Fuzzy FMEA Risk Analysis on Chemical Industry

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ABSTRACT

Nowadays, green engineering strategies have become important for the industries, so global warming and landslides are a sign that nature is disturbed, the sustainability of green engineering and to leave a better environment for the future generation we need to show importance to the consumption of natural resources.

There are different methods in production to protect green engineering and environmental resources.These techniques vary depending on the production or service sector and their application areas.Some of these techniques are Environmental Failure Mode and Effect Analysis (EFMEA) and Process Failure Mode and Effect Analysis (PFMEA). These two tools were used to evaluate Risk Priority (RPN) numbers for prioritizing the risk assignment in a chemical factory in the concept of green engineering. The identified components are calculated in the multi-criteria decision making (MCDM). This technique identifies RPN numbers and combines the weighting factor to the fuzzy parameter by the help of AHP. The effectiveness of this method is explained in fuzzy parameters of AHP and indicated with numerical example in a case study. In this study, the experts have evaluated fuzzy AHP.

Keywords: FMEA, AHP, Risk Assignment, Risk Priority Number,Fuzzy FMEA,green engineering.

ÖZ

Günümüzde yeşil mühendislik stratejileri endüstriler için önem kazanmıştır. Küresel ısınma ve toprak kaymaları doğanın rahatsız edildiğinin göstergesidir. Gelecek nesile daha iyi bir ortam bırakmak için doğal kaynakların tüketimine önem vermemiz gerekir.

Bu nedenle bu calışmada yeşil mühendisliğin sürdürebilirliği için iki araç kullanılmıştır.Bunlar EFMEA ve PFMEA dır. Bu iki araç RPN sayısını değerlendirmek için kimyasal fabrikada risk derecelendirmesinde kullanıldı.Tanımlanan bileşenler çok kriterli karar vermede (MCDM) hesaplanır ve bu teknik RPN numaralarını tanımlar ve AHP nin yardımıyla ağırlıklandırma faktörünü bulanık parametreye birleştirir.Bu yöntemin etkinliği AHP nin bulanık parametrelerinde acıklanır ve bir vaka calışmasında sayısal örneklerle gösterilir.

Bu vaka calismasinda klasik ve bulanık FMEA arasında karşılaştırma yapıldı ve bu ankete katılan uzmanlara göre risk faktörleri geliştirildi.

Anahtar Kelimeler: FMEA, AHP, Risk Ataması, Risk Öncelik Numarası, Bulanık FMEA, yesil mühendislik.

DEDICATION

To my father Guven Alacan

ACKNOWLEDGMENT

I would first like to thank my thesis advisor, Assist Prof. Dr Sahand Daneshvar of the Engineering Faculty of Industrial Engineering Department. He guided me in the right way when I needed him during work.

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
ANP	Analytical Network Process
D	Detection
DFMEA	Design Failure Mode and Effect Analysis for Products/project
EFMEA	Environmental Failure Mode Effect Analysis
FM	Failure Modes
FDFMEA	Fuzzy Development Failure Mode Effect Analysis
FMEA	Failure Mode Effect Analysis
FWGM	Fuzzy Geometric Means
HACCP	Hazardous Critical Control Point
HFMEA	Health Failure Mode and Effect Analysis
ISO	International Organizational for Standardization
LSS	Lean Six Sigma
LFMEA	Logistic Failure Mode and Effect Analysis for Logistic process
MAFMA	Engine Failure Mode
MCDM	Multi-Criteria Decision Making
MFMEA	Multi-Attribute Failure Mode Analysis
PFMEA	Process Failure Mode Effect Analysis
RFMEA	Reversed Failure Mode and Effect Analysis
RPN	Risk Priority Number
S	Severity

TOPSIS	Technique for Order Preference by Similarity to Ideal Solution in MCDM
US	United States
VIKOR	Vise Kriterijumska Optimizacija 1 Kompromisno Resenje

Chapter 1

INTRODUCTION

1.1 Overview

Risk management is a tool to facilitate informed decision making. It is one of the most effective phases of design management. There are many methods to control the risk and its effect on the outcomes of the projects.

Cyprus is the one of the largest island in the Mediterranean and its surface area is 9250 square kilometers. The TRNC's limited natural resources, which constitute 36 percent of the island's territory and approximately 22 percent of the total population, face a small domestic market with an economy dependent on imports and several problems specific to such small economies Akis et al. in 1996 [1].

Although tourism gains importance in all world economies, environmental resources such as clean air, an unspoiled nature also included in natural resources. According to the data obtained from the TRNC environmental department, the first four environmental problems are defined as follows:

1. Air pollution
2. Slaughter of trees
3. Fires
4. Not creating new green spaces

One of the most shouting issues today are the disastrous landscapes created by the quarries, as well as the dust, pollution and the destruction of some greenery. In this thesis, a case analysis is applied which is an example of these environmental effects and sustainability of green engineering concepts in a chemical factory.

The environmental risks created by 7 problems are as followed: Akis, Peristianis & Werner in 1996 [1]:

- Damages caused by exhaust gas
- Pollution of groundwater as a result of mixing of waste waters with groundwater
- Environmental waste packaging wastes
- Office waste

And in this study, these risks were graded according to their order of importance by using Fuzzy, Environmental Failure Mode Effect Analysis E-FMEA and FUZZY Analyitical Hierarchy Process (AHP).

Failure Modes and Effect Analysis (FMEA) is one of these techniques that minimize the risks that need to be taken once in the production and service sector in terms of quality management. There are many criteria used for this, FMEA and VIKOR are the methods of decision making. Analytical Hierarchy Process (AHP) is a tool that provides a substructure to help the FMEA technique. AHP method was first introduced to Thomas L Saaty- 1977 “Mangeli et al. in 2018 [2] .” It can be used as a tool in AHP by being associated with FUZZY FMEA. In this way, problems in the factory can be determined and evaluated in order of importance by independent experts.

FMEA is successfully applied in many areas such as automobiles, electronics, consumer products, power plants, and telecommunications [3]. FMEA is used as a risk healer with Hazardous Critical Control Point (HACCP) in the fare industry and the surgical industry. It is used as a methodically to associated the risk with helping of the chemical. This technique in quality management was used for occupational health and safety management, also it is a method used to prevent material loss, health, and life loss and improve service quality in the service sector.The FMEA is named according to the sector which is used.

The FMEA groups are defined as follows:

DFMEA: Design Failure Mode and Effect Analysis for projects;

SFMEA: System Failure Mode and Effect Analysis- for a system;

PFMEA: Process Failure Mode and Effect Analysis- for manufacturing process or service;

LFMEA: Logistic Failure Mode and Effect Analysis- for the logistic process;

EFMEA: Environmental Failure Mode and Effects Analysis-having an impact on the environment.

SWFMEA-Software Failure Mode and Effects Analysis-for software;

MFMEA: Machine Failure Mode and Effect Analysis- for machines and devices;

RFMEA- Reversed Failure Mode and Effect Analysis.

1.2 Problem Statement

The company concerned in this thesis is the chemical factory. This company is aware of the environmental problems, but is not able to see it on its own. The factory does not know how to identify risks and what method to use them in order of importance. This thesis will help the firm.In this study, Failure Modes are detected and placed in the order of importance with fuzzy method based on the information of the experts.

1.3 Aim of the Study

Introducing and reducing the hazardous effects of chemical productions on the environment is one of the most important problems in green engineering.

The main aim of the study is to minimize the environmental impact of chemical products and to identify risks. In order to reduce the impact of production on employees and the environment during production at the chemical plant, there must be some satndart criteria. The Environmental Protection Agency (EPA) criteria were used in this study. These criteria are used to match problems and environmental damages. Also, this study will contribute to find the risk factors and to put in order according to importance sequence by fuzzy FMEA and emphasize the significance of green engineering sustainability. The goal is to use these methods in the right way and come to conclusions.

The project risk is measured by 3 factors in terms of RPN numbers, denominate "severity", "likelihood", and "detection" that compose fuzzy FMEA and also two different parameteres denominate the plan process weights and risks weights. Besides these two parameters risk priority number (RPN) factors may lead to the application of preferable risk management. In this study, classical and fuzzy FMEA were used and compared. In a classical FMEA, risk parameters; severity (S), likelihood (O) and detectability (D) are calculated and risk priority numbers (RPN) are found by multiplying of these parameteres. Each risk factor was ranked between 1 and 0 (1-best; 10- worst case). RPN=O×S×D significance for each insufficiencies is graded according to a sequence of higher risk to lower. If we want to give detailed information on risk priority number (RPN) methodology for emphasizing insufficiency modes is an inseparable of the chemical industry FMEA method. The method is formed of numbering the potential insufficiencies from 1 to 10 with respect to their severity, probability of occurrence, and the likelihood of detection in later tests, and multiplying the numbers together. The result is ranked which is called the RPN, on a scale from 1 to 1000.

The use of versatility variables refers to the operates of computing with words (CW). The several computational approximations might be found in the literature to succeed those steps. In this study, a fuzzy linguistic methodology will be used to overcome the unbalanced linguistic term. The recommended method uses simplified fuzzy number arithmetic operations and fuzzy number.

Aggregating data and defuzzification procedure which is the most important issue in this study will be explained in detail in Chapter 3.

1.4 Limitation of the Study

In this study, one case study was selected because it is a unique household cleaning production factory in North Cyprus. Other types of companies are just importing the products without any production.

The selected company has ISO & HACCP criteria for production and adopts green engineering principles. The responded profile was determined according to their experience, title, and field of education. It includes:

-One production manager

- One technician

- One worker

- One general manager

7 problems that are determined by the general manager are included in the questionnaire.

1.5 Organization of the Thesis

This study comes off five chapters. The first part is an introduction. The second part is a literature review of fuzzy FMEA and classic FMEA, risk analysis, fuzzy AHP, green engineering; methodology of the classical and fuzzy developed failure mode and effect analysis in chemical production is broadly explained in the third part. In part 4 data analysis and results were shown, last and the fifth part is a conclusion with recommendations.

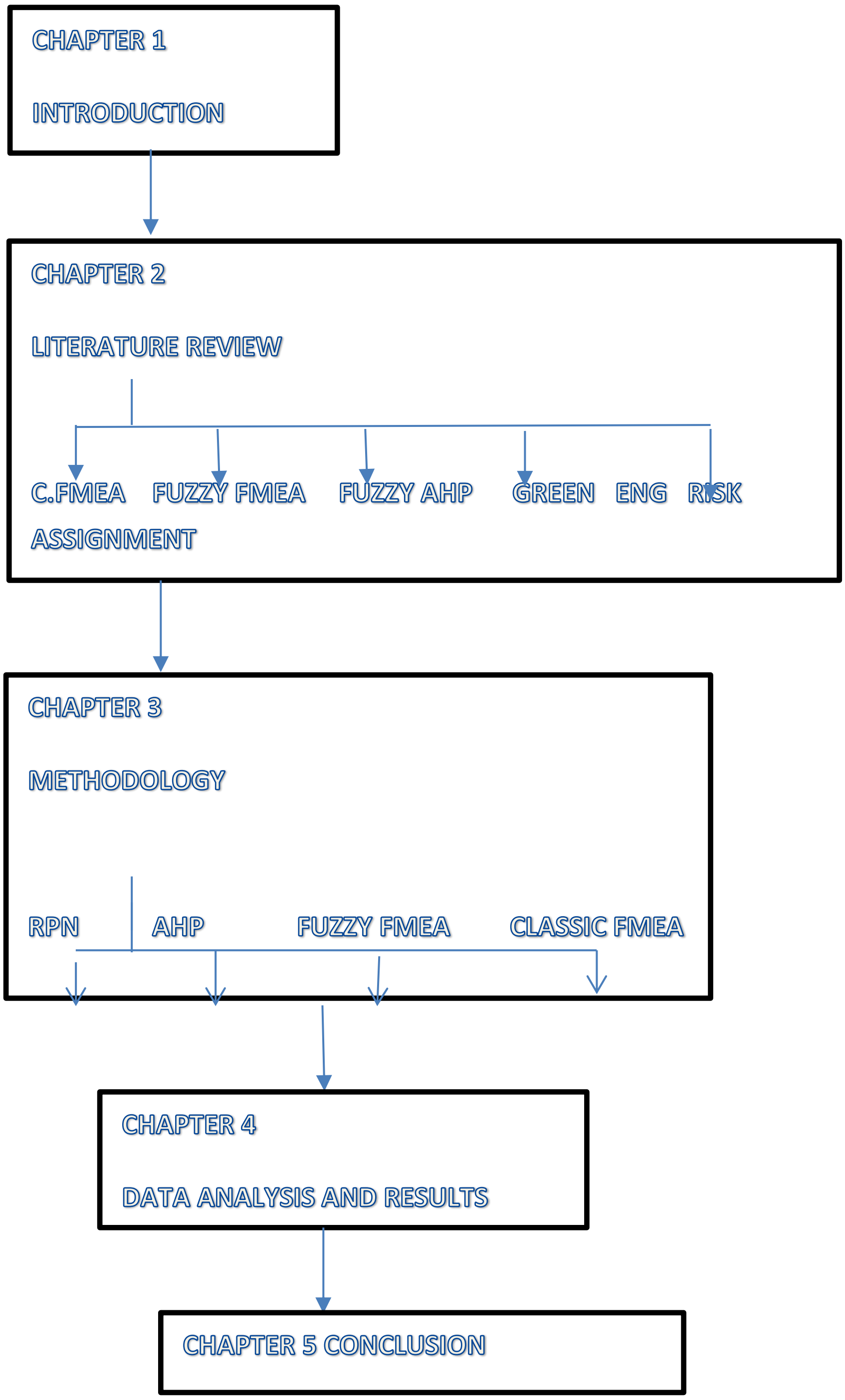

Figure1: Flow Diagram of Chapters

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The main aim of this thesis is to state the environmental impact of chemical factory in Famagusta at the production stage. The precise ways applied in this research were the Environmental Failure Mode and Effects Analysis (E-FMEA) and Fuzzy AHP. The E-FMEA method was used first to calculate the risk priority number (RPN) for each environmental perspective.

In these days, cosmetics and cleaning household products are strongly related to environmental issues[4]. Environmental issues were studied with the aid of Environmental Failure Mode and Effect Analysis in this study. Today's manufacturing industry is experimenting with different methods to increase its competitive power. These companies have to increase the production quality of their marketing i.e, to emphasize the importance of producing environmentally sensitive products and to be one step ahead. For this reason, E-FMEA is one of the methods which assess the risks and determines the importance of them by a team of experts and type of FMEA. Different quantitative or qualitative methods might be used for risk assignment, FMEA is one of them [5]. FMEA was first applied in the 1940s by the US military in the aerospace industry. This technique was first used by NASA in the 1960s (Helvacioglu and Ozen, 2014) [6]. In the last decades, FMEA will be successfully applied in different areas such as energy, manufacturing, automobiles, and chemical production.

Different types of mathematical techniques are available for the evaluation of risk assignments such as heuristic[7], AHP [8],fuzzy ANP [9].

2.2 Classic FMEA

Recently, increasing environmental awareness, the use of waste recycling and the identification of environmental risk factors are very important for green engineering. Non-pecuniary damages caused by production to the environment, conscious acts of consumers, waste damage to the environment and attempts to reduce electricity consumption increase the interest of E-FMEA. It is a multi-purpose problem solving technique which is being used by factories and service sector in detecting and grading environmental risks. E-FMEA tool increases the impact of the production of the process and its impact on the environmental aspects [10] E-FMEA technique authorize for a scientific summation of potential failures incorporated with a product or process, before their results appear.

