

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**A DECISION MODEL FOR DYNAMIC
ASSESSMENT AND MANAGEMENT OF RISKS
IN FIRMS**

by
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August, 2020
İZMİR

A DECISION MODEL FOR DYNAMIC ASSESSMENT AND MANAGEMENT OF RISKS IN FIRMS

**A Thesis Submitted to the
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**by
Zeynep Nur KÖSTEPEN**

August, 2020

İZMİR

M.Sc. THESIS EXAMINATION RESULT FORM

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A DECISION MODEL FOR DYNAMIC ASSESSMENT AND MANAGEMENT OF RISKS IN FIRMS

ABSTRACT

Risk management defined as that the risks that the companies may be exposed are determined in advance and thus minimizing their negative effects. Risk management studies play important role in providing efficiency, safe working environment for employees and sustainable competitive advantage. In this thesis, production risks of an international manufacturing company producing kitchen systems are evaluated. In this evaluation process, FMEA was employed as the risk assessment method. However, FMEA suffers from some deficiencies in prioritizing the risks. To overcome the deficiencies, a multi criteria decision making method, TOPSIS, is utilized. It was used to evaluate and prioritize the precautions by using the evaluation criteria. In addition, an interface was designed in this study to calculate the RPNs of the selected fault group quickly and see the precautions to be taken. With this interface, it is facilitated to monitor and access to FMEA in case of renewal of the faults. This screen program was developed with Excel VBA and quick access to the data was realized. Thanks to the proposed approach, it has been provided to give implementation priority to the precautions besides giving priority to the risks as traditional risk analysis methods do.

Keywords: Risk analysis, FMEA, multi criteria decision making, TOPSIS, VBA

FİRMALARDAKİ RİSKLERİN DİNAMİK OLARAK DEĞERLENDİRİLMESİ VE YÖNETİLMESİNE YÖNELİK BİR KARAR MODELİ

ÖZ

İşletmelerin maruz kalabilecekleri risklerin önceden belirlenerek değerlendirilmesi ve bu sayede olumsuz etkilerinin minimize edilmesi risk yönetimi olarak tanımlanmaktadır. Risk yönetimi çalışmaları, verimlilik, çalışanlar için güvenli bir çalışma ortamı ve sürdürülebilir rekabet avantajı sağlamada çok önemli bir role sahiptir. Bu tez kapsamında, mutfak sistemleri üreten uluslararası bir imalat firmasının üretim sürecindeki riskleri değerlendirilmiştir. Bu değerlendirme sürecinde FMEA kullanılmıştır. Ancak, FMEA yönteminin bazı eksiklikleri olduğu gözlenmiştir. Bu nedenle, bu çalışmada çok kriterli karar verme yöntemlerinden biri olan TOPSIS yöntemi kullanılarak bu eksikliklerinin giderilmesi amaçlanmıştır. TOPSIS yöntemi önlemlerin değerlendirme kriterlerine göre analiz edilmesi ve önceliklendirilmesi amacı ile kullanılmıştır. Buna ek olarak bu çalışmada, istenen tehlike grubuna ait RPN değerinin hesaplanabilmesi ve alınması gereken önlemlerin kolaylıkla görülüp kontrol edilebilmesi için bir program tasarlanmıştır. Bu program ile tehlikelerin yinelenmesi durumunda takibi ve FMEA çalışmasına ulaşma konularında kolaylık sağlanması amaçlanmıştır. Bu ekran programı, Excel VBA ile elde edilmiş ve verilere hızlı erişim bu sayede gerçekleştirilmiştir. Geliştirilen sistem sayesinde, geleneksel risk analizi yöntemleri gibi risklere öncelik sıralaması verilmesi yanında risklere karşı alınacak önlemlere uygulama önceliği atanması sağlanmıştır.

Anahtar Kelimeler: Risk analizi, FMEA, çok kriterli karar verme, TOPSIS, VBA

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CHAPTER ONE

INTRODUCTION

Risk and uncertainty are observed all production and service sectors. If these risks and uncertainties are not prevented, it may a danger to employees and a great threat to the company. Today, companies give great importance to risk management studies in order to gain profit and gain advantage in a competitive environment. Analyzing the risks that may occur and taking the necessary precautions at the right time provides companies with a competitive advantage. For these reasons, risk management studies are very important for companies. Although there are many different risk management methods, many of them have some limitations. Failure Mode and Effects Analysis-FMEA method is the most frequently used method of risk management. FMEA method, which is a very wide area of use, is an important method in defining the types of faults, calculating the risk priority numbers of the defined fault types and determining the precautions to be taken.

The RPN value, which is the risk priority number, is obtained by multiplying the probability, severity and detectability values of the risks. Although the FMEA method is used frequently, it is criticized for the deficiencies in the calculation of the RPN value. The reason for this is that the values taken in the calculation are weak for many problems. FMEA method can be used with other methods to eliminate these deficiencies. In this study, the FMEA method was used together with the TOPSIS method, which is a multi-criteria decision making method, in order to complete the deficiencies and to evaluate the precautions to be taken according to some criteria. This system is supported by a program to obtain faster returns and to quickly see the precautions to be taken according to the risk priority numbers. For this reason, the codes of the heuristic algorithm are written in the MS Excel interface using VBA (Visual Basic for Application).

This work was done in a factory that produces kitchen systems. The production flow of the most produced product at the factory was observed and a risk management

study was planned. The risks encountered in the processes in this production flow were evaluated.

This thesis consists of eight chapters. The remainder of the thesis is organized as follows:

In the chapter two, risk management concepts are defined, and general information is given on this subject. The second chapter, which also describes the methods used in risk analysis, is completed by comparing the risk analysis methods.

In the chapter three, FMEA method is explained with details. The implementation steps of the method are presented.

In the chapter four, the concept and techniques of multi-criteria decision making are defined. The most used multi-criteria decision making methods in risk analysis studies are explained and implementation stages are presented.

In the chapter five, a literature review for the FMEA method is presented. Studies using FMEA method with multi-criteria decision making techniques are described.

In the chapter six, FMEA and TOPSIS study is presented. Application of TOPSIS method all steps are defined and shown.

In the chapter seven, the design and implementation steps of the Excel VBA program are explained. The outputs obtained as a result of using the program are presented. With the help of this algorithm, the company will be able to easily calculate the RPN value and quickly access the necessary precautions by entering the results obtained from the risk management studies into the program.

Finally, chapter eight includes concluding remarks and outputs obtained.

CHAPTER TWO

RISK MANAGEMENT

2.1 Definition of Risk

Risk, is the uncertain situation and events that may arise today or in the future and are likely to affect the realization of business goals and objectives. For the uncertainty in question not to harm the goals and objectives, the risks that may arise must be analyzed well in advance and the necessary precautions must be taken. For this reason, companies should give importance to risk management in order to make risk analysis and evaluations in the best way in order to avoid accidents and losses that may arise as a result of risks.

The use of the word risk can have different meanings in different societies. For example, in developed societies, risk is defined as loss of profit and gain, while in developing societies it is defined as damage or loss (Al-Bahar & Crandall, 1990). Definition of risk may also differ across sectors. For example, in the financial sector, risk can be defined as both the probability of loss that may occur and the dangers that threaten planned activities.

Risk can be defined as the occurrence of the probability of occurrence of events that affect our goals in a good or bad way (Ababneh, 2000). According to another opinion, risk is not a problem, it is only a factor that causes the problem to occur (Molenaar, 2005). Amos & Dent (1997) argued that once the risk is identifiable, it will cease to be a risk and become a manageable problem. While they define risk as measurable uncertainty, they define uncertainty as an immeasurable risk. Drehmann & Nikolaou (2013) defined risk as the probability of results and uncertainties being better or worse than expected.

When we look at all the definitions, even though it contains a few changes, the main theme is uncertainty and loss. In general, the risk is the possibility of events that are unknown and not expected to occur in the future due to uncertainties and cause a loss.

2.2 Types of Risk

Risks for businesses are described under two main headings.

Commercial Risks: Businesses face risks in this group as a result of their decisions. There is a possibility of earning, but operating losses are incurred in case of a possible loss.

Incidental Risks: Unlike commercial risks, there is no possibility to make a profit in this group of risks. Companies can transfer losses that may be caused by these risks to other institutions for a worth. These risks are insurable risks.

2.3 Risk Analysis

Risk analysis involves identifying potential risks before they occur. After the risks are defined, the risk priority coefficients for each risk are calculated and a priority ranking is created between the risks. While making risk analysis studies, the priority ranking of the risks is determined by the severity of the negative situation that the risks may cause and the probability of occurrence of risks. The methods used in the risk analysis process are the methods where the risks are expressed quantitatively and formulated and interpreted mathematically (Thieme, Mosleh, Utne & Hegde, 2020).

2.3.1 Situations Requiring Risk Analysis

There are various risks arising from the processes in businesses. If potential risks are not prevented before they occur, these risks may lead to accidents and losses. Therefore, there is a loss of trust against the firm and it has a negative impact on the competitiveness. It is very important for firms to take their precautions against risks at the right time in order to maintain their market share in today's competitive environment and not to lose trust (Yousefi, Jahangoshai Rezaee & Moradi, 2020). For taking the precautions at the right time, the processes and risk points with high risk must be determined correctly. Risks whose identification have been completed should

be identified and analyzed, and then necessary precautions should be taken for each risk group. The benefits of the precautions to be taken should be well estimated and a ranking should be set accordingly. Costs of precautions are very important for businesses. Therefore, they want to take precautions with minimum cost. The process of determining and analyzing the risks and taking the necessary precautions continues with monitoring of the precautions taken. By controlling whether the desired goal is achieved with the precautions, the negative effects of the risks are prevented. With a proper application of risk analysis, firms can reduce costs against the negative effects of risks. The accidents can be prevented by the identification of risks in the processes, and consequently efficiency of the processes and the quality of the products and services increase (Akintoye & MacLeod, 1997).

As consequence, risk analysis studies are of great importance for firms. For maintain their market shares, remain strong in the competitive environment and not to lose trust, companies must apply risk analysis methods in all their processes.

2.4 Risk Management

Effective risk management studies are needed as the conditions constantly change with the developing world and these changes create great confusion (Emhan, 2009).

Risk management ensures that all factors that cause risk are identified before they occur and with the necessary interventions negative effects are minimized. If the risks are determined correctly, its controllability increases. Risk management studies enable companies to take as much risk as they can struggle. Some golden rules have been created for risk management. Some of them are listed in the following (Amos & Dent, 1997).

- Risks must be accurately identified, classified and analyzed.
- Identifiable risks cease to be a risk for companies and become problems that need to be solved.
- Risks should not be evaluated with intuitive approaches.

- Unless the risks are defined correctly, they can cause more risks.

2.5 Risk Management Processes

Risk management includes many processes as well as detecting and eliminating risks. There exist three basic processes in risk management. These processes are; risk identification, risk analysis and risk mitigation.

2.5.1 Risk Identification

It is the first step in which we get information about the correct identification of risks and which risk groups we should work on. Identifying risk sources is the most fundamental part of risk management at this stage.

In addition to correctly identifying the risks, it is very important to identify them at the right time. Defining a risk that has passed the intervention period is lost its importance, even if it is correctly defined. For this reason, risks should be identified as soon as possible.

2.5.2 Risk Analysis

Risk analysis stage includes analyzing the effects of the risks identified during risk definition. The first and the most important step in risk analysis is to decide on the right technique that can be applied (Alali & Pinto, 2009).

The first purpose of the risk analysis is to understand the effects caused by the risks well. In this way, it becomes possible to assess risks systematically and to provide solutions.

2.5.3 Risk Mitigation

Risk mitigation studies are carried out with the aim of preventing risks, increasing opportunities and reducing the negative situation that may arise from risks. This whole process is called risk mitigation. This process provides continuous monitoring of risks and precautions against new risks.

2.6 Risk Identification Methodologies

It is very important that risks are handled in detail and defined in this way in risk identification processes. Risks that are not defined in detail and neglected may cause major problems in ongoing processes and make analysis difficult. Therefore, different information groups are used in risk identification phase.

There exists many different ways to identify risks. The most commonly used methods in risk identification processes are as follows (Chapman, 2004):

- Sole risk expert approach
- Project team approach
- One or more working group approach.

2.7 Risk Mitigation Strategies

2.7.1 Risk Avoidance

Risk avoidance covers not doing or terminating the activity causing risk. This strategy may cause opportunity cost. In some cases, risk avoidance costs may be higher than risk reduction costs.

2.7.2 Risk Reduction

The goal of the risk reduction strategy is to reduce the probability of risk. Some researchers have argued that existing risk must be correctly identified before risk

reduction. Thus, the probability of realization of risks can be determined correctly (Hallikas, Virolainen & Tuominen, 2002).

2.7.3 Risk Acceptance

Risk acceptance involves the acceptance of all positive and negative effects of identified risks. It is a strategy that should be implemented in some cases. Many studies argue that risks with low impact and negligible levels should be accepted (Akintoye & MacLeod, 1997).

2.7.4 Risk Transfer

The most frequently used risk mitigation strategy is risk transfer. The purpose of this strategy is to transfer the risk to the party who can manage its effects with the least cost. In this strategy, all stakeholders to whom the risk is transferred carry out improvement studies to prevent negative effects (Jia, Chen, Zuo, Lin & Song, 2018).

2.8 Risk Analysis Methodologies

Risk analysis is a process in which risk assessments are made as a result of using the data collected in the related risk group as input in the methods to be applied. Appropriate methods are needed to understand the dynamic structure and variability of risks. Frequently used risk analysis methods are listed in the following (Tixier, Dusserre, Salvi & Gaston, 2002).

- Preliminary Hazard Analysis (PHA)
- Job Safety Analysis (JSA)
- Risk Assessment Decision Matrix
- What if Analysis?
- Hazard and Operability Studies (HAZOP)
- Fault Tree Analysis (FTA)

- Event Tree Analysis (ETA)
- Cause and Consequence Analysis
- Failure Mode and Effects Analysis (FMEA)

2.8.1 Preliminary Hazard Analysis (PHA)

Preliminary hazard analysis is utilized to identify possible risks before they cause an accident and to determine their probabilities. Checklists are created at the beginning of the preliminary hazard analysis. Then, the risks in the checklists are taken into risk assessment forms and the analysis begins. Preliminary hazard analysis, which is a qualitative method, is a guide to comprehensive risk analysis studies and can be used at the initial stage. As a result of the method, precautions that can be taken against risks are determined. Thus, the probability of occurrence of risks and the precautions to be taken can be reported. While applying the preliminary hazard analysis, past data and experiences can be used. Figure 2.1 illustrates the stages of preliminary hazard analysis (Özkılıç, 2005).

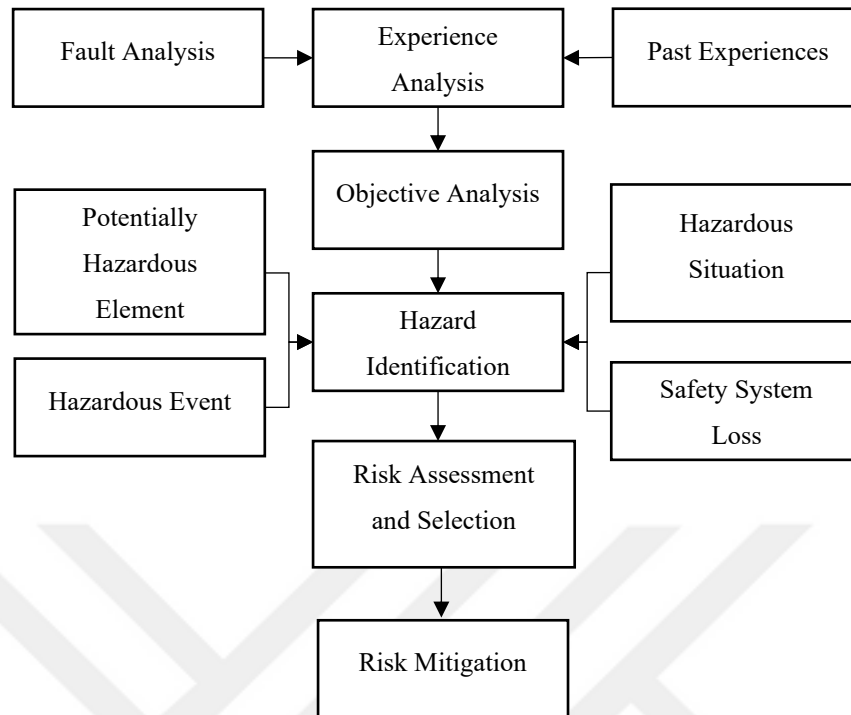


Figure 2.1 Stages of preliminary hazard analysis (Özkılıç, 2005)

2.8.2 Job Safety Analysis (JSA)

Job safety analysis focuses on the work of individuals and groups working in the processes. It can be used in processes where the tasks and jobs performed are well defined. A properly implemented job safety analysis provides that possible risks in firms are prevented before they cause an accident. The method, which starts with the correct determination of the tasks of all employees, continues with the identification of hazards in the processes. Consequently, the precautions to be taken are determined by utilizing the method (Rozenfeld, Sacks, Rosenfeld & Baum 2010).

2.8.3 Risk Assessment Decision Matrix

Risk assessment decision matrix is a frequently used method in risk analysis. The relationships between the variables in the systems can be analyzed by the method. There exists two types of risk assessment decision matrix.

