REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF INDUSTRIAL ENGINEERING

FUZZY BASED INTEGRATED RISK PRIORITIZATION AND ACTION SELECTION UNDER CONSTRAINTS: AN APPLICATION STUDY

SEÇKİN ÇELİKER
MASTER OF SCIENCE

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ASSOC. PROF. DR. MURAT OTURAKÇI

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

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ABSTRACT

FUZZY BASED INTEGRATED RISK PRIORITIZATION AND ACTION SELECTION UNDER CONSTRAINTS: AN APPLICATION STUDY

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Risk analyzes should not be considered only in the field of occupational health and safety. Risk analyzes can also be used effectively to improve the processes of companies. With appropriate evaluations, companies can improve their processes and products, reduce costs and prevent possible accidents. Hence, preventive actions should be determined as a result of an objective risk analysis study. Actions should be chosen and implemented by taking into account the company's interests. In this study, a risk analysis study covering the processes of a medium-sized production company and an integrated risk assessment including action selection for high-score hazards as a result of risk analysis are presented. Hazards identified in company processes were evaluated using Failure Mode and Effect Analysis (FMEA) and Analytic Hierarchy Process (AHP), and integrated scores were obtained. In order to increase objectivity and remove the uncertainties, these methods were evaluated with fuzzy logic and the hazards were re-evaluated. Preventive action planning was performed for high-score hazards based on the integrated scores obtained as a result of fuzzy logic integration. Determining which of the actions will be implemented optimally is very important in terms of using the limited resources of the company effectively. Therefore, a mathematical model was created for action selection by using binary programming. The mathematical model was solved using the LINGO 19.0 program. Finally, sensitivity analysis was performed and the limits of the model were determined.

Keywords: Risk analysis, FMEA, AHP, Fuzzy Logic, Binary programming, Action selection

ÖZET

BULANIK TABANLI ENTEGRE RİSK ÖNCELİKLENDİRME VE KISITLAR ALTINDA AKSİYON SEÇİMİ: BİR UYGULAMA ÇALIŞMASI

Seçkin ÇELİKER
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Risk analizleri sadece iş sağlığı ve güvenliği alanında düşünülmemelidir. Risk analizleri, şirketlerin süreçlerini iyileştirmede de etkin bir şekilde kullanılabilir. Yapılacak uygun değerlendirmeler ile beraber şirketler süreçlerini ve ürünlerini daha kaliteli hale getirebilir, maliyetler azaltılabilir ve oluşabilecek kazalar engellenebilir. Bunun için objektif bir risk analizi çalışması sonucu önleyici aksiyonlar belirlenmeli ve şirket çıkarları göz önünde bulundurularak aksiyonlar arasından seçim yapılıp uygulanmalıdır. Bu çalışmada orta ölçekli bir şirketin süreçlerini kapsayan bir risk analiz çalışması ve risk analizi sonucu yüksek skorlu tehlikeler için aksiyon seçimini de içeren entegre bir risk değerlendirmesi sunulmuştur. Şirket süreçlerinde belirlenen tehlikeler Failure Mode and Effect Analysis (FMEA) ve Analytic Hierarchy Process (AHP) kullanılarak değerlendirilmiş ve entegre skorlar elde edilmiştir. Objektifliği artırabilmek ve belirslizlikleri ortadan kaldırabilmek adına bu yöntemler bulanık mantık ile entegre edilerek tehlikeler tekrar değerlendirilmiştir. Bulanık mantık entegrasyonu sonucu elde edilen entegre skorlar üzerinden yüksek skorlu tehlikeler için önleyici aksiyon planlaması yapılmıştır. Akisyonlar arasından hangilerinin uygulanacağını optimum şekilde belirlemek, şirketin kısıtlı kaynaklarını etkili bir şekilde kullanmak açısından oldukça önemlidir. Bu yüzden 0-1 tamsayılı programlama kullanılarak aksiyon seçimi için matematiksel model oluşturulmuştur. Matematiksel model LINGO 19.0 programı kullanılarak çözülmüştür. Son olarak duyarlılık analizi gerçekleştirilmiş ve modelin sınırları belirlenmiştir.

Anahtar Kelimeler: Risk analizi, FMEA, AHP, Bulanık Mantık, Tamsayılı programlama, Aksiyon seçimi

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NOMENCLATURE

FMEA	: Failure Mode and Effects Analysis
AHP	: Analytic Hierarchy Process
FTA	: Fault Tree Analysis
HAZOP	: Hazard and Operational Analysis
PHA	: Preliminary Hazards Analysis
ETA	: Event Tree Analysis
JSA	: Job Safety Analysis
S	: Severity
P	: Probability
D	: Detectability
RPA	: Risk Priority Score
MCDM	: Multi Criteria Decision Making
F-FMEA	: Fuzzy Failure Mode and Effects Analysis
F- AHP	: Fuzzy Analytic Hierarchy Process
GPP	: Geothermal Power Plants
SMEs	: Small and Medium Enterprises
ESP	: Enterprise Security Program
DEA	: Data Envelopment Analysis
NPD	: New Product Development
TBM	: Tunnel Boring Machine
DDP	: Drug Development Process
TOPSİS	: Technique for Order of Preference by Similarity to Ideal Solution
CHU	: Compressor Room Unit
CR	: Consistency Ratio
CI	: Consistency Indicator

1. INTRODUCTION

1.1. Risk Analysis

Risk analysis is the analysis made to determine the order of importance of the risks after the hazards are identified in a specific area (Dağsuyu et al, 2016). In other words, risk analysis is a security method used in organizations to check whether the necessary precautions have been taken to eliminate potential hazards and the harms of these hazards (Gul et al, 2018).

It is vital to conduct risk analysis in government institutions and private workplaces. Performing risk analysis at workplaces enables potential hazards to be identified in advance. With the taking of various measures, these hazards are eliminated or their effects are reduced. In our country, it has been made compulsory for all organizations since 2013 with the Occupational Health and Safety Law No. 6331 (6331 Sayılı İş Sağlığı ve Güvenliği Kanunu, 2012). The working environment is taken into account when applying risk analysis. In this way, it can be accurately determined which group will be affected by potential hazards and how. With the measures to be taken for the hazards determined as a result of the risk analysis, accidents are prevented in the workplace. Thus, the probability of serious health problems such as accidental injury, permanent damage and death is reduced.

