İSTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A METHODOLOGY PROPOSAL TOWARDS SCHEDULING OF SHIP REPAIR AND MAINTENANCE OPERATIONS

M.Sc. THESIS

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Department of Maritime Transportation Engineering

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JUNE 2018

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GEMİ BAKIM VE ONARIM OPERASYONLARININ PROGRAMLANMASINA YÖNELİK BİR YÖNTEM ÖNERİSİ

YÜKSEK LİSANS TEZİ

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HAZİRAN 2018

Barış YİĞİN, a M.Sc. student of ITU Institute of / Graduate School of Science Engineering and Technology student ID 512161023, successfully defended the thesis entitled "A METHODOLOGY PROPOSAL TOWARDS SCHEDULING OF SHIP REPAIR AND MAINTENANCE OPERATIONS", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Assoc. Prof. Dr. Metin ÇELİK** İstanbul Technical University	....
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Date of Submission : 04 May 2018
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To my wife and my son,

FOREWORD

I would like to thank my thesis advisor Assoc. Prof. Dr. Metin ÇELİK for his continuous support and guidance during my research, my colleagues and friends for their encouragements during my research.

I would like to also thank my wife for her patience and understanding during my lectures and research and support she has provided for me to accomplish my targets.

May 2018

Barış YİĞİN
(Marine Engineer)

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ABBREVIATIONS

AHP : Analytic Hierarchy Process
ANP : Analytic Network Process
CBM : Condition Based Maintenance
CM : Corrective Maintenance
ELECTRE : Elimination Et Choix Traduisant la Realité
FMECA : Failure Mode Effect and Criticality Analysis
FTA : Fault Tree Analysis
IMO : International Maritime Organization
ISM : International Safety Management
MARPOL : The International Convention for the Prevention of Pollution from Ships
MCDM : Multi Criteria Decision Making
OPEX : Operating Expenses
PM : Preventive Maintenance
PMS : Planned Maintenance System
PROMETHEE : Preference Ranking Organization Method for Enrichment Evaluations
RCA : Root Cause Analysis
RCM : Reliability Centered Maintenance
RRCM : Reliability and Risk Centered Maintenance
SMAA : Stochastic Multicriteria Acceptability Analysis
SOLAS : Safety of Life At Sea
TOPSIS : Technique for Order of Preference by Similarity to Ideal Solution
VIKOR : Multicriteria Optimization and Compromise Solution

SYMBOLS

$\boldsymbol{\lambda}$	**:** Normalized Direct Relation Matrix
$\boldsymbol{X}$	**:** Direct Relation Matrix
$\boldsymbol{D}$	**:** Normalized Fuzzy Direct-Relation Matrix
$\boldsymbol{Z^k}$	**:** Fuzzy Direct Relation Matrix
$\boldsymbol{W_{kUB}}$	: Upper Bound Priority Value
$\boldsymbol{W_{kLB}}$	: Lower Bound Priority Value

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A METHODOLOGY PROPOSAL TOWARDS SCHEDULING OF SHIP REPAIR AND MAINTENANCE OPERATIONS

SUMMARY

On a global scale, the majority of goods transported internationally travel by sea. Despite the significant role of maritime transportation in supporting international trade and commerce, the volume and complexity of international regulations continues to increase. This inevitably creates additional costs for ship operators, requires business managers to comply with ever-growing regulations as a cost of doing business, and makes it harder for companies to be profitable. In this environment, increasing or even maintaining profits requires ship-owners to reduce operating costs, which is often achieved by reducing personnel or cutting maintenance expenses.

It is therefore becoming increasingly important to achieve maintenance targets to support decision-makers in identifying the appropriate places to make economies. Implementation of particular maintenance approaches, such as preventive, predictive, or corrective maintenance, is not, in itself, sufficient to maintain or increase profits because of the multiple factors that affect the business environment, including supply, logistics, safety, operations, and regulations. Nevertheless, the overlapping of maintenance activities in such a way as to reduce both the time allocated for these activities, and the costs of logistics and labour, can increase efficiency. Within the maintenance literature, most research examines failure prediction, studying different approaches for increasing the running time of machinery while identifying failures early.

Continuing this pattern of enquiry, this study uses multi-criteria decision-making tools to develop mathematical models for focused decision problems. The DEMATEL (Decision-Making Trial and Evaluation Laboratory) methodology is used to identify important company maintenance policies and targets, and SMAA (Stochastic Multi-objective Acceptability Analysis) is applied to support the analysis of the criteria used as inputs for ranking maintenance alternatives in different scenarios. In the demonstration phase, an illustrative case is used to analyse the maintenance operation

scheduling for the main engine of a new-build LNG vessel. Subsequently, a methodology for maintenance operations scheduling is developed and demonstrated

GEMİ BAKIM VE ONARIM OPERASYONLARININ PROGRAMLANMASINA YÖNELİK BİR YÖNTEM ÖNERİSİ

ÖZET

Dünya genelinde taşımacılığın büyük çoğunluğu deniz taşımacılığı vasıtası ile gerçekleştirilmektedir. Deniz taşımacılığının bu kadar önemli bir rolü olduğu ortamda bütün otoriteler deniz taşımacılığının düzenlenmesi ve belirli kurallar çerçevesinde gerçekleşmesi için çaba sarf etmektedir. Bu önemli rolün yanı sıra artan uluslararası yönetmelikler gemi işletmecilerine ek maliyetler getirirken, işletme yöneticileri görev ve pozisyonları gereği zorunlu düzenlemelere uymaya çalışmakta bunun yanı sıra şirketin karlılığını artırma arayışlarını sürdürmektedirler. Firmalar karlılıklarını korumak veya artırmak adına işletme maliyetlerini azaltmaya yönelmekte ve bu eylemler genel olarak personel sayısını azaltmak, bakım – onarım maliyetlerini azaltmak gibi aktivitelerden oluşmaktadır.

İşletmeciler bakım ve onarım faaliyetlerinin makinenin yararlı ömrünün uzatılması için vazgeçilemez bir unsur olduğunun farkına varması ve taviz verilmeden bu faaliyetlerin yerine getirilmesi gerekmektedir. Üretici firmaların ürün bildirimlerine bağlı olarak yayınlamış oldukları talimat kitapları, ürünün ömrü esnasında karşılaşılmış sorunlara istinaden yayınlamış oldukları güncellenmiş bültenlerin gerek karadaki işletmeciler gerekse gemide çalışmakta olan vardiya zabitleri tarafından detaylıca incelenmesi ve planlı bakım sistemindeki talimatların bu bültenler doğrultusunda güncellenmesi, genişletilmesi veya eklenmesi çok büyük önem taşımaktadır.

İşletmeciler makinelerin çalışmakta olduğu süre içerisinde makinelerden çeşitli cihazlar vasıtası ile very toplama yoluna giderek makinelerin çalışabilirlik süresini artırmayı hedeflemekte olup bakım ve onarım faaliyetlerini bu veriler doğrultusunda yön vermektedirler. Bu yöntemler denizcilik sektöründe önemli bir paya sahip olmakta olup ekipmanlardan toplanan verilerin farklı kurum ve kuruluşlardan da uzman görüşü

alınabilmesi gibi bir imkan sağlamasından dolayı gemide çalışmakta olan işletmecilere kestirimci bakım yöntemlerinin uygulanmasında uzman görüşlerine de yer verilmesi olanağı sağlamaktadır. Bu bağlamda gerek klas kuruluşlarının gerekse bağımsız kuruluşların oluşturmuş olduğu şirketler mevcuttur.

Bütün bu gelişmeler ışığında şirket yöneticilerini bakım – onarım faliyetlerinin en etkin ve en verimli şekilde yerine getirildiğini ispatlamak, bu faaliyetlerin hayati öneminin vurgulanması bakım – onarım faaliyetlerinin devamlılığının sağlanabilmesi açısından önemli bir yere sahiptir. Şirket bakım – onarım politikalarının efektif bir şekilde uygulanması, önleyici bakım, kestirimci bakım, düzeltici bakım vb faaliyetlerinin adapte edilmesinden ibaret olmayıp, lojistik, tedarik, güvenlik, sefer süresi gibi etkenlerede bağlıdır. Bakım – onarım aktivitelerinin çeşitli aktivitelerle örneğin, klas testleri, havuzlama aktivitleri gibi aktiviteler ile birlikte planlaması ve bu sayede gerek geminin sefer sürelerine etkilemeden bunun yanı sıra lojistik ve iş gücü gibi gereksinimlerin kullanımının aza indirgenmesi hedeflenmelidir.

Bütün bu gelişmelerin yanı sıra bakım ve onarım faaliyetlerinin programlanması denizcilik sektöründe planlı bakım ve onarım sisteminin pek dışına çıkamamış olup planlama faaliyetleri geri planda bırakılmıştır. Bu çalışmada bakım ve onarım faaliyetlerinin sörvey faaliyetleri ile birlikte planlanmasının bunun yanı sıra seyir halinde ki gemide gerçekleştirilmesinin detaylı incelemesi gerçekleştirilmiş olup bu incelemelerde sadece maliyet unsuru ele alınmamış olup emniyet, güvenilirlik, geminin operasyonel kayıplarıda değerlendirilmeye alınmış olup farklı opsiyonların seçilebilirliği tartışılmıştır. Bu bağlamda literatürde yer alan çalışamalar çoğunlukla sistemlerde kullanılması gereken bakım ve onarım methodlarının belirlenmesini hedeflerken bu çalışmada bakım ve onarım methodlarının belirlenmesi değil, bu faaliyetlerin çizelgelenmesi, programlanması ve bu yaklaşım ile belirlenen kriterler doğrultusunda geminin operasyonun şirket hedefleri doğrultusunda hareket edip edilmediğinin belirlenmesi hedeflenmiştir.

Bu sebeplerden ötürü çok kriterli karar verme araçları kullanılarak bu çalışma çerçevesinde matematiksel bir model geliştirilmesi hedeflenmiştir. Metodoloji olarak, DEMATEL, şirket bakım politikalarının ve hedeflerinin önemini belirlemek için kullanılmaktadır. Bu bağlamda DEMATEL in diğer çok kriterli karar verme araçlarına kıyasla üstünlüklerinden dolayı seçilmiştir. Bir diğer yöntem SMAA sıralama yapmadaki üstünlükleri ile öne çıkmış olup dinamik bir ortamdaki değişkenlerinde göz önünde bulundurulması ile verilerin eksikliği gibi durumlarda da uygulanabilirlik imkanı vermektedir. Ek olarak, SMAA, farklı senaryolar için bakım alternatiflerinin sıralaması için girdi olarak kullanılan kriterlerin analizini desteklemektedir.

Vaka analizi olarak yeni inşaa edilmiş bir sıvılaştırılmış gaz tankerinin dizel makinelerinin bakım ve onarım faalitelerinin programlanması analiz edilmiştir. Bu analiz bir sonuç vermekte olmayıp bu Sonuç olarak, bakım operasyon çizelgelemesi üzerine bir metodoloji geliştirilmiş ve gösterilmiştir.

1. INTRODUCTION

Meantime shipping industry keeps control of carriage of about 90% of goods worldwide and is crucial part of global economy, it is full of untrodden areas such as safety, innovation, security, maintenance etc. The reason for lack of development in shipping industry due to high profit within the past decades. However, with past accidents in shipping industry brought attention of everyone and force governments to take necessary steps to protect both environment and life. One of those neglected areas is maintenance. Maintenance mostly disregarded by all organizations and one of them is shipping industry. Maintenance has an utmost importance to keep machinery up time and allow them to reach intended life time. However, there is several reasons for organizations to avoid implementation of maintenance policy such as high initial investments with long time return, difficulties at implementation of maintenance policy, communication problems between management and workforce, corporate culture etc. This challenges can be overcome by big corporations, but those who has work with very small profitability and limited capital it creates bigger travail. In this point regulatory bodies enforce minimum requirements to establish safe, secure and efficient shipping on clean oceans which are those classification societies, port state authorities etc. trying to improve vessel machinery reliability with activities such as enhanced survey programs, docking activities, random inspection on board vessels in operation and/or during out of service periods like layout.

i) providing mechanism for cooperation among parties in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade.

ii) encouraging the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships.

IMO's first mission was to interiorize and enlarge rules and requirements of International Convention for the Safety of Life at Sea. After achieving this target in 1960, IMO divert their focus on maritime traffic, load lines, carriage of dangerous goods by ships for to develop international industry standards for ships and shipping industry.

While IMO primarily focus on maritime safety by the increasing numbers of ships new problems started to rise. In 1967, by following Torrey Canyon disaster IMO started to work on new conventions to prevent accidents, minimize their consequences to environment. One of the most crucial of these convention was the International Convention for the Prevention of Pollution from Ships, 1973, as known as MARPOL. MARPOL covers both operational and accidental pollution such as Oil pollution, Noxious liquid substances, harmful substances in packaged form, sewage from ships, garbage from ships and air pollution from ships.

In 1979, by adoption of International Convention on Maritime Search and Rescue, also known as SAR, search and rescue systems standards established. Following of establishment of International Mobile Satellite Organization, IMSO, developed under the auspices of IMO, which was significantly enhanced the arrangement of radio and messaged to ships.

In 1988, as part of SOLAS, The Global Maritime Distress and Safety System, as known as GMDSS, introduced and by 1999 became fully functioning which allows any ship anywhere in the world is in distress cannot disappear without trace even though crew has no room to send radio for help auto message will be transmitted so that more lives will be saved at sea.

In 1998, the International Safety Management Code entered into force which aims to provide an international standard for the safe management and operation of ships. The ISM code sets out requirements by the Company which can be identified as the ship owner, bareboat charterer who has the responsibility to operate the ship. The ISM Code was amended several times for to meet and develop industry expectations. The ISM Code amended in June 2013 by resolution MSC.353(92) and amendments entered into force on 1 January 2015.

As it stated by the ISM Code, "Companies should establish procedures to ensure that the ship is maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may be established by the company." Within this definition, dedicated to ship management companies, the relevant managers are responsible for the regular inspections in appropriate intervals. Moreover, the records of these activities are needed to maintain. So it is fair enough to say that clearly highlighted maintenance requirements mentioned for the first time in the ISM Code by IMO or any regulatory authority.

Since IMO established in 1948, till the maintenance and requirements clearly stated in any regulations takes decades. So it wouldn't be surprising that maintenance neglected within shipping organizations.

1.1 Motivation

According to operating costs of handy size bulker from database of OpCost 2004 (Počuča, 2006), crew costs is major expenses in OPEX budget, however ship owners cut down crew up to minimum manning requirement, as it defined by IMO resolution A.1047(27) 30 November 2011, and it is not possible to lower more because of putting ship, crew and environment in endanger (IMO, 2011). So ship owners and operators trying to cut additional items to increase benefit from shipping. Thus all items subjected to budget control and one of the item is maintenance costs.

Even though maintenance costs include spares, repairs and maintenance, it is around 15% of OPEX (Počuča, 2006). However, lack of maintenance can cause bigger repair costs, operational delays resulting with reclamation, environmental threat, damage to reputation etc. So considering all those results, ship owners and operators must give extra attention to maintenance activities. To achieve that maintenance philosophy must be understanding at corporate level.

Shipping has one of the longest history as use of transportation, commercial trading, fishing etc. Due to the nature of shipping in the past, shipping community is a closed community. So changing things in the industry relatively harder. Considering great and long history of shipping, maintenance has a very short history especially in shipping industry. As a meaning of maintenance, it exists since mankind started to use first tools. However development of maintenance takes ages and started after industrial revolution (Kister and Hawkins, 2006).

Planned maintenance system is a tool which allows ship owners to carry out maintenance in a systematic way to meet manufacturers' instructions, flag state, port state, classification society requirements and the last and the most importantly to maintain machinery at running condition. On board vessel, maintenance carried out by ship's crew, engineering officers, then reviewed by shore personnel as required. In addition to that schedule ship's goes through periodic surveys by class societies, internal audits, flag state certificate renewals and unexpectedly by port state authorities. During those inspections, planning and scheduling of the maintenance is important as well as its documentation which is the only proof of job has been carried out. The planned maintenance system on vessels is now mandatory as per International Safety Management Code (International Maritime Organization, 2014). However recent surveys indicate that implementing Planned Maintenance System in the shipping industry is still a big challenge for a ship owner.

Implementation of planned maintenance system can be costly which requires initial investment for software, training cost for ship's crew etc. In addition to that choosing maintenance strategy is requiring vast amount of time, knowledge, expertise in maintenance field. However, all these investments have a return to owners like significant amount of increase in the ship reliability, availability and machinery up time.

In this respect, before implementing maintenance strategy care must be given to choosing appropriate maintenance strategy for ships and machineries. Since ship's are subject to so many variables such as wind, current, temperature etc. and these variables are dynamic, which is subject to change any time makes harder to implement one type of maintenance for all machineries. For example, considering shipping company implemented condition monitoring system for their rotating machineries like pumps, can give different vibration readings with different liquid temperatures so condition based maintenance might lead supervisors to an unnecessary maintenance actions such as bearing inspection, replacement etc. but approaching with case dependent maintenance policy can prevent both wasting money, time and workforce.

Having mentioned the above, the study is conducted to find alternative way of finding maintenance policy within dynamic components.

1.2 Purpose of Study

It is important to understand importance of effective maintenance policy for efficient, safe and reliable shipping. For instance, considering while a vessel transiting a busy strait loss of propulsion can result with catastrophic events such as collision, grounding, environmental pollution and loss of lives. From this point of view, thesis main objective is to identify selection criteria's for maintenance policy, prioritization of those criteria's and scheduling those maintenance activities within busy sailing schedule.

Maintenance on board ships require both side contribution shore and on-board to develop advance and functioning maintenance system. It is obvious that it cannot achieved without input from on board personal who carries out the maintenance. From this point, not only individuals from both academia and industry advised within this study for their expertise for selection criteria's but also extensive literature research was also carried out.

Further in this study, to enable good understanding of maintenance methodology, maintenance history and maintenance approaches examined in details. Therefore, it allows to evaluate and compare different maintenance frameworks for indicate the best maintenance policy for different situations.

1.3 Research Methodology

This study begins with extensive literature review through understanding the existing approach to maintenance scheduling problem in theory and practice. Besides various industries, the studies on the maritime and shipping is particularly considered. This also allow us to review both academic and industrial viewpoints to clarify where the researches leading the industry.

Secondly, brief explanation of methods used within this study explained. Several example problems solved within this study to create clear understanding of those approaches. Also literature review take place along with expert's applications in the several studies.

Thirdly, maintenance history and different maintenance approaches reviewed in details. That allows to short listing of maintenance policies which is currently in use within industry and shipping. Current condition of shipping industry also highlighted within this study. Technical background in this study allows also to review all maintenance applications in field with their application.

Lastly, proposed approach applied to a case study and maintenance scheduling carried out for a shipboard system with proposed method. Findings and future research suggestions given at conclusion section in this study.

1.4 Thesis Organization

The thesis consists of five chapters, begin with the general overview of necessities for this research and research question. Mainly first chapter is to ratify the existence of this study within the literature. Exclusively, in the first chapter, highlighted that the given importance to maintenance in shipping industry is inadequate. In conjunction with that, development of maritime regulations reviewed. The reason for reviewing maritime regulations development is to highlight that it takes significant amount of time required to implement those requirements.

Second chapter of the study is an overview of maintenance optimization literature. This chapter includes the analysis of scientific research for maintenance development, optimization methods, scheduling activities and approaches in industry.

Third chapter of the study includes methodological background and their applications. This section explains methods used in this study. Brief explanation of Decision-making trial and evaluation laboratory method and Stochastic multiobjective acceptability analysis methods explained with their examples.

Fourth chapter is consisting of a case study examined under proposed methodology. The case study demonstrates the specific example of application on a practical shipping application which includes description of problem. DEMATEL method is used for prioritization of maintenance criteria's and SMAA is used for choosing best alternative.

Last chapter in this study gives results of case study with recommendations and future research questions. As this study combining different analytical approaches to eliminate their gaps during application and is only for a research for discovering advance, most reliable and applicable maintenance scheduling methods.

2. LITERATURE REVIEW

The literature review for this study is presented along with the basics of maintenance concepts extended with the studies on the maintenance operation planning. Specifically, a number of studies on the ship maintenance is addressed.

2.1 Maintenance Concept

Maintenance can be described as the activities conducted to retain or restore a system (a machine, equipment, a vehicle etc.) to its original condition to preserve the useful lifetime and decrease the failure rate of the systems (Url-1, 2018; Dekker, 1996).

According to UNI 13306, maintenance is: “the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function” (UNI EN 13306:2010).

In order to maintain the failure rate of a system in a reasonable level, it has to be maintained in sequential intervals. Otherwise, the wearing and aging of the components would yield some catastrophic failures, which ultimately necessitate expense for replacement and downtime of business. Worse than that, the system can drop a state where no restoring effort could suppress resurrection (Jayabalam, 1992). In other words, If the system fails to operate, there will be a delay for the completion of the products and there will be vitally adverse effects on all various pre-planned processes for an organization. Ultimately, products won’t be delivered timely, and give rise to forfeits and destruction of image for the organization, which ultimately result in loss of revenues (Chung, 2009).

Today, the importance of maintenance bears a vital role on manufacturing and service sectors. There is a paradigm shift in the way of production process where machinery replaced human work, which also gave rise to additional operational and man-power costs. As an example, it is common that maintenance man-power comprises nearly 30 % of a production workforce, let alone the capital spent on maintenance facilities

(Dekker, 1996). Hence, the maintenance has to be wisely and robustly put forward, in order to account for the company profit and efficient deployment of man-power and materials.

The maintenance concept can be broadly grouped as the corrective maintenance (CM) and the preventive maintenance (PM) strategies. While PM activities are carried out in accordance with particular time intervals, on the other hand, CM activities are fulfilled during a failure, which can be regarded as “fix it when broken” (UNI EN 13306:2010). However, it is a common sense to deploy PM methods instead of CM ones, where maintenance strategies evolved from the corrective concept to the probabilistic and preventive concept (Ghosh and Roy, 2009). In addition, there remains a question on the amount of capital that a company is due for establishing a PM approach, which necessitates the minimization of the overall costs.

Among other maintenance strategies, such as Reliability Centred Maintenance (RCM)(Moubray, 1997), Predictive Maintenance (Gu et al., 2017), Condition Based Maintenance (CBM) (Jardine et al., 2006), in real world scenarios, CM and PM strategies are vastly appreciated among companies.

CM can be specified as repairing or changing the parts of a system when they are failed or close to be failing. The system is not intervened until it fails, which yields a notion of “let it work until it breaks”. However, CM approach comprises an interesting advantage, where no time is spoiled for replacing components of a system before it fails. On the other hand, a Detective Maintenance (DM) approach can also be conducted with failure-finding steps, in order to reveal the hidden failures of the components (Tsang 2002). In contrary to CM, PM approach aims to replace or repair components in advance of the failures. Obviation of failures is vitally important for the systems where human life is in concern. Also by PM, consequential damage can also be prevented. Aircraft technologies, ship and shipyard industry, military armory, nuclear plants, etc. can be given as few of examples.

The prominent disadvantage of the PM method is that the determination of the most suitable maintenance repetition is usually difficult. Hence, in order to keep self-assurance component replacement takes place in advance of their service expiration time, which gives rise to futile time, capital requirements, component lifetime and man-power. Thus, determining the best-fit replacement time interval is hard which is vastly studied in the maintenance literature (Tsang, 2002).

The implementation of maintenance concept/strategy promise low costs while maintaining high availability, where the product environment would be maintained according to the available capital, man-power, technical abilities and importance level. Hence, optimization of the maintenance strategy would significantly boost the productivity and help to improve company's productivity.

Availability is connected to the maintenance of a component. It is defined as the likelihood, where the component will be up for the job and operation whenever checked. This checking or controlling process can be running randomly (point availability) or within specific time intervals (interval availability) (Kumar et al., 2000). The achievement of availability depends mostly on the maintenance done. However, allowances and budged is not a limitless source, which necessitate to be spent at minimums. Thus there is a trade-off between keeping the availability at higher levels and minimizing the costs related to the maintenance issues.

