	13:52	09:43	15:33	14:38	16:18	13:48	13:18	12:03	15:40	13:03	13:40	13:05	15:06	13:12	09:36
8.Time of preparing/pressurizing fire hoses	13:50	09:43	15:36	14:36	16:22	13:54	13:28	12:10	15:38	13:10	13:43	13:10	15:09	13:11	09:36
9.Time of isolation of electrical supply	13:50	09:43	15:36	14:36	16:16	13:51	13:22	12:08	15:38	13:08	13:45	13:09	15:09	13:11	09:37
10.Time of closing down of fans ventilations and watertight doors	13:53	09:42	15:35	14:31	16:20	13:50	13:20	12:08	15:37	13:08	13:43	13:09	15:08	13:10	09:35
11.Time of getting in fire zone in logical and safe way and successfully extinguishing fire	14:05	09:45	15:49	14:51	16:32	14:09	13:34	12:27	15:59	13:27	13:54	13:27	15:10	13:28	09:36
12.Time of starting cooling process with sea water	13:52	09:45	15:47	14:52	16:30	13:54	13:37	12:13	15:42	13:13	13:46	13:13	15:13	13:21	09:40
13.Time of putting back the equipments used in drill	14:13	09:48	15:59	14:56	16:36	14:15	13:40	12:30	16:17	13:30	14:04	13:30	15:26	13:35	10:00

Table 4.4 (continued) : Drill durations of the vessels.

Process	Vessel 31	Vessel 32	Vessel 33	Vessel 34	Vessel 35	Vessel 36	Vessel 37	Vessel 38	Vessel 39	Vessel 40	Vessel 41	Vessel 42	Vessel 43	Vessel 44	Vessel 45
1.Time of sounding the fire alarm	12:02	16:16	16:17	15:35	15:02	13:18	11:06	15:02	13:06	15:02	16:02	13:30	16:06	16:40	15:35
2.Time of announcing the fire via public addressor system	12:02	16:16	16:17	15:36	15:02	13:19	11:07	15:03	13:06	15:03	16:03	13:30	16:06	16:41	15:36
3. Time of mustering	12:04	16:19	16:19	15:38	15:04	13:20	11:08	15:06	13:08	15:04	16:05	13:33	16:08	16:44	15:38
4.Time of enumeration	12:06	16:19	16:21	15:38	15:04	13:20	11:08	15:06	13:08	15:04	16:05	13:33	16:08	16:44	15:38
5.Time of donning a fire suit	12:09	16:21	16:24	15:41	15:08	13:24	11:11	15:12	13:12	15:08	16:10	13:34	16:15	16:46	15:41
6.Time of putting on breathing apparatus	12:10	16:21	16:24	15:41	15:08	13:24	11:11	15:12	13:12	15:08	16:10	13:34	16:15	16:46	15:41
7.Time of starting fire pums	12:03	16:18	16:18	15:41	15:03	13:23	11:09	15:10	13:12	15:03	16:03	13:33	16:10	16:46	15:41
8.Time of preparing/pressurizing fire hoses	12:11	16:23	16:26	15:45	15:08	13:25	11:13	15:10	13:14	15:08	16:10	13:34	16:17	16:46	15:45
9.Time of isolation of electrical supply	12:07	16:21	16:22	15:40	15:07	13:21	11:09	15:09	13:14	15:07	16:09	13:38	16:14	16:46	15:42
10.Time of closing down of fans ventilations and watertight doors	12:07	16:21	16:22	15:42	15:07	13:22	11:09	15:09	13:13	15:07	16:09	13:35	16:13	16:45	15:40
11.Time of getting in fire zone in logical and safe way and successfully extinguishing fire	12:14	16:35	16:38	15:50	15:26	13:33	11:18	15:26	13:29	15:25	16:26	13:55	16:25	16:55	15:53
12.Time of starting cooling process with sea water	12:18	16:36	16:34	15:51	15:19	13:30	11:17	15:12	13:16	15:10	16:12	14:20	16:25	16:48	15:51
13.Time of putting back the equipments used in drill	12:29	16:39	16:40	16:02	15:30	13:45	11:32	15:30	13:35	15:30	16:30	14:30	16:30	17:00	16:05

After data have been gathered, outlier analyses have been carried out via Minitab version 18.1 statistical software. An outlier can be defined as an ‘‘observation that deviates so much from other observations as to arouse suspicion that it was generated by a different mechanism’’ (Hawkins, 1980). The presence of outliers in a dataset can dramatically undermine the analysis and any subsequent results based on the data (Thennadil et al., 2018). After outlier analyses have been carried out, for distribution fitting, the Input Analyzer tool in Arena was utilized.

4.4.4. Run length and number of replications

Since our model has one entity, statistics started at the beginning. Therefore, there is no warm up period at the model. To calculate the sufficient number of replications, the below formula (Toledo et al., 2003) is used:

$$Nm=\left(\frac{s(m) \times t_{m-1,1-\frac{\alpha}{2}}}{\bar{x}(m)£}\right) \tag{4.1}$$

where N_m is the number of replications, s(m) is the data standard deviation, t is the test statistic obtained from t-table, m is the number of initial replications that was assumed to be 10, α is the confidence interval as 90%, x(m) is the data mean and £ is the allowable percentage error. The allowable error percentage of 10% with t9; 0:95 equals 1.833. Table 4.5 shows calculations based on 10 replications. The Nm represents the necessary number of replications as 10.409. Consequently, the model was run for 11 replications and by putting the results in the formula again, the new number of replications 9.31, which verifies that 10 replications were already sufficient. Table 4.6 shows the result summary.

Table 4.5 : Initial replication results with 10 replication.

Rep	Min.
1	32,7
2	25,1
3	32,9
4	22,3
5	28,4
6	29,7
7	20,6
8	21,2
9	29,4
10	32,5
Mean	27,48
SD	4,84
N	10

Table 4.6 : Initial replication results.

Rep	Min.
1	32,7
2	25,1
3	32,9
4	22,3
5	28,4
6	29,7
7	20,6
8	21,2
9	29,4
10	32,5
11	27,48
Mean	27,35
SD	4,607
N	11

4.4.5. Validation of the model

Validation is concerned with constructing the correct model. Validation, data collection and analysis of drills were performed thanks to the ship operators and experts. They checked the model with the authors in order to ensure that all the important components were included in the model in the right sequence. Then, the validation phase took place in order to ensure that the simulation model represents the reality. First of all, model result in ideal shipboard conditions was discussed with the same panel of experts based on their experience. Then, it is tried to compare the actual system and the simulated model. In this phase, usually a steady output of the model is considered to be compared with its real value obtained from data collection. To do so, the average time for process 12 was selected since it also states total drill duration. Obtained from 10 replications, the average is 27.47455 minutes. The observed average time for process 12 is 27.3456 minutes. Thus, based on the following calculation, the percentage error of the model is 0.47 % and considering 90% level of confidence the model is valid.

$$\frac{\text{Average Time Real} - \text{Average Time Model}}{\text{Average Time Real}} = \frac{27.3456 - 27.4755}{27.3456} X\,100 = 0.47 \quad (4.2)$$

4.4.6. Analysis of initial model

In the structured initial model there is no negative factor which will affect drill duration adversely and all data have been gathered in ideal conditions. Having run the model, the average time for firefighting drill on board were retrieved as 27.47 minutes.

4.5 Integration of Fuzzy DEMATEL with Discrete Event Simulation in Arena Software

A comprehensive survey was performed with five marine experts. The survey was sent to the experts in excel format along with cover letter, instructions, descriptions of dimensions and the criteria, pair-wise comparison of the criteria, demographic data and company information. The experts were asked to score the pair wise influence between criteria, such as what is the degree of influence that “Un pre-defined scenario and scenario realism” has on “Crew reliability”, giving five choices in linguistic terms: very high influence, high influence, low influence, very low influence, no influence. Marine experts have been working in a reputable tanker ship management company which has six crude oil tanker ships in their fleet and reputable bulk carrier company which has 16 bulk vessels in their fleet. The profile of marine experts includes superintendents and managers with high experiences on-board as a Master and Chief Engineer. They all have “Advanced Fire Fighting Training Certificate” as per STCW Code Reg. VI/3, Sec A-VI/3, and Table VI/3. They meet minimum requirements for standard of competence in advanced firefighting such as; controlling firefighting operations on board ships, organizing and training fire parties, inspecting and servicing fire detection and fire extinguishing systems and equipment, investigating and compiling reports on incidents regarding fire. Moreover, the experts participated various drills on-board ships as a supervisor and team member during their sea service. The experts whose competencies are oceangoing master had role as supervisors during fire drills conducted on deck, accommodation, bridge, paint store etc. The expert whose competency is oceangoing chief engineer had role as supervisor on fire drills conducted in engine room. Detailed characteristics of the five decision-making experts are given in Table 4.7. Since five experts ensured participation to survey, the arithmetic means of their judgments are gained.

Table 4.7 : The characteristics of the 5 decision-making experts.

Experts	Age	Education Level	Competency	Sea Exp. (Years)	Shore Exp. (Years)	Job Title	Job Responsibility
Expert 1	49	Bachelor in Maritime Management and Transportation Engineering	Oceangoing Master	14	12	HSEQ Manager	To monitor the effectiveness and compliance with HSEQ programs and initiatives; to develop policies, procedures and campaigns to enhance health, safety, environment and quality assurance on board; to track internal alcohol tests and initiate external D&A tests as necessary; to ensure that the emergency response room is updated and in readiness at all times to manage an emergency; to ensure effective closure of audit findings and incidents, and inspection deficiencies related to HSEQ, through appropriate corrective and preventive actions and to approve close out of incidents and audit corrective actions. Fire related job responsibilities: to investigate and prepare reports of fire incidents; to prepare campaigns to increase fire safety awareness; to prepare close out of deficiencies / non conformities related fire recorded on both internal and external audits/inspections.
Expert 2	44	Bachelor in Maritime Management and Transportation Engineering	Oceangoing Master	12	9	Safety Superintendent	To carry out ISM/ISPS internal audits; to schedule and organize external audits; to implement ISM procedures; GAP analyses and research the innovative ideas to improve the system to meet industrial requirements. Fire related job responsibilities: to inspect fire extinguishing and fire detection equipments and systems on board and train the personnel if needed; to arrange service for the certification and calibration of the fire-extinguishing systems and equipment; to decide the selection of most appropriate fire equipment purchase as per rules and regulations.

Table 4.7 (continued) : The characteristics of the 5 decision-making experts.

Experts	Age	Education Level	Competency	Sea Exp. (Years)	Shore Exp. (Years)	Job Title	Job Responsibility
Expert 3	41	Bachelor in Marine Engineering	Oceangoing Chief Engineer	10	8	Marine Superintendent	Responsible for the overall technical operations that include overseeing the daily operations of maintenance and repair, budgeting, survey schedules, inspections of the assigned fleet Vessels. To monitor the PMS and ensure proper implementation on board the Managed vessels and upgrade company's PMS to improve reliability of machinery, equipment and ensuring the application in the most efficient way while complying with the SMS. Fire related job responsibilities: to control fire-detection and fire-extinguishing systems and equipment on board such as isolation valves, fire pumps, etc. and to ensure their proper working and leak tightness; to track maintenance of fixed CO2, fixed foam and hyper mist systems; to prepare reports of fire incidents in machinery.
Expert 4	42	Bachelor in Maritime Management and Transportation Engineering	Oceangoing Master	8	8	Marine Superintendent	To ensure certification of vessel are valid and to avoid failure due noncompliance; to ensure vessels are meeting reporting requirements and proper documentation as per ISM, ISPS, OHSAS 18000 & ISO 14001; to ensure ISM, ISPS and ISO compliances, with properly organized audit plans and efficient preparation, to minimize NCN and OBS; to ensure compliance with applicable legal and other requirements by all vessels and raise corrective action when necessary; and a member of the shore Emergency Response Team for the vessels they are in charge of. Fire related job responsibilities: to inspect fire extinguishing and fire detection equipments and systems on board, to arrange service for the certification and calibration of the fire-extinguishing systems and equipment; to request extension for the annual service from flag state if needed.