When risk analysis is mentioned, the first thing that comes to mind is the identification and evaluation of hazards to occupational health and safety. However, risk analyzes are used not only for occupational health and safety in companies but also for identifying and analyzing hazards that prevent workflow and reduce productivity. By identifying the hazards in the workflow, various improvements can be made in the processes from raw material entry to the final product. In this way, companies are more likely to have a more productive, efficient and controllable system.

There are various risk analysis methods to identify and evaluate hazards that have a negative impact on occupational health and safety and workflow. Risk analysis methods have been started to be applied since the 1950s and have shown many developments until today. With these developments, risk analysis methods have emerged for different occupational groups or these methods have been revised by occupational groups (Emhan, 2009). Risk analysis methods that are frequently used today are given below;

- Failure Mode and Effect Analysis (FMEA)
- Fine-Kinney Method
- Fault Tree Analysis (FTA)
- Hazard and Operational Analysis (HAZOP)
- L Type Matrix Analysis
- X Type Matrix Analysis
- Preliminary Hazards Analysis (PHA)
- Event Tree Analysis (ETA)
- Job Safety Analysis (JSA)

Failure Mode and Effect Analysis (FMEA) is a risk analysis method that helps identify and prioritize both existing and potential hazards. Assessment is made by taking into account the 3 parameter values of the identified hazards, namely severity (S), probability (P) and detectability (D). By multiplying the determined parameter values, the risk priority score (RPN) is obtained for each hazard and the hazards are prioritized according to this score. Today, FMEA is frequently used in sectors such as aviation, military, electricity and automotive (Sharma and Sriavastava, 2018).

Fine Kinney is a risk analysis method that takes into account the exposure (E), probability (P) and possible consequences (C) of a hazard. Fine Kinney is used in many areas because it is a simple and effective method to apply (Wang et al, 2018).

Fault Tree Analysis (FTA) is a widely used risk analysis method. The basis of this analysis method is based on logical connections. The error tree contains errors and their causes (Kang et al, 2019).

HAZOP is a method for systematically examining the design of a process. The HAZOP method is performed by experts from various disciplines. In general, the brainstorming technique is used. Hazards are identified and recorded (Marhavilas et al, 2020).

In the L Type Matrix method, risk assessment is performed by multiplying the probability and severity values of the hazard. The cause-effect relationship is used. Matrices are in the form of 3*3,4*4 and 5*5 (Gur et al, 2021).

The X Type Matrix method is similar to the L Type Matrix. In this method, a risk team is established. A disciplined study is carried out. There is only a shape difference between the en X Type Matrix and L Type Matrix. Generally, a 5*5 matrix is preferred (Gur et al, 2021).

Preliminary Hazard Analysis is a qualitative risk analysis method for predicting and analyzing the hazards of any system. After the hazards are determined, the consequences of the accidents are estimated and analyzed, considering that the hazards have occurred. In this way, potential hazards related to the system are prevented in advance (Yan and Xu, 2019).

Event Tree Analysis, any system failure is considered a starting event. Then, various results are tried to be obtained by proceeding from the initial event. Finally, these results are presented graphically. Event Tree Analysis was first used in the field of atomic energy. Later, it started to be used in fields such as mechanical engineering (Hong et al, 2009).

Job Safety Analysis is an effective method among risk analysis methods. The JSA consists of four different parts. These sections are job selection, process decomposition, potential hazards analysis and preventive measures, respectively. According to the JSA, all business segments contain threats. However, due to various constraints of companies, not all of these hazards can be examined. Therefore, only threats that will cause severe injury or death are examined (Li et al, 2018).

1.2. Problem Definition

In this study, an approach that includes risk analysis and the decision-making process has been tried to be put forward. In this approach, it is of great importance that the risk analysis and decision-making process be carried out objectively. In risk analysis studies, hazards are generally evaluated according to various parameters and prioritized. However, the parameter values used in the hazard evaluation process are shaped according to the opinions of the evaluator. This situation causes subjectivity to be included in the evaluation process of hazards.

In such a case, the parameter values for the identified hazards and the priority order of the hazards may change according to various criteria such as the evaluator's perspective, attitude, mood, and personal equipment. Therefore, a hazard that is important in order of priority can be ignored and can cause various problems with an incorrect assessment. The subjective nature of risk analysis methods has led to the evaluations in this analysis to be handled with different analytical techniques. Multi-criteria decision-making (MCDM) approaches, fuzzy logic approaches or integrated versions of these two approaches allow objective results of assessments in risk analysis.

Considering the subjectivity matter, in this study, hazards were evaluated with FMEA, one of the risk analysis methods, and the Analytic Hierarchy Process (AHP), one of the MCDM techniques, to solve this problem. Then both methods are re-evaluated with fuzzy logic integration. Integrated weights were obtained by multiplying the F-RPN obtained as a result of Fuzzy FMEA (F-FMEA) and the N_i weights obtained as a result of Fuzzy AHP (F-AHP) of the hazards. In this way, a risk analysis approach is presented, in which both uncertainties are significantly eliminated and an objective evaluation is attempted to perform.

Another problem that is tried to be solved in the study is the planning of actions for the hazards in the important group as a result of the performed risk analysis. Many studies have been limited to evaluating the identified hazards and determining the order of priority. In terms of the effectiveness of risk analysis studies, it is necessary to determine various actions for hazards, make choices and implement the selected actions. In this way, the effect of hazards is tried to be minimized or hazards are eliminated. However, the determination and implementation of actions for companies contain various difficulties. The limited resources of the companies are among the main reasons for these difficulties. In addition, when the actions determined for hazards are implemented, they may not always yield effective results in order to prevent hazards or reduce their effects. In order to achieve effective results, the departments affected by the hazards were also determined and evaluated in this study. With this information, it is necessary to determine the constraints of the companies for both the correct determination of the actions, the correct selection of the actions, and the selection of the actions. Therefore, in order to overcome this problem, an binary mathematical model of action choices was formed in this study. Considering the actions, action weights and company constraints in the mathematical model, the selection of action has been tried to be performed objectively and effectively.