Risk is defined as the possibility that something unpleasant or unwelcome will happen [11] .The first step of risk management is risk assignment which means identifying sources and ranking of risks in order of importance[12]. The risk might be expressed in different types and variables and can be evaluated by technique E-FMEA.

Risk analysis will be defined in six steps. These are:

1. Organizing ,
2. Recognition,

3. Qualitative analysis,
4. Quantitative analysis,
5. Reaction planning,
6. Risk monitoring.

If occupational accidents are not avoided they will cause financial and moral damages to investors and employees. Therefore the protection of public, hardware and the environment are the most important factors in risk assignments.

One of the most popular methods of risk assignment is FMEA which define failure modes by using the risk priority number (RPN). Risk Priority Numbers consists of 3 factors, Likelihood (O), Severity (S), and Detection (D) [2]. The RPN value for each failure is ranked from higher to lower. The calculation of RPN value is found by multiplying 3 factors[13]. In the classic FMEA, the RPN is used to evaluate the risk assignment. The potential failure describes the risk factors as:

Severity (S): Failure-generated

Occurrence (O): Opportunity of a failure

Detection (D): Opportunity for an unidentified failure.

The 3 factors are all scored from 1 (best) to 10 (worst) on the basic degree. RPN is calculated as $RPN = S \times O \times D$. The RPN is a mathematical product of the 3 risk factors i.e, severity, occurrence and detection. Classic FMEA can be adjusted by risk using (RPN) number [14].

A similar calculation might be calculated risk FMEA (RFMEA) regarding $RPN\ risk = RC \times D$, whereas $RC = O \times S$, RC=Risk Cost

In the following table, a comparison between traditional FMEA and RFMEA was made.

Table 1: Comparison Table of RFME and FMEA

Type of FMEA	**Quantity**	**Case**	**Likelihood**	**Utility**	**Calculation of Risk**	**Detectability**	**RPN**
FMEA	Risk Number	Design of Activity	Likelihood	Severity	Risk Mark	Detection	RPN-Risk Prioriy Number
Risk FMEA	Risk Number	Risk Case	Likelihood	Effect on the Organization	Risk Mark	Detection	RPN-Risk Prioriy Number
Risk Disruption FMEA	Risk Number	Risk Case	Likelihood	Profit	Risk Mark	Detection	RPCN-Risk Priority Correction Number

The RPN rate is found by multiplication of these 3 parameteres which given below such as:

Likelihood= Occurrence, Impact= Severity, Detection.

Likelihood, Impact, and Detection values are explained in tables 2, 3 and 4 [18]. The impact (severity) values of the risk factor are grouped by the experts in the factory.

Table 2: Occurrence Evaluation Elements [18]

Rank	**Occurence**	**Criteria**
10	Definetly	Failure is almost unavoidable
9	Very high	
8	High	Repeated failures
7	Above average	
6	Aveerage	Occasional Filures
5	Below average	
4	Unlikely	
3	Very Unlikely	
2	Nearly Impossible	Rare filures
1	Impossible	Failure is unlikely

Table 3: Severity Evaluation Element [18]

Grade	**Impact**	**Criteria**
9,10	Very High	This rating indicates death and serious losses
7,8	High	Severe injury, damage
4,5,6	Moderate	Process may be lost
2,3	Low	Minor injury
1	Minor	General injury does not ocur

Table 4: Detectability Evaluation Element [18]

Grade	**Detectability**	**Criteria**
10	Non-detection	No User may find the failure mode
9	Very Low	No user will detect a potential cause
7,8	Low	Program control is not likely to detect a potential cause
5,6	Moderate	Program control may detect potential cause
3,4	High	Program control has an accurate chance of detecting a potential cause
1,2	Very High	Program user will precisely detect a potential cause

In this study impact values are defined as; customer satisfaction, cost, and production waste. ISO 9004: 2000 use FMEA as an international model for technical applications for patient safety[17]. FMEA is a technique that minimizes the risks that need to be taken once in the production and service sector in terms of quality management. FMEA is a group decision task and it should not be applied individually[18]. Classic FMEA is used as a healing method in many sectors such as energy; manufacturing, logistic, software etc. FMEA is a technique that has been used in different types of industries for years. When measuring household products and environmental hazards a classical FMEA is the suggested risk assignment technique[19].

Failure Modes and effects analysis (FMEA) was original applied in NASA in 1963 as a methodology and then Ford Motor applied and developed this methodology in 1977. There are other methods used in risk management. One of them which is the most popular one was Lean Six Sigma. Lean Six Sigma is defined as also Define-measure-analyze-improve-control (DMAIC) [20]. If we want to talk about this subject briefly Lean Six Sigma is focused on seven codified and well-known wastes[21];

1- Overproduction
2- Inventories
3- Defects
4- Motion
5- Transportation
6- Waiting
7- Processing

The aim of the six sigma methodology is to increase the customer's satisfaction. The LSS approach improves service quality. The LSS method provides better solutions to customer satisfaction. LSS concept was tested and applied by many firms such as Motorola, Allied Signal, Toyota and General Electric.

The combination of Lean & Six Sigma has a compulsory relationship with each other. These days many firms are using a combination of Lean Six Sigma (LSS). The LSS method might be used to reduce waste and tools as defined DMAIC

(Define, Measure, Analyze, Improve and Control). However, this tool can be applied to the efficiently organizational type of problem[22]. If this is mentioned briefly three issues which are mostly used in food and healthcare; HFMEA, FMEA, and HACCP. HACCP is a standard procedure for direct food and food production. HACCP is a quality system that was first introduced by the Food & Drug Administration to protect the food supply from physical hazards. HACCP cannot be applied directly to the health sector because of its focus on food processing and handling.

Table 5: Comparison tables of HFMEA, FMEA and HACCP [15]

EMPLOYED NOTIONS	**HFMEA**	**FMEA**	**HACCP**
Team Membership	X	X	
Schematization Duration	X	X	X
Causes of Failure	X	X	
Hazards Score	X		
Occurrance and Severity Definitions	X		
Decisions Tree	X		X
Actions	X		

HFMEA is focused on the process that manufactures healthcare products. Failure is the terminology of (ISO 26262-1, 2011) it is the ability to perform an essential function. The insufficiencies of the classic FMEA method are inspired by Jamsidi & Kazemzadeh in 2010 [23].

The RPN memberships have may even numbers because of this, different combinations of O, S, D can act the same number of RPN despite their hidden risk inclusions shall be completely distinct[24]. It is hard to adjust these 3 factors. Because of this situation fuzzy FMEA is preffered [25].

The performance of the FMEA technique is low because of the emotional effect of personnel viewpoints in the calculation of risk factors, so each decision team might have the different outputs for risk.

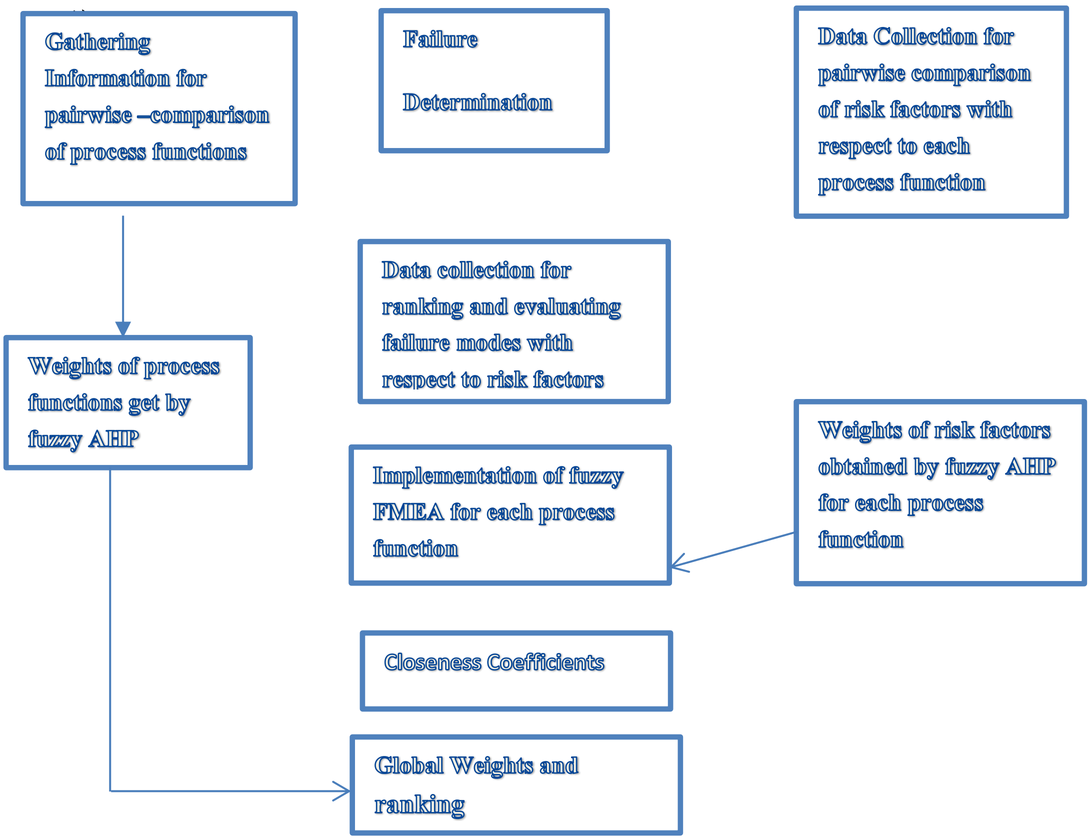

Figure 2: Flow Process Chart of PFMEA

Table 6: Assortments of FMEA

CLASSES	**AREA**	**LITERATURE REVIEW**	**PROBLEM IDENTIFICATION & RESULT**	**APPROACHES**
FMEA	Public Administration	[26]	Analysis of Corruption in Bulgaria	Principal-Agent Theory-FMEA
FMEA	Customer Oriented Search	[27]	In a case study, RPN calculation has been identified and compared with the previous customer-oriented approach as well as the old one	Kano Model-FMEA
FMEA	Regional Hospital In Dialysis Units in Italy	[17]	Database Improved and Nurse Errors Resulting from information sharing implemented.	FMEA
FDFMEA	Aircraft Landing System in Iran	[16]	Determination of risk factors for the prevention of aircraft landing accidents	Traditional and fuzzy FMEA
FDFMEA	Numerical Case Study	[28]	Implementation of FRNS and Comparison of Traditional and Fuzzy FMEA	Fuzzy AHP and fuzzy FMEA
SWFMEA	University Research Group Project	[29]	5 Dimensional Analysis of Information Security was succeeded and developed by using fuzzy logic.	Fuzzy FMEA
SWFMEA	Construction Project Selection	[30]	Insufficient use of resources in construction project selection and problem solved by two-phase group decision making and helping of VIKOR	Fuzzy ANP and VIKOR

PFMEA	Poultry Production Process	[31]	Fuzzy FMEA is minimized the risk factor	Fuzzy FMEA
PFMEA	Sterilization Unit in the Hospital	[32]	26 Units hazards were found grouped and conducted using expert opinion and then the most important risks were found and implemented	Traditional and Fuzzy FMEA
PFMEA	Purchasing Process in a hospital	[8]	High lead time and cost during the purchasing process	Fuzzy AHP and FMEA
PFMEA	Manufacturing Process	[13]	Problems encountering by spindle manufacturing	Fuzzy AHP and fuzzy TOPSIS
PFMEA	Sugar Industry	[33]	Cogeneration process problem in sugar boiler	FMEA and Taguchi Method
MAFMA	Copper Leaching Factory	[2]	Occupation Hazards and Prevention	Fuzzy TOPSIS and FMEA
EFMEA	Urban Utilities	[34]	Identifying and Solving Problems which arise from urban land utilization	EFMEA
EFMEA	Environmental Management	[10]	Identifying and preventing risks for environmental impact assessment	FMEA

According to Ochrana, Pucek & Placek in 2015 [26] used FMEA technique in the government BULGARIA to prevent corruption. Principal-agent theory and FMEA used together.The principal-agent theory identifies the risks arising from the use of the rules in their favor.

Gusmao, Poleto, Silva & Costa in 2014 [29] defined SWFMEA used in the area of information security. 5-dimensional analysis of information security was succeeded and developed by using fuzzy logic. Wessiani & Sarwoko in 2015 used [31] another PFMEA in the poultry food production process in Indonesia. 89 potential risks of poultry feed production defined and the first very important risks were identified and improved by using PFMEA. Ebrahimnejad & Vahdani in 2012 [30] used this technique for define insufficiencies of resources in construction project selection and this problem was solved by two-phase group decision making and by helping of VIKOR which is a Multi-Criteria Decision Making.

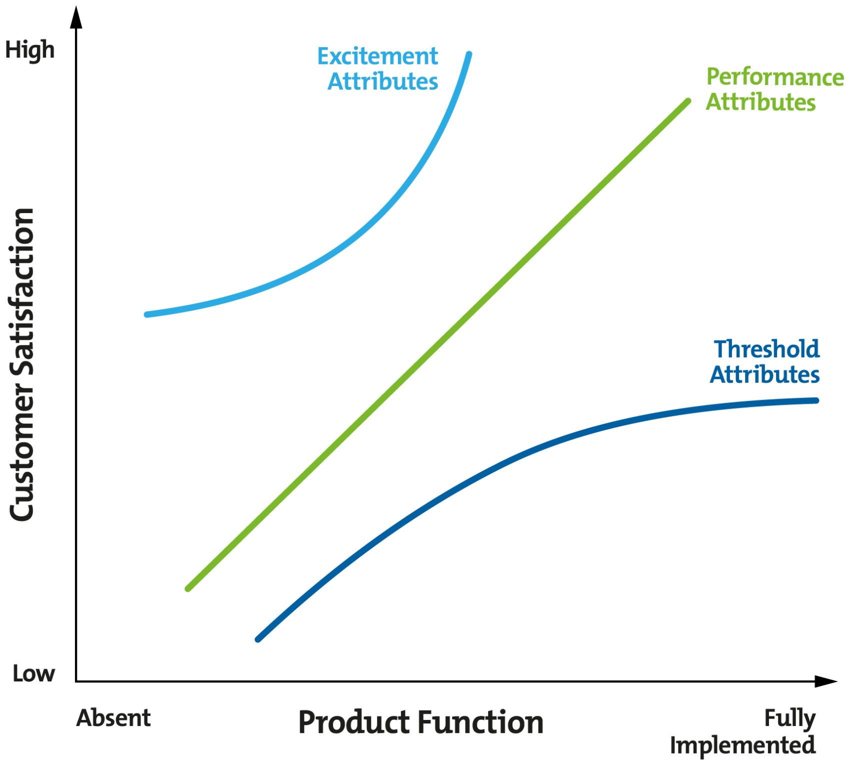

Figure 3: Kano Model [27]

Koomsap & Charoenchokdilok in 2018 [27] was used FMEA for improving risk assessment. RPN calculation has been identified and compared with the previous customer-oriented approach as well as the old one. Kano model is a tool that can be useful. It is a sophisticated technique for deciding which features a product or service should have. The Kano model of product development was first introduced in 1980 by Dr. Noriaki Kano, professor of quality management at the Tokyo University of Science.

Yazdi, Daneshvar &Seterah in 2017 [16] used FDFMEA for aircraft landing system in IRAN. In their study determination of risk factors were categorized for the prevention of aircraft landing accidents. Dağsuyu, Göçmen, Narlı & Kokangül in 2016 [32] performed FMEA technique as a detectable for risk prioritization and 26 units' hazards were found grouped and conducted using expert opinion and then the most important risks were found and improved by using classical and fuzzy Fmea.This technique was applied in the sterilization unit of a public hospital. Lin & Zeng in 2009 [9] defined fuzzy AHP and FMEA in the procurement procedure of the public hospital. The problem was the high lead time and cost. It was implemented by using fuzzy AHP. Bonfant, Belfanti, Paternoster, Gabrielli, Manes & Nebiolo in 2010 [17] used FMEA for identifying clinical risk analysis; this technique was applied in regional hospitals in Italy. The database improved in this way and nurse errors were implemented.

