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A METHOD FOR MANAGING THE RISK: A HYBRID APPROACH TO FMEA

Master's Thesis

ALİ KAAN PASTIRMACI

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I certify that this thesis meets all the requirements as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Barış SELÇUK

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This is to certify that we have read this thesis and that we find it fully adequate in scope, quality and content, as a thesis for the degree of Master of Science.

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ABSTRACT

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Ali Kaan PASTIRMACI

Industrial Engineering Master Program

Supervisor: Asst. Prof. Dr. Ahmet Beşkese

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In today's competitive business world, companies from all sectors are aiming maximum profit with minimum effort. In order to accomplish this goal, companies can ignore or do not give importance to the potential failures that may give devastating harm to their reputation. These potential failure modes do not only endangering the health/safety of workers and their working conditions but also the reputation of the company. Therefore, companies should also take precautions for potential failure mode to fulfill the obligations of occupational health and safety (OHS) and maintain the reputation of the company. OHS concept requires a detailed and renewable risk analysis methodology. A risk analysis methodology that is used for eliminating the risk related to OHS concept should be simple, straightforward and easy to apply. Indeed, a vast majority of these failure modes can be prevented in advance. A risk analysis methodology which is suitable to the characteristic of the company may help. Risk analysis should be applied by experienced and knowledgeable analysts.

In this thesis, one of the most widely used risk analysis methodologies, Failure Mode and Effect Analysis, is proposed. Failure mode and effects analysis is a widely used engineering technique for designing, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the costumer (Schneider & Stamatis 1996). Unfortunately, traditional FMEA methodology has several shortcomings. This work has been planned to eliminate these shortcomings with the help of Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and Grey Relational Analysis (GRA). Fuzzy AHP method is used to determine the importance weights for Decision Makers (DMs) and to calculate the criteria weights of decision factors both for First Risk Priority Number (RPN1) and Second Risk Priority Number (RPN2). RPN1 is calculated by using decision factors, occurrence, severity and detectability (O, S and D) with the help of GRA methodology. According to RPN1 values, FMEA team prioritizes the failure modes and determines the proper corrective actions. The team also determines the threshold intervals for corrective actions to make the work more realistic. Then, RPN2 is calculated by means of five additional decision factors (criteria). Criteria consider the cost, time, regulatory obligations, prevention policy of company, and reputation of company. Thanks to RPN2, a contribution to the literature is made. After that, RPN3 is obtained from the summation of RPN1 and RPN2 that are multiplied with their corresponding coefficients. Finally, FMEA team reprioritizes the corrective actions according to RPN3 values and the corrective actions are performed according to this prioritization.

To demonstrate the effectiveness of the proposed methodology, a case study is applied in a yarn manufacturing company from Turkey.

Keywords: Risk Analysis, Occupational Health and Safety, FMEA, GRA, fuzzy AHP.

ÖZET

RİSK YÖNETİMİ İÇİN BİR YÖNTEM: HTEA'NE HİBRİT BİR YAKLAŞIM

Ali Kaan PASTIRMACI

Endüstri Mühendisliği Yüksek Lisans Programı

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Günümüz rekabetçi iş dünyasında, tüm sektörlerdeki şirketler en az çaba ile en fazla karı elde etmeyi hedeflemektedirler. Bu gayelerini gerçekleştirebilmek için şirketin itibarına önemli derecede zarar verebilecek olan potansiyel hataları ya görmezden gelirler ya da önem vermezler. Bu potansiyel hata türleri sadece işçilerin sağlığını/güvenliğini ve çalışma ortamlarını tehlikeye atmakla kalmayıp, şirketin itibarını da tehlikeye atmaktadırlar. Bu yüzden, şirketler, iş sağlığı ve güvenliliğinin gereklerini yapabilmek için ve de şirketin itibarını devam ettirebilmek için potansiyel hata türleri için önleyici tedbirleri almalıdırlar. İSG hususu, detaylı ve yenilenebilir bir risk analizi metodolojisi gerektirir. İSG hususu ile ilgili riskleri gidermek için kullanılacak risk analiz metodolojisi, basit anlaşılır ve uygulaması kolay olmalıdır. Aslında bu hata türlerinin çok büyük bir bölümü önceden engellenebilecektir. Şirketlerin karakteristik özelliklerine uygun risk analiz yöntemi bu konuda yardımcı olabilir. Risk analizi tecrübeli ve bilgili analistler tarafından yapılmalıdır.

Bu tez, çok geniş kullanıma sahip olan bir risk analiz yöntemi olan Hata Türü ve Etkileri Analizi (HTEA) öne sürmektedir. Hata türü ve etkileri analizi, potansiyel hata türlerini, problemleri, aksaklıkları, benzerlerini sistem, tasarım, süreç ve/veya servis üzerinden müşteriye ulaşmadan önce tasarlayan, tanımlayan ve ortadan kaldıran çok geniş kullanıma sahip bir mühendislik tekniğidir (Schneider & Stamatis 1996). Ne yazık ki, geleneksel HTEA metodolojisi birçok eksikliği içermektedir. Bu çalışma, Bulanık Analitik Hiyerarşi Proses (Bulanık AHP) ve Gri İlişkisel Analiz (GİA) yardımıyla bu eksiklikleri gidermeyi planlamıştır. Bulanık AHP, Karar Vericilere önem ağırlıkları vermek ve de birinci risk öncelik sayısının (RÖS1) ve ikinci risk öncelik sayısının (RÖS2) karar faktörlerini ağırlıklandırmak amacıyla kullanılmıştır. RÖS1, karar faktörlerini (ortaya çıkma durumu, şiddet, tespit edilebilirlik) kullanarak ve GİA yardımıyla hesaplanır. RÖS1 değerlerine göre HTEA takımı hata türlerini önceliklendirir ve bunlara uygun düzeltici faaliyetleri belirler. Takım ayrıca yapılan çalışmanın daha gerçekçi olabilmesi için sıralanan bu düzeltici faaliyetler için eşik sayısı belirler. Sonrasında RÖS2 beş ek karar faktörleri (kriterler) ile hesaplanır. Kriterler, maliyeti, zamanı, kanuni gereklilikleri, işçilerin sağlığını/güvenliğini, ürünün/servisin kalite artırımını, müşteri memnuniyetini ve şirketin itibarını değerlendirmektedir. RÖS2 sayesinde, literatüre katkı yapılmıştır. Daha sonar RÖS3 değeri, uygun katsayılarla çarpılmış olan RÖ1 ve RÖS2 nin toplamıyla elde

edilir. Son olarak takım, düzeltici faaliyetleri RÖS3 değerlerine göre tekrardan önceliklendirir ve düzeltici faaliyetleri bu sıraya göre gerçekleştirir.

Öne sürülen bu metodolojinin etkinliği ispat edebilmek için Türkiye'den bir iplik üretim şirketinde örnek çalışma gerçekleştirilmiştir.

Anahtar Kelimeler: Risk Analizi, İş Sağlığı ve Güvenliği, HTEA, GİA, Bulanık AHP.

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

AHP	:	Analytical Hierarchy Process
ANP	:	Analytical Network Process
CF	:	Cause of failure
CA.	:	Corrective action
DEA	:	Data Envelopment Analysis
DF	:	Decision factor
DM	:	Decision Maker
D	:	Detectability
ETA	:	Event Tree Analysis
ER	:	Evidential Reasoning
FE	:	Failure effects
FM	:	Failure mode
FMEA		Failure Mode and Effects Analysis
FMECA	:	Failure Mode, Effects and Criticality Analysis
FTA	:	Fault Tree Analysis
FRPN	:	Fuzzy Risk Priority Number
CA.1	:	First corrective action
RPN1	:	First Risk Priority Number
GRA	:	Grey Relational Analysis
HAZOP	:	Hazard and operability Analysis
JSA	:	Job Safety Analysis
MIL-STD	:	Military Standard
MCDM	:	Multiple Criteria Decision Making
O	:	Occurrence
OHS	:	Occupational Health and Safety
PHA	:	Process Hazard Analysis
RPN	:	Risk Priority Number
RPN2	:	Second Risk Priority Number
S	:	Severity
RPN3	:	Third Risk Priority Number
TFN	:	Triangular Fuzzy Number

SYMBOLS

Piarwise comparision matrix that established by decision maker k	:	A_k
TFN that demonstrates the comparison of criteria	:	a_{ij}
Fuzzy multiplication	:	$\otimes$
Geometric mean of fuzzy comparison value of criterion i to each criterion	:	r_i
Fuzzy weight of criterion I	:	w_i
A crisp weight number	:	w_r
Comparative series	:	$X_i(k)$
Standard series	:	$X_0(k)$
Differences between comparative series and standard series	:	$\Delta_i(k)$
Grey relational coefficient	:	Γ
An identifier coefficient	:	ζ
The weighting coefficient of the risk factors (O, S, and D)	:	B
RPN1 coefficient	:	ρ_1
RPN2 coefficient	:	ρ_2
Degree of grey relation	:	τ_i

1. INTRODUCTION

1.1 MOTIVATION OF THE RESEARCH

All companies want to make maximum profit with minimal capital, minimum number of workers and without any accident or event that hinder the process. Unfortunately, it is not possible in the normal condition. Risk and uncertainty are associated with all projects undertaken by individuals and organizations, regardless of their size, nature, and place of execution (Abdelgawad et al. 2010). Instead of trying to deal with a problem that is appeared, it makes more sense to apply an effective risk analysis methodology. Although there are so many methodologies about risk management, each of them has some limitations together with their advantages. Risk analysis methodology should be applied by talented and experienced experts. Experts should also have detailed information about the process so they can determine the most appropriate risk analysis method.

One of the most widely used risk analysis method is Failure Mode and Effects Analysis FMEA. Failure mode and effects analysis is a widely used engineering technique for designing, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the costumer (Schneider & Stamatis 1996). In this method, the failure modes are identified and ranked with help of Risk Priority Number (RPN) by FMEA team. RPN is the product of occurrence (O), severity (S) and detection (D) of failures. That is, RPN = O*S*D (Yang et al. 2011). Based on RPNs, corrective actions of failure modes are prioritized and then proper corrective actions are performed by responsible person.

FMEA is chosen because it can be applied in all workplaces and from all sectors. In detail, FMEA is the only risk analysis methodology that considers detectability of failure modes. In this study, occupational health and safety requirement, risk analyzing, is fulfilled with the help of FMEA because of its decision factors and detectability property.

Despite the effectiveness of the method, calculations of RPNs have been criticized for many reasons because the crisp RPN calculation method shows some important weaknesses when FMEA is applied in the real-world cases (Liu et al. 2013). A List of these shortcomings is stated in the second section of the research. There are significant efforts which have been made in FMEA literature to overcome the shortcomings of the traditional RPN. Several new approaches have been made. Fuzzy approach, Multiple Criteria Decision Making (MCDM) technique, group-based evidential reasoning (ER), DEA/ Fuzzy DEA, ANP/AHP, Grey theory, Cost based model are most used approaches. A detailed literature review that contains more approach is stated in the second part of this study.

Traditional FMEA is basic and practical risk analysis methodology. It is easy to renew traditional FMEA application. Although firms and experts want to apply FMEA or another risk analysis methodology in a short time period and with minimum cost, the proven effects of the shortcomings of traditional RPN calculation force experts to make contribution to the current methodology. In this research, firstly decision makers and decision factors (severity, occurrence and detectability) will be weighted with the help of Fuzzy Analytical Hierarchy Process (FAHP). Secondly, Grey Relational Analysis (multi criteria decision making method) is used to calculate and determine the proper first risk priority numbers (RPN1) for failure modes. RPN1 values are used for prioritizing the corrective actions of corresponding failure modes. GRA is mainly used to incorporate the weights of decision factors to RPN1 calculation. Then, RPN2 is calculated. RPN2 is derived from the need for reprioritization of corrective actions. Even though failure modes are prioritized with the help of Fuzzy AHP and GRA methodologies, it is not enough to perform the corresponding corrective actions. Additional five criteria are added to calculate RPN2. By multiplying criteria’s scores with their weights and then the summation of all five, RPN2 value is calculated. In the last step, RPN3 values are calculated. RPN1 and RPN2 values are multiplied with their different coefficients and then summation of these two RPN gives us RPN3. Reprioritization is done based on RPN3 and the corrective actions are performed according to this reprioritization. A threshold interval values should be determined by decision makers because firms have several limitations such as cost, time, and capacity of workers.

The point that makes this research different is fact of the new approach to FMEA. This approach gives importance to what the corrective action is in essence. In this study, FMEA is performed to overcome occupational health and safety drawbacks in the workplace. FMEA should be applied by employees of company. According to their education level, experience, job relevance, risk analyzing test result, and experiences on risk analysis methodology (repetition number of risk analysis methodology), these employees, decision makers, are given weights. Traditional RPN, in this study RPN1, is calculated by using three decision factors O, S and D. These three decision factors have equally importance in the traditional RPN calculation but in this research, fuzzy AHP is used to determine reasonable weights for them. Detailed explanations of these methods are stated in the third part of this research.

1.2 RESEARCH OBJECTIVES

The objectives of this research are as follows:

i. To understand risk analysis, occupational health and safety (OHS) concept.
ii. Review of FMEA researches, new calculation approaches of RPNs.
iii. Review of fuzzy approaches and grey relational analysis used in FMEA application.
iv. To introduce the most common FMEA application of which can be used in wide range of working condition.
v. To obtain more realistic corrective actions and prioritization of corrective actions with the help of RPN2.
vi. To obtain more realistic applicability of corrective action by means of threshold interval values.
vii. To weight decision makers and decision factors with the help of prepared criteria charts.
viii. To apply more consistent and reasonable FMEA application with the help of weighted decision factors and decision makers.
ix. To generate a FMEA application that is easy to make and renew periodically.
x. Quality and reputation contribution to the literature by means of RPN2 which considers the corrective actions in detail.
xi. To take the corrective actions into action which satisfies customer’s demands?
xii. To calculate all calculations in this proposed method faster and to spend little

time consumption, thanks to excel templates.

1.3 THESIS ORGANIZATION

In this study, the fuzzy AHP approach is adopted to determine the weights of decision factors (both for RPN1 and RPN2) and decision makers. Then, the optimization and the calculation of RPN1s are made by using grey relational analysis. After that, the RPN2 values are calculated by means of five additional criteria. RPN2 considers the real life needs and the feasibility of corrective actions. Finally, RPN3s are calculated and the reprioritization is made based on these values.

This thesis is organized as follows:
In section II literature review is presented. A brief information is presented about risk, risk analysis, risk analysis methodologies. Then, reasons for choosing FMEA as a risk analysis methodology are explained. Another subheading of section II is occupational health and safety (OHS). This topic clarifies the contribution to OHS with the help of weighted corrective actions. Fuzzy approaches and grey relational analysis adoption to FMEA are also stated in section II.

In section III, the proposed methodology is explained. Detailed information about Fuzzy AHP, GRA, and proposed method are presented step by step.

In section IV, a case study is presented. A yarn manufacturing company from Turkey is used. The case study considers the requirements of the company's OHS concept. Thus, the proposed FMEA methodology is used to meet the OHS needs of the company.

The thesis ends with a discussion and conclusion given in section V.

2. LITERATURE REVIEW

2.1 RISK ANALYSIS AND OCCUPATIONAL HEALTH AND SAFETY

2.1.1 Risk Assessment and Risk Analysis

In today's competitive world, a firm's success does not only depend on its performance, but also many other factors, contributing this process. One of these factors is risk management. In engineering contexts, risk is often linked to the expected loss so that a proper risk management process should be applied by the firms (Lirer et al. 2001).

Risk is defined in many ways. More common definitions are below:

i. Risk is the measure of the probability and severity of adverse effects.
ii. Risk is the combination of probability of an event and its consequences.
iii. Risk refers to uncertainty of outcome, of actions and events.
iv. Risk is a situation or event where something of human value (including human themselves) is at stake and where the outcome is uncertain.
v. Risk is an uncertain consequences of an event or an activity with respect to something that humans value.
vi. Risk is equal to the two-dimensional combination of events/consequences and associated uncertainties.
vii. Risk is uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value (Aven 2010).
viii. A risk is a future event that may or may not occur.
ix. A risk must also be an uncertain event or condition that, if it occurs, has an effect on, at least, one of the project objectives, such as scope, schedule, cost or quality.
x. The impact or consequence of the future event must be unexpected or unplanned (Nieto-Morote & Ruz-Vila 2011).

People talk about risk when there is the chance, but not the certainty, that something they don't want may happen (Covello & Merkhoher 1993). As to these definitions, risk is usually an undesirable and uncertain event. Nowadays, to protect firms from encountering unexpected situations, systematic well-designed precautions are taken by experts.

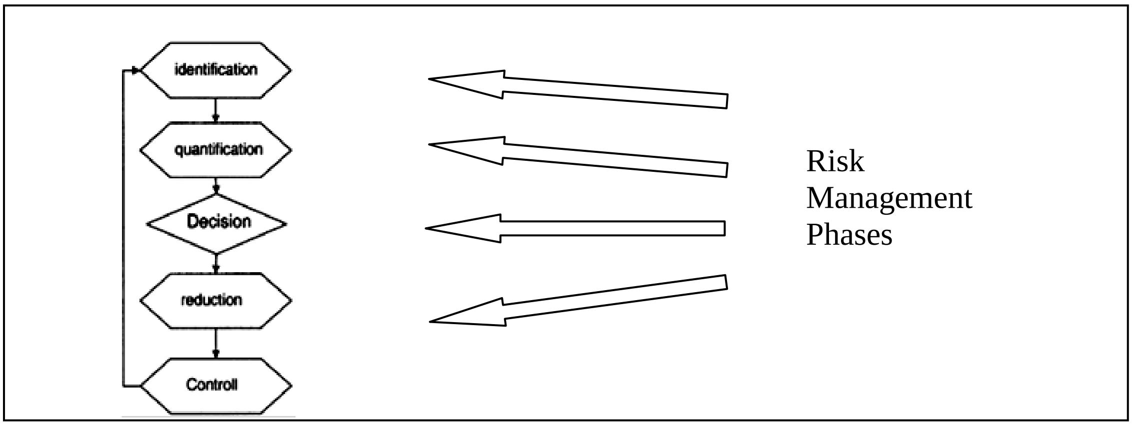
To reduce the effects of the risks, risk management and risk assessment strategies should be applied by the firms. Size of the firm is not the decision factor while experts are considering the risk analysis necessity. The scope of the risk analysis application is normally less detailed in small sized firms.

Risk management is the identification, assessment, prioritization of risks and finally eliminating them. Risk assessment provides a mechanism for identifying which risks represent opportunities and which represent potential pitfalls. If the risk assessment performed right, a risk assessment provides organizations a clear view of variables of which they may be exposed. Thus, it is really crucial for the organizations to determine the right and proper risk assessment methodology.

Firstly, a detailed risk management plan is prepared by experts. After risk management plan proper risk assessment methodology should be applied by experts.
Risk management is divided into four phases:

a. Identification
b. Quantification
c. Decision
d. Reduction and Control (Ale 2002)

Figure 2.1: Risk management phases



Source: Ale 2002

Risk assessment process is crucial for the firms at least profit performance. Some unheeded risky activities may cause huge damage and loss. Risk assessment includes both risk estimation (identifying hazard and estimating their outcomes and probabilities) and risk evaluation (determining the significance or value of risks to those concerned with or affected by the decision). Risk estimation is about situations, and risk evaluation about the effect on people (Cohen 1984). When experts are estimating, evaluating risks or deciding the risk assessment methodology, there should be some criteria about firm. For instance, firm’s old data and attendance of workers should be considered while experts are analyzing the risks. Moreover, experts should have ability on risk assessment. In addition, experiences and education level of experts who know the firm’s operational goal are also crucial for this process.

Many risk assessment methodologies are applied by the firms. Some of them are required an experienced team others do not require. Moreover, some of them are suitable for comprehensive risk analysis and need for long time for application. Comparisons of these methodologies can help decision makers to choose the most appropriate methodology. Table 2.1 shows the comparisons of mostly used risk analysis methodologies.

Table 2.1: Risk assessment methodologies comparison

Criteria / Risk Assessment Type	Short Description & Advantages of Method	Experience of Team Leader & Teamwork	Quantitative or Qualitative & Need For Documentation	Appropriate Business Sector	The Success Rate of Application
What if?	A structured brainstorming method of determining what thing can go wrong and judging the likelihood and consequences of those situation occurring.	Mid-level experience & Can be done by an analyst	Qualitative & Very little	Simple procedure works	Not enough alone while the analyst determining the risks. Success of application is based on team leader's success and experience.
PHA	A risk analysis that is performed to identify all potential hazard and accidental event, rank them according to their severity and finally identify required hazard controls and follow-up actions.	Mid-level experience & Can be done by an analyst	Qualitative & Medium	Fits all sectors	Not enough alone while the analyst determining the risks. Success of application is based on team leader's success and experience.
JSA	The JSA is very effective tool for helping to reduce incidents, accidents, and injuries in the workplace.	So much experience & Teamwork	Qualitative & Too much	Oil and gas industry	It is an excellent tool if it is used during new employee orientations and training and also can be used to investigate “near misses” and accidents..
Checklist	A type of informational job that helps to reduce failure by compensating for potential limits of human memory and attention.	Mid-level experience & Teamwork	Qualitative & Medium	Fits all sectors	Success proportion is based on the checklist preparation.
HAZOP	The basic principle of HAZOP is to have full process description and to ask in each node what deviations to the design purpose can occur, what causes produce them, and what consequences can be presented.	So much experience & Teamwork	Qualitative & Too much	Chemical industry	This method is quite tough one to apply and need for high level of experience and performance of the team.
FMEA/FMECA	Failure mode and effects analysis is a widely used engineering technique for designing, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the costumer.	So much experience & Teamwork	Can be both of them & Too much	Fits all sectors	If done by experienced analysts, the success rate increases.

Criteria / Risk Assessment Type	Short Description & Advantages of Method	Experience of Team Leader & Teamwork	Quantitative or Qualitative & Need For Documentation	Appropriate Business Sector	The Success Rate of Application
Safety audit	Safety audit is a systematic and independent examination to determine whether activities and related results conform to planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve the organization' policy and objectives.	Mid-level experience & Can be done by an analyst	Qualitative & Very little	Fits all sectors	Not enough alone while the analyst determining the risks. Success of application is based on team leader's success and experience.
FTA	A systematic safety analysis tool that proceeds deductively from the occurrence of accident to the identification of the failure cause or accident cause of that event.	So much Experience & Teamwork	Can be both of them & Too much	Fits all sectors	This method needs for high level of experience and performance of the team. FTA is very effective method for determining the risks.
ETA	ETA is an established risk analysis tool to assess likelihood of an accident. The aim of this technique to estimate the likelihood of event that often missing with the help of collected data.	So much experience & Teamwork	Can be both of them & Too much	Fits all sectors	This method needs for high level of experience and performance of the team. Eta is very effective method for determining the risks.
L -type matrix	L-type matrix is based on cause and effect relationship. It a simple and can be done quickly.	Mid-level experience & Can be done by an analyst	Qualitative & Very little	Simple procedure works	This method can be applied for simple procedure and urgent works. Success of application is based on team leader's success and experience.
X-type matrix	This technique makes a research on accidents that have occurred in the past in the workplace. It also considers the corrective actions' cost.	So much experience & Teamwork	Qualitative & Too much	Fits all sectors	This method can be applied for all works. Success of application is based on team leader's success and experience.
Cause-effect analysis	This diagram based technique, which depend on brainstorming, pushes you to consider all possible causes of a problem, rather than just ones that are most obvious.	So much experience & Teamwork	Can be both of them & Too much	Fits all sectors, especially chemical industry	This method needs for high level of experience and performance of the team. Cause-effect analysis is very effective method for determining the risks.