In order to achieve the determined objectives, the study was carried out in a medium-sized company that has been in the iron and steel industry for many years. Within the scope of this study, first of all, the hazards affecting the work processes in the company were determined. Then, these hazards were evaluated with FMEA, one of the risk analysis methods, and the Risk Priority Number (RPN) of the hazards was calculated. The same hazards were weighted with the Analytic Hierarchy Process (AHP) and the hazards Wi were obtained. Since both methods contain subjectivity, the methods are integrated with fuzzy logic to increase objectivity. An integrated result was obtained by multiplying the FRPNs of the hazards obtained as a result of fuzzy FMEA and the Ni weights of the hazards obtained as a result of fuzzy AHP. In addition, the departments affected by the hazards were determined and these departments were weighted using fuzzy AHP. The final risk score was calculated by multiplying the department weights and the integrated results of the hazards with each other. Thus, departments were included in the process of evaluation of hazards and it was aimed to consider the consequences of hazards in a more realistic way. The hazards are then ranked according to the integrated scores. Pareto Analysis was performed to determine the hazards representing the important group among the hazards. Then the company's constraints were determined. While determining the actions for the hazards determined as a result of the Pareto Analysis, the company's constraints were taken into account. No company has unlimited resources. Therefore, companies need to use their existing resources by managing them in the best way possible. Therefore, the company's constraints on the choice of action have been determined. By creating a mathematical model that includes these constraints, it is ensured that the company resources are used in an optimum way in the selection of actions. An binary mathematical model was formed to choose between these actions. Operational constraints, actions and weights of actions are included in this model. The mathematical model was solved using the LINGO 19.0 package program. Finally, since the company's constraints may change under various conditions, a sensitivity analysis was performed and the results were compared.

1.3. Purpose of the Study

The risk analysis carried out within the scope of the study includes not only the occupational health and safety, but also the identification of the hazards that prevent the workflow. It has been tried to present an objective approach to this risk analysis by integrating fuzzy logic with risk analysis methods and multi criteria decision making methods. Then, actions were planned for the identified hazards and a selection was made by taking into account the company's constraints. With this study, the following objectives were tried to be achieved;

- Providing an objective risk analysis framework,
- Presenting an integrated and different approach using methods from different disciplines,
- Identifying hazards that negatively affect work processes and disrupt the workflow in the company where the study is carried out,
- Identifying the hazards that represent the important group among the hazards,
- Identifying the departments directly or indirectly affected by the hazards and including them in the action selection process,
- Determining and selecting actions for these hazards,
- Increasing traceability in the company where the study is carried out,
- It is aimed to increase the efficiency of the processes in the company where the study is carried out.

2. LITERATURE REVIEW

2.1. Failure Mode and Effect Analysis (FMEA) Studies

Bonfant et al. (2010), a risk analysis study was conducted in a healthcare institution to improve both the safety of patients and the quality of healthcare services. Accordingly, a risk analysis study was conducted for chronic hemodialysis patients using the Mode of Failure and Effect Analysis (FMEA) method. As a result of FMEA applied, it was observed that clinical risks were reduced. Various measures were taken for the identified risks, and as a result of these measures, the total RPN value was reduced to 8.6%.

Feili et al. (2013), a risk analysis study was conducted using the Failure Mode and Effect Analysis (FMEA) method to identify common hazards for Geothermal Power Plants (GPP) and reduce their probability of occurrence. As a result of the study, 25 hazards were identified for GPP. XFMEA software was used for FMEA in terms of the fast conclusion of the study. In the study, the importance of the study was emphasized by pointing out that there was no joint study for GPPs before. As a result, all identified hazards were evaluated and preventive action was recommended for each hazard.

Li and Zeng (2016) conducted a risk analysis study for supplier selection by using the Failure Mode and Effect Analysis (FMEA) method in the study. Because it is stated that companies have to choose their suppliers well for lower costs and higher quality. Therefore, it was decided to minimize the risks involved in this process. A case study was conducted to demonstrate the effectiveness of the proposed method. The proposed study also includes the FMEA decision analysis approach. The choice of methanol supplier was examined in the case study. As a result, the risks in the methanol supplier selection process were evaluated with FMEA.

Parsana and Patel (2014) aimed to increase the quality of a production process by using the Failure Mode and Effect Analysis method in their studies. For this study, the cylinder head production process was examined. In this process, both current and potential hazards are taken into account. As a result of the study, these dangers are eliminated, increasing customer satisfaction, reducing costs and increasing quality.

Doshi and Desai (2017) tried to achieve continuous quality improvement by using Failure Mode and Effect Analysis (FMEA) in their studies. For this, multiple case study was performed. Four different Small and Medium Enterprises (SMEs) were selected for the case study. It has been observed that all of these enterprises are located in the automotive sector. As a result of FMEA implementation, companies' product and process improvements have been observed. In addition, as a result of the study, a 3-4% decrease was found in the number of products marked as poor quality.

De Oliveira et al. (2020) performed a risk analysis using Failure Mode and Effect Analysis. Therefore, a case study was conducted in the medium-sized state of Maranhão (Brazil). In the case study, the maintenance of the city's water resources was evaluated in terms of occupational safety. Observations were made and recorded in the study. Then these records were examined and hazards were determined accordingly. These hazards identified by FMEA were evaluated and the RPNs of the hazards were calculated.

Taghipour et al. (2020) discussed the risk management of the ERP implementation process in this article. It has been seen that the implementation of ERP systems is quite long and costly. Therefore, there should be no errors while performing this operation. It was decided by the Power Engineering and Development Company (Mapna Pars) to implement the Enterprise Security Program (ESP) in the company. In this process, Failure Mode and Effect Analysis were used to evaluate the risks. As a result, 5 factors to be considered in the ESP application were determined. In addition, it was thought that this study could provide a method for designing a risk management model in organizations.