Table 4.7 (continued) : The characteristics of the 5 decision-making experts.

Experts	Age	Education Level	Competency	Sea Exp. (Years)	Shore Exp. (Years)	Job Title	Job Responsibility
Expert 5	45	Bachelor in Maritime Management and Transportation Engineering	Oceangoing Master	13	10	ISM/Vetting Superintendent	To promote the SMS Policy and culture on board vessels; to demonstrate his commitment to safety and environmental excellence, by his behavior; to suggest improvements/modifications of the SMS; to carry out Investigating accidents, incidents and serious near misses; to review all reports of non-conformities, incidents or near misses received by the vessels assigned to him and to follow-up the implementation and verification of corrective/preventive actions process inclusive their effectiveness. To participate in the Emergency Response Team, as delegated by the General Manager. Fire related job responsibilities: to arrange service for the certification and calibration of the fire-extinguishing systems and equipment; to request extension for the annual service from flag state if needed; to track fire-extinguishing systems and equipment certificates updated.

After evaluation of group decision makers are obtained, initial direct-relation fuzzy matrix $\tilde{\mathrm{E}}$ and normalized direct-relation fuzzy matrix $\tilde{\mathrm{F}}$ have been established. Then, a total-relation fuzzy matrix is found, and structural model has been analyzed by determining $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$.Lastly determined $\tilde{r}_i + \tilde{c}_j$ + and $\tilde{r}_i - \tilde{c}_j$ numbers have been defuzzied by adopting COA defuzzification method and cause and effect relation diagrams have been built for each firefighting drill step.

Realizing the fire till sounding fire alarm has been ignored in this dissertation. Analyses have been carried out by starting from sounding alarm till announcing the fire via public addressor system to step putting back equipment's used in drill. Accordingly, all empirical analyses have been given in the next sections.

The effect of defuzzied values for all generic factors was determined by getting percentages. Generic factors were entered as VARIABLE in ASSIGN module in Arena software. In the ideal condition, there was no generic factor effect, but in the worst-case scenario all of these factors were accepted as existing. Once the percentages have been determined, they were added to the expression which found at ideal conditions. The revised expression was added to PROCESS module in Arena software. This procedure enabled to track the changes in response time.

4.6 Factor Analysis

Integration of Fuzzy Dematel method along with Discrete Event Simulation in Arena Software is expressed in detail in the previous section. In this step, factor analysis for the step announcing the fire via public addressor system will be analyzed as an example.

The firefighting drill on-board ship is discussed with marine experts along with generic factors before empirical analysis. The marine experts assess relationship between the generic factors by using fuzzy linguistic scale presented in Table 3.6. Accordingly, Table A.1 depicts linguistic assessments of the marine experts for the step announcing the fire via public addressor system which is provided in the appendix section.

After aggregating marine experts' evaluation, an initial direct-relation fuzzy matrix, as illustrated in Table A.2, is figured out. Then, a normalized direct-relation fuzzy matrix is established by using equations (3.15 – 3.16 – 3.17) respectively. Table A.3

shows the normalized direct-relation fuzzy matrix. Following, a total-relation fuzzy matrix can be constructed by adopting equations (3.18 – 3.22). Table A.4 ensures the total-relation fuzzy matrix. Mentioned Tables A.1 to A.4 are provided in the appendix section.

The fuzzy values of $\tilde{r}_i, \tilde{c}_j,\ \tilde{r}_i + \tilde{c}_j, \tilde{r}_i - \tilde{c}_j$, figured in Table 4.8, is calculated by using total relation matrix. Then, defuzzification process is performed to convert the fuzzy numbers into crisp values. By using equation (22) and (23), the crisp values of the $r_i,\ c_j,\ r_i + c_j, r_i - c_j$, provided in Table 4.9, is calculated to assess cause-effect relation.

Table 4.8 : Fuzzy values of $\tilde{r}_i, \tilde{c}_j,\ \tilde{r}_i + \tilde{c}_j, \tilde{r}_i - \tilde{c}_j$.

	$\tilde{r}_i$			$\tilde{c}_j$			$\tilde{r}_i + \tilde{c}_j$			$\tilde{r}_i, - \tilde{c}_j$		
F1	0,16	0,53	2,50	0,22	0,70	2,81	0,37	1,23	5,32	-2,66	-0,17	2,29
F2	0,14	0,49	2,38	0,37	0,92	3,33	0,51	1,40	5,71	-3,19	-0,43	2,01
F3	0,24	0,63	2,72	0,35	0,27	0,96	0,59	0,90	3,68	-0,72	0,36	2,37
F4	0,12	0,42	2,25	0,02	0,13	0,62	0,14	0,55	2,86	-0,50	0,30	2,23
F5	0,08	0,34	2,05	0,08	0,23	0,62	0,16	0,57	2,68	-0,54	0,11	1,98
F6	0,14	0,43	2,28	0,09	0,53	2,51	0,23	0,96	4,79	-2,37	-0,10	2,19
F7	0,10	0,37	2,13	0,18	0,68	2,80	0,28	1,05	4,93	-2,70	-0,30	1,96
F8	0,15	0,48	2,37	0,16	0,61	2,41	0,31	1,09	4,78	-2,27	-0,13	2,21
F9	0,03	0,25	1,86	0,02	0,08	1,50	0,05	0,33	3,36	-1,47	0,16	1,84
F10	0,15	0,51	2,43	0,08	0,29	1,98	0,23	0,80	4,41	-1,83	0,21	2,36
F11	0,21	0,65	2,70	0,13	0,30	1,99	0,33	0,94	4,69	-1,78	0,35	2,57
F12	0,14	0,45	2,32	0,27	0,79	3,07	0,42	1,24	5,39	-2,92	-0,34	2,05
F13	0,01	0,20	1,76	0,02	0,08	1,50	0,03	0,28	3,26	-1,49	0,12	1,74
F14	0,12	0,37	2,14	0,03	0,42	2,26	0,16	0,79	4,40	-2,13	-0,05	2,11
F15	0,28	0,63	2,54	0,16	0,65	2,78	0,43	1,28	5,31	-2,50	-0,02	2,38
F16	0,05	0,40	2,21	0,14	0,35	2,10	0,19	0,75	4,31	-2,06	0,05	2,07
F17	0,27	0,65	2,67	0,18	0,68	2,80	0,44	1,33	5,46	-2,53	-0,02	2,49
F18	0,13	0,45	2,31	0,13	0,53	2,49	0,25	0,98	4,79	-2,36	-0,09	2,18
F19	0,15	0,49	2,40	0,12	0,26	1,88	0,27	0,75	4,28	-1,73	0,23	2,28
F20	0,11	0,42	2,23	0,05	0,11	1,56	0,17	0,53	3,79	-1,45	0,30	2,18

Table 4.9 : Crisp values of the r_i, c_j, $r_i + c_j, r_i - c_j$.

	r_i	c_j	$r_i + c_j$	$r_i - c_j$
F1	1,06	1,24	2,31	-0,18
F2	1,00	1,54	2,54	-0,54
F3	1,20	0,53	1,72	0,67
F4	0,93	0,25	1,18	0,68
F5	0,82	0,31	1,14	0,51
F6	0,95	1,05	1,99	-0,10
F7	0,87	1,22	2,09	-0,35
F8	1,00	1,06	2,06	-0,06
F9	0,71	0,54	1,25	0,18
F10	1,03	0,78	1,81	0,25
F11	1,18	0,81	1,99	0,38
F12	0,97	1,38	2,35	-0,41
F13	0,66	0,53	1,19	0,13
F14	0,88	0,90	1,78	-0,03
F15	1,15	1,20	2,34	-0,05
F16	0,89	0,86	1,75	0,02
F17	1,20	1,22	2,41	-0,02
F18	0,96	1,05	2,01	-0,09
F19	1,02	0,75	1,77	0,26
F20	0,92	0,58	1,50	0,35

4.6.1 Findings and discussion of factor analyses

In the view of outcomes presented in r_i, c_j, $r_i + c_j, r_i - c_j$ table 4.9, figure 4.3 illustrates the cause-effect relation diagram for the step. As per diagram, the factors affecting step of announcing the fire via public addressor system drill can be divided into two significant groups; cause and effect factors.

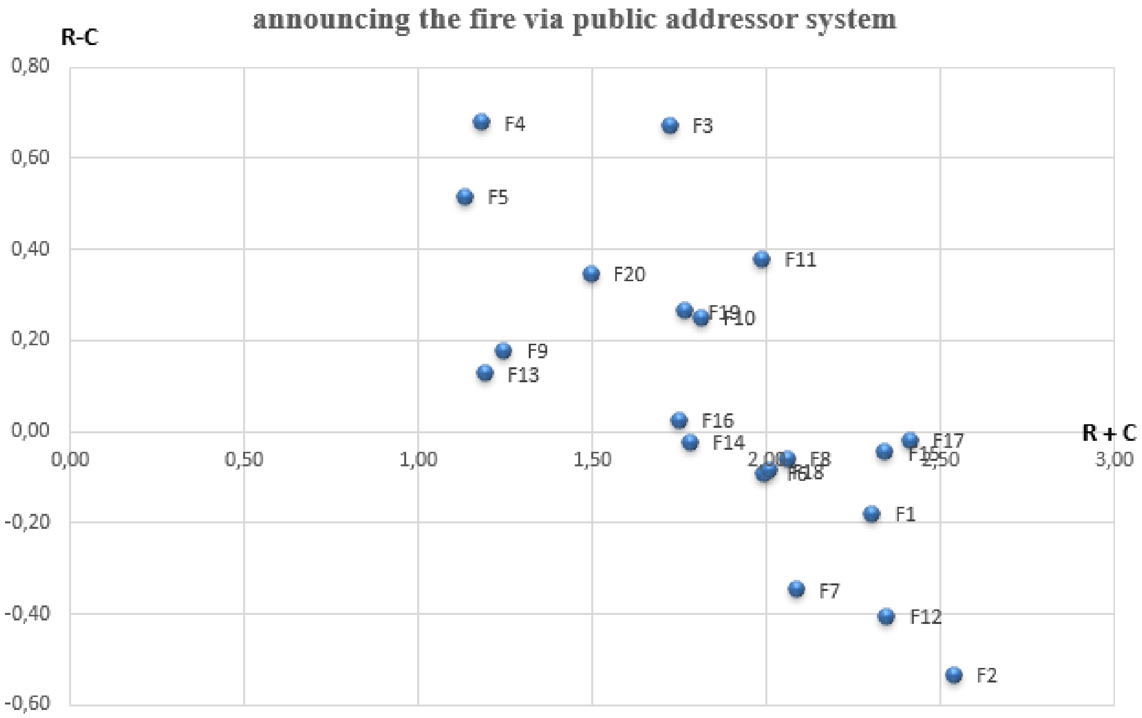

Figure 4.3 : Cause-effect relation diagram for announcing the fire via public addressor system.

4.6.1.1 Cause factors

The value of $r_i - c_j$ gives significant casual factors affecting the predefined steps of an operational firefighting drill. In the step announcing the fire via public addressor system, according to the table 4.9, F4 (Missing crew) and F3 (Insufficient firefighting training and practice) have the highest $r_i - c_j$ value among all the factors respectively. It means that F4 and F3 has significant influence. The third most important causal factor is F5 (Missing supervisor) as it has the third highest $r_i - c_j$ value. Sequentially, F11 (Lack of safety culture and discipline about the use of personnel protective/firefighting equipment and firefighting) and F20 (Wrong IMO labeling of firefighting equipment) are other significant factors affecting predefined steps of an operational firefighting drill since they have quite higher $r_i - c_j$ values as well as $r_i$values.