Mangeli, Shahraki & Saljooghi in 2018 [2] was used FMEA, for improving risk assessment in copper leaching factory. Fuzzy TOPSIS and FMEA were applied in the copper leaching factory in IRAN. This model has a prediction capability of severity & occurrence refers to occupational hazards. Kania, Rozsak & Spilka in 2014 [10] used EFMEA for identifying and preventing environmental impact assessment in green engineering. Another EFMEA was used in urban utilities, Vazdani, Sabzghabaei, Dashti, Cheraghi, Alizadeh & Hemmati in 2017 [34] they studied EFMEA, the problem arises from urban land utilization and it was implemented by helping of this technique. Kutlu & Ekmekçioğlu in 2012 [13] was defined PFMEA in spindle manufacturing. Problems encountered by spindle manufacturing fuzzy AHP and fuzzy TOPSIS. FDFMEA in the numerical case study was applied. Implementation of FRPN and comparison of classic FMEA and fuzzy FMEA was done. Mariajayaprakash & Senthilvelan in 2013 [33] was used FMEA in sugar manufacturing sector.Cogeneration is an important source of income for this type of sector. The problem in this study was arising from the boiler which is the most essential components used in this process. Taguchi and the FMEA method were used in this study for solving this problem.

2.3 Fuzzy AHP and FMEA

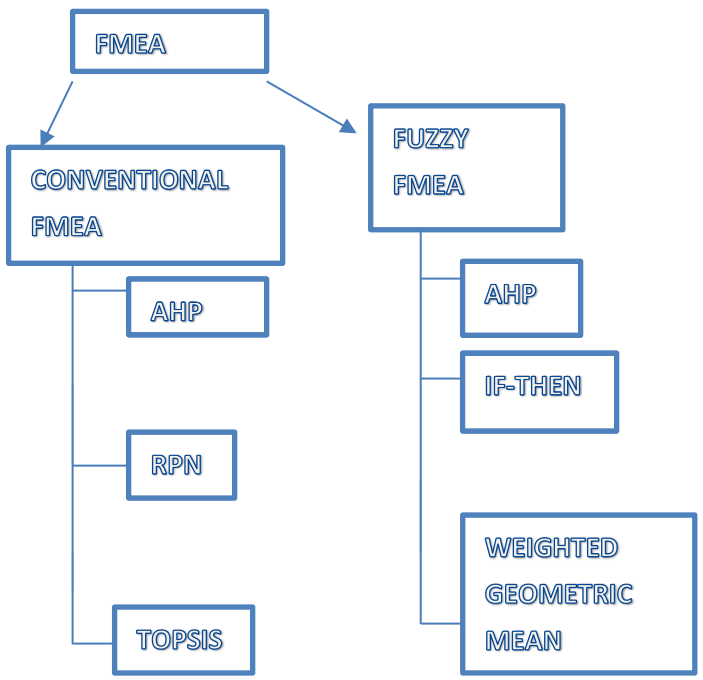

Figure 4: Flow Diagram of Fuzzy AHP and FMEA

Analytic Hierarchy Process is the multi-attribute mathematical programming model[35]. An AHP based on a fuzzy logic approach, it is helped to find the importance weights of risk factors. The AHP can be used effectively to solve the decision-making problems it can combine fuzzy logic to the FMEA. AHP tool has been applied to both qualitative and quantitative data to deal with the problem. AHP was first proposed by L. SAATY (1980). AHP is a method for avoiding the use of emotions for the decision- making mechanism and for removing uncertainty. AHP is first defined as a fuzzy logic by Learhoven and Pedrycz in 1983 [14.] AHP converts a pair-wise comparison of different alternatives with respect to various criteria. The AHP method consists of 4 levels. The objective is at the first level, the criteria are in the second and third level. The alternatives are determined in the last level. The concept of fuzzy numbers is the generalization of the notion of real numbers. Different types of fuzzy numbers are available these are; triangular fuzzy numbers, trapezoidal fuzzy numbers, Pentagonal fuzzy numbers, Hexagonal, Octagonal, and pyramid fuzzy numbers have been introduced with its membership functions. The evaluation of the weighting score is done by helping of measurement criteria of this table.

Table 7: Measurement Criteria of the Weighting Factor [16]

Linguistic Terms	**Fuzzy Score**
Absolutely Strong (AS)	(2,2.25, 2.75, 3)
Very Strong (VS)	(1.5, 1.75, 2.25, 2.5)
Fairly Strong (FS)	(1, 1.25, 1.75, 2)
Slightly Strong (SS)	(1,1.25, 1.25, 1.5)
Equal	(1, 1, 1, 1)
Slightly Weak (SW)	(2/3, 1, 1, 1)
Fairly Weak (FS)	(1/2, 2/3, 0.85, 1)
Very Weak (VW)	(2/5, 1/2, 3/5, 2/3)
Absolutely Weak (AW)	(1/3, 2/5, 0.45, 0.5)

Table 8: Linguistic Variable of Detection [16]

Linguistic	**Crisp Scale of Traditional Detection**	**Scale**	**Triangular Fuzzy Number**
Almost Certain	1-2	Failure is Unlikely	(0,0,1)
Very Low	3	Very Few failures	(0,1,3)
Low	4	Relatively Few Failures	(1,3,5)
Moderate	5	Occasional Failures	(3,5,7)
High	6	Number of fail is high	(5,7,9)
Very High	7-8	Repeated Failures	(7,9,10)

	9-10	Failure if almost inevitable	(9,10,10)

In fuzzy FMEA, the studies generally are interested in fuzzy logic. Fuzzy set theory was first applied by Zadeh [38]. Different types of fuzzy functions are available. These are Sigmoid, Gaussian, Bell, S-shaped, Triangular and Trapezoidal [36]. In this study, fuzzy AHP & fuzzy FMEA are applied in a linguistic variable which is defined as triangular fuzzy numbers Wang et al. in 2009 [18] defined an FDFME, using the group-based evidential reasoning (ER) tool to deal with FMEA- experts-group which has a different opinion and decide failure modes under different types of uncertainty.

Table 9: Linguistic Variables of Occurrance [16]

Linguistic Variables	**Crisp Scale of Traditional Occurrence**	**Scale**	**Triangular Fuzzy Number**
Almost Never	1	Failure is unlikely	(0, 0, 1)
Very Low	2	Very Few Failures	(0, 1, 3)
Low	3	Relatively Few Failures	(1, 3, 5)
Moderate	4	Occasional Failure	(3, 5, 7)
High	5	Number of Failure is high	(5, 7, 9)
Very High	6	Repeated Failure	(7, 9, 10)
Extremely high	7	Failure is almost inevitable	(9, 10, 10)

Table 10: Lingusitic Variables of Severity [16]

Linguistic Variables	Crisp Scale of Traditional Detection	Scale	Triangular Fuzzy Number
None	1	First Aid Case	(1.1, 2, 5)
Very Low	2-3	First Aid Case	(2, 3, 4)
Low	4-5	Medical Treatment Case	(3, 4, 5)
Medium Low	6	Partial permanent Disable	(4, 5, 6)
Medium	7	Partial permanent Disable	(5, 6, 7)
Medium High	8	Total Permanent Disable	(6, 7, 8)
High	9	Fatality	(7, 8, 9)
Very High	10	Multiple Fatality	(8.5, 10, 10)

A fuzzy system formalizes the reasoning process of human language by fuzzy logic (IF-THEN RULES). The fuzzy system will be used to solve decision problems [3] The most important factor for this study is deciding if the criterion has more weight in risk prioritization.

Two methods are generally applied in fuzzy logic. These are IF-THEN rules and fuzzy weighted geometric mean. In this study instead of IF-THEN rules, the fuzzy weighted geometric mean approach was used for risk prioritization. Tay & Lim in

2006 [37] discussed that IF-THEN rules might not be certain and equal importance. Ambivalence and emotional specialists cause fuzzy logic to be used in these types of problems.Fuzzy methods consist of two parts; these are direct methods and indirect methods. Direct methods Mamdani and Sugeno are the two most preferred methods. In the min-max operation, Mamdani method is generally preferred [39] 3 approaches will be applied in fuzzy logic. Applied areas are mathematics-based, areas of science, engineering, medicine the last and third one is education [40].

The first international organization supporting fuzzy logic (IFSA) was established in 1984. The textbook on fuzzy logic began to appear in the 1980s.Different ways to turn the disadvantage of classic FMEA into advantages these are SVM, TOPSIS, VIKOR, and FUZZY LOGIC. In fuzzy linguistic variables, quantity can be taken on instead of accurate values [3].SVM, are the other tools for categorization of problems, support vector machine was first developed by Vapnik. Support Vector Machine (SVM) is thought of as the main subject of the machine learning branch [41].The VIKOR (Multi-criteria Decision Making) this method solves the problem in fuzzy logic. VIKOR is generally used in material or personnel selection [42].TOPSIS has been defined for multi-attribute decision-making problems. TOPSIS is generally used for plant location and supplier selection[14]. Ekmekcioglu et al. in 2010 [43] used a modified fuzzy TOPSIS to select municipal solid waste disposal methods and sites.

15 articles have been reviewed up until here and found that in some articles FMEA has been studied in the service sector and some in the production sector. In these studies, the risk factors were determined and ranked by the expert, and the risks

were classified according to the order of importance. And according to the order of importance, these risks have been improved. As a result, some problems have been eliminated before they appear.This study was first thought in the northern part of Cyprus in the chemical industry following the concept of green engineering. FMEA is applied in the environment and product category in this case study.

Chapter 3

METHODOLOGY

In this study, FMEA is described as a method with the performance evaluation of the chemical industry using fuzzy arithmetic operation. Chen in 1996 [44] used to FMEA to solve the optimal design weapon systems which are multiple criteria decision-making problems.

The purpose of this study is to reduce the degree of error of risk factors in decision-making problems in the chemical factory. The proposed method uses AHP and fuzzy FMEA techniques to show an accurate hierarchy that evaluates risk weights in the risk assignment process.

Each decision team (expert) may have a different output for risk, despite experts who may not have the same decision this causes a problem in traditional AHP. To based on these types of problems, a new method for the chemical industry on the green engineering concept was used which is handled with fuzzy number arithmetic operation.

In this study which is inspired by the Chen in 1996 [44] fuzzy arithmetic operation where sustainability ratings for each system were ranked by an integer number and the summation of these ranked defines the degree of satisfiability of the system which is represented by a triangular fuzzy number. FMEA has evaluated in two ways one of them is traditional the other is fuzzy. Fuzzy logic includes crisp numbers and linguistic variables basically, both of them use the AHP tool for evaluating the weighting factor. When AHP is used as a linguistic variable this name was changed to fuzzy AHP. The flow diagram of this chapter is explained below.

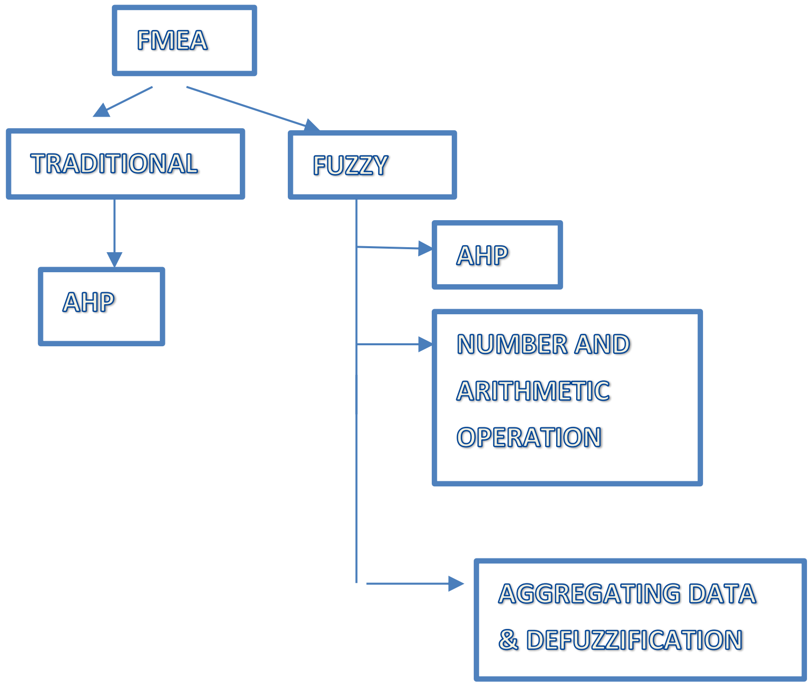

Figure 5: Flow Diagram of Chapter 3

3.1 Traditional FMEA

In real life, FMEA is a qualitative method that reduces risks during the design stage before they occur. The result of FMEA makes possible for managers and engineers to identify the failure modes and their causes, and then correct them during the phase of design and production.

Each FMEA included the following items:

- Failure Mode
- Failure Cause
- Failure Effects
- Detection Methods

RPN is a technique used for analyzing risks corporated with potential problems identified during a FMEA. RPN in traditional FMEA is used to evaluate risk by 3 criteria. These are:

1. Occurrence
2. Severity
3. Detection

The range of each criterion is scaled from 1 to 10. RPN might be evaluated by the following equations.

$$\text{RPN}= O \times S \times D \tag{1}$$

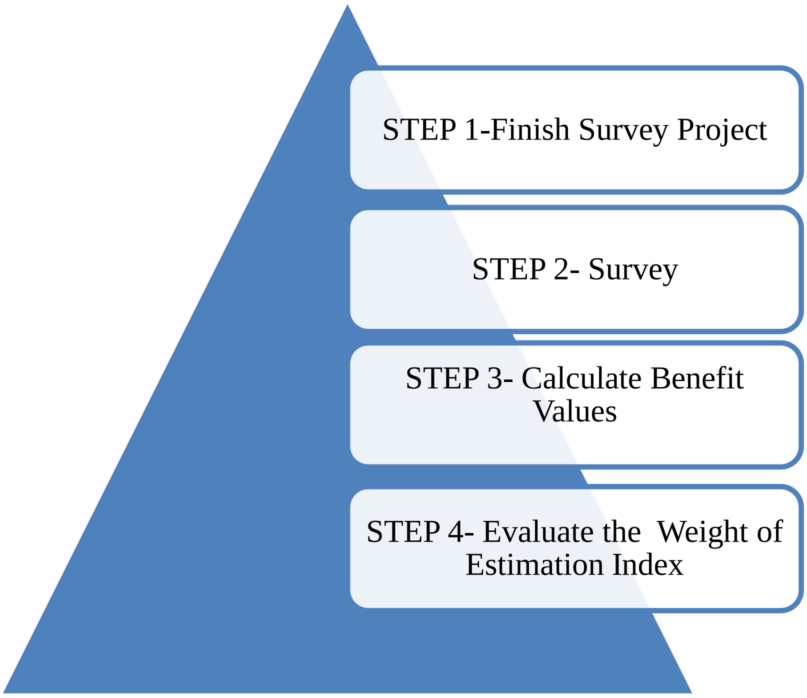

Figure 6: Steps of Classic AHP Method [54]

Table 11: Measurement Criteria of RPN [45]

CATALOG OF REQUIREMENTS			
	CRITERIA		
RANKING	**SEVERITY (S)**	**OCCURRENCE(O)**	**DETECTION (D)**
10	Very High	500000	90
9	Very High	100000	90
7	High	10000	98
5	Moderate	1000	99.7
4	Moderate	500	99.7
3	Low	100	99.7
2	Low	50	99.9
1	Very Low	1	99.9

This table shows the criteria of risk priority including ranking scores on a catalog of requirements which was taken into consideration for general evaluation.