Moreira et al. (2020) used Failure Mode and Effect Analysis (FMEA) in New Product Development (NPD). In the study, it was aimed to identify risks and reduce their effects in the early stages of the product development process. For this, a case study was carried out. A hydro plumbing company was selected for the case study. FMEA was used by the engineers at the company during the design stages of the NPD process. As a result, waste has been reduced and quality products have been produced and delivered to the customer successfully.

Dziuba et al. (2021), it is aimed to reduce the hazards of the window guide manufacturing process by using Failure Mode and Effect Analysis (FMEA) in the study. In this way, it was thought to increase the quality. During the implementation, the complaints of the business partners and customers were taken into account. As a result, the main source of complaints was identified. Corrective actions related to the problem were determined and these corrective actions were controlled by FMEA. In addition, it contributed to the improvement of the production process in the same production line and to the increase of the quality of similar products.

2.2. Risk Analysis Studies Using Multi-Criteria Decision Making (MCDM) Methods

Wang et al. (2008) proposed a new methodology for the assessment of bridge risks of bridge construction. For the case study, 20 out of 160000 bridges in England were selected. The Analytical Hierarchy Process (AHP) method was used to determine the weights of the risks. Then, the DEA method was used to evaluate the risks. As a result, AHP and DEA have been integrated into the proposed methodology and thousands of alternatives have been made comparable.

Hyun et al. (2015), potential hazards that arise during the application of the shield tunnel boring machine (TBM) method are analyzed. Fault Tree Analysis (FTA) and Analytical Hierarchy Process (AHP) was used for this risk analysis. For risk analysis, previous studies were examined and opinions were exchanged with experts. Then, four main categories were determined to group the risks. A series of fault trees were constructed using risk factors. Then the risks were evaluated with FTA and AHP. To prove the effectiveness of the study, the results were compared with the results of field observations. It was also decided that the study is suitable for risk management purposes for TBM tunnels.

Fazli et al. (2015) conducted a risk analysis study on the crude oil supply chain. In this way, it is aimed for supply chain managers to make decisions more effectively and easily. In this study, DEMATEL and ANP methods were used for risk analysis. In the study, first the main risks were identified. Then, the DEMATEL method was used to determine the dependence between the risks. The ANP method was then used to evaluate and rank the risks. As a result of the implementation, a comprehensive risk analysis study for supply chain management was carried out, contributing to the development of crude oil supply chain management throughout Iran.

Raka and Liangrokapart (2017), in the study, aimed to determine the important risks by performing risk analysis in the new generic drug development process (DDP). The new generic DDP is the first phase of the pharmaceutical supply chain network. A case study was carried out for this article. The Thai pharmaceutical supply chain network was chosen as the case study. A focus group was formed to identify possible risks and evaluate risks using the Analytical Hierarchy Process (AHP) method. As a result of the study, the risks for the new generic drug development process were classified into 7 categories and the most important category was determined. In the study, it was determined that the purpose of using AHP is to assess risks and also to evaluate alternative risk reduction methods.

Bid and Siddique (2019) analyzed the risks to human life for the dam type in this article. Because it has been seen that dams built on rivers pose a risk to human life in the long run. For this purpose, a case study was carried out. The Panchet Dam on the Damodar River on the Indian border of West Bengal was chosen as the case study. Delphi Method was used to identify risks. The risks identified using TOPSIS and WASPAS methods were evaluated. As a result of the analysis, similar results were obtained for some risks, while different results were obtained for some risks. Thus, the final result was obtained with the Average Rank method. According to the final result, the most important risk to human life was determined.

Lo et al. (2020) proposed an integrated risk analysis approach to identify and evaluate risks in the manufacturing industry. It has been seen that this integrated model includes FMEA from risk analysis methods, DEMATEL and TOPSIS methods from multi-criteria decision-making methods. A company producing machine tools was selected for the implementation phase of the study. The data to be used in the analysis process were collected through a questionnaire. First of all, costs and various indicators were transferred to FMEA. Then, the DEMATEL method was used to see and determine the relationship between risk factors. Finally, using the TOPSIS method, the risks were evaluated and the priority order was determined.

Li et al. (2021), a risk analysis methodology is proposed in the study that integrates Analytical Hierarchy Process (AHP) and Failure Mode and Effects Analysis (FMEA). The proposed methodology was used to identify and analyze the failure causes of wind turbines. AHP was used to weight the criteria in the study. FMEA is used to analyze the main components, important systems and causes of failure. As a result, 15 faults were detected and analyzed. As a result of the study, important errors in wind turbines were minimized.

Gül (2021), in the study, the risks in the metal sector were evaluated in terms of Occupational Health and Safety. In the study, the risks in the field of aluminum extrusion from the metal sector were examined. The TOPSIS-Sort method was used to examine the risks. As a result of the study, 28 risks were determined. These risks were evaluated by considering the parameters of severity, probability and frequency. As a result of the analysis, the risks were grouped into five categories (risk, possible risk, significant risk, high risk and very high risk). It has been determined which group the risks belong to.

Bathrinath et al. (2021), a risk analysis study was carried out for the textile industry. In the study, the risks that cause failure and accidents in the textile sector were examined. In the study, a case study was conducted in a textile business located in the southern region of Tamil Nadu state of India. The risks identified as a result of the case study were evaluated using the Analytical Hierarchy Process (AHP) and the Ranking of Preference Technique by Similarity to Ideal Solution (TOPSIS). As a result of the study, factors such as insufficient lighting, insufficient ventilation and noisy environment were determined among the causes of accidents.

Lin (2022) conducted a risk analysis study for maritime accidents in the study. DEMATEL, ANP and BSC methods were used for risk analysis. For the risk analysis application, first of all, a survey study was carried out. As a result of the survey study, 30 surveys were conducted and 5 important factors for maritime accidents were determined from these surveys. Risk analysis criteria were established with BSC. Then, the risks were determined according to these criteria were evaluated with DEMATEL and ANP. As a result of the study, it was thought that improvements were made to maritime safety and the causes of accidents.