It is a well-known fact that the level of maintenance done is well-proportioned to the performance of the components. In other words, without a robust maintenance strategy, the expected performance levels will not be fulfilled. However, the availability also depends on many other issues (Van Bussel and Zaaijer, 2001). In fact maintenance cost minimization, keeping an up-to-date and off-the shelf spare part inventory, maximization of personnel-equipment-environment safety and minimization of downtime etc. have to be considered. Conclusively, in order to furnish the availability, the maintenance strategy has to handled very rigorously. Thus, planning and designing an effective maintenance strategy and concept is very important (Gallimore and Penlesky, 1988)

Considering the industrial review, the maintenance concept mainly focuses on the design of an effective maintenance planning for an organization by which the most necessary maintenance processes are determined. While the definition of the maintenance concept is vast in literature, in this study we quote the maintenance concept definition as "blending of maintenance policies, backup equipment, equipment upgrades, and the identification, resource allocation and execution of repair, inspection and replacement decisions". Thus, the maintenance concept comprises both the determination of the optimum maintenance policy and focuses on the expenses and utilization of man power (Pun et al., 2002, Tinga, 2013)

2.2 Maintenance Strategy, Planning and Scheduling

The maintenance strategy has to be determined by the upper layer managers, who will particularly focus on the organizational settlements and decisions. After defining the appropriate maintenance strategy, it has to be planned on both the operational tactical levels, which necessitate addressing the maintenance activities for each maintenance policy (Márquez, 2007). Detecting, monitoring, overhauling, rebuilding, replacing and repair can be given as examples for such maintenance activities. After then, the criteria and alternatives have to be determined and the necessary maintenance recourses must be allocated for the activities, which can vary from work force, materials, tools, equipment etc., to fulfil the maintenance plan. Consequently, on the operational level, the maintenance activities have to be inspected if they are done by skilled personnel, within the time limits, obeying the procedures and with appropriate tools (Pun et al., 2002). Today, the amount of capital spent for maintenance and requirement of skilled personnel for maintenance activities has increased tremendously. The main objectives of maintenance planning for an industry is to maximizing production by maintaining the availability and reliability of equipment and to optimize environmental and employee safety.

The aforementioned objectives necessitate deployment of an optimization and selection making techniques. However, utilization of MCDM methods on maintenance activities is a new this topic where there are still plenty of gaps for modelling various concepts, such as outsourcing the man-power or splitting the maintenance procedure into parts to be handled more easily (Tsang, 1995). In addition, Barnabas and Janani (Barnabas and Janani, 2015) stated that the vitality of maintenance is increasing vastly, which puts maintenance to be a subject to be optimized instead of a cost to be minimized (Van Horenbeek et al., 2010). Following that, many maintenance-planning approaches were put forward. Much of these approaches utilize only a single criterion or objective, which makes the methods that will be conducted by utilizing MCDM methods to be an under explored field for maintenance optimization. In addition, there is a vast difference between the proposed academic models and real-world applications, which makes it hard for industrial companies to adapt single objective methods to the particularly complex business context.

There are many studies concerned to maintenance planning activities utilized with MCDM methods. For example, Demirtaş (2013) proposed a maintenance strategy selection method, which takes the advantage of MCDM technique. In their method, they deployed the AHP method, they aimed to choose the best maintenance strategy among corrective, preventive, opportunistic, condition-based and predictive maintenance. Considering they took into account of environmental problems, budget constraints and work force utilization by considering expert decisions and related literature. As the other extension, Demirtaş (2013) proposed another AHP method, which presents the evaluation results for the strategic outsourcing decisions at aviation maintenance industry. In his study, both quantitative and qualitative criteria were also considered for the determination of the core capabilities. The criteria, such as operational effectiveness, safety, technological properties, cost effectiveness, usage quantity, and man-power, are utilized in the model. The research data is retrieved from three aviation maintenance companies and the results indicates that the core competence logistic parts are the structural parts on airplanes and the brake system parts for the aviation maintenance centres.

Similarly, an AHP based approach is conducted for the determination of the best maintenance strategy for aircraft systems proposed(Nordgard et al., 2003). In their study, they stated that MCDM methods are perfect alternatives for selection of a maintenance strategy to assure the consistency and effectiveness of maintenance decisions. The method is primarily based on an AHP and TOPSIS, which provides a basis for consideration of different alternatives including the rate of return, total profit, or lowest investment. The study states that shows that applying a merged MCDM method, such as AHP and TOPSIS, is an efficient attitude to achieve a robust approach to identify the best maintenance alternative.

In addition, (Nordgard et al., 2003)handled the maintenance priorities by using the AHP model in constructing the criteria and to obtaining the weight relations of various criteria. (Ilangkumaran and Kumanan, 2009), focused on the use of AHP under fuzzy environments and TOPSIS in order for selection of the best maintenance strategy for a textile company. First, the weight of each criterion is calculated and then a method that integrates the fuzzy AHP with TOPSIS method in order to route to successful selection of maintenance strategy is presented. It is stated that by utilization of AHP method with fuzzy inference and TOPSIS will yield to an effective pair-wise comparison of the criteria and ranking of alternatives. (Wang et al., 2010) proposed an AHP method combined with Genetic Algorithm (GA) to maintain the reliability of aircraft engines in a reasonable level, which requires a maintenance concept and maintenance planning for the aviation company.

When we analyse studies in the literature specifically aimed for maintenance planning, we observe that most of the studies are conducted utilizing the AHP, TOPSIS and an integration of two, as presented above. Although scarce, there are some studies, which base on MCDM methods, other than AHP or TOPSIS. As an example, Trojan and Morais (2012) proposed a method to be used for the maintenance of water distribution networks, which mainly based on the ELECTRE-TRI method. They state that their model presents a fast results of priority class determination and maintenance planners would use that data to react swiftly in situations that necessitate prioritizing the maintenance actions. They also emphasized that there is need for maintenance management systems especially for outranking subjects.

In another study, Cavalcante and Almeida (2007) proposed a method, which helps planning a PM method by failure controlling in focus of equipment failures and breakdown (Cavalcante, 2007). In their model, they proposed a MCDM method which is an adaptation of the previous MCDM models. They state that the model easily overcomes the main difficulties related to PM which are: determination of the replacement interval and providing a valid solution when the situations are uncertain and ambiguous. Procedures are divided into segments upon the type of the uncertainty levels. Thus, the external ones are handled first and internal ones are handled next. Then the analysis of the decision is evaluated by PROMETHEE III method that allows the amplification of the notion of indifference.

Mousavi et. al, (2009) proposed, a hybrid fuzzy group decision making method which can be used for maintenance strategy determination processes. They state that selecting the best-fit maintenance strategy requires different alternatives to be handled for a variety of criteria, which puts the problem to be a MCDM method. There are various key factors, which affect the determination of the best-fit strategy, namely reliability, services quality, risk, etc. In considering all of the aforementioned factors all together, decision-makers would come across to a vast amount of data that might be accounted as redundancy. Hence, a fuzzy TOPSIS approach is utilized in dealing with the uncertainties and imprecise judgments of decision-makers, which would easily be translated into fuzzy numbers.

Nezami and Yıldırım (2011) presented a framework maintenance strategy selection method based on Fuzzy VIKOR. They state that maintenance strategy selection is a MCDM problem with objectives in cost, resource utilizations, reliability, availability and safety. They present a framework in which the decision-makers can define the weight of each sustainability criteria and the ratings of maintenance strategies with respect to the corresponding criteria utilizing natural linguistic terms. Such linguistic terms are then converted to fuzzy triangular numbers and the most appropriate maintenance strategy is selected using a fuzzy VIKOR method.

In a similar study, Nagar (2011) proposed a fuzzy approach based on MCDM methodology for selecting the optimal maintenance alternative. The state that, the reason of choosing a fuzzy method stems from the fact that the quantifying the qualitative factors is very hard. However, such factors can be expressed easily in linguistic terms.

As explained in previous chapters, in this study the Fuzzy-DEMATEL and SMMA-2 methods are utilized. Although maintenance planning studies which are conveyed with these MCDM methods are rare, there are a few related studies which we surveyed within the following chapters.

For example, Aksakal and Dağdeviren (2010) presented a personnel selection method, which uses ANP and DEMATEL methods. In this study the bilateral and mutual dependence relations between the criteria are determined with the DEMATEL method and the selection phase is processed with ANP.

Tseng and Lin (2009) developed a waste management model using Fuzzy-DEMATEL. In their study, they state that Fuzzy-DEMATEL easily converts the correlation of the causes and effects of criteria into a model. In addition, it is also possible to use the aforementioned relations as a way to deal with the inner dependences within a set of criteria. In another study, Varma and Kumar (2012) proposed a criteria analysis aiding method for portfolio selection problems using the DEMATEL method. In that study, it is reflected that application of MCDM techniques gains importance for industries for selection problems where their study illustrates and puts forward different criteria which are related for companies and which can aid in developing a framework for portfolio analysis. The DEMATEL method is used for identifying the importance and causal relationship among the identified criteria. The evaluated results are regarded to be promising to facilitate the selection process under conflicting multi-criteria scenarios.

We can list other studies, which are conducted using DEMATEL and Fuzzy-DEMATEL methods, in numerous numbers (Lahdelma, Makkonen et al., 2006, Wu and Lee, 2007, Lin and Tzeng, 2009, Chang, Kuan et al., 2011, Vujanović, Momčilović et al., 2012, BaykasoğLu, KaplanoğLu et al., 2013, Çınar, 2013, Horng, Liu et al., 2013, ORGAN, 2013, Sumrit and Anuntavoranich, 2013)

Another group of studies which are conveyed utilizing the SMAA method is as follows: Lahdelma and Salminen (2006), proposed a method in order to efficiently classify the selection alternatives using the SMAA technique and cross confidence factors. In their study, they emphasize that the SMAA method is a type of method which can easily be used for multi-criteria group decision making problems. SMAA mainly bases on exploring the weight space in order to describe the preferences that make each alternative the most preferred one.

In another study, Kangas (2003) proposed a multi-criteria approval and SMAA-O method for natural resources decision analysis with the existence of both ordinal and cardinal criteria (Kangas, 2003). They state that multi-criteria approval (MA) and SMMA with ordinal criteria (SMAA-O) methods have been particularly designed for making use of low-quality information in multi-criteria decision support problems. Also, Okul et.al. (2013) presented a method which bases on the novel SMAA-TOPSIS method for a real-world application. They state that, SMAA is a kind of MCDM method, which is vastly utilized for solving MCDM problems where there are uncertainties, when the information is not accurate and when there is not a requirement of preference information from the decision-makers. Their study presents a novel method, which is named as the SMAA-TOPSIS, where the SMAA and TOPSIS methods are blended.

There are many other studies which are presented with the utilization of the SMMA method (Durbach, 2006, Lahdelma and Salminen, 2006, Tervonen et al., 2008, Lahdelma and Salminen, 2009, Aertsen et al., 2011, Tervonen et al., 2011) However, as stated earlier, the studies conducted on maintenance subjects is still an unexplored area. On the other hand, Goossens and Basten (2015) investigated maintenance policy selection for naval ships with use of AHP. In this paper author explains how Analytical Hierarchy Process Works and explains the reason for choosing the AHP method. Briefly described maintenance policies in this research and classification of them. They have accessed to a wide range of industrial experts for selection of Key Performance Indicators.

Dahal et al. (1998) highlighted importance of scheduling generator maintenance due to such decision affects each other. Authors proposed genetic algorithm for scheduling of 21 generator units within a 52 weeks' period. They have used fuzzy evaluation function to develop a combination of a penalty function for restrictions such as manpower, electricity requirements etc. where fuzzy logic approach allows test results to be represented in the evaluation of genetic algorithm solutions.

Deris et al. (1997), proposed genetic algorithm and constraint-based reasoning to solve ship maintenance scheduling problem. The study conducted based on requires start times of the first cycle of maintenance for solving the problem with constraint-based reasoning where the genetic algorithm adopted to find start times of maintenance activities. Authors tried to randomize first maintenance activities before trying genetic algorithm where they were unable to optimize the solution without knowing how many times randomization required for to get optimal result. As the study results pointed out the genetic algorithm provides invaluable advantage of finding combination of start times of the first maintenance cycle and the CBR allows to create a suitable maintenance schedule.

Nordgård et al. (2003), used analytical hierarchy process to assess priority of maintenance activities. The approach in this study based on analytical hierarchy process used in a case study to make maintenance priority decision in hydropower plants. The AHP method in this case provide objective and systematic view to the decision maker in a standardized way where it allows consistency for project evaluation for either different cases or decision makers.

Compression the application of four different multi criteria decision making methods (i.e. AHP, Elimination and Choice expressing reality, simple additive weighting and technique for order preference by similarity to ideal solution) in maintenance alternative selection. The study demonstrates while it is impossible to announce one against other, TOPSIS methods exhibited highest potential for the Maintenance Management problems in terms of consistency, core process problem structure, concept and final results. Varghese and Kumar (2014) conducted on a two component deteriorating system. Authors used the Markov and the Monte Carlo Simulation methods for Availability analysis of system with different level of degradation. The study conducted for four different states are solved with analytical Markov approach and all validated using the Monte Carlo Simulation since use of Markov approach was limited with exponential failure and repair rates. The study shows that the method provides a realistic assessment of availability of system and a cost function can be calculated to analyse economic advantages and disadvantages of carrying out opportunistic maintenance.

Cassady et al. (2001) studied a mathematical programming framework proposed for assisting decision makers for process of determining the optimal maintenance activities to perform which is called selective maintenance. Study consists of two selective maintenance problems analysed using three different mathematical programming formulations developed in this study. The study points out that crucial importance of maintenance activities such as corrective, preventive, predictive etc. for increasing life time of the machinery and reliability.

Sabaei et al (2015) aims to review MCDM extensions to evaluate and compare each model to assess them from a management view for a help industry to choose appropriate decision making methods as per their maintenance delivery goals. Authors analysed five MCDM techniques AHP, PROMOTHEE, ELECTRE, SMART and TOPSIS. Brief description of each method followed by classification of MCDM methods in two subgroups as a multi attribute decision making and multi objective decision making. They have also points out literature gaps for decision making for different aspects of maintenance management such as spare parts control, total maintenance activities etc. Besides, Jafarnejad et al (2014) proposed approach in this study is based on logarithmic fuzzy preference programming method for ranking effective barriers on adaptation of computerized maintenance management system. Study stats with literature review, brief description of maintenance techniques and followed by in depth review of CMMS. Expert opinions gathered for identifying critical factors for adaptation of CMMS and pair comparison of those factors. LFPP technique used for ranking of factors and modelling was performed. Study highlights the importance of planning and execution of computerized maintenance management system can yield a maximum return on investments.

Emovon et al (2016), discussed the three critical parts of a maintenance system, tools utilized inside the structure of RCM for carrying out these assignments and restrictions of the tools. Significant parts of maintenance systems; risk assessment, Maintenance strategy selection and maintenance interval determination discussed in details. FMEA was particularly focused during risk assessment. This literature review aimed that the maintenance personal to be equipped with basic knowledge of tools for a maintenance optimization methods and encourage researchers to develop alternative tools for application of RCM techniques to a real life plants. From the study it shown that some of the tools and their varieties utilized within the RCM structure for the optimization of the significant parts of maintenance systems have restrictions and require special attention by researchers to find new approaches to eliminate that restrictions.

Vujanovic et al (2012) studied on a basis of increasing fleet energy efficiency through increasing effectiveness of maintenance activities and management tools. So from this point authors used DEMATEL and ANP to calculate level of interdependencies between indicators. Case study conducted within several companies' road vehicle fleet to implement proposed model. Applying proposed model to gathered data, proved to a company manager there is a significant potential to improve which will allow them to increase efficiency of maintenance activities. Dorri et al (2014) conducted on a cement factory to assist selection of maintenance and repair strategy on a scientific basis. Authors carried out an extensive survey within the industry from 86 experts in their field to address effective indicators for maintenance and repair activities within IT industry. Identification of those indicators, experts advised for weighing of each indicator with different questionnaires. DEMATEL method and Fuzzy Analytic Network Process used in this study for to measuring of weight of each indicator. Authors also highlights missing research areas on maintenance and repair of IT systems.

Emovon (2016), used combined methodologies (Delphi-AHP-TOPSIS) in his study to select ship system maintenance strategy. Case study carried out about sea water circulating pump and central cooling system modified from bulk carrier. Delphi methodology used for selection of decision criteria within both industrial and academicals expert opinions. TOPSIS used in this study for ranking of maintenance techniques for their application on this system. Author also explains disadvantages of choosing PROMETHEE and AHP as a research methodology. Smith (1993), defines RCM approaches and explains failure patterns as per RCM understanding. Primary driving forces behind RCM, maintenance costs, reviewed in study clearly. Smith shows this on a study made on major U.S. airlines and proves cost benefits of RCM to the industry. Also first RCM pilot study in Nuclear Plant analysis demonstrates 30 to 40 percent savings occurred with implementation of RCM (Smith, 1993). Reliability centred maintenance approach is another concept. Rausand 1998 studied the requirements and information for reliability models are put into the foreground. It is emphasized that there will be some future changes for RCM with maintenance optimization and work done between RCM practitioners and scientists.(Swanson 2001) Swanson (2001) explores the use of correlative factor analysis between proactive and aggressive maintenance strategies and performance, conducted in a comprehensive survey with factory managers and maintenance managers, in a study of the results of correlations between maintenance strategies and company performance (Swanson, 2001). Mokashi et al. (2002) identifies specific problems encountered during reliability centred maintenance applications. He benefited from process differences and problems between the maritime industry and different industries. Especially, it has been emphasized that the costs and irrecoverable problems that would arise with the different approaches of the failure occurring in the maritime industry become more economical and reliable system with RCM. However, as in any system, it is tatted that RCM has problems in implementation (Mokashi et al., 2002). The efficient way to optimize equipment or plant maintenance is to prove that it can be achieved through the combination of various maintenance approaches and functional systems and they have proposed the RCM process for this. They stated that their application had a yield above the classical maintenance approach of the CMMS based RCM process and optimized maintenance system (Gabbar et al., 2003)

Zhou et al. (2007), proposes and RCM model for a system that begins to wear out due to a defective maintenance schedule. It is assumed that the system is constantly monitored and the state is not variable. Reliability of the system, time limit maintenance approaching R limit value is realized. In the direction of the simulations, the maintenance intervals of the system were observed to decrease when RCM was applied (Zhou et al., 2007).

According to Çebi et al (2008) the Reliability Based Maintenance method is based on the principle that all tools in the process do not have the same qualification and the superior aspects of the method eliminating unnecessary control and maintenance activities. Thus, the maintenance cost is reduced, the control frequency is reduced. Unexpected tools, hardware impairments are minimal, requiring focus on critical hardware. Hardware reliability can be improved and root cause analysis can be performed. The weaknesses of the method are first investment cost is high, the cost of training staff and profit made by made is not easily recognized by the management.(Çebi et al., 2008)

Cheng et al. (2008) investigated the intelligent reliability centred maintenance analysis and combined the artificial intelligence technology with RCM analysis to increase the effectiveness of the RCM. On the basis of intelligent RCM analysis, it is inferred that the old record of the RCM analysis are taken as reference and used during the new analysis. The complex and repetitive tasks in the RCM analysis can be simplified on this method. Intelligent RCM analysis increases efficiency and quality of RCM analysis.(Cheng et al., 2008)

Vishnu and Regikumar (2016), defines implementation methodology of RCM process and simulate on case study. They list the components within the plant and define reliability parameters of components, criticality of the equipment's. As per simulation results they define maintenance strategy for all equipment's within the plant to prevent/minimize unexpected failures during operation. According to results they proposes Analytical Hierarchy Process based framework for RCM strategy selection for process plants. (Vishnu and Regikumar, 2016)

Eisinger and Rakowsky (2001), discusses uncertainty in the decision making of RCM. Considering RCM introduced in the aircraft industry this uncertanities might become unacceptable and leading to non-optimum maintenance strategies. They combine probabilistic RCM method on fire detection and extiguishing system with failure mode effects and criticality analysis (FMECA) and they prove that probabilistic RCM is superior to traditional decision making analysis.(Eisinger and Rakowsky, 2001)

Li and Gao (2010), defends traditional RCM focuses on the function of failures of system and claims traditional RCM is not bothered with failure mechanisms and real causes of failures. However, radical maintenance involves the fundamental factors causing failures and investigates the factors affects the reliability of the system. They use FMECA and Fault Tree Analysis to implement Root Cause Analysis on a component failure to perform combined RCM with Radical Maintenance on ethylene refrigerant compressor. In this study they prove that root cause analysis can combined with FMECA and FTA very smoothly for failures and this strengthening the combination of radical maintenance with RCM(Li and Gao, 2010). Selvik and Aven (2011), focuses uncertainty factors on their study which can change probability of an event and in result consequences. They integrate those factors to FMECA table and extend with uncertainty assessments. Within this framework, Reliability and Risk centered maintenance (RRCM) decisions can result differently compared to RCM analysis depending on uncertainty, sensitivity and importance of the equipment. By RRCM method, system reliability may or may not change however importance of risk and uncertainties is more effectively taken into account while planning maintenance (Selvik and Aven, 2011).

Emovon 2016 in this study used Delphi – AHP – TOPSIS methodology for selection of maintenance strategy for shipboard central cooling system. Total 22 decision criteria within the study collected from literature and the number of criteria reduced to 12 with expert analysis and surveys. Author choose experts from both industry and academia so elimination of criteria relies on both industrial and academic perspective(Emovon, 2016).

Dorri et al. (2014) used DEMATEL and ANP Fuzzy process to selection of repair and maintenance strategy for IT systems in cement factory. Identification of criteria for selection of strategy decided by 86 experts within their field of study. Initially addressed 51 criteria reduced to 21 after survey done with industrial experts. (Jafarnejad, Soufi et al., 2014) aimed to identify critical factors for implementing Computerized Maintenance Management System for Concrete plant and ranking of those factors. Total number of 6 critical factors broke down to 51 effective barriers and Logarithmic fuzzy preference programming method used for weighing of those barriers. Baidya and Ghosh (2015) focused on improving predictive maintenance indicator effectiveness with utilizing the analytical hierarchy process. Different than many other approach within the field of study, particularly this one focuses of improving the single type of maintenance approach and proposes robust model for improving the PMIE with utilizing newly available technologic development in CBM approach and/or excludes out dated methodologies in CBM approach. While PMIE break in to 3 nodes such as finance, technological and environmental total sub criteria used within the study for improving PMIE is clustered to 10 criteria. Vujanović, Momčilović et al. (2012) proposes a maintenance management model for increasing vehicle fleet energy efficiency by improving maintenance process. 8 different criteria determined to be effecting fleet efficiency and 4 of those criteria directly related with maintenance process. Authors used DEMATEL and ANP to determine interdependencies of those factors and relative weighing of selected criteria's.

Carnero and Gómez (2017) focuses on selection of most suitable maintenance strategy for electric power distribution systems. Method described in this study used in Health Care Organization in Spain to choose combination of maintenance methods to be used in hospital power distribution system. Maintenance cost, Level of Suitability of Maintenance action, Safety of workers and Impact on hospital activities are the criteria's used to evaluate maintenance effectiveness on power grid of hospital(Carnero and Gómez, 2017).

Lazakis and Ölçer (2016) addresses advantages and gaps of current maintenance methodologies and difficulties of implementing those methods to shipboard systems due to involvement of uncertainties in dynamic shipping environment. To eliminate this gap fuzzy multiple attributive group decision making technique used in the proposed method. To achieve the objective, choosing the best maintenance approach, authors break in to total 8 attributes which is maintenance cost, effectiveness, reliability, management commitment, crew training, company investment, spare part inventory and operational loss.(Lazakis and Ölçer, 2016)

2.3 Discussion on Review

As part of literature review total 106 article reviewed and summarized as above. Within the literature, it is commonly found methodologies such as AHP, TOPSIS used for solving MCDM problems. Researches focuses on big variety of maintenance techniques such as CM, PM, RCM and supported by means of available tools such as FTA, RCA, FMEA, FMECA widely used to identify possible failures on machinery systems. Increasing complexity of machinery systems installed on board machineries makes impossible for both researchers and industrial experts to rely on one simple technique so combination of those tools widely implemented by researchers. While implementing those tools individuals most take into account case specific criteria for problem solution, which makes great challenge for those individuals. We have shortlisted several criterias among others to highlight specific concerns for the company maintenance perspective. Within the literature while dozens of research can be found for use of DEMATEL for MCDM problems number is relatively less within maintenance activities. In this perspective, we have implemented DEMATEL and SMAA to highlight this gap in the literature to assess both uncertainty within vessel trade activities and scheduled trade with maximized efficiency of service activities by overlapping those activities and increasing the service speed.

3. METHODOLOGY

In this part of this study, first we present the basics of the methods and algorithms in this section that we have utilized. Followed by a short introductory explanation of the classical Fuzzy Logic concept is given. The DEMATEL and Fuzzy-DEMATEL, SMAA and SMAA-2 methods are explained consecutively. Finally, we present the Proposed Method in detail, which we followed throughout this thesis study.

3.1 Fuzzy Logic

Fuzzy logic is a generalization of conventional set theory and an extension of Boolean logic, which was first introduced by Zadeh (1965), in order to express everyday life problems with simple linguistic terms (Bezdek, 1993). Lotfi Zadeh (1965) introduced the mathematical theory of fuzzy sets, which is an extension of the generic set theory.