4.6.1.2 Effect factors

The value of $r_i + c_j$ gives idea about the influence of effect factors. In the view of findings, F2 (Lack of knowledge and education level of officers/engineers) has the highest $r_i + c_j$ value among the all factors. In addition, it is degree influenced impact index (c_j) value is considerable high among all factors. Thus, F2 has potential effect on predefined steps of an operational firefighting drill. Likewise, F17 (Failure on firefighting/communication equipment) has the second highest $r_i + c_j$ values. The c_j and r_i value of F17 seemingly are quite high when compared to other factors. Therefore, the F17 has significant effects on the on predefined steps of an operational firefighting drill. The other influential factor over the firefighting drill is F12 (Fatigues of crews on board) as it ranks on the third according to the $r_i + c_j$.

4.7 Case Studies and Findings

The proposed model is demonstrated with four different cases. Firstly, it is demonstrated in ideal ship board conditions along with the actual time data obtained from commercial vessels and then worst-case scenario has been constructed as per Fuzzy Dematel Analysis results by accepting all generic factors exist during drill. Lastly, in order to test effectiveness of the model; two different case studies have been analyzed and compared with their real drill durations. For the two case studies, ship management companies have been asked for their fleet vessels drill durations except than ideal conditions which have at least one of mentioned generic factors.

Four different cases have been given in the following: i) Ideal shipboard conditions, ii) The worst-case scenario, iii) Ship-A operational situations and iv) Ship-B operational situations. First of all, initial model has been constructed in Arena software with no negative generic factor which will affect drill duration adversely. Operational situations which have no generic factors have been accepted as ideal conditions. Shipping companies had been informed regarding ideal conditions and they were requested to send drill reports which had been carried out in ideal conditions. The demonstration of the developed initial model in ideal conditions reveals the results given in Table 4.10.

Table 4.10 : Model results in ideal shipboard conditions.

Interval	Average	Minimum Average	Maximum Average
Process 1: Announcing the fire via public addressor system	0.7595	0.01112383	2.9787
Process 2: Mustering	2.8353	1.1481	3.8617
Process 3: Enumeration	3.8118	2.3127	5.9031
Process 4: Donning a fire suit	7.2715	4.2626	9.3772
Process 5: Putting on breathing apparatus	7.6826	5.2967	11.3349
Process 6: Starting Fire pump	6.1255	1.9452	10.9083
Process 7: Preparing fire hoses	7.1581	4.5861	10.7916
Process 8: Isolation electric supply	5.4762	3.0472	8.5500
Process 9: Closing down of fans	5.9808	4.7669	7.5874
Process 10: Getting in fire zone	21.1631	13.2362	26.1211
Process 11: Starting cooling process with a sea water	11.7893	5.3106	18.3275
Process 12: Putting back equipments used in drill	27.4723	20.5516	32.9486

Secondly, model is demonstrated in worst case scenario. A worst-case scenario is established by assuming that all negative generic factors exist during the whole drill via the values obtained Fuzzy DEMATEL analysis. Having run the model, durations for each step was found approximately 2 times more than initial drill results which were gathered in ideal conditions. While the whole drill duration was 27.47 minutes, it reached up 51.49 minutes by the effect of all generic factors. The demonstration of the developed model in worst case scenario reveals the results given in Table 4.11.

Table 4.11 : Model results in worst case scenario.

Interval	Average	Minimum Average	Maximum Average
Process 1: Announcing the fire via public addressor system	1.2809	0.3772	3.3513
Process 2: Mustering	5.3716	4.7835	6.2610
Process 3: Enumeration	5.8228	3.2755	7.3748
Process 4: Donning a fire suit	13.0169	7.8293	17.4774
Process 5: Putting on breathing apparatus	15.3235	13.1547	18.7753
Process 6: Starting Fire pump	10.7228	7.7925	15.2378
Process 7: Preparing fire hoses	15.2845	12.2671	17.4637
Process 8: Isolation electric supply	11.6574	8.6302	14.6549
Process 9: Closing down of fans	11.9716	9.8956	14.5597
Process 10: Getting in fire zone	38.8127	30.7951	46.4212
Process 11: Starting cooling process with a sea water	26.2537	18.8298	38.2978
Process 12: Putting back equipments used in drill	51.4903	43.9562	59.6698

Thirdly, model has been run for the first case study Ship-A operational situations. The fire drill was conducted on 13th July, 2018 in oil product tanker vessel. It was performed at Trinidad Anchorage area. Watch keepers and 3rd officer could not participate fire drill. 3rd officer had injured his hand when opening water ballast tank manhole on board and he was suffering fracture of the tuft of the distal phalanx during the drill. Also, the vessel was sailing between closer terminals for 4 months; there were violations of rest hours and/or work hours regulations. So, fatigue has been accepted as other generic factor. In addition, it had been realized that, there were lots of small holes in fire hoses. In summary, following generic factors were considered in this case:

i. Illness and health problems of crew member
ii. Fatigue
iii. Failure on firefighting/communication equipment

Lastly, model has been run for the second case study Ship-B operational situations. The fire drill was conducted on 23th March 2018 in bulk carrier vessel. It was performed while the vessel was sailing towards Richards Bay/South Africa. All crew members participated to fire drill except watch keepers. The following generic factors were considered in this case:

i. Insufficient firefighting training and practice
ii. Insufficient physical capability (age, weight): 1 crew member were above 55 years
iii. Insufficient supervisor experience in rank: 3 months
iv. External factors (bad weather/sea conditions: NW 6/5)

In order to test the model, generic factors were integrated into Arena program and run the model to estimate drill duration of the vessels irrespective from drill duration results gathered from the vessels. The other factors are not taken into consideration since they will not affect drill duration. This step has been applied to Arena separately for Ship-A and Ship-B. Finally, the operational survey results derived from Ship-A and Ship-B are considered.

Table 4.12 : Generic factors of five scenarios.

Generic factors	Ideal conditions	Ship A	Ship B	Worst Case Scenario
Un pre-defined scenario and scenario realism	-	-	-	√
Lack of knowledge and education level of officers/engineers	-	-	-	√
Insufficient firefighting training and practice	-	-	√	√
Missing crew	-	-	-	√
Missing supervisor	-	-	-	√
Experience of crew member	-	-	-	√
Insufficient supervisor experience in rank	-	-	√	√
No learning objectives defined in previous drills	-	-	-	√
External factors (weather, sea state, wind, etc.)	-	-	√	√
Unclearly pre-defined crew member’s task in muster list	-	-	-	√
Lack of safety culture and discipline about the use of personal protective/firefighting equipment and firefighting	-	-	-	√
Fatigues of crew member on board	-	√	-	√
Insufficient physical capability (age, weight)	-	-	√	√
Illness and health problems and of crew members	-	√	-	√
Being under the influence of alcohol and drug	-	-	-	√
Crew member reliability	-	-	-	√
Failure on firefighting/communication equipment.	-	√	-	√
Neglected items in firefighting equipment routine inspection check list	-	-	-	√
Incorrect placement of portable tools, equipment or material in firefighting system	-	-	-	√
Wrong IMO labelling of firefighting equipment.	-	-	-	√

Table 4.13 represents the findings of Ship A operational situation during fire drill received by proposed model and real results gathered from vessel.

Table 4.13 : Findings of Ship A.

Interval	Simulation Average	Simulation Minimum Average	Simulation Maximum Average	Ship A Results
Process 1: Announcing the fire via public addressor system	0.9240	0.2159	3.1088	1.0
Process 2: Mustering	3.3167	2.6000	4.3360	3.0
Process 3: Enumeration	3.0860	2.8296	4.4167	3.5
Process 4: Donning a fire suit	7.5800	4.9567	11.9838	8.5
Process 5: Putting on breathing apparatus	8.8814	6.3608	12.2267	10.0
Process 6: Starting Fire pump	6.6008	2.4733	11.8186	8.0
Process 7: Preparing fire hoses	9.4328	6.1434	11.6741	11.0
Process 8: Isolation electric supply	7.0314	4.5049	9.8191	9.0
Process 9: Closing down of fans	6.9645	5.2287	9.5419	9.0
Process 10: Getting in fire zone	22.4639	13.3036	29.8087	19.0
Process 11: Starting cooling process with a sea water	14.8745	7.0808	25.3053	16.0
Process 12: Putting back equipments used in drill	29.9965	21.6833	38.0708	31.5

According to the findings of Ship A operational situation during fire drill obtained by the proposed model and real results gathered from vessel, it is clearly seen that real results and simulation average results are parallel with each other and they are in the limits of minimum and maximum simulation averages.

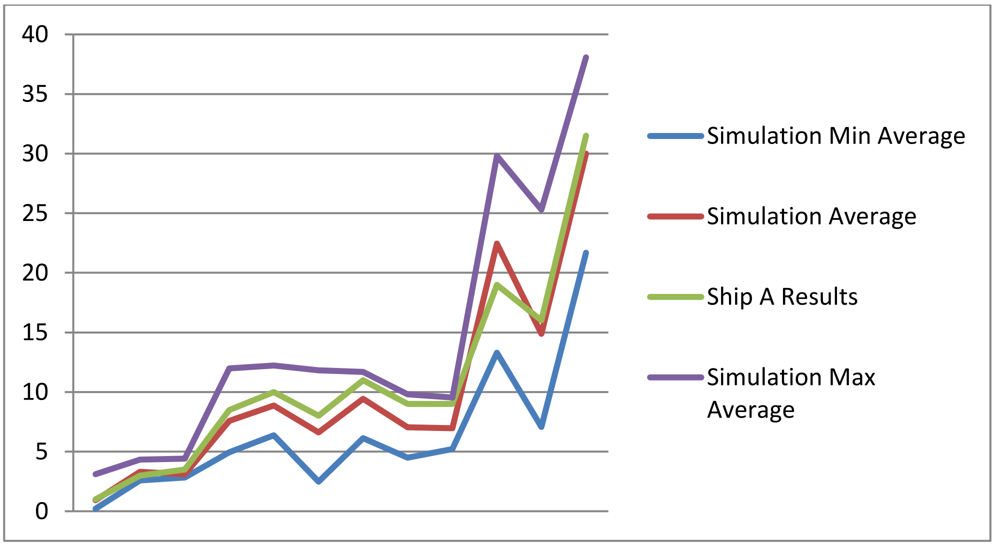

Figure 4.4 : Distribution of Ship A findings.

Table 4.14 represents the findings of Ship B operational situation during fire drill received by proposed model and real results gathered from vessel.

Table 4.14 : Findings of Ship B.