- L Type Matrix
- X Type Matrix

2.8.4 Risk Assessment Decision Matrix – L Type Matrix

The L-type matrix is often used for the analysis of cause and effect relationships. The method is easy to implement and can be easily applied to uncomplicated processes by an analyst. However, several analysts with high knowledge and experience are needed in complex and comprehensive processes. In systems that need to be analyzed quickly, L-type matrix is often employed. While applying the method, two variables are used. These variables are the probability of occurrence of risks and the degree of harm they will cause in case of occurrence of risks. The evaluation tables for the L matrix are shown in

Table 2.1, Table 2 and Table 2.3. A risk score is obtained by multiplying these variables so that risks can be classified (see, Equation 2.1).

$$\text{Risk Score} = \text{Probability} * \text{Degree of Harm} \quad (2.1)$$

Table 2.1 The probability and definition of risk occurring - L type (Steenbergen, van Gelder, Miraglia & Vrouwenvelder, 2013)

Probability	Definition of Occurring
Very Low	Hardly ever
Low	Once a year
Moderate	A few times in a year
High	Often (once a month)
Very High	Very often (once a week, every day)

Table 2.2 Degree of harm - L type (Steenbergen, 2013)

Conclusion	Degree of Harm
Very Low	No job time loss, requiring first aid
Low	No working days loss, requiring outpatient treatment with no permanent effect
Moderate	Slightly injury, inpatient treatment required
Critical	Critical injury, long-term treatment, occupational illness
Very Critical	Death, permanent incapacity

Table 2.3 Risk score matrix – L Type (Marhavalas, Koulouriotis & Gemeni, 2011; Steenbergen, 2013)

	Severity				
Probability	1 (Very Low)	2 (Low)	3 (Moderate)	4 (Critical)	5 (Very Critical)
1 (Very Low)	Acceptable 1	Acceptable 2	Acceptable 3	Acceptable 4	Tolerable 5
2 (Low)	Acceptable 2	Acceptable 4	Tolerable 6	Tolerable 8	Tolerable 10
3 (Moderate)	Acceptable 3	Tolerable 6	Tolerable 9	Tolerable 12	Unacceptable 15
4 (High)	Tolerable 4	Tolerable 8	Tolerable 12	Unacceptable 16	Unacceptable 20
5 (Very High)	Tolerable 5	Tolerable 10	Unacceptable 15	Unacceptable 20	Unacceptable 25

The risk score is obtained by evaluating the probability of occurrence and degree of harms of the risks as shown in the tables. Risks with a risk score of 25 represent risks that are too high to be tolerated. Jobs should not be started until the risks in this group are reduced. If the process is continuing, it must be stopped immediately. After the precautions taken against these risks, which are evaluated according to the risk score matrix, the same procedures should be continued, then the risk scores should be checked again.

2.8.5 Risk Assessment Decision Matrix – X Type Matrix

The X type of the risk assessment decision matrix is a multivariable matrix form. Providing a multi-dimensional analysis, the X-type decision matrix considers all parameters of the problem and their relationships, and it can be utilized in complex problems. The method, which is not suitable for the work of a single analyst, necessitates an experienced group of experts and past data. It together evaluates the probability of recurrence of a risk encountered in the past and the costs of the precautions to be taken. Table 2.4 gives the grades used in the X-type decision matrix.

Table 2.4 Probability of occurrence of a risk – X Type (Steenbergen, 2013)

Probability	Probability of a Occurrence
Very High	Simple equipment error or human error that can occur under normal conditions
High	Dual equipment error, human error
Moderate	The combination of human error and equipment error and error in the process line
Low	Multiple equipment, human error or spontaneous errors in processes
Very Low	Occurs only in extraordinary situations

In the X-type decision matrix method, a risk score is obtained by considering multiple parameters.

- *A*: Possibility of risk-related severity
- *B*: Probability of occurrence of the previous risk
- *C*: Number of staff affected by the previous risk
- *D*: The degree of severity on the staff

$$\text{Risk Rating Score} = A + B + C + D \quad (2.2)$$

Risk rating score is calculated as formulated in Equation 2.2. Risks are classified according to the risk rating score and necessary precautions are taken starting from the risk with the highest score.

2.8.6 What If Analysis

"What if Analysis" includes reducing the risks that may be encountered in production and service processes with necessary precautions. It is a qualitative analysis and it is started by asking the question "What if". Questions and answers are prepared and evaluated by a team of experts who have knowledge and experience about the operation of the processes. The analysis can be applied in all processes of the production and service systems. It is easy and fast in terms of implementation. However, it generally requires an expert team and the opinions of the staff performing the processes. Knowledge and experience about the processes greatly affect the effectiveness of the method (Khan & Abbasi, 1998).

2.8.7 Hazard and Operability Studies (HAZOP)

HAZOP was developed by evaluating potential risk groups that could be encountered in the chemical industry. For the implementation of the method, the risks are determined, analyzed and the necessary precautions are taken by the team, and the risks are eliminated. The method proceeds similarly to the brainstorming study and asks the expert team what results will be encountered in the event of occurrence or not of risks. The team answers the questions with specific keywords such as much, less, ever. The method is a qualitative method and responses from the whole team are evaluated and necessary decisions are made. HAZOP is frequently employed in the control of various systems (Kotek & Tabas, 2012).

2.8.8 Fault Tree Analysis (FTA)

Fault tree analysis is one of the risk analysis methods evaluating risks by sub-components. It is a useful method in terms of its qualitative and quantitative characteristics. The method examines possible risks through the figure and obtains root causes. The main purpose of the method is to reveal what the risks are caused by. Precautions are taken according to the favorable source by separating the risks arising from material, equipment or people. It requires high experience as it is concerned with the whole system (Seber, 2012).

The first goal of FTA is to determine system reliability. Another goal is to identify interactions in the systems. Thus, the factors affecting each other are known and more comprehensive precautions can be taken when a problem is encountered (Lauer, German & Pollmer, 2011). Figure 2 shows the basic steps of fault tree analysis (Ford et al., 2017).

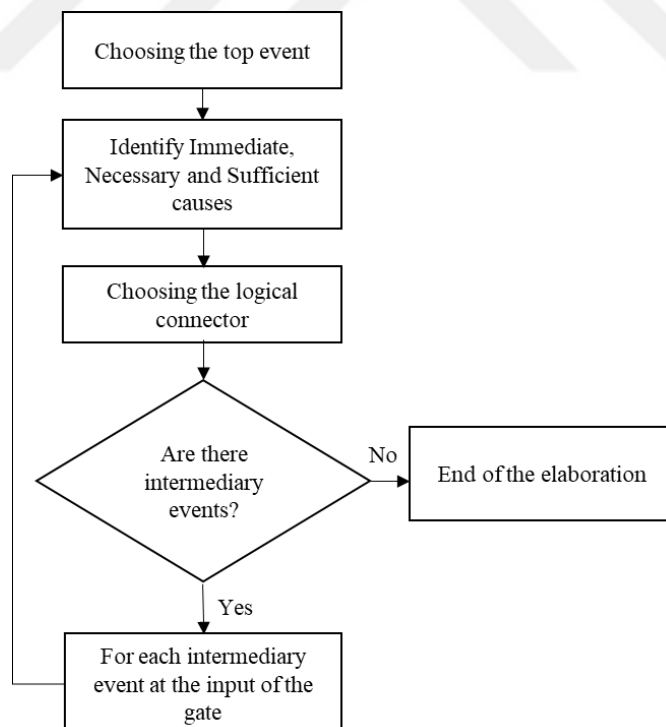


Figure 2.2 The main steps for a fault tree analysis (Ford et al., 2017)

2.8.9 Event Tree Analysis

Event tree analysis describes the flow of situations that occur after a specified risk occurs. It examines all the sub-components in the systems and creates a model with induction logic. The method is based on potential events affecting a risk. It is both a qualitative and quantitative method such as FTA. The need for documentation is very high in the application of the method, and it is applied by an experienced group of experts. It is an advantageous method in terms of explaining the related risks that are difficult to detect in systems (Andrews & Dunnett, 2000). Figure 2.3 defines the inputs and possible outputs of the event tree analysis.

Input	Output
• Initiating events • Mitigating precaution overview	• Visual representation • Combination of events leading up to an outcome • Quantitative estimates of event frequencies • Relative importance of failure sequences and contributing (Marhavilas, Koulouriotis and Gemeni, 2011)

Figure 2.3 List of input and possible output for an event tree analysis (Ford et al., 2017)

2.8.10 Cause and Consequence Analysis

Cause and consequence analysis is the combination of FTA and event tree analysis. It requires high experience and is both a qualitative and quantitative method. The purpose of the analysis is to determine the negative events occurring in the flow of the events in the systems. It provides great advantage in systems with many interrelated errors (Poortinga & Pidgeon, 2005). Figure 2.4 defines the input and possible outputs of cause and consequence analysis.

Input	Output
• Failure modes • Failure scenarios	• Diagram representation of system failure with both causes and consequences • Probability of each potential consequence

Figure 2.4 List of input and output for the cause-consequence analysis (Ford et al., 2017)

2.8.11 Failure Mode and Effects Analysis – FMEA

Failure mode and effects analysis does not require high level of experience and is easy to use. Therefore, it is a frequently preferred method in risk analysis. It is an advantageous method to be applied in all risky processes. FMEA establishes a priority ranking for the risks. The precautions to be taken are applied according to these risk priority rankings. The risk priority coefficient used in the FMEA method is obtained by multiplying the probability of occurrence, severity and detectability values. The method provides many information such as detection of faults and the way it works and facilitates the understanding of various systems (Feili, Akar, Lotfizadeh, Bairampour & Nasiri, 2013). FMEA is explained in detail in Section 3.

2.9 Comparison of Risk Analysis Methods

There exist several methods that can be utilized in risk analysis. These methods differ from each other in terms of their risk value calculations. Comparison of the risk analysis methods is reported in Table 2.5 and Table 2.6. The methods have been evaluated and compared in many aspects such as its qualitative and quantitative characteristics, the sectors applied, and their success rates (Özkılıç, 2005).

Table 2.5 Comparison of risk analysis methods (Özkılıç, 2005)

	Criteria					
Methods	Document Requirement	Teamwork	Team Leader's Experience	Qualitative-Quantitative	Special Branch	Success Rate
Preliminary Hazard Analysis (PHA)	Moderate	With an Analyst	Intermediate Experience	Qualitative	Suitable for all Sectors	Not Enough by Itself
Risk Assessment Decision Matrix (L Type)	Very Low	With an Analyst	Very High Experience	Qualitative	Simple Procedural Jobs	Applied in Simple Jobs, Team Leader's Experience is Decisive
Risk Assessment Decision Matrix (X Type)	Very High	Teamwork	Very High Experience	Qualitative	Suitable for All Sectors	Applied in All Sectors, Team Leader's Experience is Decisive
What If?	Very Low	With an Analyst	Intermediate Experience	Qualitative	Simple Procedural Jobs	Not Enough by Itself
Job Safety Analysis (JSA)	Very High	Teamwork	Very High Experience	Qualitative	Suitable for All Sectors	Success Can Be Achieved If People's Task Definition is Made
Check List	Moderate	Teamwork	Intermediate Experience	Qualitative	Suitable for All Sectors	Success Rate May Vary Depending on Who Prepared to Work
HAZOP	Very High	Teamwork	Very High Experience	Qualitative	Chemical Industry	Requires High Performance
FMEA	Very High	Teamwork	Very High Experience	Qualitative-Quantitative	Electric / Machine / Service	Very Effective in Risk Analysis
Security Audit	Very Low	With an Analyst	Intermediate Experience	Qualitative-Quantitative	Suitable for All Sectors	Team Leader's Experience is Decisive
Fault Tree Analysis (FTA)	Very High	Teamwork	Very High Experience	Qualitative-Quantitative	Suitable for All Sectors	Very Effective in Risk Analysis
Event Tree Analysis (ETA)	Very High	Teamwork	Very High Experience	Qualitative-Quantitative	Suitable for All Sectors	Very Effective in Risk Analysis
Cause and Consequence Analysis	Very High	Teamwork	Very High Experience	Qualitative-Quantitative	Suitable for All Sectors	Requires High Experience

Table 2.6 Risk analysis methods and risk assessment phase

Method	Risk Assessment Phase		
	Risk Identification	Risk Analysis	Risk Evaluation
PHA – Preliminary Hazard Analysis	X	X	
JSA – Job Safety Analysis	X	X	
Risk Assessment Decision Matrix	X	X	X
What if Analysis	X	X	
HAZOP – Hazard and Operability Studies	X	X	X
FTA – Fault Tree Analysis	X	X	X
ETA – Event Tree Analysis	X	X	
Cause Consequence Analysis		X	X
FMEA – Failure Mode and Effects Analysis	X	X	X

The selection of the risk analysis method to be performed in the businesses is very important. If the method is chosen false, the business may experience financial losses and make wrong decisions in processes. Businesses should decide on a method according to their risk groups and production processes. For example, if small businesses choose a hard method to apply for small potential risks, time and material loss may be incurred.

In this study, FMEA will be employed because of its higher suitability for the operating conditions.

CHAPTER THREE

FAILURE MODE AND EFFECTS ANALYSIS

3.1 Definition of FMEA and Basic Concepts

FMEA is a frequently used and preferred method in risk analyses. By observing the whole system, it evaluates how potential risks encountered by a subsystem affect the whole system (Vodenicharova, 2017). FMEA aims to detect and prevent potential problems in the systems before they occur, and to interfere and eliminate them with necessary precautions (Stamatis, 2003). With the method, risks can be grouped in order of importance and detailed risk analyses can be made. Past experiences and data can guide the implementation of FMEA studies (Geum, Shin & Park, 2011).

FMEA aims to identify risks as quickly as possible before they occur. It also aims to analyze what is effective in the occurrence of risks and the precautions to be taken to mitigate these effects. As the risks are identified before they occur, precautions can be taken on time (Braaksma, Meesters, Klingenberg & Hicks, 2012).

The difference of FMEA method from other methods is that it also evaluates the probability of occurrence of risks while doing risk analysis. With FMEA, various precautions are taken for the risks with the highest risk priority by evaluating the identified risks. The risk priority value is the result obtained by the multiplication of the probability of occurrence of risks, the severity of the risks and the detectability values of the risks. Risks can be ranked and classified according to these risk priority values.

3.2 Historical Development of FMEA

FMEA was used for the first time in order for flight controls in the army, and the first book on this subject was written in 1949. Then, NASA used FMEA to create the lunar travel program. The method was employed in industrial applications after 1972.

In addition, it is referred in many quality management systems standards such as QS 9000, ISO / TS 16946, ISO 9001: 2015 (Demirer & Kahraman, 2010). Nowadays, FMEA continues to be applied in various fields such as automotive, pharmaceutical and communication sector.

3.3 Aims and Benefits of FMEA

FMEA is a method used to identify the types of faults that cause a risk and the effects of the faults (Karunathilake et al., 2020). For this purpose, before the defined fault occurs, the necessary precautions can be taken and prevented. The use of FMEA in all processes of businesses minimizes changes and faults (Shahin, 2004).

3.4 Difficulties in the Applications of FMEA

The deficiencies in the systems make it difficult to apply FMEA method. The biggest of these deficiencies is the lack of data. This makes it difficult to implement the method and affects the accuracy of the results. Failure in recording the information required for FMEA, causes the method to give erroneous results (Stamatis, 2003).

While applying FMEA, probability, severity and detectability values of faults are used as data. In case of the data are missing or not kept correctly, they are obtained by getting expert opinions. However, expert opinions may differ due to the differences in experience levels of experts.

3.5 Types of FMEA

There exist different types of FMEA that can be used in all processes of production and service systems. Figure 3.1 illustrates the types of FMEA.



Figure 3.1 Types of FMEA

3.5.1 System FMEA

System FMEA is concerned with minimizing fault types and effects in systems and increasing the efficiency of the system. The aim is to achieve balance between all factors. Sub-systems are also analyzed, and possible risks are emphasized in system FMEA. Thus, it is easier to identify unnecessary processes and sections in systems with system FMEA. As a result of the implementation of system FMEA, necessary precautions can be taken with the detection of possible risks in all systems and subsystems (Stamatis, 2003).

3.5.2 Design FMEA

It is a type of FMEA used to observe the types and effects of errors in the design processes of production and service systems. Risks can be identified, and necessary precautions can be taken before starting production with design FMEA. It is very important due to the importance of the design process. It is not possible to return and correct the risks that are not noticed and prevented in this process. For this reason, changes and arrangements made after the design process cause error costs (Stamatis, 2003).

3.5.3 Process FMEA

Process FMEA evaluates all processes in production and service systems. It also examines sub-processes and aims to identify all types of faults and their effects (Press, 2003). Process FMEA provides convenience for analyzing processes and monitoring possible risks. Error types lists are prepared by using process FMEA.

3.5.4 Service FMEA

Service FMEA provide to control the whole system. By calculating the risk priority coefficients of the identified possible risks, potential errors that may occur during the service can be prevented. The biggest benefit of service FMEA, which we can gather many outputs such as error types, critical processes and precautions to be taken, is that it can create a priority order for the precautions to be taken.

3.6 FMEA Processes

FMEA follows implementation steps such as calculating risk priority coefficients and taking precautions regarding possible error types in a timely manner in order to detect errors that may cause risks in the processes. Information about the risks that cause faults is collected with FMEA studies (Pillay & Wang, 2003). The general flow of implementation steps followed in FMEA studies is presented in Figure 3..