3.2 Fuzzy FMEA

Fuzzy set theory was first introduced by Zadeh to resolve for the uncertainty in real-life problems [38]. In fuzzy logic, a quantity that might be defined on linguistic variables. A linguistic means a variable whose values are artificial language. For example, "Age" is a linguistic variable if its values are linguistic rather than numerical, i.e., young, not young, very young, quite young, old, not very old and not very young, etc., rather than 20, 21,22, 23.

In fuzzy logic, the degree of truth of expression can vary from 0 to 1 and cannot be constrained between those two real values. This theory defines that if X is a relevance set, then the fuzzy set $\tilde{A} = \{(X, \mu\widetilde{A}\,(\mathrm{x}))\quad \mathrm{x} \in X\}$. Where $\mu\bar{A}$ defines the degree of membership x in fuzzy set A and is a number between 0 and 1. The all group of all fuzzy sets in X is defined by F(X).

If X=$(x1, \ldots\ldots\ldots..xn)$ is a finite set and A is a fuzzy set in X and A is defined as the following

$$A= \frac{\mu 1}{X1} + \cdots \frac{\mu n}{xn}. \quad (2)$$

Where the term $\frac{\mu i}{xi}, i = 1, \ldots.., n$ defines that μi is the grade of membership of xi in A and the plus sign represents the union.

3.3 Fuzzy Number and Fuzzy Arithmetic Operation

A fuzzy number is a generalization that refers to a group of possible values connected to a normal real number instead of a single value, where each value has its weight between 0 and 1. A fuzzy set A in R is called a fuzzy number if it satisfies the following conditions:

1. A is a normal fuzzy set.
2. Aα is a closed interval for every $\alpha \epsilon (0, 1]$
3. Thought as A is bounded.

A fuzzy set $\bar{P} \in \bar{P}$ (R) is called a fuzzy number. Fuzzy sets, are defined on the universal set R of real numbers. It plays many important rules in many areas such as decision making, optimization and statistics, and fuzzy control. The interval might be defined. An arithmetic operation on fuzzy number introduced $[[\alpha]]$-cut of a fuzzy set F is a crisp set $F_{[[\alpha]}$ that includes all the elements of the universal set of U that have a membership grade in F greater than or equal to the specified value of α. This definition can be written as $F_{[[\alpha]]} = \{u \ U| \ _F(u) \ \alpha \ \}$. The α-cuts of a TFN define a set of closed intervals. The intervals are: [(b-a)α+a, (b-c)α+c] , ∀ α ∈]0, 1]

Fuzzy numbers are frequently used to indicate non-probabilistic uncertainty in engineering and decision making implementations. In these implementations, fuzzy arithmetic operations are usually used for solving mathematical equations that contain fuzzy numbers. There are two approaches recommended in the literature for applying fuzzy arithmetic operations which are $\alpha - cut$ approach and the extension principle approach using different t-norms, according to Seresht, Zhang & Balakrishran in 2018 [58] .Calculation efficiency for evaluations of all system in many applications limit the membership functions of the fuzzy numbers to triangular or trapezoidal fuzzy numbers. In this study, triangular fuzzy numbers (TFN) are applied. The membership function for this TFN is defined as:

a) Triangular form, $\tilde{A}$=($a1, a2, a3$)

The three main basic specialties included in characterizing membership function are the following.

Core: The core of a membership function for some fuzzy set A is introduced as that region of space which is defined by complete membership function in the set.T he core has elements x of the space such that μA (x). = 1.

Support: The support of a membership function for some fuzzy set A is introduced as that space of universe that is characterized by non-membership function in the set. The support consists of elements x of the universe such that μA (x). > 0.

Boundary: The support of a membership function for some fuzzy set A is defined as that space of universe including that have a non zero but not finish membership function in the set. The boundary contains these elements x of the universe such that:

0 < μA (x) < 1.

$$\mu_A(x) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{m-a}, & a < x \leq m \\ \frac{b-x}{b-m}, & m < x < b \\ 0, & x \geq b \end{cases} \quad (3)$$

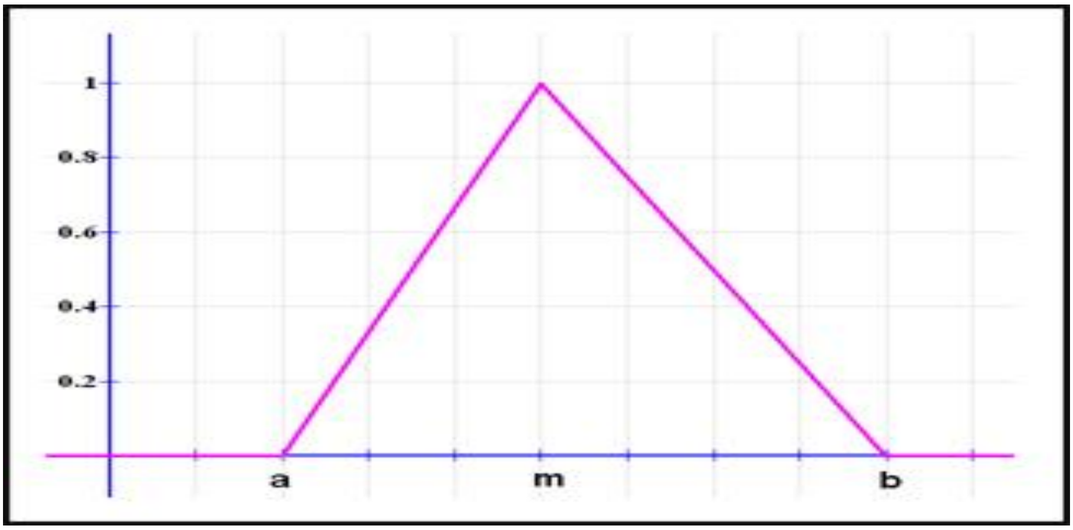

Figure 7: Triangular Form [55]

Trapezodial Form, $\tilde{A}$=(a1,a2,a3,a4)

$$\mu_A(x) = \begin{cases} 0, & (x < a) \text{ or } (x > d) \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c \le x \le d \end{cases} \tag{4}$$

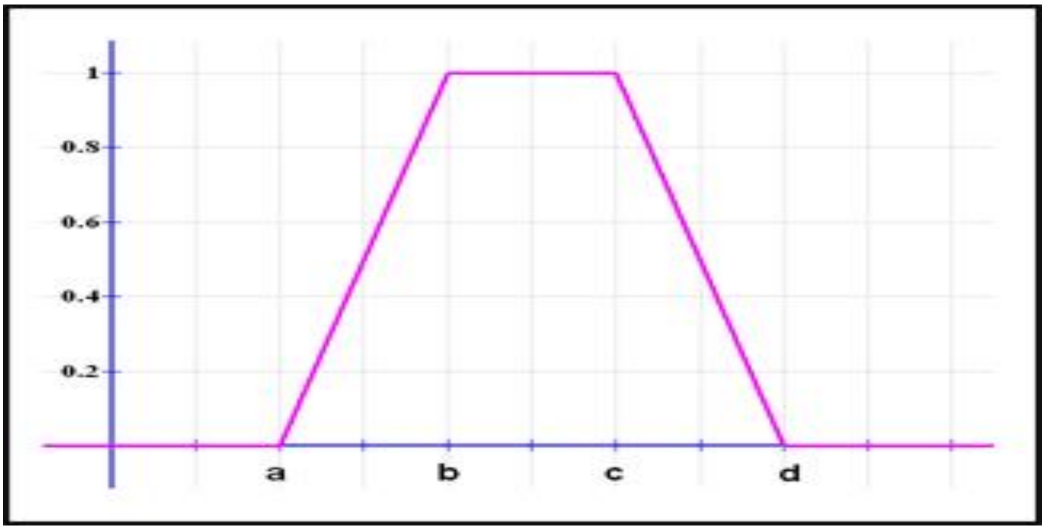

Figure 8: Trapezoidal Form [55]

Trapezoidal function: defined by a lower limit **a**, an upper limit **d**, a lower support limit **b**, and an upper support limit **c**, where **a < b < c < d**.

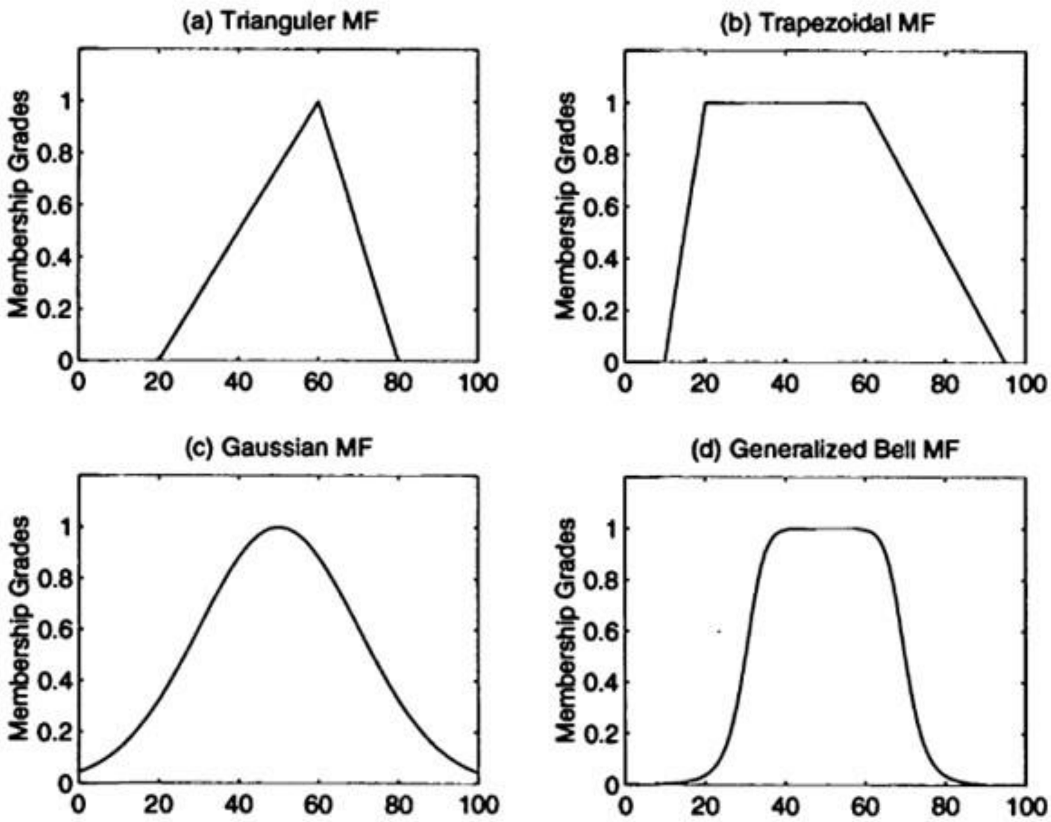

Figure 9: The Graph of Typical Fuzzy Numbers [56]

Some basic definitions of fuzzy numbers and sets are defined as follows:

Definition 1:

Let U be an original universal set and E be a set of parameters. The power set of U is defined by P(U) and A is a subset of E. A pair (F, A) is called a set over U, where F is marking out given by F: A $\rightarrow$ P(U).

Definition 2:

A fuzzy subset μ of U is defined as a mark out from U to [0,1]. The family of all fuzzy subsets of U is defined by F(U). Let μ, ν ∈ F(U) and x ∈ U. Then the union and intersection of μ and ν are defined as follows:

$(\mu \vee \nu)(x) = \mu(x) \vee \nu(x)$,

$(\mu \wedge \nu)(x) = \mu(x) \wedge \nu(x)$,

$\mu \leq \nu$ if and only if $\mu(x) \leq \nu(x)$ for all x ∈ U.

Definition 3:

Let (F, A) and (G, B) be two fuzzy sets over a common universe U.Then the union of fuzzy sets (F,A) and (G,B) is defined as the fuzzy set $(H,C)=(F,A)\tilde{\cup}(G,B)$ over U,

where C = A ∪ B and:

$H(c) = F(c)$ if $c \in A \setminus B$, for all $c \in C$ (5)

$G(c)$ if $c \in B \setminus A$ (6)

$F(c) \vee G(c)$ if $c \in A \cap B$ (7)

(ii) The restricted intersection of fuzzy sets (F,A) and (G,B) is defined as the fuzzy set:

$(H,C)=(F,A)\tilde{\cap}(G,B)$ over U,where $C=A\cap B = \emptyset$ and $H(c) = F(c) \wedge G(c)$ for all c.

(iii) The restricted union of fuzzy soft sets (F,A) and (G,B) is defined as the fuzzy set

$(H,C)=(F,A)\tilde{\cup}(G,B)$ over U, where $C=A\cap B = \emptyset$ and $H(c) = F(c) \vee G(c)$ for all $c \in C$.

3.3.1 Fuzzy Arithmetic Operations

Arithmetic operation on TFNs and their definitions are briefly defined as follows:

Addition

Let $\tilde{A} \rightarrow \langle a1, b1, c1\rangle$ $\tilde{B} \rightarrow \langle a2, b2, c2\rangle$

$$\tilde{A} \oplus \tilde{B} = \langle a1 + a2, b1 + b2, c1 + c2\rangle \quad (8)$$

Multiplication

$\tilde{A} \rightarrow \langle a1, b1, c1\rangle$ $\tilde{B}\langle a2, b2, c2\rangle$

$$\tilde{A} \otimes \tilde{B} = \langle a1 \times a2, b1 \times b2, c1 \times c2\rangle \quad (9)$$

Subtraction

Similarly, the subtraction of A and B,

$$\tilde{A}(-)\tilde{B} = \langle a1 - a2, b1 - b2, c1 - c2\rangle \quad (10)$$

Division

$$\tilde{A}(/)\tilde{B} = \langle a1/a2, b1/b2, c1/c2) \quad (11)$$

3.4 Fuzzy AHP

A multicriteria decision-making problem is arranged according to the hierarchical structure. In the Analytic Hierarchy Process, the most important task is deciding to choose the failures which are important for that decision. The AHP is particularly concerned with the scaling problem and what sort of numbers to use. An evaluation scale includes 3 levels.

- A set of objects
- A set of numbers

- Matching objects to the numbers.

Buckleys Fuzzy AHP

For the calculation of FWGM, these criteria were compared by each other using a reciprocal comparison matrix.

$$C=\begin{bmatrix} C11\,C12 & \cdots & C1N \\ \vdots & \ddots & \vdots \\ CN1\,CN2 & \cdots & CNM \end{bmatrix} \tag{12}$$

The fuzzy geometric mean of each row is calculated as

$$ZJ=[\prod_{k=1}^{n} C_{jk}]^{\frac{1}{n}} \tag{13}$$

Where Cjk evaluation of the experts on the pairwise comparison importance of jth and kth criteria.

The weighting factor wi is evaluated as:

$$Wj=zj\div z1+z2+z3+\cdots zn,\forall j \tag{14}$$

Fuzzy AHP is explained in steps which are mentioned below:

Pairwise comparison is used to evaluate the calculation of relative importance. The experts might be attending their knowledge. According to the linguistic fuzzy parameters scale which was first introduced by L. SAATY. Many AHP studies literature review applications based on this scale in fuzzy logic. In this study, the scale and TrFNS were used which is modified from the paper of [13].