Interval	Simulation Average	Simulation Minimum Average	Simulation Maximum Average	Ship B Results
Process 1: Announcing the fire via public addressor system	0.9048	0.2500	3.0279	0.5
Process 2: Mustering	3.0864	2.3606	4.0775	2.5
Process 3: Enumeration	3.0675	2.7856	4.3829	3.0
Process 4: Donning a fire suit	7.7467	4.5263	12.0945	9.0
Process 5: Putting on breathing apparatus	8.8949	6.3234	12.4577	8.0
Process 6: Starting Fire pump	6.5456	2.8237	11.4534	7.0
Process 7: Preparing fire hoses	9.2862	5.7264	11.5912	8.0
Process 8: Isolation electric supply	6.8293	4.2445	9.4175	8.0
Process 9: Closing down of fans	7.2021	5.5816	9.8523	8.0
Process 10: Getting in fire zone	22.6546	13.2345	30.4183	23.0
Process 11: Starting cooling process with a sea water	15.3808	8.0579	27.2780	16.0
Process 12: Putting back equipments used in drill	28.1294	21.7349	35.8234	29.0

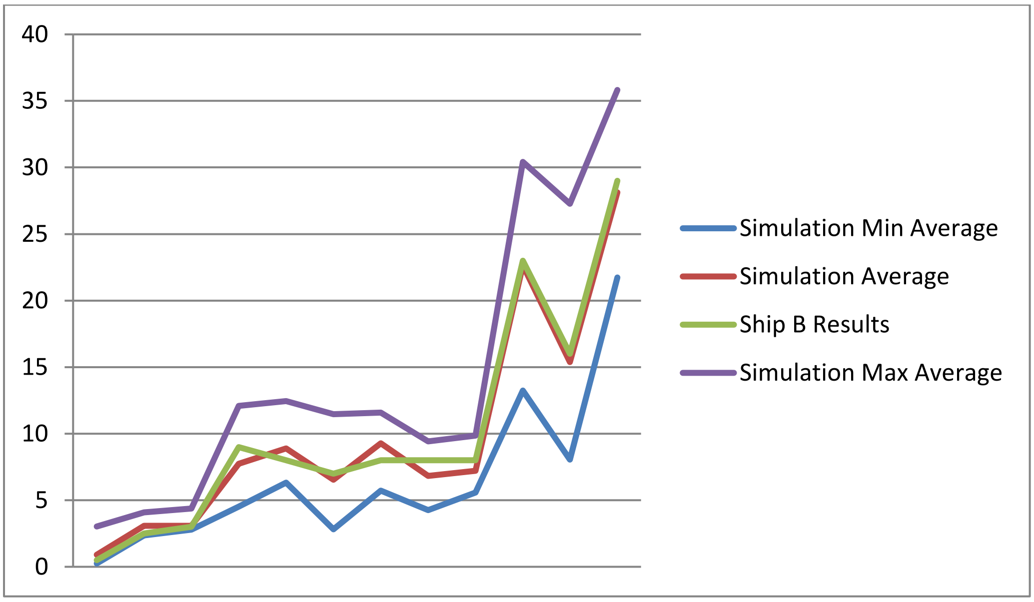

Figure 4.5 : Distribution of ship B findings

According to the findings of Ship B operational situation during fire drill obtained by the proposed model and real results gathered from vessel, it is clearly seen that real results and simulation average results are parallel with each other and they are in the limits of minimum and maximum simulation averages.

These results supported our proposed model which enables to measure emergency preparedness with condition analysis without performing drill.

Table 4.15 illustrates the emergency preparedness level comparison of the four different situations.

Table 4.15 : Comparisons of the four situations.

Interval	Ideal Conditions Average	Ship A Average	Ship B Average	Worst Case Average
Process 1	0.7595	0.9240	0.9048	1.2809
Process 2	2.8353	3.3167	3.0864	5.3716
Process 3	3.8118	3.0860	3.0675	5.8228
Process 4	7.2715	7.5800	7.7467	13.0169
Process 5	7.6826	8.8814	8.8949	15.3235
Process 6	6.1255	6.6008	6.5456	10.7228
Process 7	7.1581	9.4328	9.2862	15.2845
Process 8	5.4762	7.0314	6.8293	11.6574
Process 9	5.9808	6.9645	7.2021	11.9716
Process 10	21.1631	22.4639	22.6546	38.8127
Process 11	11.7893	14.8745	15.3808	26.2537
Process 12	27.4723	29.9965	28.1294	51.4903

4.8 Proposed Improvements

As it is discussed in the previous section, while the whole drill duration was 27.47 minutes, it reached up to 51.49 minutes by the effect of all generic factors which are not acceptable for real fire. In order to minimize and avoid the effect of generic factors, actions proposed for each determined factor. Suggested actions for each factor are given in the Table 4.16. By fulfilling the suggested actions, it is thought to minimize effect of factors during operational firefighting drill.

These actions have been inserted Arena software in decide modules. If determined actions exist, effect of generic factor will be disregarded. The layout of proposed model with suggested actions is shown in Figure 4.6.

Table 4.16 : Suggested actions.

Factor	Suggested Actions
F1	Toolbox meeting and briefing
	Emergency response matrix for each type of fire for each designated place
	Determine response attack route
F2	Advanced shore training and exam
	Advanced training and exam on board
F3	Combine drills with trainings, teach and demonstrate before use
F4	Determine stand ins for crew members
	Change duties in muster list regularly and switch positions and duties for crew members
F5	Determine stand ins for supervisor
	Change duties in muster list regularly (switch positions and duties) for supervisor
F6	Crew matrix regarding on same type ship should be established like officers
F7	Combined aggregate for Master and C/O shall not be less than 3 years sea time in rank
F8	Evaluation of drill after completion for previous drills
	Define best practice and lessons learnts for previous drills and apply
	Determine response target and put goal for crew member
F9	Adjust heading for wind and swell direction
	Collect weather info to establish course to avoid bad weather condition
F10	More specific listed muster lists
	More specific listed crew emergency duty placard ready to use in emergency
F11	Creating safe behave to eliminate confusion of thinking during chaos
	Publishing safety campaigns by office
F12	No overtime for non-emergency use
	Extra watch keepers for vessels which have short voyages
F13	Stress effort test before each vessel attendance
	Age scale below 55
F14	Enhanced checkup before each vessel attendance
F15	No alcohol policy
	Unannounced internal and external drug and alcohol test
F16	Retention rate should be increased
F17	Spares of critical equipment’s should be supplied
F18-19-20	Cross check of equipment’s by different persons
	Controls should be done against approved fire control plan

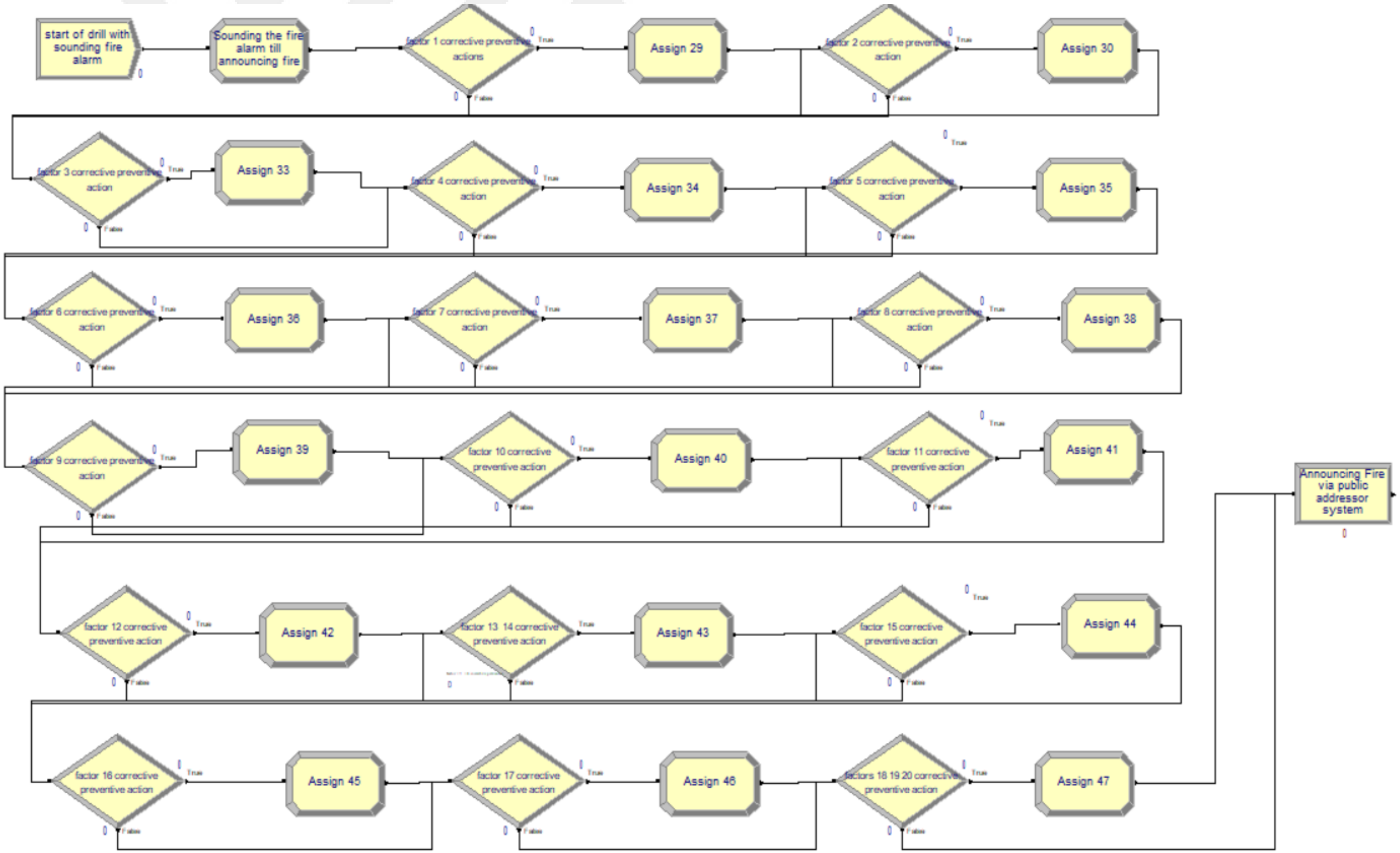

Figure 4.6 : Model with suggested action.

5. CONCLUSION

One of the focused subject by maritime transportation industry is the effectiveness of ship safety implementations. Rule makers, leading regulatory authorities such as IMO, European Union, flag states, etc and commercial shipping company managers are working for the enchancement of safety implemantations on board. However, although there have been sufficient number of rules; there are implementation deficiencies in operation level and recent accidents addressed the weakness at emergency situations. Therefore, academic and industrial organizations have focused on improving ship safety management at emergency situations.

Emergency preparedness is being ready to respond for an emergency situation before an unwanted accident/incident occurs. Ship emergency preparedness is still crucial concern and an open question. Emergency preparedness has vital importance in maritime domain comparing with other industries since its structure prevents external help, heavy weather conditions, and having long distances with closest emergency teams such as fireman, hospital, etc.

In this study, it is aimed to analyse cargo ships emergency preparedness level. Before starting the study, interviews with shipping companies performed in order to discuss emergency preparedness activities on their fleet vessels. In the light of interviews with shipping companies, it is clearly seen that; companies determine their fleet vessels emergency preparedness level through inspection/audit results, incident, accident, near miss analyses and drill performances. Then, systematic literature review has been carried out and found that; large and growing body of literature regarding emergency preparedness in maritime industry has evaluated oil spill and prevention, supply chain, personnel transfer from offshore facilities and hazard identification. There is still need for an approach which is practical to implement on board in order to evaluate emergency preparedness. Considering the literature and industrial gaps & expectations it is aimed to evaluate operational drills on board which addresses emergency preparedness level directly.

It is required to establish strict procedures including drill and exercise programs to response emergency situations at any time. According to O'Brien (2003), companies that hold regular training drills are better equipped to cope with large-scale emergencies than those that are not prepared.

The main aim of this paper is to predict the level of emergency preparedness on board vessels in different emergency situations. In order to achieve this purpose, integrated Fuzzy Dematel method along with Discrete Event Simulation in Arena software has been proposed. Fire has been chosen as a case study in this thesis due to high likelihood of occurrence and severe consequences among other types. Firstly, steps of operational firefighting drill and their affecting factors were determined by Fuzzy Dematel method. A fuzzy DEMATEL method is considered a suitable method for the problem. While the DEMATEL method provides an opportunity to determine and analyze the critical factors with respect to causal-effect relation, fuzzy sets tackle the uncertainty in decision-making. A set of generic factors affecting firefighting drills on-board ship are evaluated by taking into consideration of causal-effect relation. The most significant factors, affecting predefined steps of an operational firefighting drill, are revealed and evaluated for each drill step. The results of the study demonstrate that insufficient firefighting practice and training, missing crew & supervisor and incorrect placement of portable tools, equipment or material in firefighting system should be given highest priority for effective preparedness in case of fire on board since they are cause factors. On the other hand, the factors lack of safety culture and discipline about the use of personnel protective/firefighting equipment and firefighting, crew fatigues of crews, lack of knowledge and education level of officers/engineers on board should be given utmost attention since they are in effect group and may cause unintended consequences in emergency. While the cause and effect factors change for every drill step, below mentioned factors are the common factors affecting majority of the steps. The condition of vessels which has none of these factors has been selected as ideal conditions. The vessels having all defined factors have been selected as worst-case scenario.