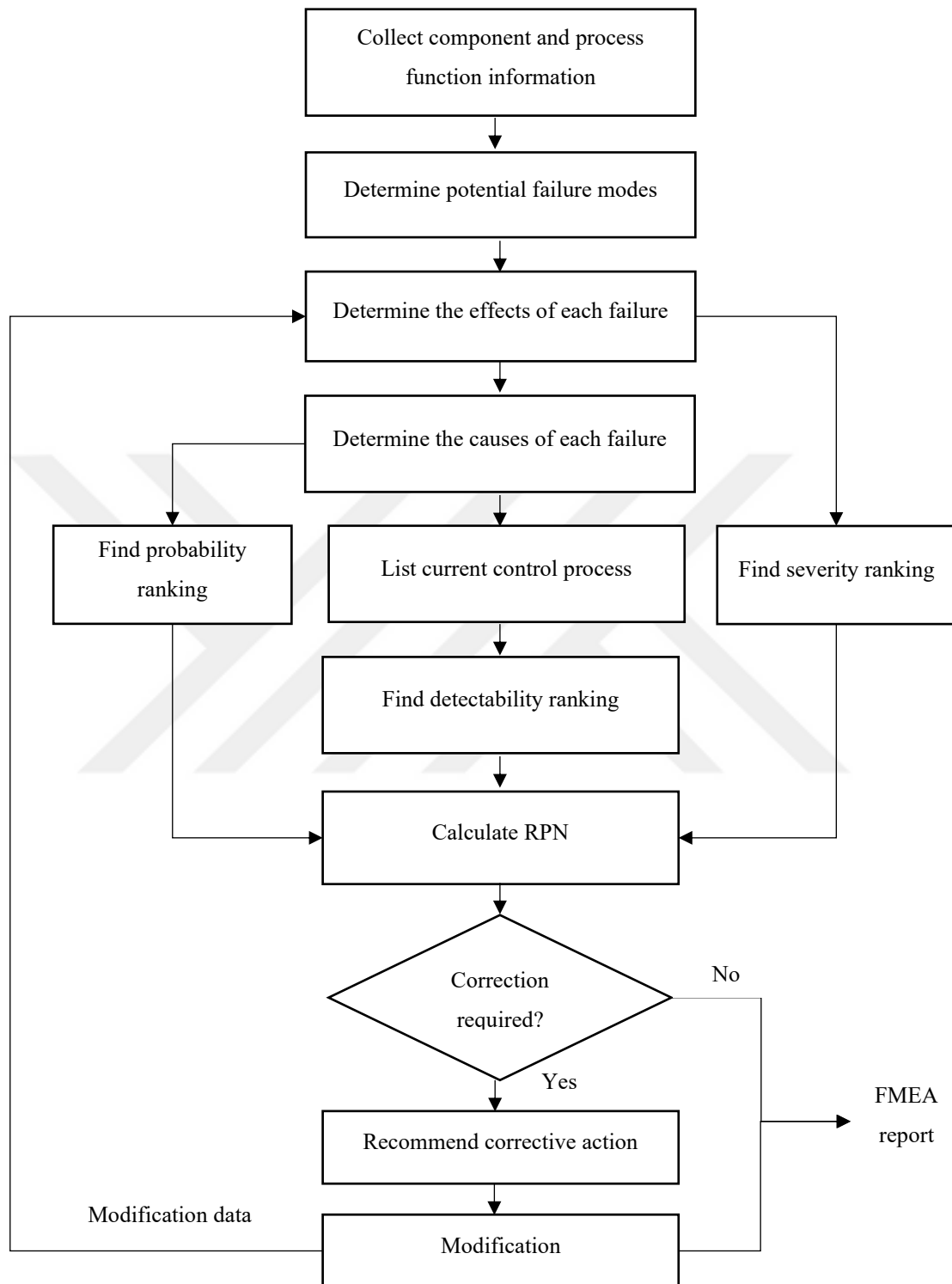


Figure 3.2 FMEA process (Pillay & Wang, 2003)

FMEA can be used in production and service systems, when a new design is to be made, when changes are made to existing ones, and for system improvements (Eleren, 2007).

3.6.1 Determination of FMEA Scope

FMEA can be used in all processes of production and service type businesses. The aim of the study must be clearly determined before starting the study. FMEA studies require continuity. The process should be checked regularly during the study, and new risk groups should be continuously reviewed. Necessary precautions must be taken against the identified risks and the method must be repeated in the process. Therefore, continuity should not be ignored while determining the scope of FMEA (Özfirat, 2014).

3.6.2 Determination of Possible Failure Types and Effects

Failure types in FMEA studies are defined by considering the system's inability to produce appropriate results. There are some points of view for detecting the faults in systems. One of them is a perspective on what end users will not accept. Factors that cause faults in the system can be observed by evaluating the situations that the end user will not accept.

Besides the types of faults in systems, the root causes of the faults should be determined. By identifying the root causes correctly, the processes that need to be improved in the system can be determined, and eliminating faults becomes easier. Therefore, determining the root causes is of great importance (Teoh & Case, 2004).

Determining the root causes of the faults provides an examination of the effects of the faults on the system. The effects can be defined as negativities that can be faced in the systems. While determining the effects of failures, experience, past data and results can be utilized. The effects of all identified failure types must be defined. When

defining the effects, changes caused by the failures in the system and satisfaction of the end user should be observed well.

3.6.3 Determination of Probability, Severity and Detectability Values

Various scales are used to determine the probability, severity and detectability values. In one of these scales, the probability value takes between 1 and 10 by considering the probability of occurrence of the failure (Yücel, 2007). While determining the probability value, past experiences and experimental data can be used. The scale used for defining the probability value in FMEA studies is reported in Table 3..

Table 3.1 The probability of occurrence criteria (Chin, Chan & Yang, 2008)

Occurrence	Meaning	Quantitative failure probability	Rating/scale
Very high	Failure is almost inevitable	≥ 1 in 2	10
Very high		1 in 3	9
High	Repeated failures	1 in 8	8
High		in 20	7
Moderate	Occasional failures	1 in 80	6
Moderate		1 in 400	5
Moderate		1 in 2000	4
Low	Few failures	1 in 15000	3
Very low	Relatively few failures	1 in 150000	2
Remote	Failure is unlikely	≤ 1 in 1.5×10^6	1

While determining the severity value of failure types, end user opinions can be used. Table 3. shows the scale used for the value of severity. If the error is on a scale that the end user will not notice, it is evaluated as 1, if it is on a scale that it will not accept it is evaluated as 10. Improvement of the severity values of the failure types is possible only with changes in the design and processes.

Table 3.2 The severity criteria (Chin, Wang, Poon & Yang, 2009)

Effect	Severity Level	Rating/Scale
Hazardous	When a potential failure mode effects	10
Very high	When a potential failure mode effects	9
High	System inoperable due to destructive failure	8
Moderately high	System inoperable due to harsh failure	7
Moderately low	System inoperable with minor or notable failure	6
Low	System inoperable with minor or prominent failure	5
Very low	System operable with relatively few failures	4
Very remote	System operable with relatively few failures	3
Remote	No effect	2
None	No effect	1

While finding the detectability value of failure types, past experiences and experiences can be used. The scale used for the detectability value is shown in the Table 3.. It is thought that the failure occurred while giving the detectability value. Thus, necessary precautions can be taken before reaching the end user.

Table 3.3 Detectability evaluation criteria (Balaraju, Raj & Murthy, 2019))

Effect	Detection criteria	Rating/Scale
Not possible	Controls actions are not available	10
Very remote	Extremely low possibility of noticing the breakdown	9
Remote	Low possibility of noticing the breakdown	8
Low	Low possibility of noticing the reasons for the occurrence of breakdown	7
Low	Low chance of detecting a possible cause and consequent failure mode	6
Moderate	Reasonable possibility of noticing the reasons for the occurrence of breakdown	5
Moderately high	Reasonably high possibility of noticing the possible reasons for occurrence of breakdown	4
High	High probability to notice the potential reasons for the occurrence of breakdown	3
Very high	Very high probability of noticing the potential reasons for occurrence of breakdown	2
Assured controls	Required controls are available to detect a failure mode	1

3.6.4 Calculation of The Risk Priority Coefficient

When calculating the risk priority coefficient, probability, severity and detectability values are used. These values are the numerical values determined according to the scales, and the risk priority coefficients are obtained by their multiplication (Vykydal, Plura, Halfarova & Klaput, 2015). All the multipliers used in the calculation of the risk priority coefficient have an equal degree of importance.

$$\text{Risk Priority Number} = \text{Probability} * \text{Severity} * \text{Detectability} \quad (3.1)$$

In FMEA studies, the risk priority coefficient is calculated with the formula given in Equation 3.1. In line with this calculation, RPN takes the value between 1 and 1000 (Chin et al., 2009).

3.6.5 Evaluation According to the Risk Priority Coefficient

The aim of calculating the risk priority coefficients in FMEA studies is to rank the risks according to their importance (Mirzaei & Avakhdarestani, 2016). By classifying risks according to their RPN, precautions to be taken for these risks can be planned.

Firms can determine the risks to be focused by using the RPN values considering their risk management capacities. In FMEA studies, RPN values of different failure types may be equal. In such a case, priority can be determined by looking at the severity values. If the severity value is also equal, priority can be determined by looking at the detectability value (Chin et al., 2009).

3.6.6 Implementation and Monitoring of Precautions to be Taken

There are some points to be taken into consideration when determining the precautions to be focused against risks in FMEA studies. Firstly, the precaution to be taken should be a precaution that will reduce the probability value of the relevant type

of failure. Another point is that the precaution should reduce the value of the severity of the failure type. The last point is that the precaution should reduce the detectability value of the failure type. Thus, the risk priority coefficient can be reduced, and the precautions taken show their effect. The purpose of taking precautions is to decrease the probability, severity and detectability values of the failures as much as possible. The precautions implemented by the FMEA team should be reported (Teng & Ho, 1996).

By means of the precautions taken, RPNs of the failures should be monitored regularly and followed up to an acceptable level. As the risk priority coefficients decrease, the rankings and classifications of failure types change, and the improvement cycles continue. Risk priority coefficients are recalculated after the implementation of the precautions. RPNs reaching the desired level means that the precautions are successful. Otherwise, the probability, severity and detectability values should be rechecked, and new precautions should be taken if possible.

CHAPTER FOUR

MULTI-CRITERIA DECISION MAKING

There is a decision making in every positive and negative situation in life. Decisions based on past experiences and environmental impacts can be in many subjects. Various factors are evaluated in making a decision. Evaluation of these factors may sometimes make the decision making process difficult (Chen & Hwang, 1992).

Another difficulty encountered in decision making stages is uncertainties. The process of evaluating the criteria and uncertainties within the rules and concluding them in a way to make the best decision is defined as multi-criteria decision making.

4.1 The Concept of Decision Making

Various decisions are made as a result of their perspectives and knowledge in many processes of daily life. Decision making is a systematic concept. Although all external factors are considered important before making decision, the main thing is the groups that will be affected by the decisions made (Saaty, 2008). For example, while making a decision, besides using the past experiences the requirements of that period should be considered.

The concept of decision making includes evaluating the related problems in all aspects and turning them into opportunities. This concept requires determining the criteria to be used in solving the problems, alternative solution suggestions for the problem and making a choice accordingly (Shao et al., 2020). For the decision maker to make a choice, there should be more than one alternative to the problem. If this condition is not met, the decision cannot be made (Zeleny, 2011).

Decision making can be defined as the systematic definition of alternatives in order to solve a problem and choosing the best alternative according to the desired criteria (Kahraman et al., 2019; Sağır, 2006). In order to make decision, it is necessary to know

all the details of the problem, the purpose of the decision, the factors affecting the problem and the alternatives related to the problem (Saaty, 1994).

4.2 Multi-Criteria Decision Making Techniques

Multi-criteria decision making techniques are examined in two groups according to their objectives. The first is multi-objective decision making (MODM), and the other is multi-attribute decision making (MADM) (Tzeng & Huang, 2011). In the Table 4. there are differences between multi-objective decision making and multi attribute decision making techniques (Hwang & Yoon, 1981).

Table 4.1 MODM and MADM comparison (Hwang & Yoon, 1981).

	MODM	MADM
Definition of Criteria	Objective	Attribute
Definition of Objectives	Distinct	Undefined
Definition of Attributes	Undefined	Distinct
Definition of Constraints	Active	Passive
Number of Alternatives	Infinite	Finite
Area of Usage	Design	Selection / Evaluation

The multi-objective decision making approach involves selecting the best alternative by evaluating the criteria according to the desired objective. In multi-attribute decision making approach, a selection is made among the pre-determined and preferred alternatives (Tzeng & Huang, 2011).

4.3 Multi-Criteria Decision Making Stages

With multi-criteria decision making approach, the best alternative is determined by evaluating the predetermined criteria (Mendoza & Prabhu, 2000). Stages of multi-criteria decision making method are illustrated in Figure 4.1 (Mahapatara, Sharma & Parappagoudar, 2013).

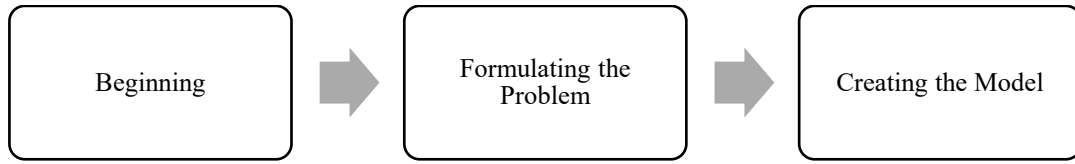


Figure 4.1 Stages of multi-criteria decision making (Balkuvar, 2015)

In the initial phase, the decision maker, who will manage the multi-criteria decision making process, recognizes the system and starts to identify the problem. In this step, the objectives are determined, and the multi-criteria decision making process begins. With determination of the problem and objective, the criteria are defined. After all the information needed by the decision maker is obtained, the model for the multi-criteria decision making process is created. The model covers the whole system and the variables within the system (Balkuvar, 2015).

While applying multi-criteria decision making methods, scales are defined according to criteria in order to evaluate alternatives, which are compared according to the expressions and values in the scales (Kahraman et al., 2019). Multi-criteria decision making methods can be used in selection problems, ranking problems and classification problems. The purpose of using multi-criteria decision making methods in selection problems is to choose the best among the alternatives. In ranking problems, the purpose is to choose the best among the alternatives, as well as to create a priority order among the alternatives (Akten, 2013). In classification problems, alternatives are classified according to their objectives with multi-criteria decision making methods (Wang, Huang & Dismukes, 2004).

4.4 Multi-Criteria Decision Making Methods

There are many decision making methods that can be used while applying multi-criteria decision making process. Some of these methods can only be used for selection, ranking or classification problems, while some methods can be used for all problem types. Table 4. shows the multi-criteria decision making methods and the type of problem that can be used (Erdoğan, 2018).

Table 4.2 Multi-criteria decision making methods according to the problem types (Erdoğan, 2018)

Problem Type	Multi-Criteria Decision Making Methods
Selection	AHP, MACBETH, ELECTRE I, TOPSIS, PROMETHEE, ANP
Ranking	FLWSORT, ELECTRE III, AHP, TOPSIS
Classification	AHP, MACBETH, ELECTRE I, TOPSIS, PROMETHEE, ANP

Multi-criteria decision making methods provide easy decision making (Wang, 2011). When applying multi-criteria decision making methods, alternatives are evaluated according to criteria (Yücenur & Şubası, 2019).

4.4.1 Analytical Hierarchy Process - AHP

The Analytical Hierarchy Process was developed by Thomas L. Saaty in the 1970s (Akten, 2013). It is used frequently for selection, ranking and classification problems as it can evaluate the alternatives both qualitatively and quantitatively (Saaty, 1994). AHP, which can be implemented in various sectors and areas, is a flexible method in order to be evaluated with subjective judgments. As the alternatives are evaluated according to all criteria, the best result is obtained by the method.

Stage 1: Determine the objective, evaluation criteria and alternatives

At this stage, the objective, evaluation criteria and alternatives are determined for the problem (Chen, Hu, Kuo & Liang, 2010). This stage is very important as it affects the solution of the problem. Figure 4. illustrates the scheme of AHP. This scheme includes the expression of criteria and alternatives in achieving the objective (Yumoto, 2017).

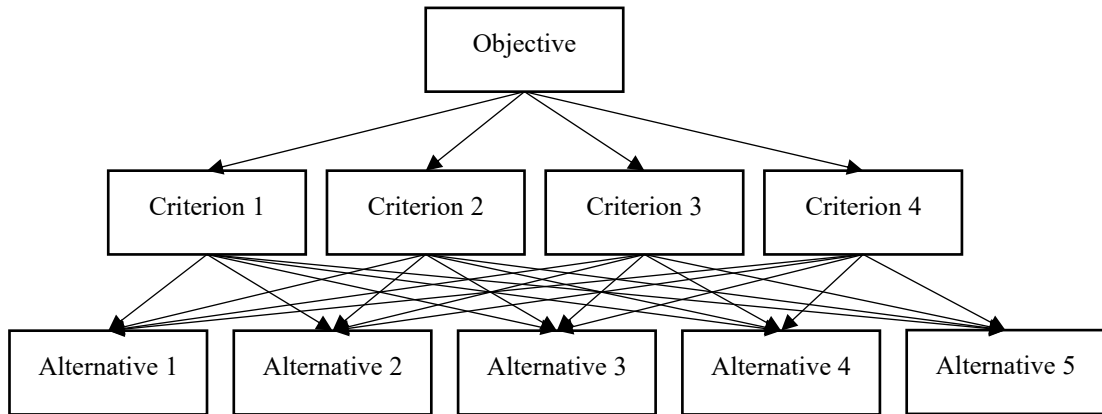


Figure 4.2 The scheme of AHP (Wang, Ran, Chen, Yu & Zhang, 2020)

Stage 2: Determine the relative importance with respect to the objective

Relative importance levels are determined, and pair-wise comparison matrices are created by the decision maker at this stage (Samuel, Asogbon, Sangaiah, Fang & Li, 2017). Pair-wise comparison values are created according to the scales given in Table 4. (Sakthivel & Ikua, 2017). Pairwise comparison matrix is prepared as shown Equation 4.1.

Table 4.3 Scale for pair-wise comparison (Aryanpur, Atabaki, Marzband, Siano & Ghayoumi, 2019; Samuel et al., 2017)

Relative importance levels	Scale of Importance
1	Equal preference
3	Moderately preference
5	Strong preference
7	Very strong preference
9	Extreme preference
2, 4, 6 and 8	For compromise between the above values

$$A = \begin{bmatrix} 1 & a_{21} & a_{31} & \cdots & a_{n1} \\ 1/a_{21} & 1 & a_{32} & \cdots & a_{n2} \\ 1/a_{31} & & 1 & \cdots & a_{n3} \\ \vdots & & & \ddots & \vdots \\ 1/a_{n1} & 1/a_{n2} & 1/a_{n3} & \cdots & 1 \end{bmatrix} \quad (4.1)$$

Stage 3: Determination of relative importance vector

The next step after the creation of pair-wise comparison matrices is to calculate the eigenvector, which shows the importance of each element in the matrix relative to the others (Wang et al., 2020). The eigenvector of the matrix in $n \times 1$ dimension is determined as follows (Saaty, 2003).

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad i = 1, 2, 3, \dots, n \text{ and } j = 1, 2, 3, \dots, n \quad (4.2)$$

$$w_i = \frac{\sum_{j=1}^n b_{ij}}{n} \quad i = 1, 2, 3, \dots, n \text{ and } j = 1, 2, 3, \dots, n \quad (4.3)$$

Significance values of the criteria are obtained by calculating the column vectors. The W column vector is derived from the arithmetic mean of the line elements of the matrix consisting of the b_{ij} values specified in Equations 4.2 and Equations 4.3 (Krejci & Stoklasa, 2018).