Source: Özkılıç 2005, Diberardinis 1998, Ferdous et al. 2009 and Gharahasanlou 2014

2.1.2 Occupational Health and Safety (OHS)

Every morning in Africa, a Gazelle wakes up. It knows it must run faster than the fastest lion or it will be killed. Every morning a Lion wakes up. It knows it must outrun the slowest Gazelle or it will starve to death. It doesn't matter whether you are a Lion or a Gazelle.

Nowadays, as implied in the fable above, companies may lose everything just because of instant error. Financial losses can be compensated by means of extra effort. In particular, it is really hard to provide former prestige if the company makes a mistake regarding with safety (of product, process), health of workers or any other mistake that can harm to reputation of company. Companies aim to get maximum profit by spending minimum money. Reputable and long-term companies not only focus on making money but also some other institutionalization requirements. One of the most important considerations in this regard is occupational health and safety activities. It is meaningless to see the OHS activities as a procedure that the law obligates. Attention to OHS in the construction industry has increased dramatically over the past decades. The time for OHS awareness has arrived and that OHS is no luxury, it is a necessity (Geminiani et al. 2013).

OHS is similar to health insurance. For instance, a person does not need to make health insurance because he/she feels good. Unluckily, he/she is 65 years old. It means that a risky situation is present because of his/her age. If this person faced with health problem that requires a lot of money means that he/she has not much chance surviving. If he/she had insurance, insurance company pays the treatment cost. OHS activities are so similar to that situation. If a boss ignores some potential failures due to financial burden or apply OHS activities just on paper, he/she will most likely to encounter an excess losses, health problems of workers and/or reputation loss.

Another benefit of OHS is that OHS makes workers feel comfortable while they are working. Workers give an instinctive reaction by means of good working conditions. For instance, think about a baby. If a baby lives in clean, warm and relaxing condition and the baby food is of good in quality and also if the parents take preventative measure to reduce the likelihood of any accident (for example, the parent provide something that prevents baby from reaching the stove or provide safe electrical outlets) the baby would be feel happy and his/her behavior will show this happiness to the parents. This example is compatible with OHS activities. If the boss provides workers a working environment where all safety measures and personal protective equipment are provided besides of good quality food then workers concentrate on their job and feel confidence about the company.

In Turkey, firms had not fulfilled the occupational health and safety essentials until the recent years. After establishment of National Occupational Health and Safety Council, some radical changes made thanks to governmental sanctions (Karabulut 2012). In 2006, council prepared the "National Occupational Health and Safety Policy" and determined the action plan. Table 2.2 contains requirements of plan.

Table 2.2: An action plan made by National Occupational Health and Safety Council (2006-2008)

Targeted Issue	Fulfillment Status
Putting the occupational health and safety law that compatible with EU norms.	X
To apply occupational health and safety regulations to all employees.	X
Occupational health and safety regulations will be extended to all sectors.	X
Occupational health and safety services would be more efficient units.	X
The number of occupational accidents will be reduced by at least 20 percent.	X
Occupational disease diagnosis system will be developed.	X
Thanks to the technical support services that carried out by public, health and safety status of people will be increased by 20 percent.	X

Source: Karabulut 2012

Two-year action plan (2006-2008) could not be realized as we see in Table 2.2 because the government did not put law about OHS. Furthermore, no occupational disease diagnosis system had been developed. Thus, the number of occupational accidents was not reduced by at least 20 percent (Karabulut 2012).

A four-year action plan was held by Ministry of Labour and Social Security (2009-2013). Table 2.3 contains requirements of plan.

Table 2.3: An action plan made by Ministry of Labour and Social Security (2009-2013)

Targeted Issue	Fulfillment Status
Providing the occupational health and safety law come into force and completion of the relevant legislation.	✓
To ensure the implementation of the new legislation giving the information to the interested groups and the public.	✓
Increasing the number of the employees who work in OHS laboratory by 20 percent.	✓
Increasing the detecting of occupational disease by 500 percent.	X
The number of occupational accidents will be reduced by at least 20 percent.	X
Increasing the number of projects, education and publicity that related to OHS by 20 percent.	✓

Source: Karabulut 2012

As presented in Table 2.3, the detailed law come into force but can be partially fulfilled by companies. On this subject, Turkey is in the transition period. More clearly, although there is a law in force, most of the small workshops cannot meet the obligations of the law yet. Government noticed this case and extended the law's obligation due time to a later date. During this time interval, numerous education program, publicity activities and projects related OHS are provided. Turkey shows development about the OHS necessity. Companies began to employ OHS specialist who is suitable for their job and law requirements. Three levels (class-A, class-B and class-C) are available for specialist in Turkey. There are some criteria that determine danger level of work process. Companies should employ suitable class specialist considering the danger level of work process.

It is impossible to apply a risk analysis method that fits to all work process because danger level of work process, materials used in this process, working place, working hours and other criteria affects the risk analysis method.

A detailed and renewable risk analysis which is compatible with the current business process provides convenience to the company to impose OHS. One of the fundamental steps of OHS is risk analyzing. There are many risk analysis method in the literature as mentioned in the above. With few additions, FMEA methodology can help OHS specialists to make risk analysis of their responsible work process. FMEA considers the possibility, severity and detectability of failure modes. These decision factors help risk analysts to evaluate risks more consistently. Especially the decision factor of detectability makes the FMEA differ from the other risk analysis methodologies. Detectability plays important role while identifying the risks so that this factor helps us in OHS concept. FMEA also provides experts to take corrective actions for failure modes, in addition to identify responsible person.

As presented above, risk management requires identification, quantification, decision, reduction and control. In table 2.4 the reasons for applying FMEA as a necessity of OHS and risk management methodology are explained by comparing these two concepts.

Table 2.4: The reasons for applying FMEA as a risk management methodology

Risk Management	FMEA
Introduction	Identifying the failure modes
Quantification	RPN calculation.
Decision	Deciding to corrective actions
Reduction	Corrective actions
Control	Determining control period of eliminated failure modes

In table 2.4, it is presented that the steps of risk management are parallel with FMEA. In this research, additional steps are added for deciding on the corrective actions. One of these steps is the calculation of RPN2 values. RPN2 values mostly consider occupational health and safety concept with the help of additional five decision criteria. By considering these criteria and then adding RPN2 values to the calculation of final RPN values (RPN3), the requirements of OHS concept are met.

2.2 REVIEW OF MODELS

2.2.1 Failure Mode and Effects Analysis (FMEA)

Companies aim to make profit without spending a lot of money. All works that companies carry out should be completed without any occupational accident, machine breakdown or anything that hinder the process. Unfortunately, in real life, this is just a dream. There cannot be a perfect worker, so it is normal to encounter with failure modes. In fact, it is normal that failure modes are under the determined limits. At this point, talented and experienced experts or occupational health and safety specialists should determine the failure modes by means of previous year's data, foreman's', workers' and their own experiences. Failure mode and effects analysis (FMEA) methodology helps experts to see failure modes visually and make risk analysis easily. FMEA is used to anticipate and mitigate risk (Cody 2006). Failure mode and effects analysis is intended to provide information for making risk management decisions (Pillay & Wang 2003).

While the FMEA team is applying FMEA as a risk analysis methodology they should be aware of several definitions. These definitions are presented below:

FMEA team: FMEA team should be formed up three or more people. The team members should be experienced persons. They should have been active in FMEA or another risk analysis methodology. His/her education level and knowledge on the FMEA are other important criterion.

Failure mode: Failure mode is the failure that hinders process success. It describes what could go wrong in the process. A failure mode can be the result of another failure mode. On the other hand, a failure mode can be the cause of another failure. It is crucial that the FMEA team have to identify all potential failure modes that may hinder the process.

Potential failure effect: Potential failure effect can be defined by answering to this question: How does the failure affect the function of the step? Usually, failure affects customers. Customers may be the internal customer or the last user of the product. Team should consider the customer's situation and determine the potential failure effect properly.

Cause of failure: It is inevitable that all failure modes have root cause or reason. When the team determines the causes of failure, this process can save time effectively. If the cause of failure affects the failure mode in a special way, the team should eliminate the cause directly. Therefore, there is no need to maintain successive FMEA steps for this failure mode.

Severity: If a failure were to occur, what effect would that failure have on the product quality and on the customer (if any)?

Probability (of occurrence): How likely is it for a particular failure to occur? (Kahraman et al. 2013).

Detectability: Chance of detection of failure mode before it causes an accident.

RPN: The three values of severity, frequency and detectability of each potential failure are multiplied, forming a risk priority number (RPN) (Sant'Anna 2012).

Corrective action: All failure modes should have corrective actions. Corrective actions are performed as to the RPN values. In traditional RPN calculation, RPN value can take on values between 1-1000. The prioritization is made as to these values. The bigger RPN value implies that the higher priority of corrective actions should be performed.

Responsible: A person who is responsible for performing the corresponding corrective action. Responsibility can be given to a group of people.

Due time (Target completion date): Due time is the last day to perform the corrective action completely.

Next control time/ control period: FMEA should be applied periodically even if there is no undesirable risky event occurred or nearly occurred. Thus, the next control time or control period of the current failure mode should be determined by FMEA team.

The main objective of FMEA is to identify the potential failure modes, evaluate the causes and effects of different component failure modes, and determine what the chance of failure could eliminate and reduce. FMEA allows the analysts to identify and prevent known and potential problems from reaching the customer (Liu et al. 2011).

The first work in establishing a procedure for performing FMEA was created by the U.S. military in 1949. In the early 1960s, the U.S. military established a military standard (MIL-STD-1629a) for systematically evaluating the potential impact of functional or hardware failures on mission success, system performance, maintainability, and maintenance requirements. In the early 1980s, the automotive industry began to incorporate FMEA into the product development process (Abdelrahman & Abdelgawad 2011). In 1993, firms created FMEA to meet the requirement of QS-9000 (Chang et al. 2013). Nowadays, FMEA is a method applied in various industries such as the machinery, medical, aviation, automotive, food industry, OHS.

A careful construction of decision factors' scales should be formed. Scale of values from 1 to 10 is for the classification of events involving possible causes and effects of failures from three independent points of view: severity, frequency (occurrence) and detectability of the event. Sample scales are represented in Figure 2.2**.** Traditional FMEA works by a series of successive steps. To understand FMEA steps more clearly, whole FMEA application can be divided into several steps as shown in Figure 2.3.

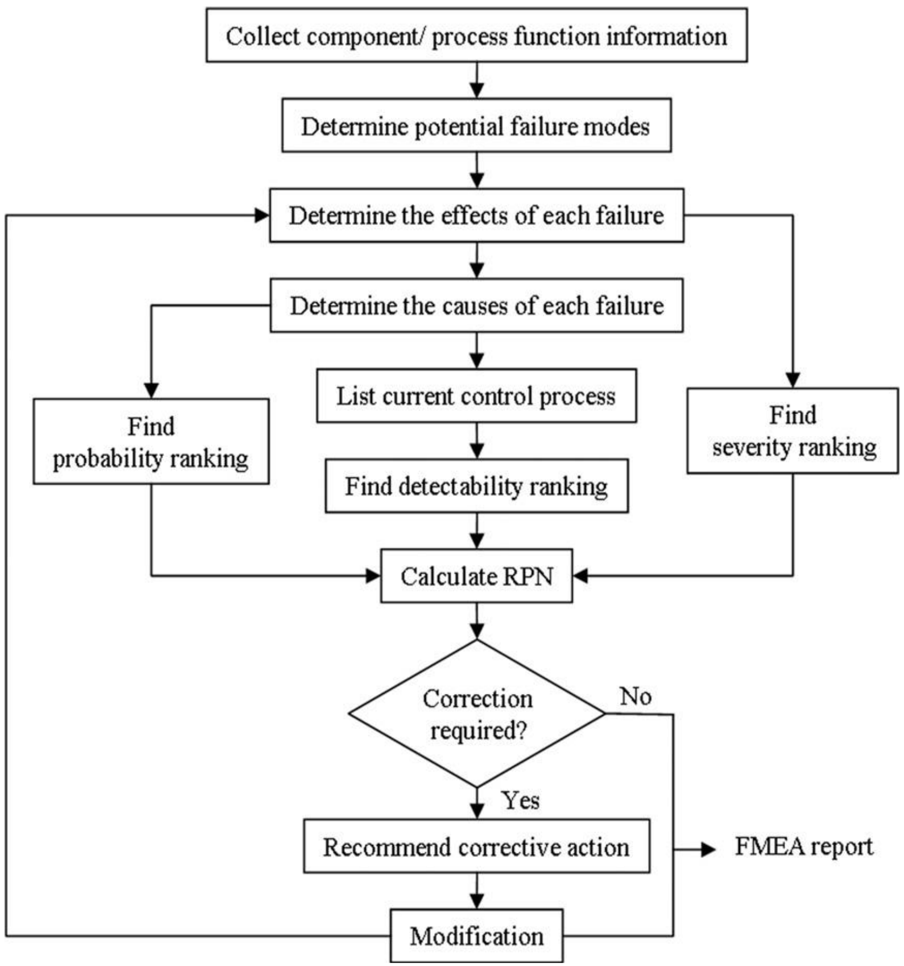
Figure 2.2 Sample 10 point scales for Occurrence, Severity, and Detectability

Definition of occurrence of failure mode	(O)	Definition of detection of failure mode	(D)	Definition of severity of failure mode	Consequence of failure mode with this severity	(S)
Negligible	1	Certainly	1	Dangerously high	People can get severely wounded	10
Very low	2	Very likely	2	Extremely high	Fail does no longer meet legal rules	9
Low	3	Likely	3	Very high	Customer end up with faulty report/product	8
Occasionally	4	More than average	4	High	Rejection of produced products	7
Now and then	5	Average	5	Moderate	Long delay in process due to carrying out repairs	6
Regularly	6	Low	6	Low	Moderate delay in process	5
Very regularly	7	Very low	7	Very low	Short delay in process	4
Often	8	Unlikely	8	Extremely low	Extra effort to produce, no delay	3
Very often	9	Very unlikely	9	Almost none	Failure not noticed; little effect	2
Extremely often	10	Excluded	10	None	Unnoticed; no relevant effect	1

Source: Barends et al 2012

The importance and the meaning of the scores change according to the structure of company and also expectations of customer (Sofyalıoğlu & Öztürk 2012). By using these 10-point scales, experts give score to the each decision factors. After that, RPN values of each failure modes are calculated by multiplying these three. As the RPNs increase, risk of failure modes increase too. Experts then determine the proper corrective actions and follow these actions. The FMEA application should be done in periods after the corrective actions are performed and new RPNs should be calculated for current failure modes again. Here is the graphical presentation and list of the FMEA steps shown in Figure 2.3.

Figure 2.3 FMEA application process



1. Develop a good understanding of what the system is supposed to do when it is operating properly.
2. Divide the system into sub-systems and/or assemblies in order to localize the search for components.
3. Use blue prints, schematics and flow chart to identify components and relations among components.
4. Develop a complete component list for each assembly.
5. Identify operational and environmental stresses that can affect the system. Consider how these stresses might affect the performance of individual components.
6. Determine failure modes of each component and the effects of failure modes on assemblies, sub-systems, and entire system.
7. Categorize the hazard level (severity) of each failure mode.
8. Estimate the probability.
9. Estimate the detectability.
10. Calculate the risk priority number (RPN).
11. Determine if action needs to be taken depending on the RPN.
12. Develop recommendations to enhance the system performance.
13. Prepare FMEA report by summarizing the analysis.

Source:(Liu et al. 2011)

One of the beneficial aspects of the FMEA that makes it widely accepted is the group dynamic in which personnel from different functional groups are gathered to evaluate the risk associated with a system from various standpoints (Abdelrahman & Abdelgawad 2011). It is not forgotten that the FMEA application would be successful if only made by a group of people instead of only one person. The optimal size of the FMEA team is 3 to 6, and the maximum is 10 (Goel & Graves 2007).

One of the most important factors affecting the success of FMEA is timing. It should be done before any problem occurred. There is a Turkish saying like “Önlemek, ödemekten daha ucuzdur”. It means that taking precaution for a problem is cheaper than paying the cost of event that derives from that problem.

2.2.1.1 Types of FMEA

In the literature, there are several types of FMEAs, which are system, design, process, service, and software, are available (Kahraman et al. 2013).

2.2.1.1.1 System FMEA

This type of FMEA aims to identify potential failure modes in the system functions by analyzing the systems, sub-systems and interactions of these systems with each other (Sofyalıoğlu & Öztürk 2012). System FMEA concerns the failure modes that are resulted from design FMEA. Potential failure causes differentiate from other types because failures are occurred due to direct customer contact. Broken pieces by accident, technical errors, and electrical errors can be good examples. The aim of the System FMEA is to develop the quality, reliability and the maintainability of the system.

2.2.1.1.2 Design FMEA

This type of FMEA aims to identify and prevent possible failures, their causes and effects during a product design. Design FMEA should start before the concept design (Sofyalıoğlu & Öztürk 2012). For instance in the automotive industry, design FMEA is a procedure to identify that the right materials are being used, to conform the customer specifications, and to ensure that government regulations are being met, before finalizing the product design.

2.2.1.1.3 Service FMEA

A service failure occurs when customers' needs are not met and or service performance falls below a customer's expectation (Goldstein et al. 2002). Service failure is essentially a flawed outcome that reflects a breakdown in reliability. It compasses any problematic situation during service while service is delivered to a customer, causing significant damage to customer satisfaction (Reichheld 1996).

2.2.1.1.4 Software FMEA

Software base FMEA worksheet helped us to utilize entered data to ensure the consistency of analyzing the worksheet of FMEA with minimum time requirements. First of all, each data of various functions and failures entered. Then the causes and effects on each failure were assigned. Moreover, Risk Priority Numbers (RPNs) of each failure were calculated automatically right after allocating rating scales for severity, occurrence and detection (Feili et al. 2013).

2.2.1.1.5 Process FMEA

All of the possible problems that may arise during the product creation can be overcome with help of process FMEA. Process FMEA deals with the manufacturing and assembly processes. It identifies any potential failures that could be caused by manufacturing/assembly processes, machines, fixtures, and production. Before the application, it is important to determine which part of the production process will be taken into account. Process FMEA traditionally begins when the design FMEA report is available. The purpose of process FMEA is to determine and correct the weak points of production.

In this research, the combination of system, design, service and mostly the process FMEA is used in case study. The combination of four types meets the needs of OHS in workplace.

2.2.1.2 Shortcomings of FMEA

It is true that the FMEA is the simple risk analysis methodology to apply, instruct and understand (Chang et al. 2013). FMEA helps experts to detect failure modes, cause of failures quickly and also diminish the frequency of failures. On the other hand, traditional calculation of RPN (occurrence* severity* detectability = RPN) has several shortcomings that presented below (Liu et al 2013; Liu et al. 2012; Chang et al. 2013; Helvacioglu & Ozen 2014; Kutlu & Ekmekcioglu):

a. The acceptance of three decision factors equally important. If there are no weights determined for each of them, it is ⅓. Every company or even each process has failure modes that have different number of frequency, importance level of severity importance and importance level of detectability.
b. Since all of three decision factors have 10-point scale it is possible that the different combinations of decision factors may produce same RPN value, but their hidden risk implications may be totally different. For example, three failure modes with O, S, D values of 8, 9, 1; 6, 6, 2 and 4, 3, 6 have the same RPN and same prioritization too.
c. Although FMEA assumes the RPN is distributed 1 to 1000 it not true exactly because only 120 numbers can generated. Thus, traditional FMEA gives high duplication rate.
d. The mathematical form adopted for calculating the RPN is strongly sensitive to variations in risk factor evaluations. Small variations in one rating may lead to vastly different effects on the RPN, depending on the values of the other risk factors. For instance, assume that occurrence and severity ratings are both 9. One point difference in detectability rating results in an 81 point differences. On the other hand, if occurrence and severity ratings are both 2, then one point differences in detectability rating results in a 4 point differences.
e. The RPN values are heavily distributed at the bottom of the scale from 1 to 1000.

f. The RPN does not consider cost of corrective actions, workers health and safety, regulatory obligations aspects. The RPN only considers three decision factors.
g. The calculation of RPN is not accepted completely because there is no meaningful explanation as to why three decision factors are multiplied instead of summation.
h. It is really hard and mostly subjective to determine the ratings for decision factors. Much information in FMEA is often uncertain or vague and can be expressed in a linguistic way such as likely, important, high and so on.
i. It is hard to interpret the RPNs which are closed in numbers. For instance, one failure mode has the RPN equal to 80. Another failure mode has 81. The second one should be resolved first because of greater RPN but some other factors may need to be considered to make the right and reasonable decision.
j. Traditional FMEA methodology fails to consider the direct and indirect relationship between failure modes and cause of failures. Interdependencies among the various failure modes and effects on the same level and different levels of hierarchical structure of an engineering system are not taken into account.
k. Traditional FMEA methodology also fails to consider customer satisfaction.
l. Traditional RPN calculation does not take decision makers' experiences, education levels, and academic knowledge levels into account.
m. The RPN cannot be used to measure the effectiveness of corrective actions.
n. The traditional RPN method is only measuring from the risks viewpoint while ignoring the importance of corrective actions.
o. FMEA is a time-consuming and very tedious activity; hence it is highly prone to errors.

To overcome the above shortcoming of traditional FMEA, many approaches have been suggested in FMEA literature. Most of the approaches have used fuzzy approach. The studies about FMEA that considering fuzzy approach describe risk factors O, S, D by using fuzzy linguistic terms. The linguistic variables were used for evaluating three decision factors (Kutlu & Ekmekçioğlu 2012).

Distinct studies about fuzzy approach used FMEA are presented in this research. For instance, Wang et al. (2009) use fuzzy risk priority numbers (FRPN) to prevent false prioritization. False prioritization occurs because of direct judgment of decision makers. It is crucial to consider real applications to determine relevant prioritization of failure modes. In this research, the decision factors occurrence, severity and detectability are treated as fuzzy variables and evaluated by using fuzzy linguistic terms and fuzzy grades. Wang et al. (2009) also treat the decision factors O,S and D as fuzzy variables and evaluate them using fuzzy linguistic terms and fuzzy ratings. After proposing FRPNs, FRPNs are defined as fuzzy weighted geometric means of the fuzzy ratings for O,S and D, and can be computed using alpha-level sets and linear programming models.

Xu et al. (2002) proposed a fuzzy logic based method for FMEA to address the problem of interdependencies among various failure modes with uncertain and imprecise information. The validity of the results may be questionable just because of this uncertainty. Thus, the potential problems in sharing information among experts are resolved with the help of a platform. This platform for a fuzzy expert assessment and it is integrated with proposed system.