2.3. Studies with Fuzzy Logic Approach

Choobar and Nazari (2012) aimed to identify and prioritize risks by conducting a risk analysis study for power plants in developing countries. A case study was carried out in the study. Yazd Power Plant, owned by the Power Plant Projects Management Company in Iran, was chosen for the case study. Fuzzy logic was integrated with ANP and TOPSIS for risk study. In the risk analysis, fuzzy ANP was used to determine the weights of the risks. Then fuzzy TOPSIS was used to evaluate the risks. Additionally, a sensitivity analysis was performed to discuss the results of the proposed model. As a result, more than 100 risks have been evaluated. Among these risks, the most important risks were identified. It was recommended to use different MCDM methods for future studies.

Oturakçı et al. (2015), a new approach is proposed for the Fine-Kinney risk analysis method. Sensitivity and importance levels have been increased. An application has been made for the proposed approach and the results have been observed. According to the results of the study, the proposed approach was gave more sensitive results than the traditional Fine-Kinney method.

Mangla et al. (2016) aimed to analyze the risks of the green supply chain. Quantitative and qualitative information was used for risk analysis. FTA and fuzzy AHP were used for risk analysis. For the proposed risk analysis approach, the green supply chain of a plastics manufacturing enterprise has been taken into account. A fault tree diagram was created in the risk analysis included in the study. It has been determined that the fault tree diagram includes the possible criteria of the green supply chain and the sub-criteria of the criteria. Under these criteria, a total of 8 risk criteria and 30 sub-risk criteria were determined. Then, using fuzzy AHP, these criteria and sub-criteria were prioritized and important criteria were determined.

Panchal and Kumar (2017) aimed to use integrated methods for risk analysis in different fields. To achieve this aim, a case study was carried out. For the case study, a risk analysis of a compressor house unit (CHU) was conducted in a medium-sized coal fired power plant in North India. Fuzzy logic and Failure Mode and Effect Analysis (FMEA) were integrated for risk analysis. In addition, the GRA method was also used. RPN score was calculated by FMEA. A fuzzy FMEA approach was used to overcome FMEA limitations while risk prioritization. Using the same linguistic terms defined for fuzzy FMEA, GRA was used for intelligent decision making of critical or risky components of the system under study. As a result, the prioritization results were obtained using RPN, FRPN and gray analysis were compared. Comparison of these results enabled decision makers to make more efficient decisions for risky components.

Hayati and Abroshan (2017) aimed to perform a risk analysis for tunnel construction. It has been determined that tunnel constructions require high costs. For this reason, it was decided to analyze the risks well. Tehran metro project was chosen for the case study. Because the metro project has been seen to be a difficult project in terms of factors such as land characteristics, activity and equipment diversity. Fuzzy FMEA was used for risk analysis. It was determined that the fuzzy FMEA contains three parameters. As a result, significant risks have been identified. It was thought that a more objective evaluation was made by applying fuzzy FMEA and uncertainties that were difficult to detect were detected more easily.

Yazdi (2017) proposed a fuzzy approach to increase risk assessment and objectivity in failure probability analysis. In this study, a case study was conducted. As a case study, a granule storage tank in a petrochemical plant was chosen. In this study, fuzzy logic was integrated with FTA and AHP methods. Fuzzy FTA was used to determine known and unknown failure probabilities. Fuzzy AHP was used to calculate the probability of failure. As a result, the values were calculated and compared with the conventional model. It has been determined that the proposed model gives more objective and accurate results than traditional models. A dynamic FTA with Petri Net, Markov Chain was proposed for future work

De Gusmão et al. (2018) proposed a risk analysis method to find the causes of failures in preventing cyber attacks and to identify the weaknesses of the network security system. A case study was carried out in the study. The risks associated with attacking a website, e-commerce and ERP are analyzed for the case study. Fault Tree Analysis (FTA) was used to identify cyber attacks and possible consequences of cyber attacks. Then FTA and fuzzy logic were integrated to evaluate the alternatives. According to the results of the study, it was revealed which application could be vulnerable in case of a cyber attack (example: credit card transactions, ID verification).

Ganguly and Kumar (2019), in this article, it is aimed to propose a methodology to best manage the risks of the supply chain. It has been determined that the supply chain is important for organizations. At the same time, it has been seen that managing the risks of the supply chain poses great challenges. No case study was conducted in this article. However, the effectiveness of the proposed methodology has been discussed. Attention has been drawn to the difficulty of weighing risks in traditional methods. Because it has been mentioned that traditional methods contain subjectivity. Therefore, a more objective approach has been proposed, thanks to fuzzy logic. The Fuzzy AHP method was used to evaluate the risks. As a result, it is proposed to validate the proposed model in practice. For this, a developed model has been proposed for 5 different companies. At the same time, it has been accepted that the study is one of the rare studies on SCRM.

Tian et al. (2020), in this article, it is aimed to propose a risk analysis method that will help design effective safety management methods and reduce the frequency of accidents. To achieve this aim, a case study was carried out. For the case study, the company that owns one of the large-scale mines planned by the National Development and Reform Commission in China's Shenfu Southern Region was selected. The fuzzy TOPSIS method was used to evaluate the risks. As a result, the audit report was created according to the results of the risk analysis. Various improvements have been proposed for priority risks in this report. Fuzzy TOPSIS has been applied to get rid of the subjectivity brought by the traditional TOPSIS.

Fattahi et al. (2020) proposed a new risk analysis approach in the study. With this risk analysis approach, it was aimed to evaluate the risks that cause different error types. It has been seen that the proposed risk analysis approach includes the FMEA model based on multi-criteria decision making. In the proposed model, in addition to the parameters of FMEA such as severity, probability and detectability, time, cost and profit criteria are also added. Fuzzy AHP and fuzzy MULTIMOORA methods were used to determine and evaluate the weights of these criteria. A case study was conducted to demonstrate the effectiveness of the proposed risk analysis approach. The case study was conducted at Kerman Steel Industry factory in Iran. According to the results obtained, a new risk analysis approach was adopted.

Karatop et al. (2021), it is aimed to determine how optimum investment decisions can be taken in the renewable energy sector. In this article, decision analysis and risk analysis are applied together. A case study was carried out in the study. Turkey was chosen as the region for the case study. The information used for the study was obtained from the reports of the Ministry of Energy and Natural Resources of the Republic of Turkey and experts consisting of energy sector employees and academicians. For risk analysis, fuzzy logic is integrated with AHP and FMEA methods. Fuzzy AHP was used to determine the weights and priority order of renewable energy sources. EDAS was used to determine the weights and priority order of renewable energy sources. Fuzzy FMEA was used to find and evaluate the risks of renewable energy source alternatives. As a result, a model has been proposed that enables more reliable investment decisions in the field of renewable energy by applying prioritization and risk analysis together. In addition, a more detailed study was conducted compared to the literature.