Whole experts (decision maker) individual preferences into group preference by applying the fuzzy trapezoidal averaging operator, which is described by

$$\tilde{C}jk=1\div K\left[\widetilde{C^1}jk(+)\widetilde{C^2}(+)\ldots(+)\tilde{C}jk^K\right] \tag{15}$$

K is the number of experts and $C\ j^K$ is the determination of the K^{th} decision-maker on the pairwise importance comparison of j^{th} and k^{th} criteria..To procure the fuzzy weights $\widetilde{WJ}$. The derivation of $\widetilde{zj}$ values (Eq.13) and fuzzy weights $\widetilde{WJ}$ (Eq.14) can be detailed as follows. Let,

$$\text{j}= \left[\prod_{j=1} n\ \tilde{a}jk\right]^{1/n} \tag{16}$$

And $\sum_{j=1}^{n} aj$ (17)

At the same time, bj and b, cj and c, dj and d can be defined. The fuzzy weight wj is evaluated as wj=(dj/d,cj/c,bj/b,aj/a), each j (18)

To defuzzify the TrFN is used

$$wj \quad = \quad \frac{aj}{d} + 2\left(\frac{bj}{c} + \frac{cj}{b}\right) + \frac{dj}{a} \Big/ 6 \tag{19}$$

Then normalize the weights Eq. (19) is used:

$$w_j = w'_j \Big/ \sum_{j=1}^{n} w'_j, \qquad j = 1, 2, ..., n \tag{20}$$

An expert (decision maker) should determine the priority of the system. The main object of setting priorities requests that the future of the alternatives being compared. The AHP is used with two types of measurement, relative and absolute. In both, paired comparisons it is necessary to prioritize according to the aim. In relative measurement, paired comparisons are evaluated throughout the hierarchy comprising on the alternatives in the lowest level of the hierarchy with respect to the criteria in the level mentioned above. In absolute measurement, paired comparisons are evaluated through the hierarchy with the exclusions of the alternatives themselves. In the end, after all the judgments have been made on the system and priorities have been calculated in the hierarchy, as a whole; less important elements might be dropped.

Let's assume that n books are given, $A1$,..., An, whose weights w1 ..... w n, respectively, are known to us. Form of the matrix of pairwise ratios whose rows give the ratios of the weights of each book concerning all others. When some measurements were done about a future concerning a property some known scale is used for that purpose. If a basic contribution is made to the subject of this study, the Analytic Hierarchy Process (AHP) derives relative scales using data from a standard scale and shows how to perform the next arithmetic process on such scales which is avoiding useless number crunching.

Matrix equation of AHP of example:

$$\begin{pmatrix} W1/W1 & W1/W2 & W1/Wn \\ \vdots & \ddots & \vdots \\ Wn/W1 & Wn/W2 \cdots & Wn/Wn \end{pmatrix} \begin{pmatrix} W1 \\ W2 \\ . \\ . \\ .\,Wn \end{pmatrix} = n \begin{pmatrix} W1 \\ W2 \\ . \\ . \\ . \\ Wn \end{pmatrix} \qquad (21)$$

The solution of *Aw=nw* defined principal right eigenvector of A. In relative measurement, paired comparisons are evaluated by the 3 levels throughout the separation of the problem into hierarchy including on the alternatives in the lowest level of the problem. In the first level which is the main object of 'Effect of a chemical plant on the environment'. In the second level, four criteria are available which contribute the main objective and the last level which are to be evaluated in terms of the criteria in the second level.

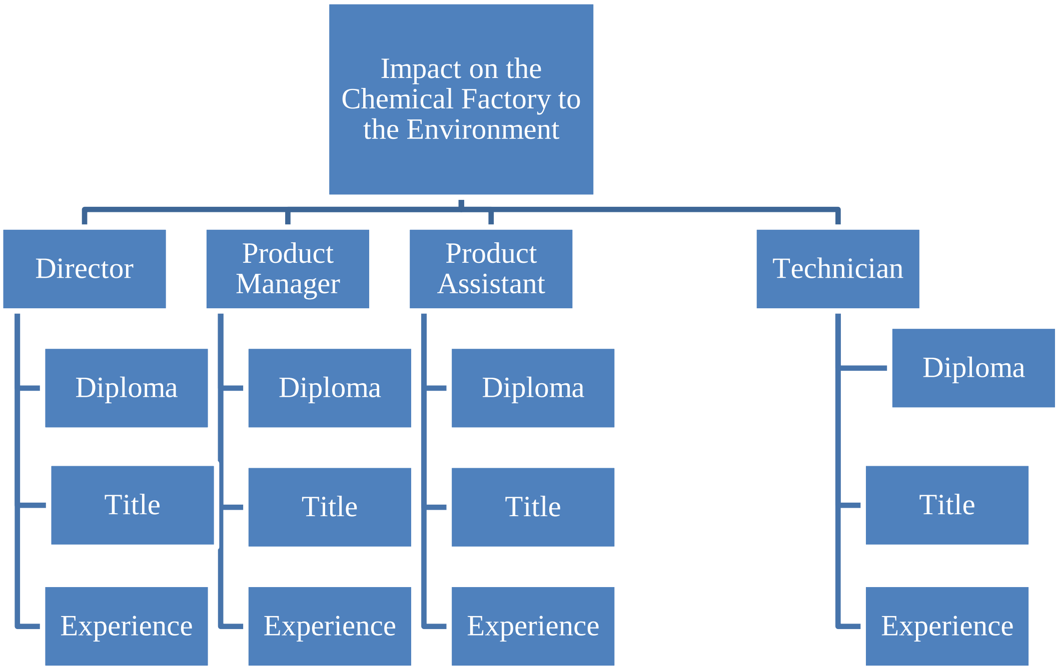

Figure 10: Separation of the Problem into a Hierarchy [46]

The AHP calculation of this study is explained below. This table is inspired by the Saaty in 1990 [46].

Table 12: Fundamental Scales of AHP [59]

Intensity of importance on an absolute scale	**Definition**	**Explanation**
1	Equal Importance	Two activities have equal contribution to the objective
3	Moderate importance	Experience strongly favor one activity over another
5	Strong importance	Experience strongly favor one activity over another
7	Very strong importance	Strongly preferred activity
9	Extreme importance	Very strongly preferred activity
2,4,6,8	Intermediate values between two adjacent judgments	When comprimises needed

This table is used for AHP calculations. This table is also inspired by the Partovi, Burton & Banerjee in 1990 [47] which describes the AHP in detail.

Third level criteria are calculated using the AHP evaluation as follows. At the end of this evaluation, the weight factors of these criteria are found. These criteria which are defined in figure 9 are:

- Diploma
- Title
- Experience

Table 13: Evaluation of this Internal Criterion

Criteria	D	T	E
D	1.00	0.50	0.14
T	2.00	1.00	1.20
E	7.00	5.00	1.00
Total	10.00	6.50	2.34

Table 14: Weight Factor

	Weight Factor
DIPLOMA	0.09
TITLE	0.17
EXPERIENCE	0.76
	1.03

3.5 Aggregating Data and Defuzzification Procedure

3.5.1 Aggregating Data

Aggregating data is any process in which information is collected and defined in a summary form, for purposes such as statistical analysis. A common aggregation intention is to get more information about particular groups based on specific variables such as age, profession or income. The steps of aggregating data are as follows according to Hsu & Chen in 1996 [48].

Calculate the degree of similarity by using evaluated weighting factor of expert opinion $(Eu\ and\ Ev)$. This is defined as $\mathrm{S}uv(\tilde{R}u, \widetilde{R}v)$ is defined as opinions between each pair of experts $Eu\ and\ Ev$. $\mathrm{S}uv(\tilde{a}, \tilde{R}v)$ when $\tilde{A}$(a1,a2,a3) and $\tilde{B}$(b1,b2,b3) are two standard triangular fuzzy numbers, degree of agreement function of S is defined as follows:

$$\mathrm{S}(\tilde{A}, \tilde{B})\text{=1-1/j}\textstyle\sum_{1}^{j}|ai - bi| \tag{22}$$

Then next step is evaluating the AA(Average of Agreement) degree of the expert opinion which is defined

$$AA(Eu) = \text{1/j-1}\textstyle\sum_{v=1}^{j} u \neq v\ S(\tilde{R}\mathrm{u}, \widetilde{R}v) \tag{23}$$

Calculation of the Relative Agreement degree is the third step which is defined $RA(Eu)$ of the experts.

$$RA(Eu) = AA(Eu)/\textstyle\sum_{1}^{J} AA(Eu) \tag{24}$$

Define the Consensus Coefficient (CC) degree, of experts opinion which is evaluated as follows:

$$\mathrm{CC(Eu)}=\beta.W(Eu) + (1-\beta).RA(Eu) \tag{25}$$

At the last step aggregated result of judgment $\tilde{R}ag$ can be defined as follows:

$$\tilde{R}ag = \text{CC(E1)} \otimes \tilde{R}2 \oplus \text{CC(E2)} \otimes \tilde{R}2 \oplus \dots \dots \oplus \text{CC(Em)} \otimes \tilde{R}\text{m} \qquad (26)$$

Table 15: Score Rating According to Experts Traits

Item	**Categorize**	**Score**
Title	High-ranking academic	5
	Low ranking academic	4
	Engineer	3
	Technician	2
	Worker	1
Experience	More than 25 years	5
	20-24	4
	10-19	3
	6-9	2
	< 5	1

Table 16: Expert Weighting Group Decision Making

EXPERT WEIGHTING OF GROUP DECISION MAKING				
EXPERT	**DIPLOMA**	**TITLE**	**EXP**	**WS**
EXP1	PHD	DIRECTOR	<=5	0.22
EXP2	BACHELOR	PROD MNG	20-29	0.63
EXP3	BACHELOR	PROD ASST	6_10	0.09
EXP4	BACHELOR	TECH	6_10	0.08

3.5.2 Defuzzification Procedure

The concept of the fuzzy set was first defined by Zadeh (1965) as a generalization of the crisp set which is very important for nondeterministic real problems. Defuzzification is the process of getting a single number from the output of the aggregated fuzzy set. Defuzzification is realized by a decision making algorithm that selects the best crisp value based on a fuzzy set.

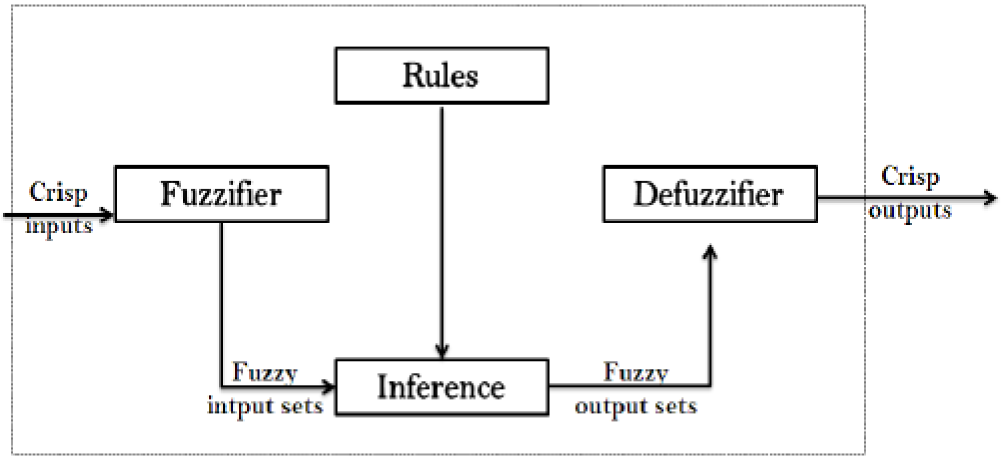

Figure 11: The Place of Defuzzification in a Fuzzy Control System [60]

This method was improved from Hsu & Chen in 1996 [48] and the generally mathematically formula define as follows:

$$x *= \int vi(x)xdx \div \int vi\,(x)dx \tag{27}$$

x∗= $Defuzzified\ output$;

vi(x)= $Aggregated\ membership\ function$;

x= $output\ variable$

Defuzzification of triangular fuzzy number $\tilde{A}$(a1,a2,a3) is:

$$x^* = \int_{a1}^{a2}(x-a2) \div (a2-a1)xdx + \int_{a2}^{a3}(a3-x) \div (a3-a2)xdx / \int_{a1}^{a2}(x-a2) \div (a2-a1)dx + \int_{a2}^{a3}(a3-x) \div (a3-a2)dx = 1/3(a1+a2+a3) \tag{28}$$

Defuzzification of trapezoidal fuzzy number $\tilde{A}$(a1,a2,a3,a4) is:

$$x^* = \int_{a1}^{a2} (x - a2) \div (a2 - a1) x dx + \int_{a2}^{a3} x dx + \int_{a3}^{a4} (a4 - x) \div (a4 - a3) x dx \; /$$

$$\int_{a1}^{a2} (x - a1) \div (a2 - a1) dx + \int_{a2}^{a3} dx \int_{a3}^{a4} (a4 - x) \div (a4 - a3) dx =$$

$$1/3(a4 + a3)^2 - a4a3 - (a1 + a2)^2 + a1a2 \div (a4 + a3 - a1 - a2) \qquad (29)$$

Shortly the process of transforming the final fuzzy set into a crisp number is called defuzzification, this integrates the information contained in the resulting fuzzy sets with a number.

Chapter 4

DATA RESULTS

4.1 Case Study

Reducing the hazardous effects of chemical productions on the environment is one of the most important problems in green engineering. In this case study the selected company is a unique home and industrial grade cleaners and Cosmetics Company in Famagusta which also exports to numerous countries.

Their manufacturing plant carries BS EN ISO 9001 Quality Management, ISO 14000 Environmental Management and Good Manufacturing Practice quality certifications. The factory faces some environmental problems after production and during production stage. These problems are summarized as 7 failures.

For the risk, assignment calculations were done by using the AHP tool. First of all the profile was selected according to their experience, title, and field of education. The responded profile includes:

- one production manager
- one general manager
- one technician
- one worker

This profile which is mentioned above was our decision-makers in this study. 7 problems were detected in the factory by the general manager and these are reported in the questionnaire. Each expert answered the questionnaire questions independently and rated the question from 1 to 10.

Table 17: FMEA of the Chemical Industry of this Study

Numbers	**Potential failure modes**	**Process step**	**Potential effect(s) of failure**
1	Release of carbon emissions from the logistic part in raw material procurement	FM1	Smog from the fuel burned in cars and trucks. Smog menace the heath of millions of human each year, and is dangerous to children also causes respitory diseases according to the EPA
2	Wastes from washing of production boilers in the factory	FM2	Wastewater unloades charges from industrial sources might contain pollutants at levels that could affect the quality of receiving waters or interfere with publicly owned treatment works (POTWs) that receive those discharges.
3	Electricity use in the factory	FM3	Because of a unique combination of high energy usage and potential for significant savings, utilities are turning to energy-efficient technologies to help save money
4	The degree of carbon emission emitted by the vehicles to the environment during the delivery of the finished product in shipment	FM4	Smog from the fuel burned in cars and trucks. Smog menace the heath of millions of human each year, and is dangerous to children also causes respitory diseases according to the EPA
5	Cardboard,plastic,tape etc resulting from raw materials.	FM5	Reducing industrial and packaging waste saves money, reduces the environmental impacts of waste, and improves organizational image.
6	Consumers use the resulting waste etc	FM6	Reducing industrial and packaging waste saves money, reduces the environmental impacts of waste, and improves organizational image.
7	Office waste	FM7	Binders, clipboards, file folders, clip portfolio, and presentation folders are commonly used office products made from a variety of materials. Chipboard, pressboard, plastic-covered chipboard or paperboard, cloth-covered chipboard or paperboard, and solid plastic binders might be made with recovered materials. Clipboards, file folders, clip portfolios and presentation folders can be made of solid plastic containing recovered materials.