Garcia et al. (2005) present a data envelopment analysis approach for determining prioritization of failure modes in which the typical FMEA decision factors are modeled as fuzzy sets. Inference rules of the IF THEN can be bypassed by means of this approach.

Chin et al. (2009) also use data envelopment analysis to determine the risk priorities of failure modes. The maximum and the minimum score of each failure mode are measured and two score are then geometrically averaged to measure the overall risk of failure modes.

Braglia (2000) occurred a multi-attribute failure mode analysis (MAFMA) approach based on AHP technique. Braglia incorporate the decision factors O, S, D and expected cost as decision criteria. Alternatives are possible causes of failures and the decision goal is the selection of cause of failure.

Chang, Wei, and Lee (1999) used fuzzy method and grey theory for FMEA, where linguistic variables were used to evaluate to decision factors O, S, and D and grey relational analysis was applied to determine the risk priority of potential causes.

Chang et al. (2013) try to eliminate four chief shortcomings of FMEA: High duplication rate, assumption of equal importance of O, S, and D, not following the ordered weighted rule and failure to consider the direct and indirect relationship between the failure mode and the cause of failure. To resolve these drawbacks, they propose a novel approach, integrating GRA and decision making trial and evaluation laboratory (DEMATEL) approach to rank the risk of failure. GRA is used to modify RPN values to lower duplications. By integrating grey relational analysis and the decision making trial evaluation laboratory (DEMATEL) method, to rank the risk of failure, wherein GRA is used to modify RPN values to lower duplications and the ordered weighted rule is followed; then, the DEMATEL method is applied to examine the direct and indirect relationship between failure modes and cause of failures. This approach gives higher priority when a single cause of failure causes failure modes to occur multiple times.

Liu et al. (2011) used fuzzy evidential reasoning approach and GRA. Fuzzy evidential reasoning approach is used to solve the problem of the acquirement of FMEA team members' diversity opinions. GRA is used to solve the problem of prioritization of the modes that have been identified and then calculated based to this new approach. Unluckily, this research does not concern the DMs ability, experiences, education level and their job relevance with FMEA application.

FMEA should be made by team and it is based on group decision function and cannot be done on an individual basis. The FMEA team often demonstrates different opinions and knowledge with each other. To resolve this issue Chin et al. (2009a) proposed a new model that allows FMEA team members to assess risk factors independently. They presented an FMEA that uses the evidential reasoning (ER) approach to model the diversity and uncertainty of the assessment information in FMEA.

Mandal & Maiti (2014) tries to overcome the drawbacks of RPN calculation. According to study, it is hard to interpret failure modes by using crisp numbered scales. To overcome this drawback they developed a new methodology integrating the concepts of similarity value measure of fuzzy numbers and possibility theory. Similarity value measure has been applied to group together failure modes having similar amount of risk value.

Su et al. (2014) try to improve the reliability of the thin-film transistor liquid crystal display products with the help of a combined approach integrating failure mode and effect analysis (FMEA) and Taguchi methods. Considering the issues during design and manufacturing phases simultaneously, the proposed approach provides a systematic framework to find the causes of failure, to conduct experiments, and to optimize the process output.

Liu et al. (2014) a new approach to RPN calculation is presented. This study based on a more effective representation of uncertain information, called D numbers, and an improved grey relational analysis method, grey relational projection (GRP), a new risk priority model is proposed for the risk evaluation in FMEA.

Helvacioglu & Ozen (2014) criticizes the RPN calculation. Another point that is criticized is that the differences among the decision makers are not mentioned enough. According to the study, RPN method cannot emphasize the nature of the problem, which is multi-attributable and has a group of experts' opinions. Furthermore, attributes are subjective and have different importance levels. Therefore, they propose a framework to overcome the shortcomings of the traditional method through the Fuzzy Multi-Attribute Group Decision Making (FMAGDM), which helps to solve the selection of risky failure modes. Fuzzy sets are utilized for expressing fuzziness of crisp/linguistic knowledge coupled with the well-known TOPSIS methodology for decision making.

So many approaches applied and important contributions were made to the FMEA literature. Liu et al. (2013) made a literature review on FMEA, especially RPN calculation. As to this study methods used in FMEA literature may be divided into five main categories: Multi-criteria decision making (MCDM), mathematical programming (MP), artificial intelligence (AI), hybrid approaches and others. Table 2.5 represent these methods in detail and gives the proportion of usage.

Table 2.5: Classification of risk evaluation methods in FMEA

Categories	Approaches	Total number
MCDM (22,50%)	ME-MCDM	1
	Evidence theory	2
	AHP/ANP	4
	Fuzzy TOPSIS	1
	Grey theory	7
	DEMATEL	1
	Intuitionistic fuzzy set ranking technique	1
	VIKOR	1
Mathematical programming (8,75%)	Linear programming	4
	DEA/ Fuzzy DEA	3
Artificial intelligence (40,00%)	Rule-base system	1
	Fuzzy rule-base system	29
	Fuzzy ART algorithm	1
	Fuzzy cognitive map	1
Integrated approaches (11,25%)	Fuzzy AHP- Fuzzy rule-base system	1
	WLSM-MOI-Partial ranking method	1
	OWGA operator DEMATEL	1
	IFS-DEMATEL	1
	Fuzzy OWA operator-DEMATEL	1
	2-tuple-OWA operator	1
	FER-Grey theory	1
	Fuzzy AHP-fuzzy TOPSIS	1
	ISM-ANP-UPN	1
Other approaches (17,50%)	Cost based model	6
	Monte Carlo simulation	1
	Minimum cut sets theory (MCS)	1
	Boolean representation method (BRM)	1
	Diagraph and matrix approach	1
	Kano model	1
	Quality functional deployment (QFD)	2
	Probability theory	1

Source: Liu et al. (2013)

In this thesis research, fuzzy AHP is used for weighting of decision factors O, S, and D. After that, weights of each decision factors are incorporated to RPN calculation by means of GRA. Fuzzy AHP technique is also used for weighting process of decision factor. By determining weights for each decision makers, FMEA can be applied more consistently. Each decision maker applies FMEA by himself. At the final step, weighted arithmetic means are calculated and then weighted team decisions appears. Each decision maker applies FMEA individually and also team decisions give us more convenient results. Fuzzy AHP technique is finally used to weight RPN2 criteria weights.

3. METHODOLOGY

3.1 ANALYTICAL HIERARCHY PROCESS (AHP) AND FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP)

3.1.1 Analytical Hierarchy Process (AHP)

One of the crucial approaches that underlie the proposed methodology of this thesis is Analytical Hierarchy Process. AHP is one of the well-known multi-criteria decision making techniques that was first proposed by Saaty (1980). AHP is used in various decision-making areas such as planning, R&D, choosing the best policy alternative, predicting outcomes, measuring performance, and optimizing and resolving decision conflicts (Saaty 1986). This method mainly based on human experiences and ability to make judgments about small problems. "It facilitates decision making by organization perceptions, feeling, judgment, and memories into framework that exhibits the forces that influence a decision." (Çakır 2009). After introduction of AHP, it has become one of the most used multiple-criteria-decision-making techniques.

Thanks to AHP, decision makers structure a complex problem in the form of a simple hierarchy and to evaluate a factors, criteria and alternatives (Lee et al. 2008). After constructing the hierarchy, the DMs begin to determine the relative importance of the elements in each level. DMs make judgments to determine the dominance of one element over another with the help of 9-point ratio scaling. Scale is presented in Table 3.1. Pairwise comparisons can be done by asking decision makers how valuable a criterion (C1) when compared to another criterion (C2) with respect the overall goal (Oztaysi 2014).

The decision makers are not forced to determined crisp number. They can express their opinion by means of linguistic terms such as equally important, moderately more important, strongly more important, very strongly more important, and extremely strongly more important. These linguistic terms would then be translated into numerical values as presented in Table 3.1.

Table 3.1: 9- Point ratio scale for AHP

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strong over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it

Source: Oztaysi 2014

DMs make judgment to compare criteria and then they form the comparison matrix. The prioritization of criteria is then calculated.

As stated above, AHP can be used to solve MCDM problem. Similar procedure can be applied to calculate the weight of alternatives. For each criterion respectively, the pairwise comparison matrix for all alternatives should be formed. After that the value of each alternative is multiplied by the weights of the corresponding criterion. Finally, to find out the importance and weight of each alternative, all alternative values are summed up.

To make this technique successful, there should be a little subjectivity of judgment of criteria or alternative comparison. Comparison scores should be determined by precise explanation so that the experts make definite judgments. If the experts make a decision on criteria in a subjective way, this method cannot help perfectly.

3.1.2 Fuzzy Analytical Hierarchy Process (FAHP)

Fuzzy set and fuzzy logic, first proposed by Lotfi A. Zadeh in 1965, are useful for modeling the uncertain system in industry, nature and humanity. They have crucial role when applied to complex phenomena not easily described by traditional mathematic methods, especially when the goal is to find a good approximate solution. A set is the extended crisp set. While crisp sets only allow full membership or non-membership, fuzzy sets allow partial membership. This property helps FMEA team to evaluate failure modes and give score to them easily. Zadeh proposed to use values ranging from 0 to 1. 0 means complete non-membership whereas 1 means complete membership. Values between 0 and 1 represent intermediate degrees of membership.

Fuzzy approach is used in FMEA by so many researches. Kahraman et al. (2013) represented a literature review on this topic (see in Table 3.2). In this thesis research, fuzzy AHP and the GRA approach are used.

Table 3.2 Literature review of fuzzy FMEA approaches

Authors and year	FMEA type	Computational technique	Application area
Pelaez and Bowles 1995	Design	Fuzzy cognitive maps knowledge representation	Pressure tank system
Xu et al. 2002	Design	Fuzzy inference system (FIS) Fuzzy expert assessment system	Mechanical system
Guimares and Lapa 2004a	System	Fuzzy inference system (FIS)	Nuclear reliability engineering
Guimares and Lapa 2004b	System	Fuzzy inference system (FIS) Knowledge-based fuzzy system	Reactor nuclear problem
Garcia et al. 2005	System	Fuzzy data envelopment analysis	Nuclear safety systems
Guimares and Lapa 2007	System	Fuzzy inference system (FIS) Knowledge-based fuzzy system	Nuclear engineering systems
Yang et al.2008	Design	Fuzzy rule-based Bayesian reasoning	Offshore engineering systems
Chin et al. 2008	Design	Fuzzy knowledge based system	Knowledge based product design system
Tay et al. 2008	Process	Fuzzy inference system based occurrence updating model	Semiconductor manufacturing environment
Nepal et al. 2008	Design	Rule-based fuzzy logic	Product architecture (PA) capturing interaction failures between different modules
Huadong and Zhigang 2009	Design	Fuzzy inference system	Risk evaluation of boiler tube
Rivera and Nunez 2009	Design	Fuzzy inference system	Discontinuous distillation plant of biofuel

Abdelgawad and Fayek 2010	Design	Fuzzy inference system, fuzzy AHP and fuzzy expert systems	Risk management in the construction industry
Hakeem et al. 2010	System	Fuzzy logic, fuzzy rule base, ANN model	Batch reactor system
Yang et al. 2010	Design	Fuzzy FMEA integrated with fuzzy linguistic scale method	CNC machine tool
Chang and Cheng et al. 2010	Process	Intuitionistic fuzzy set (IFS) and decision making trial and evaluation laboratory (DEMATEL)	DRAM etching process
Zhang and Chu 2011	Design	Fuzzy-RPNs-based method integrating weighted least square method, the method of imprecision and partial ranking method	New product development of a new horizontal directional drilling (HDD) machine
Kutlu and Ekmekcioglu 2011	Process	Fuzzy TOPSIS-based fuzzy AHP	Manufacturing facility of a SME in automotive industry

Source: Kahraman et al. 2013

Although AHP is practical and includes the opinions of experts and the use of AHP does not involve cumbersome mathematics, it is criticized because this technique is not capable of reflecting human's vague thoughts about complicated issue (Seçme et al. 2009). As it is known, AHP involves decomposition, pairwise comparisons, and priority vector generation and synthesis. Though the purpose of AHP is to capture expert's knowledge, the traditional AHP cannot reflect the experts thinking style. It is hard to determine the values of AHP scale. Experts may prefer intermediate judgments rather than certain judgments. For this reason, a method based on fuzzy approach, fuzzy AHP, make the comparison process more flexible and capable to explain experts' preferences (Kahraman et al. 2003). There are so many methods presented for the fuzzification of AHP technique. In this study, Buckley's fuzzy AHP method is used because this method has not been criticized heavily or refuted for its mathematical calculations (Buckley 1985; Kahraman & Çebi 2009). In this method problems should be presented by a hierarchical structure so as to make the solutions of these problems. Then, decision makers determine the linguistic terms for pairwise comparisons of criteria. These linguistic terms should then be converted to fuzzy numbers with the help of Table 3.3 Triangular fuzzy numbers are defined by real numbers, expressed as (l, m, u). l, m and u respectively indicate the smallest, most promising and the largest possible value that describe the fuzzy event (see in Figure 3.1).

Figure 3.1 A triangular fuzzy number, M

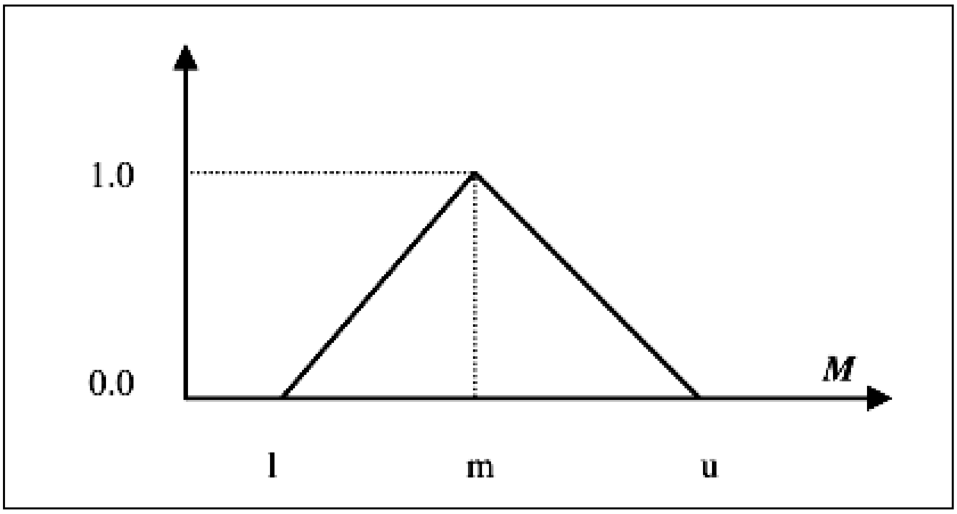


Table 3.3: Triangular fuzzy numbers for linguistic terms

Linguistic Scale	TFN
Just equal	(1,1,1)
Equally important	(1,1,3)
Weakly important	(1,3,5)
Essentially important	(3,5,7)
Very strongly important	(5,7,9)
Absolutely important	(7,9,9)

Source: Kahraman & Çebi 2009

The steps of Buckley's fuzzy AHP method can be given as in the following:

Step 1: The importance of the weights is obtained by pairwise comparisons. Linguistic variables are used to evaluate criteria. These variables convert into fuzzy numbers by using Table 3.1. Then, the pairwise comparison matrices for each decision makers obtained.

$$\mathcal{A}_k = \begin{vmatrix} 1 & a_{12} & . & . & a_{1n} \\ a_{21} & 1 & . & . & a_{2n} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ a_{n1} & a_{n2} & . & . & 1 \end{vmatrix} \quad (3.1)$$

$\mathcal{A}_k$: Piarwise comparision matrix that established by decision maker k.

a_{ij}: TFN that demonstrates the comparison of criteria

i: criterion i

j: criterion j

n: number of criteria

k: number of decision makers

An aggregated pairwise comparison matrix is established to incorporate all decision makers' pairwise comparison matrices. Aggregate matrix is calculated with the help of geometric mean and brings each decision maker evaluations together.

$$a_{ij} = \sqrt[K]{a_{ij}^1 \otimes a_{ij}^2 \otimes \ldots \otimes a_{ij}^K} \quad (3.2)$$

$\otimes$: fuzzy multiplication

Step 2: The fuzzy weight matrix is calculated by Buckley's method (Kahraman & Çebi 2009) as follows:

$$\tilde{r}_i = \sqrt[n]{\tilde{a}_{i1} \otimes \tilde{a}_{i2} \ldots \otimes \tilde{a}_{in}} \quad (3.3)$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \ldots \oplus \tilde{r}_n)^{-1} \quad (3.4)$$

$\oplus$: fuzzy addition

$\tilde{r}_i$: geometric mean of fuzzy comparison value of criterion I to each criterion.

$\tilde{w}_i$: weight of criterion i

Step 3: The final step requires defuzzification and normalization of calculated fuzzy weights (w_i) in order to convert them into crisps values (Eq. (5)). For the defuzzification process, centroid method is selected since it is the most commonly used method (Opricovic & Tzeng 2004)

$$w_r = \frac{\tilde{w}_r}{\sum_{i=1}^{n} \tilde{w}_i} = \frac{w_{rl} + w_{rm} + w_{ru}}{\sum_{i=1}^{n} \tilde{w}_i} \quad (3.5)$$

$w_{r:}$ a crisp weight number

3.1.2.1 Assigning different weights to decision makers with Fuzzy AHP

Decision makers have an important role in FMEA application. Their judgments on decision factors determine and bring about the values of RPN1s, RPN2s and RPN3s. Therefore the prioritization of failure modes depends on DMs' judgment. To reduce the responsibility of DMs and the difficulty of making decision, a fuzzy approach is added to this research. Thanks to fuzzy approach, DMs have chance to make their judgment by using linguistic terms. Unfortunately it is not enough for getting satisfied results from FMEA. Each firm employs different decision makers who have different ability on risk analyzing. FMEA team often demonstrates different opinions and knowledge from one team member to another and produces different types of assessment information because they differ from each other with their experience, knowledge, education level. FMEA team members cannot possess the same feature about evaluating the risks. For instance, FMEA team consists of four people. One of them is C-class OHS specialist, another one is A-class OHS specialist and the others are company's maintenance workers. Maintenance workers are always be in the same place (a place that the FMEA applied in) so they know the workplace very well. On the other hand, OHS specialists are good at laws and regulations. For these reasons, DMs should be weighted and their judgment should be associated with corresponding weights.

In this research, five criteria are presented in Table 3.4. The criteria are objective so at least two experienced and knowledgeable risk analysts/experts/occupational health and safety specialists can determine these five criteria's importance weights. They make pairwise comparisons of criteria and then calculate the crisp number of criteria weights by using Buckley's fuzzy AHP approach as presented above.

Once the analysts/experts/occupational health and safety specialists determine the criteria's weights, the weights are not change anymore. They also determine the importance weights for decision makers of current FMEA application. Risk analysts/experts/occupational health and safety specialists give scores to FMEA team's member (decision makers) by using Table 3.5-3.9. It is easy because they are not forced to make subjective judgment.

Each DM's weight is calculated by multiplying each criterion score with its criterion weight and then the summation of all five gives the weights of DM. Remember that the criteria weights derive from the fuzzy AHP calculations. Finally, we normalized these five weights and obtain the crisp values of DMs' weights.

Table 3.4 Criteria of decision makers

Criteria
1- Decision maker's job relevance with the process
2- The number of years of experience in the current sector
3- Education level and the relevance of decision maker's job with his/her education
4- The result of test which is about FMEA and risk analyzing
5- The number of times that the decision maker has took part in FMEA application or another risk analysis methodology and the similarity between the current process and the process that have been already experienced

Table 3.5: Criterion-1, job relevance

Criterion-1 Decision maker's job relevance with the current process of FMEA application	***Score***
The application of FMEA is taken place in DM's workplace and DM is a member of this process already	5
The application of FMEA is taken place in DM's workplace and DM was a member of this process already	4
The application of FMEA is taken place in DM's workplace and DM has never be a member of this process	3
The application of FMEA is not taken place in DM's workplace but DM had been worked similar process in the past	2
The application of FMEA is not taken place in DM's workplace and DM has never be a member of similar process but DM is able to make judgment	1

Criterion-1, decision maker's job relevance with the current process of FMEA application, provides us an ability to evaluate FMEA team member's routine job relevance with the current FMEA process. For instance, a person who is responsible for maintenance work in the workplace can easily evaluate the potential failure modes. On the other hand, an OHS specialist may not be aware of the failure modes in the current workplace because of his/her lack of knowledge about the process. It is normal that the maintenance worker knows about the workplace's failures and possible risks. It is also normal that the OHS specialist does not know about the workplace's failures like maintenance person does.

Table 3.6: Criterion-2, experience

Criterion-2 The number of years of experience in the current sector	***Score***
DM has/had worked in this sector for more than 10 years	5
DM has/had worked in this sector for more than 6-10 years	4
DM has/had worked in this sector for more than 3-6 years	3
DM has/had worked in this sector for more than 1-3 years	2
DM has/had worked in this sector for more than 0-1 year	1

Decision maker should be an experienced one. We cannot learn everything by reading books or being educated in school. If the knowledge is not used in the workplace arena, it is almost nothing. Criterion-2 is about the decision maker's experiences. Experiment can contribute beneficial features to the DMs.

Table 3.7: Criterion-3, education level

Criterion-3 The education level and the relevance of decision maker's job with his/her education	***Score***
Bachelor's degree/ Master degree or better and the current process is parallel with DM's education	5
Bachelor's degree/ Master degree or better and the current process is partially or less related with DM's education	4
DM graduated from high school and the process is parallel with DM's education	3
DM graduated from high school and the process is partially or less related with DM's education	2
DM graduated from any school that is below the high school and the process is parallel with DM's education	1

Education makes people think more analytically. The more education means the more knowledgeable people. Decision makers should be educated persons because they determine the failure modes, risks, and so the health and safety of people in general. Besides the level of education, it is also important that the relevance is between the education of decision maker and his/her current job.

Table 3.8: Criterion-4, test result

Criterion-4 The result of test which is about FMEA and risk analyzing	***Score***
DM's test result is between 91-100 points	5
DM's test result is between 81-90 points	4
DM's test result is between 66-80 points	3
DM's test result is between 56-65 points	2
DM's test result is between 50-55 points	1

FMEA team member should be given information about risk analyzing and especially FMEA methodology before the application of FMEA. After that a test should be applied to decision makers (FMEA team). The test should evaluate the knowledge level of risk analyzing and FMEA methodology. If the DM gets the grade that is under the 50 points, he/she will be re-educated and then re-evaluated. Sample test is presented in Appendix C-1.

Table 3.9: Criterion-5, repetition number

Criterion-5 The number of times that the decision maker has took part in FMEA application or another risk analysis methodology	***Score***
DM has took part in FMEA application or another risk analysis methodology that is relevant with his/her job 5 or more times	5
DM has took part in FMEA application or another risk analysis methodology that is relevant with his/her job 1-5 times	4
DM has took part in FMEA application or another risk analysis methodology that is not relevant with his/her job 3 or more times	3
DM has took part in FMEA application or another risk analysis methodology that is not relevant with his/her job 1-3 times	2
DM has took part in FMEA application or another risk analysis methodology 0-1 time.	1

In the criterion-2, the importance of experiment is mentioned. Criterion-5 is also about experience but it considers the repetition number of risk analyzing that the DM has been taken part in. The relevance of risk analysis methodology and DM's routine job is important for this criterion. For example, it makes no sense that the industrial engineer applies FMEA in the architecture office to meet the OHS needs.