Dagsuyu et al. (2021), a study was carried out to identify the hazards in the cold chain and to prevent these hazards. Since the actions to be taken to prevent hazards depend on company resources, a mathematical model has been developed that will use these resources to the maximum. This proposed model also includes AHP and FMEA methods. As a result of the study, it has been determined that the improvement in 14 hazards will be realized with 5 actions.

Dogan et al. (2022), the Fine-Kinney risk analysis method was used to identify and evaluate the hazards involved in a gas filling facility. Fuzzy logic and Fine Kinney method are integrated to make the study more objective. The AHP method was used for the applications of the study related to the company resource other than the risk analysis. For the final result in the study, the AHP weights were integrated with the TOPSIS method and the action selection was made for the hazards.

Gul et al. (2022), an approach used for risk analysis and prioritization of measures to be taken was proposed in this study. The proposed approach has been implemented for the fuel tank located at the gas station. For the risk analysis carried out in the study, the Fine Kinney risk analysis method was used. The BBWM method was used to weight the criteria of the actions. The fuzzy-based VIKOR method was used for the selection of actions. As a result, it was thought that this study will bring a new perspective to occupational health and safety studies.

2.4. Criticism of Literature

When the studies in the literature are examined, the following statements can be said;

- Studies using risk analysis methods and MCDM methods generally only identify risks. But the effectiveness of the analyzes has not been proven. At the same time, the results of the analysis may not reflect the truth, since the evaluation process includes subjectivity while performing the analysis.

- It can be said that more objective results have been achieved in studies in which risk analysis methods and MCDM methods are integrated with fuzzy logic. In some studies, it has been seen that the two methods are integrated (example: Fuzzy AHP - Fuzzy TOPSIS). More objective results were obtained in these studies compared to the other group.

- In some studies, risk assessment was carried out by integrating fuzzy risk analysis methods and fuzzy MCDM methods. These studies are much more comprehensive than other studies in the literature. For example, the places where risk assessment is applied are government institutions such as ministries or the production facilities of very large companies. In addition, as a result of the use of these methods, it was thought that the subjectivity in the evaluation process was minimized.

Considering the studies in the literature and the inferences of these studies, it is thought that the following contributions will be made to the literature;

- In this study, expert opinions were taken into account in the process of identifying hazards in the company for which risk analysis was carried out. Hazards have been identified as a result of interviews and observations with people working in the company for many years. Accurate identification of hazards is of great importance for the efficiency of the study.

- While evaluating the identified hazards, they were first evaluated with FMEA, which is the most common and effective method among risk analysis methods. Then, the hazards are weighted with the AHP, which is one of the multi-criteria decision-making techniques. The scores obtained from both methods were integrated with each other and an objective and common result was tried to be obtained from two different subjective methods.

- Since FMEA and AHP methods contain subjectivity and evaluation scales contain definite judgments, it has been decided to evaluate the hazards with fuzzy logic. As a result of fuzzy logic integration, hazards were first evaluated with fuzzy FMEA and then weighted with fuzzy AHP. Then, the obtained scores were integrated with each other and a common score was obtained that is more objective and responsive to uncertainties compared to the integration of traditional approaches. Later, the results obtained using traditional methods and fuzzy approaches were compared. Thanks to this comparison, the effectiveness of fuzzy logic integration and its ability to find solutions to emerging uncertainties are clearly revealed. With this stage, the study is different from many studies in the literature that include traditional methods.

- Many studies in the literature have used traditional scales for grouping the assessed hazards and risks or for inclusion in the action plan. However, the fact that the risk scores calculated as a result of the evaluations are high for most of the hazards makes the selection process difficult. In addition, having more than one hazard with the same score makes it difficult for the decision maker to make the right choice. Any major hazard that is ignored at this stage will directly affect the outcome of the study and have negative consequences. In this study, Pareto Analysis was applied to determine the hazards in the important group. In this way, a systematic and proven approach to the selection of hazards has been used. With the use of Pareto Analysis, it is ensured that the errors to be made at this stage are minimized.

- Many risk analysis studies in the literature have resulted in prioritizing identified hazards and risks. Fewer studies, on the other hand, offered various recommendations against the identified hazards and risks. In this study, various actions were determined for the important group risks determined as a result of Pareto Analysis. While determining the actions, interviews were held with the experts working in the company. In the process of determining the actions, not the actions that temporarily eliminate the danger, but also permanent solutions that will both eliminate the danger and benefit the company in the long term by considering various criteria have been produced. The suggested actions are not with a general approach, but by going to the root of the problem, specific actions are suggested.

- It has been seen that many studies in the literature, in which actions are suggested, contain general judgments. In many studies, when making suggestions, it is not taken into consideration to what extent the resources of the company will be used or whether the company has the potential to meet the suggestions. In this study, operating constraints were taken into account for the determined actions. For this, first of all, company constraints were determined. Factors such as the current situation of the company, the future plans of the company, and the future workforce planning of the company were taken into account while determining the operating constraints.

- The original difference of this study and its contribution to the literature are given after this step. The choice of action for the company has turned into a decision problem. When the studies in the literature are examined, the selection process among the determined preventive actions was not carried out based on numerical data. Therefore, while the actions to be taken by the company eliminate the identified hazards, the possibility of new hazards in case of wrong decisions are increased. Within the scope of this study, a mathematical model has been created to choose which actions the company will implement. For the mathematical model to be more effective, the weights of the actions were determined. In this way, a model including action weights and company constraints has been created, and it has been tried to provide maximum benefit for the company in the decision problem.

- As a result of solving the mathematical model, a sensitivity analysis was carried out to see the efficiency of the model, to prevent unnecessary resource consumption and to determine the limits of the model. In this way, it was tried to get the maximum efficiency from the solution of the decision problem. In the literature, the study that integrates risk analysis and mathematical model is very few and not of sufficient quality. Therefore, this study presents a different framework to the literature as it includes not only the evaluation of risks but also the determination of actions and the selection process for risk analysis.