In the classic set theory, the membership of a set is crisp and unambiguous. Specifically, an entity can just be a member of a set or not a member of the set. The boundary of the set is crisp, which reflects the involvement of the entity to the sector not. Moreover, when the question is asked: “Is this entity a member of that set?” The answer would be either “yes” or “no.” Similarly, when one expects an answer to the statement “The earth is round” The answer to that statement will be either “true” or “false” or in binary computational terminology “1” or “0”.

By providing the notion of “degree” or “the amount of membership” in proving of a statement, hence, determining the statement to be in a state other than yes/no, true/false or 1/0, fuzzy set theory presents more flexible reasoning results, in which the ambiguous and vague information would also be taken into account (Dernoncourt, 2013).

In Fuzzy logic, the rules are represented and determined by “human-friendly” linguistic terms. Such representation is regarded to be the main superior property of fuzzy logic systems that the human reasoning can easily be formalized with every-day language.

For example, when your friend's car mileage indicator shows 49.900 km and you must advise your friend to have the maintenance done, would you say, "When the indicator shows exactly 50.000 km then stop the car, tow it for the maintenance service"? Or would your advice be more like, "Have the maintenance pretty soon"? While the first on is too much certain to be achieved, the second one would definitely will be done. Likewise, in real-world situations, there is need for modelling of computations to perceive, present, differentiate, explain, and utilize both vague and statistical uncertainties. Besides, the fuzzy implementations of the computational data structures are a very intrinsic and rational by nature to define and model various problems. On the other hand, a classical set contains entities that reflect crisp and certain attributes required for membership (Bezdek, 1993). Hence, a vast number of real-world problems is not possible to be implemented and/or modelled with the conventional set theory, specifically the ones that involve entities having only partial membership of a set. However, it is easy to implement partial memberships in fuzzy set approach, which tailors and extends the conventional set theory in a reasonable way. Conclusively, the fuzzy set theory is regarded to be an intrinsic extension of the conventional set theory, and it is also a rational mathematical modelling (Chen and Lake, 2001).

As an example let's take set S of "the numbers between 5 and 8". We write $S = \{r \in \mathbb{R} \mid 5 \leq r \leq 8\}$. Similarly, S is explained by its membership function (MF), $m_S: \mathbb{R} \rightarrow \{0,1\}$, which can be defined as:

$$m_S(r) = \begin{Bmatrix} 1; & 5 \leq r \leq 8 \\ 0; & otherwise \end{Bmatrix}$$

The crisp set of $\boldsymbol{S}$ and the graph of $\boldsymbol{m_S}$ is shown in Figure 3.1. As it can be inferred from the figure, crisp set corresponds to two-valued logic. For example, as we ask "Is number 6 belong to set S?" then the answer will be "yes" if $\boldsymbol{m_S(r) = 1}$; othervise the answer will be "no". When we utilize fuzzy logic, we use a fuzzy set of "close to 6". In this case the designer should decide what the $\boldsymbol{m_F}$ values should be (i.e. the closer to number 6, the closer $\boldsymbol{m_F}$ to 1). As an example, in Figure 3.1, the $\boldsymbol{m_F(5.8)}$ equals to 0.8, which means that the degree of closeness of number 5.8 to number 6 equals to 0.8.

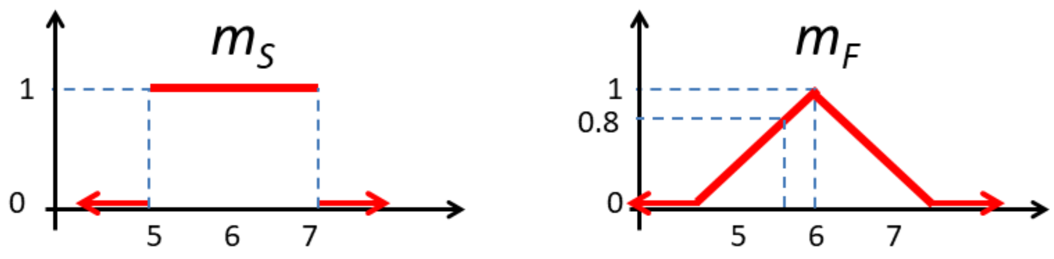

Figure 3.1 Membership functions for the crisp (left) and fuzzy subset (right)(Tiwary).

An FIS (Fuzzy Inference System) is used for modelling and designing of a system by utilizing the acquaintance and experiences of an expert, where the inputs are generally in linguistic terms. With FIS, it is possible to construct a system that controls a process, in which the input–output relations are defined by a set of fuzzy control rules (i.e. IF–THEN statements) (Cavallaro, 2015).

There are two main information types in fuzzy logic reasoning. The first one deals with the labels and membership functions assigned to the input and output variables. The rigorous determination of them is one of the most important part of the model designing. The second type of information is used convert the rule-based fuzzy input values to fuzzy values of the outputs.

As shown in Figure 2.2, FIS can be analysed within three main blocks, which are explained briefly as follows:

Fuzzification: In this block the crisp input values are converted into linguistic variables by utilizing the membership functions provided by the knowledge base.

Inference Engine: This block evaluates the membership degrees of the inputs to the fuzzy output sets by utilizing the fuzzy rules. Actually, the heart of the FIS is the inference engine block. In this block, in order to reach to a reasonable control strategy, various approximation reasoning are processed. By doing so, the human decision-making process can be reproduced (Cavallaro, 2015).

Defuzzification: This block is used to transform the crisp input values to fuzzy outputs

Knowledge Base: This block is where the set of rules defined by an expert resides.

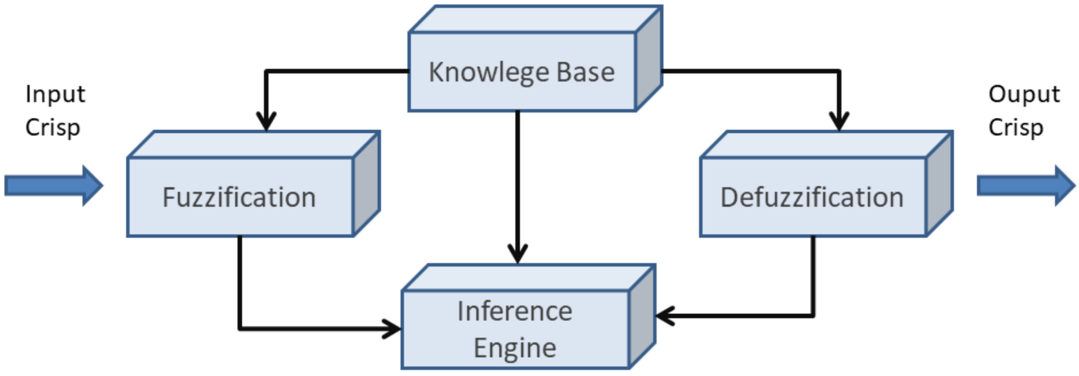

Figure 3.2: Architecture of the fuzzy inference system.(Tiwary)

In conclusion, the most important advantage of utilizing the fuzzy logic instead of the conventional set theory is that an inference system can be established which are closer to the human thinking and linguistic terms. Moreover, the fuzzy logic systems are flexible, nonlinear and without discontinuities which are the same as the human way of reasoning. Moreover, the decision matrix rules are expressed with common natural language terms. This comes up with various advantages, such as the ability to include the experience of a non-expert computer system at the heart of decision-making model or detailed aspects of natural language (Dernoncourt, 2013).

3.2 DEMATEL and Fuzzy – DEMATEL Methods

As discussed in previous section, traditional quantification methods which base on crisp sets are not adequate enough to resolve human-centric problems because, such problems have to be handled with linguistic terms rather than exact numbered inputs. Hence, the fuzzy set theory is applied when there is vagueness and ambiguity specifically in real-world application and problems (Zadeh, 1965).

When dealing with real-world problems, usually the decision-makers face problems that need to be addressed under uncertainty because of the ambiguous targets and vague constraints (Tsai, 2015). In this sense, DEMATEL approach provides a robust and comprehensive algorithm for obtaining a structural model that provides casual relationships between complex real-world factors. It is a robust MCDM method because it accounts for the interdependence among the factors of a system via causal diagram, which is neglected in conventional methods. It was developed by the Battelle

Memorial Institute of Geneva, in 1974 which aims to help to identify the best-fit solutions specifically for complex and intertwined problem groups (Fontela and Gabus, 1974, 1976; Aksakal and Dağdeviren, 2010). In other words DEMATEL approach is vastly utilized to construct inter-relations between criteria or attributes and to reveal the central criteria to represent the effectiveness of each criterion or factor.

The basis of the DEMATEL method comprises the following steps (Seker, 2017; Aksakal and Dağdeviren, 2010):

In step 1, the objects that are related to the problem and degree of influence between these objects are determined. The influential attributes of the complex system are defined with pair-wise comparisons based on data from literature reviews, brainstorming, or expert opinions.

In step 2, the direct relation matrix ($\boldsymbol{X}$) is evaluated. Afterwards, a questionnaire survey approach is followed and the importance of the measurement scales is defined. An example of a relation matrix is illustrated in equation 3.1:

$$\boldsymbol{X} = \begin{Bmatrix} 0 & x_{12} & \dots & x_{1n} \\ x_{21} & 0 & \dots & x_{2n} \\ & & \dots & \\ x_{n1} & x_{n2} & \dots & x_{nn} \end{Bmatrix} \tag{3.1}$$

In step 3, the normalized direct relation matrix is built utilizing the direct relation matrix with equation (3.2)

$$\boldsymbol{\lambda} = \frac{1}{max(\sum_{j=1}^{n} x_{ij})}, \qquad N = \lambda X \tag{3.2}$$

where $i, j = 1,2, \dots, n$

In step 4 the total relation matrix (T) is evaluated with the following formula:

$$\boldsymbol{T} = N(1 - N)^{-1} \tag{3.3}$$

In step 5, the values in the rows and columns in relation matrix is summed as two groups, where $\boldsymbol{R_i}$ represents the sum of the $\boldsymbol{i_{th}}$ row and $\boldsymbol{C_j}$ represents the sum of the $\boldsymbol{j_{th}}$ column.

$$\boldsymbol{R_i} = \sum_{i=1}^{n} T_{ij}, \qquad \boldsymbol{C_i} = \sum_{j=1}^{n} T_{ij} \tag{3.4}$$

In step 6, cause and effect diagram is constructed by summing R and C which will be the horizontal axis, and subtracting R from C that comprises the vertical axis. While (R + C) is defined as “prominence”, which reflects the importance degree of the criterion, (R − C) is defined as “relation”, which illustrates the influence. If the (R − C) is negative, it means that it is influenced by other criteria. If (R − C) is positive, it means that it has a particularly more effect that needs to be handled firstly.

As explained in previous paragraphs, DEMATEL approach is usually utilized for identification of affected and affecting criteria that have a complex structure. This method basically helps to identify the cause and effect of relations and interpret the identified values by visualizing them. However, one may not be able to get clear information from the decision-makers’ or experts’ expressions. Hence, their expressions have to be turned into numerical scales during the identification of the relations. To overcome this challenge, responses via linguistic expressions may be desired. Fuzzy DEMATEL is a widely used method which facilitates such linguistic expressions.

Fuzzy- DEMATEL method comprises the following phases (Öztürk, 2009: 78-84; Baykaşoğlu, 2013:900-902; Aksakal and Dağdeviren, 2010:907- 908):

In step 1, in order make a decision, the criteria have to be determined. Depending on the type of the problem the criteria may be identified with the use of questionnaires or face-to-face conversations with experts or by referring to the literature. The fuzzy linguistic scale may be triangular, trapezoidal or other fuzzy numbers produced (Li, 1999). In this study, triangular fuzzy numbers, which are the most frequently preferred in the literature, are selected which is shown in Table 3.1.

In step 2, an initial direct relation matrix with pair-wise comparison is obtained. The decision makers or experts are asked to make pairwise comparisons in order to clarify the degrees of relations between the criteria. The decision makers are asked to explain their thoughts about the direct influence between any two criteria by an integer score ranging from 0 to 4. The fuzzy direct relation matrix is not symmetrical and its diagonal elements are 0, which can be shown as follows:

$$\boldsymbol{z_{ij}^{k}} = (l_{ij},\ m_{ij,}\ u_{ij})$$

$$\boldsymbol{Z^{k}} = \begin{Bmatrix} 0 & z_{12}^{k} & \dots & z_{1n}^{k} \\ z_{21}^{k} & 0 & \dots & z_{2n}^{k} \\ & & \dots & \\ z_{n1}^{k} & z_{n2}^{k} & \dots & 0 \end{Bmatrix} \tag{3.5}$$

If we denote the initial fuzzy direct-relation matrix as $\boldsymbol{Z^{k}}$, where *k* is is the number of experts. Accordingly, the direct-relation matrix is established as $\boldsymbol{Z^{k}} = \left[z_{ij}^{k}\right]$ where *Z* is a $\boldsymbol{n} \times \boldsymbol{n}$ non-negative matrix; z_{ij} represents the direct impact of factor *i* on factor *j*. Here $\boldsymbol{l_{ij}}$ is the first and the smallest of the triangular fuzzy numbers; $\boldsymbol{m_{ij,}}$ is the middle value; and $\boldsymbol{u_{ij}}$ is the largest value.

Table 3-1 : Triangular Fuzzy Numbers

Linguistic Terms	Influence Score	Fuzzy Values
No influence	0	(0; 0; 0.25)
Very low influence	1	(0; 0.25; 0.50)
Low influence	2	(0.25; 0.50; 0.75)
High influence	3	(0.50; 0.75; 1)
Very high influence	4	(0.75; 1; 1)

In step 3, the normalized fuzzy direct-relation matrix "*D*" is obtained using equation (3.6), which is related to the overall fuzzy direct-relation matrix *Z*.

$$\mathbf{D} = \frac{z^{k}}{max(\sum_{j=1}^{n} z_{ij})},\ i,j = 1,2,\dots,n \tag{3.6}$$

In step 4, the fuzzy total relation matrix is formed by using equations (3.7), where "*I*" expresses the identity matrix, and the *D* express the decreasing indirect effects.

$$\boldsymbol{T} = D + D^{2} + D^{3} + \dots + D^{\infty} \rightarrow T = D(I - D)^{-1} \tag{3.7}$$

Step 5 is the defuzzification phase. The defuzzification is performed by using an appropriate defuzzification method. Two different defuzzification methods are used for the solution of the problem, namely the α-cut method and CFCS (Converting the

Fuzzy data into Crisp Scores) respectively. As the explanations of these methods are out of scope of this this study, we just focus on how they can be utilized for Fuzzy-DEMATEL method.

The first preferred method is the α-cut method where optimism degree (index) of the decision maker; λ; is $0 \leq \alpha \leq 1$. As λ increases, it means decision maker is an optimistic and as it decreases a pessimistic one. When fuzzy priority values are taken as (*l*, *m*, *u*) for the k_{th} alternative, the Lower Bound (LB) and Upper Bound (UB) priority values can be found by using the equations (2.8) and (2.9):

$$\boldsymbol{LB} = \propto (m - l) + l \tag{3.8}$$

$$\boldsymbol{UB} = r(m - l) + l \tag{3.9}$$

Afterwards, the evaluated lower and upper bound priority values are merged by using the equations (3.10) and (3.11) as follows:

$$\boldsymbol{W_{kLB}} = \frac{\sum_{l=1}^{L} \propto_l (LB_k)_l}{\sum_{l=1}^{LB} \propto_l} \qquad (3.10)$$

$$\boldsymbol{W_{kUB}} = \frac{\sum_{l=1}^{L} \propto_l (UB_k)_l}{\sum_{l=1}^{LB} \propto_l} \qquad (3.10)$$

where, $\boldsymbol{W_{kLB}}$ is the lower bound priority value for the k_{th} alternative and $\boldsymbol{W_{kUB}}$ is the upper bound priority value for the k_{th} alternative. Finally, the defuzzification is calculated as follows:

$$\boldsymbol{W_d} = \lambda W_{kUB} + W_{kLB}(1 - \lambda) \tag{3.11}$$

The second preferred method is the CFCS (Converting the Fuzzy data into Crisp Scores) method (Opricovic, 2003). In this method, evaluation starts with normalization as follows:

$\boldsymbol{xl_{ij}^k} = (l_{ij}^k - \min l_{ij}^k)/(\max r_{ij}^k - \min l_{ij}^k)$ (3.12)

$\boldsymbol{xm_{ij}^k} = (m_{ij}^k - \min m_{ij}^k)/(\max r_{ij}^k - \min l_{ij}^k)$ (3.13)$\boldsymbol{xr_{ij}^k} =$
$(r_{ij}^k - \min r_{ij}^k)/(\max r_{ij}^k - \min l_{ij}^k)$ (3.14)

Afterwards, the left ($\boldsymbol{xls}$) and right ($\boldsymbol{xrs}$) normalized values are calculated according to equations (3.15) and (3.16):

$$\boldsymbol{xls_{ij}^{k}} = xm_{ij}^{k}/(1 + xm_{ij}^{k} - xl_{ij}^{k}) \tag{3.15}$$

$$\boldsymbol{xrs_{ij}^{k}} = xr_{ij}^{k}/(1 + xr_{ij}^{k} - xm_{ij}^{k}) \tag{3.16}$$

Then, the total normalized value is calculated as follows:

$$\boldsymbol{x_{ij}^{k}} = \frac{\left[xls_{ij}^{k}\left(1 - xls_{ij}^{k}\right) + xrs_{ij}^{k} \times xrs_{ij}^{k})\right]}{\left[1 - xls_{ij}^{k} + xrs_{ij}^{k})\right]} \tag{3.17}$$

Finally the defuzzification is calculated as follows:

$$\boldsymbol{Z_{ij}^{k}} = \min l_{ij}^{k} + x_{ij}^{k}((\max r_{ij}^{k} - \min l_{ij}^{k})) \tag{3.18}$$

In step 6, the causer and receiver groups are identified. The sum of the i_{th} row of the Fuzzy Total Relation Matrix $\boldsymbol{Di}$, shows the sum of the direct and indirect effects send by criterion i to the other criteria. The sum of the column $\boldsymbol{Ri}$ shows the sum of the effects coming from the other criteria to the criterion. The ($\boldsymbol{Di + Ri}$) index, determined by the sums of the row and column for each criterion shows the total sent and received value; and the ($\boldsymbol{Di - Ri}$) value shows the total net effect that the i factor has on the system. If this value is positive, it shows that i criterion is a “Net Causer” and when it is negative it means it is a “Net Receiver”. The ($\boldsymbol{Di + Ri}$) value shows the degree of criterion i within the total system $\boldsymbol{Di}$ is the sent effects; $\boldsymbol{Ri}$ is the received effects; ($\boldsymbol{Di + Ri}$) is the degree of central role and ($\boldsymbol{Di - Ri}$) is the degree of effect (Çınar, 2013).

Lastly, in step 7 the criterion weights are identified by using equations (3.19) and (3.20) (organ, 2013):

$$\boldsymbol{W_i} = \sqrt{(D_i + R_i)^2 + (D_i - R_i)^2} \tag{3.19}$$

$$\boldsymbol{W_i} = w_i/\sum_{i=1}^{n} w_i \tag{3.20}$$

The causal diagram is built with the horizontal axis ($\boldsymbol{Di + Ri}$) and the vertical axis ($\boldsymbol{Di - Ri}$). The horizontal axis “Prominence” refers the importance degree of the factor, whereas the vertical axis “Relation” shows the extent of the influence. If the $(\boldsymbol{Di}-\boldsymbol{Ri})$ axis is positive, the factor is in the cause group. Otherwise, the factor is in the effect group. Causal diagrams can convert complex relationships of factors into an easy to understand structural model, providing awareness for problem solving. In other words, Every element in the Total Relation Matrix represents the effect sent by the i_{th} criterion to the j_{th} criterion. If all values in the matrix considered, the possibility of diverging from the goal increases.

3.3 SMAA and SMAA – 2 Methods

SMAA (Stochastic Multi Criteria Acceptability Analysis) is a method, which is vastly used for MCDM problems (Kangas, 2003; Lahdelma, 1998; Lahdelma, 2006; Durbach, 2008; Ternoven, 2008; Lahdelma, 2009; Tervonen, 2011; Aertsen, 2011). It is usually preferred when the information is inaccurate or partially missing (Lahdelma and Salminen, 2001).

In MCDM problems utilization of different types of criteria forms the basis of the solution methods. In literature, there has been a huge amount of weight elicitation methods have been proposed so far, where the proposed methods biased to to provide different weight values for the same problem (Weber and Borcherding 1993). In addition, in real-world problems there may be more than one decision-maker, who would easily conflict to each other to reach to a common consensus. Also the decision-makers usually neglect to fill out all of the weightings, due to pressure limits or they think their weights will change over time (Kornbluth, 1992).

The main instinct for the development of the SMAA technique method is the necessity of a robust problem solution method for discrete group decision-making problems. Specifically, for the aforementioned scenarios in which weight information is vague or partially missing (Lahdelma et al., 1998). In the traditional SMAA method, an approach to support alternative as it is the most preferred one is followed. Thus, in this method detailed and reasonably rigorous information of the sets of weight vectors are utilized.

As stated in previous sections, the of any MCDM method is to guide the decisions-makers to select the most appropriate among various alternatives. In this sense, SMMA utilizes a ranking approach where the acceptability indices are calculated that measure the variety of various choices. Furtherly, such information is used to classify the alternatives. The classification yields a degree of acceptable and non-acceptable alternatives.

Besides the advantages of the standard SMMA method, there is a weakness in the algorithm. When identifying the "best" alternative, it is highly possible to ignore the information about the other ranks, specifically when the aforementioned degree of acceptance is disseminated among the alternatives, each of which bear the best ranking when a few of weights, which has worse ranking compared to the other weights, are taken into account. Conclusively, there is risk to select an alternative that exhibit an adequately good rank but not the best one when many other weights are taken into account (Lahdelma, 2010).

The algorithm for the SMMA method is as follows (Lahdelma and Salminen, 2001):

We assume that there is group of *m* alternatives, *A*, for a group of decision-makers, *D*, such that $\boldsymbol{A} = \{\boldsymbol{x_1}, \boldsymbol{x_2}, \dots\ \boldsymbol{x_m},\}$. In addition, we assume that the number of the criteria is *n*. In this case, the decisions of decision-makers can be represented a real-valued utility function $\boldsymbol{u}(\boldsymbol{x_i}, \boldsymbol{w})$, where the alternatives are mapped to utility values,

$$\boldsymbol{u}(\boldsymbol{w}) = u(x_i, w). \tag{3.21}$$

where *w* is the weight vector for each decision-maker. When the criteria values and weights are not known precisely, they can be represented by stochastic variables $\boldsymbol{\xi_{ij}}$, with a joint probability distribution and density function $\boldsymbol{f}(\boldsymbol{\xi})$ in space *X*. Likewise, the DMs' unknown or partially known preferences are determined by a weight distribution with density function $\boldsymbol{f}(\boldsymbol{w})$ in the set of feasible weights, *W*, which can be given as:

$$\boldsymbol{W} = \{w \ \in \ R^r : w \geq 0 \ and \ \textstyle\sum_i w_i = 1\} \tag{3.22}$$

The SMAA approach determines the set of favourable weights $\boldsymbol{W_i}(\boldsymbol{\xi})$ for each alternative, which can be given as:

$$\boldsymbol{W_i}(\boldsymbol{\xi}) = \{w \in W : u(\xi_i, w) \geq u(\xi_k, w), \forall_k\}. \tag{3.23}$$

Any weight $\boldsymbol{w} \in \boldsymbol{W_i}(\boldsymbol{\xi})$ makes the overall utility of $\boldsymbol{x_i}$ greater than or equal to the utility of another alternative.

The acceptability index is a measure of the variety of different valuations making the studied alternative preferred, and it is calculated with a multidimensional integral over the criteria distributions $\boldsymbol{\xi}$ and favorable weight space as:

$$\boldsymbol{a_i} = \int_x f(\xi) \int_{w_i(\xi)} f(w) dw d\xi. \tag{3.24}$$

The acceptability index can be used for classifying the alternatives into more or less acceptable ones $\boldsymbol{a} > \boldsymbol{0}$, and those which are not acceptable ($\boldsymbol{ai} = \boldsymbol{0}, \boldsymbol{or}\ \boldsymbol{ai} \cong \boldsymbol{0}$). When $\boldsymbol{ai} = \boldsymbol{0}$, it is assumed that the alternative is not efficient in regard of the assumed utility function.