3.1.2.2 Assigning different weights to decision factors (both for RPN1 and RPN2) with Fuzzy AHP

Remember that RPN1 is calculated by using decision factors O, S, and D. Weighted DMs give scores for each of decision factors. After that, GRA is applied to obtain RPN1 values. RPN1 values are more consistent and convenient from traditional RPN because DMs and decision factors have been weighted and GRA is applied to incorporate decision factors' weights to the calculation.

RPN2 values are obtained because of the need for reprioritization of corrective actions. Corrective actions should be reprioritized because RPN1 values do not consider the cost of C.A., time loss due to C.A. performing, regulations, firm's prevention policy and so on. Thus, five additional criteria are added to calculate RPN2. RPN2 calculated by means of summation of decision factors (criteria) scores that scores are multiplied with corresponding weights.

Both RPN1 and RPN2 have their own decision factors and these factor need for weights. These weights are derived from pairwise comparison of Fuzzy AHP approach in the calculation of RPN1 values and added to RPN1 calculation with the help of GRA. While RPN2 is calculating, the weight is added to calculation directly by multiplying corresponding score of decision factor. While decision makers make pairwise comparisons for both RPN1 and RPN2 calculation, they evaluate factors such as cost, time, worker's ability, capability, obligation, in addition to their experiences about OHS concept. Then, they determine the comparison terms with respect to overall goal.

3.2 GREY RELATIONAL ANALYSIS

Another approach that underlies the proposed methodology of this thesis is grey relational analysis. Firstly, the grey theory should be understood to comprehend the aim of grey relational analysis. There exists any system that is capable of capturing all information perfectly without uncertainty (Chang et al. 2013). Deng (1982) first proposed the Grey theory to deal with the analysis of systems that are struggle with incomplete information. Grey theory asserts that the system is a white system when the required information is entirely available. On the other hand, the system is black if the required information is entirely unavailable. A system with partially available information is called as a grey system (Chang et al. 2013). Deng (1989) presented that the grey theory consist of six major components: grey generating, grey relational analysis, grey prediction, grey model, grey decision making and grey control. Grey relational analysis is the part of grey theory, dealing with the multiple criteria decision making problem, and it is consists of a complicated interrelationship between multiple factors. GRA can be adapted to FMEA especially to RPN calculations because GRA is suitable for solving problems with complicated relationship between multiple factors and variables. The use of grey theory and so the GRA within the FMEA framework is practical and can be accomplished (Liu et al. 2011). GRA also fits FMEA because its decision factors have all of these characteristics of being existent, countable, extensible and independent. These characteristics derive from a grey theory. Grey theory provides for experts a measure to analyze relationship between discrete quantitative and qualitative series.

As stated above, under the sub-title of "Shortcomings of FMEA", the traditional RPN calculation method is criticized because of several shortcomings. To handle with these drawbacks, incorporating GRA method to the FMEA may help in many ways and these ways are presented below:

i. GRA eliminates high duplication rate problem. Because the combinations of S, O and D are a discrete series and the statistical distribution is unknown. Some of the duplication problems that the GRA improves are listed below:

   a. Traditional RPN calculation includes 120 unique RPN values; whereas GRA integrated RPN calculation include 220 unique GRA values.
   b. Traditional RPN calculation can be have 24 times duplication; whereas GRA integrated RPN calculation can be have 6 times duplication.
   c. Almost all RPN values are less than 500 in the traditional RPN calculation; whereas GRA values are more uniformly distributed (Chang et al. 2013).

ii. By grey relational analysis, the deviation in traditional RPN calculation due to excessive classified levels is eliminated and the accuracy is improved.

iii. GRA has competitive advantages in terms of the effective processing of uncertainty, multi-input, discreet data, and data incompleteness. Especially, the flexibility that enables to assign different weighting coefficients to the decision factors O, S, and D.

iv. GRA is not requiring utility function of any form.

v. GRA can be adapted to FMEA especially to RPN calculations because GRA is suitable for solving problems with complicated relationship between multiple factors and variables.

3.2.1 Application of Grey Relational Analysis to FMEA

GRA can be applied FMEA easily. To carry out the GRA, firstly fuzzy linguistic variables are defuzzified as crisp values. These fuzzy linguistic variables are about the decision factors O, S, and D. The crisp value for them can be incorporated to the GRA. The lowest levels of the three decision factors are defined as standard series (1,1,1). The evaluation information of the three decision factors for each failure mode is viewed as comparative series. After that the grey relational coefficient and degree of relational with standard series are computed in terms of the grey theory. By incroprating weights of O, S, and D to the calculation, we finally get the RPN values. The greater RPN value means that the smaller effect of the current failure mode. In the following part, the steps of grey relational analysis to the FMEA are presented (Chang et al. 1998).

*Step 1**:** Establish the comparative series*

An information series with n components or decision factors, such as chance of occurrence, chance of undetection and severity of failure is the comparative series.

Comparative series can be expressed as,

$$X_i(k) = \left[X_i(1), X_i(2), X_i(3)\right]$$

k= 1,2 or 3 (number of decision factors)

i= 1,2,3,….n (n is the number of failure modes)

Here k has the value of 1,2 and 3; meanings $X_i(1), X_i(2), X_i(3)$ are the scores of each decision factors respectively. If all series are comparative series, the n information series can be defined as followin matrix, equation 1.

$$X_i(k) = \begin{bmatrix} X_1(k) \\ X_2(k) \\ \vdots \\ X_n(k) \end{bmatrix} = \begin{bmatrix} X_1(1) & X_1(2) & X_1(3) \\ X_2(1) & X_2(2) & X_2(3) \\ & \vdots & \\ & \vdots & \\ X_n(1) & X_n(2) & X_n(3) \end{bmatrix} \tag{3.6}$$

Step 2: Establish the standard series

Degree of relation can describe the relationship of two series, thus, an objective series called as standart series can be expressed as the following;

Series notation: $X_0(k) = \{X_0(1), X_0(2), X_0(3)\}$

Matrix notation: $X_0(k) = [X_0(1)\ X_0(2)\ X_0(3)]$

When applying the traditional FMEA, the smaller the score, the less the risk, therefore the standart series should be the lowest score of occurrence, detectability and severity factors which is shown as following:

Matrix notation is:

$$X_0(k) = \{X_0(1), X_0(2), X_0(3)\} = \{1,1,1\}$$
$$X_0(k) = [1\ \ 1\ \ 1] \tag{3.7}$$

Step 3: Obtain the differences between comparative series and standard series

To discover the degree of grey relationship, the difference between the scores of decision factors and scores of standard series must be calculated and expressed as the matrix shown below**.**

$$\Delta_i(k) = \begin{bmatrix} \Delta_{01}(k) \\ \Delta_{02}(k) \\ \vdots \\ \Delta_{0n}(k) \end{bmatrix} = \begin{bmatrix} \Delta_{01}(1) & \Delta_{01}(2) & \Delta_{01}(3) \\ \Delta_{02}(1) & \Delta_{02}(2) & \Delta_{02}(3) \\ & \vdots & \\ & \vdots & \\ \Delta_{0n}(1) & \Delta_{0n}(2) & \Delta_{0n}(3) \end{bmatrix} \tag{3.8}$$

Here, i= 1,2,3….n (n is the number of failure modes)

$\Delta_i(k)$ is calculated as the following;

$$\Delta_{0i}(k) = |X_0(k) - X_i(k)| \tag{3.9}$$

Step 4: Compute the grey relation coefficient

To compute the relation coefficient, the decision factors of the failure model are compared with the standard series, and the relation coefficient is expressed as:

$$\gamma\left[X_0(k), X_i(k)\right] = \frac{\Delta_{\min} + \varsigma\Delta_{\max}}{\Delta_i(k) + \varsigma\Delta_{\max}} \tag{3.10}$$

$X_0(k)$: standard series

$X_i(k)$: comparative series

i = 1,2,3…..n (n is the number of failure modes)

k= 1,2 or 3 (number of risk factors)

$\Delta_{\min}$ = Minimum value of all $\Delta_i(k)$

$\Delta_{\max}$ = Maximum value of all

ς is an identifier coefficient and only affects the relative value of the risk without changing priority. It is equals to **0,5.**

Step 5: Determine the degree of relation

To find the degree of relation, weighting coefficient of the decision factors must be first decided. The relative weights of decision factors will be used in the following formulation.

$$\tau_i(k) = \beta_k \sum_{k=1}^{3} \Delta_i(k) \tag{3.11}$$

β_k = the weighting coefficient of the risk factors and $\sum_{k=1}^{3} \beta_k = 1$

In the proposed methodology $\sum_{k=1}^{3} \beta_k \neq 1$. Each of the risk factors (decision factors O, S, and D) has different weight. A numerical example is represented in the case study.

3.3 THIRD RISK PRIORITY NUMBER (RPN3)

Traditional FMEA uses the old-fashioned RPN calculation that requires the multiplication of O, S, and D scores. Although decision makers and decision factors are weighted by using Fuzzy AHP and calculation of RPN values (RPN1) by the help of GRA, there should be last step before performing the corrective actions. So far, we try to remove the shortcomings of RPN calculations. There exists almost no study that considers the need for corrective actions as to in real life situation. More clearly, the prioritization by using RPN1 scores is not enough to realize the corrective actions. This research is presented a new approach, a new logic. "Is it really worth to do the corrective action of failure mode 12?". All firms want to get rid of all failure modes but there are some limitations such as cost, time, and obligation of laws. Unfortunately, a firm may contain hundreds of failure modes and the decision makers should make reasonable decisions about corrective action realization. Thus, a new RPN (RPN2) is added to realize this notion. The steps of this approach are stated below:

Step 1: Weighting of criteria

Five criteria are determined as decision factors of RPN2 calculations. First, these 5 criteria are weighted by using Fuzzy AHP. Criteria are presented in Table 3.11.

Step 2: Determining the threshold integral for corrective actions

Although the determination of threshold for traditional has criticized a lot in so many study, for instance in the study of Abdelgawad et al. (2010). This approach determines a threshold interval. The threshold is not only a crisp RPN value or a number of corrective actions. In this study, a threshold interval is asserted. Table 3.10 represent threshold interval.

Table 3.10: Threshold intervals for corrective actions of failure modes

Threshold interval for corrective actions of failure modes	
RPN ≤ 0,600	Corrective action should be performed immediately
RPN > 0,600	Corrective action should be performed according to the company's prevention policy within a reasonable time

We determine the two parts. In the first part, corrective actions should be performed as soon as possible. In the second part, corrective action should be performed again but it should be done after the first part's corrective action. Every company has prevention policy to meet the needs for OHS concept. In this policy, a reasonable time should be identified clearly. For each corrective action which is in the second part, a reasonable time to perform the corrective action should be determined under the leadership of OHS specialist. The threshold should be determined based on the cost, number, frequency and time consuming criteria of corrective actions. Moreover, the capabilities of firm (cost, labor force, time limitation and so on) and also time period of FMEA renewing are other important factors. Therefore the value of 0,6000 may differ from company to company.

Step 3: Determining scores for decision factors (criteria)

Each criterion has 5-point decision scale and scales are presented in Table 3.12-3.16. Decision makers determine scores for each corrective action. DMs use the linguistic terms in that criteria scales while giving scores. Each DM make pairwise comparison matrix and evaluate criteria individually. At the final step, each DM's weights are incorporated into the calculation so that the weighted RPN2 values are occurred.

Table 3.11: Criteria for RPN2 evaluation

Criteria
1- Additional cost due to corrective action
2- Time loss due to the performing of corrective action
3- Regulation obligatory
4- Prevention policy
5- Customer satisfaction and reputation of firm

Table 3.12: Criterion-1, additional cost

Criterion-1 Additional cost due to corrective action	***Score***
Corrective action causes very little additional cost	0
Corrective action causes little additional cost	0,25
Corrective action causes ordinary additional cost	0,50
Corrective action causes serious additional cost	0,75
Corrective action causes huge additional cost	1

When we talk about the applicability of corrective actions, it is important additional cost due to corrective action. Although safety and health issues are more crucial, cost of C.A. should be considered when there are big differences in cost of C.A. For example, the absence of fire extinguisher can be eliminated for a few dollars. On the other hand, buying a good quality earplug for 1000 workers require more money to handle it. Therefore, if these two corrective actions have very closed RPN1 values, it is possible that the fire extinguisher will be bought before the earplugs.

Table 3.13: Criterion-2, time loss

Criterion-2 Time loss due to the performing of corrective action	***Score***
Corrective action causes very little additional time loss	0
Corrective action causes little additional time loss	0,25
Corrective action causes acceptable additional time loss	0,50
Corrective action causes serious time loss	0,75
Corrective action causes huge time loss	1

Corrective action can cause time loss in two ways. First, corrective action needs new machine or new operator. Finding new operator or supplying new machine may take too much time. Consider that a failure mode is detected and, as to management decision, the machine stopped working. As far as the time that the corrective action is performed there would be time loss and it causes additional cost. In clear, time loss may cause additional cost. Second, machine may need to be repaired and this process also takes some time.

Table 3.14: Criterion-3, regulation obligatory

Criterion-3 Regulation obligatory	***Score***
Corrective action have to be done because of the regulation obligatory	0
Corrective action must be done because of the regulation obligatory	0,25
Corrective action ought to be done because of the regulation obligatory	0,50
Corrective action can be postponed to a later date	0,75
Managers do not have to do corrective action just because of the regulation obligatory	1

Criterion-3 is more about the OHS concept. Almost all countries have laws and regulation to provide the welfare and satisfaction for workers and the customers. Regulations force companies to take some precautions. Companies have to meet the requirement of regulations because of worker’s and customer’s health and safety. Moreover, they have to meet the requirements to be able to avoid from governmental punishment.

Table 3.15: Criterion-4, prevention policy

Criterion-4 Prevention policy of the company	***Score***
Corrective action have to be done because of the prevention policy of the company	0
Corrective action must be done because the prevention policy of the company	0,25
Corrective action ought to be done because of the prevention policy of the company	0,50
Corrective action can be postponed to a later date	0,75
Managers do not have to do corrective action just because of the prevention policy of the company	1

In Turkey and other developed/developing countries, firms have to form their own prevention policy to meet the requirements of OHS. Prevention policy helps FMEA team member to apply the methodology faster. Furthermore, prevention policy provides old data in some way. Decision makers can use them effectively.

Table 3.16 Criterion-5, customer satisfaction and reputation

Criterion-5 Customer satisfaction and reputation of firm	***Score***
Corrective action have to be done because of customer satisfaction and/or reputation of firm	0
Corrective action must be done because of customer satisfaction and/or reputation of firm	0,25
Corrective action ought to be done because of customer satisfaction and/or reputation of firm	0,50
Corrective action can be postponed to a later date	0,75
Managers do not have to do corrective action just because of customer satisfaction and/or reputation of firm	1

The reputation of the firm is one of the fundamental properties that affect the firms in many ways. For instance, the reliability, prestige of firm and sales ratio of the products are affected by reputation of the firm. If a failure mode is missed out by risk analysts and then this failure mode cause to big accident, poisoning, etc. that affects the reputation of the firm negatively. Another point is that once a time the reputation is exposed to reputational harm; it is really hard to gain past reputation and prestige of the firm again. Criterion-5 considers customer satisfaction status of firms. Responds and complaints from customer play important role.

Step 4: Determining RPN2 value

For each decision factors, decision makers give scores. Multiplication of each corrective actions' scores with corresponding weights of criteria (decision factors) together with weights of decision makers and then the summation of all what we calculate the value of RPN2 for current corrective action. Finally, the RPN2 values are normalized. For example, we have 5 criteria and the weights are 0,25, 0,15, 0,20, 0,10, 0,30 by DM1; 0,25, 0,20, 0,10, 0,30, 0,15 by DM2 and 0,40, 0,25, 0,10, 0,15, 0,10 respectively. And the scores given by each DMs are 0,25, 0,50, 0,50, 0, 0,75 by DM1; 0,50, 0,75, 0,75, 0,25, 0,25 by DM2 and 0,50, 0,25, 0,75, 0,50, 0,50 by DM3. The weights of DMs are 0,40, 0,25, 0,35 respectively. RPN2 value for that failure mode is presented below:

RPN2= (0,25*0,25+0,15*0,50+0,2*0,50+0,10*0+0,30*0,75)*0,40

+ (0,25*0,50+0,20*0,75+0,10*0,75+0,30*0,25+0,15*0,25)*0,25

+(0,40*0,50+0,25*0,25+0,10*0,75+0,15*0,50+0,10*0,50)*0,35

= 0,247

Step 5: Calculation of RPN3

RPN1 is calculated by means of three decision factors O, S, and D and RPN2 is calculated by means of five decision factors (criteria). As to 3 occupational health and safety specialists (One of them is class-A, one of them class-B and the other one is class-C) the reasonable coefficient for RPN2 is 0,05. Thus, RPN1 has a coefficient equal to 0,95. They determined these number as to their experiences (the application number of FMEA in different firms) and academic knowledge.

After calculating RPN3 values, FMEA team should prepare report paper to follow the actions, check the calculation and keep the record of failure modes. A sample paper is presented in Figure 3.2.

Date: 28.06.2014	***FAILURE MODE AND EFFECTS ANALYSIS (FMEA) RISK ANALYSIS FORM***	**FMEA Type:** Proses
Proses: Fuel Tanks		**FMEA NO.** 1

FMEA Team Member: Chemist Ece ESEN, C-Class OHS Specialist Fulya DURU, Maintenance worker Ahmet TAYLAN,

No.	*System/ Part*	*FM*	*FE.*	*CF.*	*DM. NO. & Weights*	*Weights of DF (O,S, and D)*	*DF scores for each DMs*	*RPN1*	*RPN2*	*RPN3*	*Pr.*	*Corrective Action*	*Responsibility*	*Due Time*	*Next Control Time/ Control Period*	*DF scores for each DMs after C.A.*	*RPN1*
1	Tank	Liquid Burst	Poisoning	Measurement Error	1 (0,44)	O= 0,25	O= 6	0,540	0,207	0,552	6	New measurement machine should be bought.	Laboratory (Ece ESEN)	08.07 2014	08.10 2014	O= 2	0,920
						S=0,45	S=7									S=1	
						D=0,30	D=6									D=1	
					2 (0,18)	O= 0,25	O= 7									O= 1	
						S=0,45	S=6									S=2	
						D=0,30	D=5									D=1	
					3 (0,38)	O= 0,25	O= 5									O= 3	
						S=0,45	S=7									S=2	
						D=0,30	D=4									D=2	

Figure 3.2: FMEA report paper (Sample)

4. CASE STUDY

4.1 ADOPTATION THE PROPOSED METHODOLOGY TO THE CASE COMPANY

The application of the proposed FMEA approach has been applied in a yarn manufacturing company. The company is in the Turkey, covered 35000 m^2 area. Its annual production is 6000 tons. Target market is European countries (%70) and the remaining is for domestic market.

In recent years, occupational health and safety concept is rapidly growing in Turkey. Thus, the company fulfills the obligations which are about the OHS. One of the fundamental steps of OHS activities is risk analyzing. The risk analysis is made with the help of proposed FMEA methodology.

Three decision makers are assigned to apply the proposed FMEA methodology. Thanks to the visual research in all departments of the company, risk analysis, accidents and near misses event records from previous years, in addition to getting feedback from engineers, foremen and workers, 50 failure modes are determined. The list of failure modes is presented in Table 4.1.

Table 4.1: A list of failure modes

FM NO.	System/ Part	Failure Mode
1	Husks storage	Too high stacking
2	Waste landfill area	Fluorescent dust is breathed by workers
3	Blow room section	Working in high places
4	Blow room section	Dusty air condition in workplace
5	Manufacturing section	It seems hard to reach fire extinguisher in emergency
6	Manufacturing section	Non-ergonomic way of working
7	Manufacturing section	Working without steel consolidated shoes
8	Manufacturing section	The absence of fire extinguisher
9	Manufacturing section	Working in dusty workplace
10	Manufacturing section	Workers do not use earmuff
11	Welding workshop	Workers use no vise while they use drill machine
12	Mess hall	Workers in mess hall do not wear protective shoes
13	Packaging section	Working without machine protector
14	Packaging section	There is no automatic stopper mechanism and any sensor when the door is opened

15	Packaging section	Inconvenient conversation for Solvent
16	Packaging section	Manometer’s limits is not identified
17	Packaging section	Workers enter the machine and then carry out materials from the inside
18	Mess hall	Electric plug is very close to LPG connection cable
19	Operation-1 section	The possibility of deactivation of safety cover of machine
20	Operation-1 section	There are unnecessary materials inside the fire cabinet
21	Operation-1 section	Opening the iron bale package by using iron scissors
22	Operation-1 section	The workplace is not isolated against the risk of cylinder falling
23	Operation-1 section	Workers put order the items one by one by using their naked hands.
24	Operation-1 section	The machine door is throwing back too fast
25	Operation-2 section	The possibility of fire in BOX machine
26	Operation-2 section	The absence of middle-railing
27	Operation-1&2 section	The safety wire of Bobbin machine is worn out
28	Administrative building	Machine of drinking water is placed on the wet floor
29	Administrative building	Workers monitor the PC screen for a long time period without break
30	Administrative building	The possibility of existence of Legionella bacteria inside air conditioner water
31	Administrative building	The emergency door is opening to the inside of workplace
32	Husks pressing section	Workers put their naked hands inside the press machine
33	Husks pressing section	The usage of falcate
34	Husks pressing section	Working in high workplace without preventative measurement
35	Husks pressing section	The absence of fire extinguisher
36	Items winding section	Workers use their naked hands to put items into rotating parts of machine
37	Items winding section	Too much stacking of items
38	Carder machine	There some snacks, drinks etc. exist inside the machine
39	Carder machine	Broken safety switches on the control panel
40	Carder machine	Workers insert cotton into machine by their naked hands
41	Carder machine	Workers clean the moving parts of machine with naked hand
42	Ring machine	There is no dust absorber mechanism in the workplace
43	Ring machine	Rotating parts of the machine have no protective cover
44	Bobbin machine	Coiling up the reel too much forces the reel to fly off
45	Bale opener machine	The possibility of deactivation of safety chains and safety sensor
46	Fuel tank (Across the Box storage)	The tank is plastic and has no earthling
47	Diesel forklift (Warehouse)	Using diesel forklift in closed workplace
48	Diesel forklift (Warehouse)	Driving forklift uncontrollable and fast
49	Diesel forklift (Warehouse)	Safety lock which is for forklift basket is broken
50	Laboratory	The rotating parts of the machine has no preventative cover

4.1.1 Decision Makers Weighting

Firstly, 3 experienced and knowledgeable occupational health and safety specialists (One of them is class-A, one of them class-B and the other one is class-C) determine weights for FMEA team members (decision makers, DMs) with the help of interpersonal comparisons and fuzzy AHP. Fuzzy AHP is used for determining the criteria weights of DMs and the interpersonal comparison is used for determining scores to DMs. In this case, three decision makers are employed to apply proposed FMEA methodology for the case company. One of the decision makers (FMEA team member) is experienced maintenance worker; the other one is C-Class OHS specialist and last one is one of supporting worker. DMs' features are presented below:

Maintenance worker (DM1): Maintenance worker has worked for that firm for 8 years. He graduated from industrial vocational high school. He always tries to eliminate the failures in the workplace. He tries to repair the machines, provide maintenance of machines, machine parts and so on. He has 54 from the test risk analyzing test. He has been a member of risk analysis application for 4 times (2 of them has taken part in his workplace the other two has not).