3. MATERIALS AND METHODS

3.1. Materials

The material for this study was obtained from a medium-sized production company. The medium-sized production company has been operating in the iron and steel industry for more than 50 years. Specialized in hot rolling, especially for the past 25 years. In this regard, this company serves both domestic and international customers. The company, aims to be the leading company both in Turkey and one of the leading companies in this sector in the international arena in the production of all kinds of machinery used in rolling machines and iron and steel production.

Starting from the feasibility stage of the turnkey rolling mill facilities, the medium-sized production company specializes in project design, machinery-equipment design, manufacture, shipment and assembly, and has successfully completed more than 40 projects. The company's productions include hot rolling mill, cranes, gearboxes, steel mills and other iron and steel products.

Aiming to be a leader in Turkey and internationally, the company has various problems in terms of hazards and risks. The company, which has serious rivals especially in the international arena, has difficulty in following its processes. Traceability cannot be fully ensured during the manufacturing of the products in the company. Therefore, they cannot realize projects larger than their current projects in the international arena. The situation is the opposite for the company's international competitors. Competitors can track even the smallest piece of a project in the field. Therefore, rival companies are in a much more advantageous position for large projects. In addition, there are various problems in the warehouse and production area of the company. All these problems directly affect the quality of the products, the completion time of the projects and occupational health and safety. With this study, it is aimed to identify and eliminate the mentioned problems.

3.2. Methods

In this study, the hazards that directly or indirectly affect the manufacturing processes of a medium-sized company's products are determined and analyzed. In this way, it is thought that the company's production processes will improve and its products will be faster and of higher quality. In addition, with this study, an increase in customer satisfaction is expected by ensuring traceability. The steps of the study carried out in line with this information are given below;

Figure 3.1. Steps of the study

The steps of the study carried out are given in Figure 3.1. In this direction, the methods and techniques used in this study are examined in this section.

3.2.1. Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is a risk analysis method that has been used for many years, is reliable, simple to implement and can yield effective results. The FMEA method was first used secretly by the American army towards the end of the 1940s. The US military has applied FMEA to detect system and equipment failures. Later, it started to be used by the National Aeronautics and Space Administration (NASA) in the 1960s. FMEA method came out of secrecy in the 1970s and started to be used in the industry (Aran, 2006).

In the FMEA method, the potential hazards of the applied process are determined. The effects of these hazards for the customer are evaluated and current controls are reviewed. In addition to existing controls, various preventive actions are planned and implemented. Then the results of these applications are observed. In the FMEA method, three parameters are taken into account to evaluate the hazards. These parameters are the severity (S), probability (P) and detectability (D) of hazards (Goddard, 2000). Table 3.1, Table 3.2 and Table 3.3 are used when determining these parameter values for hazards.

After the parameter values of the hazards are determined, the Risk Priority Number (RPN) is calculated by multiplying the parameter values of the hazard. After calculating the RPN scores of each hazard, a ranking is made from the highest value to the smallest value. Then, the scale in Table 3.4 is used to classify the hazards.

Table 3.1. Severity scale of FMEA (Xu et al. 2002)

Effect	Effect of Severity (S)	Degree
Warning	Potential error that can cause catastrophe	10
Warning	Failure of warning and failure, which can lead to high damage and mass deaths	9
Too High	Failure of warning and failure, which can lead to high damage and mass deaths	8
High	It causes complete damage to the equipment and has the effect of death, poisoning, 3rd degree burn, acute fatal disease, etc.	7
Middle	Affecting the performance of the system, causing loss of limb and organ, severe injury, cancer, etc.	6
Low	Fracture, permanent minor disability, 2nd degree burn, brain concussion etc.	5
Very Low	Error causing short-term discomfort with minor injuries such as being injured, minor cuts and abrasions, crushes, etc.	4
Small	Error slowing down system operation	3
Very Small	Error slowing down system operation	2
No	No effect	1

Table 3.2. Probability scale of FMEA (Xu et al. 2002)

Error Probability (P)			
Effect	Error Probability		Degree
Too high: Unavoidable Error	More than 1/2	50,00%	10
	1/3	33,33%	9
High: Error Repeatedly	1/8	12,50%	8
	1/20	5,00%	7
Moderate: Occasional Error	1/80	1,25%	6
	1/200	0,50%	5
	1/2.000	0,05%	4
Low: Relatively Few Errors	1/15.000	0,006%	3
	1/15.0000	0,0006%	2
Few: Unlikely Error	Lower than 1/1.500.000	-	1

Table 3.3. Detectability scale of FMEA (Xu et al. 2002)

Detectability (D)		
Detectability	**Detectability Probability**	**Degree**
Unnoticeable	It is not possible to discover the cause of the potential error	10
Very little	It is too far to discover the cause of the potential error	9
Little	It is far to discover the cause of the potential error	8
Very low	Low potential to detect the cause of the potential error	7
Low	The cause of the potential error is too low to discover	6
Middle	The cause of the potential error can be discovered medium	5
High Average	High average for discovering the cause of potential error	4
High	High potential to detect the cause of the potential error	3
Very High	The cause of the potential error is too high to be discovered	2
Almost Certain	It is almost certain that the cause of the potential error can be discovered.	1

Table 3.4. RPN scale of FMEA (Xu et al. 2002)

RPN	FMEA-Measure
RPN < 40	No need to take precautions
40 ≤ RPN ≤ 100	It is useful to take precautions
100 < RPN	Precautions must be taken

3.2.2. Fuzzy Logic

Fuzzy logic first entered academic life in 1965. Fuzzy logic is introduced in the article The Theory of Fuzzy Logic and Fuzzy Sets published by Lotfi A. Zadeh. After the introduction of fuzzy logic, it started to become widespread in 1907. Fuzzy logic has become more popular and has reached a wide range of use, mainly in the 1980s, with its use in the field of production in Japan. By definition, fuzzy logic is a multiple logic system that helps to determine to what extent events have developed by assigning membership degrees to variables used in daily life.