Then, 45 real shipboard firefighting drill is applied in Arena to demonstrate the model. First of all, needed modules are decided by investigating real situation. After model has been constructed, necessary data collected from commercial vessels and their distributions specified. In the experimental stage, the run length and the number of replications were designated. Model has been run and it is found that, drill duration in ideal conditions is 27.47 minutes. When Fuzzy Dematel analysis findings integrated into Arena software, whole drill duration reached up 51.49 minutes which is unacceptable for operational firefighting drill on board. These findings suggest that, the effect of generic factors should be decreased, and corrective/preventive actions should be established in order to be prepared for real fire on board. Then, in order to test effectiveness of the model; two different case studies have been analyzed and compared with their real drill durations and found proper. Finally, suggested actions have been determined for all generic factors which have adverse effect on drill steps.

5.1 Contributions

Since the weakness in emergency sitautions can pose potential harm to ship, commodity, human life and environment; emergency preparedness awareness is very important for shipping companies. According to interviews with companies, there is a need for an approach to determine emergency preparedness level of their fleet vessels. Therefore, shore-based shipping companies are eager to take benefits of academic researches. At this point, the need for a marine-specific methodology to evalute emergency preparedness level is required. The following contributions are made with respect to the thesis into maritime sector:

- The present study raises the possibility that operational drills can be simulated in order to achieve emergency response time
- Generic factors which influence emergency situation directly can achieved by taking into consideration of causal-effect relation via Fuzzy Dematel method
- The proposed approach can assist ship owners/manageners to evaluate their fleet vessel status
- The proposed approach can assist ship owners/manageners to improve their performances by remedying deficiencies and reducing risk factors to minimum
- The study shows how a comprehensive insight into the ship emergency preparedness can be gained by maritime safety managers and professionals.

- The proposed combined method will contribute to specifying current level of preparedness for various emergency situations not only on board but also ports/terminals/offshore facilities since it is practical and applicable to implement.

Also, the study has eventful contributions to academic literature in significant points. A brief list of the expected contributions is given as follows:

- The study shows how Arena software can be integrated with Fuzzy Dematel method
- The study provides a basis to examine the effectiveness of the current system by obtaining and analyzing the related data obtained from the simulation and to establish a marine-specific methodology to evaluate emergency preparedness level.

5.2 Further Research Proposal

Consequently, the outcomes presented in this dissertation primarily contribute to evaluation of emergency preparedness level in case of fire. Thus far, this study encourages the maritime managers in addition to the researchers/practitioners in the maritime field. Actually, additional investigations might extensively be carried out regarding with a few points of the research.

- Drills should be performed after working hours and unplanned drills should be performed in order to find the effect of decreased alertness of seafarers.
- Drills should be performed with multinational crew in order to avoid effect of national behavior pattern
- Combined drills such as firefighting and abandon ship should be simulated in order to make detailed analyses for emergency preparedness level
- In this study, overall drill duration has been analyzed. However, each drill step duration for different fire teams should be analysed.
- The approach has been applied and tested in cargo ships. Passenger vessels emergency preparedness level should also be evaluated.
- Audit/inspection results and incident/accident analyses should be evaluated along with drill duration for comprehensive insight into determining ship emergency preparedness level.

- Cooling process which is one of the fire fighting drill steps should be evaluated before and after the step getting in fire zone.
- Approach developed in this study should be applied to any emergency at port/terminal/offshore facilities.

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APPENDICES

APPENDIX A: Factor Analysis for the Step Announcing the Fire via Public Addressor System

APPENDIX A: Factor Analysis for the Step Annuoncing the Fire via Public Addressor System.

Table A.1 : Linguistic assessments of the marine experts for announcing the fire via public addressor system.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
F1	NO, NO, NO, NO, NO	L, H, L, H, L	L, L, L, L, L	NO, NO, NO, NO, NO	NO, H, NO, NO, NO	L, NO, VL, VL, VL	L, VL, VL, VL, VL	L, L, VL, VL, VL	NO, NO, NO, NO, NO	H, VL, NO, VL, VL	H, L, NO, NO, NO	L, NO, VL, L, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	L, L, VL, VL, VL	H, NO, NO, H, L,	L, NO, VL, VL, VL	NO, VL, VL, VL, VL	NO, VL, NO, NO, NO	NO, VL, NO, NO, NO
F2	VH, VL, VL, VL, VL	NO, NO, NO, NO, NO	H, H, L, H, L	NO, NO, NO, NO, NO	NO, L, NO, NO, NO	L, NO, VL, VL, VL	VH, VL, VL, L, L	L, H, VL, L, L	NO, NO, NO, NO, NO	L, NO, NO, VL, NO	L, L, NO, NO, NO	NO, L, VL, VL, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	L, L, VL, VL, VL	L, NO, NO, NO, NO,	H, NO, VL, VL, VL	NO, NO, VL, VL,V L	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F3	VH, H, VL, L,V L	L, H, L, L, H	NO, NO, NO, NO, NO	NO, L,N O,N O, NO	NO, L, NO, NO, NO	L, NO, VL, VL, VL	H, VL, VL, L, L	VH, No, VL, L, L	NO, NO, NO, NO, NO	L, VL, NO, NO, NO	L, H, NO, NO, NO	NO, H, VL, L, L	NO, VL, NO, NO, NO	NO, VL, VL, VL, VL	L, H, VL, L, L	L, NO, NO, NO, NO	H, NO, VL, VL, VL	NO, H, VL, L, H	NO, H, NO, L, L	NO, H, NO, NO, NO
F4	NO, H, VL, L, VL	NO, H, L, L, L	NO, L, L, L, L	NO, NO, NO, NO, NO	NO, L, NO, NO, NO	NO, NO, VL, VL, VL	NO, L, VL, VL, VL	NO, L, VL, VL, VL	NO, L, NO, NO, VL	NO, NO, NO, NO, NO	NO, H, NO, NO, NO	NO, VH, VL, VL, H	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, H, VL, VL, VL	NO, NO, NO, NO, NO,	NO, L, VL, VL, VL,	NO, NO, VL, VL, VL,	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F5	NO, H, VL, VL, L	NO, VL, L, VL, VL	NO, VL, L, L, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, NO, VL, VL, NO	NO, VL, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, H, NO, NO, NO	NO, VH, VL, L, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, H, VL, VL, H	NO, NO, NO, NO, NO,	NO, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO

Table A.1 (continued) : Linguistic assessments of the marine experts for announcing the fire via public addressor system.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
F6	H, NO, VL, L, VL	H, NO, L, L, H	H, NO, L, L, L	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	H, NO, VL, L, L	H, NO, VL, VL, L	NO, NO, NO, NO, NO	L, NO, NO, NO, VL	L, L, NO, NO, NO,	NO, NO, VL, VL, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, NO, VL, VL, VL	L, NO, NO, L, L	H, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F7	VH, NO, VL, VL, L	H, NO, L, H, L	L, NO, L, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	H, NO, VL, VL, L	NO, NO, NO, NO, NO	L, NO, NO, NO, VL	L, NO, NO, NO, NO,	NO, NO, VL, L, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, NO, VL, VL, VL	L, NO, NO, VL, VL	H, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F8	VH, NO, VL, L, VL	NO, VL, L, VL, VL	H, VH, L, H, H,	NO, VL, NO, NO, NO	NO, L, NO, NO, NO	NO, NO, VL, VL, VL	VL, L, VL, VL, NO	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	H, VL, NO, L, L	H, L, NO, NO, NO	L, NO, VL, VL, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	L, NO, VL, VL, VL	H, NO, NO, NO, H	L, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F9	NO, NO, VL, VL, NO	NO, NO, L, NO, VL	NO, NO, L, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, NO, VL, NO, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	VL, NO, NO, NO, NO	L, NO, NO, NO, NO	L, NO, VL, L, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO,	L, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F10	H, VH, VL, L, H	L, H, L, L, H	L, VL, L, VL, VL	NO, NO, NO, NO, NO	NO, L, NO, NO, NO	L, L, VL, VL, VL	L, L, VL, VL, L	L, VL, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	H, VL, NO, NO, NO,	L, NO, VL, VL, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	L, NO, VL, VL, VL	H, L, NO, NO, NO,	L, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO,	NO, NO, NO, NO, NO,

Table A.1 (continued) : Linguistic assessments of the marine experts for announcing the fire via public addressor system.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**	**F19**	**F20**
F11	H, L, VL, VL, L	VL, L, L, VL, VL	VH, VL, L, L, L	NO, VL, NO, NO, NO	NO, H, NO, NO, NO	VL, L, VL, VL, VL	VL, H, VL, L, L	VL, VL, VL, VL, VL	NO, NO, NO, NO, NO	VL, VL, NO, VL, NO	NO, NO, NO, NO, NO,	VL, L, VL, L, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	VL, H, VL, VL, VL	H, L, NO, NO, NO	VH, NO, VL, VL, VL	VH, VL, VL, L, H	VH, VL, NO, L, H	VH, VL, NO, NO, NO
F12	NO, H, L, VL, L	NO, L, H, NO, VL	NO, NO, L, VL, VL	NO, NO, NO, NO, NO	NO, VL, NO, NO, NO	NO, VL, L, L, L	NO, VL, L, VL, VL	NO, NO, L, VL, VL	NO, L, NO, VL, NO	NO, NO, NO, NO, NO	NO, VL, NO, NO, NO	NO, NO, NO, VL, VL	NO, VL, NO, NO, VL	NO, VL, L, L, VL	NO, H, L, L, L	NO, VL, NO, NO, NO,	H, L, L, L, L,	NO, NO, L, L, L,	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F13	NO, NO, VL, VL, NO	NO, NO, L, VL, VL	NO, NO, L, VL, VL	NO, NO, NO, NO, NO;	NO, NO, NO, NO, NO	NO, NO, VL, NO, NO	NO, NO, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO,	NO, NO, VL, VL, L	NO, NO, NO, NO, NO	NO, VL, VL, VL, VL	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO,	NO, NO, VL, VL, VL,	NO, NO, VL, VL, VL	NO, NO, NO, NO, NO,	NO, NO, NO, NO, NO,
F14	NO, NO, L, VL, NO	NO, NO, H, L, VL	NO, NO, H, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, NO, L, VL, VL	NO, NO, L, VL, VL	NO, NO, L, VL, VL	NO, L, NO, NO, L	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO,	NO, H, L, L, L	NO, L, NO, NO, L	NO, NO, NO, NO, NO	NO, L, L, VL, VL	NO, NO, NO, NO, NO,	NO, L, L, L, L,	NO, NO, L, L, L,	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO
F15	NO, VL, VH, VL, NO	NO, VL, VH, VL, L	NO, VL, VH, VH, VH	NO, VL, NO, NO, NO	NO, VL, NO, NO, NO	NO, L, VH, L, VL	NO, VL, VH, VL, NO	NO, VL, VH, VL, L	NO, NO, NO, NO, NO	NO, L, NO, L, NO	NO, L, NO, NO, NO,	NO, H, VH, L, L	NO, L, NO, NO, L	NO, L, VH, VL, VL	NO, NO, NO, NO, NO	NO, L, NO, L, NO,	H, VL, VH, VH, VH,	NO, NO, VH, VL, NO	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO

Table A.1 (continued) : Linguistic assessments of the marine experts for announcing the fire via public addressor system.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
F16	VL, NO, VL, VL, NO	VL, VL, L, VL, VL	VL, VL, L, VL, VL	VL, L, NO, NO, NO;	VL, VL, NO, NO, NO	VL, L, VL, VL, VL	VL, VL, VL, VL, VL	VL, VL, VL, VL, VL	NO, NO, NO, NO, NO	VL, NO, NO, NO, NO	VL, NO, NO, NO, NO,	VL, H, VL, L, L	VL, NO, NO, NO, NO	VL, NO, VL, VL, VL	VL, H, VL, VL, VL	NO, NO, NO, NO, NO	VL, NO, VL, VL, VL	NO, VL, VL, VL, VL	NO, VL, NO, NO, NO	NO, VL, NO, NO, NO
F17	NO, H, VL, VL, L	NO, VH, L, L, H	NO, VH, L, L, L	NO, H, NO, NO, NO	NO, VH, NO, NO, NO	NO, H, VL, L, VL	NO, VH, VL, VL, L	NO, VH, VL, VL, VL	NO, L, NO, VL, NO	NO, H, NO, L, VL	NO, NO, NO, NO, NO	NO, VH, VL, L, L	NO, NO, NO, NO, NO	NO, NO, VL, VL, VL	NO, VH, VL, VL, VL	NO, H, NO, L, H,	NO, NO, NO, NO, NO	NO, VH, VL, VL, VL	NO, VH, NO, H, L	NO, H, NO, NO, NO
F18	NO, NO, VL, NO, VL	NO, VH, L, L, H	NO, L, L, L, NO	NO, NO, NO, NO, NO	NO, H, NO, NO, NO	NO, VL, VL, VL, VL	NO, H, VL, VL, VL	NO, L, VL, VL, VL	NO, VL, NO, NO, NO	NO, L, NO, O, VL	NO, H, NO, NO, NO	NO, L, VL, VL, L	NO, VL, NO, NO, NO	NO, VL, VL, VL, VL	NO, L, VL, VL, VL	NO, VL, NO, NO, NO	NO, VL, VL, VL, VL	(NO, NO, NO, NO, NO	(NO, H, NO, H, L	(NO, H, NO, NO, NO
F19	NO, L, VL, NO, VL	NO, VH, L, L, L	NO, H, L, L, L	NO, NO, NO, NO, NO	NO, H, NO, NO, NO	NO, L, VL, VL, VL	NO, H, VL, L, VL	NO, H, VL, VL, VL	NO, NO, NO, NO, NO	NO, VL, NO, NO, VL	NO, H, NO, NO, NO,	NO, L, VL, L, L	NO, NO, NO, NO, NO	NO, VL, VL, VL, VL	NO, L, VL, VL, VL	NO, L, NO, NO, L	L, NO, VL, VL, VL	NO, H, VL, VL, VL	NO, NO, NO, NO, NO	NO, H, NO, NO, NO
F20	NO, NO, VL, VL, NO	NO, VH, L, L, L	NO, L, L, L, L	NO, NO, NO, NO, NO	NO, L, NO, NO, NO	NO, NO, VL, VL, VL	NO, L, VL, VL, VL	NO, L, VL, VL, VL	NO, NO, NO, NO, NO	NO, NO, NO, NO, NO	NO, H, NO, NO, NO	NO, L, VL, VL, L	NO, NO, NO, NO, NO	NO, L, VL, VL, VL	NO, VL, VL, VL, VL	NO, NO, NO, NO, NO,	NO, NO, VL, VL, VL	NO, H, VL, VL, VL	NO, H, NO, L, H	NO, NO, NO, NO, NO

Table A.2 : The initial direct-relation fuzzy matrix.

	F1			F2			F3			F4			F5			F6			F7		
F1	0,00	0,00	0,25	0,35	0,60	0,85	0,25	0,50	0,75	0,00	0,00	0,25	0,10	0,15	0,40	0,05	0,25	0,50	0,05	0,30	0,55
F2	0,00	0,40	0,60	0,00	0,00	0,25	0,40	0,65	0,90	0,00	0,00	0,25	0,05	0,10	0,35	0,05	0,25	0,50	0,25	0,50	0,70
F3	0,30	0,55	0,75	0,35	0,60	0,85	0,00	0,00	0,25	0,05	0,10	0,35	0,05	0,10	0,35	0,05	0,25	0,50	0,20	0,45	0,70
F4	0,15	0,35	0,60	0,25	0,45	0,70	0,20	0,40	0,65	0,00	0,00	0,25	0,05	0,10	0,35	0,00	0,15	0,40	0,05	0,25	0,50
F5	0,15	0,35	0,60	0,05	0,25	0,50	0,10	0,30	0,55	0,00	0,00	0,25	0,00	0,00	0,25	0,00	0,15	0,40	0,00	0,10	0,35
F6	0,15	0,35	0,60	0,30	0,50	0,75	0,25	0,45	0,70	0,00	0,00	0,25	0,00	0,00	0,25	0,00	0,00	0,25	0,20	0,40	0,65
F7	0,20	0,40	0,60	0,30	0,50	0,75	0,10	0,30	0,55	0,00	0,00	0,25	0,00	0,00	0,25	0,00	0,15	0,40	0,00	0,00	0,25
F8	0,20	0,40	0,60	0,05	0,25	0,50	0,50	0,75	0,95	0,00	0,05	0,30	0,05	0,10	0,35	0,00	0,15	0,40	0,05	0,25	0,50
F9	0,00	0,10	0,35	0,05	0,15	0,40	0,05	0,20	0,45	0,00	0,00	0,25	0,00	0,00	0,25	0,00	0,15	0,40	0,00	0,10	0,35
F10	0,40	0,65	0,85	0,35	0,60	0,85	0,10	0,35	0,60	0,00	0,00	0,25	0,05	0,10	0,35	0,10	0,35	0,60	0,15	0,40	0,65
F11	0,20	0,45	0,70	0,10	0,35	0,60	0,30	0,55	0,75	0,00	0,05	0,30	0,10	0,15	0,40	0,05	0,30	0,55	0,20	0,45	0,70
F12	0,20	0,40	0,65	0,15	0,30	0,55	0,05	0,20	0,45	0,00	0,00	0,25	0,00	0,05	0,30	0,15	0,35	0,60	0,05	0,25	0,50
F13	0,00	0,10	0,35	0,05	0,20	0,45	0,05	0,20	0,45	0,00	0,00	0,25	0,00	0,00	0,25	0,00	0,05	0,30	0,00	0,15	0,40
F14	0,05	0,15	0,40	0,15	0,30	0,55	0,10	0,25	0,50	0,00	0,00	0,25	0,00	0,00	0,25	0,05	0,20	0,45	0,05	0,20	0,45
F15	0,15	0,30	0,50	0,20	0,40	0,60	0,45	0,65	0,75	0,00	0,05	0,30	0,00	0,05	0,30	0,25	0,45	0,65	0,15	0,30	0,50
F16	0,00	0,15	0,40	0,05	0,30	0,55	0,05	0,30	0,55	0,05	0,15	0,40	0,00	0,10	0,35	0,05	0,30	0,55	0,00	0,25	0,50
F17	0,15	0,35	0,60	0,35	0,55	0,75	0,30	0,50	0,70	0,10	0,15	0,40	0,15	0,20	0,40	0,15	0,35	0,60	0,20	0,40	0,60
F18	0,00	0,10	0,35	0,35	0,55	0,75	0,15	0,30	0,55	0,00	0,00	0,25	0,10	0,15	0,40	0,00	0,20	0,45	0,10	0,30	0,55
F19	0,05	0,20	0,45	0,30	0,50	0,70	0,25	0,45	0,70	0,00	0,00	0,25	0,10	0,15	0,40	0,05	0,25	0,50	0,15	0,35	0,60
F20	0,00	0,10	0,35	0,30	0,50	0,70	0,20	0,40	0,65	0,00	0,00	0,25	0,05	0,10	0,35	0,00	0,15	0,40	0,05	0,25	0,50

Table A.2 (continued) : The initial direct-relation fuzzy matrix.

	F8			F9			F10			F11			F12			F13			F14		
F1	0,10	0,30	0,50	0,00	0,00	0,25	0,10	0,30	0,55	0,15	0,25	0,50	0,15	0,35	0,60	0,00	0,00	0,25	0,00	0,15	0,40
F2	0,25	0,45	0,65	0,00	0,00	0,25	0,05	0,15	0,40	0,10	0,20	0,45	0,10	0,30	0,55	0,00	0,00	0,25	0,00	0,15	0,40
F3	0,25	0,40	0,60	0,00	0,00	0,25	0,05	0,15	0,40	0,15	0,25	0,50	0,20	0,40	0,65	0,00	0,05	0,30	0,00	0,20	0,45
F4	0,05	0,25	0,45	0,05	0,15	0,40	0,00	0,00	0,25	0,10	0,15	0,40	0,25	0,45	0,65	0,00	0,00	0,25	0,00	0,15	0,40
F5	0,00	0,20	0,40	0,00	0,00	0,25	0,00	0,00	0,25	0,10	0,15	0,40	0,25	0,45	0,65	0,00	0,00	0,25	0,00	0,15	0,40
F6	0,15	0,30	0,50	0,00	0,00	0,25	0,05	0,15	0,40	0,10	0,20	0,45	0,05	0,20	0,45	0,00	0,00	0,25	0,00	0,15	0,40
F7	0,15	0,30	0,50	0,00	0,00	0,25	0,05	0,15	0,40	0,05	0,10	0,35	0,10	0,25	0,50	0,00	0,00	0,25	0,00	0,15	0,40
F8	0,00	0,00	0,20	0,00	0,00	0,25	0,20	0,40	0,65	0,15	0,25	0,50	0,10	0,30	0,55	0,00	0,00	0,25	0,00	0,15	0,40
F9	0,00	0,15	0,35	0,00	0,00	0,25	0,00	0,05	0,30	0,05	0,10	0,35	0,15	0,35	0,60	0,00	0,00	0,25	0,00	0,15	0,40
F10	0,05	0,25	0,45	0,00	0,00	0,25	0,00	0,00	0,25	0,10	0,20	0,45	0,10	0,30	0,55	0,00	0,00	0,25	0,00	0,15	0,40
F11	0,00	0,20	0,40	0,00	0,00	0,25	0,00	0,15	0,40	0,00	0,00	0,25	0,15	0,40	0,65	0,00	0,00	0,25	0,00	0,15	0,40
F12	0,05	0,20	0,40	0,05	0,15	0,40	0,00	0,00	0,25	0,00	0,05	0,30	0,00	0,10	0,35	0,00	0,10	0,35	0,10	0,30	0,55
F13	0,00	0,15	0,35	0,00	0,00	0,25	0,00	0,00	0,25	0,00	0,00	0,25	0,05	0,20	0,45	0,00	0,00	0,25	0,00	0,20	0,45
F14	0,05	0,20	0,40	0,10	0,20	0,45	0,00	0,00	0,25	0,00	0,00	0,25	0,25	0,45	0,70	0,10	0,20	0,45	0,00	0,00	0,25
F15	0,20	0,40	0,55	0,00	0,00	0,25	0,10	0,20	0,45	0,05	0,10	0,35	0,35	0,55	0,75	0,10	0,20	0,45	0,20	0,40	0,60
F16	0,00	0,20	0,40	0,00	0,00	0,25	0,00	0,05	0,30	0,00	0,05	0,30	0,20	0,45	0,70	0,00	0,05	0,30	0,00	0,20	0,45
F17	0,15	0,35	0,50	0,05	0,15	0,40	0,15	0,30	0,55	0,00	0,00	0,25	0,25	0,45	0,65	0,00	0,00	0,25	0,00	0,15	0,40
F18	0,05	0,25	0,45	0,00	0,05	0,30	0,05	0,15	0,40	0,10	0,15	0,40	0,10	0,30	0,55	0,00	0,05	0,30	0,00	0,20	0,45
F19	0,10	0,30	0,50	0,00	0,00	0,25	0,00	0,10	0,35	0,10	0,15	0,40	0,15	0,35	0,60	0,00	0,00	0,25	0,00	0,20	0,45
F20	0,05	0,25	0,45	0,00	0,00	0,25	0,00	0,00	0,25	0,10	0,15	0,40	0,10	0,30	0,55	0,00	0,00	0,25	0,05	0,25	0,50

Table A.2 (continued) : The initial direct-relation fuzzy matrix.