Stage 4: Calculate the consistency ratio

Consistency rate (CR) is calculated for each pair-wise comparison matrix. The upper limit of this ratio is desired to be 0.10. If the rate is above 0.10, it means that there is an inconsistency in the judgment of the decision maker. In such a case, judgments need to be improved. To reach the CR value, it is necessary first to calculate the largest eigenvector of the matrix A (Noble & Sanchez, 1993). The small CI value means that there is a small deviation from the consistency (Finan & Hurley, 1997) (See, Equation 4.4).

$$CI = (\lambda_{max} - M) / (M - 1) \quad (4.4)$$

The consistency rate is calculated as $CR = CI / RI$. If the CR value is less than or equal to 0.1, it can be accepted (Wedley, 1993). Random Index values are reported in Table 4..

Table 4.4 Random index (RI) values (Wedley, 1993)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Stage 5: Obtain the general result of the hierarchical structure

The stages up to this stage are calculated for the hierarchical structure. The vectors with size of $m \times 1$ priority column created by each of the n criteria in hierarchical structure are brought together. Consequently, DW decision matrix with size of $m \times n$ is created. R result vector is obtained by multiplying the obtained matrix with priority vector, W (Kwiesielewicz & Uden, 2004).

4.4.2 TOPSIS

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was generated by Hwang and Yoon in 1981. It is a frequently used method among multi-criteria decision making methods. While applying TOPSIS method, positive ideal solution and negative ideal solution points are used. In the evaluation stage, alternatives that are close to the positive ideal solution point and far from the negative ideal solution point are preferred (Khorshidi, Hassani, Rauof & Emamy, 2013; Tzeng & Huang, 2011). Quantitative values are used in the TOPSIS method.

When applying the TOPSIS method, the decision matrix must first be created. The matrix must be normalized and then weighed. Therefore, a normalized weighted decision matrix is formed. Positive and negative ideal solutions are calculated based on normalized weighted decision matrices. Thus, the distances of alternatives to positive ideal and negative ideal solution points are determined (Hwang & Yoon, 1981). Figure 4. illustrates the application stages of the TOPSIS method.

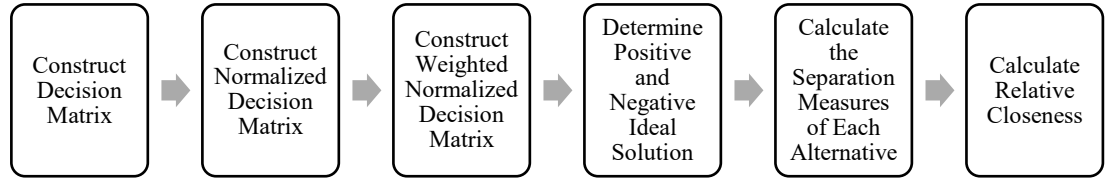


Figure 4.3 TOPSIS methodology (Daghour, Mansouri & Qbadou, 2018)

Stage 1: Construct the Decision Matrix

Decision matrix should be created by determining the alternatives and criteria by considering the purpose of the problem (Arslan & Cunkas, 2012). Decision matrix contains the values of alternatives in the rows and criteria in the columns (Triantaphyllou & Lin, 1996). There exist n criteria and m alternatives in the matrix presented in the following (Yousefi & Hadi-Vencheh, 2010) (See, Equation 4.5).

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \quad (4.5)$$

Stage 2: Construct the Normalized Decision Matrix

Square roots of the sum of the squares of the column values in the decision matrix are taken, and all cells are divided by these values. By applying this process to each column, the R matrix is formed in Equation 4.6 and Equation 4.7.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}} \quad (i = 1, 2, \dots, m ; j = 1, 2, \dots, n) \quad (4.6)$$

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdot & r_{1n} \\ r_{21} & r_{22} & \cdot & r_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ r_{m1} & r_{m2} & \cdot & r_{mn} \end{bmatrix} \quad (4.7)$$

Stage 3: Construct Weighted Normalized Decision Matrix

With the creation of the normalized matrix, the process of weighting is started. In order to obtain the weighted normalized matrix, the weight of each criterion must be calculated (Wang, Fan, Su, Liang & Wang, 2008). The decision matrix is multiplied by the weights of the criteria, and the weighted normalized decision matrix is obtained (Fattahi, Tavakkoli-Moghaddam, Khalilzadeh, Shahsavari-Pour & Soltani, 2020). In the formula, W_j refers to the weights of criteria (See, Equation 4.8 and Equation 4.9).

$$\sum_{j=1}^n W_j = 1 \quad V_{ij} = W_j * X_{ij}, \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, n) \quad (4.8)$$

$$V_{ij} = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \cdot & w_n x_{1n} \\ w_1 x_{21} & w_2 x_{22} & \cdot & w_n x_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ w_1 x_{m1} & w_2 x_{m2} & \cdot & w_n x_{mn} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & \cdot & v_{1n} \\ v_{21} & v_{22} & \cdot & v_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ v_{m1} & v_{m2} & \cdot & v_{mn} \end{bmatrix} \quad (4.9)$$

Stage 4: Determine Positive and Negative Ideal Solution

By using the weighted normalized decision matrix, positive ideal solution and negative ideal solutions that help us choose between alternatives are calculated. If the problem is the maximization problem, the maximum value in each column is determined. These maximum values are the positive ideal solutions (See, Equation 4.10 and Equation 4.11). The formulas of the positive ideal and negative ideal solutions are presented in the following (Olson, 2004).

Positive Ideal Solution

$$A^+ = \{ \max v_{ij} | j = 1, 2, \dots, p ; i = 1, 2, \dots, m \} \quad (4.10)$$

$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\}$ Maximum values in columns

Negative Ideal Solution

$$A^- = \{ \min v_{ij} | j = 1, 2, \dots, p ; i = 1, 2, \dots, m \} \quad (4.11)$$

$A^- = \{v_1^-, v_2^-, \dots, v_n^-\}$ Minimum values in columns

Stage 5: Calculate the Separation Measures of Each Alternative

In TOPSIS method, alternatives are selected according to their distance from the positive ideal and negative ideal solutions. Therefore, distances to ideal solutions are determined in this stage. The formulas of the distances are presented in the Equation 4.12 and Equation 4.13.

$$\text{Positive Ideal Measure } S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad (4.12)$$

$$\text{Negative Ideal Measure } S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad (4.13)$$

Stage 6: Calculate Relative Closeness

In order to choose the alternatives, the distances of the alternatives to positive ideal and negative ideal solution points should be known. The closeness value to the ideal solution is calculated with the following Equation 4.14.

$$C_i^+ = \frac{S_i^-}{S_i^- + S_i^+} \quad (4.14)$$

The C_i^+ value must be between 0 and 1. The value of 0 for C_i^+ indicates that the alternative is at the negative ideal solution, while 1 indicates that it is at the positive ideal solution (Deng, Yeh & Willis, 2000).

4.4.3 VIKOR

VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje), is a multi-criteria decision making method that can be used in optimization of complex problems. The method was first described in 1997 by Opricovic, Trajkovic and Avakumovic (Liu, 2019). Optimum solution and weighted decision intervals can be obtained by VIKOR.

In some decision making processes, decision makers may want to remark their own opinions and preferences. In addition, a decision maker may not be available in some decision making processes. In such cases, the decision making process can be performed by using VIKOR method. The solution obtained by VIKOR method aims at maximum group benefit (Opricovic & Tzeng, 2004).

All alternatives are evaluated in terms of each criterion in order to create a consensus for the compromise solution. Thus, the closeness of the alternatives to the ideal solution is determined. Compromised solution and ranking are obtained by using the closeness to the ideal solution (Chamodrakas, Alexopoulou & Martakos, 2009). The criterion L_p expresses the total function in VIKOR method. Solution is reached with the L_p value while creating a ranking. f_{ij} value used in Equation 4.15 denotes the value of the criterion i for alternative a_j .

$$L_{pj} = \left\{ \sum_{i=1}^n [w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-)]^p \right\}^{1/p}, \quad (4.15)$$

$$1 \leq p \leq \infty ; j = 1, 2, 3, \dots, j$$

When starting the VIKOR method, like other multi-criteria decision making methods, firstly, alternatives and criteria are determined related to the problem, and a

decision matrix is created from the scores of the alternatives according to the criteria. In the equations, i symbolize the criteria and j symbolize the alternatives.

Stage 1: Determine the Best f_i^* and the Worst f_i^- Values for the Criteria

When applying the VIKOR, the best f_i^* and the worst f_i^- values for the criteria are determined after the decision matrix is created (see, Equations 4.16 and 4.17). These values are determined considering the criterion type (Jahan, Mustapha, Ismail, Sapuan & Bahraminasab, 2011; San Cristobal, 2012).

If the relevant criterion is the benefit criterion:

$$\begin{aligned} f_i^* &= \max_j f_{ij} \\ f_i^- &= \min_j f_{ij} \end{aligned} \quad (4.16)$$

If the relevant criterion is the cost criterion:

$$\begin{aligned} f_i^* &= \min_j f_{ij} \\ f_i^- &= \max_j f_{ij} \end{aligned} \quad (4.17)$$

Stage 2: Compute the Values S_j and R_j

After determining the f_i^* and f_i^- values, S_j and R_j values are calculated for the alternatives. The average group value S_j and the worst group value R_j can be obtained by Equation 4.18. Herein, w_i indicates the criterion weights (Sayadi, Heydari & Shahanaghi, 2009).

$$S_j = \sum_{i=1}^n \frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i)} \quad R_j = \max \left[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i)} \right] \quad (4.18)$$

Stage 3: Compute the Q_j Values

While calculating the Q_j , which indicates the maximum group benefit, the maximum and minimum values of S_j and R_j are utilized (see, Equations 4.19 and 4.20) (Azarnivand & Chitsaz, 2015). In the equations, v symbolizes the weight of maximum group benefit, and it is used when calculating the maximum group benefit. In addition, $(1-v)$ symbolizes the minimum regret value. In the decision process, if v equals to 0.5, there is a match, if $v < 0.5$, veto, if $v > 0.5$, majority vote decisions can be taken.

$$S^* = \min S_j \quad S^- = \max S_j \quad (4.19)$$

$$R^* = \min R_j \quad R^- = \max R_j$$

$$Q_j = \frac{v(S_j - S^*)}{S^- - S^*} + \frac{(1-v)(R_j - R^*)}{R^- - R^*} \quad (4.20)$$

Stage 4: Rank the Alternatives, Sort by the Values of S , R and Q

For all alternatives, it is necessary to make a decision between the alternatives by calculating S_j , R_j and Q_j values.

Stage 5: Determine the Acceptable Alternative

As a result of obtaining the ranking for the alternatives, some evaluations should be made for the alternative with minimum Q_j value. The first of these evaluations is “acceptable advantage” and another is “acceptable stability”. For the alternative with minimum Q_j value to be within the acceptable advantage class, it must fulfilled the conditions shown in Equation 4.21. The equation also includes the alternative with the second smallest Q_j in the ranking. A_1 refers to the alternative with the first smallest Q_j value, A_2 refers to the alternative with the second smallest Q_j value. DQ value varies according to the number of alternatives and m is calculated according to the number of alternatives (San Cristobal, 2012).

$$Q(A_2) - Q(A_1) \geq DQ \quad (4.21)$$

$$DQ = \frac{1}{m-1}$$

While checking acceptable stability conditions, S_j and R_j ranking are evaluated as well as Q_j ranking. The S_j and R_j values of the alternative, which takes the first place according to the Q_j value, should also have minimum value.

4.4.4 ELECTRE

The ELECTRE (Elimination and Choice Translating Reality) is a multi-criteria decision making method based on binary superiority comparisons between alternatives (Benayoun, Roy & Sussman, 1996; Kahraman et al., 2019). The stages of the method is presented in the following.

Stage 1: Construct Decision Matrix

When starting the ELECTRE method, a decision matrix denoting the alternatives in its rows and the criteria in its columns is created as presented in Equation 4.22 (Munier, 2011).

$$D_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdot & x_{1n} \\ x_{21} & x_{22} & \cdot & x_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ x_{m1} & x_{m2} & \cdot & x_{mn} \end{bmatrix} \quad (4.22)$$

Stage 2: Construct the Normalized Decision Matrix

A new matrix is obtained by normalizing the decision matrix created in the first stage. Equation 4.23 is utilized in normalization.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (i = 1, 2, \dots, m ; j = 1, 2, \dots, n) \quad (4.23)$$

Stage 3: Construct the Weighted Normalized Decision Matrix

After obtaining the normalized decision matrix, the weights should be included in the normalized decision matrix (Deepa, Ganesan and Sethuramasamyraja, 2019). In obtaining this matrix, the normalized weights are multiplied by the normalized decision matrix (see, Equation 4.24).

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdot & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdot & w_n r_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ w_1 r_{m1} & w_2 r_{m2} & \cdot & w_n r_{mn} \end{bmatrix} \quad (4.24)$$

Stage 4: Determine the Concordance and Discordance Sets

In applying the ELECTRE method, concordance and discordance sets are created (Çalı & Balaman, 2019). Binary comparisons are made by evaluating the alternatives in terms of the criteria. While these binary comparisons are made, the criteria are divided into two groups. As shown in Equation 4.25, alternative A_p is preferred as a result of comparing A_p and A_q in the concordance set.

$$C(p, q) = \{j | V_{pj} \geq V_{qj}\} \quad (4.25)$$

If alternative A_p is worse than alternative A_q , a discordance set is created as in Equation 4.26.

$$D(p, q) = \{j | V_{pj} \leq V_{qj}\} \quad (4.26)$$

Stage 5: Calculate the Concordance and Discordance Indexes

By using the concordance and discordance sets, concordance and discordance matrices are created by Equation 4.27.

$$C_{pq} = \sum_{j \in C_{pq}} w_j \quad (4.27)$$

The advantages of alternatives against each other are determined by the C_{pq} , which indicates the concordance index. For example, if $C_{12} = (1, 4)$, the value of element C_{12} in the matrix is equal to $w_1 + w_4$ (see, Equation 4.28). The concordance matrix is presented in the following (Almeida, 2007).

$$C = \begin{bmatrix} - & C_{12} & \cdots & C_{1m} \\ C_{21} & - & \cdots & C_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ C_{m1} & C_{m2} & \cdots & - \end{bmatrix} \quad (4.28)$$

After obtaining the concordance matrix, the discordance matrix is obtained with the discordance sets. Values for the discordance matrix are obtained as shown in Equations 4.29 and 4.30).

$$d_{pq} = \frac{\max_{j \in D_{pq}} |y_{pj} - y_{qj}|}{\max_{j \in J} |y_{pj} - y_{qj}|} \quad (4.29)$$

By calculating the d_{pq} values for all elements, the discordance matrix, D , is obtained as follows (Zhuang, Chiang, Su & Chen, 2017).

$$D = \begin{bmatrix} - & d_{12} & \cdots & d_{1m} \\ d_{21} & - & d_{23} & d_{2m} \\ \vdots & \cdots & \cdots & \vdots \\ d_{m1} & d_{m2} & d_{m(m-1)} & - \end{bmatrix} \quad (4.30)$$

Stage 6: Compare the Outranking Alternatives

After creating the concordance and discordance matrices, appropriateness of the elements should be checked. Thus, unsuitable alternatives are deleted. In control process, C_{pq} and D_{pq} and average C and D values are evaluated. If $C_{pq} \geq C$ and $D_{pq} \leq D$, alternative A_p is preferred to alternative A_q .

Using ELECTRE method, set K is created from the alternatives selected (Tzeng & Huang, 2011).

Stage 7: Calculate the Net Concordance and Net Discordance Indexes

The last step to be taken is to calculate the net concordance and net discordance indexes (Tozan & Karatas, 2018). In order to determine the superiority of alternatives and to make a choice, an alternative with the largest net concordance index and the lowest net discordance index is determined. For each alternative, the ranking is made according to C_p value that can be obtained by Equation 4.31. The alternative with the highest C and the lowest D values is preferred (See, Equation 4.32).

$$C_p = \sum_{k=1, k \neq p}^m C_{pk} - \sum_{k=1, k \neq p}^m C_{kp} \quad (4.31)$$

$$D_p = \sum_{k=1, k \neq p}^m D_{pk} - \sum_{k=1, k \neq p}^m D_{kp} \quad (4.32)$$

CHAPTER FIVE

LITERATURE REVIEW

Nowadays, risk factor is very important for businesses. The fact that they have an active role in the competitive environment they rely on the precautions they take against the risks. For this reason, businesses carry out various risk management studies. In this chapter, a literature review on studies employing FMEA in risk assessment is presented. FMEA is frequently used in risk analysis, and it provides an assessment taking into account the probability, severity and detectability of the risks (Feng & Chung, 2013). Today, the method can be used in many areas of production and service sectors.

Franceschini & Galetto (2001) argued that there are deficiencies in the RPN values calculated in FMEA method. They stated that FMEA could become more advantageous by including a qualitative analysis in the RPN calculation. Scipioni, Saccarola, Centazzo & Arena, (2002) apply FMEA in the food sector, and exposed that the method is suitable for use in food sector. Zhou & Stalhane (2004) argued that FMEA can be used to improve system quality, and they exemplify this by a web-based system analysis.

Pantazopoulos & Tsinopoulos (2005) aimed to minimize the frequency of occurrence of risks in FMEA applied in automotive industry. In another research, Segismundo & Migual (2008) employed FMEA in automotive sector and provided improvements in new product development processes.

Santos & Cabral (2008) defined that FMEA can be used in project management, and analyzed possible risks that may be observed during the project management process. In another study, Chen (2013) emphasized the importance of autonomous care in preventing risks and analyzed the risks arising from equipment or operator in autonomous processes using FMEA.

Chanamool & Naenna (2016) applied FMEA method in health sector. The risks that can be seen in the emergency departments are very important for the condition of the patients and the reliability of the hospital. Therefore, they applied FMEA to emergency services in their studies. They argued that the effectiveness of emergency services could be increased by preventing potential risks before they cause a fault. Thus, trust in hospitals can be increased.

Peeters, Basten & Tinga (2018) stated that FMEA and FTA methods are suitable for use together but it takes a long time to complete and therefore it is not preferred to use them together. In their study in the manufacturing sector, they developed a new method combining these two methods. They applied this method by applying firstly FTA to a process they determined. Then, FMEA was employed for a group of faults they obtained by using the result of FTA, and selected the critical faults. Subsequently, they applied FTA again for each fault and used their results in FMEA. In the analysis, they applied the methods separately and applied them recursively.