The expected centre of gravity of the favourable weight space is defined as the *central weight vector*, $\boldsymbol{w_i^c}$, which is computed as an integral of the weight vector over the criteria and weight distributions as follows:

$$\boldsymbol{w_i^c} = \int_x f(\xi) \int_{w_i(\xi)} f(w) w dw d\xi / a_i. \tag{3.25}$$

The *confidence factor* $\boldsymbol{p_i^c}$ is defined as the probability for the alternative to be the preferred one if the central weight vector is selected. The confidence factor is computed as an integral over the criteria distributions $\boldsymbol{\xi}$ by:

$$\boldsymbol{p_i^c} = \int_x f(\xi) \int_{w_i(\xi)} f(w) dw d\xi / a_i. \tag{3.26}$$

The *confidence factor* measures whether the criteria data are accurate enough to discern the alternatives when the central weight vector is used. The confidence factor can, in a similar manner, be calculated for any given weight vector and alternative.

As explained earlier, the utilization of the SMAA method is often preferred for the discrete problems. In such problems the decision-makers have to connote their attitudes, for the degrees of the importance of the criteria, with implicit or explicit expressions. Besides this, SMMA conveys a method to explore the weight space for describing the evaluations, where every alternative would be the preferred one.

In real world and discrete problems, the criteria weights are usually vague and uncertain. In such situations, the criteria values are evaluated with probability distributions. The evaluation of the probability distributions yields the confidence factors, which ultimately give idea on the reliability of the overall analysis.

SMAA-2 method is an extension to SMMA in problems where every rank is taken into account. Moreover, in the standard SMMA method, an elastic approach is followed where the alternative, which has the top-most evaluation result, is chosen. However, there may be situations where the remaining alternatives must not be disregarded. As an alternative, SMMA-2 regards the problem with a more comprehensive and holistic approach, by giving chance to other good compromise candidates (Lahdelma and Salminen, 2001).

In SMMA-2 it is assumed that the criteria weights are positive and normalized and the inaccurate and ambiguous criteria values are expressed with the $\boldsymbol{f(\xi)}$ compound probability distributed density function in X space, and the stochastic variable, $\boldsymbol{\xi}$.

When the best rank of an alternative equals to 1 and the worst one equals *m*, then the rank acceptability index can be calculated with equation (3.27).

$$\boldsymbol{rank(i,\xi,w)} = 1 + \sum_{k \neq i} \rho(u(\xi_k, w) > u(\xi_k, w)) \tag{3.27}$$

where $\boldsymbol{\rho}$(true)=1 and $\boldsymbol{\rho}$(false)=0. Rank Acceptability Index is calculated by multi-dimensional integrals as follows:

$$\boldsymbol{b_i^r} = \int_{\xi \in X} f_x(\xi) \int_{w \in W_i^r(\xi)} f(w) dw d\xi \tag{3.28}$$

The central weight vector $\boldsymbol{w_i^c}$ is defined as the expected center of weight of the appropriate weight set. Central weight vector defines the assumed preference model and the preferences of the decision makers that supports this alternative.

$$\boldsymbol{w_i^c} = \int_x \ f(\xi) \sum_{r=1}^{c} \int_{w_i(\xi)} f(w) w dw d\xi / a_i. \tag{3.29}$$

The confidence factor, $\boldsymbol{p_i^c}$, defines the probability of an alternative being the preferred alternative in the case that the central weight vector is selected. Safety factors measure if the criterion measurements are sufficiently correct in distinguishing the efficient alternatives.

$$\boldsymbol{p_i^c} = \int_{\xi:rank(\xi_i, w_i^k) \leq k} f(\xi) d\xi \tag{3.30}$$

3.4. Proposed Method

In this study we have proposed approach for scheduling of ship repair and maintenance operations with combination of two MCDM approach fuzzy DEMATEL and SMAA as explained each method previously on this chapter. This combined approach consists of total 11 steps as it summarized in Figure 3.3.

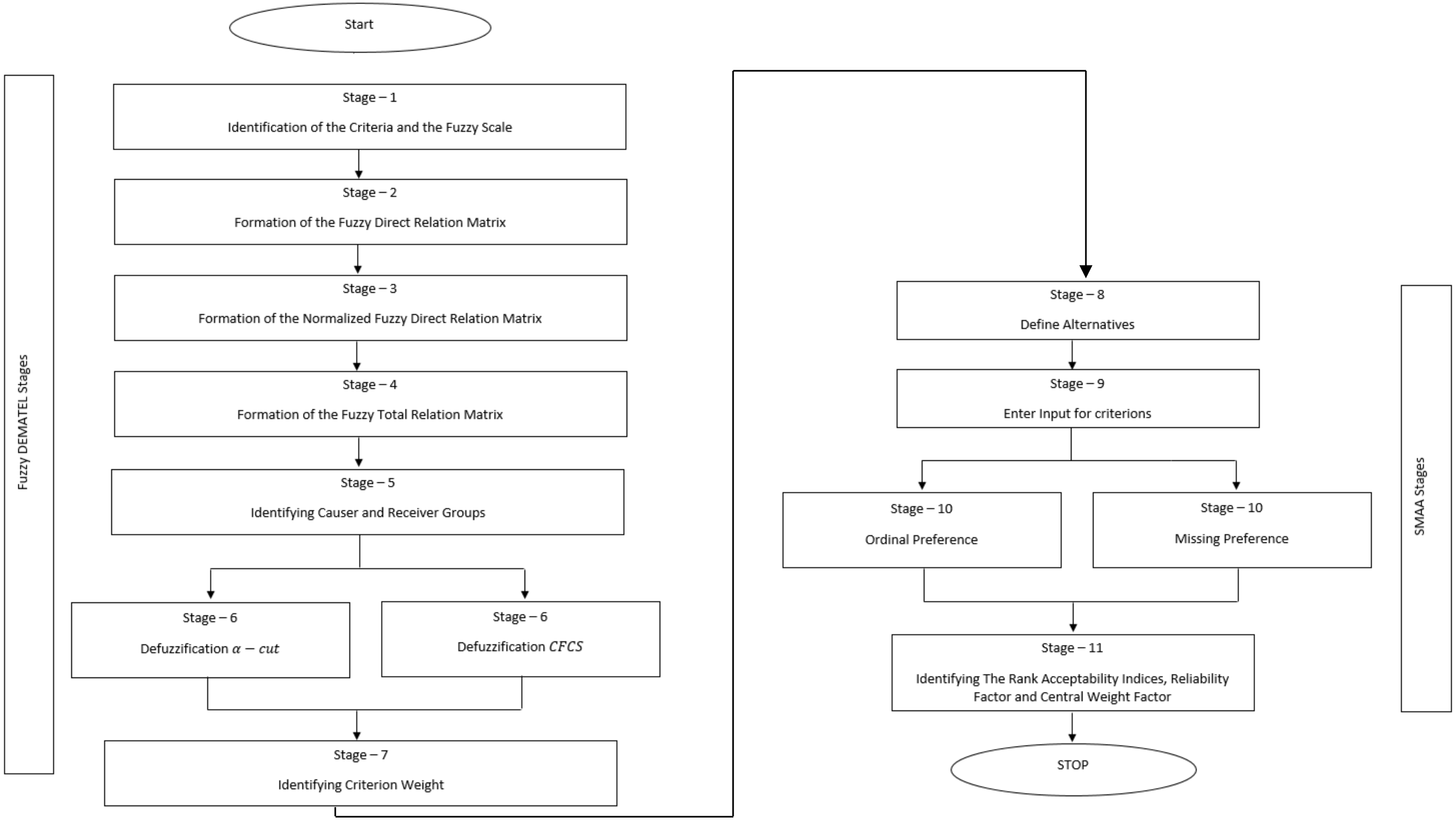

Figure 3.3 Stages of combined fuzzy DEMATEL and SMAA approach

4. CASE STUDY

4.1 Problem Statement

To allow ships moving from port to another port, ship machineries must be running free of failures and to allow owners to make profit from the shipping business operations must be efficient which also includes maintenance activities though. To achieve system to run within designed parameters all maintenance requirements must followed in the light of makers' instructions. Choosing the best maintenance approach is one of the most crucial step in maintenance management.

Maintenance superintendents, supervisor and managers are the ones who involved in this decision making process. After successful decision made about maintenance approach to be followed by managers, maintenance cost and optimization of the costs is second step in the process of maintenance activities.

This study proposes to choose best maintenance alternative for the shipping company depending on company's maintenance priorities. Company owns big variety of different class and size of vessels including oil carriers including VLCC's, Aframax's, Dynamic Positioning vessels and liquefied gas carriers including steam and dual fuel diesel engine propulsion system. Study based on company's new build 6 LNG carriers equipped with dual fuel diesel engine propulsion system and allows choosing most suitable maintenance approach for their power production plants. Vessel equipped with two electric propulsion motor ABB AMZ 1120MS08 LSF each one requires 12,650 kW for vessel to sail at full speed. Ship power produced by four stroke engine Wärtsila 12V50DF total 3 sets and 1 set of Wärtsila 6L50DF which able to use as HFO, MGO and Gas as a source of fuel. While all types of maintenance taken care by ship's crew on board carrying out a major overhaul on the power production plants require more than manpower. Due to nature of items listed by makers' it requires not only great amount of time but also inventory management, crew training, safety of crew, equipment and environment and operational lost must be taken into consideration before planning those activities. While some of the requirements can be handled on board some of them must be handled at shore by authorized workshops like cylinder heads overhaul.

4.2 Criteria Set

Criteria's used for solving the maintenance problem is identified with extensive literature review, company expectations and maintenance management system, expert opinions.

Even though literature review demonstrates us there is enormous number of items used for solving maintenance optimization problems, the most important is they should be in line with company maintenance policies to achieve business targets.

In this case study considering the company main target, maintenance policies, management view to maintenance is reviewed and 6 criteria short listed and those are C_1 Maintenance Cost, C_2 Spare Part Inventory, C_3 Personal Safety, C_4 Environment Safety, C_5 Equipment Safety and C_6 Reducing Operational Loss.

4.2.1 Maintenance cost

By means of maintenance cost it is defined in literature as anything involved for repairing activity such as, spare parts, labour force, transportation of parts and service supplied by 3rd parties for repair activities, workshop costs for service on 3rd party facilities, warehouse fees, waste and scrap handling – storage – disposing fees etc. In this case study labour force for different situations, material handling, service fee taken into consideration. All prices taken from the service suppliers and depending on the maintenance alternative chosen for servicing ships machinery maintenance cost has effect on decision making.

4.2.2 Spare parts inventory

Ship owners has to take into consideration that during ships operation machinery failure can occur unexpectedly even though all counter measures such as condition monitoring and calendar based maintenance activities are in place. In addition to that failure or machinery part breakdowns can occur during maintenance because of miss operation. In the light of that ship operators have to keep minimum spare parts as per guidelines from makers and guidance of their technical departments. Purchasing and receiving can be an another challenge during ships operation due to port operations, unavailability of items from manufacturers and aligning those with the ship schedule. It is impossible and costly for operators to have all spare parts for every machinery on-board not only because of the cost but also storing those items will be another difficulty due to limited storing capacity on the vessel. However, it is anticipated by the technical team both on-board and ashore to identify critical parts with analysing both failure data from industry and in company surveys. In this case study since the job scope identified spare parts required for all cases. Only variable is receiving and handling costs will show difference due to location of warehouses.

4.2.3 Personal safety

It is not only part of maintenance process but also key factor of success on every operation. It requires utmost importance due to the nature of shipping environment, unavailability of professional care and limited capability of on board personal on such medical cases. While personal safety is requiring special attention from the point of maintenance perspective endangering crew safety means of disruption of maintenance activities, changes on ships operation due to medical evacuation is likely to occur. So operators must give extra care into this matter in way of safety trainings, operational trainings or mitigating hazard by assigning duties to service providers.

4.2.4 Equipment safety

Equipment safety can be achieved in several ways such as improving level of responsibility within on board crew, proper training given to crew and service providers where responsibility and consequences of failure transferred to 3rd parties. In this case study all instances taken into consideration for different cases.

4.2.5 Environmental safety

It is not only by the law, but also responsibility of operators to protect the environment within the trade. Consequences of breach of environmental safety can be severe unless crew safety is in endanger which can result imprisonment, severe liability, being banned from certain ports by local authorities such as port states. Where having profit from shipping will be impossible such cases like grounding, collision, explosion etc. can occur during and/or after maintenance activities or as a result of them. Mitigating those risk such as P&I clubs doesn't eliminate the risk just decreases of their severity. So operators must have a policy inforce to protect environment.

4.2.6 Minimisation of operational loss

While losing ships propulsion can cause severe results as mentioned previously, failure of machineries like pumps, boilers etc. can result on speed limitations which can cause damage on company reputation and revenue. Proper maintenance policy and effective maintenance activities can decrease the frequency of operational losses and/or required time for those activities. In our case study, maintenance activity effects ship in such cases like immobilization of the vessel or speed limitations due to power restrictions taken in to consideration within the allocated time for the job by both service providers and on board crew to complete the job safely and effectively.

4.3 Alternatives

In our case study three maintenance scenarios developed by company for their major engine overhaul and they listed below.

4.3.1 Shipyard overhaul

IMO adopted a resolution in 1994 SOLAS conference with guidelines on the enhanced survey programme for ships inspection and surveys and companies who trades in international water has to comply with these requirements. As part of this resolution ships has to go through several inspections and surveys on regular basis and those are Annual survey, Intermediate survey, Renewal survey and Dry Dock survey. Within this cycle vessel has to have out of service period to go to shipyards and carry out required inspections and surveys. So while it is impossible for vessels to avoid out of service period it is possible to overlap major overhaul activity with out of service period and overhaul activities can be done by shipyard staff during the period. While maintenance activities and responsibilities transferred to shipyard and to the shipyard personal, development of ship staff will be come to a standstill.

4.3.2 Partial overhaul at shipyard and partial on board by vessel staff

In this scenario while two out of four engine overhauls done at shipyard, remaining to will be done prior arrival to shipyard by vessel staff on the way while vessel proceeding to shipyard for survey. While overall capabilities of vessel staff significantly increased in this scenario, biggest hustle is to purchasing materials beforehand and keeping them ready for maintenance activity. However, loss or damage of assets during maintenance might result with delay on maintenance schedule. It is another option to order extra spare parts to prevent accidental delay as it comes with additional cost.

4.3.3 Partial overhaul at shipyard and partial on board by service engineers

Both manufacturers and industrial service companies offer wide range of services for their customer and allow them to use their field of expertise. After ship owner requests service engineers, maker or service companies prepares job plan as per job scope and supplies spare parts and special tools as requested from company.

4.4 Application

For determining the criteria priorities, fuzzy DEMATEL approached used. The method puts criteria in order as per their relationship in between and their effects on each other. Another saying arranges criteria as per their relation. Criteria sets which has the most effect on others considered as cause criteria those which has priority and criteria with lower priority as considered as result criteria.

Main reason for choosing fuzzy logic in this research is to allow field experts to express their opinions in a better way with linguistic expressions compare to mathematical expressions. Another reason is advantages of linguistic expressions compare to traditional logic as explained previously.

In stage 1, Identification of the criteria and fuzzy scale, criteria bearing the basic purpose of the research can be obtained in many ways; among them; expert / researcher's views, face-to-face information, or other methods in the literature. The criteria used in this study are given in the Table 4.1.

Table 4-1: Criterion and Their Symbols

Symbol	Criterions	Source
C1	Maintenance Cost	Dorri, Kazemipour et al., 2014
C2	Spare Parts Inventory	Emovon, 2016
C3	Personal Safety	Jafarnejad, Soufi et al., 2014
C4	Equipment Safety	Vujanović, Momčilović et al., 2012
C5	Environmental Safety	Iraklis Lazakis, 2016
C6	Minimisation of Operational Loss	Carnero and Gómez, 2017

The fuzzy scale may be triangular, trapezoidal or other fuzzy numbers produced. In this study, triangular fuzzy numbers, which are the most frequently preferred in the literature, are selected and shown in Table 4.2.

Table 4-2: Triangular Fuzzy Numbers

Linguistic Terms	Influence Score	Fuzzy Values
No influence	0	(0,0,0.25)
Very Low influence	1	(0,0.25,0.50)
Low influence	2	(0.25,0.50,0.75)
High influence	3	(0.50,0.75,1)
Very high influence	4	(0.75,1,1)

In stage 2, Formation of the Fuzzy Direct Relation Matrix, 6 experts includes 3 engineering superintendent sailed up to rank of chief engineer, 2 chief engineer on board vessel and 1 shipyard superintendent who held naval architecture degree were asked to carry out pairwise comparison regarding the effect of the criterions. 6 separate linguistic evaluations were converted into fuzzy numbers. One of the experts opinion is presented in Table 4.3-Table 4.8.

Table 4-3: Expert – 1 Pairwaise Comparision

	C1	C2	C3	C4	C5	C6
C1	0	2	0	1	0	2
C2	2	0	0	2	0	0
C3	4	4	0	3	2	4
C4	3	2	1	0	1	1
C5	4	4	2	3	0	4
C6	2	4	0	3	0	0

Table 4-4: Expert – 2 Pairwaise Comparision

	C1	C2	C3	C4	C5	C6
C1	0	4	1	2	3	2
C2	0	0	0	2	1	1
C3	3	4	0	1	1	3
C4	2	2	3	0	2	2
C5	3	3	3	2	0	2
C6	4	3	1	2	2	0

Table 4-5: Expert – 3 Pairwise Comparision

	C1	C2	C3	C4	C5	C6
C1	0	3	1	2	1	3
C2	1	0	1	3	3	2
C3	3	3	0	3	2	4
C4	2	1	1	0	3	3
C5	3	1	2	1	0	3
C6	1	2	0	1	1	0

Table 4-6: Expert – 4 Pairwise Comparision

	C1	C2	C3	C4	C5	C6
C1	0	3	1	1	1	3
C2	1	0	0	1	1	2
C3	3	4	0	3	1	3
C4	3	3	1	0	2	3
C5	3	3	3	2	0	4
C6	1	2	1	1	0	0

Table 4-7: Expert – 5 Pairwise Comparision

	C1	C2	C3	C4	C5	C6
C1	0	4	1	1	0	2
C2	0	0	2	3	2	2
C3	3	2	0	2	2	3
C4	3	1	2	0	2	3
C5	4	2	2	2	0	3
C6	2	2	1	1	1	0

Table 4-8: Expert – 6 Pairwise Comparision

	C1	C2	C3	C4	C5	C6
C1	0	3	0	1	0	2
C2	1	0	0	1	0	2
C3	4	4	0	2	2	4
C4	3	3	2	0	2	4
C5	4	4	2	2	0	4
C6	2	2	0	0	0	0

In the Table 4.3-4.8, opinions of experts are given. In this study; In order to apply the fuzzy DEMATEL method, the data in the above tables are transforming in Tables 4.9-4.14, taking into account the triangular fuzzy clusters.

Table 4-9: Expert – 1 Pairwise Comparision (Fuzzy Scale)

Expert 1	C1	C2	C3	C4	C5	C6
C1	(0,0,0.25)	(0.25,0.50,0.75)	(0,0,0.25)	(0,0.25,0.50)	(0,0,0.25)	(0.25,0.50,0.75)
C2	(0.25,0.50,0.75)	(0,0,0.25)	(0,0,0.25)	(0.25,0.50,0.75)	(0,0,0.25)	(0,0,0.25)
C3	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0.75,1,1)
C4	(0.50,0.75,1)	(0.25,0.50,0.75)	(0,0.25,0.50)	(0,0,0.25)	(0,0.25,0.50)	(0,0.25,0.50)
C5	(0.75,1,1)	(0.75,1,1)	(0.25,0.50,0.75)	(0.50,0.75,1)	(0,0,0.25)	(0.75,1,1)
C6	(0.25,0.50,0.75)	(0.75,1,1)	(0,0,0.25)	(0.50,0.75,1)	(0,0,0.25)	(0,0,0.25)

Table 4-10: Expert – 2 Pairwise Comparision (Fuzzy Scale)

Expert 2	C1	C2	C3	C4	C5	C6
C1	(0,0,0.25)	(0.75,1,1)	(0,0.25,0.50)	(0.25,0.50,0.75)	(0.50,0.75,1)	(0.25,0.50,0.75)
C2	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.50,0.75)	(0,0.25,0.50)	(0,0.25,0.50)
C3	(0.50,0.75,1)	(0.75,1,1)	(0,0,0.25)	(0,0.25,0.50)	(0,0.25,0.50)	(0.50,0.75,1)
C4	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.50,0.75,1)	(0,0,0.25)	(0.25,0.50,0.75)	(0.25,0.50,0.75)
C5	(0.50,0.75,1)	(0.50,0.75,1)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0,0,0.25)	(0.25,0.50,0.75)
C6	(0.75,1,1)	(0.50,0.75,1)	(0,0.25,0.50)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0,0,0.25)

Table 4-11: Expert – 3 Pairwise Comparision (Fuzzy Scale)

Expert 3	C1	C2	C3	C4	C5	C6
C1	(0,0,0.25)	(0.50,0.75,1)	(0,0.25,0.50)	(0.25,0.50,0.75)	(0,0.25,0.50)	(0.50,0.75,1)
C2	(0,0.25,0.50)	(0,0,0.25)	(0,0.25,0.50)	(0.50,0.75,1)	(0.50,0.75,1)	(0.25,0.50,0.75)
C3	(0.50,0.75,1)	(0.50,0.75,1)	(0,0,0.25)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0.75,1,1)
C4	(0.25,0.50,0.75)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0,0.25)	(0.50,0.75,1)	(0.50,0.75,1)
C5	(0.50,0.75,1)	(0,0.25,0.50)	(0.25,0.50,0.75)	(0,0.25,0.50)	(0,0,0.25)	(0.50,0.75,1)
C6	(0,0.25,0.50)	(0.25,0.50,0.75)	(0,0,0.25)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0,0.25)

Table 4-12: Expert -4 Pairwaise Comparision (Fuzzy Scale)

Expert 4	C1	C2	C3	C4	C5	C6
C1	(0,0,0.25)	(0.50,0.75,1)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0.25,0.50)	(0.50,0.75,1)
C2	(0,0.25,0.50)	(0,0,0.25)	(0,0,0.25)	(0,0.25,0.50)	(0,0.25,0.50)	(0.25,0.50,0.75)
C3	(0.50,0.75,1)	(0.75,1,1)	(0,0,0.25)	(0.50,0.75,1)	(0,0.25,0.50)	(0.50,0.75,1)
C4	(0.50,0.75,1)	(0.50,0.75,1)	(0,0.25,0.50)	(0,0,0.25)	(0.25,0.50,0.75)	(0.50,0.75,1)
C5	(0.50,0.75,1)	(0.50,0.75,1)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0,0,0.25)	(0.75,1,1)
C6	(0,0.25,0.50)	(0.25,0.50,0.75)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0,0.25)	(0,0,0.25)

Table 4-13: Expert – 5 Pairwaise Comparision (Fuzzy Scale)

Expert 5	C1	C2	C3	C4	C5	C6
C1	(0,0,0.25)	(0.75,1,1)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0,0.25)	(0.25,0.50,0.75)
C2	(0,0,0.25)	(0,0,0.25)	(0.25,0.50,0.75)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0.25,0.50,0.75)
C3	(0.50,0.75,1)	(0.25,0.50,0.75)	(0,0,0.25)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.50,0.75,1)
C4	(0.50,0.75,1)	(0,0.25,0.50)	(0.25,0.50,0.75)	(0,0,0.25)	(0.25,0.50,0.75)	(0.50,0.75,1)
C5	(0.75,1,1)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0,0,0.25)	(0.50,0.75,1)
C6	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0,0.25)

Table 4-14: Expert – 6 Pairwaise Comparision (Fuzzy Scale)

Expert 6	C1	C2	C3	C4	C5	C6
C1	(0,0,0.25)	(0.50,0.75,1)	(0,0,0.25)	(0,0.25,0.50)	(0,0,0.25)	(0.25,0.50,0.75)
C2	(0,0.25,0.50)	(0,0,0.25)	(0,0,0.25)	(0,0.25,0.50)	(0,0,0.25)	(0.25,0.50,0.75)
C3	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.75,1,1)
C4	(0.50,0.75,1)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0,0,0.25)	(0.25,0.50,0.75)	(0.75,1,1)
C5	(0.75,1,1)	(0.75,1,1)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0,0,0.25)	(0.75,1,1)
C6	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)

In stage 3, Formation of the normalized fuzzy direct relation matrix, normalized direct relation matrices are calculated according to the following equation (4.1) and equation (4.2) and are given in Tables 4.15-4.16.

$$X_{ij} = \left(\frac{C}{r}\right) = \left(\frac{l_{ij}}{r_1}, \frac{m_{ij}}{r_2}, \frac{u_{ij}}{r_3}\right) \qquad (4.1)$$

$$r_1 = max_{1 \le j \le n}\left(\sum_{j=1}^{n} l_{ij}\right), \quad r_2 = max_{1 \le j \le n}\left(\sum_{j=1}^{n} m_{ij}\right), \quad r_3 = max_{1 \le j \le n}\left(\sum_{j=1}^{n} u_{ij}\right) \qquad (4.2)$$