C-Class OHS specialist (DM2): OHS specialist has worked for that firm for 2 years. He graduated from industrial engineering department. He is aware of workplace failures but not as maintenance worker does. He has deep knowledge about the regulations and laws regarding with OHS concept. He has 96 from the test risk analyzing test. He has been a member of risk analysis application for 3 times (none of them has taken part in his workplace before).

Supporting worker (DM3): Supporting worker is the worker who is employed by employer for preventing, protecting, evacuating and firefighting issues regarding with OHS. He/she is specifically assigned for first-aid and other similar matters. He/she has proper equipment and adequate knowledge. These definitions are taken from the Turkish OHS law. In the case study, supporting worker has worked for that firm for 5 years. He graduated from university, philosophy department. Unluckily he could not find a job that is related his education so that he began to work for that firm as a production worker. He partially knows and is unaware of failure in the workplace because he works in the same place. He has 70 from the test risk analyzing test. He has been a member of risk analysis application for 4 times (1 of them has taken part in his workplace the other three has not).

After three experienced and knowledgeable occupational health and safety specialists determine weights for DMs' criteria by using fuzzy AHP, they give scores to DMs for each criterion. By multiplying each criterion weight with the decision makers' criterion score we obtain the DMs' weights. Finally, the normalization of calculated weights gives us the crisp values of DMs' weights. A numerical study is presented below:

Step 1: Determination of DMs' criteria weights

Pairwise comparison matrices are established by three OHS specialists as shown in Table 4.2-4.4. Each OHs specialist makes pairwise comparisons for five criteria.

Table 4.2: A pairwise comparison matrix of DMs (OHS-1)

OHS-1	Job relevance	Experience	Education Level	Test Result	Repetition Number
Job relevance	(1.00,1.00,1.00)	(0.20,0.33,1.00)	(3.00,5.00,7.00)	(5.00,7.00,9.00)	(3.00,5.00,7.00)
Experience	(1.00,3.00,5.00)	(1.00,1.00,1.00)	(3.00,5.00,7.00)	(7.00,9.00,9.00)	(5.00,7.00,9.00)
Education Level	(0.14,0.20,0.33)	(0.14,0.20,0.33)	(1.00,1.00,1.00)	(1.00,3.00,5.00)	(0.33,1.00,1.00)
Test Result	(0.11,0.14,0.20)	(0.11,0.11,0.14)	(0.20,0.33,1.00)	(1.00,1.00,1.00)	(0.20,0.33,1.00)
Repetition Number	(0.14,0.20,0.33)	(0.11,0.14,0.20)	(1.00,1.00,3.00)	(1.00,3.00,5.00)	(1.00,1.00,1.00)

Table 4.3: A pairwise comparison matrix of DMs (OHS-2)

OHS-2	Job relevance	Experience	Education Level	Test Result	Repetition Number
Job relevance	(1.00,1.00,1.00)	(0.33,1.00,1.00)	(1.00,3.00,5.00)	(5.00,7.00,9.00)	(5.00,7.00,9.00)
Experience	(1.00,1.00,3.00)	(1.00,1.00,1.00)	(3.00,5.00,7.00)	(5.00,7.00,9.00)	(5.00,7.00,9.00)
Education Level	(0.20,0.33,1.00)	(0.14,0.20,0.33)	(1.00,1.00,1.00)	(3.00,5.00,7.00)	(0.14,0.20,0.33)
Test Result	(0.11,0.14,0.20)	(0.11,0.14,0.20)	(0.14,0.20,0.33)	(1.00,1.00,1.00)	(0.11,0.14,0.20)
Repetition Number	(0.11,0.14,0.20)	(0.11,0.14,0.20)	(3.00,5.00,7.00)	(5.00,7.00,9.00)	(1.00,1.00,1.00)

Table 4.4: A pairwise comparison matrix of DMs (OHS-3)

OHS-3	Job relevance	Experience	Education Level	Test Result	Repetition Number
Job relevance	(1.00,1.00,1.00)	(0.33,1.00,1.00)	(5.00,7.00,9.00)	(7.00,9.00,9.00)	(3.00,5.00,7.00)
Experience	(1.00,1.00,3.00)	(1.00,1.00,1.00)	(5.00,7.00,9.00)	(7.00,9.00,9.00)	(1.00,3.00,5.00)
Education Level	(0.11,0.14,0.20)	(0.11,0.14,0.20)	(1.00,1.00,1.00)	(3.00,5.00,7.00)	(0.14,0.20,0.33)
Test Result	(0.11,0.11,0.14)	(0.11,0.11,0.14)	(0.14,0.20,0.33)	(1.00,1.00,1.00)	(0.11,0.14,0.20)
Repetition Number	(0.14,0.20,0.33)	(0.20,0.33,1.00)	(3.00,5.00,7.00)	(5.00,7.00,9.00)	(1.00,1.00,1.00)

Step 1.1: Calculation of r_i *and* w_i *values*

After obtaining the pairwise comparison matrix, geometric mean values of fuzzy comparison values and fuzzy weight matrix is calculated by using Eqs. (3.3) and (3.4) as follows in the Table 4.5 and 4.6:

Table 4.5: Geometric mean values of fuzzy comparison values

	OHS-1			OHS-2			OHS-3		
	l	m	n	l	m	n	l	m	n
r_1	1,5518	2,2552	3,3798	1,5281	2,7131	3,3227	2,0362	3,1598	3,5540
r_2	2,5365	3,9363	4,9036	2,3714	3,0049	4,4273	2,0362	2,8529	4,1392
r_3	0,3686	0,6544	0,8891	0,4146	0,5818	0,9510	0,3505	0,4592	0,6223
r_4	0,2181	0,2814	0,4911	0,1813	0,2255	0,3056	0,1813	0,2039	0,2671
r_5	0,4366	0,6118	1,0000	0,7137	0,9349	1,2030	0,8441	1,1847	1,8384

Table 4.6: Fuzzy weights matrix

	OHS-1			OHS-2			OHS-3		
	l	m	n	l	m	n	l	m	n
w_1	0,1455	0,2914	0,6612	0,1497	0,3637	0,6379	0,1954	0,4020	0,6523
w_2	0,2379	0,5086	0,9593	0,2323	0,4028	0,8499	0,1954	0,3629	0,7597
w_3	0,0346	0,0846	0,1739	0,0406	0,0780	0,1826	0,0336	0,0584	0,1142
w_4	0,0205	0,0364	0,0961	0,0178	0,0302	0,0587	0,0174	0,0259	0,0490
w_5	0,0409	0,0791	0,1956	0,0699	0,1253	0,2309	0,0810	0,1507	0,3374

Step 1.2: Calculation of w_r values

The defuzzification and normalization is calculated by using Eq.(3.5) as presented in Table 4.7:

Table 4.7: The crisp values of DMs criteria weights

	OHS-1 Weights	OHS-2 Weights	OHS-3 Weights	Arithmetic mean
w_1	0,3080	0,3317	0,3638	0,3345
w_2	0,4784	0,4279	0,3837	0,4300
w_3	0,0822	0,0868	0,0600	0,0763
w_4	0,0429	0,0307	0,0269	0,0335
w_5	0,0885	0,1228	0,1657	0,1257

To see the criteria weights more visually;

Job relevance = 0,3345
Experience = 0,4300
Education level = 0,0763
Test Results = 0,0335
Repetition Number = 0,1257

Step 2: Giving scores to DMs by using criteria scales

The criteria scores that are given by three OHS specialists are shown in Table 4.8.

Table 4.8: Criteria score table of DMs

	Job relevance	Experience	Education Level	Test Result	Repetition Number
DM1	5	4	3	1	4
DM2	2	2	4	5	3
DM3	3	3	4	3	4

Step 3: Calculation of the final crisp values of DMs' weights

And finally the crisp values of DMs' weight are obtained as shown in Table 4.9.

Table 4.9: The final crisp values of DMs' weights

	Job Relevance x 0,3345	Experience x 0,4300	Education Level x 0,0763	Test Result x 0,0335	Repetition Number x 0,1257	Weights of DMs	Normalized Weights of DMs
DM1	5	4	3	1	4	4,1577	0,4269
DM2	2	2	4	5	3	2,3788	0,2442
DM3	3	3	4	3	4	3,2020	0,3288

4.1.2 Determining RPN1 values

Then, each decision maker makes judgments on decision factors (O, S and D) and determines their weights separately with the help of fuzzy AHP. At this point, GRA is applied to calculate RPN1 values. The first prioritization of failure modes and the prioritization of corresponding corrective actions are made according to RPN1 values.

Step 1: Assigning different weights to decision factors O, S, and D

At this point each decision makers makes judgments on decision factors (O, S and D) and determine their weights separately with the help of fuzzy AHP. To be able to incorporate these weights to the calculations GRA is used.

First, to assign weights to decision factors O, S, and D we should establish a pairwise comparison matrix of decision factors for each of the decision makers as shown in Table 4.10-4.12. Then, DMs apply Buckley's Fuzzy AHP method to obtain the weights. Steps are similar to DMs' weighting process.

Table 4.10: DM1 pairwise comparison matrix

DM1	O	S	D
O	(1.00,1.00,1.00)	(0.11,0.14,0.20)	(0.20,0.33,1.00)
S	(5.00,7.00,9.00)	(1.00,1.00,1.00)	(3.00,5.00,7.00)
D	(1.00,3.00,5.00)	(0.14,0.20,0.33)	(1.00,1.00,1.00)

Table 4.11: DM2 pairwise comparison matrix

DM2	O	S	D
O	(1.00,1.00,1.00)	(0.14,0.20,0.33)	(0.20,0.33,1.00)
S	(3.00,5.00,7.00)	(1.00,1.00,1.00)	(1.00,3.00,5.00)
D	(1.00,3.00,5.00)	(0.20,0.33,1.00)	(1.00,1.00,1.00)

Table 4.12: DM3 pairwise comparison matrix

DM3	O	S	D
O	(1.00,1.00,1.00)	(0.14,0.20,0.33)	(0.33,1.00,1.00)
S	(3.00,5.00,7.00)	(1.00,1.00,1.00)	(1.00,1.00,3.00)
D	(1.00,1.00,3.00)	(0.33,1.00,1.00)	(1.00,1.00,1.00)

Step 1.1: Calculation of r_i and w_i values

After obtaining the pairwise comparison matrix, geometric mean values of fuzzy comparison values and fuzzy weight matrix is calculated by using Eq. (3.3) and Eq. (3.4) as follows in the Table 4.13 and 4.14:

Table 4.13: Geometric mean values of fuzzy comparison values

	DM1			DM2			DM3		
	l	m	n	l	m	n	l	m	n
r_1	0,3625	0,5848	0,6934	0,4055	0,6934	1,0000	0,6934	1,0000	1,4422
r_2	1,4422	2,4662	3,2711	1,0000	1,4422	2,4662	1,0000	1,0000	2,0801
r_3	0,5848	0,6934	1,4422	0,6934	1,0000	1,4422	0,4807	1,0000	1,0000

Table 4.14: Fuzzy weights matrix

	DM1			DM2			DM3		
	l	m	n	l	m	n	l	m	n
w_1	0,0670	0,1562	0,2902	0,0826	0,2211	0,4765	0,1533	0,3333	0,6634
w_2	0,2668	0,6586	1,3689	0,2037	0,4600	1,1750	0,2211	0,3333	0,9568
w_3	0,1082	0,1852	0,6036	0,1413	0,3189	0,6872	0,1063	0,3333	0,4600

Step 1.2: Calculation of w_r values

The defuzzification and normalization is calculated by using Eq.(3.5) as follows in Table 4.15:

Table 4.15: The crisp values of DMs criteria weights

	DM1 Weights	DM2 Weights	DM3 Weights
w_1 (occurrence)	0,1386	0,2072	0,3230
w_2 (severity)	0,6193	0,4882	0,4244
w_3 (detectability)	0,2421	0,3046	0,2526

Step 2: Giving scores to decision factors O, S, and D

After determining the decision factors' weights, each DM gives scores to decision factors from 10-point scales. According to these scores and determined weights of decision factors, the application of GRA is performed individually for all failure modes and with each DMs individually. The score that are given by DMs is presented in Table 4.16. At the end of GRA methodology, we obtain RPN values for each of DMs. Finally, the weighted arithmetic means is calculated to obtain RPN1 values of failure modes.

Table 4.16: FM scores given by three DMs

No	System/ Part	Failure Mode	DM1			DM2			DM3		
			O	S	D	O	S	D	O	S	D
1	Husks storage	Too high stacking	3	2	3	7	5	3	4	3	4
2	Waste landfill area	Fluorescent dust is breathed by workers	3	5	3	6	4	5	4	4	3
3	Blow room section	Working in high places	3	5	3	6	6	2	4	5	3
4	Blow room section	Dusty air condition in workplace	3	5	6	7	2	4	4	5	6
5	Manufacturing section	It seems hard to reach fire extinguisher in emergency	6	6	3	6	7	3	7	7	3
6	Manufacturing section	Non-ergonomic way of working	3	5	4	7	5	4	4	5	4
7	Manufacturing section	Working without steel consolidated shoes	7	3	5	9	4	2	7	4	3
8	Manufacturing section	The absence of fire extinguisher	6	7	4	5	8	3	6	8	4
9	Manufacturing section	Working in dusty workplace	3	5	5	7	3	4	6	3	5
10	Manufacturing section	Workers do not use earmuff	3	5	5	7	6	3	5	4	5
11	Welding workshop	Workers use no vise while they use drill machine	6	7	5	5	9	6	6	8	5
12	Mess hall	Workers in mess hall do not wear protective shoes	3	4	6	5	2	3	3	3	5
13	Packaging section	Working without machine protector	6	5	5	4	7	5	6	5	5
14	Packaging section	There is no automatic stopper mechanism and any sensor when the door is opened	3	5	6	6	7	6	5	6	6
15	Packaging section	Inconvenient conversation for Solvent	5	7	5	8	8	6	7	8	6
16	Packaging section	Manometer's limits is not identified	3	6	5	2	6	8	3	6	6

17	Packaging section	Workers enter the machine and then carry out materials from the inside	3	3	4	7	7	4	5	5	5
18	Mess hall	Electric plug is very close to LPG connection cable	3	7	4	8	7	6	5	6	4
19	Operation-1 section	The possibility of deactivation of safety cover of machine	1	3	7	3	7	3	2	4	2
20	Operation-1 section	There are unnecessary materials inside the fire cabinet	3	3	4	8	2	5	4	3	4
21	Operation-1 section	Opening the iron bale package by using iron scissors	3	3	5	4	3	4	3	3	4
22	Operation-1 section	The workplace is not isolated against the risk of cylinder falling	3	2	5	6	7	5	3	3	5
23	Operation-1 section	Workers put order the items one by one by using their naked hands.	3	6	3	7	7	5	3	6	3
24	Operation-1 section	The machine door is throwing back too fast	3	3	6	6	7	6	3	5	4
25	Operation-2 section	The possibility of fire in BOX machine	3	6	7	3	7	5	3	6	4
26	Operation-2 section	The absence of middle-railing	3	4	4	6	2	2	3	3	3
27	Operation-1&2 section	The safety wire of Bobbin machine is worn out	3	5	7	3	7	5	3	6	6
28	Administrative building	Machine of drinking water is placed on the wet floor	3	6	5	8	5	2	4	5	3
29	Administrative building	Workers monitor the PC screen for a long time period without break	6	5	4	9	3	3	7	3	3
30	Administrative building	The possibility of existence of Legionella bacteria inside air conditioner water	3	6	6	2	7	9	2	6	8
31	Administrative building	The emergency door is opening to the inside of workplace	3	6	5	5	6	5	4	6	5
32	Husks pressing section	Workers put their naked hands inside the press machine	5	5	4	3	7	6	3	6	5
33	Husks pressing section	The usage of falcate	3	3	4	8	4	4	6	3	4
34	Husks pressing section	Working in high workplace without preventative measurement	4	6	3	6	8	3	4	7	3
35	Husks pressing section	The absence of fire extinguisher	3	6	5	4	7	3	4	6	3
36	Items winding section	Workers use their naked hands to put items into rotating parts of machine	4	5	4	6	7	4	4	5	4
37	Items winding section	Too much stacking of items	6	2	3	7	4	3	6	3	3
38	Carder machine	There some snacks, drinks etc. exist inside the machine	7	3	4	8	2	4	7	2	4
39	Carder machine	Broken safety switches on the control panel	3	5	6	3	5	5	3	5	5
40	Carder machine	Workers insert cotton into machine by their naked hands	6	5	6	7	6	4	6	5	6
41	Carder machine	Workers clean the moving parts of machine with naked hand	4	5	4	6	7	4	4	4	4
42	Ring machine	There is no dust absorber mechanism in the workplace	6	3	5	8	5	5	6	5	5
43	Ring machine	Rotating parts of the machine have no protective cover	4	4	5	6	7	3	4	8	6
44	Bobbin machine	Coiling up the reel too much forces the reel to fly off	3	2	5	5	6	5	4	4	4
45	Bale opener machine	The possibility of deactivation of safety chains and safety sensor	2	6	7	2	7	7	2	6	6
46	Fuel tank (Across the Box storage)	The tank is plastic and has no earthling	6	6	7	7	8	7	7	7	7
47	Diesel forklift (Warehouse)	Using diesel forklift in closed workplace	5	5	4	6	6	3	5	5	4
48	Diesel forklift (Warehouse)	Driving forklift uncontrollable and fast	3	6	7	6	7	3	4	5	6
49	Diesel forklift (Warehouse)	Safety lock which is for forklift basket is broken	6	6	6	2	6	8	7	6	5
50	Laboratory	The rotating parts of the machine has no preventative cover	3	3	5	4	7	3	4	4	3

Step 3: Incorporating the weights of decision factors (O, S, and D) to the RPN1 calculation and determining threshold

At this point, GRA is used to incorporate the weights of decision factors and then to calculate RPN1 values. GRA is applied by DMs individually. To demonstrate the proposed methods, second decision maker's (DM2) calculations are obtained as following steps:

Step 3.1: Establishing the comparative series

$$\begin{vmatrix} X_1(1) X_1(2) X_1(3) \\ X_2(1) X_2(2) X_3(3) \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ X_{49}(1) X_{49}(2) X_{49}(3) \\ X_{50}(1) X_{50}(2) X_{50}(3) \end{vmatrix} = \begin{vmatrix} O & S & D \\ 7 & 5 & 3 \\ 6 & 4 & 5 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 2 & 4 & 8 \\ 4 & 7 & 3 \end{vmatrix}$$

To reduce the potential risk, all decision factors should be as small as standard series.

Step 3.2: Establishing the standard series

$$X_0(k) = [X_0(1), X_0(2), X_0(3)] = [1,1,1]$$

$$\begin{vmatrix} \Delta_{01}(1) & \Delta_{01}(2) & \Delta_{01}(3) \\ \Delta_{02}(1) & \Delta_{02}(2) & \Delta_{02}(3) \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \Delta_{49}(1) & \Delta_{49}(2) & \Delta_{49}(3) \\ \Delta_{50}(1) & \Delta_{50}(2) & \Delta_{50}(3) \end{vmatrix} = \begin{vmatrix} 5 & 4 & 2 \\ 5 & 3 & 4 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 1 & 3 & 7 \\ 3 & 6 & 2 \end{vmatrix}$$

Step 3.3: Computing the grey relation coefficient

To compute grey relation coefficient, O, S, and D are compared with the corresponding standard series by using Eq. (3.10).

To be able to use Eq. (3.10) the minimum value of all Δ_i (k) and the maximum value of all Δ_i (k) should be obtained.

$\Delta_{min} = 1$,

$\Delta_{max} = 8$

And the $\zeta = 0,5$

Step 3.4: Computing the DM1's grey relation coefficients:

$$\begin{vmatrix} \gamma_{01} & \gamma_{01} & \gamma_{01} \\ \gamma_{02} & \gamma_{02} & \gamma_{02} \\ . & . & . \\ . & . & . \\ \gamma_{49} & \gamma_{49} & \gamma_{49} \\ \gamma_{50} & \gamma_{50} & \gamma_{01} \end{vmatrix} = \begin{vmatrix} 0,556 & 0,625 & 0,833 \\ 0,556 & 0,714 & 0,625 \\ . & . & . \\ . & . & . \\ 1,000 & 0,714 & 0,455 \\ 0,714 & 0,500 & 0,833 \end{vmatrix}$$

Step 3.5: Computing the degree of relation

At the final stage, decision factors' (O, S, and D) weights are incorporated into calculation of degree of relation for all failure modes by using Eq. (3.11).

$\tau_{i} =$ i^{th} degree of relationship

For all failure modes, 50 degree of relationship is calculated and then the relational series for each DM are presented in table 4.17.