According to the failures they cause many effects on the environment. Definitions of failures and potential effects of failure were explained in figure 12. This figure shows us the categorization of failures and the effects of the failure.These failures matches the potential effects by using Environmental Protection Agency (EPA) After identification of each failure risk factor; RPN numbers are evaluated according to the traditional FMEA .In this figure each expert ranks the risk factors independently from each other and when these risk factors multiplied RPN numbers are gathered. Firstly classical RPN numbers of each failure are evaluated according to the risk factors; severity, occurrence, detectability. These risk factors of the failures are evaluated from each expert independently.

Table 18: RPN Number

	FM1	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
EXP 1							
O	10	10	5	10	10	10	10
S	1	3	10	1	3	5	1
D	10	1	2	1	2	2	1
Classic RPN	100	30	100	10	60	100	10
EXP2							
O	9	8	5	9	10	10	10
S	2	3	10	2	3	3	1
D	8	2	3	2	3	1	1
Classic RPN	144	48	150	36	90	30	10
EXP 3							
O	9	8	10	9	10	10	9
S	4	4	2	3	5	5	3
D	2	9	8	9	6	6	9
Classic RPN	72	288	160	243	300	300	243
EXP 4							
O	8	7	8	7	9	10	9
S	3	4	3	3	5	5	2
D	7	3	6	5	7	8	7
Classic RPN	168	84	144	105	315	400	126
Average RPN Number	121	113	139	99	191	208	97
Weighting factor RPN Number	133	76	144	60	110	81	44

The average RPN number was evaluated by the average of the multiplication of the risk factors, weighting factor RPN number was evaluated by the weighting factor of the experience criteria. Then these two RPN numbers are compared to each other.

Table 19: Risk Factors of Failure

According to Weighting Factor	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
Occurrence	9	9	6	9	10	10	10
Severity	2	3	9	2	3	4	1
Detection	8	3	4	3	3	2	2

Table 20: Classical Fmea RPN Numbers

According to Weighting Factor	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
RPN Number	133	76	144	60	110	81	44

As mentioned before the aim of this study is to combine FMEA procedure with the AHP tool for the chemical industry to create better RPN scores.

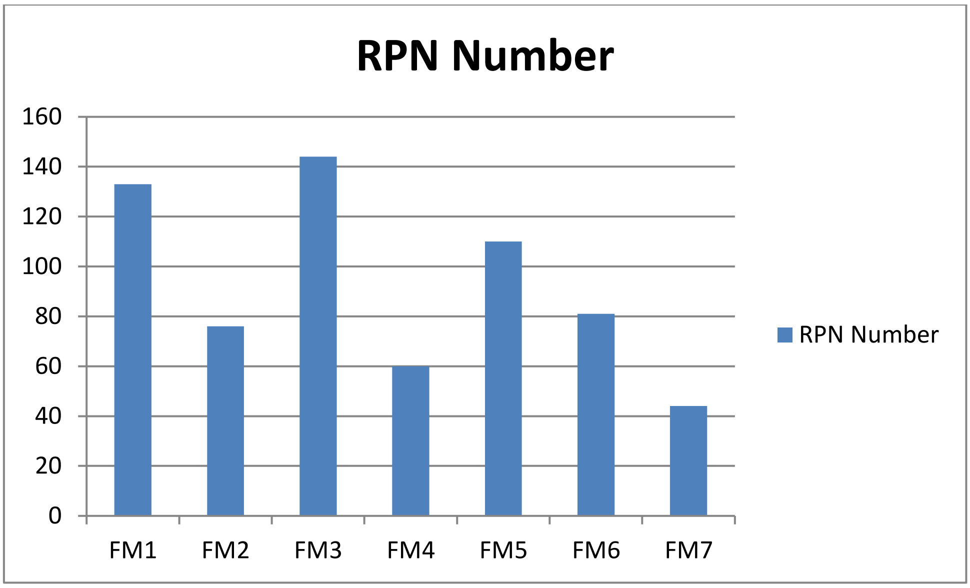

Figure 12: RPN Numbers of all Failures in Classical FMEA

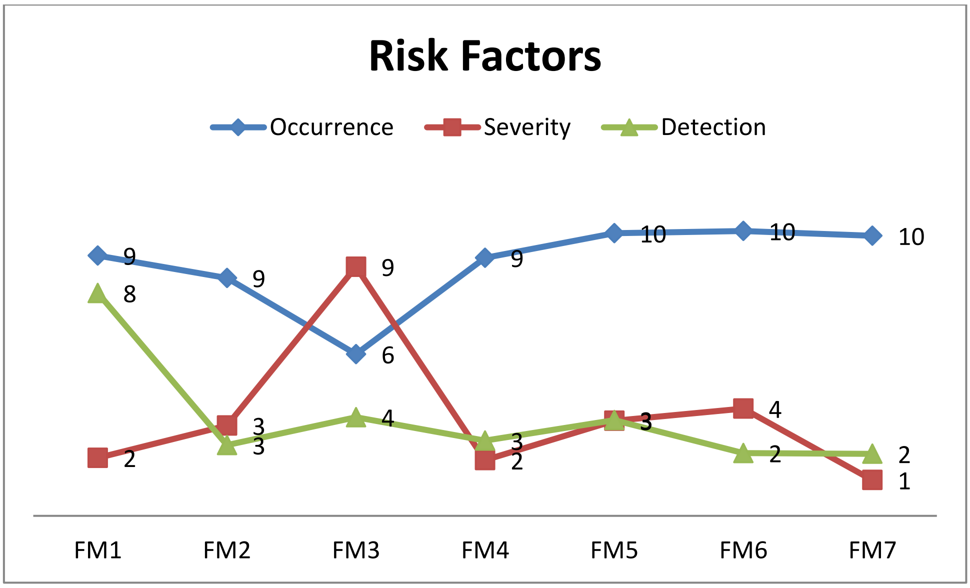

Figure 13: Comparison of Risk Factors

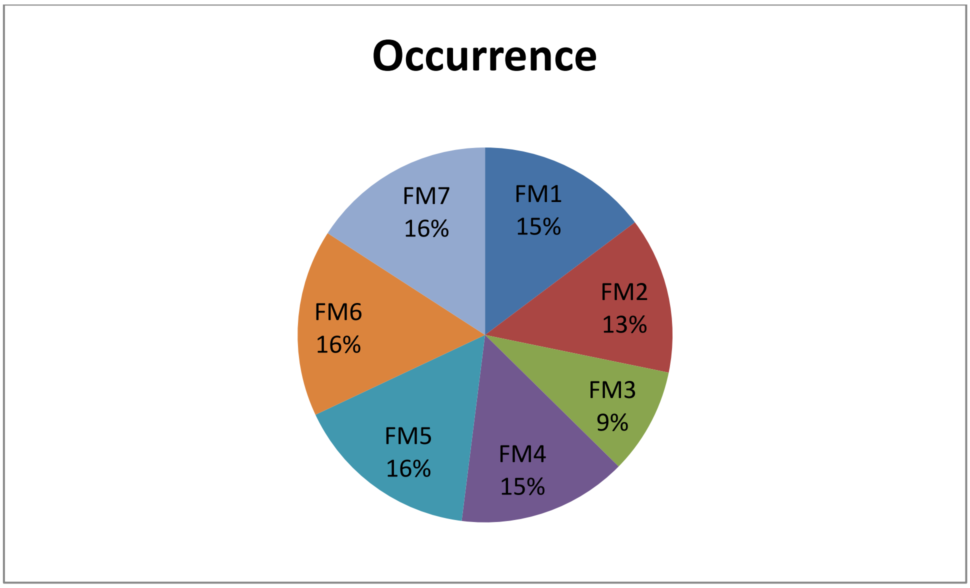

Figure 14: Occurrence

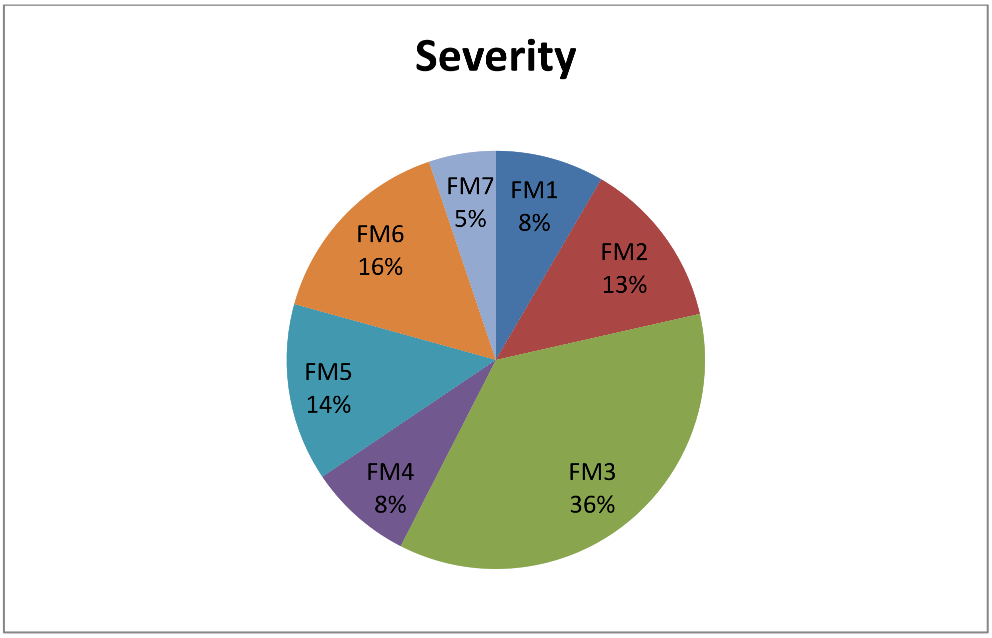

Figure 15: Severity

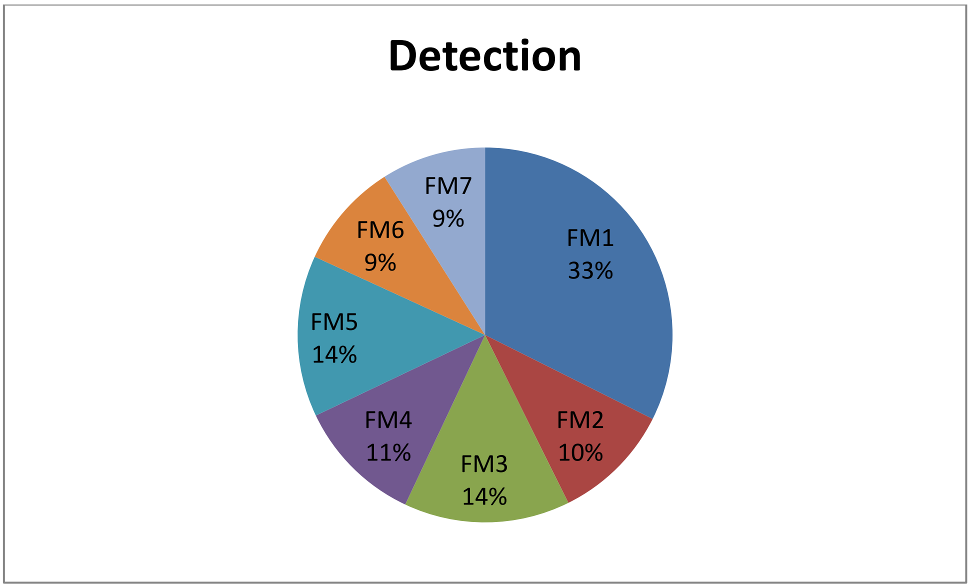

Figure 16: Detection

Table 21: Comparison Table of RPN Numbers

FAILURE NUMBER	**AVR RPN NUMBER(RPN NUMBER 1)**	**RPN NUMBER ACCORDING TO WEIGTINGFACTOR(RPN NUMBER 2)**
FM1	121	133
FM2	113	76
FM3	139	144
FM4	99	60
FM5	191	110
FM6	208	81
FM7	97	44

Comparison of failures according to RPN NUMBER 1 as follows:

FM6>FM5>FM3>FM1>FM2>FM4>FM7

Comparison of failures according to RPN NUMBER 2 as follows:

FM3>FM1>FM5>FM6>FM2>FM4>FM7

According to RPN NUMBER 1, we see failure 6 is the most important problem that needs to be improved. But according to RPN number 2 we see that failure 3.

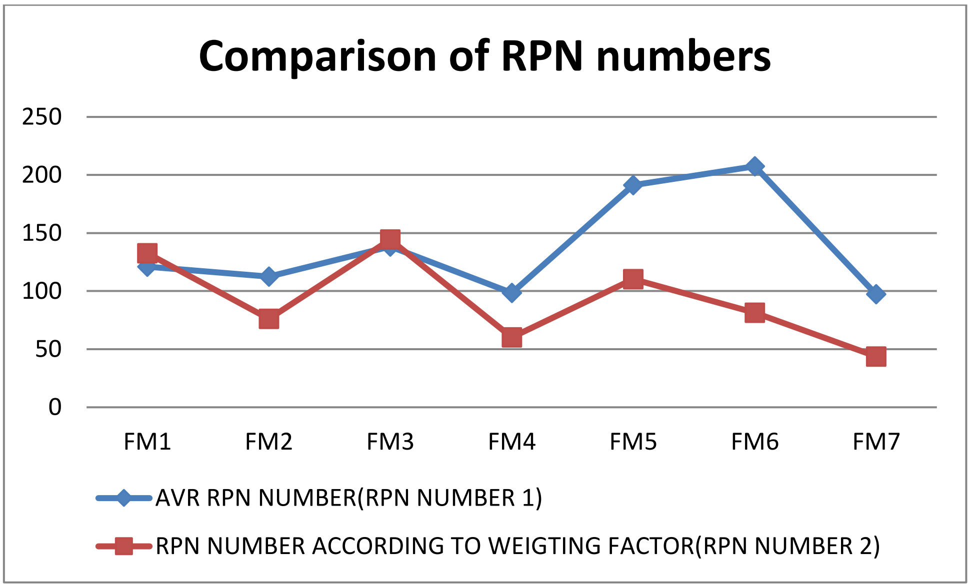

Figure 17: Comparison of RPN numbers

Failure Modes and Effects Analysis (FMEA) is a scientific, proactive technique of calculating a process. An FMEA defines the opportunities for failure, in each step of the process. Each failure mode acquires a numeric score that quantifies (a) likelihood that the failure will occur, (b) likelihood that the failure will not be detected, and (c) the amount of injury the failure mode shall cause to a person, equipment or environment. The product of these three scores is the Risk Priority Number (RPN) for that failure mode.

Secondly, fuzzy RPN calculations were done according to the corresponding fuzzy number. Each corresponding fuzzy number, defined by linguistic variable and criteria are evaluated according to the corresponding fuzzy number. Corresponding fuzzy number of occurrence, severity, and detection are attached in the Appendix. Thirdly fuzzy AHP calculations were done according to the Bucleys Fuzzy AHP.

In the Analytic Hierarchy Process, the most important assignment is deciding to choose the problems which are important for the concept of "impact on the chemical factory to the environment". After selecting the most important problems, criteria are determined to evaluate them. These criteria are a diploma, title, and experience. For the calculation of WGM, these criteria were compared by each other using a reciprocal comparison matrix that is explained in chapter 3. Figure 18 was used for the calculation of AHP in this study. Each criterion is evaluated by the four experts separately from each other by using a reciprocal comparison matrix and elements of figure 18 intensity of importance on an absolute scale help this evaluation.