Table 4-15: Fuzzy Direct Relation Matrix

	C1			**C2**			**C3**			**C4**			**C5**			**C6**		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C1	0,00	0,00	0,00	0,541	0,791	0,958	0,00	0,166	0,416	0,083	0,333	0,583	0,083	0,208	0,458	0,333	0,583	0,833
C2	0,0416	0,208	0,458	0,00	0,00	0,00	0,041	0,125	0,375	0,25	0,5	0,75	0,125	0,291	0,541	0,166	0,375	0,625
C3	0,583	0,833	1,00	0,625	0,875	0,958	0,00	0,00	0,00	0,333	0,583	0,833	0,166	0,041	0,666	0,625	0,875	1,00
C4	0,416	0,666	0,916	0,25	0,5	0,75	0,166	0,416	0,666	0,00	0,00	0,00	0,25	0,5	0,75	0,416	0,666	0,875
C5	0,625	0,875	1,00	0,458	0,708	0,875	0,333	0,583	0,833	0,25	0,5	0,75	0,00	0,00	0,00	0,583	0,833	0,958
C6	0,25	0,5	0,75	0,375	0,625	0,833	0,00	0,125	0,375	0,125	0,333	0,583	0,041	0,166	0,416	0,00	0,00	0,00

Table 4-16: Normalized Fuzzy Direct Relation Matrix

	C1			C2			C3			C4			C5			C6		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C1	0,000	0,000	0,000	0,241	0,226	0,219	0,000	0,048	0,095	0,037	0,095	0,133	0,037	0,060	0,105	0,148	0,167	0,190
C2	0,019	0,060	0,105	0,000	0,000	0,000	0,019	0,036	0,086	0,111	0,143	0,171	0,056	0,083	0,124	0,074	0,107	0,143
C3	0,259	0,238	0,229	0,278	0,250	0,219	0,000	0,000	0,000	0,148	0,167	0,190	0,074	0,012	0,152	0,278	0,250	0,229
C4	0,185	0,190	0,210	0,111	0,143	0,171	0,074	0,119	0,152	0,000	0,000	0,000	0,111	0,143	0,171	0,185	0,190	0,200
C5	0,278	0,250	0,229	0,204	0,202	0,200	0,148	0,167	0,190	0,111	0,143	0,171	0,000	0,000	0,000	0,259	0,238	0,219
C6	0,111	0,143	0,171	0,167	0,179	0,190	0,000	0,036	0,086	0,056	0,095	0,133	0,019	0,048	0,095	0,000	0,000	0,000

In stage 4, the Formation of the fuzzy total relation matrix, (F) is formed by using equations (4.3-4.4). "I" expresses the identity matrix, and the C express the decreasing indirect effects. Here *lij* is the first and the smallest of the triangular fuzzy numbers; *mij* is the middle value; and u_{ij} is the largest value.

$$\lim_{H \to \infty} C + C^2 + \cdots + C^H \approx C.(C - I)^{-1} \qquad (4.3)$$

$$F = C.(C - I)^{-1} \qquad (4.4)$$

Table 4-17: Normalized Fuzzy Direct Relation Matrix (Re-arranged)

	L						M						U					
C1	0,000	0,241	0,000	0,037	0,037	0,148	0,000	0,226	0,048	0,095	0,060	0,167	0,000	0,219	0,095	0,133	0,105	0,190
C2	0,019	0,000	0,019	0,111	0,056	0,074	0,060	0,000	0,036	0,143	0,083	0,107	0,105	0,000	0,086	0,171	0,124	0,143
C3	0,259	0,278	0,000	0,148	0,074	0,278	0,238	0,250	0,000	0,167	0,012	0,250	0,229	0,219	0,000	0,190	0,152	0,229
C4	0,185	0,111	0,074	0,000	0,111	0,185	0,190	0,143	0,119	0,000	0,143	0,190	0,210	0,171	0,152	0,000	0,171	0,200
C5	0,278	0,204	0,148	0,111	0,000	0,259	0,250	0,202	0,167	0,143	0,000	0,238	0,229	0,200	0,190	0,171	0,000	0,219
C6	0,111	0,167	0,000	0,056	0,019	0,000	0,143	0,179	0,036	0,095	0,048	0,000	0,171	0,190	0,086	0,133	0,095	0,000

Table 4-18: Fuzzy Total Direct Relation Matrix

	L						M						U					
C1	0,078	0,331	0,025	0,101	0,075	0,229	0,207	0,448	0,146	0,262	0,167	0,375	0,575	0,805	0,478	0,628	0,518	0,763
C2	0,102	0,098	0,045	0,151	0,088	0,160	0,237	0,209	0,125	0,268	0,168	0,291	0,616	0,558	0,435	0,604	0,491	0,668
C3	0,435	0,545	0,055	0,278	0,165	0,492	0,507	0,592	0,142	0,401	0,177	0,552	0,966	1,020	0,527	0,846	0,700	1,002
C4	0,324	0,324	0,112	0,103	0,167	0,350	0,463	0,448	0,250	0,241	0,272	0,493	0,884	0,910	0,613	0,624	0,663	0,908
C5	0,463	0,497	0,190	0,249	0,096	0,488	0,573	0,615	0,318	0,421	0,178	0,601	0,967	1,008	0,668	0,832	0,568	0,995
C6	0,163	0,248	0,020	0,103	0,053	0,081	0,304	0,377	0,123	0,238	0,142	0,201	0,679	0,738	0,442	0,590	0,479	0,559

In stage 5, Identifying cause and receiver groups

Table 4-19: Cause and Receiver Groups

		$\tilde{D}_i$			$\tilde{R}_i$			$\tilde{D}_i+\tilde{R}_i$			$\tilde{D}_i-\tilde{R}_i$	
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C1	0,839	1,605	3,767	1,565	2,291	4,687	2,404	3,896	8,454	-0,726	-0,686	-3,767
C2	0,644	1,298	3,372	2,043	2,689	5,039	2,687	3,987	8,411	-1,399	-1,391	-3,372
C3	1,970	2,371	5,061	0,447	1,104	3,163	2,417	3,475	8,224	1,523	1,267	-5,061
C4	1,380	2,167	4,602	0,985	1,831	4,124	2,365	3,998	8,726	0,395	0,336	-4,602
C5	1,983	2,706	5,038	0,644	1,104	3,419	2,627	3,81	8,457	1,339	1,602	-5,038
C6	0,668	1,385	3,487	1,800	2,513	4,895	2,468	3,898	8,382	-1,132	-1,128	-3,487

We will show the row sum of the fuzzy total relation matrix given in Table 4-18 with D_i and the column sums with R_i. Table 4-19 gives the values of row and column sums of the fuzzy total correlation matrix. Accordingly, if the value of $\tilde{D}_i-\tilde{R}_i$ is positive, the causer group represents while the negative value represents the receiver group. In stage 6, defuzzification, two different methods of defuzzification were used in this phase. First method α-cutting method, and the second method is the CFCS method. The reason for using these methods is that the α-cutting method is fuzzy the numbers have the highest degree of representation and both methods is frequently used in the literature.

Before cutting the α-cutting method, α cutting levels 0.7; 0.8 and 0.9, respectively. Optimism value, λ is 0 (Pessimistic), 0.5 (Moderate) and 1 (Optimistic). The following steps are applied to $\widetilde{D}_i+\tilde{R}_i$ and $\widetilde{D}_i-\tilde{R}_i$ respectively The defuzzified values are presented in Table 4-20.

The α-cutting can be done in three steps which is step 1 identification of lower and upper bound priority values, when the fuzzy priority value for the k-th alternative is taken as (l, m, r) the upper limit can be found by using the following equalities.

Lower bound (LB): $\alpha * (m - l) + l$

Upper bound (LB): $r - \alpha * (r - m)$

In step 2, the determined lower and upper bound priority values are merged by using the equations below.

W_{kL}: Lower bound priority value for the k.th alternative

W_{Ku}: Upper bound priority value for the k.th alternative

$$\mathrm{W_{kL}} = \frac{\sum_{l=1}^{L}(\alpha_l).(\mathrm{LB_k})_l}{\sum_{i=1}^{L}(\alpha_l)}$$

$$\mathrm{W_{kU}} = \frac{\sum_{i=1}^{L}(\alpha_l).(\mathrm{UB_k})_l}{\sum_{i=1}^{L}(\alpha_l)}$$

After that in step 3, obtaining defuzzified values for $\lambda \in [0,1]$.

$$W_d = \lambda.W_{kU} + (1-\lambda).W_{kL}$$

Table 4-20: The Deffuzzified Values by α-cutting Method

		Fuzzy values			Cutting levels			Lower bound values	Cutting levels			Upper Bound values	Defuzzified values (W_d) Degree of optimism (λ)		
		l	***m***	***u***	**0,70**	**0,80**	**0,90**	W_{kL}	**0,70**	**0,80**	**0,90**	W_{kU}	**0,00**	**0,50**	**1,00**
C1	$\widetilde{D}_i+\widetilde{R}_i$	2,404	3,896	8,454	3,448	3,598	3,747	3,610	5,263	4,808	4,352	4,770	3,610	4,190	4,770
C2		2,687	3,987	8,411	3,597	3,727	3,857	3,738	5,314	4,872	4,429	4,835	3,738	4,286	4,835
C3		2,417	3,475	8,224	3,158	3,263	3,369	3,272	4,900	4,425	3,950	4,385	3,272	3,829	4,385
C4		2,365	3,998	8,726	3,508	3,671	3,835	3,685	5,416	4,944	4,471	4,904	3,685	4,295	4,904
C5		2,627	3,81	8,457	3,455	3,573	3,692	3,583	5,204	4,739	4,275	4,701	3,583	4,142	4,701
C6		2,468	3,898	8,382	3,469	3,612	3,755	3,624	5,243	4,795	4,346	4,757	3,624	4,191	4,757
C1	$\widetilde{D}_i-\widetilde{R}_i$	-0,726	-0,686	-3,767	-0,698	-0,694	-0,690	-0,694	-1,610	-1,302	-0,994	-1,277	-0,694	-0,985	-1,277
C2		-1,399	-1,391	-3,372	-1,393	-1,393	-1,392	-1,393	-1,985	-1,787	-1,589	-1,771	-1,393	-1,582	-1,771
C3		1,523	1,267	-5,061	1,344	1,318	1,293	1,316	-0,631	0,001	0,634	0,054	1,316	0,685	0,054
C4		0,395	0,336	-4,602	0,354	0,348	0,342	0,347	-1,145	-0,652	-0,158	-0,610	0,347	-0,132	-0,610
C5		1,339	1,602	-5,038	1,523	1,549	1,576	1,552	-0,390	0,274	0,938	0,329	1,552	0,940	0,329
C6		-1,132	-1,128	-3,487	-1,129	-1,129	-1,128	-1,129	-1,836	-1,600	-1,364	-1,580	-1,129	-1,354	-1,580

While the D values are the sum of the rows of the defuzzified total relation matrix, R values are the sum of the columns of the same matrix. When we consider D+R values, according to the degree of optimism (1) Criterion 1, Criterion 2 and Criterion 4 are more important than the other criteria with the values of 4,770; 4,835 and 4,904, respectively. When we consider the degree of optimism (0,5) Criterion 4, Criterion 2, Criterion 6 and Criterion 1 have more importance in comparison with the values of 4,295; 4,286, 4,191 and 4,190, respectively. When we consider the degree of optimism (0) Criterion 2, Criterion 4 and Criterion 6 have more importance in comparison with the values of 3,738; 3,685 and 3,624, respectively. The negative D-R values indicate the affected criteria and positive values indicate the affecting criteria.

When the degree of optimism is 1, Criterion 1 with the value of -1,277; Criterion 2 with the value of -1,771; Criterion 4 with the value of -0,610, Criterion 6 with the value of -1,580 constitute the affected group (Receiver); Criterion 3 with the value of 0,054 and Criterion 5 with the value of 0,329 constitute the affecting group (Causer). When the degree of optimism is 0,5; Criterion 1 with the value of -0,985; Criterion 2 with the value of -1,582; Criterion 4 with the value of -0,132; Criterion 6 with the value of -1,354 constitute the affected group (Receiver); Criterion 3 with the value of 0,685; Criterion 5 with the value of 0,940 constitute the affecting group (Causer). When the degree of optimism is 0; Criterion 1 with the value of -0,694; Criterion 2 with the value of -1,393; Criterion 6 with the value of -1,129 constitute the affected group (Receiver); Criterion 3 with the value of 1,316; Criterion 4 with the value of 0,347; and Criterion 5 with the value of 1,552 constitute the affecting group (Causer).

The second preferred method is the CFCS method which is four-step algorithm expressed below.

In the second method, CFCS method, the following steps are applied in order. The Defuzzified total related matrix is shown in the Table 4-21 as a result of the operations and the values defuzzified by CFCS are shown in the Table-22. Here, the triangular fuzzy cluster is taken as

$$Z_{ij}^{k} = (\boldsymbol{l_{ij}^{k}}, \boldsymbol{m_{ij}^{k}}, \boldsymbol{r_{ij}^{k}}).$$

Firstly normalization done by below formula;

$$xl_{ij}^{k} = \frac{(l_{ij}^{k} - minl_{ij}^{k})}{\Delta_{(min,\ \mathrm{max})}}$$

$$xm_{ij}^{k} = \frac{(m_{ij}^{k} - minl_{ij}^{k})}{\Delta_{(min,\ \mathrm{max})}}$$

$$xu_{ij}^{k} = \frac{(u_{ij}^{k} - minl_{ij}^{k})}{\Delta_{(min,\ \mathrm{max})}}$$

$$\Delta_{(min,\ \mathrm{max})} = maxu_{ij}^{k} - minl_{ij}^{k}$$

After normalization calculations of right (rs) and left (ls) normalized values to be completed

$$xls_{ij}^{k} = \frac{xm_{ij}^{k}}{(1 + xm_{ij}^{k} - xl_{ij}^{k})}$$

$$xrs_{ij}^{k} = \frac{xr_{ij}^{k}}{(1 + xr_{ij}^{k} - xm_{ij}^{k})}$$

Total normalized values can be calculated as;

$$x_{ij}^{k} = \frac{[xls_{ij}^{k}\left(1 - xls_{ij}^{k}\right) + \left(xrs_{ij}^{k}\right)^{2}]}{1 - xls_{ij}^{k} + xrs_{ij}^{k}}$$

Deffuzzified values calculated with below formula

$$z_{ij}^{k} = minl_{ij}^{k} + x_{ij}^{k}\Delta_{(min,\mathrm{max})}$$

Table 4-21: The Defuzzified Total Related Matrix by CFCS

	C1	C2	C3	C4	C5	C6
C1	0,264	0,498	0,197	0,314	0,225	0,428
C2	0,295	0,264	0,174	0,319	0,221	0,348
C3	0,580	0,660	0,206	0,467	0,276	0,623
C4	0,518	0,514	0,304	0,299	0,336	0,544
C5	0,622	0,659	0,369	0,471	0,244	0,647
C6	0,359	0,428	0,172	0,291	0,197	0,257

Table 4-22: The Deffuzified Values by CFCS

Criteria	Fuzzy values			Normalization						Left and right normalize values		Total normalize values	Defuzzified Values
	l	m	u	Min(l)	Max(u)	Δ	xl_{ij}^{k}	xm_{ij}^{k}	xr_{ij}^{k}	xls_{ij}^{k}	xrs_{ij}^{k}	x_{ij}^{k}	z_{ij}^{k}
C1	0,078	0,207	0,575	0,020	1,02	1	0,058	0,187	0,555	0,166	0,406	0,244	0,264
C2	0,102	0,237	0,616	0,020	1,02	1	0,082	0,217	0,596	0,191	0,432	0,275	0,295
C3	0,435	0,507	0,966	0,020	1,02	1	0,415	0,487	0,946	0,454	0,648	0,560	0,580
C4	0,324	0,463	0,884	0,020	1,02	1	0,304	0,443	0,864	0,389	0,608	0,498	0,518
C5	0,463	0,573	0,967	0,020	1,02	1	0,443	0,553	0,947	0,498	0,679	0,602	0,622
C6	0,163	0,304	0,679	0,020	1,02	1	0,143	0,284	0,659	0,249	0,479	0,339	0,359
C1	0,331	0,448	0,805	0,020	1,02	1	0,311	0,428	0,785	0,383	0,578	0,478	0,498
C2	0,098	0,209	0,558	0,020	1,02	1	0,078	0,189	0,538	0,170	0,399	0,244	0,264
C3	0,545	0,592	1,020	0,020	1,02	1	0,525	0,572	1,00	0,546	0,700	0,640	0,660
C4	0,324	0,448	0,910	0,020	1,02	1	0,304	0,428	0,89	0,381	0,609	0,494	0,514
C5	0,497	0,615	1,008	0,020	1,02	1	0,477	0,595	0,988	0,532	0,709	0,639	0,659
C6	0,248	0,377	0,738	0,020	1,02	1	0,228	0,357	0,718	0,316	0,528	0,408	0,428
C1	0,025	0,146	0,478	0,020	1,02	1	0,005	0,126	0,458	0,112	0,344	0,177	0,197
C2	0,045	0,125	0,435	0,020	1,02	1	0,025	0,105	0,415	0,097	0,317	0,154	0,174
C3	0,055	0,142	0,527	0,020	1,02	1	0,035	0,122	0,507	0,112	0,366	0,186	0,206
C4	0,112	0,250	0,613	0,020	1,02	1	0,092	0,230	0,593	0,202	0,435	0,284	0,304
C5	0,190	0,318	0,668	0,020	1,02	1	0,170	0,298	0,648	0,264	0,480	0,349	0,369
C6	0,020	0,123	0,442	0,020	1,02	1	0	0,103	0,422	0,093	0,320	0,152	0,172
C1	0,101	0,262	0,628	0,020	1,02	1	0,081	0,242	0,608	0,208	0,445	0,294	0,314
C2	0,151	0,268	0,604	0,020	1,02	1	0,131	0,248	0,584	0,222	0,437	0,299	0,319
C3	0,278	0,401	0,846	0,020	1,02	1	0,258	0,381	0,826	0,339	0,572	0,447	0,467
C4	0,103	0,241	0,624	0,020	1,02	1	0,083	0,221	0,604	0,194	0,437	0,279	0,299
C5	0,249	0,421	0,832	0,020	1,02	1	0,229	0,401	0,812	0,342	0,575	0,451	0,471
C6	0,103	0,238	0,590	0,020	1,02	1	0,083	0,218	0,570	0,192	0,422	0,271	0,291
C1	0,075	0,167	0,518	0,020	1,02	1	0,055	0,147	0,498	0,135	0,369	0,205	0,225
C2	0,088	0,168	0,491	0,020	1,02	1	0,068	0,148	0,471	0,137	0,356	0,201	0,221
C3	0,165	0,177	0,700	0,020	1,02	1	0,145	0,157	0,680	0,155	0,446	0,256	0,276
C4	0,167	0,272	0,663	0,020	1,02	1	0,147	0,252	0,643	0,228	0,462	0,316	0,336
C5	0,096	0,178	0,568	0,020	1,02	1	0,076	0,158	0,548	0,146	0,394	0,224	0,244
C6	0,053	0,142	0,479	0,020	1,02	1	0,033	0,122	0,459	0,112	0,343	0,177	0,197
C1	0,229	0,375	0,763	0,020	1,02	1	0,209	0,355	0,743	0,310	0,535	0,408	0,428
C2	0,160	0,291	0,668	0,020	1,02	1	0,140	0,271	0,648	0,240	0,471	0,328	0,348
C3	0,492	0,552	1,002	0,020	1,02	1	0,472	0,532	0,982	0,502	0,677	0,603	0,623
C4	0,350	0,493	0,908	0,020	1,02	1	0,330	0,473	0,888	0,414	0,628	0,524	0,544
C5	0,488	0,601	0,995	0,020	1,02	1	0,468	0,581	0,975	0,522	0,699	0,627	0,647
C6	0,081	0,201	0,559	0,020	1,02	1	0,061	0,181	0,539	0,162	0,397	0,237	0,257

Now, the values of $\widetilde{D}_i + \tilde{R}_i$ and $\widetilde{D}_i - \tilde{R}_i$ are calculated from the total relation matrix obtained using the CFCS method and are given in Table 4.23.

Table 4-23: $\widetilde{\boldsymbol{D}}_{\boldsymbol{i}} + \widetilde{\boldsymbol{R}}_{\boldsymbol{i}}$ ve $\widetilde{\boldsymbol{D}}_{\boldsymbol{i}} - \widetilde{\boldsymbol{R}}_{\boldsymbol{i}}$ Values by CFCS

	C1	C2	C3	C4	C5	C6
$\widetilde{\boldsymbol{D}}_{\boldsymbol{i}}$	1,926	1,621	2,812	2,515	3,012	1,704
$\widetilde{\boldsymbol{R}}_{\boldsymbol{i}}$	2,638	3,023	1,422	2,161	1,499	2,847
$\widetilde{\boldsymbol{D}}_{\boldsymbol{i}} + \widetilde{\boldsymbol{R}}_{\boldsymbol{i}}$	4,564	4,644	4,234	4,676	4,511	4,551
$\widetilde{\boldsymbol{D}}_{\boldsymbol{i}} - \widetilde{\boldsymbol{R}}_{\boldsymbol{i}}$	-0,712	-1,402	1,390	0,354	1,513	-1,143

When the above table is examined; The criteria C1, C2 and C6 form the affected (receiver) group with values of -0.712, -1.402 and -1.143, respectively. The C3, C4, and C5 criteria form the causer group, which affects the values 4.234, 4.676, and 4.511, respectively.

In Table 4-23 also has a C4 criterion with a value of 4.676, a C2 criterion with a value of 4.644 and a relatively higher importance than the other criteria. There is not also a relatively large difference in terms of importance among all the criteria. In stage 7, Determination of importance degree of criterions, the degree of importance of these criterions is calculated using the following equation ** and equation ***. Accordingly, the degree of importance obtained according to the above-mentioned α-cutting method and CFCS method are given in the table 4.24.

$$w_i = \sqrt{\left(\widetilde{D}_i + \tilde{R}_i\right)^2 + \left(\widetilde{D}_i - \tilde{R}_i\right)^2} \qquad (**)$$

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (***)$$

Table 4-24: The Degree of Importance of The Defuzzified Criterions by α-cutting Method

	Degree of optimism		
Criterions	$\lambda = 1$	$\lambda = 0,50$	$\lambda = 0$
C1	0,1695	0,1671	0,1612
C2	0,1767	0,1773	0,1749
C3	0,1505	0,1510	0,1546
C4	0,1696	0,1688	0,1716
C5	0,1617	0,1649	0,1712
C6	0,1720	0,1710	0,1664

According to the above table, the rank of importance of criterions according to the degree of optimism (1) and (0.5): C2>C6>C4>C1>C5>C3, the rank of importance of criterions for degree of optimism (0): C2>C4>C5>C6>C1>C3.

Table 4-25: The Degree of Importance of Criterions by CFCS Method

Criterions	Degree of Importance
C1	0,1634
C2	0,1716
C3	0,1577
C4	0,1726
C5	0,1683
C6	0,1660

The rank of importance of criterions according to CFCS method; C4>C2>C5>C6>C1>C3.

There are several different methods in the literature to determine the threshold value; the first is the selection of the researcher and the other is the average of the total relation matrix. Which of these two methods is the researcher's choice to implement. In order to determine the threshold value in this study, it is preferred to average the fuzzy total relation matrix. If the defuzzified total relation matrix is obtained and then continued in the DEMATEL method, it will be seen that $\widetilde{D}_i + \tilde{R}_i$ and $\widetilde{D}_i - \tilde{R}_i$ have not changed. In Table 4-26, information about defuzzified total relation matrices is given according to the degree of optimism. If you take arithmetic averages of this matrix; the threshold value of 0.394 for the degree of optimism (1), the threshold value for the degree of optimism (0) is 0.299 and finally the threshold value for the degree of optimism (0.5) is 0.346.