	F15			F16			F17			F18			F19			F20		
F1	0,10	0,35	0,60	0,25	0,40	0,65	0,05	0,25	0,50	0,00	0,20	0,45	0,00	0,05	0,30	0,00	0,05	0,30
F2	0,10	0,35	0,60	0,05	0,10	0,35	0,10	0,30	0,55	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F3	0,25	0,50	0,75	0,05	0,10	0,35	0,10	0,30	0,55	0,25	0,45	0,70	0,20	0,35	0,60	0,10	0,15	0,40
F4	0,10	0,30	0,55	0,00	0,00	0,25	0,05	0,25	0,50	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F5	0,20	0,40	0,65	0,00	0,00	0,25	0,00	0,15	0,40	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F6	0,00	0,15	0,40	0,15	0,30	0,55	0,10	0,30	0,55	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F7	0,00	0,15	0,40	0,05	0,20	0,45	0,10	0,30	0,55	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F8	0,05	0,25	0,50	0,20	0,30	0,55	0,05	0,25	0,50	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F9	0,00	0,15	0,40	0,00	0,00	0,25	0,05	0,25	0,50	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F10	0,05	0,25	0,50	0,15	0,25	0,50	0,05	0,25	0,50	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F11	0,10	0,35	0,60	0,15	0,25	0,50	0,15	0,35	0,55	0,30	0,55	0,75	0,30	0,50	0,70	0,15	0,25	0,45
F12	0,25	0,45	0,70	0,00	0,05	0,30	0,30	0,55	0,80	0,15	0,30	0,55	0,00	0,00	0,25	0,00	0,00	0,25
F13	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,15	0,40	0,00	0,15	0,40	0,00	0,00	0,25	0,00	0,00	0,25
F14	0,10	0,30	0,55	0,00	0,00	0,25	0,20	0,40	0,65	0,15	0,30	0,55	0,00	0,00	0,25	0,00	0,00	0,25
F15	0,00	0,00	0,25	0,10	0,20	0,45	0,55	0,80	0,90	0,15	0,25	0,45	0,00	0,00	0,25	0,00	0,00	0,25
F16	0,10	0,35	0,60	0,00	0,00	0,25	0,00	0,20	0,45	0,00	0,20	0,45	0,00	0,05	0,30	0,00	0,05	0,30
F17	0,15	0,35	0,55	0,25	0,40	0,65	0,00	0,00	0,25	0,15	0,35	0,55	0,30	0,45	0,65	0,10	0,15	0,40
F18	0,05	0,25	0,50	0,00	0,05	0,30	0,00	0,20	0,45	0,00	0,00	0,25	0,25	0,40	0,65	0,10	0,15	0,40
F19	0,05	0,25	0,50	0,10	0,20	0,45	0,05	0,25	0,50	0,10	0,30	0,55	0,00	0,00	0,25	0,10	0,15	0,40
F20	0,00	0,20	0,45	0,00	0,00	0,25	0,00	0,15	0,40	0,10	0,30	0,55	0,25	0,40	0,65	0,00	0,00	0,25

Table A.3 : The normalized direct-relation fuzzy matrix.

	F1			F2			F3			F4			F5			F6			F7		
F1	0,00	0,00	0,02	0,03	0,05	0,07	0,02	0,04	0,06	0,00	0,00	0,02	0,01	0,01	0,03	0,00	0,02	0,04	0,00	0,02	0,04
F2	0,00	0,03	0,05	0,00	0,00	0,02	0,03	0,05	0,07	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,02	0,04	0,02	0,04	0,06
F3	0,02	0,04	0,06	0,03	0,05	0,07	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,02	0,04	0,02	0,04	0,06
F4	0,01	0,03	0,05	0,02	0,04	0,06	0,02	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,02	0,04
F5	0,01	0,03	0,05	0,00	0,02	0,04	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03
F6	0,01	0,03	0,05	0,02	0,04	0,06	0,02	0,04	0,06	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,00	0,02	0,02	0,03	0,05
F7	0,02	0,03	0,05	0,02	0,04	0,06	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,00	0,02
F8	0,02	0,03	0,05	0,00	0,02	0,04	0,04	0,06	0,08	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,02	0,04
F9	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03
F10	0,03	0,05	0,07	0,03	0,05	0,07	0,01	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,03	0,05	0,01	0,03	0,05
F11	0,02	0,04	0,06	0,01	0,03	0,05	0,02	0,04	0,06	0,00	0,00	0,02	0,01	0,01	0,03	0,00	0,02	0,04	0,02	0,04	0,06
F12	0,02	0,03	0,05	0,01	0,02	0,04	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,01	0,03	0,05	0,00	0,02	0,04
F13	0,00	0,01	0,03	0,00	0,02	0,04	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,01	0,03
F14	0,00	0,01	0,03	0,01	0,02	0,04	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,02	0,04	0,00	0,02	0,04
F15	0,01	0,02	0,04	0,02	0,03	0,05	0,04	0,05	0,06	0,00	0,00	0,02	0,00	0,00	0,02	0,02	0,04	0,05	0,01	0,02	0,04
F16	0,00	0,01	0,03	0,00	0,02	0,04	0,00	0,02	0,04	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,02	0,04	0,00	0,02	0,04
F17	0,01	0,03	0,05	0,03	0,04	0,06	0,02	0,04	0,06	0,01	0,01	0,03	0,01	0,02	0,03	0,01	0,03	0,05	0,02	0,03	0,05
F18	0,00	0,01	0,03	0,03	0,04	0,06	0,01	0,02	0,04	0,00	0,00	0,02	0,01	0,01	0,03	0,00	0,02	0,04	0,01	0,02	0,04
F19	0,00	0,02	0,04	0,02	0,04	0,06	0,02	0,04	0,06	0,00	0,00	0,02	0,01	0,01	0,03	0,00	0,02	0,04	0,01	0,03	0,05
F20	0,00	0,01	0,03	0,02	0,04	0,06	0,02	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,02	0,04

Table A.3 (continued) : The normalized direct-relation fuzzy matrix.

	F8			F9			F10			F11			F12			F13			F14		
F1	0,01	0,02	0,04	0,00	0,00	0,02	0,01	0,02	0,04	0,01	0,02	0,04	0,01	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03
F2	0,02	0,04	0,05	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,02	0,04	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03
F3	0,02	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,02	0,04	0,02	0,03	0,05	0,00	0,00	0,02	0,00	0,02	0,04
F4	0,00	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,01	0,01	0,03	0,02	0,04	0,05	0,00	0,00	0,02	0,00	0,01	0,03
F5	0,00	0,02	0,03	0,00	0,00	0,02	0,00	0,00	0,02	0,01	0,01	0,03	0,02	0,04	0,05	0,00	0,00	0,02	0,00	0,01	0,03
F6	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,02	0,04	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03
F7	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03
F8	0,00	0,00	0,02	0,00	0,00	0,02	0,02	0,03	0,05	0,01	0,02	0,04	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03
F9	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03
F10	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,01	0,02	0,04	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03
F11	0,00	0,02	0,03	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,00	0,02	0,01	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03
F12	0,00	0,02	0,03	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,01	0,02	0,04
F13	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,02	0,04
F14	0,00	0,02	0,03	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,02	0,04	0,06	0,01	0,02	0,04	0,00	0,00	0,02
F15	0,02	0,03	0,04	0,00	0,00	0,02	0,01	0,02	0,04	0,00	0,01	0,03	0,03	0,04	0,06	0,01	0,02	0,04	0,02	0,03	0,05
F16	0,00	0,02	0,03	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,00	0,02	0,02	0,04	0,06	0,00	0,00	0,02	0,00	0,02	0,04
F17	0,01	0,03	0,04	0,00	0,01	0,03	0,01	0,02	0,04	0,00	0,00	0,02	0,02	0,04	0,05	0,00	0,00	0,02	0,00	0,01	0,03
F18	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,01	0,03	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,02	0,04
F19	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,01	0,03	0,01	0,03	0,05	0,00	0,00	0,02	0,00	0,02	0,04
F20	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02	0,01	0,01	0,03	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,02	0,04

Table A.3 (continued) : The normalized direct-relation fuzzy matrix.

	F15			F16			F17			F18			F19			F20		
F1	0,01	0,03	0,05	0,02	0,03	0,05	0,00	0,02	0,04	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02
F2	0,01	0,03	0,05	0,00	0,01	0,03	0,01	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F3	0,02	0,04	0,06	0,00	0,01	0,03	0,01	0,02	0,04	0,02	0,04	0,06	0,02	0,03	0,05	0,01	0,01	0,03
F4	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F5	0,02	0,03	0,05	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F6	0,00	0,01	0,03	0,01	0,02	0,04	0,01	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F7	0,00	0,01	0,03	0,00	0,02	0,04	0,01	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F8	0,00	0,02	0,04	0,02	0,02	0,04	0,00	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F9	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F10	0,00	0,02	0,04	0,01	0,02	0,04	0,00	0,02	0,04	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F11	0,01	0,03	0,05	0,01	0,02	0,04	0,01	0,03	0,04	0,02	0,04	0,06	0,02	0,04	0,06	0,01	0,02	0,04
F12	0,02	0,04	0,06	0,00	0,00	0,02	0,02	0,04	0,06	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02
F13	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,01	0,03	0,00	0,01	0,03	0,00	0,00	0,02	0,00	0,00	0,02
F14	0,01	0,02	0,04	0,00	0,00	0,02	0,02	0,03	0,05	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02
F15	0,00	0,00	0,02	0,01	0,02	0,04	0,04	0,06	0,07	0,01	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02
F16	0,01	0,03	0,05	0,00	0,00	0,02	0,00	0,02	0,04	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,00	0,02
F17	0,01	0,03	0,04	0,02	0,03	0,05	0,00	0,00	0,02	0,01	0,03	0,04	0,02	0,04	0,05	0,01	0,01	0,03
F18	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,02	0,04	0,00	0,00	0,02	0,02	0,03	0,05	0,01	0,01	0,03
F19	0,00	0,02	0,04	0,01	0,02	0,04	0,00	0,02	0,04	0,01	0,02	0,04	0,00	0,00	0,02	0,01	0,01	0,03
F20	0,00	0,02	0,04	0,00	0,00	0,02	0,00	0,01	0,03	0,01	0,02	0,04	0,02	0,03	0,05	0,00	0,00	0,02

Table A.4 : The total-relation fuzzy matrix.