Veronese et al. (2015) used FMEA to evaluate the risks that patients may face in hospitals. They classified the risks by ranking the RPN values obtained by FMEA method, and used them to better define the treatment processes and sub-processes. The researchers indicated that more effective solutions had been started to be produced for the safety of patients in hospitals by means of their study.

Rezaee, Salimi & Yousefi (2017) evaluated FMEA method for manufacturing sector in their study. They used FMEA and data envelopment analysis together. After defining the possible fault types and the precautions to be taken, they calculated the costs of the faults in the systems. Then, they determined their risk priority ranking based on the value obtained from FMEA and data envelopment analysis. Accordingly, they included the cost values of the faults in the method.

By scrutinizing the previous studies, it can be seen that FMEA method is utilized in many sectors. Huang et al. (2020) presented a review of the sectors in which FMEA

method was mostly used between 1998 and 2018. As illustrated in Figure 5.1, FMEA was used mostly in the manufacturing industry (Huang et al., 2020).

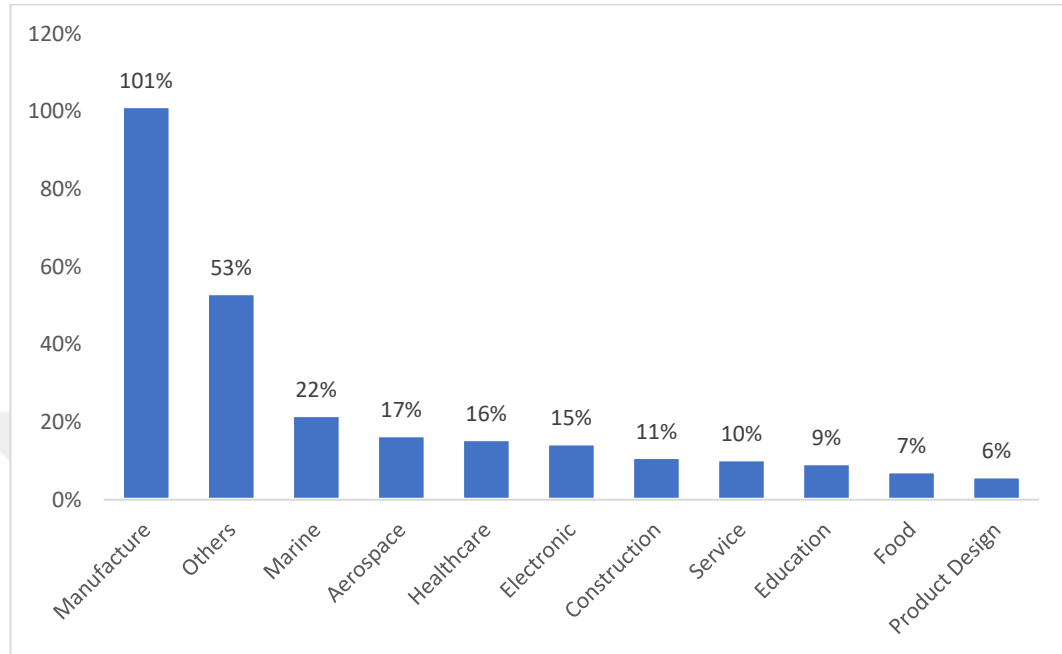


Figure 5.1 Distribution of articles by application fields (Huang, You, Liu & Song, 2020)

In traditional risk analysis methods, only probability, severity and detectability values are used when calculating the risk value. In addition to these, values such as cost, employee performance, loss of motivation and productivity are not taken into consideration. The same situation exists for FMEA, which is one of the risk analysis methods. Many studies have been carried out to complement the deficiencies in traditional risk analysis methods and to evaluate different factors. These studies focused on prioritizing critical risk groups determined by FMEA according to various risk factors. While making these prioritization, they used various methods. The first and the most frequently used of them are multi-criteria decision making methods. Although mathematical modeling ranks second among the methods used, many researchers have preferred to apply multi-criteria decision making methods.

Braglia (2000) presented FMEA with AHP, which is one of the multi criteria decision making approaches. Braglia (2000) defined probability, severity and detectability factors in FMEA as criteria and possible causes of failures as alternatives.

Therefore, a priority order among the causes of failure is formed. Similarly, Hu, Hsu, Kuo & Wu (2009) obtained the weights by using AHP, and declared that their weights better evaluate the risk factors used in FMEA.

Kutlu & Ekmekcioglu (2012) used fuzzy TOPSIS method with fuzzy AHP to prioritize the causes of failure in their studies so that they were able to effectively evaluate risk factors.

Zammori & Gabbrielli (2012) employed ANP for the factors and sub-criteria used in the calculation of the RPN values obtained by FMEA. They calculated the new RPN values with binary comparisons.

Braglia, Frosolini & Montanari (2003) applied TOPSIS method by defining the risk groups they obtained with FMEA. In another study, Seyed-Hosseini, Safaei & Asgharpour (2006) argued that DEMATEL method can be used to evaluate risk groups in FMEA. In the approach that cares about the effects of the two alternatives on each other, the alternative with the higher effect has the higher priority.

Liu, Liu, Liu & Mao (2012) argued that VIKOR method, which is one of the multi-criteria decision making methods, can be used with FMEA method. The critical risk groups were determined by FMEA, and priorities were obtained by VIKOR in the study.

Liu (2016) aimed to expand the use of FMEA in the construction industry. The researcher presented a case study using fuzzy AHP method and FMEA together. He advocated the need to develop proactive approaches to risks.

Vahdani, Salimi & Charkhchian (2015) used TOPSIS method together with the FMEA to overcome some deficiencies in FMEA method. They determined a priority ranking in their study for precautions in the manufacturing sector.

Safari, Faraji & Majidian (2016) employed FMEA and VIKOR to assess the architectural risks.

Fattahi & Khalilzadeh (2018) examined the faults by using fuzzy AHP, Multimoora and FMEA. Instead of the RPN value, they prioritized the risks based on the value calculated by fuzzy AHP. They also consider the cost criteria in the new value they obtained.

Lolli, Ishizaka, Gamberini, Rimimi & Messori (2015) aimed to separate faults according to their priority classes by integrating multi-criteria decision making approach to FMEA. They developed a new multi-criteria decision-making method called FlowSort. Thus, they were able to make a comparison between risk factors by considering the causes of failure.

Tsai et al. (2017) argued that FMEA can only classify possible errors according to their priority order, but the method is insufficient in cases where there are many types of interaction. They stated that in such a case, many important risk groups were assumed to be of low priority and therefore no solution could be developed. They preferred to apply DEMATEL method, which is one of the multi-criteria decision-making methods, to complement the deficiencies of the method in this regard (Durakbasa & Gencyilmaz, 2019). They were able to establish causal relationships and obtain effective solutions against errors by determining risk factors.

Wang, Liu, Qin & Fu (2018) argued that evaluating the risks in FMEA method and prioritizing fault types is an important multi-criteria decision-making problem. The study, which argues that the effect of the psychological behavior of the decision maker on the method is quite large, also included the psychological behavior in the method. In the proposed approach, they also evaluated the relationships between risk factors. To this aim, they used entropy weighting method and FMEA together.

Table 5.1 reports the previous studies using multi-criteria decision making methods with FMEA.

Table 5.1 Studies using multi-criteria decision making methods with FMEA

	MCDM	Risk Analysis	Risk Evaluation	Risk Assessment
Abdelgawad & Fayek (2010)	Fuzzy AHP	X		
Ahmadi, Molana & Sajadi (2017)	TOPSIS	X		
Arabzad, Razmi & Ghorbani (2011)	TOPSIS - Entropy			X
Braglia (2000)	AHP		X	
Braglia et al., (2003)	TOPSIS	X		
Carmignani (2009)	AHP	X		
Chang and Cheng (2010)	DEMATEL			X
Chin et al., (2009)	Evidence Theory	X		
Fattahi & Khalilzadeh (2018)	Fuzzy AHP – Multimoora		X	
Hu et al. (2009)	AHP		X	
Hu, You, Wang & Liu (2019)	GRA - TOPSIS	X		
Kutlu & Ekmekcioglu (2012)	Fuzzy AHP – TOPSIS		X	
Liu (2016)	Fuzzy AHP		X	
Liu et al. (2012)	VIKOR		X	
Lolli et al. (2015)	FlowSort			X
Mangeli, Shahraki & Saljooghi (2019)	Fuzzy TOPSIS			X
Mohsen & Fereshteh (2017)	VIKOR			X
Safari et al. (2016)	VIKOR		X	
Şenel, Şenel & Havle (2018)	Fuzzy TOPSIS	X		
Seyed-Hosseini et al., (2006)	DEMATEL		X	
Shahin, Khodadady & Shirouyehzad (2015)	TOPSIS	X		
Song, Ming, Wu & Zhu (2013)	Fuzzy TOPSIS	X		
Tsai et al. (2017)	DEMATEL	X		
Vahdani et al. (2015)	TOPSIS		X	
Zammori & Gabbrielli (2012)	ANP			X
Wang et al., (2018)	TOPSIS		X	
Yang, Huang, He, Zhu & Wen (2011)	Evidence Theory		X	

It is observed that multi-criteria decision making methods are frequently used in FMEA studies, and most of these studies addresses the deficiencies of the RPN value obtained by FMEA. Priority rankings are given to the fault types by FMEA. Therefore, it was generally recognized as a multi-criteria decision making method. Accordingly, the deficiencies identified in the RPN value are developed by applying multi-criteria decision making methods such as TOPSIS, DEMATEL, VIKOR and AHP (Huang et al., 2020). Table 5.1 reports which multi-criteria decision making method is used together with FMEA.

In this study, TOPSIS method will be used together with FMEA. Precautions determined by FMEA will be evaluated by TOPSIS method. Priority ranking will be made among the precautions to be taken with four different criteria.



CHAPTER SIX

APPLICATION

6.1 RPN Calculation with FMEA

In this thesis, a risk management study is carried out in the production processes of the selected product in an international manufacturing firm producing kitchen systems. Accordingly, 52 failures were encountered, and the risks that these failures can cause have been identified. FMEA method is utilized in order to identify the failure and the precautions to be taken against risks.

In the FMEA study, the risks were evaluated using the scales determined by the firm. On the scale of the risks reported in Table 6., 6.2 and 6.3, the value of 0.25 represents the contusion and the value of 65 indicates disaster.

Table 6.1 Scale for the severity values

<i>Severity</i>	
0.25	Contusion
0.50	Laceration/ Tomy/ Slight Burns
3	Fracture - Finger, Toe
5	Fracture – Hand, Arm, Leg
8	1 or 2 Finger / Toe Loss or Serious Burns
11	Leg / Hand Loss, Vision or Hearing Loss
15	Two Legs / Hand Loss, Vision / Hearing Loss in Both Eyes and Ears
25	Critical Injuries or Permanent Injury / Disease
40	Death
65	Disaster

Table 6.2 Scale for the probability of occurrence

<i>Probability of Occurrence</i>	
0.05	Almost impossible
1.25	Not Possible
2.50	Possible
4	Potential
6	Exact

Table 6.3 Scale for the frequency of exposure

<i>Frequency of Exposure</i>	
0.5	Year to Year
1	Monthly
2	Weekly
3	Diary
4	Hourly
5	Continuous

The firm uses an additional parameter in calculating the RPN value. This parameter is the number of exposed people. The related scale is presented in Table 6..

Table 6.4 Scale for the number of exposed people

<i>Scale</i>	<i>Number of Exposed People</i>
1	1-2 People
2	3-7 People
4	8-17 People
8	18-49 People
12	Over 50 People

A part of the FMEA study conducted in this thesis is presented in Table 6. to give insight to the readers. Complete results of the study are reported in Appendix 1.

Table 6.5 Sample results of the FMEA

Definition of Hazard	Severity	Risk	Probability of occurrence	Number of people exposed	Frequency of exposure	RPN	Precautions
High pressure	15	Uncontrolled pressure rise as a result of not using the pressure relief valve	4	1	3	180	The circuit must be protected with pressure relief valves. These valves cannot change without using a tool. In addition, they should be set at a pressure not higher than 10% of the maximum working pressure.
High pressure	15	Hand operated valves-No control and monitoring functions	4	1	3	180	The protective locking device must be positively connected to the actuator directly to the manually operated valve to reverse or interrupt the hydraulic fluid flow.
Liquid spraying at the high pressure	11	Loosening of hydraulic hoses, affecting the health of the worker under pressure	2,5	1	5	138	Pressure hoses and similar equipment designed and mounted closed.
Pipes and connections	3	Burrs in pipes and connections	2,5	1	5	38	Attaching a filter and monitoring from hydraulic circuit diagram.
Dangerous movement during maintenance and adjustment	15	Dangerous movement during tool setting, maintenance and lubrication (en 16092-3 5.5)	2,5	1	5	188	Facilities will be provided to perform sled / ram movement during tool setting, maintenance and lubrication with protective and protective devices in place and in working condition.
Uneducated or patient staff work	3	The work of sick, tired, untrained and careless staff	2,5	1	5	38	Giving necessary warning instructions in the maintenance manual book. Also, warning labels are placed on the press.
Crushing, Shearing, Cutting, Chopping	8	Access to the mold site	2,5	1	5	100	Designing the machine to stop automatically when there is an intervention in the mold area.
Mass and balance	25	Potential energies of the elements that can move with the effect of gravity	1,25	1	0,5	16	Designing the bench parts so that they do not fall with the effect of gravity.

The risks are classified by calculating the RPN values. The acceptability levels of the risks are determined by the firm as reported in Table 6.67.

Table 6.67 Acceptability levels of the risks

<i>RPN</i>	<i>Risk</i>	<i>Explanation</i>
1-10	Negligible Risk	It does not exposure a hazard to health and safety. No additional risk reduction precautions are required.
11-20	Very Low Risk	There is very low risk for health and safety. Risk-reducing precautions are not required. Personal protective equipment and / or training may be required.
21-45	Low Risk	There is a low risk to health and safety. Risk reduction precautions should be taken.
46-160	Significant Risk	The risk-related hazard is serious enough to require taking mitigation precautions. These precautions should be taken at the first available opportunity.
161-500	High Risk	Severe hazards require immediate action to reduce risk mitigation.
501+	Very High Risk	Risk reduction precautions should be taken immediately, management should be informed.

The precautions to be taken against the risks are evaluated considering the predetermined criteria by using TOPSIS method. Accordingly, besides the probability, severity and frequency of occurrence, other criteria that are important for the firm are evaluated and ranking of taking the precautions is determined. Giving a priority ranking to the precautions to be taken provide a road map for the firm's risk management studies.

6.2 Application of TOPSIS Method

Possible risks and the precautions to be taken were identified by FMEA. The risks with an RPN value of 100 or more were focused in the study. The groups covering these risks are defined as dangerous risk groups. Therefore, it is very important to take precautions at the right time and in the right way against these risks. In this study, 30 risks with an RPN value of 100 or more were evaluated and the precautions to be taken

against these risks were evaluated using the predetermined criteria. TOPSIS method was utilized to determine the priority of the precautions to be taken.

While applying TOPSIS method, alternatives and criteria are determined and an evaluation matrix is created. The alternatives take place in the rows and criteria in the columns of the evaluation matrix. The precautions to be taken against the risks are listed. Negative effect of the precaution on other risks, cost of the precaution, the time needed for the application of the precaution, and the difficulty in the implementation of the precaution are the predetermined criteria.

6.2.1 Creating the Evaluation Matrix

While creating the evaluation matrix, the criteria are graded by using the predefined scales. The negative effect of the precaution on other risks and the difficulty criteria in the implementation of the precaution were evaluated according to the scales presented in Table 6. and 6.8. The cost of the precaution and the time required for the application of the precaution were evaluated with the expected costs and times for each precaution regardless of the scale. The evaluation matrix was created as reported in Table 6. by evaluating the precautions and criteria with the firm.

Table 6.7 Scale for the negative effect of the precaution on other risks

Scale	Weights
Very High Effective	1
Highly Effective	2
Moderately Effective	3
Low Effective	4
Ineffective	5

Table 6.8 Scale for the difficulty in the implementation of the precaution

Scale	Weights
Very Difficult	1
Difficult	2
Moderately Difficulty	3
Low Difficulty	4
Easy	5

Table 6.9 The evaluation matrix

No	Risk	RPN	Precautions	CRITERIA			
				Negative Effect of the Precaution on Other Risks	Cost of the Precaution (TL)	Time Required for the Application of the Precaution (min)	Difficulty in the Implementation of the Precaution
1	Not leaving power sources and dissipating stored energy	300	The system should be designed to provide positive separation from energy sources	3	15000	3600	3
2	Failure to make grounding device	250	Body and panel grounding should be done with yellow and green cables and PE and warning labels should be hung	5	1000	600	5
3	No power cut during maintenance and use	200	Hanging electrical product pictograms on electrical panels and install grounding line	4	3000	1000	3
4	Dangerous movement during tool setting, maintenance and lubrication (en 16092-3 5.5)	188	Facilities will be provided to perform sled / ram movement during tool setting, maintenance and lubrication with protective and protective devices in place and in working condition	3	60000	6000	2
5	Reset buttons are not in the system by controlling the dangerous area	187,5	If persons can remain in hazardous areas without being seen by the operator, a means of preventing restart must be provided, for example, with a gripper-sensing device or fixed switches to prevent close the door	3	30000	5000	1
6	Uncontrolled pressure rise as a result of not using the pressure relief valve	180	The circuit must be protected with pressure relief valves. These valves cannot change without using a tool. In addition, they should be set at a pressure not higher than 10% of the maximum working pressure	4	25000	4000	2
7	No pressure relief valve	180	In the downward-moving presses, preparation should be made to protect the roller and the components containing the fluid at the bottom of the roller from damage caused by pressure condensation. A relief valve used for this purpose must be operated directly, closed and locked against unauthorized adjustment, and set at a pressure of at least 10% above the maximum system pressure	4	15000	3000	3
8	Hand operated valves-No control and monitoring functions	180	The protective locking device must be positively connected to the actuator directly to the manually operated valve to reverse or interrupt the hydraulic fluid flow	4	15000	3000	3

Table 6.9 (cont.)