Linguistic Term	Positive Triangular Fuzzy Scale (l, m, u)
Extreme unimportance	(1/10, 1/9, 1/8)
Intermediate value	(1/9, 1/8, 1/7)
Very unimportant	(1/8, 1/7, 1/6)
Intermediate value	(1/7, 1/6, 1/5)
Essential unimportance	(1/6, 1/5, 1/4)
Intermediate value	(1/5, 1/4, 1/3)
Moderate unimportance	(1/4, 1/3, 1/2)
Intermediate value	(1/3, 1/2, 1)
Equally important	(1, 1, 1)
Intermediate value	(1, 2, 3)
Moderate importance	(2, 3, 4)
Intermediate value	(3, 4, 5)
Essential importance	(4, 5, 6)
Intermediate value	(5, 6, 7)
Very vital importance	(6, 7, 8)
Intermediate value	(7, 8, 9)
Extremely vital importance	(8, 9, 10)

Figure 18: Triangular Fuzzy Scale [61]

Education, title and work experience of the employees were evaluated in this case study. The demographic statistics of respondents are conceptualized such as in Figure (19), (20), (21)

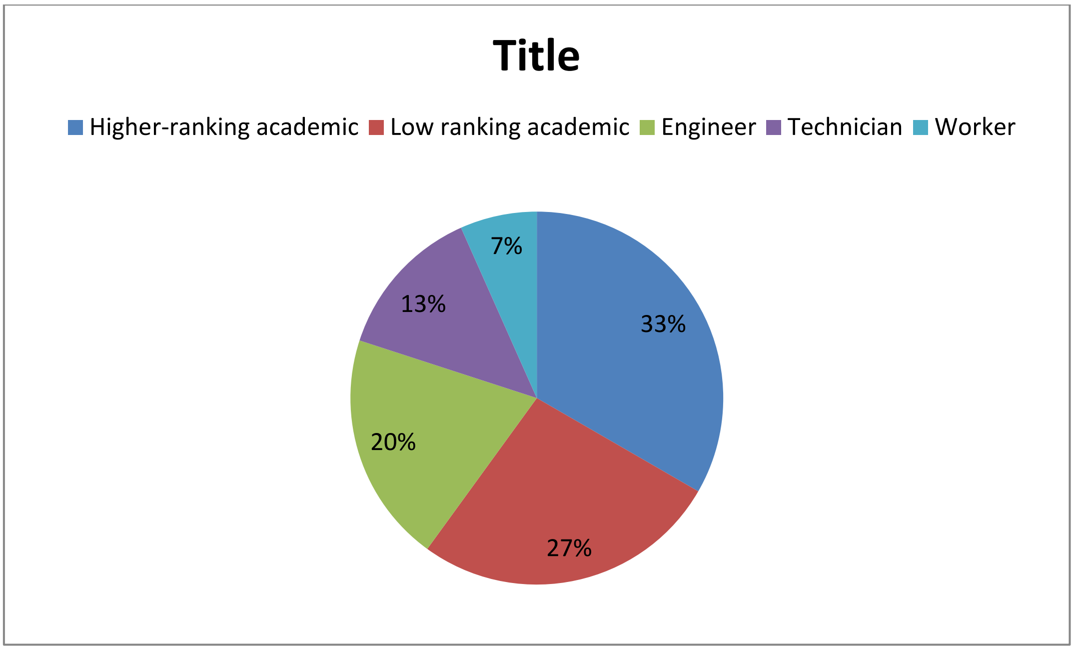

Figure 19: Spread of the Title

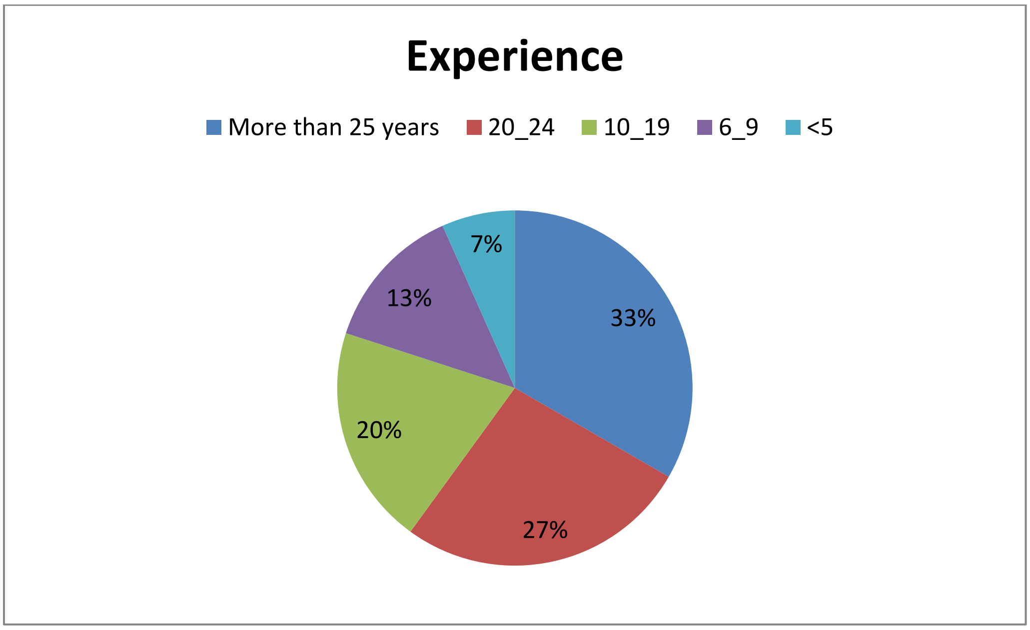

Figure 20: Spread of the Experience

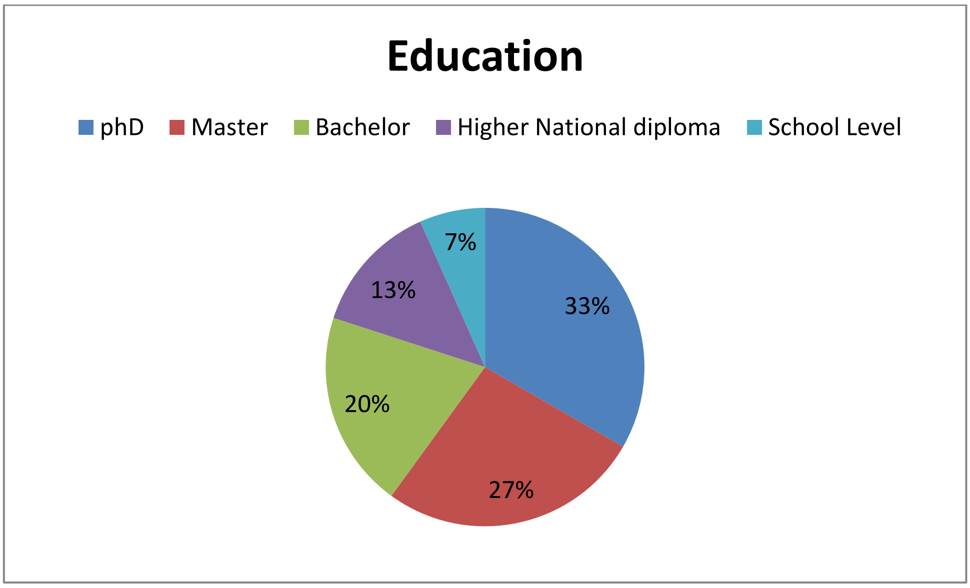

Figure 21: Spread of the Education

For finding the weighting factor of this case study AHP tool was used. The step of this study such as defined as follows:

Firstly diploma, title, and experience are compared to each other.

Table 22: Comparison of Crtiteria

	D	T	E
D	1.00	0.50	0.14
T	2.00	1.00	1.20
E	7.00	5.00	1.00

At the end of the calculation's weighting factors were found then the criteria of the diploma are calculated in the same way by using reciprocal matrix an evaluated by the 4 experts such as:

Table 23: Evaluation of Diploma Criterion

DIPLOMA	Director	Production Mng	Production Asst	Technician
Director	1.00	0.20	3.00	4.00
Production Mng	5.00	1.00	9.00	7.00
Production Asst	0.33	0.11	1.00	1.00
Technician	0.25	0.14	1.00	1.00
	6.58	1.45	14.00	13.00

Table 24: Weighting Factor of Diploma Criterion

DIPLOMA	**WEIGHTING FACTOR**	**WE**
Director	0.20	D1
Production Mng	0.66	D2
Production Asst	0.07	D3
Technician	0.07	D4

The title is calculated also by using a reciprocal matrix of comparison result was found such as:

Table 25: Evaluation of the Title Criterion

TITLE	**Director**	**Production Mng**	**Production Asst**	**Technician**
Director	1.00	0.17	2.00	3.00
Production Mng	6.00	1.00	8.00	4.00
Production Asst	0.50	0.13	1.00	1.00
Technician	0.33	0.25	1.00	1.00
	7.83	1.54	12.00	9.00

Table 26: Weighting Factor of the Title Criterion

TITLE	**WEIGHTING FACTOR**	**WE**
Director	0.18	T1
Production Mng	0.68	T2
Production Asst	0.09	T3
Technician	0.09	T4

Table 27: Evaluation of Experience Criterion

EXPERIENCE	Director	Production Mng	Production Asst	Technician
Director	1.00	0.13	3.00	5.00
Production Mng	8.00	1.00	4.00	6.00
Production Asst	0.33	0.25	1.00	1.00
Technician	0.20	0.17	1.00	1.00

	9.53	1.54	9.00	13.00

Table 28: Weighting Factor of Experience Criterion

TITLE	**WEIGHTING FACTOR**	**WE**
Director	0.23	E1
Production Mng.	0.63	E2
Production Asst.	0.09	E3
Technician	0.08	E4

The highest factor belongs to the experience criterion according to table 10. All explanations were explained in Chapter 3 respectively.

After all these calculations the other step is transferring the opinion of the experts to the fuzzy memberships function. Rating fuzzy numbers acts as important role in linguistic decision making. Several strategies have been recommended for a rating of fuzzy numbers. In this study membership’s function of triangular and trapezoidal form were used. In this approach, measurements are defined by linguistic terms. The information fuzzification occurred in fuzzy values respect of input measures, severally output in/from the controller which is explained in figure 6.

Table 29: Linguistic Expression and Their Corresponding Fuzzy Number [16]

Linguistic expressions	Scale 1	Scale 2	Scale3	Scale 4	Scale 5	Scale 6	Scale 7	Scale 8
None						(0,0,0.1,0.2)	(0,0,0.2)	(0,0,0.1)
Very Low			(0,0,0.2)		(0,0,0.1,0.2)		(0,0,0.1,0.3)	(0,0.1,0.2)
Low-very						(0.1,0.25,0.4)	(0,0.2,0.4)	(0.1,0.2,0.3)
Low		(0,0,0.2,0.4)	(0.1,0.2,0.3)	(0,0,0.3)	(0,0.2,0.4)		(0.2,0.35,0.5)	(0.1,0.3,0.5)
Fairy Low				(0,0.25,0.5)	(0.2,0.4,0.6)			(0.3,0.4,0.5)
Mol,Low								(0.4,0.45,0.5)
Medium	(0.4,0.6,0.8)	(0.2,0.5,0.8)	(0.3,0.5,0.7)	(0.3,0.5,0.7)		(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
Mol,High								(0.5,0.55,0.6)
Fairy High				(0.5,0.75,1)	(0.4,0.6,0.8)		(0.5,0.65,0.8)	(0.5,0.6,0.7)
High	(0.6,0.8,0.1)	(0.6,0.8,1,1)	(0.6,0.8,0.1)	(0.7,1,1)	(0.6,0.75,0.9)	(0.6,0.75,0.9)	(0.6,0.8,0.1)	(0.5,0.7,0.9)
High-very high							(0.7,0.9,1,1)	(0.7,0.8,0.9)
Very High			(0,8,1,1)		(0.8,0.9,1.1)	(0.8,0.9,1.1)	(0.81,1)	(0.8,0.9,1)
Excellent								(0.9,1,1)
more or less								

As mentioned in Chapter 3 detailed each risk factor which is occurrence, severity and detectability is given as the fuzzy parameter of the linguistic value of these factors. These are tabulated according to the degrees given by the experts. In Table 15 the fuzzy corresponding numbers are illustrated which are based on decision-makers' opinion. The main aim of this study is to build basics for constructing four operations on fuzzy numbers in a way that makes them a field of numbers. Moreover, definitions of four main operations addition, subtraction, multiplication, and subtraction have to be introduced in the form suitable for their algorithmization.

Table 30: Corresponding Fuzzy Numbers for Each Expert Opinion [16]

	FM1	FM2	FM3	FM4	FM5	FM6	FM7
EXPERT1							
O	(0.8,0.9,1.1)	(0.8,0.9,1.1)	(0.3,0.5,0.7)	(0.8,0.9,1.1)	(0.8,0.9,1.1)	(0.8,0.9,1.1)	(0.8,0.9,1.1)
S	(0,0,0.1,0.2)	(0.1,0.3,0.5)	(0.8,0.9,1.1)	(0,0,0.1,0.2)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0,0,0.1,0.2)
D	(0.8,0.9.1)	(0,0,0.1)	(0,0,0.1)	(0,0,0.1)	(0,0,0.1)	(0,0,0.1)	(0,0,0.1)
EXPERT2							
O	(0.6,0.75,0.9)	(0.6,0.75,0.9)	(0.3,0.5,0.7)	(0.6,0.75,0.9)	(0.8,0.9,1.1)	(0.8,0.9,1.1)	(0.8,0.9,1.1)
S	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.8,0.9,1.1)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0,0.1,0.2)
D	(0.5,0.7,0.9)	(0,0,0.1)	(0.1,0.3,0.5)	(0,0,0.1)	(0.1,0.3,0.5)	(0,0,0.1)	(0,0,0.1)
EXPERT3							
O	(0.6,0.75,0.9)	(0.6,0.75,0.9)	(0.8,0.9,1.1)	(0.6,0.75,0.9)	(0.8,0.9,1.1)	(0.8,0.9,1.1)	(0.6,0.75,0.9)
S	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.1,0.3,0.5)
D	(0,0,0.1)	(0,0.1,0.2)	(0.5,0.7,0.9)	(0,0.1,0.2)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0,0.1,0.2)
EXPERT4							
O	(0.6,0.75,0.9)	(0.3,0.5,0.7)	(0.6,0.75,0.9	(0.6,0.75,0.9)	(0.6,0.75,0.9	(0.6,0.75,0.9	(0.6,0.75,0.9)
S	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.8,0.9,1.1)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.1,0.3,0.5)
D	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0,0.1,0.2)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,0.9)

After all these procedures the most important part of this study begins that is aggregation data.

The aggregation part of this study builds basics for constructing four operations on fuzzy numbers in a way that makes them a field of numbers. Furthermore, definitions of four main operations addition, subtraction, multiplication, and division have to be introduced in the form suitable for their algorithmization.

Table 31 gives an example of the calculation of a risk factor for only one failure. All other calculations based on this example are given in the appendices in the table form.