Table 4-26: The Defuzzified Total Related Matrix by $\boldsymbol{\alpha}$-cutting Method for $\boldsymbol{\lambda = 1}$

Criterions	Degree of Optimism ($\boldsymbol{\lambda = 1}$)					
C1	0,278	0,516	0,210	0,332	0,234	0,449
C2	0,310	0,276	0,184	0,332	0,230	0,363
C3	0,595	0,674	0,216	0,486	0,277	0,638
C4	0,544	0,537	0,320	0,314	0,347	0,573
C5	0,649	0,690	0,385	0,500	0,253	0,677
C6	0,376	0,446	0,184	0,305	0,207	0,270

Table 4-27: The Defuzzified Total Related Matrix by $\boldsymbol{\alpha}$-cutting Method for $\boldsymbol{\lambda = 0}$

Criterions	Degree of Optimism ($\boldsymbol{\lambda = 0}$)					
C1	0,182	0,426	0,123	0,231	0,149	0,347
C2	0,211	0,188	0,110	0,246	0,153	0,266
C3	0,493	0,583	0,125	0,377	0,175	0,541
C4	0,436	0,424	0,224	0,215	0,252	0,466
C5	0,552	0,592	0,293	0,388	0,162	0,579
C6	0,277	0,352	0,103	0,212	0,125	0,178

Table 4-28: The Defuzzified Total Related Matrix by $\boldsymbol{\alpha}$-cutting Method for $\boldsymbol{\lambda = 0.5}$

Criterions	Degree of Optimism ($\boldsymbol{\lambda = 0.5}$)					
C1	0,230	0,471	0,166	0,282	0,192	0,398
C2	0,260	0,232	0,147	0,289	0,191	0,315
C3	0,544	0,629	0,171	0,432	0,226	0,589
C4	0,490	0,480	0,272	0,264	0,299	0,519
C5	0,600	0,641	0,339	0,444	0,208	0,628
C6	0,326	0,399	0,144	0,259	0,166	0,224

In Table 4.21, defuzzified total relation matrix was calculated according to the CFCS method. According to the table, the threshold value for the CFCS method is calculated as 0.377.

While creating the effect diagram, the values are plotted on the basis of the values of x-axis $\widetilde{D}_i + \tilde{R}_i$ and y-axis values $\widetilde{D}_i - \tilde{R}_i$. The impact diagrams according to the degree of optimism at this stage are given in Figures 4-7. In addition, the effect diagram obtained using the CFCS method is also shown in Figures 4.1-4.4.

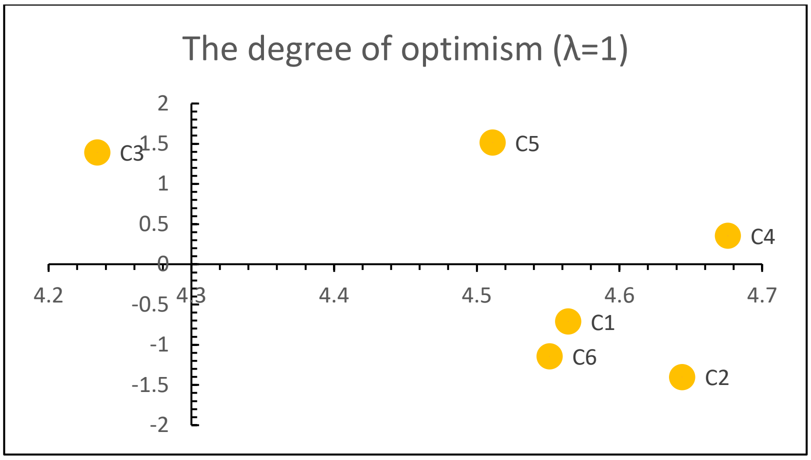

Figure 4.1: The Effect Diagram for λ=1

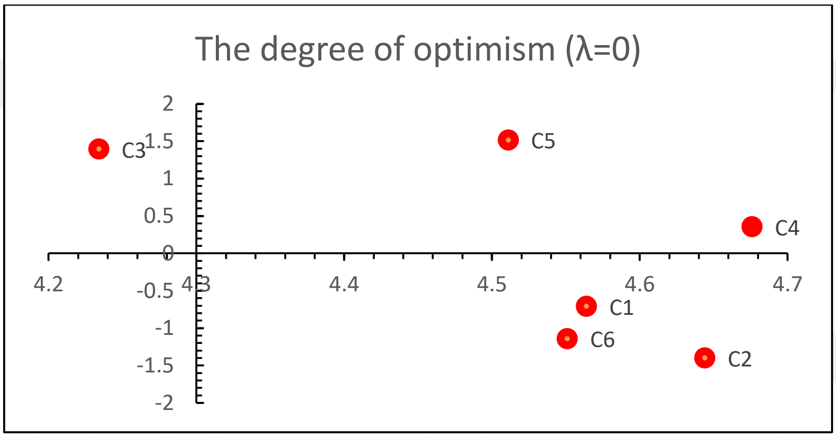

Figure 4.2: The Effect Diagram for λ=0

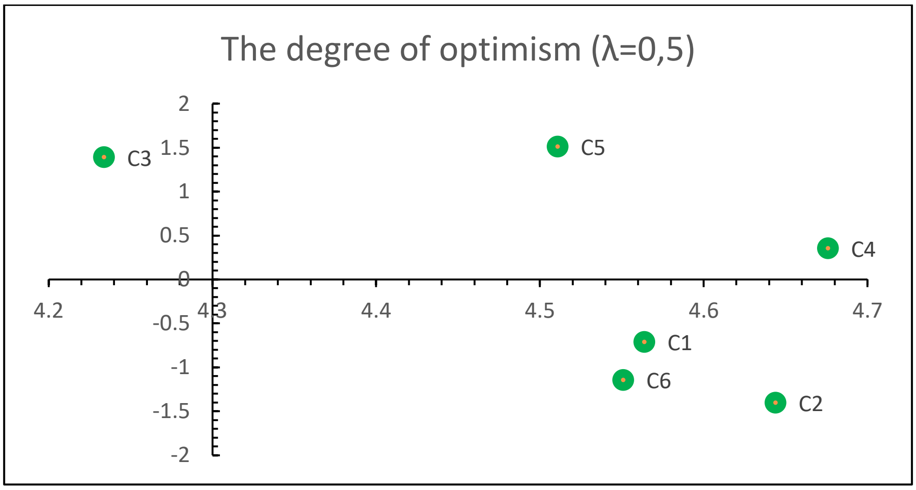

Figure 4.3: The Effect Diagram for λ=0,5

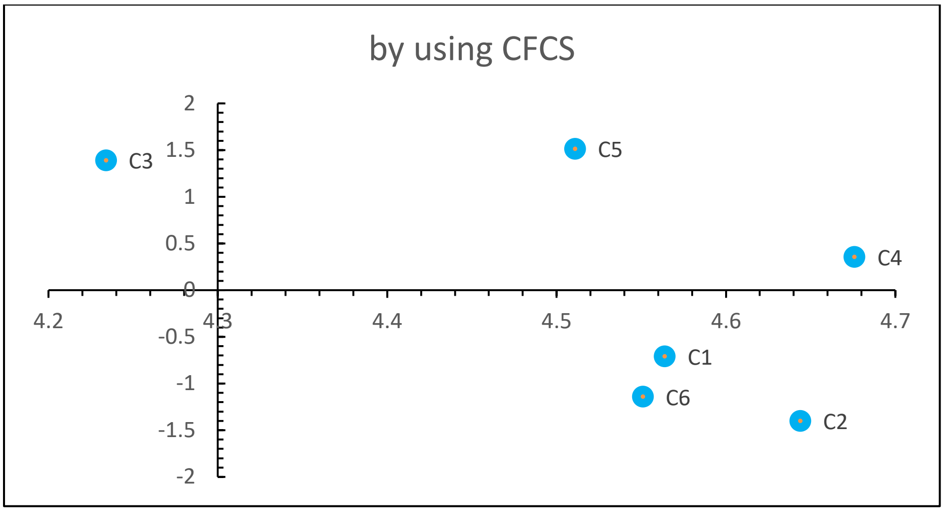

Figure 4.4: The Effect Diagram by CFCS Method

4.5 Ranking of Alternatives

Many of the information gathered in real life problems is not certain. Sometimes there can be many judgments about a subject, and it is doubtful whether one of these judgments is correct or an incomplete judgment. In these cases, the SMAA method is a technique used to solve the problem.

In this study; the SMAA-2 method was preferred because of the inclusion of the problem, the use of criteria weights and rankings.

For the SMAA-2 method, the open source JSMAA version 1.0.3 software, which provides great ease of use, is used. The rank of the criteria is identified by the fuzzy DEMATEL method. In preferences section of the software; three types of Preference information can be used as an input. In this study; Ordinal and Missing Preferance Types are used. Ordinal inputs are received from the fuzzy DEMATEL results. The rank of criteria is used as an Ordinal Preference in JSMAA.

In this study; three scenarios have been identified:

Scenario-1: Vessel under bareboat charter

Scenario-2: Vessel under time charter

Scenario-3: Vessel under voyage charter

Table 4-29: Scenario – 1 Inputs

		CRITERIONS					
ALTERNATİVES		C1	C2	C3	C4	C5	C6
		Maintenance Cost	Spare Parts Inventory	Personal Safety	Equipment Safety	Environmental Safety	Minimisation of Operational Loss
A-1	Shipyard Overhaul	2,896,542	3	3	2	1	2
A-2	Partial Overhaul at Shipyard and Partial On Board by Vessel Staff	2,841,108	1	1	1	2	1
A-3	Partial Overhaul at Shipyard and Partial On Board by Service Engineers	2,914,641	2	2	3	3	1
		$\Delta \pm \%10$					

Once the values of the alternatives and criteria are entered in the JSMAA program, preference information should be selected. JSMAA inputs for criteria added on appendix section Appendix A-B-C-D-E-F. There are three alternatives to the program: Missing, Ordinal and Cardinal.

The rank of criteria obtained using DEMATEL method are entered in the Ordinal Preferences section in JSMAA. When the degree of optimism is (1) and (0,5) the order is C2>C4>C5>C6>C1>C3; when the degree of optimism is (0), the order is C2>C4>C5>C6>C1>C3 and defuzificaition is made by CFCS the order is C4>C2>C5>C6>C1>C3. Appendix G – H and I show the values entered into the JSMAA program.

The missing preference value is used where there is no weight or ranking information. Appendix J shows the values entered into the JSMAA program.

The results are analysed from the RESULTS section. Here, the anticipatory admissibility indices, the reliability factor and the central weight vector antagonism are emerging.

Rank acceptability indices according to the degree of Optimism (1) and (0.5) are shown in Appendix K of the program screen and the results are shown in Table-4.30. Columns and rows can be viewed separately:

Table 4-30: Scenario-1 Rank Acceptability Indices for the Degree of Optimism (1) and (0.5)

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,00	0,00	1,00
A2	1,00	0,00	0,00
A3	0,00	1,00	0,00

According to the rank acceptability indices shown in Appendix K and Table 4-30, the second alternative is the partial overhaul at shipyard and partial on board by vessel staff criterion is preferred to in first place with 100% probability. Other alternatives are the first choice with 0% probability.

A third alternative is the partial overhaul at shipyard and partial on board by service engineers in second place with a probability of 100% while the other alternatives are in second place with 0% probability.

The first alternative is shipyard overhaul in third place with 100% probability. The other alternatives are in the third place with 13% probability and 0% probability respectively.
The first alternative is in the 1 st order with 0% probability; Second with 0% probability; 100% will be preferred in the third place.
The second alternative is in the 1 st order with 100% probability; Second with 0% probability; 0% will be preferred in third place.
The third alternative is in the 1 st order with 100% probability; Second with 0% probability; It will be the third place with 0% probability.

Accordingly, the rank of the alternatives is A2> A3> A1.

This result is tested by calculating the center weight vector values with the reliability factor of the obtained ranking.
JSMAA screen image with calculated reliability factor and central weight vector values is shown in Appendix L , and the results are shown in Table 4-31.

Table 4-31: Scenario-1 Reliability Factors and Centre of Weight Vectors According to the Degree of Optimism (1) and (0.5)

Alternatives	Reliability Factor	Maintenance Cost	Spare parts inventory	Personal safety	Equipment Safety	Environmental Safety	Minimisation of operational loss
A1	1,00	NA	NA	NA	NA	NA	NA
A2	1,00	0,10	0,41	0,03	0,16	0,06	0,24
A3	1,00	NA	NA	NA	NA	NA	NA

The Reliability Factor value is 100% for the first alternative. That is, the probability of preferring the first alternative in the first order (0%) is 100%. The centre weight vectors of the criteria are not calculated as there is no probability of being in the first place.

The Reliability Factor value is 100% for the second alternative. In other words, the probability of preferring the second alternative in the first order (100%) is 100%. When we look at the central weight vectors, the second most important criterion for taking these values is the spare parts inventory (C2) with 41% probability.

The Reliability Factor value is 100% for the third alternative. That is, the probability of preferring the first alternative in the first order (0%) is 100%. The centre weight vectors of the criteria are not calculated as there is no probability of being in the first place.

The degree of optimism (0) and the Evaluations Made According to the CFCS defuzzification method are presented in Appendix M.

Table 4-32: Scenario-1 the Rank Acceptability Indices by CFCS Method

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,00	0,95	0,05
A2	1,00	0,00	0,00
A3	0,00	0,05	0,95

According to the rank acceptability indices shown in Appendix M and Table-4.32, the second alternative is preferred in first place with 63% probability. Other alternatives are the first choice with 0% probability.

The first alternative, the shipyard overhaul, is preferred in second place with 95% probability, while the other alternatives are the second with 0% and 5% probability respectively.

Third alternative is preferred in third place with 95% probability, while the other alternatives are the second with 5% and 0% probability respectively.

The first alternative is in the 1 st order with 0% probability; Second with 95% probability; 5% will be preferred in the third place.

The second alternative is in the 1 st order with 100% probability; 0% likely second; 0% will be preferred in third place.

The third alternative is in 1 st order with 0% probability; Second with 5% probability; It will be the third place with 95% probability.

Accordingly, the rank of the alternatives is A2> A1> A3.

Calculated reliability factor and center weight vector values are shown in Appendix N and Table-4.32.

Table 4-33: Reliability Factors and Centre Weight Vector Values for Scenario-1 by CFCS Method

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	1,00	NA	NA	NA	NA	NA	NA
A2	1,00	0,06	0,24	0,03	0,41	0,16	0,10
A3	1,00	NA	NA	NA	NA	NA	NA

The Reliability Factor value is 100% for the first alternative. That is, the probability of preferring the first alternative in the first order (0%) is 100%. The centre weight vectors of the criteria are not calculated as there is no probability of being in the first place.

The Reliability Factor value is 100% for the second alternative. In other words, the probability of preferring the second alternative in the first order (100%) is 100%. When we look at the central weight vectors, the second most important criterion for taking these values is the spare parts inventory (C2) with 24% probability.

The Reliability Factor value is 100% for the third alternative. That is, the probability of preferring the first alternative in the first order (0%) is 100%. The centre weight vectors of the criteria are not calculated as there is no probability of being in the first place.
Assessments made in the absence of weight and ranking information (Missing) are presented in Appendix O and Table 4-34.

Table 4-34: Rank Acceptability Indices for Scenario-1 by Missing Preference

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,02	0,35	0,63
A2	0,97	0,03	0,00
A3	0,01	0,62	0,37

According to Appendix O and Table 4.34, the rank of the alternatives is A2> A3> A1. Calculated reliability factor and center weight vector values are shown in Appendix N and Table-4.35.

Table 4-35: Reliability Factors and Center Weight Vector Values for Scenario-1 by Missing Preference

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	0,54	0,23	0,06	0,06	0,10	0,49	0,06
A2	1,00	0,16	0,17	0,17	0,17	0,16	0,17
A3	0,13	0,55	0,08	0,07	0,06	0,06	0,17

Table 4-36: Scenario-2 Inputs

		CRITERION					
	ALTERNATİVES	C1 Maintenance Cost	C2 Spare Parts Inventory	C3 Personal Safety	C4 Equipment Safety	C5 Environmental Safety	C6 Minimisation of Operational Loss
A-1	Shipyard Overhaul	4,296,542	3	3	2	3	1
A-2	Partial Overhaul at Shipyard and Partial On Board by Vessel Staff	3,561,108	1	1	3	1	2
A-3	Partial Overhaul at Shipyard and Partial On Board by Service Engineers	3,634,641	2	2	1	2	2
		$\Delta \pm \%\mathbf{10}$					

The values entered in Scenario-2 were evaluated with missing and ordinal preference information. According to the ordinal preference information, the results according to the degree of optimism (1) and (0.5) are presented in Table-4.37 and Table-4.38.

Table 4-37: Scenario-2 Rank Acceptability Indices for Degree of Optimism (1) and (0.5)

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,01	0,11	0,88
A2	0,84	0,12	0,03
A3	0,14	0,77	0,09

According to Table-4.37, the rank of alternatives is A2>A3>A1. Table-37 presents the Reliability Factors and Central Weight Vectors for Scenario-2 according to degree of optimism (1) and (0.5).

Table 4-38: Scenario-2 Reliability Factors and Center Weight Vector Values for Degree of Optimism (1) and (0.5)

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	0,69	0,08	0,36	0,01	0,19	0,03	0,34
A2	1,00	0,10	0,42	0,03	0,15	0,06	0,24
A3	0,78	0,12	0,32	0,02	0,22	0,06	0,26

The acceptability indices obtained from Scenario-2 according to the reliability factor and the information obtained from the CFCS method are shown in Table 4.39; reliability factors and central weight factors are presented in Table-4.40.

Table 4-39: Scenario-2 Rank Acceptability Indices by CFCS Method

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,00	0,13	0,87
A2	0,03	0,84	0,13
A3	0,97	0,03	0,00

Table 4-40: Scenario-2 Reliability Factors and Center Weight Vector Values by CFCS Method

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	1,00	NA	NA	NA	NA	NA	NA
A2	0,55	0,10	0,23	0,06	0,25	0,20	0,15
A3	1,00	0,06	0,24	0,03	0,41	0,16	0,10

According to Table 4.39 – 4.40, the rank of alternatives is A3>A2>A1.

The results are shown in Table-40 and Table-41 according to Missing preference, in which there is no weight or ranking information.

Table 4-41: Scenario-2 Rank Acceptability Indices by MISSING Preference

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,10	0,12	0,78
A2	0,65	0,24	0,11
A3	0,25	0,64	0,11

Table 4-42: Scenario-2 Reliability Factors and Center Weight Vector Values by Missing Preference

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	1,00	0,13	0,09	0,09	0,14	0,09	0,45
A2	1,00	0,17	0,20	0,20	0,10	0,20	0,14
A3	1,00	0,18	0,12	0,12	0,35	0,11	0,12

According to Table 4.41 and Table 4.42, the rank of alternatves is A2>A3>A1.

Table 4-43: Scenario – 3 Inputs

		CRITERIONS					
	ALTERNATİVES	C1 Maintenance Cost	C2 Spare Parts Inventory	C3 Personal Safety	C4 Equipment Safety	C5 Environmental Safety	C6 Minimisation of Operational Loss
A-1	Shipyard Overhaul	4,296,542	3	3	1	1	1
A-2	Partial Overhaul at Shipyard and Partial On Board by Vessel Staff	3,561,108	1	2	3	2	1
A-3	Partial Overhaul at Shipyard and Partial On Board by Service Engineers	3,634,641	2	1	2	3	2
		$\Delta \pm \%10$					

The values entered in Scenario-3 were evaluated with missing and ordinal preference information. According to the ordinal preference information, the results according to the degree of optimism grade (1) and (0.5) are presented in Table-4.44 and Table-4.45.

Table 4-44: Scenario-3 Rank Acceptability Indices for the Degree of Optimism (1) and (0.5)

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,00	0,85	0,15
A2	1,00	0,00	0,00
A3	0,00	0,15	0,85

According to Table 4.44 and Table 4.45, the rank of alternatives is A2>A1>A3. Table 44 presents the Reliability Factors and Central Weight Vectors for Scenario-3 according to the degree of optimism (1) and (0.5).

Table 4-45: Scenario-3 Reliability Factors and Centre Weight Vector Values for the Degree of Optimism (1) and (0,5)

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	0,12	0,16	0,25	0,03	0,21	0,12	0,23
A2	1,00	0,10	0,41	0,03	0,16	0,06	0,24
A3	1,00	NA	NA	NA	NA	NA	NA

The acceptability indices obtained from Scenario-3 according to the reliability factor and the information obtained from the CFCS method are shown in Table 4.46; reliability factors and central weight factors are presented in Table 4.47.

Table 4-46: Scenario-3 Rank Acceptability Indices for CFCS Method

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,99	0,01	0,00
A2	0,01	0,80	0,19
A3	0,00	0,19	0,81

Table 4-47: Scenario-3 Reliability Factors and Center Weight Vector Values by CFCS Method

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	1,00	0,06	0,24	0,03	0,41	0,16	0,10
A2	0,27	0,12	0,25	0,08	0,26	0,16	0,14
A3	1,00	NA	NA	NA	NA	NA	NA

According to table 4.46 – 4.47, the rank of alternatives is A1>A2>A3.

The results are shown in Table-4.48 and Table-4.49 according to Missing preference, in which there is no weight or ranking information.

Table 4-48: Scenario-3 Rank Acceptability Indices by Missing Preference

Alternatives	Rank 1	Rank 2	Rank 3
A1	0,38	0,30	0,32
A2	0,49	0,40	0,12
A3	0,13	0,30	0,56

Table 4-49: Scenario-3 Reliability Factors and Center Weight Vector Values by Missing Preference

Alternatives	Reliability factor	C1	C2	C3	C4	C5	C6
A1	1,00	0,13	0,09	0,11	0,26	0,23	0,18
A2	1,00	0,19	0,24	0,16	0,09	0,14	0,18
A3	0,99	0,19	0,11	0,37	0,17	0,08	0,07

According to Table 4.48 and Table 4.49, the rank of alternatives is A2>A1>A3. All the data obtained according to the three scenarios are presented in Table-4.50. When the table is examined; preference information in the problem is entered as Ordinal and Missing, that is, it is seen that the A-2 alternative is preferred in the first place when there is a ranking information.

Table 4-50: The Rank Acceptability Indices, the Reliability Factors and the Alternative Rankings for Three Scenarios

Alternatives		SCENARIO-1						SCENARIO-2						SCENARIO-3			
		Ordinal				Missing		Ordinal				Missing		Ordinal		Missing	
		The Degree of optimism (0.5) and (1)		CFCS				The Degree of optimism (0.5) and (1)		CFCS							
		RF	RAI	RF	RAI	RF	RAI	RF	RAI	RF	RAI	RF	RAI	RF	RAI	RF	RAI
A-1	**Rank 1**	1,00	0,00	1,00	0,00	0,54	0,02	0,69	0,01	1,00	0,00	1,00	0,10	0,12	0,00	1,00	0,38
	Rank 2	-	0,00	-	0,95	-	0,35	-	0,11	-	0,13	-	0,12	-	0,85	-	0,30
	Rank 3		1,00		0,05		0,63		0,88		0,87		0,78		0,15		0,32
A-2	**Rank 1**	1,00	1,00	1,00	1,00	1,00	0,97	1,00	0,84	0,55	0,03	1,00	0,65	1,00	1,00	1,00	0,49
	Rank 2	-	0,00	-	0,00	-	0,03	-	0,12	-	0,84	-	0,24	-	0,00	-	0,40
	Rank 3		0,00		0,00		0,00		0,03		0,13		0,11		0,00		0,12
A-3	**Rank 1**	1,00	0,00	1,00	0,00	0,13	0,01	0,78	0,14	1,00	0,97	1,00	0,25	1,00	0,00	0,99	0,13
	Rank 2	-	1,00	-	0,05	-	0,62	-	0,77	-	0,03	-	0,64	-	0,15	-	0,30
	Rank 3		0,00		0,95		0,37		0,09		0,00		0,11		0,85		0,56
Results		A2>A3>A1		A2>A1>A3		A2>A3>A1		A2>A3>A1		A3>A2>A1		A2>A3>A1		A2>A1>A3			

**RF: Reliability factor

**RAI: Rank Acceptability Indices

As study indicates ranking of maintenance scheduling alternatives varies from one to another depending on the occasion and correct planning increase not only efficiency of the activities but also profitability of the company from those activities. One must consider those before making decision with regards scheduling of maintenance activities. Depending of the charter type cost of maintenance activities separated between parties so that owner or charterer. It is obvious that postponing those activities will decrease vessel reliability. However with proper condition monitoring activities can help to observe overall plant condition so any unexpected breakdown can be prevented at early stages with identification of the failure.

In this case study proposed approach for ship repair and maintenance operations consist of combination of two MCDM techniques DEMATEL and SMAA helps for problem solving even when there is uncertainty and/or unknown conditions are present. Since expert opinions present in the field of study, fuzzy DEMATEL used for eliminating uncertainty and obtain input for SMAA. As it seen from table 4-50, ranking of alternatives depending on three different scenario listed. Considering scenario 3 most of the expenses while vessel under voyage charter under owner responsibility so for both preference ordinal and missing ranking of alternatives appears to be same ranking which is A2>A1>A3. In scenario 1 which is bareboat charter type, while using ordinal preference with optimism degree of 0.5 and 1, ranking of maintenance alternatives listed as A2>A3>A1 with CFCS method A2>A1>A3 and missing preference has same ranking with different acceptability indices. For time charter which is scenario 2, shows difference on applying CFCS method for ordinal preference where the results appear to be A3>A2>A1.