9	Muting: position and pressure signal-silence-Not all dangerous movements are tracked	180	Means for adjusting the point at which the protection system is turned off during the shutdown process: a position signal and a pressure signal, or a suitable alternative, signals that act when the tools are closed and the machine starts applying force	4	5000	1000	4
10	Installing a manual override valve	180	Manual override devices should not be attached to safety valves. If manual overrides are included in other valves for testing or maintenance purposes, they require the use of a tool to operate the override	3	2000	600	4
11	Not measuring the performance of security functions	180	The safety functions of the hydraulic press must meet the requirements	4	2000	1000	4
12	No emergency stop or missing	156	There must be an emergency stop button on the machine operator panel, column and double hand controls	4	1000	500	4
13	Emergency stops are not connected in parallel	156	Must comply with EN 16092-1;EN 16092-2;EN 16092-3 and EN ISO 13850	4	1000	500	4
14	Direct contact to the equipment in the electrical panel	150	Access should not be possible to shut down the equipment in the electrical panel	4	5000	1000	3
15	No insulated cables	150	Insulated cables should be used, grounded and warnings should be written to prevent anyone from interfering with the cables except the authorized electrician	5	2000	1000	5
16	Loosening of hydraulic hoses, affecting the health of the worker under pressure	138	Pressure hoses and similar equipment designed and mounted closed	4	5000	2000	3
17	Easy removal and easy access due to the fact that the protections applied to rotating parts and risky areas are not fixed	137,5	The casings of fixed protective must comply with ISO 14120. It must be securely fastened to the machine, other rigid structure or the ground	4	4000	1000	3
18	Machine does not stop when the protection covers are opened	137,5	Locking guards, early release locking guards and control guards must comply with ISO 14120, and access to the hazardous area in the tool area must be prevented during dangerous movements with fixed guards	4	3000	1000	3

Table 6.9 (cont.)

19	Control mode works in accordance with production in settings, maintenance, training etc.	137,5	Only the two-hand control or setting position operating devices provided for tool setting should be arranged so as not to be suitable for production	4	2000	600	4
20	Falling down the coach by gravity	113	Controlled landing should be provided according to EN 16092-3 clause 5.3.2.1.	3	10000	1000	3
21	Access to the mold site	100	Designing the machine to stop automatically when there is an intervention in the mold area	4	1000	300	4
22	Oil leaking around the counter	100	Precautions should be taken in terms of oil leaks in the press design	5	2000	600	5
23	No mechanical restraint assembly in the press	100	Safety wedge should be used	3	3000	300	3
24	Gravity effect in safety wedge	100	It should be ensured that the press wedges enter the press in a way that there is no gap left in the lower table and the upper table. In addition, these wedge fittings should be provided, taking into account the strength of the material used	3	3000	300	3
25	Wedge safety function review	100	It must comply with EN160921, EN 16092-2 and EN 160292-3	3	3000	300	3
26	Light curtain is not category 4	100	The photocell on the front and back is in a suitable place and complies with category 4	4	4000	500	3
27	Blanking photocell teaching	100	It should be in category 4 and the front and back photocells should be instructed	4	4000	500	3
28	Access under the light barriers	100	Must comply with EN 692 and EN ISO 13857	3	2000	600	3
29	Failure to install the light curtain according to ESPE results	100	Must comply with EN 16092-1, EN 16092-2, EN 16092-3 and EN ISO 13857	4	4000	500	3
30	Unexpected, unwanted start	100	Must have LOTO (Tag, lock, safe, audit)	4	2000	600	4

6.2.2 Normalizing the Evaluation Matrix

To normalize the evaluation matrix, Equation 6.1 can be utilized. Normalized evaluation matrix is presented in

Table 6..

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}} \quad (i = 1, 2, \dots, m ; j = 1, 2, \dots, n) \quad (6.1)$$

Table 6.10 Normalized evaluation matrix

No	RPN	CRITERIA			
		Negative Effect of the Precaution on Other Risks	Cost of the Precaution (TL)	Time Required for the Application of the Precaution (min)	Difficulty in the Implementation of the Precaution
1	300	0,142373699	0,191803938	0,323642088	0,158999682
2	250	0,237289499	0,012786929	0,053940348	0,26499947
3	200	0,189831599	0,038360788	0,08990058	0,158999682
4	188	0,142373699	0,767215754	0,53940348	0,105999788
5	187,5	0,142373699	0,383607877	0,4495029	0,052999894
6	180	0,189831599	0,319673231	0,35960232	0,105999788
7	180	0,189831599	0,191803938	0,26970174	0,158999682
8	180	0,189831599	0,191803938	0,26970174	0,158999682
9	180	0,189831599	0,063934646	0,08990058	0,211999576
10	180	0,142373699	0,025573858	0,053940348	0,211999576
11	180	0,189831599	0,025573858	0,08990058	0,211999576
12	156	0,189831599	0,012786929	0,04495029	0,211999576
13	156	0,189831599	0,012786929	0,04495029	0,211999576
14	150	0,189831599	0,063934646	0,08990058	0,158999682
15	150	0,237289499	0,025573858	0,08990058	0,26499947



Table 6.10 (cont.)

16	138	0,189831599	0,063934646	0,17980116	0,158999682
17	137,5	0,189831599	0,051147717	0,08990058	0,158999682
18	137,5	0,189831599	0,038360788	0,08990058	0,158999682
19	137,5	0,189831599	0,025573858	0,053940348	0,211999576
20	113	0,142373699	0,127869292	0,08990058	0,158999682
21	100	0,189831599	0,012786929	0,026970174	0,211999576
22	100	0,237289499	0,025573858	0,053940348	0,26499947
23	100	0,142373699	0,038360788	0,026970174	0,158999682
24	100	0,142373699	0,038360788	0,026970174	0,158999682
25	100	0,142373699	0,038360788	0,026970174	0,158999682
26	100	0,189831599	0,051147717	0,04495029	0,158999682
27	100	0,189831599	0,051147717	0,04495029	0,158999682
28	100	0,142373699	0,025573858	0,053940348	0,158999682
29	100	0,189831599	0,051147717	0,04495029	0,158999682
30	100	0,189831599	0,025573858	0,053940348	0,211999576

6.2.3 Determination and Normalization of the Weights

The weights are determined by the firm based on the importance of the criteria for the firm. The criteria weights presented in Table 6. are assigned out of ten by considering the importance of the criteria. Then the weights were normalized.

Table 6.11 Weights for the criteria

<i>Criteria</i>	<i>Weights</i>	<i>Normalized Weights</i>
Negative effect of the precaution on other risks	10	0.3333
Cost of the precaution	8	0.2667
Time required for the application of the precaution	6	0.2
Difficulty in the implementation of the precaution	6	0.2
Total	30	1

6.2.4 Weighted Normalized Matrix

Weighted normalized matrix is obtained by multiplying the normalized evaluation matrix by the weights of the criteria.

Table 6.12 Normalized value of the precaution

No	Risk	RPN	Precautions	CRITERIA			
				Negative Effect of the Precaution on Other Risks	Cost of the Precaution (TL)	Time Required for the Application of the Precaution (min)	Difficulty in the Implementation of the Precaution
1	Not leaving power sources and dissipating stored energy	300	The system should be designed to provide positive separation from energy sources	0,142373699	0,191803938	0,323642088	0,158999682
2	Failure to make grounding device	250	Body and panel grounding should be done with yellow and green cables and PE and warning labels should be hung	0,237289499	0,012786929	0,053940348	0,26499947
3	No power cut during maintenance and use	200	Hanging electrical product pictograms on electrical panels and install grounding line	0,189831599	0,038360788	0,08990058	0,158999682
4	Dangerous movement during tool setting, maintenance and lubrication (en 16092-3 5.5)	188	Facilities will be provided to perform sled / ram movement during tool setting, maintenance and lubrication with protective and protective devices in place and in working condition	0,142373699	0,767215754	0,53940348	0,105999788
5	Reset buttons are not in the system by controlling the dangerous area	187,5	If persons can remain in hazardous areas without being seen by the operator, a means of preventing restart must be provided, for example, with a gripper-sensing device or fixed switches to prevent close the door	0,142373699	0,383607877	0,4495029	0,052999894
6	Uncontrolled pressure rise as a result of not using the pressure relief valve	180	The circuit must be protected with pressure relief valves. These valves cannot change without using a tool. In addition, they should be set at a pressure not higher than 10% of the maximum working pressure	0,189831599	0,319673231	0,35960232	0,105999788
7	No pressure relief valve	180	In the downward-moving presses, preparation should be made to protect the roller and the components containing the fluid at the bottom of the roller from damage caused by pressure condensation. A relief valve used for this purpose must be operated directly, closed and locked against unauthorized adjustment, and set at a pressure of at least 10% above the maximum system pressure	0,189831599	0,191803938	0,26970174	0,158999682

As can be seen in the Table 6., the normalized value of the precaution for risk 1 is 0.1424. This value is multiplied by the weight of 0.3333, which denotes the negative effect of the precaution on other risks, and the weighted normalized value of the precaution, 0.0474579, is obtained. Elements of the weighted normalized matrix is presented in **Hata! Yer işareti başvurusu geçersiz..**

Table 6.13 Weighted normalized matrix

No	RPN	CRITERIA			
		Negative Effect of the Precaution on Other Risks	Cost of the Precaution (TL)	Time Required for the Application of the Precaution (min)	Difficulty in the Implementation of the Precaution
1	300	0,0474579	0,051147717	0,064728418	0,031799936
2	250	0,0790965	0,003409848	0,01078807	0,052999894
3	200	0,0632772	0,010229543	0,017980116	0,031799936
4	188	0,0474579	0,204590868	0,107880696	0,021199958
5	187,5	0,0474579	0,102295434	0,08990058	0,010599979
6	180	0,0632772	0,085246195	0,071920464	0,021199958
7	180	0,0632772	0,051147717	0,053940348	0,031799936
8	180	0,0632772	0,051147717	0,053940348	0,031799936
9	180	0,0632772	0,017049239	0,017980116	0,042399915
10	180	0,0474579	0,006819696	0,01078807	0,042399915
11	180	0,0632772	0,006819696	0,017980116	0,042399915
12	156	0,0632772	0,003409848	0,008990058	0,042399915
13	156	0,0632772	0,003409848	0,008990058	0,042399915
14	150	0,0632772	0,017049239	0,017980116	0,031799936
15	150	0,0790965	0,006819696	0,017980116	0,052999894

Table 6.13 (cont.)

16	138	0,0632772	0,017049239	0,035960232	0,031799936
17	137,5	0,0632772	0,013639391	0,017980116	0,031799936
18	137,5	0,0632772	0,010229543	0,017980116	0,031799936
19	137,5	0,0632772	0,006819696	0,01078807	0,042399915
20	113	0,0474579	0,034098478	0,017980116	0,031799936
21	100	0,0632772	0,003409848	0,005394035	0,042399915
22	100	0,0790965	0,006819696	0,01078807	0,052999894
23	100	0,0474579	0,010229543	0,005394035	0,031799936
24	100	0,0474579	0,010229543	0,005394035	0,031799936
25	100	0,0474579	0,010229543	0,005394035	0,031799936
26	100	0,0632772	0,013639391	0,008990058	0,031799936
27	100	0,0632772	0,013639391	0,008990058	0,031799936
28	100	0,0474579	0,006819696	0,01078807	0,031799936
29	100	0,0632772	0,013639391	0,008990058	0,031799936
30	100	0,0632772	0,006819696	0,01078807	0,042399915

6.2.5 Determination of Positive and Negative Ideal Solutions

In TOPSIS method, positive and negative ideal solutions are determined using weighted normalized matrix (Oztaysi, 2014). Then, the criteria are divided into two groups as benefit and cost criteria. If the criterion is benefit, the maximum value in the column of the criterion is the positive ideal solution and the minimum value is the negative one. If the criterion is cost, the minimum value in the column of the criterion is the positive ideal solution and the maximum value is the negative ideal solution.

The criteria for the cost of the precaution and the time required for the application of the precaution are the cost criteria. The negative effect of the precaution on other

risks, and the difficulty in the implementation of the precaution are the benefit criteria. Positive and negative ideal values for the criteria are presented in Table 6..

Table 6.14 Positive and negative ideal solutions

<i>Positive Ideal and Negative Ideal Values</i>	<i>Negative Effect of the Precaution on Other Risks</i>	<i>Cost of the Precaution</i>	<i>Time Required for the Application of the Precaution (min)</i>	<i>Difficulty in the Implementation of the Precaution</i>
A^+	0.0790965	0.003409848	0.005394035	0.052999894
A^-	0.0474579	0.204590868	0.107880696	0.010599979

6.2.6 Calculating the Distance from Positive and Negative Ideal Solutions

Distances from the positive and negative ideal solutions can be calculated by Equations 6.2 and 6.3. The distances are reported in Table 6.8.

$$S_i^+ = \sqrt{\sum_{j=1}^k (x_{ij} - x_j^+)^2} \quad (6.2)$$

$$S_i^- = \sqrt{\sum_{j=1}^k (x_{ij} - x_j^-)^2} \quad (6.3)$$

Table 6.8 Positive and negative ideal solution distances

S_i^+ and S_i^-	Result	S_i^+ and S_i^-	Result	S_i^+ and S_i^-	Result
S_1^+	0.085146	S_{11}^+	0.023079	S_{21}^+	0.019042
S_1^-	0.160799	S_{11}^-	0.220130	S_{21}^-	0.228558
S_2^+	0.005394	S_{12}^+	0.019379	S_{22}^+	0.006381
S_2^-	0.229564	S_{12}^-	0.226968	S_{22}^-	0.226581
S_3^+	0.030077	S_{13}^+	0.019379	S_{23}^+	0.038690
S_3^-	0.215773	S_{13}^-	0.226968	S_{23}^-	0.220747
S_4^+	0.230195	S_{14}^+	0.032313	S_{24}^+	0.038690
S_4^-	0.010600	S_{14}^-	0.209651	S_{24}^-	0.220747
S_5^+	0.140422	S_{15}^+	0.013040	S_{25}^+	0.038690
S_5^-	0.103864	S_{15}^-	0.223594	S_{25}^-	0.220747
S_6^+	0.111285	S_{16}^+	0.042662	S_{26}^+	0.028588
S_6^-	0.126091	S_{16}^-	0.202593	S_{26}^-	0.216660
S_7^+	0.073043	S_{17}^+	0.031028	S_{27}^+	0.028588
S_7^-	0.164785	S_{17}^-	0.212707	S_{27}^-	0.216660
S_8^+	0.073043	S_{18}^+	0.030077	S_{28}^+	0.038616
S_8^-	0.164785	S_{18}^-	0.215773	S_{28}^-	0.221337
S_9^+	0.026590	S_{19}^+	0.020083	S_{29}^+	0.028588
S_9^-	0.210987	S_{19}^-	0.223163	S_{29}^-	0.216660
S_{10}^+	0.033972	S_{20}^+	0.050504	S_{30}^+	0.020083
S_{10}^-	0.222602	S_{20}^-	0.193905	S_{30}^-	0.223163

6.2.7 Calculation of C_i Value

C_i^* is utilized in prioritizing the alternatives and calculated by using the distances from the positive and negative ideal solutions (see, Equation 6.4). C_i^* values for the alternatives are shown in

Table 6..

$$C_i^* = S_i^- / (S_i^+ + S_i^-) \quad (6.4)$$

Table 6.16 C_i^* values for the alternatives

C_i^*	Result	C_i^*	Result
C_1	0.653799	C_{16}	0.826052
C_2	0.977043	C_{17}	0.872698
C_3	0.877663	C_{18}	0.877663
C_4	0.044021	C_{19}	0.917437
C_5	0.425172	C_{20}	0.793363
C_6	0.531186	C_{21}	0.923093
C_7	0.692873	C_{22}	0.972608
C_8	0.692873	C_{23}	0.850868
C_9	0.888077	C_{24}	0.850868
C_{10}	0.867594	C_{25}	0.850868
C_{11}	0.905106	C_{26}	0.883433
C_{12}	0.921335	C_{27}	0.883433
C_{13}	0.921335	C_{28}	0.851451
C_{14}	0.866455	C_{29}	0.883433
C_{15}	0.944895	C_{30}	0.917437

6.2.8 Determining the Ranking of Precautions

The priority ranking of the precaution to be taken against the risks in the dangerous group in the firm has been determined by TOPSIS method. Priority ranking of the precautions are presented in Table 6..

Table 6.17 Priority ranking of the precautions

No	Ci	Precautions	Risk	RPN
1	0,9770425	Body and panel grounding should be done with yellow and green cables and PE and warning labels should be hung	Failure to make grounding device	250
2	0,9726075	Precautions should be taken in terms of oil leaks in the press design	Oil leaking around the counter	100
3	0,9448946	Insulated cables should be used, grounded and warnings should be written to prevent anyone from interfering with the cables except the authorized electrician	No insulated cables	150
4	0,9230926	Designing the machine to stop automatically when there is an intervention in the mold area	Access to the mold site	100
5	0,9213351	There must be an emergency stop button on the machine operator panel, column and double hand controls	No emergency stop or missing	156
6	0,9213351	Must comply with EN 16092-1;EN 16092-2;EN 16092-3 and EN ISO 13850	Emergency stops are not connected in parallel	156
7	0,9174371	Only the two-hand control or setting position operating devices provided for tool setting should be arranged so as not to be suitable for production	Control mode works in accordance with production in settings, maintenance, training etc.	137,5
8	0,9174371	Must have LOTO (Tag, lock, safe, audit)	Unexpected, unwanted start	100
9	0,9051057	The safety functions of the hydraulic press must meet the requirements	Not measuring the performance of security functions	180
10	0,8880766	Means for adjusting the point at which the protection system is turned off during the shutdown process: a position signal and a pressure signal, or a suitable alternative, signals that act when the tools are closed and the machine starts applying force	Muting: position and pressure signal-silence-Not all dangerous movements are tracked	180
11	0,8834329	The photocell on the front and back is in a suitable place and complies with category 4	Light curtain is not category 4	100

Table 6.17 (cont.)