Table 31: Aggregation Computation for the FM1 (S) Element

EXPERT	(0,0,0.1,0.2)			W(E1)	0.22	
EXPERT	(0.1,0.3,0.3,0.5)			W(E2)	0.63	
EXPERT	(0.3,0.3,0.5,0.7)			W(E3)	0.09	
EXPERT	(0.1,0.3,0.3,0.5)			W(E4)	0.08	
S(E1&E2)	0.85	$S(\tilde{A},\tilde{B})$=1-1/J$\sum_{i=1}^{J} ai - bi$				
S(E1&E3)	0.58	$S(E1\&E2)$ =1- 1/4× $(0.1 + 0.3 + 0.2 + 0.3)$ =0.85				
S(E1&E4)	0.78					
S(E2&E3)	0.80					
S(E2&E4)	1.00					
S(E3&E4)	0.80					
AA(E1)	0.73	AA(Eu)=1/j-1$\sum_{v=1}^{j} S(\widetilde{Ru},\widetilde{Rv})$				
AA(E2)	0.88	$AA(E2) = \frac{1}{3} \times (0.85 + 0.8 + 1) = 0.88$				
AA(E3)	0.73					
AA(E4)	0.86					
RA(E1)	0.23	$Ra(Eu) =$ AA(Eu)/ $\sum_{u=1}^{j} AA(Eu)$				
RA(E2)	0.27	(0,73)/(0,73+0,88+0,725+0,86)=			0.23	
RA(E3)	0.22					
RA(E4)	0.21					
CC(E1)	0.23	$CCeu = \beta.W(Eu) + (1 - \beta)RA(Eu)\beta$		$\beta = \frac{1}{2}$		
CC(E2)	0.45	1/2(0.22)+1/2(0.23)		0.23		
CC(E3)	0.16					
CC(E4)	0.17					

Aggregation for FM(1) $\tilde{R}ag = CC(E1) \otimes \tilde{R}1 \oplus CC(E2) \otimes \tilde{R}2 \oplus \ldots . \oplus$ $CC(Em) \otimes \tilde{R}m$=0,225 $\otimes$ (0,0,0.1,0.2) $\oplus$ 0,45 $\otimes$ (0.1,0.3,0.3,0.5) $\oplus$ 0,17(0.1,0.3,0.3,0.5)

=(a1,a2,a3,a4)=(0.1085,0.2635,0.286,0.46351)

The last step is defuzzification procedure which the formula is described as follows:

X^{*}=1/3× $(a4 + a3)^{2}$-(a4× $a3)(a1 + a2)^{2}$+(a1× $a2) \div (a4 + a3a2a1)$.

Fuzzyrisk factors were found by applying the defuzzification procedure in Table 32 and RPN numbers were calculated and compared with classical fuzzy.

Table 32: Defuzzified Failure Mode Elements for a Case Study

	FM1	FM2	FM3	FM4	FM5	FM6	FM7
Severity	2.9	3.3	8.7	3.4	3.7	4.2	1.6
Occurrence	8.0	7.5	6.2	10.7	9.1	9.1	8.8
Detection	7.6	1.7	2.9	1.9	3.1	1.9	1.4
Developed RPN	175	43	157	69	103	73	20
Avr RPN	121	113	139	99	191	208	97
Weighting Factor RPN	133	76	144	60	110	81	44

Table 33: Ranking of RPN Numbers

Comparison of RPN	FM1	FM2	FM3	FM4	FM5	FM6	FM7
Developed RPN	175	43	157	69	103	73	20
Avr RPN	121	113	139	99	191	208	97
Weighting Factor RPN	133	76	144	60	110	81	44

At the end of this study 3 type of RPN, numbers were found and the comparison results of these numbers are such as:

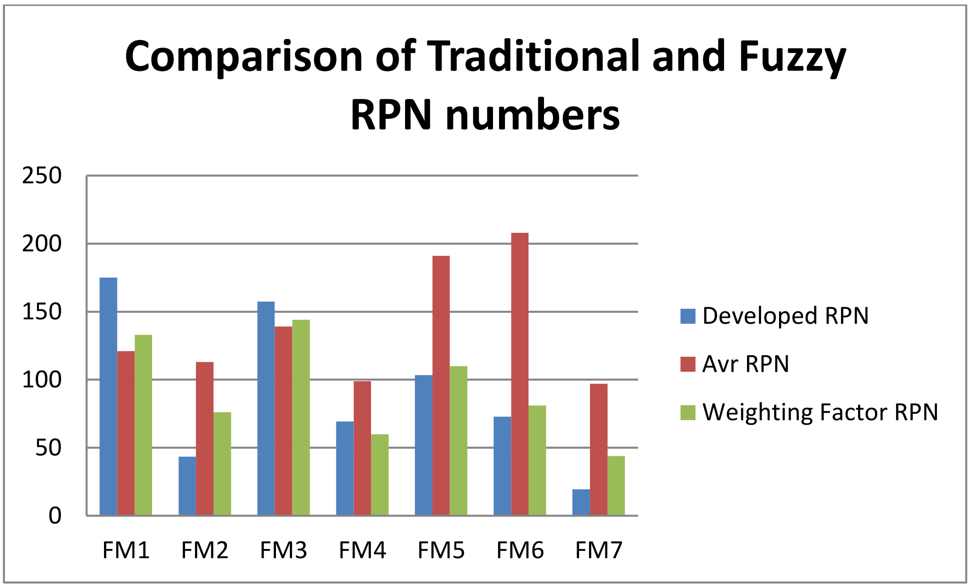

Figure 22: Comparison of Traditional and Fuzzy RPN numbers

As a result of these comparisons, it was seen that the highest fuzzy RPN score belongs to FM1. Accordingly, the most urgent problem that needs to be improved is the first failure.

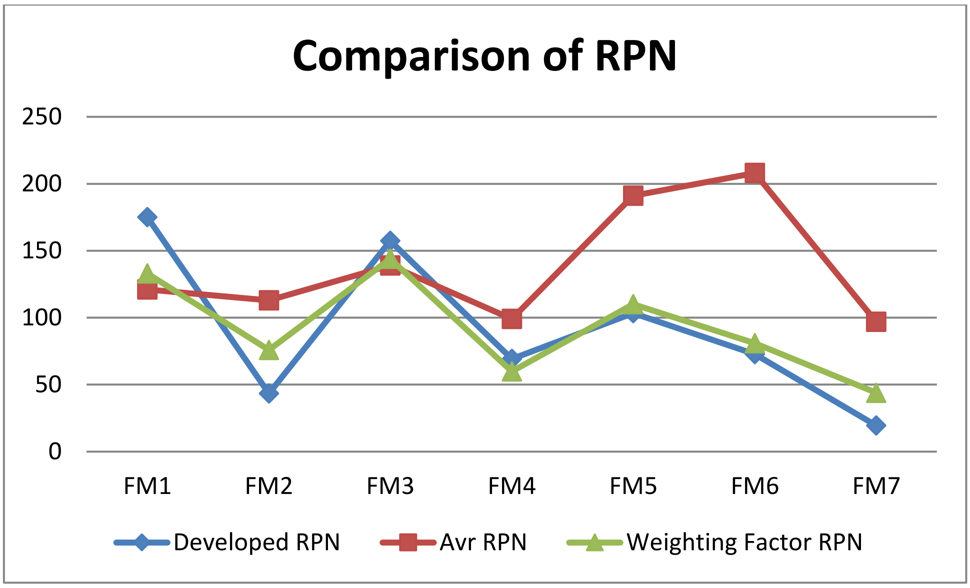

Figure 23: Comparison of RPN numbers by graphically

When we examine RPN numbers in figure 34 we see that the problems numbered 2,5 and 7 improved with defuzzification and aggregation method.

Chapter 5

CONCLUSION

5.1 Study Outcome

FMEA is a specific technique to evaluate a system, design, process for a possible way in which failures (errors, risks problems) might occur. The FMEA will assign requisite corrective actions required to prevent failures from reaching the customer. EFMEA is described in more detail in Chapter 1. A literature review has been made in Chapter 2. The case study discussed in Chapter 4 is explained and finalized with tabulated graphs according to Chapter 3.

During applying the AHP process which is a tool for FMEA 7 failures were reviewed and rated as a result of this work, some RPN numbers were found to be high.

In these 7 failures the highest RPN numbers, calculated according to the risk factors appeared to be the most urgent problems to be improved.

In this study, a model is presented which covers three phases of the risk management process which are: 1. Risk identification, 2. Quantitative risk analysis and 3. Risk response planning. After this, fuzzy FMEA and risk weights for determination of each major risk importance were aggregated. The project risk importance was obtained by fuzzy logic, and finally, the appropriate risk response was chosen. The proposed model was applied by a numerical example and results show that considering these factors altogether in project assessment, entails more exact results. Comparison of failures according to RPN number; RPN NUMBER1 (fuzzy) as ranked as follows:

FM1>FM3>FM5>FM6>FM4>FM2>FM7.

According to this ranking the first problem was determined to be failure 1 and the least important failure is 7, that is the release of carbon emissions from the logistic part in raw material procurement.

Most of the air pollution is caused by vehicles. As the vehicles drive through traffic, they gas heavy metals such as carbonmonoxide, carbondioxide, nitrogen and bullet into the air through the exhaust. To resolve failure number 1, the following healing agents are recommended.

1. Exhaust gas should me made at the time of emission measurement.
2. Maintenance and repair of vehicles should be done in time.
3. Inspection of the vehicles must be done peroidically.
4. Clean fuel should be used.
5. Passengers and cargo should not be carried above vehicle capacities
6. Catalytic converter must be installed in petrol vehicles: Catalytic converter is a steel box-shaped piece that plugs into the exhaust outlet pipe of the car and reduces harmful gas emissions.

5.2 Further Studies

In this section alternatives to risk management and multicriteria evaluation techniques are mentioned.

One of the most popular risk management methods is Lean Six Sigma.

Lean Six Sigma is defined as also Define-Measure-Analyze-Improve-Control (DMAIC).LSS improves service quality. The general difference between FMEA and LSS is application area. Because LSS is generally used service sector and cannot be evaluated by mathematically.

In multi-attribute type of decision making problem, the other alternative techniques will be used such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) .TOPSIS associated relative weights of criterion importance. TOPSIS will be used with FMEA.TOPSIS can be applied to the result of the FMEA technique. It is performed to evaluate the alternative risk criteria.

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APPENDICES

Appendix A: Defuzzification and Aggregation table of Severity Element

SEVERITY	FM1	FM2	FM3	FM4	FM5	FM6	FM7
W(E1)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
W(E2)	0.63	0.63	0.63	0.63	0.63	0.63	0.63
W(E3)	0.09	0.09	0.09	0.10	0.09	0.09	0.09
W(E4)	0.08	0.08	0.08	0.10	0.08	0.08	0.08
S(E1&E2)	0.85	1.00	1.00	0.78	1.00	0.80	0.98
S(E1&E3)	0.58	0.80	0.38	1.00	1.00	1.00	0.78
S(E1&E4)	0.78	1.00	1.00	0.80	0.80	1.00	0.78
S(E2&E3)	0.80	0.80	0.38	0.80	0.80	0.80	0.80
S(E2&E4)	1.00	1.00	1.00	1.00	0.80	0.80	0.80
S(E3&E4)	0.80	0.80	0.38	1.00	1.00	1.00	1.00
AA(E1)	0.71	0.93	0.79	0.86	0.93	0.93	0.84
AA(E2)	0.86	0.93	0.79	0.86	0.87	0.80	0.86
AA(E3)	0.73	0.80	0.38	0.93	0.93	0.93	0.86
AA(E4)	0.86	0.93	0.79	0.93	0.87	0.93	0.86
TOTAL	3.15	3.60	2.75	3.60	3.60	3.60	3.42
RA(E1)	0.22	0.26	0.29	0.24	0.26	0.26	0.25
RA(E2)	0.27	0.26	0.29	0.24	0.24	0.22	0.25
RA(E3)	0.23	0.22	0.14	0.26	0.26	0.26	0.25
RA(E4)	0.27	0.26	0.29	0.26	0.24	0.26	0.25
CC(E1)	0.22	0.24	0.25	0.23	0.24	0.24	0.23
CC(E2)	0.45	0.44	0.46	0.43	0.44	0.43	0.44
CC(E3)	0.16	0.16	0.11	0.18	0.17	0.17	0.17
CC(E4)	0.18	0.17	0.18	0.17	0.16	0.17	0.17

Appendix B: Defuzzification and Aggregation table of Occurrence Element

OCCURRANCE	FM1	FM2	FM3	FM4	FM5	FM6	FM7
W(E1)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
W(E2)	0.63	0.63	0.63	0.63	0.63	0.63	0.63
W(E3)	0.09	0.09	0.09	0.09	0.09	0.09	0.09
W(E4)	0.08	0.08	0.08	0.08	0.08	0.08	0.08
O(E1&E2)	1.18	1.18	1.00	1.18	1.00	1.00	1.00
O(E1&E3)	1.18	1.18	1.43	1.00	1.00	1.00	1.18
O(E1&E4)	1.18	1.00	1.00	1.18	0.80	1.00	1.18
O(E2&E3)	1.00	1.00	1.43	1.00	0.80	1.00	1.18
O(E2&E4)	1.00	1.00	1.00	1.00	0.80	1.18	1.18
O(E3&E4)	1.00	0.75	1.18	1.00	1.00	1.00	1.00
AA(E1)	1.18	1.12	1.14	1.12	0.93	1.00	1.12
AA(E2)	1.06	1.06	1.14	1.06	0.87	1.06	1.12
AA(E3)	1.06	0.98	1.34	1.00	0.93	1.00	1.12
AA(E4)	1.06	0.92	1.06	1.06	0.87	1.06	1.12
TOTAL	4.35	4.07	4.68	4.23	3.60	4.12	4.47
RA(E1)	0.27	0.27	0.24	0.26	0.26	0.24	0.25
RA(E2)	0.24	0.26	0.24	0.25	0.24	0.26	0.25
RA(E3)	0.24	0.24	0.29	0.24	0.26	0.24	0.25
RA(E4)	0.24	0.23	0.23	0.25	0.24	0.26	0.25
CC(E1)	0.25	0.25	0.23	0.24	0.24	0.23	0.24
CC(E2)	0.44	0.45	0.44	0.44	0.44	0.44	0.44
CC(E3)	0.17	0.16	0.19	0.16	0.17	0.17	0.17
CC(E4)	0.16	0.15	0.15	0.17	0.16	0.17	0.17

Apendix C: Defuzzification and Aggregation table of Detectability Element

DETECTABILITY	FM1	FM2	FM3	FM4	FM5	FM6	FM7
W(E1)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
W(E2)	0.63	0.63	0.63	0.63	0.63	0.63	0.63
W(E3)	0.09	0.09	0.09	0.09	0.09	0.09	0.09
W(E4)	0.08	0.08	0.08	0.08	0.08	0.08	0.08
D(E1&E2)	1.20	1.00	1.00	1.00	1.00	1.00	1.00
D(E1&E3)	1.88	0.93	1.68	1.00	1.00	1.00	0.93
D(E1&E4)	1.60	1.00	1.00	0.53	0.80	1.00	0.33
D(E2&E3)	1.68	0.93	1.40	0.80	0.80	0.53	0.93
D(E2&E4)	1.40	1.00	1.00	1.00	0.80	0.53	0.33
D(E3&E4)	1.28	1.60	1.60	1.00	1.00	1.00	1.00
AA(E1)	1.56	0.98	1.23	0.84	0.93	1.00	0.75
AA(E2)	1.43	0.98	1.13	0.93	0.87	0.68	0.75
AA(E3)	1.61	1.15	1.56	0.93	0.93	0.84	0.95
AA(E4)	1.43	1.20	1.20	0.84	0.87	0.84	0.55
TOTAL	6.02	4.30	5.12	3.55	3.60	3.37	3.00
RA(E1)	0.26	0.23	0.24	0.24	0.26	0.30	0.25
RA(E2)	0.24	0.23	0.22	0.26	0.24	0.20	0.25
RA(E3)	0.27	0.27	0.30	0.26	0.26	0.25	0.32
RA(E4)	0.24	0.28	0.23	0.24	0.24	0.25	0.18
CC(E1)	0.24	0.22	0.23	0.23	0.24	0.26	0.24
CC(E2)	0.43	0.43	0.43	0.45	0.44	0.42	0.44
CC(E3)	0.18	0.18	0.20	0.18	0.17	0.17	0.20
CC(E4)	0.16	0.18	0.16	0.16	0.16	0.17	0.13