Table 4.17: Degree of grey relationship for FMs

FM NO	DM1's relational series			DM2's relational series			DM3's relational series		
1	0,800	1,000	0,800	0,500	0,625	0,833	0,692	0,818	0,692
2	0,800	0,571	0,800	0,556	0,714	0,625	0,692	0,692	0,818
3	0,800	0,571	0,800	0,556	0,556	1,000	0,692	0,600	0,818
4	0,800	0,571	0,500	0,500	1,000	0,714	0,692	0,600	0,529
5	0,500	0,500	0,800	0,556	0,500	0,833	0,474	0,474	0,818
6	0,800	0,571	0,667	0,500	0,625	0,714	0,692	0,600	0,692
7	0,444	0,800	0,571	0,417	0,714	1,000	0,474	0,692	0,818
8	0,500	0,444	0,667	0,625	0,455	0,833	0,529	0,429	0,692
9	0,800	0,571	0,571	0,500	0,833	0,714	0,529	0,818	0,600
10	0,800	0,571	0,571	0,500	0,556	0,833	0,600	0,692	0,600
11	0,500	0,444	0,571	0,625	0,417	0,556	0,529	0,429	0,600
12	0,800	0,667	0,500	0,625	1,000	0,833	0,818	0,818	0,600
13	0,500	0,571	0,571	0,714	0,500	0,625	0,529	0,600	0,600
14	0,800	0,571	0,500	0,556	0,500	0,556	0,600	0,529	0,529
15	0,571	0,444	0,571	0,455	0,455	0,556	0,474	0,429	0,529
16	0,800	0,500	0,571	1,000	0,556	0,455	0,818	0,529	0,529
17	0,800	0,800	0,667	0,500	0,500	0,714	0,600	0,600	0,600

18	0,800	0,444	0,667	0,455	0,500	0,556	0,600	0,529	0,692
19	1,333	0,800	0,444	0,833	0,500	0,833	1,000	0,692	1,000
20	0,800	0,800	0,667	0,455	1,000	0,625	0,692	0,818	0,692
21	0,800	0,800	0,571	0,714	0,833	0,714	0,818	0,818	0,692
22	0,800	1,000	0,571	0,556	0,500	0,625	0,818	0,818	0,600
23	0,800	0,500	0,800	0,500	0,500	0,625	0,818	0,529	0,818
24	0,800	0,800	0,500	0,556	0,500	0,556	0,818	0,600	0,692
25	0,800	0,500	0,444	0,833	0,500	0,625	0,818	0,529	0,692
26	0,800	0,667	0,667	0,556	1,000	1,000	0,818	0,818	0,818
27	0,800	0,571	0,444	0,833	0,500	0,625	0,818	0,529	0,529
28	0,800	0,500	0,571	0,455	0,625	1,000	0,692	0,600	0,818
29	0,500	0,571	0,667	0,417	0,833	0,833	0,474	0,818	0,818
30	0,800	0,500	0,500	1,000	0,500	0,417	1,000	0,529	0,429
31	0,800	0,500	0,571	0,625	0,556	0,625	0,692	0,529	0,600
32	0,571	0,571	0,667	0,625	0,556	0,625	0,818	0,529	0,600
33	0,800	0,800	0,667	0,455	0,714	0,714	0,529	0,818	0,692
34	0,667	0,500	0,800	0,556	0,455	0,833	0,692	0,474	0,818
35	0,800	0,500	0,571	0,714	0,500	0,833	0,692	0,529	0,818
36	0,667	0,571	0,667	0,556	0,500	0,714	0,692	0,600	0,692
37	0,500	1,000	0,800	0,500	0,714	0,833	0,529	0,818	0,818
38	0,444	0,800	0,667	0,455	1,000	0,714	0,474	1,000	0,692
39	0,800	0,571	0,500	0,833	0,625	0,625	0,818	0,600	0,600
40	0,500	0,571	0,500	0,500	0,556	0,714	0,529	0,600	0,529
41	0,667	0,571	0,667	0,556	0,500	0,714	0,692	0,692	0,692
42	0,500	0,800	0,571	0,455	0,625	0,625	0,529	0,600	0,600
43	0,667	0,667	0,571	0,556	0,500	0,833	0,692	0,429	0,529
44	0,800	1,000	0,571	0,625	0,556	0,625	0,692	0,692	0,692
45	1,000	0,500	0,444	1,000	0,500	0,500	1,000	0,529	0,529
46	0,500	0,500	0,444	0,500	0,455	0,500	0,474	0,474	0,474
47	0,571	0,571	0,667	0,556	0,556	0,833	0,600	0,600	0,692
48	0,800	0,500	0,444	0,556	0,500	0,833	0,692	0,600	0,529
49	0,500	0,500	0,500	1,000	0,556	0,455	0,474	0,529	0,600
50	0,800	0,800	0,571	0,714	0,500	0,833	0,692	0,692	0,818

Step 4: Calculation of final RPN1 values

The RPN1 values of failure modes then obtained by arithmetic means of each decision makers RPN values. RPN values of each DMs and the final RPN2 values and prioritization are presented in Table 4.18.

Table 4.18 Final RPN1 calculation

FM NO	RPN values of DM1	Weights of DM1	RPN values of DM2	Weights of DM2	RPN values of DM3	Weights of DM3	RPN1	Prioritization
1	0,924	0,4269	0,663	0,2442	0,746	0,3288	0,801	50
2	0,658	0,4269	0,654	0,2442	0,724	0,3288	0,679	37
3	0,658	0,4269	0,691	0,2442	0,685	0,3288	0,675	36
4	0,586	0,4269	0,809	0,2442	0,612	0,3288	0,649	31
5	0,573	0,4269	0,613	0,2442	0,561	0,3288	0,579	11
6	0,626	0,4269	0,626	0,2442	0,653	0,3288	0,635	29
7	0,695	0,4269	0,740	0,2442	0,653	0,3288	0,692	38
8	0,506	0,4269	0,605	0,2442	0,528	0,3288	0,537	4
9	0,603	0,4269	0,728	0,2442	0,670	0,3288	0,655	32
10	0,603	0,4269	0,629	0,2442	0,639	0,3288	0,621	24
11	0,483	0,4269	0,502	0,2442	0,504	0,3288	0,495	3
12	0,645	0,4269	0,872	0,2442	0,763	0,3288	0,739	41
13	0,562	0,4269	0,582	0,2442	0,577	0,3288	0,572	9
14	0,586	0,4269	0,528	0,2442	0,552	0,3288	0,561	7
15	0,493	0,4269	0,485	0,2442	0,469	0,3288	0,483	2
16	0,559	0,4269	0,617	0,2442	0,623	0,3288	0,594	15
17	0,768	0,4269	0,565	0,2442	0,600	0,3288	0,663	33
18	0,548	0,4269	0,508	0,2442	0,593	0,3288	0,553	6

19	0,788	0,4269	0,671	0,2442	0,869	0,3288	0,786	48
20	0,768	0,4269	0,773	0,2442	0,746	0,3288	0,762	45
21	0,745	0,4269	0,772	0,2442	0,786	0,3288	0,765	46
22	0,869	0,4269	0,550	0,2442	0,763	0,3288	0,756	44
23	0,614	0,4269	0,538	0,2442	0,696	0,3288	0,622	25
24	0,727	0,4269	0,528	0,2442	0,694	0,3288	0,668	35
25	0,528	0,4269	0,607	0,2442	0,664	0,3288	0,592	14
26	0,685	0,4269	0,908	0,2442	0,818	0,3288	0,783	47
27	0,572	0,4269	0,607	0,2442	0,623	0,3288	0,597	16
28	0,559	0,4269	0,704	0,2442	0,685	0,3288	0,636	30
29	0,585	0,4269	0,747	0,2442	0,707	0,3288	0,664	34
30	0,542	0,4269	0,578	0,2442	0,656	0,3288	0,588	13
31	0,559	0,4269	0,591	0,2442	0,600	0,3288	0,580	12
32	0,594	0,4269	0,586	0,2442	0,641	0,3288	0,607	19
33	0,768	0,4269	0,660	0,2442	0,693	0,3288	0,717	40
34	0,596	0,4269	0,591	0,2442	0,631	0,3288	0,606	18
35	0,559	0,4269	0,646	0,2442	0,655	0,3288	0,612	21
36	0,608	0,4269	0,577	0,2442	0,653	0,3288	0,615	22
37	0,882	0,4269	0,706	0,2442	0,725	0,3288	0,787	49
38	0,718	0,4269	0,800	0,2442	0,752	0,3288	0,749	43
39	0,586	0,4269	0,668	0,2442	0,670	0,3288	0,634	27
40	0,544	0,4269	0,592	0,2442	0,559	0,3288	0,561	8
41	0,608	0,4269	0,577	0,2442	0,692	0,3288	0,628	26
42	0,703	0,4269	0,590	0,2442	0,577	0,3288	0,634	28
43	0,644	0,4269	0,613	0,2442	0,539	0,3288	0,602	17
44	0,869	0,4269	0,591	0,2442	0,692	0,3288	0,743	42
45	0,556	0,4269	0,604	0,2442	0,681	0,3288	0,609	20
46	0,487	0,4269	0,478	0,2442	0,474	0,3288	0,480	1
47	0,594	0,4269	0,640	0,2442	0,623	0,3288	0,615	23
48	0,528	0,4269	0,613	0,2442	0,612	0,3288	0,576	10
49	0,500	0,4269	0,617	0,2442	0,529	0,3288	0,538	5
50	0,745	0,4269	0,646	0,2442	0,724	0,3288	0,714	39

Step 5: Determining the threshold intervals

After establishing the RPN1 values, three OHS specialists determine the threshold interval values. They consider the factors such as budget, work-time, and labor force of company and decide to perform the corrective actions which have the RPN1 value smaller than or equal to 0,600 immediately. The failure modes that have a RPN1 value greater than the 0,600 should be performed with in a reasonable time. Table 4.20 shows the two parts separately by highlighting the part one with light grey color.

Table 4.19: Performing C.A. according to the threshold intervals

Threshold interval for corrective actions of failure modes		Number of C.A.
RPN1 ≤ 0,600	Corrective action should be performed immediately	16
RPN1 > 0,600	Corrective action should be performed according to the company's prevention policy within a reasonable time	34

Table 4.20: Prioritization and categorization of C.A.s according to RPN1 values

FM No.	Priority	Corrective action No.	RPN1 value
46	1	CA.1	0,480
15	2	CA.2	0,483
11	3	CA.3	0,495
8	4	CA.4	0,537
49	5	CA.5	0,538
18	6	CA.6	0,553
14	7	CA.7	0,561
40	8	CA.8	0,561
13	9	CA.9	0,572
48	10	CA.10	0,576
5	11	CA.11	0,579
31	12	CA.12	0,580
30	13	CA.13	0,588
25	14	CA.14	0,592
16	15	CA.15	0,594
27	16	CA.16	0,597
43	17	CA.17	0,602
34	18	CA.18	0,606
32	19	CA.19	0,607
45	20	CA.20	0,609
35	21	CA.21	0,612
36	22	CA.22	0,615
47	23	CA.23	0,615
10	24	CA.24	0,621
23	25	CA.25	0,622
41	26	CA.26	0,628
39	27	CA.27	0,634
42	28	CA.28	0,634
6	29	CA.29	0,635
28	30	CA.30	0,636
4	31	CA.31	0,649
9	32	CA.32	0,655
17	33	CA.33	0,663
29	34	CA.34	0,664
24	35	CA.35	0,668
3	36	CA.36	0,675
2	37	CA.37	0,679
7	38	CA.38	0,692
50	39	CA.39	0,714
33	40	CA.40	0,717
12	41	CA.41	0,739
44	42	CA.42	0,743
38	43	CA.43	0,749
22	44	CA.44	0,756
20	45	CA.45	0,762
21	46	CA.46	0,765
26	47	CA.47	0,783
19	48	CA.48	0,786
37	49	CA.49	0,787
1	50	CA.50	0,801

4.1.3 Determining to RPN2 values

As mentioned in the methodology, DMs should calculate one more RPN value to calculate RPN3 value. This is RPN2. While RPN2 values are calculating, five decision factors (criteria) are weighted. Each decision makers makes judgments on decision factors (criteria) and determine their weights separately with the help of fuzzy AHP. By multiplication of each corrective action's scores with corresponding weights of criteria (decision factors) together with weights of decision makers and then the summation of all, we calculate the value of RPN2 for current corrective action. The steps of RPN2 determination for the case company are as follows:

Step 1: Assigning different weights to criteria

Pairwise comparison matrices are established by DMs and presented in Table 4.21-4.23.

Table 4.21: A pairwise comparison matrices of RPN2's criteria (DM1)

DM1	cost	time loss	obligations	prevention policy	customer satisfaction and reputation
cost	(1.00,1.00,1.00)	(5.00,7.00,9.00)	(0.14,0.20,0.33)	(0.14,0.20,0.33)	(3.00,5.00,7.00)
time loss	(0.11,0.14,0.20)	(1.00,1.00,1.00)	(0.14,0.20,0.33)	(0.14,0.20,0.33)	(3.00,5.00,7.00)
obligations	(3.00,5.00,7.00)	(3.00,5.00,7.00)	(1.00,1.00,1.00)	(1.00,3.00,5.00)	(1.00,1.00,3.00)
prevention policy	(3.00,5.00,7.00)	(3.00,5.00,7.00)	(0.20,0.33,1.00)	(1.00,1.00,1.00)	(1.00,1.00,3.00)
customer satisfaction and reputation	(0.14,0.20,0.33)	(0.14,0.20,0.33)	(0.33,1.00,1.00)	(0.33,1.00,1.00)	(1.00,1.00,1.00)

Table 4.22: A pairwise comparison matrices of RPN2's criteria (DM2)

DM2	cost	time loss	obligations	prevention policy	customer satisfaction and reputation
cost	(1.00,1.00,1.00)	(1.00,3.00,5.00)	(0.11,0.14,0.20)	(0.14,0.20,0.33)	(1.00,3.00,5.00)
time loss	(0.20,0.33,1.00)	(1.00,1.00,1.00)	(0.14,0.20,0.33)	(0.14,0.20,0.33)	(3.00,5.00,7.00)
obligations	(5.00,7.00,9.00)	(3.00,5.00,7.00)	(1.00,1.00,1.00)	(1.00,1.00,3.00)	(3.00,5.00,7.00)
prevention policy	(3.00,5.00,7.00)	(3.00,5.00,7.00)	(0.33,1.00,1.00)	(1.00,1.00,1.00)	(1.00,3.00,5.00)
customer satisfaction and reputation	(0.20,0.33,1.00)	(0.14,0.20,0.33)	(0.14,0.20,0.33)	(0.20,0.33,1.00)	(1.00,1.00,1.00)

Table 4.23: A pairwise comparison matrices of RPN2's criteria (DM2)

DM3	cost	time loss	obligations	prevention policy	customer satisfaction and reputation
cost	(1.00,1.00,1.00)	(3.00,5.00,7.00)	(1.00,1.00,3.00)	(1.00,3.00,5.00)	(5.00,7.00,9.00)
time loss	(0.14,0.20,0.33)	(1.00,1.00,1.00)	(0.20,0.33,1.00)	(0.14,0.20,0.33)	(0.14,0.20,0.33)
obligations	(0.33,1.00,1.00)	(1.00,3.00,5.00)	(1.00,1.00,1.00)	(1.00,3.00,5.00)	(1.00,3.00,5.00)
prevention policy	(0.20,0.33,1.00)	(3.00,5.00,7.00)	(0.20,0.33,1.00)	(1.00,1.00,1.00)	(1.00,1.00,3.00)
customer satisfaction and reputation	(0.11,0.14,0.20)	(3.00,5.00,7.00)	(0.20,0.33,1.00)	(0.33,1.00,1.00)	(1.00,1.00,1.00)

Step 1.1: Calculation of r_i and w_i values

According to Buckley's Fuzzy AHP method the aggregate pairwise comparison matrix is the next step but we want to incorporate the DMs' importance weights to the calculation. Thus, ri, wi and crisp weight values of criteria are calculated by each of the DMs individually. To demonstrate the proposed model, Table 4.24 is presents r_i values, Table 4.25 presents w_i values and Table 4.26 presents the crisp values of RPN2's criteria weights.

Table 4.24: Geometric mean values of fuzzy comparison values (RPN2's criteria)

	DM1			DM2			DM3		
	l	m	n	l	m	n	l	m	n
r_1	0,7892	1,0696	1,4758	0,4366	0,7621	1,1076	1,7188	2,5365	3,9363
r_2	0,3686	0,4911	0,6893	0,4146	0,5818	0,9510	0,2255	0,3056	0,5173
r_3	1,5518	2,3714	3,7433	2,1411	2,8094	4,2103	0,8027	1,9332	2,6265
r_4	1,1247	1,5281	2,7131	1,2457	2,3714	3,0049	0,6544	0,8891	1,8384
r_5	0,2959	0,5253	0,6444	0,2412	0,3385	0,6444	0,4670	0,7505	1,0696

Table 4.25 Fuzzy weights matrix of RPN2's criteria

	DM1			DM2			DM3		
	l	m	n	l	m	n	l	m	n
w_1	0,0852	0,1787	0,3573	0,0440	0,1110	0,2473	0,1721	0,3954	1,0175
w_2	0,0398	0,0820	0,1669	0,0418	0,0848	0,2123	0,0226	0,0476	0,1337
w_3	0,1675	0,3962	0,9063	0,2159	0,4093	0,9400	0,0804	0,3014	0,6790
w_4	0,1214	0,2553	0,6569	0,1256	0,3455	0,6709	0,0655	0,1386	0,4752
w_5	0,0319	0,0878	0,1560	0,0243	0,0493	0,1439	0,0468	0,1170	0,2765

Step 1.2: Calculation of w_r values

Table 4.26: The crisp values of RPN2's criteria weights

	DM1	DM2	DM3
w_1	0,1684	0,1098	0,3993
w_2	0,0783	0,0924	0,0514
w_3	0,3985	0,4270	0,2672
w_4	0,2802	0,3115	0,1712
w_5	0,0747	0,0593	0,1109

Step 2: Giving scores to decision factors O, S, and D

Now, DMs give scores to criteria for each corrective action. Table 4.27 presents the first three corrective actions' criteria score table.

Table 4.27: Criteria score table of RPN2 criteria

CA.1	Cost	Time Loss	Obligations	Prevention Policy	Customer Satisfaction and Reputation
DM1	0,75	0,50	0,50	0,50	0,75
DM2	0,50	0,75	0,50	0,50	0,75
DM3	0,75	0,50	0,25	0,50	0,75
CA.2	Cost	Time Loss	Obligations	Prevention Policy	Customer Satisfaction and Reputation
DM1	0,00	0,00	0,25	0,25	0,50
DM2	0,00	0,00	0,50	0,00	0,25
DM3	0,25	0,00	0,25	0,25	0,25
CA.3	Cost	Time Loss	Obligations	Prevention Policy	Customer Satisfaction and Reputation
DM1	0,25	0,25	0,00	0,25	0,25
DM2	0,25	0,50	0,00	0,25	0,25
DM3	0,25	0,00	0,25	0,00	0,50

Step 3: Calculation of final RPN2 values

And finally the RPN2 values of corrective actions are obtained as shown in the Table 4.28. The table consists of the first corrective action RPN2 calculation. A Full list of RPN2 values of all failure modes and so the corrective actions are presented in Appendix A.

Table 4.28: RPN2 values CA.1

<table>
<tr><th rowspan="2"></th><th rowspan="2">Weights of DMs</th><th colspan="3">Criteria scores & weights</th><th rowspan="2">RPN2 values Of each of DMs</th><th rowspan="2">RPN2</th></tr>
<tr><th>Criteria</th><th>Score</th><th>Weights</th></tr>
<tr><td rowspan="15">CA.1</td><td rowspan="5">DM1 (0,4269)</td><td>Cost</td><td>0,75</td><td>0,1684</td><td rowspan="5">0,5608</td><td rowspan="15">0,5551</td></tr>
<tr><td>Time Loss</td><td>0,50</td><td>0,0783</td></tr>
<tr><td>Obligations</td><td>0,50</td><td>0,3985</td></tr>
<tr><td>Prevention Policy</td><td>0,50</td><td>0,2802</td></tr>
<tr><td>Customer Satisfaction and Reputation</td><td>0,75</td><td>0,0747</td></tr>
<tr><td rowspan="5">DM2 (0,2442)</td><td>Cost</td><td>0,50</td><td>0,1098</td><td rowspan="5">0,5380</td></tr>
<tr><td>Time Loss</td><td>0,75</td><td>0,0924</td></tr>
<tr><td>Obligations</td><td>0,50</td><td>0,4270</td></tr>
<tr><td>Prevention Policy</td><td>0,50</td><td>0,3115</td></tr>
<tr><td>Customer Satisfaction and Reputation</td><td>0,75</td><td>0,0593</td></tr>
<tr><td rowspan="5">DM3 (0,3288)</td><td>Cost</td><td>0,75</td><td>0,3993</td><td rowspan="5">0,5608</td></tr>
<tr><td>Time Loss</td><td>0,50</td><td>0,0514</td></tr>
<tr><td>Obligations</td><td>0,25</td><td>0,2672</td></tr>
<tr><td>Prevention Policy</td><td>0,50</td><td>0,1712</td></tr>
<tr><td>Customer Satisfaction and Reputation</td><td>0,75</td><td>0,1109</td></tr>
</table>

4.1.4 Determining to RPN3 values

RPN3 values are the numbers that help us to reprioritize the selected corrective actions. After calculating RPN3 values FMEA team determine responsible person for each corrective action completion and follow the activity. We have already calculated the RPN1 and RPN2 values. It is simple to calculate the RPN3. The eq. (4.1) shows the calculation of RPN3.

$$RPN3 = RPN1 \times \rho_1 + RPN2 \times \rho_2 \tag{4.1}$$

where,

ρ_1 = 0,95 (coefficient of RPN1)

ρ_2 = 0,05 (coefficient of RPN2)

Table 4.29 presents the RPN3 values of CA.1. We see that the priority of CA.1 has changed to 2. A Full list is presented in the conclusion section.

Table 4.29: RPN3 value calculation of CA.1

CA. NO	RPN1 value	ρ_1	RPN2 value	ρ_2	RPN3 value	Reprioritization No
CA.1	0,480	0,95	0,555	0,05	0,4838	3

Company should perform the corrective actions according to new prioritization that is done according to RPN3 values.

After performing corrective actions a new RPN1 calculation should be done. The calculation results of new RPN1 values can be written in the same FMEA report paper. As to the last RPN1 values, re-evaluation is done and then the FMEA team decides on the necessity of corrective action. Decision is given by the evaluation of FMEA team. It is enough for the failure modes which were in the first part that failure modes have RPN values greater than 0,6. The team can determine additional corrective actions or wait for the next FMEA application. To the time that new FMEA is applied by the team, temporary precautions should be taken for these corrective actions.

5. RESULTS AND CONCLUSION

Risk analysis and risk management are the fundamental issues for today's company. In recent years, the concept of occupational health and safety is growing rapidly in developed or developing countries. All workplaces which are aiming to meet the requirements of OHS should apply risk analysis methodology periodically. In this research, FMEA is chosen.

Although FMEA is a great method to prevent and take corrective action to the failure modes before they occur, it has several numbers of drawbacks. The main source of these drawbacks is about the calculation of RPN. We used Fuzzy AHP and GRA methodology to eliminate drawbacks. Moreover, FMEA team members (DMs) are weighted by experienced experts to get more consistent and more realistic results. Almost all criticisms for traditional RPN calculation are eliminated but there is still some evaluation and calculation to do before performing the corrective actions. First, DMs determine the threshold value, because it is just a dream that a company get rid of from all failure modes in a short time period. Thus, DMs determine threshold interval. The value of 0,6000 is the number that separates two parts. In the first part, corrective actions have to be performed as soon as possible. In second part, corrective actions have to be performed again too, but not as short as the first part. OHS specialist determines reasonable time for each corrective action that is in the second part. Table 5.2 presents the 16 corrective actions in the first part and 34 in the second part as to RPN1 values according to RPN1 values.

It is important to take the corrective actions according to the real need of company and for the workers. Five criteria are identified to consider this issue. By means of these criteria we obtained the RPN2 values. By multiplying RPN1 and RPN2 with their coefficients, we get RPN3 values. At this point, DMs determine new threshold intervals and they reprioritized the CA.s according to RPN3 values. All of the calculation results and the two prioritizations are presented in the Table 5.1. As seen in Table 5.2 the company performs 23 corrective actions in the first part and 27 in the second part according to RPN3 values. Highlighted with light grey color implies the part one corrective actions and highlighted with the dark grey color implies the second part corrective actions.