12	0,8834329	It should be in category 4 and the front and back photocells should be instructed	Blanking photocell teaching	100
13	0,8834329	Must comply with EN 16092-1, EN 16092-2, EN 16092-3 and EN ISO 13857	Failure to install the light curtain according to ESPE results	100
14	0,8776625	Locking guards, early release locking guards and control guards must comply with ISO 14120, and access to the hazardous area in the tool area must be prevented during dangerous movements with fixed guards	Machine does not stop when the protection covers are opened	137,5
15	0,8776625	Hanging electrical product pictograms on electrical panels and install grounding line	No power cut during maintenance and use	200
16	0,8726975	The casings of fixed protective must comply with ISO 14120. It must be securely fastened to the machine, other rigid structure or the ground	Easy removal and easy access due to the fact that the protections applied to rotating parts and risky areas are not fixed	137,5
17	0,8675944	Manual override devices should not be attached to safety valves. If manual overrides are included in other valves for testing or maintenance purposes, they require the use of a tool to operate the override	Installing a manual override valve	180
18	0,8664555	Access should not be possible to shut down the equipment in the electrical panel	Direct contact to the equipment in the electrical panel	150
19	0,8514512	Must comply with EN 692 and EN ISO 13857	Access under the light barriers	100
20	0,8508681	Safety wedge should be used	No mechanical restraint assembly in the press	100
21	0,8508681	It should be ensured that the press wedges enter the press in a way that there is no gap left in the lower table and the upper table. In addition, these wedge fittings should be provided, taking into account the strength of the material used	Gravity effect in safety wedge	100
22	0,8508681	It must comply with EN160921, EN 16092-2 and EN 160292-3	Wedge safety function review	100
23	0,826052	Pressure hoses and similar equipment designed and mounted closed	Loosening of hydraulic hoses, affecting the health of the worker under pressure	138

Table 6.17 (cont.)

24	0,7933633	Controlled landing should be provided according to EN 16092-3 clause 5.3.2.1.	Falling down the coach by gravity	113
25	0,6928734	In the downward-moving presses, preparation should be made to protect the roller and the components containing the fluid at the bottom of the roller from damage caused by pressure condensation. A relief valve used for this purpose must be operated directly, closed and locked against unauthorized adjustment, and set at a pressure of at least 10% above the maximum system pressure	No pressure relief valve	180
26	0,6928734	The protective locking device must be positively connected to the actuator directly to the manually operated valve to reverse or interrupt the hydraulic fluid flow	Hand operated valves-No control and monitoring functions	180
27	0,6537997	The system should be designed to provide positive separation from energy sources	Not leaving power sources and dissipating stored energy	300
28	0,5311856	The circuit must be protected with pressure relief valves. These valves cannot change without using a tool. In addition, they should be set at a pressure not higher than 10% of the maximum working pressure	Uncontrolled pressure rise as a result of not using the pressure relief valve	180
29	0,4251719	If persons can remain in hazardous areas without being seen by the operator, a means of preventing restart must be provided, for example, with a gripper-sensing device or fixed switches to prevent close the door	Reset buttons are not in the system by controlling the dangerous area	187,5
30	0,0440208	Facilities will be provided to perform sled / ram movement during tool setting, maintenance and lubrication with protective and protective devices in place and in working condition	Dangerous movement during tool setting, maintenance and lubrication (en 16092-3 5.5)	188

As stated previously, the RPNs in FMEA are calculated by multiplying the severity, probability and detectability of the risks. However, in risk management studies, it is sometimes insufficient to include only these three parameters. To overcome this difficulty, TOPSIS method has been employed in this study. Therefore, not only the severity, probability and detectability values, but also the cost, time, effect and application difficulty of the precautions are taken into consideration. Results of the application expose that the precautions to be taken against some risks with low RPN may have higher priority. The first precaution to be taken in the priority ranking was found to be “Body and panel grounding should be done with yellow and green cables, and PE and warning labels should be hung”.

CHAPTER SEVEN

DESIGNING AN INTERFACE FOR CALCULATING RPNs

An Excel VBA-based interface is designed in this section for calculating the RPNs and determining the necessary precautions. The interface is explained in detail in the following.

7.1 Purpose of the Program

An interface has been created in order to reach the precautions to be taken in a short time. The company will be able to easily calculate the RPNs as well as see the precaution on the screen.

7.2 Program Design Process

While designing the Excel VBA program, a User Form was created firstly. 30 hazards with high RPNs were defined in the ComboBox in designing the User Form. Then, TextBoxes are defined to enter probability of occurrence, severity, number of people exposed and frequency of exposure values into the User Form to calculate the RPNs. In addition, a TextBox has been defined in order to see the RPNs obtained as a result of the multiplication of these values. CommandButton has been defined so that the values entered for the selected hazard can be multiplied and printed RPNs on the screen. Call MsgBox information boxes were used to convey the precautions to be taken against the selected hazard to the user.

7.3 Designing a UserForm

The designed UserForm is illustrated in Figure 7.5. The code for the UserForm calculating the risk priority number is presented as well.

Figure 7.5 Designed UserForm

```

Private Function CalculateRPN() As Double
    Dim s1, s2, s3, s4, result As Double
    s1 = SeverityTextBox.Text
    s2 = POOTextBox.Text
    s3 = FOETextBox.Text
    s4 = NOEPTextBox.Text
    result = s1 * s2 * s3 * s4
    TextBox5.Text = result
    CalculateRPN = result
End Function

```

In the code, s1 indicates the severity, s2 indicates the probability of occurrence, s3 indicates the frequency of exposure and s4 indicates the number of people exposed. Accordingly, RPN is defined as the multiplication of s1, s2, s3 and s4. The RPNs calculated are printed on the screen with TextBox5.

The screenshot shows a VBA UserForm titled 'FMEA'. It contains several labeled input fields and a ComboBox. The labels are: **Choose Risk:**, **Severity:**, **Probability of Occurrence:**, **Frequency of Exposure:**, **Number of Exposed People:**, and **Risk Priority Number:**. The ComboBox is open, displaying a list of risks. The selected item is 'Not leaving power sources and dissipating stored energy'. Other items in the list include 'Failure to make grounding device', 'No power cut during maintenance and use', 'Dangerous movement during tool setting, maintenance and I', 'Reset buttons are not in the system by controlling the dange', 'Uncontrolled pressure rise as a result of not using the pressi', 'No pressure relief valve', and 'Hand operated valves-No control and monitoring functions'. To the right of the input fields are two buttons: 'Precautions to Take' and 'Clean'.

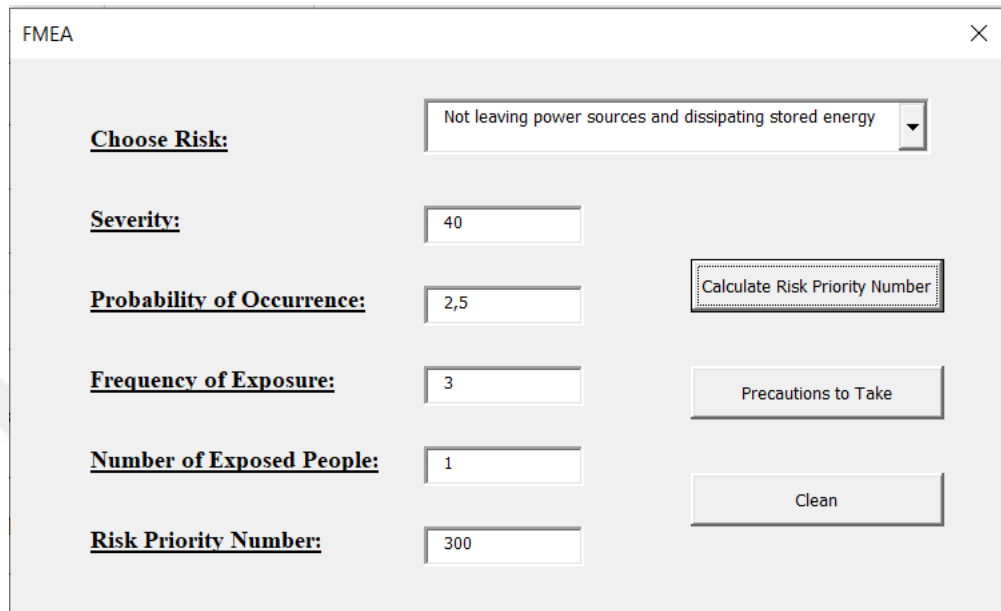
Figure 7.2 The designed ComboBox

The risks created in the UserForm are entered in a list with ComboBox. When the risk is selected and the values are entered, the “Precautions To Take” button is printed on the screen. The risks to be selected are reported in Figure 7.2 illustrating the Designed ComboBox.

```
If result >= 300 And ComboBox1.Value = "Not leaving power sources
and dissipating stored energy" Then
    Call MsgBox("The system should be designed to provide positive
separation from energy sources.", vbCritical, "Precautions to Take!")
    precautionSet = True
```

The precautions to be taken were evaluated using “if condition”. If the RPN of “*not leaving power sources and dissipating stored energy*” risk is 300, the precaution to be taken is defined by the company as “*the system should be designed to provide positive separation from energy sources*”.

It calculates the RPN value after entering probability of occurrence, severity, number of people exposed and frequency of exposure for the risk in the risk category selected from ComboBox.



The image shows a Windows-style application window titled "FMEA". It contains several input fields and buttons. The fields are labeled with underlined text: "Choose Risk:", "Severity:", "Probability of Occurrence:", "Frequency of Exposure:", "Number of Exposed People:", and "Risk Priority Number:". The values entered are: "Not leaving power sources and dissipating stored energy" (selected in a dropdown), "40", "2,5", "3", "1", and "300" respectively. On the right side, there are three buttons: "Calculate Risk Priority Number", "Precautions to Take", and "Clean". The "Calculate Risk Priority Number" button is highlighted with a dashed border.

Figure 7.3 Entering data to UserForm

For “*Not leaving power sources and dissipating stored energy*” risk, the severity value of 40, probability of occurrence value of 2.5, frequency of exposure value of 3 and number of exposed people value of 1 is entered. As a result of the multiplication of these values, the RPN value is calculated as 300, and the related precaution is printed on the screen when the “Precautions To Take” button is pressed as illustrated in Figure 7..

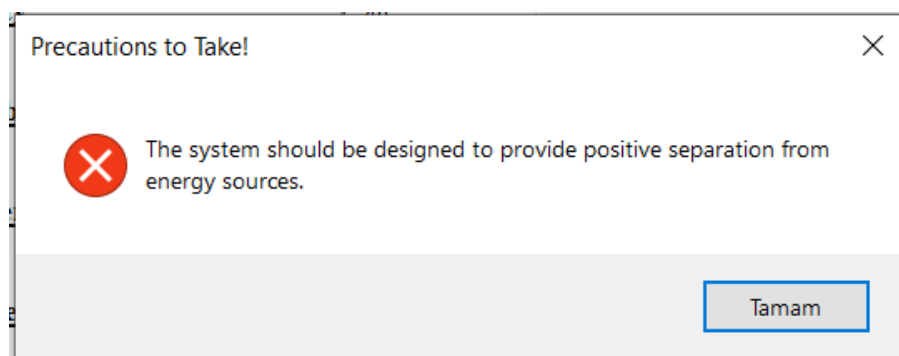
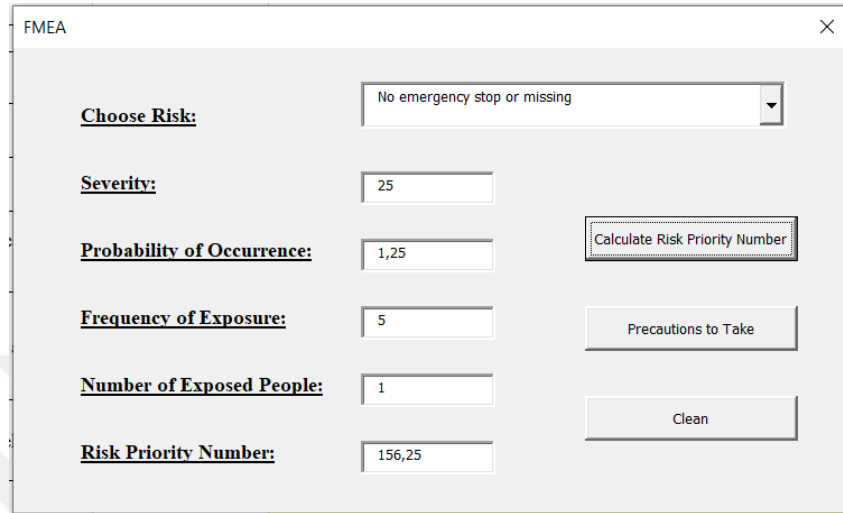


Figure 7.4 A precaution on the screen

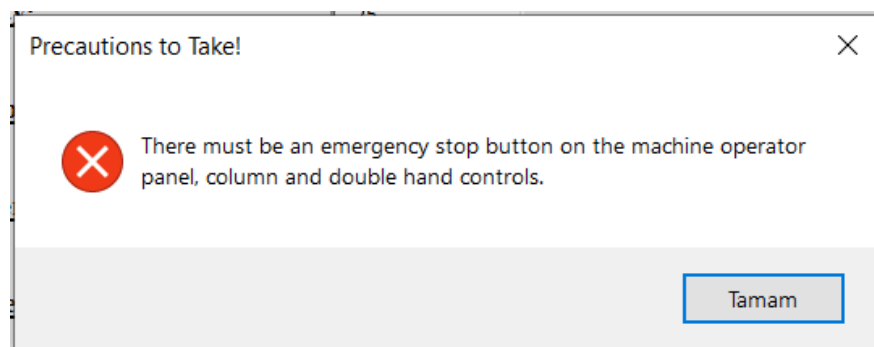
When the values are entered for another risk, “*Emergency stops are not connected in parallel*”, the RPN is calculated as 156.25, and the precaution to be taken is printed on the screen similar to the previous operations. It is shown in Figure 7.5.



The screenshot shows a Windows-style window titled "FMEA" with a close button (X) in the top right corner. The window contains several input fields and buttons. On the left, there are labels for "Choose Risk:", "Severity:", "Probability of Occurrence:", "Frequency of Exposure:", "Number of Exposed People:", and "Risk Priority Number:". To the right of these labels are corresponding input boxes. The "Choose Risk:" box is a dropdown menu showing "No emergency stop or missing". The "Severity:" box contains the value "25". The "Probability of Occurrence:" box contains "1,25". The "Frequency of Exposure:" box contains "5". The "Number of Exposed People:" box contains "1". The "Risk Priority Number:" box contains "156,25". To the right of the input boxes are three buttons: "Calculate Risk Priority Number", "Precautions to Take", and "Clean".

Figure 7.5 Entering data to UserForm for the FMEA

For “*No emergency stop or missing*” risk, the severity value of 25, the probability of occurrence value of 1.25, frequency of exposure value of 5 and number of exposed people value of 1 is entered. Accordingly, the RPN value is calculated as 156.25. Then, the precaution to be taken is printed on the screen when the “Precautions to Take button” is pressed as illustrated in Figure 7..



The screenshot shows a dialog box titled "Precautions to Take!" with a close button (X) in the top right corner. The dialog box has a red circle with a white 'X' icon on the left. To the right of the icon is the text: "There must be an emergency stop button on the machine operator panel, column and double hand controls." At the bottom right of the dialog box is a button labeled "Tamam".

Figure 7.6 Printing the precaution

The program also warns if the user misses to enter a parameter on the screen. Thus, RPN value is prevented from calculating with missing value and giving an incorrect result. The warning screen is illustrated in Figure 7..

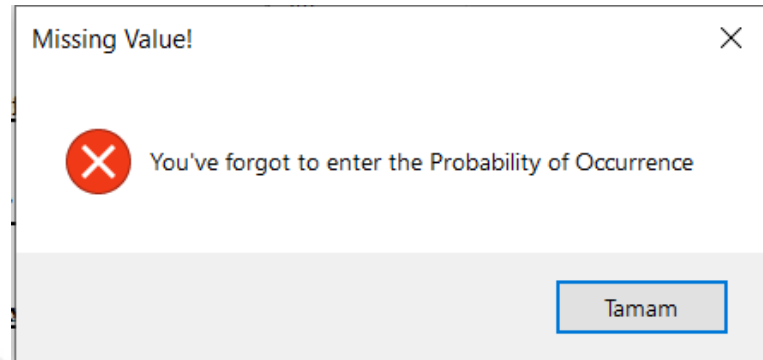


Figure 7.7 Warning screen

```

    If s1 = "" Then
        Call MsgBox("You've forgot to enter severity value", vbCritical, "Missing
Value!")
    Exit Function
End If
    If s2 = "" Then
        Call MsgBox("You've forgot to enter the Probability of Occurrence",
vbCritical, "Missing Value!")
    Exit Function
End If
    If s3 = "" Then
        Call MsgBox("You've forgot to enter the Frequency of Exposure",
vbCritical, "Missing Value!")
    Exit Function
End If
    If s4 = "" Then
        Call MsgBox("You've forgot to enter the Number of Exposed People",
vbCritical, "Missing Value!")
    Exit Function
End If

```

30 risks and 30 precautions to be taken against these risks are defined in the program. As the risks are increased, new precautions can be defined in the system and the same actions can be taken. Until new risks are identified, the system will issue a warning note for the values outside the specified RPN limits. The warning screen for undefined values is presented in Figure 7..

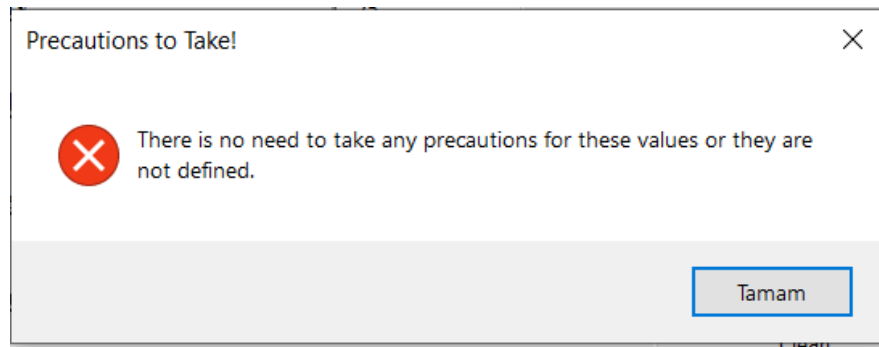


Figure 7.8 Warning screen for undefined value

```
If precautionSet = False Then  
    Call MsgBox("There is no need to take any precautions for these values  
or they are not defined.", vbCritical, "Precautions to Take!")  
End If
```

In this way, 30 risks with highly dangerous RPNs were entered the program and the precautions to be taken were identified. The codes with all risks and precautions are presented in Appendix 2.