5. CONCLUSIONS

While maintenance activities are of the utmost importance for ensuring vessel safety, they also interfere with vessel operations and require high costs, allocated time and labour force.

While companies wish to reduce their operating costs, this activity must be completed both in the most efficient manner and in compliance with codes so that ships can operate without failure or endangering the crew's safety or the environment.

The main target of maintenance management is to maximise the lifetime of the machinery and reduce the use of unnecessary spare parts that would result in increasing the vessel's operating costs. To achieve this target, companies must establish maintenance departments on shore to observe vessel activities, develop targets and institute methodologies, such as corrective, preventive and predictive maintenance. Greater importance also needs to be placed on the training of the vessel staff because the crew observes the machinery on a daily basis and should be able to address abnormalities in advance. Manufacturers develop maintenance requirements based on industrial feedback received about their products, and following those requirements is of vital importance to achieve safe operation without unexpected breakdown during the machine's lifetime.

Developing industry also brings more complexity to the system for machinery installed on board vessels. Due to the nature of shipping, it is impossible to have all of the required spare parts on board vessels for several reasons, including high cost and limited storage capacity. In addition, logistical aspects must be taken into account for supplying the required parts to the vessel. Because the time allocated for port operations is being reduced day by day, transferring parts from a factory in one part of the world to a warehouse located in another and then delivering those parts to the vessel in a timely manner must be done in a hurry. Furthermore, depending on the vessel's trade region, the prices of spare parts and logistics can vary greatly, which can cause additional increases in operational costs.

Dozens of accidents in the shipping industry have been linked to machinery failure and breakdowns. The number of accidents due to machinery failure has caused authorities to enforce surveys within specific intervals, such as the annual survey, intermediate survey, renewal survey and dry dock survey. Through such activities, authorities, such as classification societies, examine the general condition of the ship and status of the machinery. An objective of this study was to analyse the possibility of overlapping such activities with survey activities in order to eliminate ship operational losses. Alternatives include shipyard overhaul, partial overhaul at shipyard and partial on board by vessel staff, and partial overhaul at shipyard and partial on board by service engineers. Depending on the charter type, the cost of maintenance distributed between the parties and criteria ranking should be adjusted as per charter party expectations. Considering this fact, an interface should be developed and implemented for business owners to use the proposed methodology for daily decision-making processes.

In this study, we proposed a method for planning ship maintenance activities using Fuzzy-DEMATEL and SMAA. The issues consisted of six criteria and three alternatives. These criteria included the costs of the facility, equipment, staff, materials, labour, executive expenses, storage and stock expenses, maintenance expenses, transportation, waste and waste expenses, labour and spare parts, personal safety, equipment safety, environmental safety and minimisation of operational loss. Each one of them reflects not only companies' aims but also desired parameters within the industry. As the literature review demonstrates, industrial experts and researchers are trying to minimise operational losses within the machinery's lifetime. However, the safety aspects of the ships' operation should not be neglected, as such negligence can cause catastrophic failure for the environment, ships' crew and cargo. Thus, the aim of this study is to consider each of those parameters and align them with the maintenance targets.

This study underlined the fact that it is possible to evaluate these values while the expert opinions or inputs are unknown or subject to change within the work environment, which allows for assigning different rankings to parameters. Precise ranking is also possible with the CFCS method when all opinions and inputs are present.

As the results of this study clearly show, the DEMATEL-SMAA method is reliable for decision-making processes in the shipping industry and allows for the ranking of alternatives as per business expectations. This study focused on the newly-built LNG vessel, in which the ship's construction allows for the option of dividing power plants for maintenance operation; however, it is also possible to implement the DEMATEL-SMAA approach for changing scenarios and alternatives depending on the problem and criteria. In future studies, researchers should use different multi-criteria decision support systems to verify the reliability of the proposed method. Different hybrid MCDM methods could also be used in conjunction with the proposed method to increase its reliability. Another significant contribution that this study makes to the literature is offering a different approach to the maintenance programming activities. Similar approaches to the one proposed could also be implemented in other industries. Lastly, this study promotes research that combines industry and academia.

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APPENDICES

APPENDIX A

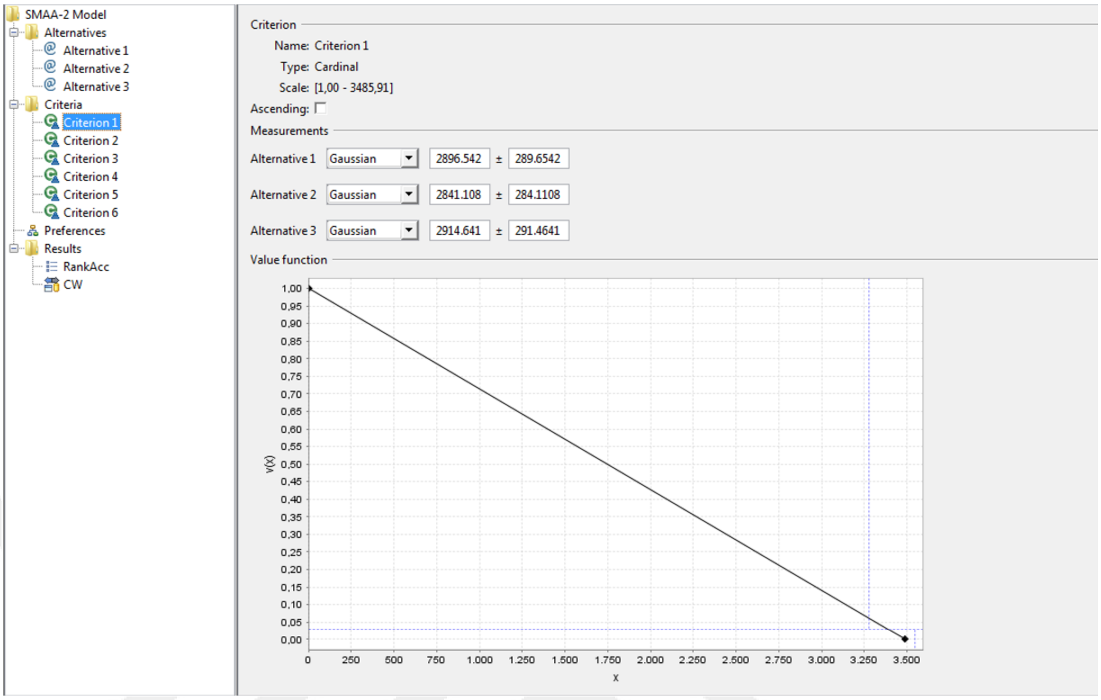

Figure A 1: JSMAA inputs for maintenance cost criterion (C1)

APPENDIX B

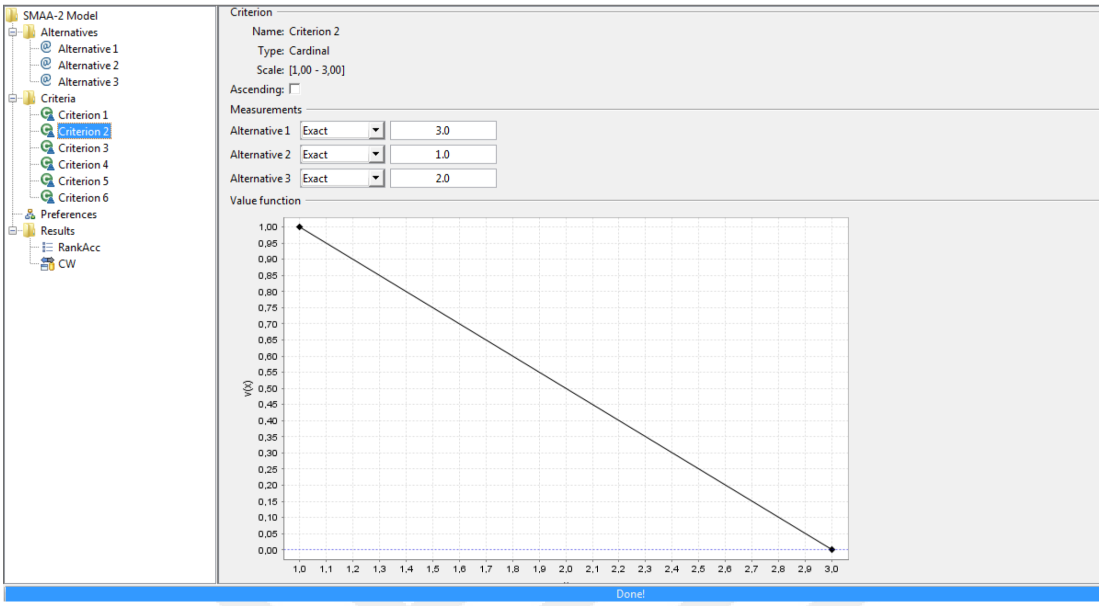

Figure A 2: JSMAA inputs for Spare Parts Inventory criterion (C2)

APPENDIX C

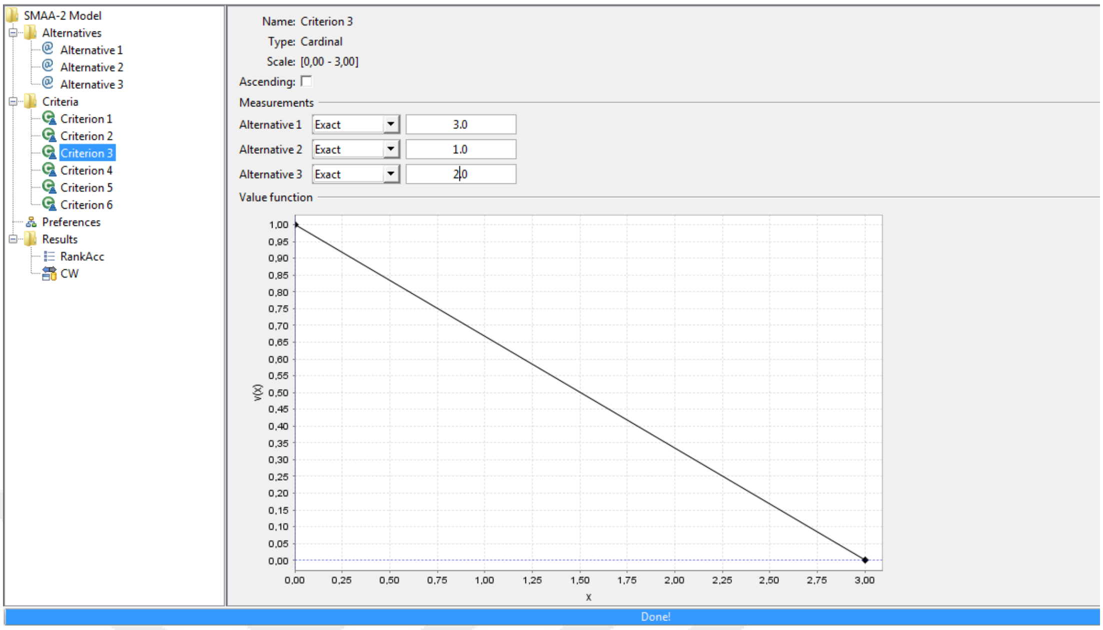

Figure A 3: JSMAA inputs for Personal safety criterion (C3)

APPENDIX D

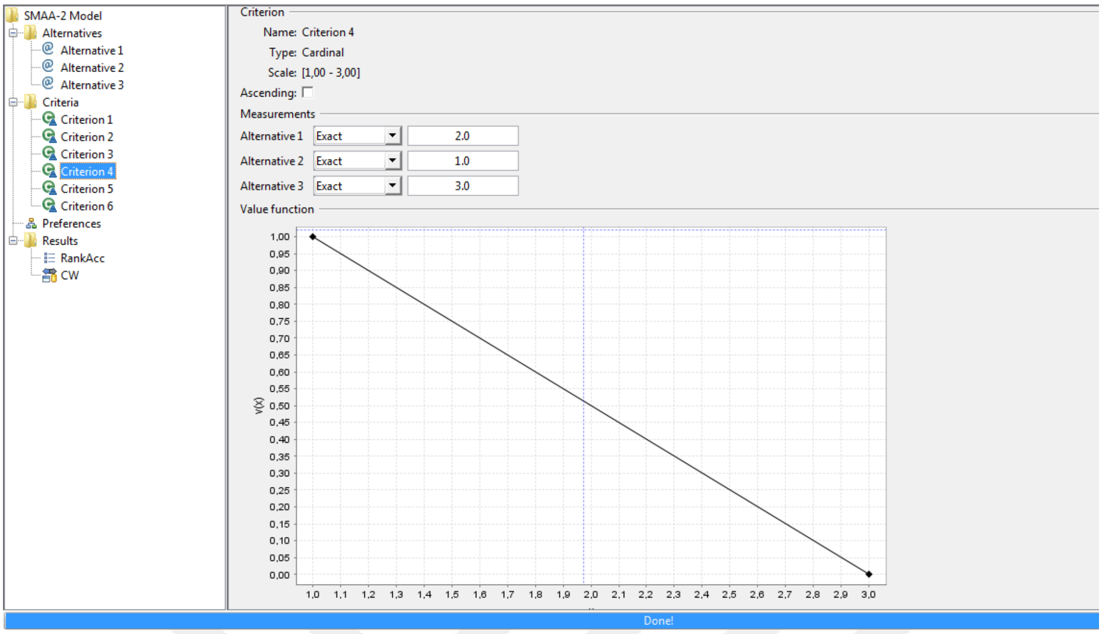

Figure A 4: JSMAA inputs for Equipment safety criterion (C4)

APPENDIX E

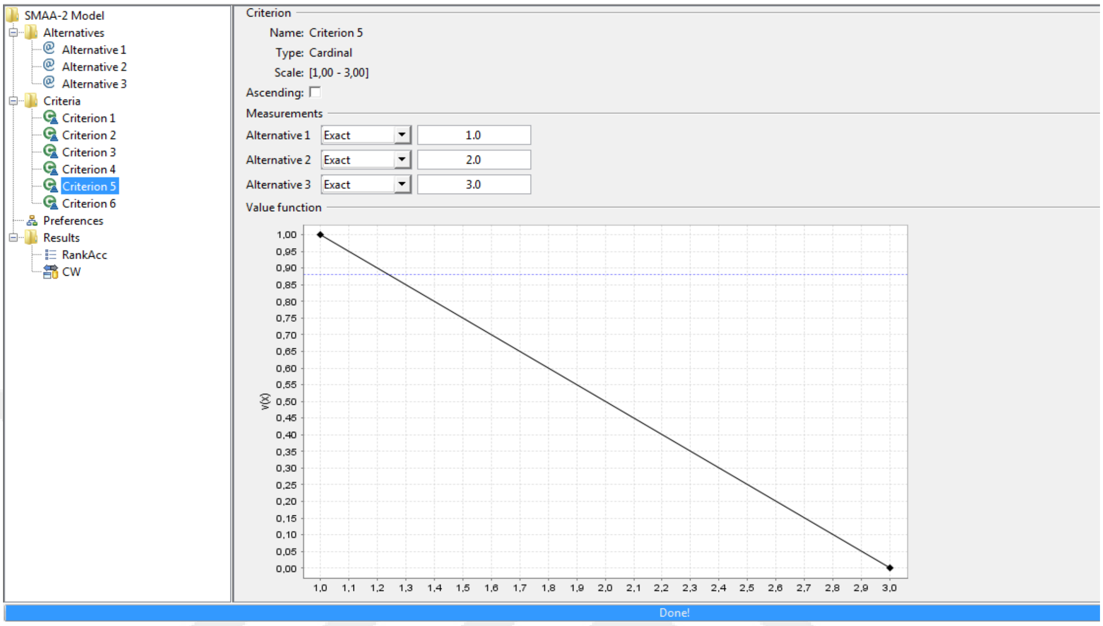

Figure A 5: JSMAA inputs for Environmental safety criterion (C5)

APPENDIX F

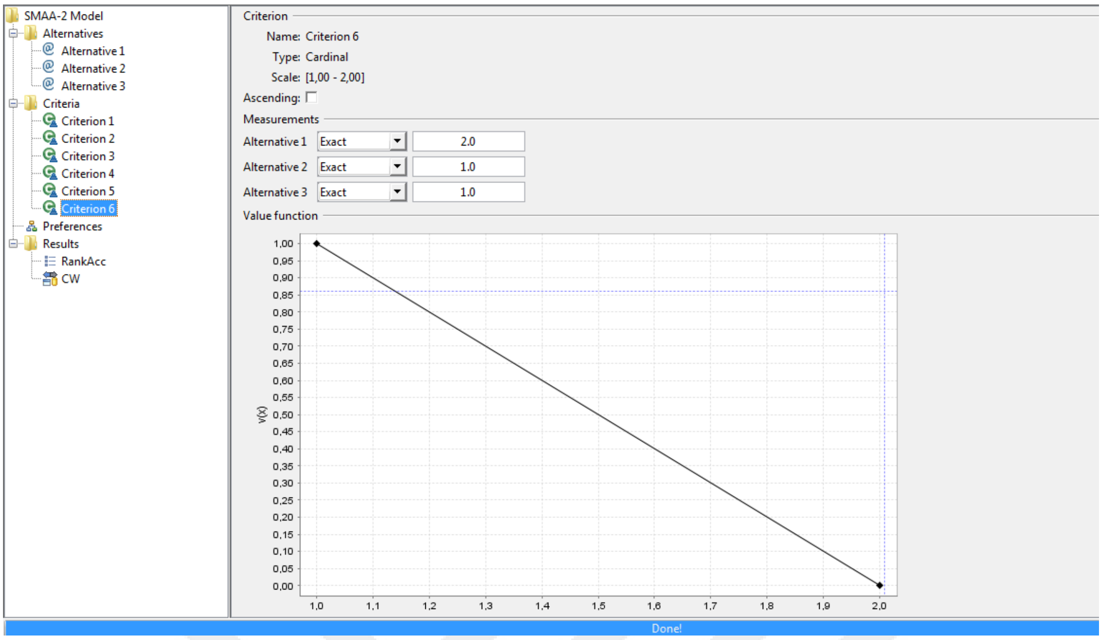

Figure A 6: JSMAA inputs for minimization of Operational Loss criterion (C6)

APPENDIX G

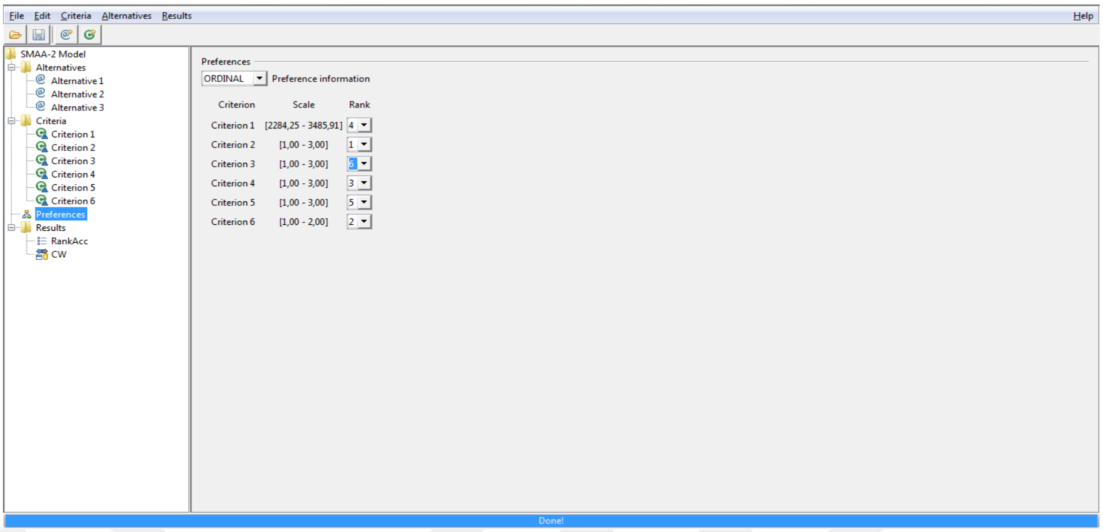

Figure A 7: The ranking of criterions for the degree of optimism (1) and (0,5)

APPENDIX H

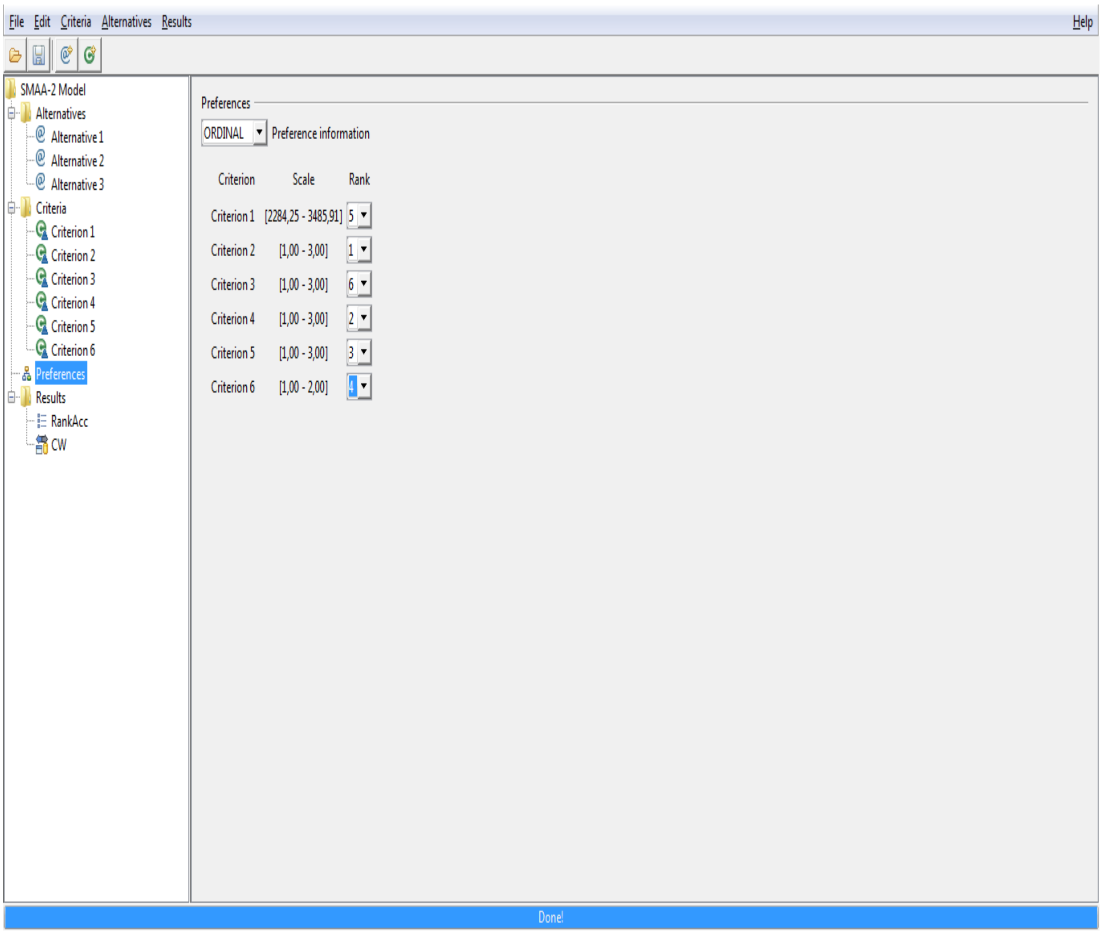

Figure A 8: The Ranking of criterions for the degree of optimism (0)