Table 5.1: RPN1, RPN2, RPN3 values and two prioritizations

Failure Mode NO	CA. NO	RPN1 value	Priority NO	CA. NO	RPN2 value	RPN3 value	Reprioritization NO
1	CA.50	0,8014	50	CA.1	0,5552	0,4838	3
2	CA.37	0,6789	37	CA.2	0,2221	0,4700	1
3	CA.36	0,6750	36	CA.3	0,1778	0,4791	2
4	CA.31	0,6490	31	CA.4	0,2913	0,5247	4
5	CA.11	0,5785	11	CA.5	0,5237	0,5373	6
6	CA.29	0,6350	29	CA.6	0,0787	0,5293	5
7	CA.38	0,6923	38	CA.7	0,7352	0,5697	11
8	CA.4	0,5373	4	CA.8	0,5652	0,5612	9
9	CA.32	0,6555	32	CA.9	0,4807	0,5674	10
10	CA.24	0,6211	24	CA.10	0,1203	0,5532	7
11	CA.3	0,4946	3	CA.11	0,4265	0,5714	13
12	CA.41	0,7390	41	CA.12	0,1213	0,5571	8
13	CA.9	0,5717	9	CA.13	0,9139	0,6043	25
14	CA.7	0,5607	7	CA.14	0,4776	0,5863	16
15	CA.2	0,4830	2	CA.15	0,1204	0,5703	12
16	CA.15	0,5940	15	CA.16	0,6574	0,6000	23
17	CA.33	0,6631	33	CA.17	0,6952	0,6029	24
18	CA.6	0,5528	6	CA.18	0,3447	0,5863	15
19	CA.48	0,7860	48	CA.19	0,6542	0,5974	18
20	CA.45	0,7616	45	CA.20	0,2814	0,5926	17
21	CA.46	0,7651	46	CA.21	0,0394	0,5834	14
22	CA.44	0,7559	44	CA.22	0,2945	0,5990	21
23	CA.25	0,6223	25	CA.23	0,5729	0,5982	20
24	CA.35	0,6677	35	CA.24	0,4290	0,5980	19
25	CA.14	0,5920	14	CA.25	0,5476	0,6183	26
26	CA.47	0,7832	47	CA.26	0,0538	0,5993	22
27	CA.16	0,5973	16	CA.27	0,3369	0,6191	27
28	CA.30	0,6357	30	CA.28	0,5666	0,6306	29
29	CA.34	0,6644	34	CA.29	0,5175	0,6291	28
30	CA.13	0,5881	13	CA.30	0,6177	0,6351	31
31	CA.12	0,5802	12	CA.31	0,3665	0,6349	30
32	CA.19	0,6072	19	CA.32	0,3077	0,6376	34
33	CA.40	0,7169	40	CA.33	0,1320	0,6365	33
34	CA.18	0,6066	18	CA.34	0,1352	0,6376	35
35	CA.21	0,6117	21	CA.35	0,0333	0,6363	32
36	CA.22	0,6150	22	CA.36	0,1033	0,6464	36
37	CA.49	0,7874	49	CA.37	0,5099	0,6705	37
38	CA.43	0,7494	43	CA.38	0,4811	0,6815	38
39	CA.27	0,6337	27	CA.39	0,6105	0,7088	40
40	CA.8	0,5609	8	CA.40	0,2007	0,6912	39
41	CA.26	0,6279	26	CA.41	0,1979	0,7119	41
42	CA.28	0,6339	28	CA.42	0,2855	0,7201	42
43	CA.17	0,6027	17	CA.43	0,4148	0,7323	44
44	CA.42	0,7427	42	CA.44	0,0907	0,7227	43
45	CA.20	0,6087	20	CA.45	0,3296	0,7404	45
46	CA.1	0,4801	1	CA.46	0,6150	0,7575	48
47	CA.23	0,6151	23	CA.47	0,1291	0,7503	46
48	CA.10	0,5764	10	CA.48	0,3489	0,7641	50
49	CA.5	0,5381	5	CA.49	0,1566	0,7555	47
50	CA.39	0,7137	39	CA.50	0,0243	0,7622	49

Table 5.2: CA.s' priority changes according to the proposed methodology

FM No.	Corrective action No.	RPN1 value	RPN3	Reprioritization of CA.s
46	CA.1	0,480	0,4838	3
15	CA.2	0,483	0,4700	1
11	CA.3	0,495	0,4791	2
8	CA.4	0,537	0,5247	4
49	CA.5	0,538	0,5373	6
18	CA.6	0,553	0,5293	5
14	CA.7	0,561	0,5697	11
40	CA.8	0,561	0,5612	9
13	CA.9	0,572	0,5674	10
48	CA.10	0,576	0,5532	7
5	CA.11	0,579	0,5714	13
31	CA.12	0,580	0,5571	8
30	CA.13	0,588	0,6043	25
25	CA.14	0,592	0,5863	16
16	CA.15	0,594	0,5703	12
27	CA.16	0,597	0,6000	23
43	CA.17	0,602	0,6029	24
34	CA.18	0,606	0,5863	15
32	CA.19	0,607	0,5974	18
45	CA.20	0,609	0,5926	17
35	CA.21	0,612	0,5834	14
36	CA.22	0,615	0,5990	21
47	CA.23	0,615	0,5982	20
10	CA.24	0,621	0,5980	19
23	CA.25	0,622	0,6183	26
41	CA.26	0,628	0,5993	22
39	CA.27	0,634	0,6191	27
42	CA.28	0,634	0,6306	29
6	CA.29	0,635	0,6291	28
28	CA.30	0,636	0,6351	31
4	CA.31	0,649	0,6349	30
9	CA.32	0,655	0,6376	34
17	CA.33	0,663	0,6365	33
29	CA.34	0,664	0,6376	35
24	CA.35	0,668	0,6363	32
3	CA.36	0,675	0,6464	36
2	CA.37	0,679	0,6705	37
7	CA.38	0,692	0,6815	38
50	CA.39	0,714	0,7088	40
33	CA.40	0,717	0,6912	39
12	CA.41	0,739	0,7119	41
44	CA.42	0,743	0,7201	42
38	CA.43	0,749	0,7323	44
22	CA.44	0,756	0,7227	43
20	CA.45	0,762	0,7404	45
21	CA.46	0,765	0,7575	48
26	CA.47	0,783	0,7503	46
19	CA.48	0,786	0,7641	50
37	CA.49	0,787	0,7555	47
1	CA.50	0,801	0,7622	49

After all, the summarized steps of the proposed FMEA methodology are presented below:

i. The FMEA team formation.
ii. Determination of the importance weights for DMs (FMEA team members) by experts.
iii. Determination of the importance weights for decision factors (O, S, and D) by DMs.
iv. Giving scores to decision factors by DMs.
v. Application of GRA by each of the DMs to obtain RPN1 values.
vi. Prioritization of failure modes according to RPN1 values.
vii. Determination of threshold intervals by DMs.
viii. Determination of the importance weights for criteria of RPN2.
ix. Giving scores to criteria from 5-point criteria scales.
x. Weighted arithmetic mean calculation to obtain RPN2 values.
xi. Calculation of RPN3 and reprioritization.
xii. Determining second threshold value.
xiii. Performing the determined corrective actions.
xiv. Follow the activities and the responsible person.
xv. Re-evaluate the failure modes and re-calculate the RPN3 values.
xvi. FMEA team decides on the necessity of corrective action for adjusted failure modes.

In the light of this study, it can be said that, the proposed FMEA methodology is useful for company. We considered company's real needs. Furthermore, the limitations of company are also evaluated. The proposed FMEA method has the following advantages:

i. In OHS concept, workers and customers safety and health are two crucial manners that the risk analysts have to give importance to. For this reason, decision factors of RPN1 calculation (O, S, and D) are given weights so that the severity gets the highest priority against other two.

ii. Although the traditional FMEA has been proven as one of the most important early preventative actions in system, design, process or service, it does not consider the DMs personnel data that affect their decision consistency. In this research, Buckley's fuzzy AHP method is used to determine weights for DMs. Thanks to this, the proposed FMEA considers the experience, education level, knowledge level on risk analyzing, his/her job relevance with the current FMEA application workplace and the repetition number of risk analysis application (FMEA or another risk analysis methodology) that he/she has taken part in.

iii. RPN1 is calculated by using decision factors O, S, and D. Instead of multiplication of these three, GRA is used to calculate RPN1. Thanks to GRA, high duplication problem of traditional RPN calculation is eliminated.

iv. In traditional FMEA, corrective actions are performed according to on RPN values prioritization. In this research, corrective actions are performed not only based on RPN1 values but also RPN2 values. RPN2 derives from the need for reprioritization of corrective actions. RPN2 considers five additional criteria that are affecting the corrective actions rationality. These criteria are about cost, time loss, regulations, firm's prevention policy, reputation of the firm. By adding RPN1 and RPN2 to the final RPN (RPN3) calculation, reprioritization is done based on RPN3 values.

v. In this research fuzzy AHP is used for three times and GRA is used for one time to apply the proposed FMEA methodology. It seems really time consuming but it is not true in reality. Fuzzy AHP method firstly used for determining the DMs' (FMEA team) criteria weights. Indeed, this step is not directly about the proposed FMEA application because DMs are given weights for only one time and the FMEA team can apply more FMEA application by using these weights. Secondly, fuzzy AHP is used for determining the RPN1's decision factors O, S, and D weights. This step is also done for only one time and then calculated weights are used in other FMEA applications. Thirdly, fuzzy AHP is used for determining the RPN2's criteria weights and this step is similar to first and the second step. While RPN1 values are calculating, GRA is used. By using GRA weights of O, S, and D are incorporated to the calculation. Besides, these methods are applied in only the first application of FMEA, previously prepared criteria charts help us to do the calculations faster. Moreover, Excel templates are used for all fuzzy AHP, GRA, RPN1, RPN2, RPN3 calculations. Previously prepared templates save really enough time.

vi. In contrast to traditional FMEA, proposed FMEA method gives more consistent results, considers decision makers background, evaluates corrective action's rationality. The proposed model has also real-time applicability and it saves money, time and reputation of company.

Future research can be focus on the RPN2 calculations and on its' criteria. These criteria may change from country from country, sector to sector and company to company. Therefore, more reasonable criteria help DMs to apply FMEA more consistently. Furthermore, RPN2 calculation is partially time consuming and it gives less consistent results when it is compared with GRA. New calculation method can be developed for better results.

Another point that can be developed by researchers is that, an automatic program or database can be developed for faster applicability of proposed model.

Lastly, customer's points of view are not considered during the proposed FMEA methodology. Decision factors' scores are determined only with respect to organization's point of view, not according to customers. This issue can be eliminated in the future research.

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APPENDICES

APPENDIX A1: RPN2 Calculation of CA.2

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.2 (FM.15)	DM1 (0,4269)	Cost	0,00	0,1684	0,2070	0,1152
		Time Loss	0,00	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,2283	
		Time Loss	0,00	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,2372	
		Time Loss	0,00	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A2: RPN2 Calculation of CA.3

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.3 (FM.11)	DM1 (0,4269)	Cost	0,25	0,1684	0,1504	0,1778
		Time Loss	0,25	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,1664	
		Time Loss	0,50	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,2221	
		Time Loss	0,00	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A3: RPN2 Calculation of CA.4

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.4 (FM.8)	DM1 (0,4269)	Cost	0,50	0,1684	0,2112	0,2913
		Time Loss	0,25	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,3154	
		Time Loss	0,50	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,3776	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A4: RPN2 Calculation of CA.5

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.5 (FM.49)	DM1 (0,4269)	Cost	0,75	0,1684	0,5413	0,5237
		Time Loss	0,25	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,75	0,1098	0,3577	
		Time Loss	0,50	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,6245	
		Time Loss	0,25	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,75	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A5: RPN2 Calculation of CA.6

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.6 (FM.18)	DM1 (0,4269)	Cost	0,0	0,1684	0,0701	0,0787
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,00	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,0148	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,1373	
		Time Loss	0,00	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A6: RPN2 Calculation of CA.7

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.7 (FM.14)	DM1 (0,4269)	Cost	0,75	0,1684	0,7688	0,7352
		Time Loss	0,75	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	1,00	0,0747		
	DM2 (0,2442)	Cost	1,00	0,1098	0,7144	
		Time Loss	0,75	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,75	0,3993	0,7072	
		Time Loss	0,75	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A7: RPN2 Calculation of CA.8

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.8 (40)	DM1 (0,4269)	Cost	0,50	0,1684	0,4478	0,5652
		Time Loss	0,25	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	1,00	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,6364	
		Time Loss	0,50	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,6651	
		Time Loss	0,50	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,75	0,1712		
		Reputation	1,00	0,1109		

APPENDIX A8: RPN2 Calculation of CA.9

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.9 (FM13)	DM1 (0,4269)	Cost	0,75	0,1684	0,5608	0,4807
		Time Loss	0,50	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,3302	
		Time Loss	0,50	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,4887	
		Time Loss	0,50	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	1,00	0,1109		

APPENDIX A9: RPN2 Calculation of CA.10

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.10 (FM.48)	DM1 (0,4269)	Cost	0,25	0,1684	0,0990	0,1203
		Time Loss	0,25	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,1721	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,1096	
		Time Loss	0,00	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,00	0,1109		

APPENDIX A10: RPN2 Calculation of CA.11

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.11 (FM.5)	DM1 (0,4269)	Cost	0,00	0,1684	0,2967	0,4265
		Time Loss	0,25	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,5941	
		Time Loss	0,50	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,4707	
		Time Loss	0,50	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,75	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A11: RPN2 Calculation of CA.12

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.12 (FM.31)	DM1 (0,4269)	Cost	0,25	0,1684	0,0617	0,1213
		Time Loss	0,25	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,00	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,0654	
		Time Loss	0,25	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,2402	
		Time Loss	0,25	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A12: RPN2 Calculation of CA.13

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.13 (FM.30)	DM1 (0,4269)	Cost	0,75	0,1684	0,9384	0,9139
		Time Loss	0,75	0,0783		
		Obligations	1,00	0,3985		
		Prevention Policy	1,00	0,2802		
		Reputation	1,00	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,9072	
		Time Loss	0,75	0,0924		
		Obligations	1,00	0,4270		
		Prevention Policy	1,00	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,75	0,3993	0,8873	
		Time Loss	0,75	0,0514		
		Obligations	1,00	0,2672		
		Prevention Policy	1,00	0,1712		
		Reputation	1,00	0,1109		

APPENDIX A13: RPN2 Calculation of CA.14

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.14 (FM.25)	DM1 (0,4269)	Cost	0,50	0,1684	0,4004	0,4776
		Time Loss	0,50	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,75	0,1098	0,5654	
		Time Loss	0,75	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,5129	
		Time Loss	0,75	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A14: RPN2 Calculation of CA.15

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.15 (FM.16)	DM1 (0,4269)	Cost	0,25	0,1684	0,1495	0,1204
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,0297	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,1502	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A15: RPN2 Calculation of CA.16

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.16 (FM.27)	DM1 (0,4269)	Cost	0,50	0,1684	0,6884	0,6574
		Time Loss	0,50	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,6306	
		Time Loss	0,75	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,75	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,6373	
		Time Loss	0,50	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,75	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A16: RPN2 Calculation of CA.17

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.17 (FM.43)	DM1 (0,4269)	Cost	0,75	0,1684	0,7688	0,6952
		Time Loss	0,75	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	1,00	0,0747		
	DM2 (0,2442)	Cost	0,75	0,1098	0,5506	
		Time Loss	0,75	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,75	0,3993	0,7072	
		Time Loss	0,75	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A17: RPN2 Calculation of CA.18

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.18 (FM.34)	DM1 (0,4269)	Cost	0,50	0,1684	0,3295	0,3447
		Time Loss	0,25	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,3716	
		Time Loss	0,25	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,3445	
		Time Loss	0,25	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A18: RPN2 Calculation of CA.19

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.19 (FM.32)	DM1 (0,4269)	Cost	0,50	0,1684	0,4300	0,5475
		Time Loss	0,50	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,5379	
		Time Loss	0,75	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,75	0,3993	0,7072	
		Time Loss	0,75	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A19: RPN2 Calculation of CA.20

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.20 (FM.45)	DM1 (0,4269)	Cost	0,00	0,1684	0,3963	0,2814
		Time Loss	0,25	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,2374	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,1651	
		Time Loss	0,00	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A20: RPN2 Calculation of CA.21

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.21 (FM.35)	DM1 (0,4269)	Cost	0,25	0,1684	0,0421	0,0394
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,00	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,0506	
		Time Loss	0,25	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,00	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,0277	
		Time Loss	0,00	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A21: RPN2 Calculation of CA.22

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.22 (FM.36)	DM1 (0,4269)	Cost	0,25	0,1684	0,3488	0,2945
		Time Loss	0,00	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,3568	
		Time Loss	0,25	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,1779	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A22: RPN2 Calculation of CA.23

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.23 (FM.47)	DM1 (0,4269)	Cost	0,00	0,1684	0,2771	0,2945
		Time Loss	0,00	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,4220	
		Time Loss	0,25	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,1779	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A23: RPN2 Calculation of CA.24

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.24 (FM.10)	DM1 (0,4269)	Cost	0,25	0,1684	0,1604	0,1601
		Time Loss	0,00	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,1284	
		Time Loss	0,25	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,00	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,1832	
		Time Loss	0,25	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A24: RPN2 Calculation of CA.25

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.25 (FM.23)	DM1 (0,4269)	Cost	0,25	0,1684	0,6659	0,5476
		Time Loss	0,75	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,5022	
		Time Loss	0,50	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,4279	
		Time Loss	0,50	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A25: RPN2 Calculation of CA.26

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.26 (FM.41)	DM1 (0,4269)	Cost	0,00	0,1684	0,0187	0,0538
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,0927	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,0705	
		Time Loss	0,00	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A26: RPN2 Calculation of CA.27

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.27 (FM.39)	DM1 (0,4269)	Cost	0,25	0,1684	0,3683	0,3369
		Time Loss	0,25	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,3071	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,3183	
		Time Loss	0,50	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A27: RPN2 Calculation of CA.28

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.28 (FM.42)	DM1 (0,4269)	Cost	0,75	0,1684	0,5608	0,5666
		Time Loss	0,50	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,75	0,1098	0,6870	
		Time Loss	0,75	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,4849	
		Time Loss	0,50	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A28: RPN2 Calculation of CA.29

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.29 (FM.6)	DM1 (0,4269)	Cost	0,25	0,1684	0,4766	0,5175
		Time Loss	0,50	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,7099	
		Time Loss	0,75	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,75	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,4279	
		Time Loss	0,50	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A29: RPN2 Calculation of CA.30

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.30 (FM.28)	DM1 (0,4269)	Cost	0,25	0,1684	0,6463	0,6177
		Time Loss	0,50	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,6364	
		Time Loss	0,50	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,5668	
		Time Loss	0,50	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A30: RPN2 Calculation of CA.31

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.31 (FM.4)	DM1 (0,4269)	Cost	0,75	0,1684	0,3716	0,3665
		Time Loss	0,25	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,3427	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,3776	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A31: RPN2 Calculation of CA.32

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.32 (FM.9)	DM1 (0,4269)	Cost	0,50	0,1684	0,3108	0,3077
		Time Loss	0,25	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,3427	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,2777	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A32: RPN2 Calculation of CA.33

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.33 (FM.17)	DM1 (0,4269)	Cost	0,25	0,1684	0,1308	0,1320
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,0654	
		Time Loss	0,25	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,1832	
		Time Loss	0,25	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A33: RPN2 Calculation of CA.34

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.34 (FM.29)	DM1 (0,4269)	Cost	0,50	0,1684	0,1216	0,1352
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,0571	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,2109	
		Time Loss	0,25	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A34: RPN2 Calculation of CA.35

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.35 (FM.24)	DM1 (0,4269)	Cost	0,00	0,1684	0,0383	0,0333
		Time Loss	0,25	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,0148	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,0406	
		Time Loss	0,25	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A35: RPN2 Calculation of CA.36

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.36 (FM.3)	DM1 (0,4269)	Cost	0,25	0,1684	0,0804	0,1033
		Time Loss	0,25	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,0802	
		Time Loss	0,25	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,1502	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A36: RPN2 Calculation of CA.37

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.37 (FM.2)	DM1 (0,4269)	Cost	0,00	0,1684	0,4345	0,5099
		Time Loss	0,50	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,6046	
		Time Loss	0,75	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,5375	
		Time Loss	0,50	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,75	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A37: RPN2 Calculation of CA.38

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.38 (FM.7)	DM1 (0,4269)	Cost	0,75	0,1684	0,4416	0,4811
		Time Loss	0,25	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	1,00	0,1098	0,3703	
		Time Loss	0,50	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,75	0,3993	0,6147	
		Time Loss	0,25	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A38: RPN2 Calculation of CA.39

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.39 (FM.50)	DM1 (0,4269)	Cost	0,25	0,1684	0,6463	0,6105
		Time Loss	0,50	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,7143	
		Time Loss	0,50	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,75	0,3115		
		Reputation	1,00	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,4872	
		Time Loss	0,25	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A39: RPN2 Calculation of CA.40

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.40 (FM.23)	DM1 (0,4269)	Cost	0,25	0,1684	0,2305	0,2007
		Time Loss	0,00	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,1202	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,2221	
		Time Loss	0,00	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A40: RPN2 Calculation of CA.41

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.41 (FM.12)	DM1 (0,4269)	Cost	0,50	0,1684	0,1216	0,1979
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,2544	
		Time Loss	0,00	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,25	0,0593		
	DM3 (0,3288)	Cost	0,50	0,3993	0,2551	
		Time Loss	0,00	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A41: RPN2 Calculation of CA.42

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.42 (FM.44)	DM1 (0,4269)	Cost	0,00	0,1684	0,3262	0,2855
		Time Loss	0,25	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,2291	
		Time Loss	0,00	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,2747	
		Time Loss	0,00	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A42: RPN2 Calculation of CA.43

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.43 (FM.38)	DM1 (0,4269)	Cost	0,00	0,1684	0,5651	0,4148
		Time Loss	0,00	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,4137	
		Time Loss	0,0	0,0924		
		Obligations	0,50	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,2207	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A43: RPN2 Calculation of CA.44

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.44 (FM.22)	DM1 (0,4269)	Cost	0,00	0,1684	0,0383	0,0907
		Time Loss	0,25	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,0297	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,2041	
		Time Loss	0,00	0,0514		
		Obligations	0,50	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,25	0,1109		

APPENDIX A44: RPN2 Calculation of CA.45

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.45 (FM.20)	DM1 (0,4269)	Cost	0,00	0,1684	0,4150	0,3296
		Time Loss	0,25	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,3301	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,50	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,2185	
		Time Loss	0,50	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,25	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A45: RPN2 Calculation of CA.46

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.46 (FM.21)	DM1 (0,4269)	Cost	0,25	0,1684	0,6463	0,6150
		Time Loss	0,50	0,0783		
		Obligations	0,75	0,3985		
		Prevention Policy	0,75	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,50	0,1098	0,7226	
		Time Loss	0,75	0,0924		
		Obligations	0,75	0,4270		
		Prevention Policy	0,75	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,4947	
		Time Loss	0,50	0,0514		
		Obligations	0,75	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,75	0,1109		