CHAPTER EIGHT

CONCLUSION

Risk analysis and risk management terms are very important today. It is very considerable for both the employees and companies. Determining uncertainties and risks in the production systems before they occur and taking the necessary precautions brings more efficient production in a reliable environment. In this study, the risks in the production flow of the product produced the most by an international manufacturing firm producing kitchen systems were evaluated. In this evaluation, FMEA was employed as the risk assessment method.

In FMEA, classifications are made according to the RPNs. However, deficiencies in the RPN may often mislead risk management study, and assessments of the precautions may be incomplete. It was aimed in this thesis to eliminate the deficiencies in RPN value by using a multi criteria decision making method, TOPSIS, together with FMEA. A 30-fault group with RPNs of 100 and above were evaluated in the FMEA study. The precautions to be taken for the faults were evaluated using the predetermined criteria. The criteria for evaluating the precautions to be taken are defined as negative effect of the precaution on other risks, cost of the precaution, time required for the application of the precaution and difficulty in the implementation of the precaution. With the TOPSIS study, it was concluded that the ranking of the fault groups according to the RPNs is an incomplete approach and the precautions should be effective in the decision making process. In our application, it is determined in which order the precautions should be implemented.

In addition, the company frequently conducts FMEA studies and sometimes returns to past studies for making controls. In these control processes, there may be problems in reaching risk priorities and RPNs. In this study, an interface is designed to calculate the RPNs of the selected fault group quickly to see the precautions to be taken according to the selected fault. The interface provide ease in following and reaching FMEA studies in case of renewal of faults. The screen program was obtained with Excel VBA and quick access to the data was achieved by this way.

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APPENDICES

APPENDIX 1: The FMEA Application

APPENDIX 2: The Codes for the Interface



APPENDIX 1: The FMEA Application

Definition of Hazard	Severity	Risk	Probability of occurrence	Number of people exposed	Frequency of exposure	RPN	Precautions
High pressure	15	Uncontrolled pressure rise as a result of not using the pressure relief valve	4	1	3	180	The circuit must be protected with pressure relief valves. These valves cannot change without using a tool. In addition, they should be set at a pressure not higher than 10% of the maximum working pressure.
High pressure	15	Hand operated valves-No control and monitoring functions	4	1	3	180	The protective locking device must be positively connected to the actuator directly to the manually operated valve to reverse or interrupt the hydraulic fluid flow.
Liquid spraying at the high pressure	11	Loosening of hydraulic hoses, affecting the health of the worker under pressure	2,5	1	5	138	Pressure hoses and similar equipment designed and mounted closed.
Pipes and connections	3	Burrs in pipes and connections	2,5	1	5	38	Attaching a filter and monitoring from hydraulic circuit diagram.
Dangerous movement during maintenance and adjustment	15	Dangerous movement during tool setting, maintenance and lubrication (en 16092-3 5.5)	2,5	1	5	188	Facilities will be provided to perform sled / ram movement during tool setting, maintenance and lubrication with protective and protective devices in place and in working condition.
Uneducated or patient staff work	3	The work of sick, tired, untrained and careless staff	2,5	1	5	38	Giving necessary warning instructions in the maintenance manual book. Also, warning labels are placed on the press.
Crushing, Shearing, Cutting, Chopping	8	Access to the mold site	2,5	1	5	100	Designing the machine to stop automatically when there is an intervention in the mold area.
Mass and balance	25	Potential energies of the elements that can move with the effect of gravity	1,25	1	0,5	16	Designing the bench parts so that they do not fall with the effect of gravity.

Overtum	40	Overturing of the bench	0,05	1	0,5	1	The benches should be designed so that they cannot be moved without a transport tool, and the way of fastening should be explained in the manual.
Fixed covers Mechanical Hazard arising from a reason	8	Cutting or breaking	2,5	1	5	100	Must comply with EN ISO 14120
Safety Rules	3	Failure to comply with safety rules.	2,5	1	5	38	Necessary warning instructions will be given in the Maintenance Manual
Uneducated or patient staff work	3	Working of sick, tired, uneducated and careless staff	2,5	1	5	38	Necessary warning instructions will be provided in the Maintenance Manual. Also, installing warning labels on the press
Trained personnel not working	3	Competent staff (educated, knowledgeable and experienced) not being employed	2,5	1	5	38	Necessary warning instructions will be provided in the Maintenance Manual. Also, installing warning labels on the press
Employee slipping and falling	8	Oil leaking around the counter	2,5	1	5	100	Precautions should be taken in terms of oil leaks by the press design.
The operator's eye strain	3	Adequate lighting is not provided	2,5	1	5	38	Providing the necessary hardware for lighting and explaining in the user manual

Safety Wedge	8	The absence of a mechanical restraint device in the press	2,5	1	5	100	Safety wedge should be used
	8	Gravity effect	2,5	1	5	100	It should be ensured that the press wedges fit into the press in a way that there is no space between the lower table and the upper table. Also, these wedge fittings should be provided by considering the strength of the material used.
	8	Review of Wedge Safety Function	2,5	1	5	100	EN160921; en 16092-2; en 160292-3 should be applied.
Pneumatic system air purge	3	Pneumatic input do not have a valve to cut and discharge air	2,5	1	5	38	Drain valve suitable for LOTO procedures should be placed.
Railing	15	Lack of railing according to ISO 14122-3	2,5	1	2	75	Railing according to ISO 14122-3 should be designed
	15	According to ISO 14122-2, span greater than 20 mm and skirting shorter than 100 mm	2,5	1	2	75	In accordance with ISO 14122-2
Fastening the railing	11	Easy removal and easy access due to the fact that the railings applied to rotating parts and risky areas are not fixed	2,5	1	5	137,5	The guards of the fixed must comply with ISO 14120. They must be securely fixed to the machine, another hard structure or the ground. Supply discharge or other spans should conform to ISO 13857: 2008, Table 4.

Fastening and control railing	11	The machine does not stop when the protection covers are opened.	2,5	1	5	137,5	Locking guards, early release locking guards and control guards must comply with ISO 14120, and access to the hazardous area in the tool area must be prevented during dangerous movements with fixed guards
Control devices for tool installation	11	Control mode works in accordance with production in settings, maintenance, training etc.	2,5	1	5	137,5	Only the two-hand control or setting position operating devices provided for tool setting should be arranged so as not to be suitable for production
Light curtain (photocell) not suitable	8	Light curtain is not category 4	2,5	1	5	100	The photocell on the front and back is in the appropriate place and category 4 is suitable.
	8	Blind photocell teaching	2,5	1	5	100	Category 4 and front and back photos should be switched.
	8	Access under the light barriers	2,5	1	5	100	Must comply with EN 692 and EN ISO 13857.
	8	The light curtain is not mounted according to the ESPE results	2,5	1	5	100	Must comply with EN 16092-1; EN 16092-2; EN 16092-3 and EN ISO 13857
Electric shock	40	No power cut during maintenance and use	2,5	1	2	200	Hanging electrical product pictograms on electrical panels and install grounding line
	40	Failure to make grounding device	1,25	1	5	250	Body and panel grounding should be done with yellow and green cables and PE and warning labels should be hung
	40	Direct contact to the equipment in the electrical panel	1,25	1	3	150	Access should not be possible to shut down the equipment in the electrical panel
	40	No insulated cables	1,25	1	3	150	Insulated cables should be used, grounded and warnings should be written to prevent anyone from interfering with the cables except the authorized electrician

Electric shock	40	No leakage current in the supply unit	1,25	1	1	50	Leakage current relay must be installed in the supply unit. 30 mA.
Emergency stop	25	No emergency stop or missing	1,25	1	5	156	There must be an emergency stop button on the machine operator panel, column and double hand controls
	25	Emergency stops are not connected in parallel	1,25	1	5	156	Must comply with EN 16092-1;EN 16092-2;EN 16092-3 and EN ISO 13850
Two-hand control	5	Two hand control does not comply with TS EN 13851	2,5	1	5	63	Design of two hand according to TS EN 13851
	5	Failure to do combination with double hand table socket	2,5	1	5	63	The press must come to the emergency stop position when the two hand sockets are inserted. The double hand should not reset without plugging in the socket, that is, the reset should be over the double hand.
Press mode change switch	5	Press mode change switch control circuit review	2,5	1	5	63	Press mode change should be monitored
Door Safety Switch	3	Not using suitable switch	2,5	1	5	38	PL level should be appropriate
Reset Function	5	Reset should be provided to reduce risk	2,5	1	5	63	Press reset is provided by resetting from the relevant region in case of safety violations made from the front region and back region.
Electric panel	8	Unexpected, unwanted start	2,5	1	5	100	Must have LOTO- EKED (Tag, lock, safe, audit)
Take precautionary measures against restart	15	Reset buttons are not in the system by controlling the dangerous area	2,5	1	5	187,5	If persons can remain in hazardous areas without being seen by the operator, a means of preventing restart must be provided, for example, with a gripper-sensing device or fixed switches to prevent close the door.



Measures related to isolation and energy distribution	40	Not leaving power sources and dissipating stored energy	2,5	1	3	300	The system should be designed to provide positive separation from energy sources.
Possible standing position	5	Physical illness as a result of not making suitable design for standing work	2,5	1	5	62,5	In cases where the press is operated in production mode and it is not possible to detect between the detection area of the AOPD and the clearance area of the press with a gap exceeding 75 mm, additional protection means will be provided.
Inhaling harmful liquids, dusts and gases	3	The operator does not wear a mask during mold lubrication	2,5	1	5	37,50	There is no harmful liquid or dust in the delivery of the press.

APPENDIX 2: The Codes for the Interface

```
Private Function CalculateRPN() As Double
Dim s1, s2, s3, s4, result As Double
s1 = SeverityTextBox.Text
s2 = POOTextBox.Text
s3 = FOETextBox.Text
s4 = NOEPTextBox.Text
If s1 = "" Then
Call MsgBox("You've forgot to enter severity value", vbCritical, "Missing Value!")
Exit Function
End If
If s2 = "" Then
Call MsgBox("You've forgot to enter the Probability of Occurrence", vbCritical, "Missing
Value!")
Exit Function
End If
If s3 = "" Then
Call MsgBox("You've forgot to enter the Frequency of Exposure", vbCritical, "Missing
Value!")
Exit Function
End If
If s4 = "" Then
Call MsgBox("You've forgot to enter the Number of Exposed People", vbCritical, "Missing
Value!")
Exit Function
End If
result = s1 * s2 * s3 * s4
TextBox5.Text = result
CalculateRPN = result
End Function
Private Sub CalcRiskButton_Click()
Call CalculateRPN
End Sub
Private Sub GetPrecautionButton_Click()
```

```

Dim result As Double
Dim precautionSet As Boolean
result = CalculateRPN
precautionSet = False
If result >= 300 And ComboBox1.Value = "Not leaving power sources and dissipating
stored energy" Then
    Call MsgBox("The system should be designed to provide positive separation from energy
sources.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 250 And ComboBox1.Value = "Failure to make grounding device" Then
    Call MsgBox("Body and panel grounding should be done with yellow and green cables and
PE and warning labels should be hung.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 200 And ComboBox1.Value = "No power cut during maintenance and use"
Then
    Call MsgBox("Hanging electrical product pictograms on electrical panels and install
grounding line.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 188 And ComboBox1.Value = "Dangerous movement during tool setting,
maintenance and lubrication (en 16092-3 5.5)" Then
    Call MsgBox("Facilities will be provided to perform sled / ram movement during tool
setting, maintenance and lubrication with protective and protective devices in place and in
working condition.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 187.5 And ComboBox1.Value = "Reset buttons are not in the system by
controlling the dangerous area" Then
    Call MsgBox("If persons can remain in hazardous areas without being seen by the operator,
a means of preventing restart must be provided, for example, with a gripper-sensing device or
fixed switches to prevent close the door.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If

```

If result >= 180 And ComboBox1.Value = "Uncontrolled pressure rise as a result of not using the pressure relief valve" Then

Call MsgBox("The circuit must be protected with pressure relief valves. These valves cannot change without using a tool. In addition, they should be set at a pressure not higher than 10% of the maximum working pressure.", vbCritical, "Precautions to Take!")

precautionSet = True

End If

If result >= 180 And ComboBox1.Value = "No pressure relief valve" Then

Call MsgBox("In the downward-moving presses, preparation should be made to protect the roller and the components containing the fluid at the bottom of the roller from damage caused by pressure condensation. A relief valve used for this purpose must be operated directly, closed and locked against unauthorized adjustment, and set at a pressure of at least 10% above the maximum system pressure.", vbCritical, "Precautions to Take!")

precautionSet = True

End If

If result >= 180 And ComboBox1.Value = "Hand operated valves-No control and monitoring functions" Then

Call MsgBox("The protective locking device must be positively connected to the actuator directly to the manually operated valve to reverse or interrupt the hydraulic fluid flow.", vbCritical, "Precautions to Take!")

precautionSet = True

End If

If result >= 180 And ComboBox1.Value = "Muting: position and pressure signal-silence-Not all dangerous movements are tracked" Then

Call MsgBox("Means for adjusting the point at which the protection system is turned off during the shutdown process: a position signal and a pressure signal, or a suitable alternative, signals that act when the tools are closed and the machine starts applying force.", vbCritical, "Precautions to Take!")

precautionSet = True

End If

If result >= 180 And ComboBox1.Value = "Installing a manual override valve" Then

Call MsgBox("Manual override devices should not be attached to safety valves. If manual overrides are included in other valves for testing or maintenance purposes, they require the use of a tool to operate the override.", vbCritical, "Precautions to Take!")

precautionSet = True

```

End If
If result >= 180 And ComboBox1.Value = "Not measuring the performance of security
functions" Then
    Call MsgBox("The safety functions of the hydraulic press must meet the requirements.",
vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 156 And ComboBox1.Value = "No emergency stop or missing" Then
    Call MsgBox("There must be an emergency stop button on the machine operator panel,
column and double hand controls.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 156 And ComboBox1.Value = "Emergency stops are not connected in parallel"
Then
    Call MsgBox("Must comply with EN 16092-1;EN 16092-2;EN 16092-3 and EN ISO
13850.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 150 And ComboBox1.Value = "Direct contact to the equipment in the electrical
panel" Then
    Call MsgBox("Access should not be possible to shut down the equipment in the electrical
panel.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 150 And ComboBox1.Value = "No insulated cables" Then
    Call MsgBox("Insulated cables should be used, grounded and warnings should be written
to prevent anyone from interfering with the cables except the authorized electrician.",
vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 138 And ComboBox1.Value = "Loosening of hydraulic hoses, affecting the
health of the worker under pressure" Then
    Call MsgBox("Pressure hoses and similar equipment designed and mounted closed.",
vbCritical, "Precautions to Take!")
    precautionSet = True

```

```

End If
If result >= 137.5 And ComboBox1.Value = "Easy removal and easy access due to the fact
that the protections applied to rotating parts and risky areas are not fixed" Then
    Call MsgBox("The casings of fixed protective must comply with ISO 14120. It must be
securely fastened to the machine, other rigid structure or the ground.", vbCritical, "Precautions
to Take!")
    precautionSet = True
End If
If result >= 137.5 And ComboBox1.Value = "Machine does not stop when the protection
covers are opened" Then
    Call MsgBox("Locking guards, early release locking guards and control guards must
comply with ISO 14120, and access to the hazardous area in the tool area must be prevented
during dangerous movements with fixed guards.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 137.5 And ComboBox1.Value = "Control mode works in accordance with
production in settings, maintenance, training etc." Then
    Call MsgBox("Only the two-hand control or setting position operating devices provided
for tool setting should be arranged so as not to be suitable for production.", vbCritical,
"Precautions to Take!")
    precautionSet = True
End If
If result >= 113 And ComboBox1.Value = "Falling down the coach by gravity" Then
    Call MsgBox("Controlled landing should be provided according to EN 16092-3 clause
5.3.2.1.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "Access to the mold site" Then
    Call MsgBox("Designing the machine to stop automatically when there is an intervention
in the mold area.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "Oil leaking around the counter" Then
    Call MsgBox("Precautions should be taken in terms of oil leaks in the press design.",
vbCritical, "Precautions to Take!")

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precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "No mechanical restraint assembly in the press"
Then
    Call MsgBox("Safety wedge should be used.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "Gravity effect in safety wedge" Then
    Call MsgBox("It should be ensured that the press wedges enter the press in a way that there
is no gap left in the lower table and the upper table. In addition, these wedge fittings should be
provided, taking into account the strength of the material used.", vbCritical, "Precautions to
Take!")
    precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "Wedge safety function review" Then
    Call MsgBox("It must comply with EN160921, EN 16092-2 and EN 160292-3.",
vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "Light curtain is not category 4" Then
    Call MsgBox("The photocell on the front and back is in a suitable place and complies with
category 4.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "Blanking photocell teaching" Then
    Call MsgBox("It should be in category 4 and the front and back photocells should be
instructed.", vbCritical, "Precautions to Take!")
    precautionSet = True
End If
If result >= 100 And ComboBox1.Value = "Access under the light barriers" Then
    Call MsgBox("Must comply with EN 692 and EN ISO 13857.", vbCritical, "Precautions to
Take!")
    precautionSet = True
End If

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    If result >= 100 And ComboBox1.Value = "Failure to install the light curtain according to
ESPE results" Then
        Call MsgBox("Must comply with EN 16092-1, EN 16092-2, EN 16092-3 and EN ISO
13857.", vbCritical, "Precautions to Take!")
        precautionSet = True
    End If
    If result >= 100 And ComboBox1.Value = "Unexpected, unwanted start" Then
        Call MsgBox("Must have LOTO (Tag, lock, safe, audit).", vbCritical, "Precautions to
Take!")
        precautionSet = True
    End If
    If precautionSet = False Then
        Call MsgBox("There is no need to take any precautions for these values or they are not
defined.", vbCritical, "Precautions to Take!")
    End If
End Sub
Private Sub CommandButton3_Click()
    For Each i In Me.Controls 'Or TypeName(i) = "ComboBox"
        If TypeName(i) = "TextBox" Then i.Value = ""
    Next i
End Sub

```