	F1			F2			F3			F4			F5			F6			F7		
F1	0,00	0,01	0,13	0,03	0,06	0,19	0,02	0,06	0,18	0,00	0,00	0,08	0,01	0,02	0,10	0,00	0,03	0,14	0,01	0,04	0,15
F2	0,00	0,05	0,15	0,00	0,02	0,14	0,03	0,07	0,19	0,00	0,00	0,07	0,00	0,01	0,09	0,00	0,03	0,13	0,02	0,05	0,16
F3	0,03	0,06	0,17	0,03	0,07	0,20	0,00	0,02	0,16	0,00	0,01	0,09	0,01	0,01	0,10	0,01	0,03	0,14	0,02	0,05	0,17
F4	0,01	0,04	0,14	0,02	0,05	0,17	0,02	0,05	0,16	0,00	0,00	0,07	0,00	0,01	0,09	0,00	0,02	0,12	0,01	0,03	0,14
F5	0,01	0,04	0,14	0,01	0,03	0,14	0,01	0,03	0,15	0,00	0,00	0,07	0,00	0,00	0,07	0,00	0,02	0,11	0,00	0,02	0,12
F6	0,01	0,04	0,15	0,03	0,05	0,17	0,02	0,05	0,17	0,00	0,00	0,07	0,00	0,00	0,08	0,00	0,01	0,11	0,02	0,04	0,15
F7	0,02	0,04	0,14	0,03	0,05	0,17	0,01	0,04	0,15	0,00	0,00	0,07	0,00	0,00	0,08	0,00	0,02	0,11	0,00	0,01	0,11
F8	0,02	0,05	0,15	0,01	0,04	0,16	0,04	0,07	0,19	0,00	0,01	0,08	0,00	0,01	0,09	0,00	0,02	0,12	0,01	0,03	0,14
F9	0,00	0,01	0,11	0,00	0,02	0,13	0,00	0,02	0,13	0,00	0,00	0,06	0,00	0,00	0,07	0,00	0,02	0,10	0,00	0,01	0,11
F10	0,03	0,06	0,17	0,03	0,06	0,19	0,01	0,04	0,17	0,00	0,00	0,07	0,00	0,01	0,09	0,01	0,04	0,14	0,01	0,04	0,16
F11	0,02	0,05	0,17	0,01	0,05	0,18	0,03	0,06	0,19	0,00	0,01	0,08	0,01	0,02	0,10	0,00	0,04	0,15	0,02	0,05	0,17
F12	0,02	0,04	0,15	0,01	0,04	0,16	0,01	0,03	0,15	0,00	0,00	0,07	0,00	0,01	0,08	0,01	0,04	0,14	0,01	0,03	0,14
F13	0,00	0,01	0,10	0,00	0,02	0,12	0,00	0,02	0,12	0,00	0,00	0,06	0,00	0,00	0,07	0,00	0,01	0,09	0,00	0,02	0,11
F14	0,01	0,02	0,12	0,01	0,04	0,15	0,01	0,03	0,15	0,00	0,00	0,07	0,00	0,00	0,08	0,00	0,02	0,12	0,01	0,02	0,13
F15	0,02	0,04	0,15	0,02	0,05	0,18	0,04	0,07	0,18	0,00	0,01	0,08	0,00	0,01	0,09	0,02	0,05	0,15	0,01	0,04	0,15
F16	0,00	0,02	0,13	0,00	0,04	0,15	0,00	0,04	0,15	0,00	0,01	0,08	0,00	0,01	0,09	0,00	0,03	0,13	0,00	0,03	0,13
F17	0,01	0,04	0,16	0,03	0,06	0,19	0,03	0,06	0,19	0,01	0,01	0,09	0,01	0,02	0,10	0,01	0,04	0,15	0,02	0,05	0,16
F18	0,00	0,02	0,13	0,03	0,06	0,18	0,01	0,04	0,16	0,00	0,00	0,07	0,01	0,01	0,09	0,00	0,02	0,12	0,01	0,03	0,14
F19	0,01	0,03	0,14	0,03	0,06	0,18	0,02	0,05	0,17	0,00	0,00	0,07	0,01	0,02	0,09	0,00	0,03	0,13	0,01	0,04	0,15
F20	0,00	0,02	0,12	0,03	0,05	0,17	0,02	0,05	0,16	0,00	0,00	0,07	0,00	0,01	0,09	0,00	0,02	0,12	0,01	0,03	0,13

Table A.4 (continued) : The total-relation fuzzy matrix.

	F8			F9			F10			F11			F12			F13			F14		
F1	0,01	0,04	0,13	0,00	0,00	0,08	0,01	0,03	0,12	0,01	0,03	0,12	0,01	0,04	0,16	0,00	0,00	0,08	0,00	0,02	0,12
F2	0,02	0,05	0,14	0,00	0,00	0,07	0,00	0,02	0,10	0,01	0,02	0,11	0,01	0,04	0,15	0,00	0,00	0,07	0,00	0,02	0,11
F3	0,02	0,05	0,15	0,00	0,00	0,08	0,01	0,02	0,11	0,01	0,03	0,12	0,02	0,05	0,18	0,00	0,01	0,09	0,00	0,03	0,13
F4	0,01	0,03	0,12	0,00	0,01	0,08	0,00	0,01	0,09	0,01	0,02	0,10	0,02	0,05	0,16	0,00	0,00	0,07	0,00	0,02	0,11
F5	0,00	0,02	0,11	0,00	0,00	0,07	0,00	0,00	0,08	0,01	0,02	0,09	0,02	0,04	0,15	0,00	0,00	0,07	0,00	0,02	0,10
F6	0,01	0,03	0,12	0,00	0,00	0,07	0,00	0,02	0,10	0,01	0,02	0,10	0,01	0,03	0,14	0,00	0,00	0,07	0,00	0,02	0,11
F7	0,01	0,03	0,12	0,00	0,00	0,07	0,00	0,02	0,10	0,00	0,01	0,09	0,01	0,03	0,14	0,00	0,00	0,07	0,00	0,02	0,10
F8	0,00	0,01	0,10	0,00	0,00	0,07	0,02	0,04	0,12	0,01	0,03	0,11	0,01	0,04	0,15	0,00	0,00	0,07	0,00	0,02	0,11
F9	0,00	0,02	0,10	0,00	0,00	0,06	0,00	0,01	0,08	0,00	0,01	0,08	0,01	0,03	0,13	0,00	0,00	0,06	0,00	0,02	0,10
F10	0,01	0,03	0,13	0,00	0,00	0,07	0,00	0,01	0,09	0,01	0,02	0,11	0,01	0,04	0,16	0,00	0,00	0,08	0,00	0,02	0,11
F11	0,00	0,03	0,13	0,00	0,00	0,08	0,00	0,02	0,11	0,00	0,01	0,10	0,01	0,05	0,18	0,00	0,00	0,08	0,00	0,02	0,12
F12	0,01	0,03	0,12	0,00	0,01	0,08	0,00	0,01	0,09	0,00	0,01	0,09	0,00	0,02	0,14	0,00	0,01	0,08	0,01	0,03	0,12
F13	0,00	0,02	0,09	0,00	0,00	0,06	0,00	0,00	0,07	0,00	0,00	0,07	0,00	0,02	0,12	0,00	0,00	0,06	0,00	0,02	0,10
F14	0,01	0,02	0,11	0,01	0,02	0,08	0,00	0,00	0,08	0,00	0,00	0,08	0,02	0,05	0,15	0,01	0,02	0,08	0,00	0,01	0,09
F15	0,02	0,05	0,14	0,00	0,00	0,08	0,01	0,02	0,11	0,01	0,01	0,10	0,03	0,06	0,18	0,01	0,02	0,09	0,02	0,04	0,13
F16	0,00	0,02	0,11	0,00	0,00	0,07	0,00	0,01	0,09	0,00	0,01	0,09	0,02	0,05	0,16	0,00	0,01	0,07	0,00	0,02	0,11
F17	0,01	0,04	0,14	0,00	0,01	0,09	0,01	0,03	0,12	0,00	0,01	0,10	0,02	0,05	0,17	0,00	0,00	0,08	0,00	0,02	0,12
F18	0,01	0,03	0,12	0,00	0,01	0,08	0,00	0,02	0,10	0,01	0,02	0,10	0,01	0,04	0,15	0,00	0,01	0,08	0,00	0,02	0,11
F19	0,01	0,03	0,13	0,00	0,00	0,07	0,00	0,01	0,10	0,01	0,02	0,10	0,01	0,04	0,16	0,00	0,00	0,07	0,00	0,02	0,12
F20	0,01	0,03	0,12	0,00	0,00	0,07	0,00	0,00	0,09	0,01	0,02	0,10	0,01	0,03	0,15	0,00	0,00	0,07	0,00	0,03	0,12

Table A.4 (continued) : The total-relation fuzzy matrix.

	F15			F16			F17			F18			F19			F20		
F1	0,01	0,04	0,15	0,02	0,04	0,13	0,01	0,03	0,15	0,00	0,03	0,13	0,00	0,01	0,10	0,00	0,01	0,08
F2	0,01	0,04	0,15	0,01	0,02	0,10	0,01	0,04	0,14	0,00	0,02	0,12	0,00	0,00	0,09	0,00	0,00	0,08
F3	0,02	0,05	0,17	0,01	0,02	0,12	0,01	0,04	0,16	0,02	0,05	0,16	0,02	0,03	0,12	0,01	0,01	0,10
F4	0,01	0,03	0,14	0,00	0,01	0,09	0,01	0,03	0,14	0,00	0,02	0,12	0,00	0,00	0,08	0,00	0,00	0,07
F5	0,02	0,04	0,14	0,00	0,00	0,09	0,00	0,02	0,12	0,00	0,02	0,11	0,00	0,00	0,08	0,00	0,00	0,07
F6	0,00	0,02	0,13	0,01	0,03	0,12	0,01	0,03	0,14	0,00	0,02	0,12	0,00	0,00	0,09	0,00	0,00	0,07
F7	0,00	0,02	0,12	0,00	0,02	0,10	0,01	0,03	0,13	0,00	0,02	0,11	0,00	0,00	0,08	0,00	0,00	0,07
F8	0,01	0,03	0,14	0,02	0,03	0,12	0,01	0,03	0,14	0,00	0,02	0,12	0,00	0,01	0,09	0,00	0,00	0,08
F9	0,00	0,02	0,11	0,00	0,00	0,08	0,00	0,03	0,12	0,00	0,02	0,10	0,00	0,00	0,07	0,00	0,00	0,06
F10	0,01	0,03	0,14	0,01	0,03	0,12	0,01	0,03	0,14	0,00	0,02	0,12	0,00	0,00	0,09	0,00	0,00	0,08
F11	0,01	0,04	0,16	0,01	0,03	0,13	0,01	0,04	0,16	0,03	0,06	0,16	0,03	0,05	0,13	0,01	0,02	0,10
F12	0,02	0,05	0,15	0,00	0,01	0,10	0,03	0,05	0,16	0,01	0,03	0,13	0,00	0,00	0,09	0,00	0,00	0,07
F13	0,00	0,02	0,11	0,00	0,00	0,08	0,00	0,02	0,11	0,00	0,02	0,10	0,00	0,00	0,07	0,00	0,00	0,06
F14	0,01	0,03	0,13	0,00	0,01	0,09	0,02	0,04	0,14	0,01	0,03	0,12	0,00	0,00	0,08	0,00	0,00	0,07
F15	0,00	0,02	0,13	0,01	0,02	0,12	0,05	0,08	0,18	0,01	0,03	0,13	0,00	0,01	0,09	0,00	0,00	0,08
F16	0,01	0,04	0,14	0,00	0,01	0,09	0,00	0,03	0,13	0,00	0,02	0,12	0,00	0,01	0,09	0,00	0,01	0,08
F17	0,01	0,04	0,16	0,02	0,04	0,14	0,00	0,02	0,13	0,01	0,04	0,14	0,02	0,04	0,13	0,01	0,01	0,09
F18	0,01	0,03	0,14	0,00	0,01	0,10	0,00	0,03	0,13	0,00	0,01	0,11	0,02	0,04	0,12	0,01	0,01	0,09
F19	0,01	0,03	0,14	0,01	0,02	0,11	0,01	0,03	0,14	0,01	0,03	0,13	0,00	0,00	0,09	0,01	0,01	0,09
F20	0,00	0,03	0,13	0,00	0,01	0,09	0,00	0,02	0,13	0,01	0,03	0,13	0,02	0,04	0,12	0,00	0,00	0,07

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- **Taç, B. Ö.,** Akyüz, E., & Çelik, M. (2018). Gemi İşletmeciliğinde Acil Durum Yönetimi Etkinliğini Değerlendirme ve İyileştirme Üzerine Uygulamalı Bir Araştırma Yaklaşımı Önerisi. *Journal of Transportation and Logistics*, *3*(2), 35-51.

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