APPENDIX I

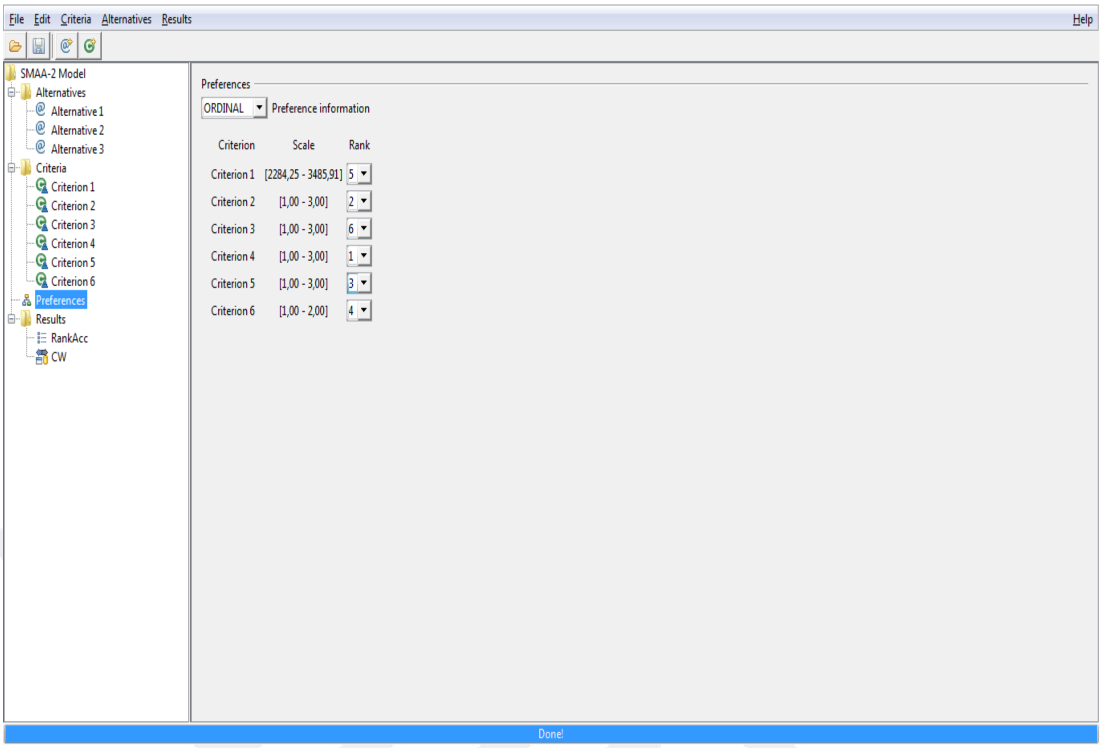

Figure A 9: The ranking of criterions by CFCS method

APPENDIX J

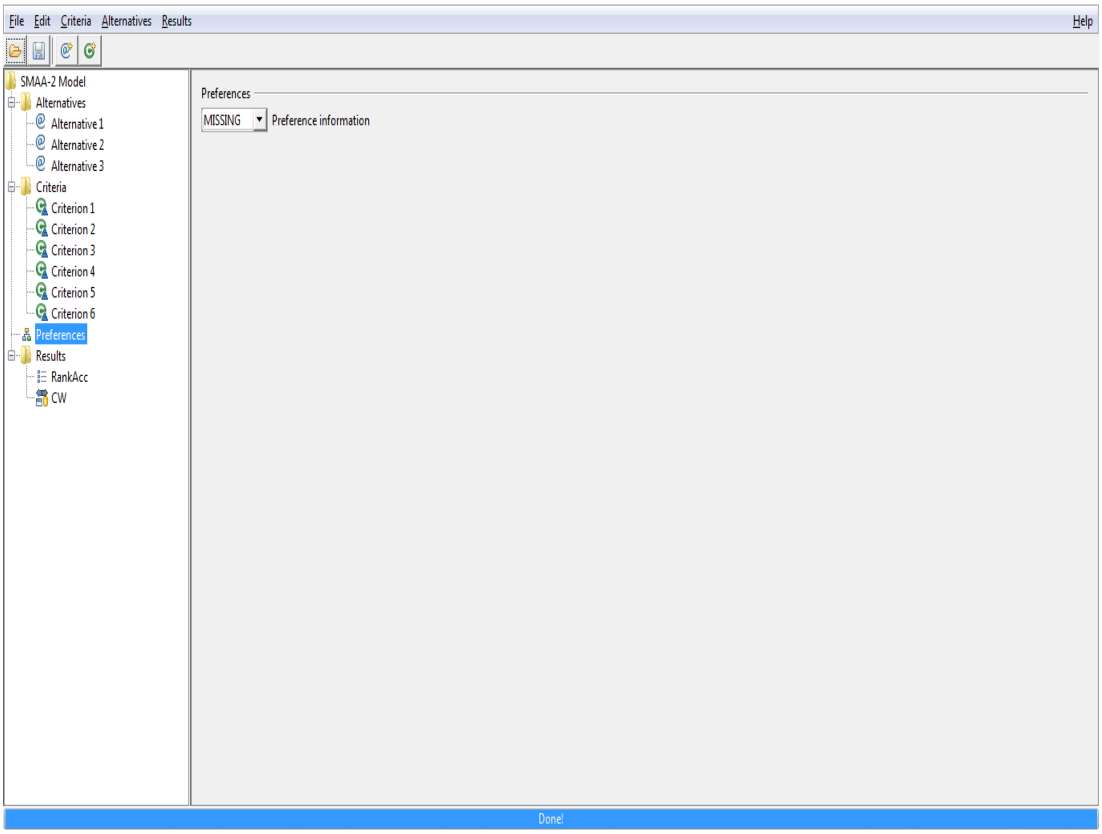

Figure A 10: The Missing Preference in JSMAA

APPENDIX K

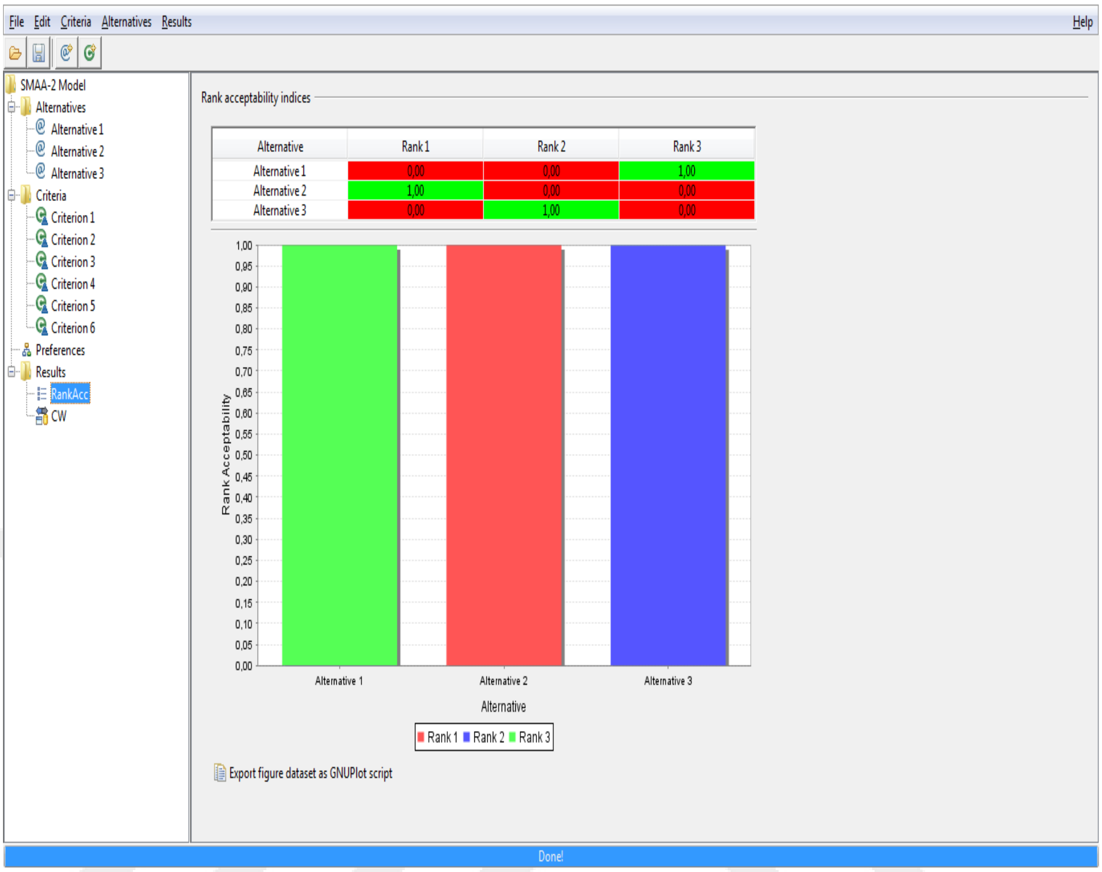

Figure A 11: Scenario – 1 The Rank Acceptability Indices for Optimism Scale (1) and (0.5)

APPENDIX L

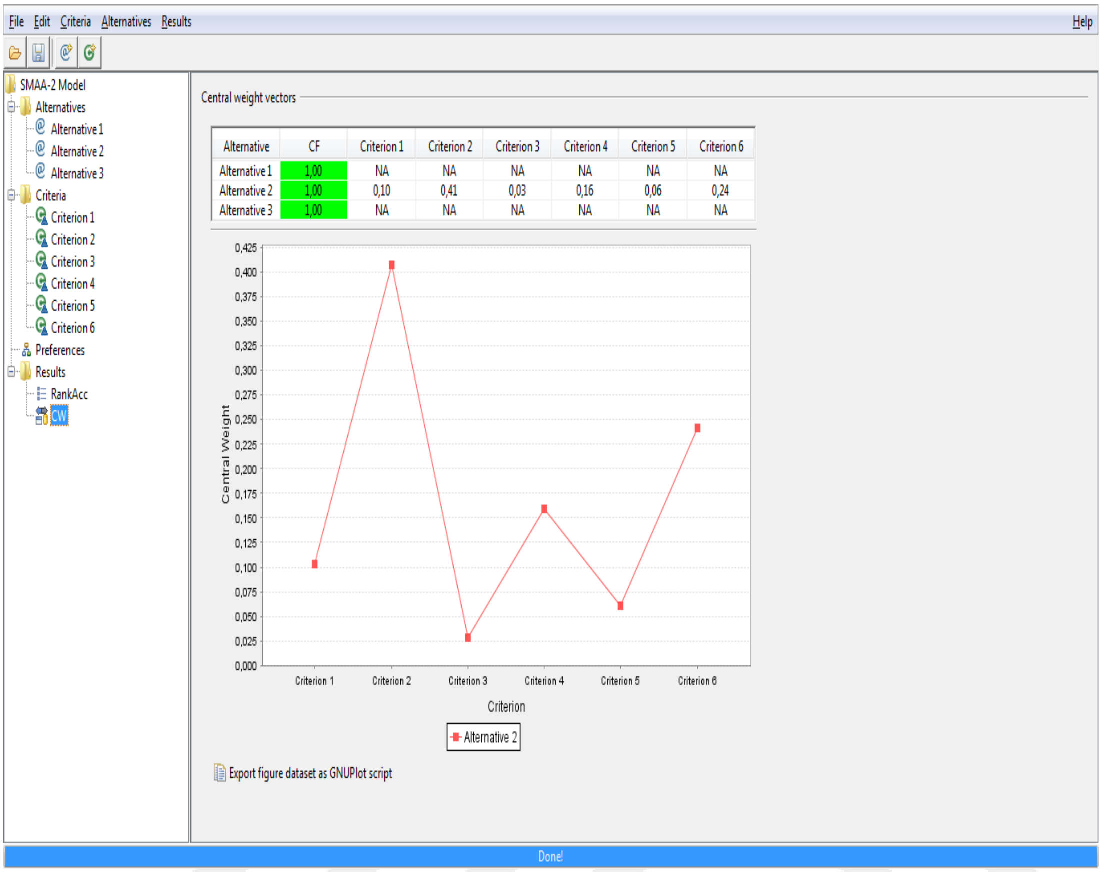

Figure A 12: Scenario – 1 the Reliability Factor and the Central Weight Vector for Optimism Scale (1) and (0.5)

APPENDIX M

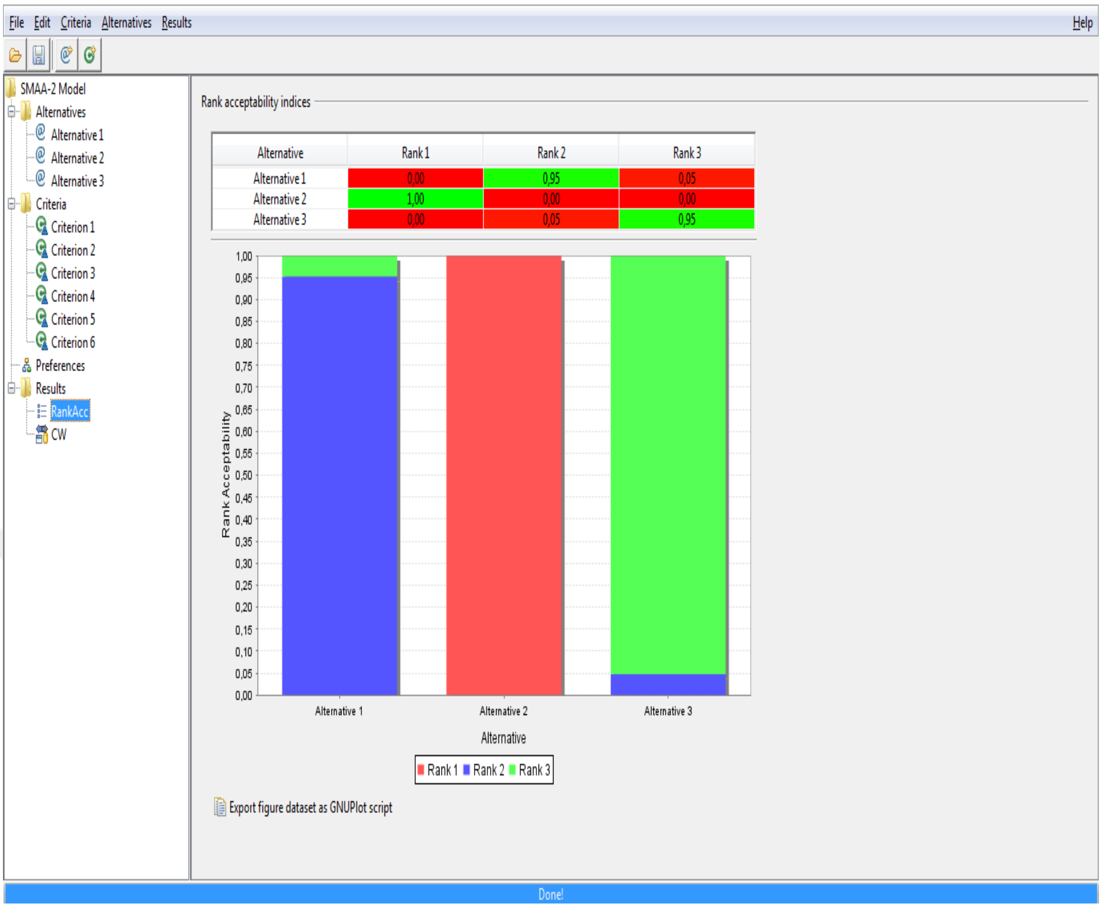

Figure A 13: Scenario – 1 Rank Acceptability Indices according to CFCS Method

APPENDIX N

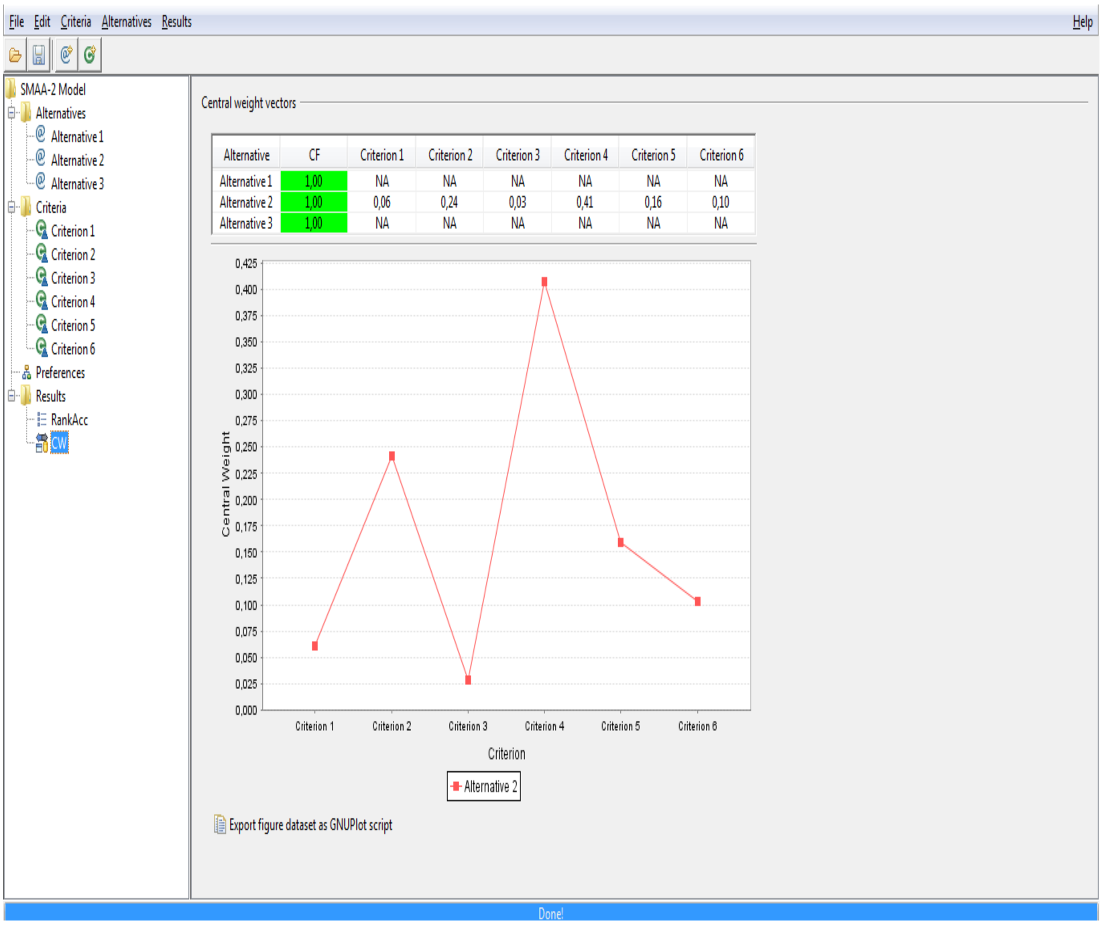

Figure A 14: Scenario – 1 the Reliability factors and center weight vectors by CFCS method

APPENDIX O

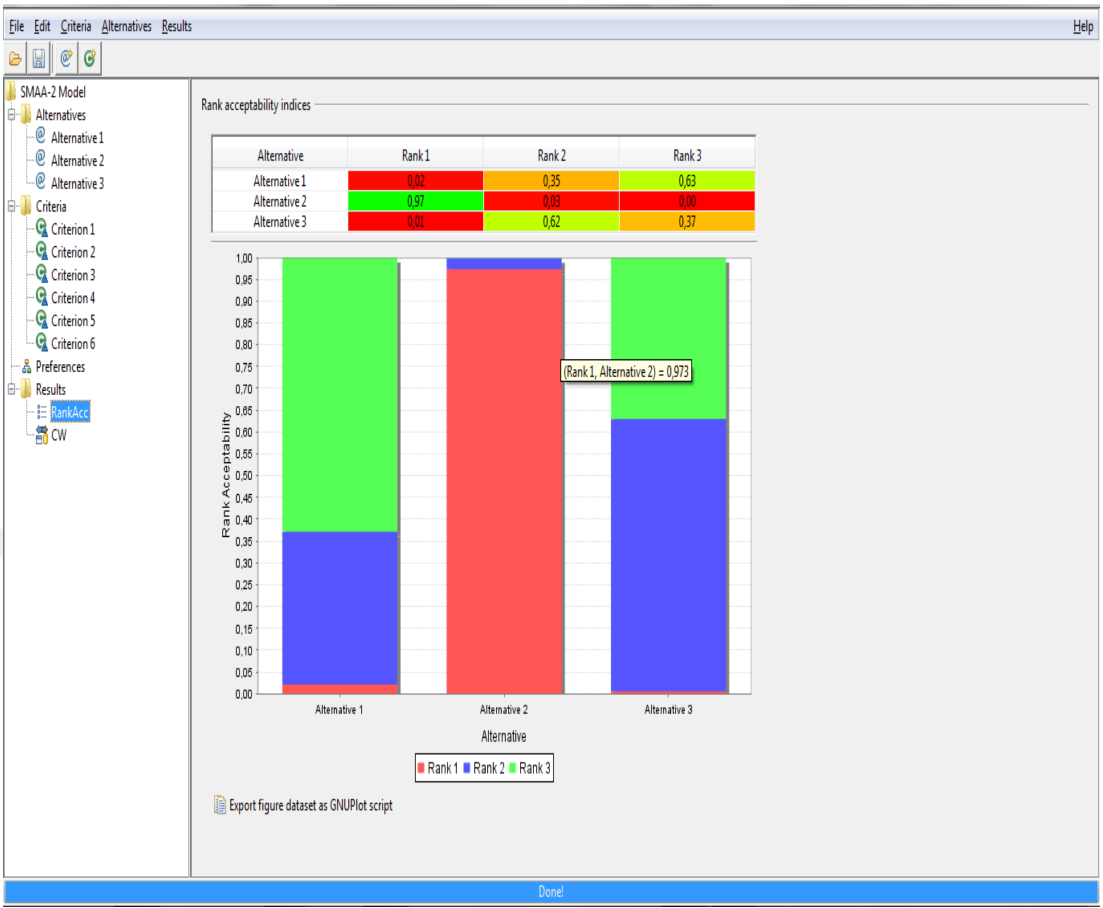

Figure A 15: Rank acceptability indices for Scenario – 1 by Missing preference

APPENDIX P

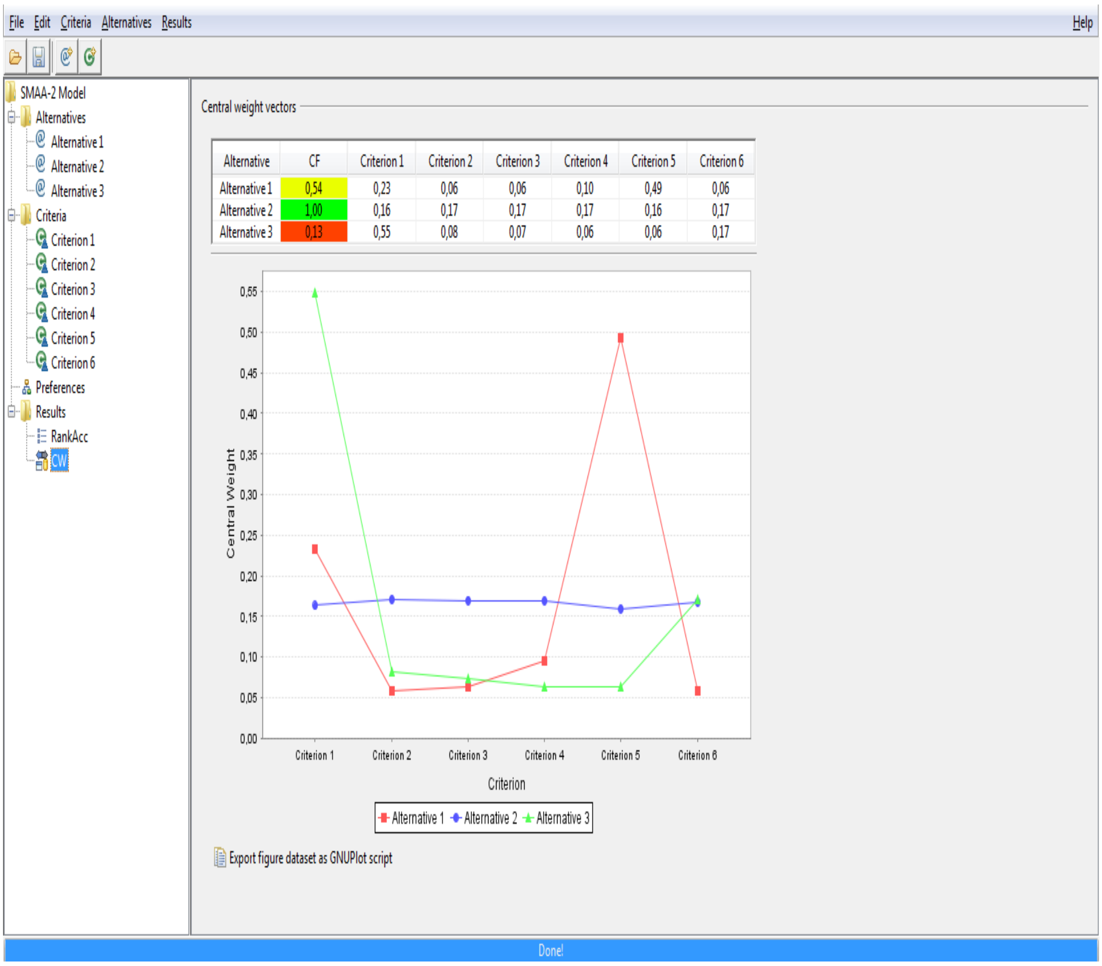

Figure A 16: Reliability factors and center weight vectors for Scenario – 1 by Missing preference

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