APPENDIX A46: RPN2 Calculation of CA.47

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.47 (FM.26)	DM1 (0,4269)	Cost	0,25	0,1684	0,1186	0,1291
		Time Loss	0,50	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,50	0,0747		
	DM2 (0,2442)	Cost	0,25	0,1098	0,0950	
		Time Loss	0,25	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,75	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,1681	
		Time Loss	0,25	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A47: RPN2 Calculation of CA.48

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.48 (FM.19)	DM1 (0,4269)	Cost	0,00	0,1684	0,4345	0,3489
		Time Loss	0,50	0,0783		
		Obligations	0,50	0,3985		
		Prevention Policy	0,50	0,2802		
		Reputation	0,75	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,2374	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,25	0,3993	0,3205	
		Time Loss	0,25	0,0514		
		Obligations	0,25	0,2672		
		Prevention Policy	0,50	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A48: RPN2 Calculation of CA.49

	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.49 (FM.37)	DM1 (0,4269)	Cost	0,00	0,1684	0,1884	0,1566
		Time Loss	0,00	0,0783		
		Obligations	0,25	0,3985		
		Prevention Policy	0,25	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,2374	
		Time Loss	0,25	0,0924		
		Obligations	0,25	0,4270		
		Prevention Policy	0,25	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,0555	
		Time Loss	0,00	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,50	0,1109		

APPENDIX A49: RPN2 Calculation of CA.50

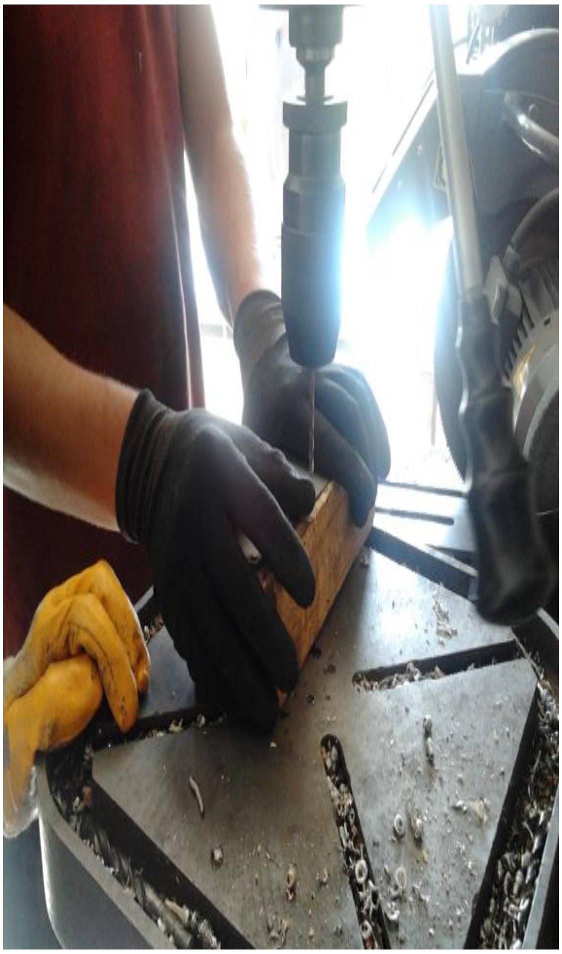
	Weights of DMs	Criteria scores & weights			RPN2 values Of each of DMs	RPN2
		Criteria	Score	Weights		
CA.50 (FM.1)	DM1 (0,4269)	Cost	0,00	0,1684	0,0187	0,0243
		Time Loss	0,00	0,0783		
		Obligations	0,00	0,3985		
		Prevention Policy	0,00	0,2802		
		Reputation	0,25	0,0747		
	DM2 (0,2442)	Cost	0,00	0,1098	0,0297	
		Time Loss	0,00	0,0924		
		Obligations	0,00	0,4270		
		Prevention Policy	0,00	0,3115		
		Reputation	0,50	0,0593		
	DM3 (0,3288)	Cost	0,00	0,3993	0,0277	
		Time Loss	0,00	0,0514		
		Obligations	0,00	0,2672		
		Prevention Policy	0,00	0,1712		
		Reputation	0,25	0,1109		

APPENDIX B1: Photos of failure modes ranked according to RPN3 values (Priority 1, Pr.1)

Failure Mode 15 (FM.15)

APPENDIX B2: Photos of failure modes ranked according to RPN3 values (Priority 2, Pr.2)

Failure Mode 11 (FM.11)



APPENDIX B3: Photos of failure modes ranked according to RPN3 values (Priority 3, Pr.3)

Failure Mode 46 (FM.46)

APPENDIX B4: Photos of failure modes ranked according to RPN3 values (Priority 4, Pr.4)

Failure Mode 8 (FM.8)

APPENDIX B5: Photos of failure modes ranked according to RPN3 values (Priority 5, Pr.5)

Failure Mode 18 (FM.18)

APPENDIX B6: Photos of failure modes ranked according to RPN3 values (Priority 6, Pr.6)

Failure Mode 49 (FM.49)

APPENDIX B7: Photos of failure modes ranked according to RPN3 values (Priority 7, Pr.7)

Failure Mode 48 (FM.48)

APPENDIX B8: Photos of failure modes ranked according to RPN3 values (Priority 8, Pr.8)

Failure Mode 31 (FM.31)

APPENDIX B9: Photos of failure modes ranked according to RPN3 values (Priority 9, Pr.9)

Failure Mode 40 (FM.40)

APPENDIX B10: Photos of failure modes ranked according to RPN3 values (Priority 10, Pr.10)

Failure Mode 13 (FM.13)

APPENDIX B11: Photos of failure modes ranked according to RPN3 values (Priority 11, Pr.11)

Failure Mode 14 (FM.14)

APPENDIX B12: Photos of failure modes ranked according to RPN3 values (Priority 12, Pr.12)

Failure Mode 16 (FM.16)

APPENDIX B13: Photos of failure modes ranked according to RPN3 values (Priority 13, Pr.13)

Failure Mode 5 (FM.5)

APPENDIX B14: Photos of failure modes ranked according to RPN3 values (Priority 14, Pr.14)

Failure Mode 35 (FM.35)

APPENDIX B15: Photos of failure modes ranked according to RPN3 values (Priority 15, Pr.15)

Failure Mode 34 (FM.34)

APPENDIX B16: Photos of failure modes ranked according to RPN3 values (Priority 16, Pr.16)

Failure Mode 25 (FM.25)

APPENDIX B17: Photos of failure modes ranked according to RPN3 values (Priority 17, Pr.17)

Failure Mode 45 (FM.45)

APPENDIX B18: Photos of failure modes ranked according to RPN3 values (Priority 18, Pr.18)

Failure Mode 30 (FM.30)

APPENDIX B19: Photos of failure modes ranked according to RPN3 values (Priority 19, Pr.19)

Failure Mode 36 (FM.36)

APPENDIX B20 Photos of failure modes ranked according to RPN3 values (Priority 20, Pr.20)

Failure Mode 41 (FM.41)

APPENDIX B21: Photos of failure modes ranked according to RPN3 values (Priority 21, Pr.21)

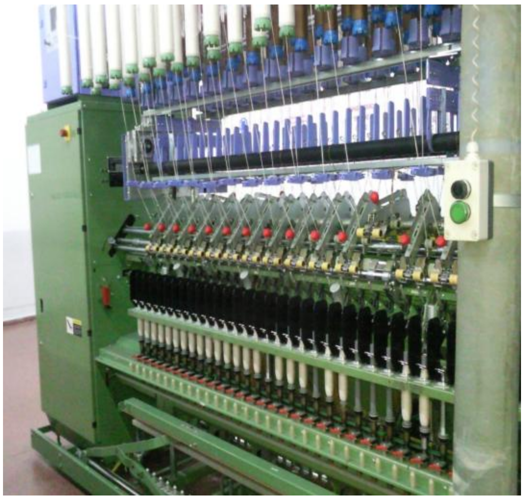
Failure Mode 27 (FM.27)

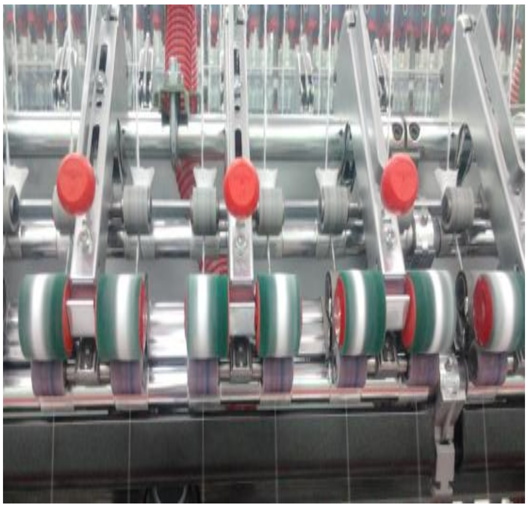
APPENDIX B22: Photos of failure modes ranked according to RPN3 values (Priority 22, Pr.22)

Failure Mode 32 (FM.32)

APPENDIX B23: Photos of failure modes ranked according to RPN3 values (Priority 23, Pr.23)

Failure Mode 43 (FM.43)





APPENDIX B24: Photos of failure modes ranked according to RPN3 values (Priority 24, Pr.24)

Failure Mode 10 (FM.10)

APPENDIX B25: Photos of failure modes ranked according to RPN3 values (Priority 25, Pr.25)

Failure Mode 47 (FM.47)

APPENDIX B26: Photos of failure modes ranked according to RPN3 values (Priority 26, Pr.26)

Failure Mode 23 (FM.23)

APPENDIX B27: Photos of failure modes ranked according to RPN3 values (Priority 27, Pr.27)

Failure Mode 39 (FM.39)

APPENDIX B28: Photos of failure modes ranked according to RPN3 values (Priority 28, Pr.28)

Failure Mode 6 (FM.6)

APPENDIX B29: Photos of failure modes ranked according to RPN3 values (Priority 29, Pr.29)

Failure Mode 42 (FM.42)

APPENDIX B30: Photos of failure modes ranked according to RPN3 values (Priority 30, Pr.30)

Failure Mode 4 (FM.4)

APPENDIX B31: Photos of failure modes ranked according to RPN3 values (Priority 31, Pr.31)

Failure Mode 28 (FM.28)

APPENDIX B32: Photos of failure modes ranked according to RPN3 values (Priority 32, Pr.32)

Failure Mode 24 (FM.24)

APPENDIX B33: Photos of failure modes ranked according to RPN3 values (Priority 33, Pr.33)

Failure Mode 17 (FM.17)

APPENDIX B34: Photos of failure modes ranked according to RPN3 values (Priority 34, Pr.34)

Failure Mode 9 (FM.9)

APPENDIX B35: Photos of failure modes ranked according to RPN3 values (Priority 35, Pr.35)

Failure Mode 29 (FM.29)

APPENDIX B36: Photos of failure modes ranked according to RPN3 values (Priority 36, Pr.36)

Failure Mode 3 (FM.3)

APPENDIX B37: Photos of failure modes ranked according to RPN3 values (Priority 37, Pr.37)

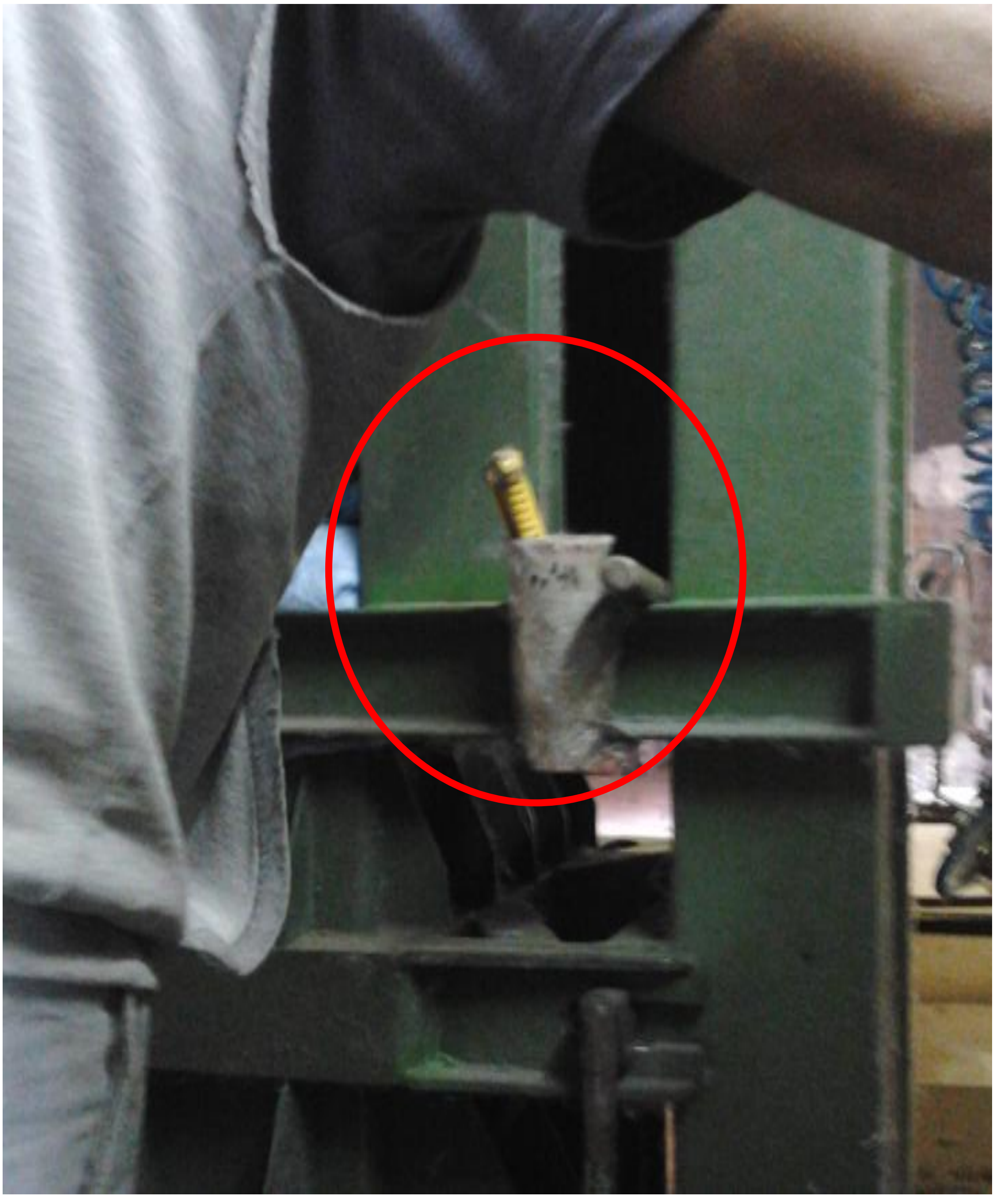
Failure Mode 2 (FM.2)

APPENDIX B38: Photos of failure modes ranked according to RPN3 values (Priority 38, Pr.38)

Failure Mode 7 (FM.7)

APPENDIX B39: Photos of failure modes ranked according to RPN3 values (Priority 39, Pr.39)

Failure Mode 33 (FM.33)



APPENDIX B40: Photos of failure modes ranked according to RPN3 values (Priority 40, Pr.40)

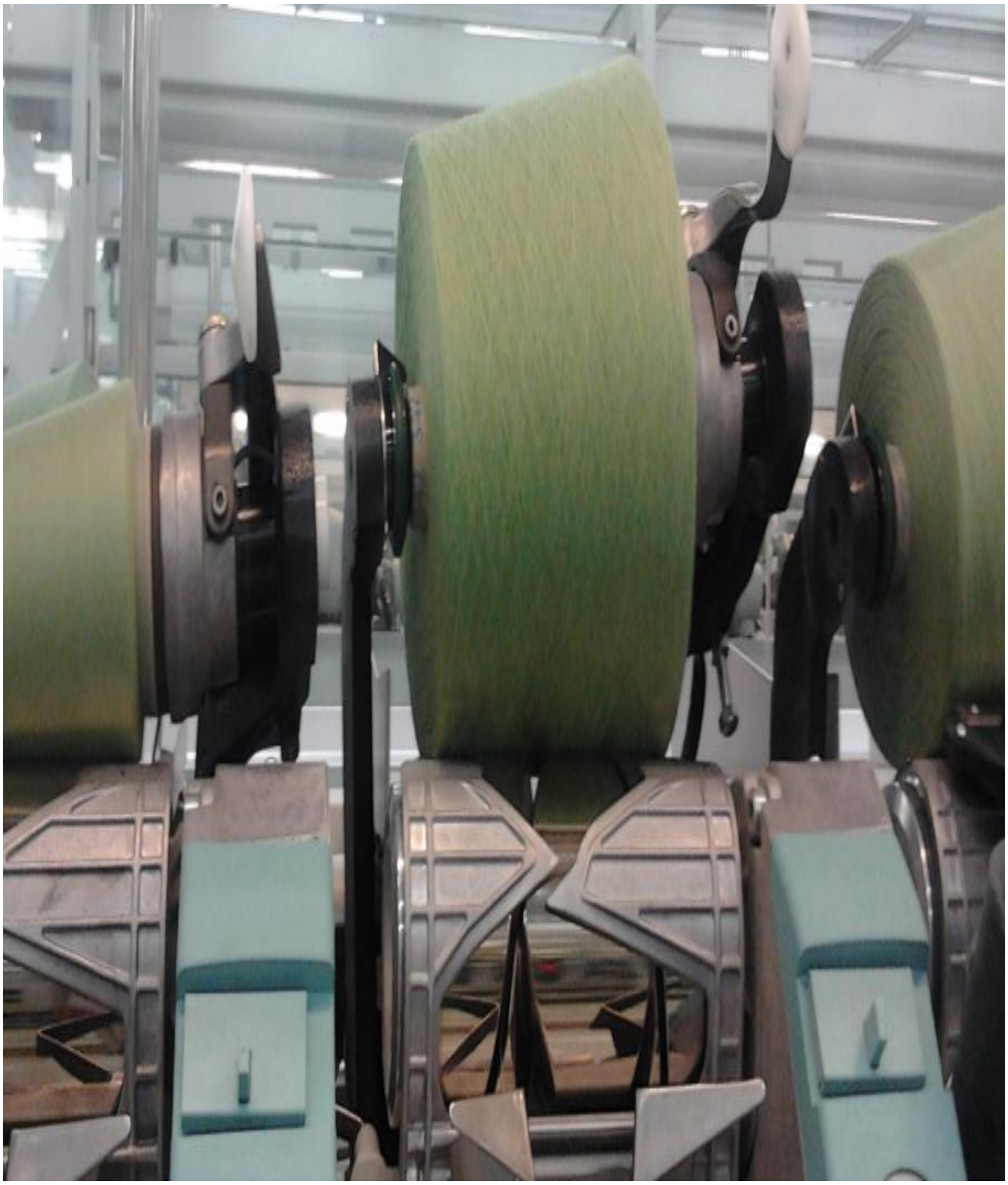
Failure Mode 50 (FM.50)

APPENDIX B41: Photos of failure modes ranked according to RPN3 values (Priority 41, Pr.41)

Failure Mode 12 (FM.12)

APPENDIX B42: Photos of failure modes ranked according to RPN3 values (Priority 42, Pr.42)

Failure Mode 44 (FM.44)



APPENDIX B43: Photos of failure modes ranked according to RPN3 values (Priority 43, Pr.43)

Failure Mode 22 (FM.22)

APPENDIX B44: Photos of failure modes ranked according to RPN3 values (Priority 44, Pr44)

Failure Mode 38 (FM.38)

APPENDIX B45: Photos of failure modes ranked according to RPN3 values (Priority 45, Pr.45)

Failure Mode 20 (FM.20)

APPENDIX B46: Photos of failure modes ranked according to RPN3 values (Priority 46, Pr.46)

Failure Mode 26 (FM.26)

APPENDIX B47: Photos of failure modes ranked according to RPN3 values (Priority 47, Pr.47)

Failure Mode 37 (FM.37)

APPENDIX B48: Photos of failure modes ranked according to RPN3 values (Priority 48, Pr.48)

Failure Mode 21 (FM.21)

APPENDIX B49: Photos of failure modes ranked according to RPN3 values (Priority 49, Pr.49)

Failure Mode 1 (FM.1)

APPENDIX B50: Photos of failure modes ranked according to RPN3 values (Priority 50, Pr.50)

Failure Mode 19 (FM.19)

APPENDIX C1: Risk analysis and FMEA test

Question 1: According to OHS risk analysis regulation, which of the followings that are regarding with the risk control measures are wrong?

a) Elimination of the hazard or sources of hazards

b) Giving priority to the use of personal protective equipment

c) Replacing the dangerous substance with the not dangerous or less dangerous substance.

d) Combating the risks at their source

Question 2: Which of the following should be considered when defining the hazards in the workplace?

I. The raw materials and semi-finished products
II. Procedures regarding with the residues and waste substances
III. Employees' experiences and thoughts.
IV. Employee education, age, gender.
V. Workers' health records.
VI. Consequences of workplace inspections

a) I-II-V-VI b) I-III-IV

c) III-IV-V-VI d) All of them

Question 3: According to OHS risk analysis regulation, which of the following need re-application of risk analysis methodology?

a) If the workplace is given break more than 30 days.

b) After the strike made in the workplace.

c) After the technological changes in the workplace.

d) At the begining of each year.

Question 4: Which of the followings are put in order correctly according to OHS risk analysis regulation?

I. To identify and analyze the risks,
II. documentation,
III. Deciding on the risk analysis methodology
IV. Defining the hazards,
V. Updating and renewal of work

a) I-IV-III-II-V   b) IV-I-II-III-V

c) IV-I-III-II-V   d) I-IV-II-III-V

Question 5: Which of the following obligates the risk assessment for occupational health and safety concept?

a) ISO 9001

b) IS014001

c) ISO 22000

d) OHSAS 18001

Question 6:

I- Risk control measures

II- The number of people that can be affected by hazards

III- Selected risk assessment methodology

IV- Potential severity of loss

V- The probability of damage

Which of the above is not effective in calculating the magnitude of the risk?

a) I, II b) I, III c) II, V d) III, IV

Question 7: Which of the following is not one of the methods of risk assessment?

a) HAZOP b) FMEA c) FTA d)HACCP

Question 8: Which of the following describes the FMEA risk assessment method?

a) A graphical representation of a logical combination of defined adverse event’s or condition’s causes.

b) It is one of the most appropriate qualitative approaches that the mechanical and electrical systems to be reviewed.

c) A brainstorming approach that is comprehensive and loosely structured query using.

d) Probability and severity is graded from 1 to 5 and this method is consist of the probability and severity multiplication matrix?

Question 9: Which of the followings are the parameters of FMEA’s risk priority number?

a) Occurrence-severity

b) Occurrence- detectability

c) Severity- detectability

d) Occurrence- severity- detectability

Question 10: What is the step that the potential failure's magnitude, detectability are evaluated in the FMEA methodology?

a) The fragmentation of system or action for analyzing

b) Identification of the accidents that are object to analysis

c) The evaluation of potential failures that can lead to accidents

d) Identification of potential error conditions for the system elements

Answers :

1- b

2- d

3- c

4- c

5- d

6- b

7- d

8- b

9- d

10- c

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