The working principle of fuzzy logic is quite different from the working principle of traditional (classical) logic. The main purpose of fuzzy logic is to remove ambiguities. Therefore, in fuzzy logic, there are no judgments such as absolute right and absolute wrong. Judgments in fuzzy logic, on the other hand, are partially true and partially false judgments with variable intervals (Tosun et al, 2019).

3.2.3. Analytic Hierarch Process (AHP)

The Analytic Hierarchy Process (AHP) was first introduced by Thomas Saaty in 1980. AHP is a multi-criteria decision making (MCDM) technique based on a hierarchical structure. In AHP, the factors affecting the decision are also included in the process. Therefore, AHP uses a predefined comparison scale in terms of both decision-influencing factors and decision points. The comparison result is converted into percentage distributions over the decision points of the significance differences (Saaty, 1980). The steps followed for AHP implementation are given below;

Step 1: Identify the Decision Making Problem

There are two stages in the first step. In the first step, decision points are determined. At this stage, the answer to how many results will be evaluated is reached. In the second stage, the factors affecting the decision points determined in the first stage are determined. Decision points are denoted by "m" and factors affecting decision points are denoted by "n". The correct determination of the decision points and the factors affecting the decision points is very important for the consistency of pairwise comparisons in the next steps.

Step 2: Create an Inter-Factor Comparison Matrix

The comparison matrix is a square matrix. The diagonal values of this matrix take the value "1". The comparison matrix is presented in Equation (3.1) (Saaty, 1980).

$$A = \begin{bmatrix} a_{11} & a_{12} \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} \ \ldots & a_{nn} \end{bmatrix} \tag{3.1}$$

The reason why the diagonal components take the value "1" in the comparison matrix is to compare the factors themselves. For instance, if the third factor appears to be more important than the fifth factor when comparing, the first row third column component of the comparison matrix (i=3, j=5) will take the value 3. When comparing the fifth factor with the third factor, the value of the matrix component will take the value of 1/3. While making this comparison, the values given in Table 3.5. are used.

Table 3.5. AHP scale (Saaty, 1980)

Importance Values	Value Definitions
1	Equal importance of both factors
3	Factor 1 is more important than factor 2
5	Factor 1 is much more important than factor 2
7	Factor 1 has a very strong importance compared to factor 2
9	Factor 1 is of absolute superiority compared to factor 2
2,4,6,8	Intermediate values

Step 3: Determining Percentage Importance of Factors

In order to determine the weights of each factor in the total, the percent significance distribution, the column vectors that make up the comparison matrix are used and the B column vector with nxn components is created (Equation 3.2 and Equation 3.3).

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix} \tag{3.2}$$

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

(3.3)

Combining the B column vectors in a matrix format will result in the C matrix (Equation 3.4)

$$C = \begin{bmatrix} c_{11} & c_{12} \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} \ \ldots & c_{nn} \end{bmatrix}$$

(3.4)

By using the Equation (3.5), the percentage distributions indicating the importance values of the factors relative to each other are calculated thanks to the C matrix. The result of this calculation is the priority vector. The priority vector is denoted by "W" and is presented in Equation (3.6) (Saaty, 1980).

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n}$$

(3.5)

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \cdot \\ \cdot \\ \cdot \\ w_n \end{bmatrix}$$

(3.6)

Step 4: Measure Consistency in Factor Benchmarks

The consistency of comparisons made in the AHP is measured. The consistency of the priority vector obtained by the calculated consistency ratio (CR) is tested. For calculations, the operations given in Equation (3.7) and Equation (3.8) (Saaty, 1980).

$$D = \begin{bmatrix} a_{11} & a_{12} \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix}$$

(3.7)

$$E_i = \frac{d_i}{w_i} \ (i = 1,2,\ldots,n)$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n}$$

(3.8)

After calculating λ the Consistency Indicator (CI) can be calculated using the formula in Equation (3.9). In the last stage, CI is divided by the standard correction value called Random Indicator (RI) to obtain CR (Equation 3.10). If the calculated CR value is less than 0.10, the comparisons made by the decision maker are consistent. A CR value greater than 0.10 indicates either a calculation error in AHP or inconsistency in decision-making comparisons (Saaty, 1980).

$$\mathrm{CI} = \frac{\lambda - n}{n - 1}$$

(3.9)

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

(3.10)

3.2.4. Fuzzy Analytic Hierarch Process (F-AHP)

Analytic Hierarchy Process (AHP) is a multi-criteria decision making (MCDM) method that is commonly used in the literature. AHP was developed by Thomas Saaty in 1980. When considering the application of AHP, pairwise comparisons are entirely up to the decision maker.

Precise judgments are used during pairwise comparisons. Therefore, evaluations cannot be made objectively. When making pairwise comparisons in AHP, the intervals used do not include uncertainties. Therefore, using fuzzy logic theory, Zadeh developed the Fuzzy Analytic Hierarch Process (F-AHP) to take into account uncertainties, not exact judgments, and to overcome the disadvantages of AHP (Oturakçı and Yıldırım, 2021).

Fuzzy numbers are used for pairwise comparisons in F-AHP. In this way, it is tried to increase the objectivity of the traditional AHP decision maker. In F-AHP, fuzzy numbers are integrated into the implementation steps of traditional AHP. Triangular form is used in F-AHP (Oturakçı and Yıldırım, 2021). Linguistic variables are in triangular form during pairwise comparisons. F-AHP steps are as follows;

Step – 1: Create Hierarchy

The same steps are applied as with conventional AHP.

Step – 2: Pairwise Comparisons

Pairwise comparisons in F-AHP are done in a similar way as with conventional AHP. However, linguistic terms are used during the comparison. These linguistic terms are in triangular form. The table with the triangular form for pairwise comparisons in F-AHP is given in Table 3.6.

Table 3.6. Fuzzy triangular scale (Vinogradova et al. 2021)

Definition of Fuzzy Triangular Scale		
1	Equally important	(1,1,1)
2	Equally to moderately important	(1,2,3)
3	Moderately important	(2,3,4)
4	Weakly important	(3,4,5)
5	Important	(4,5,6)
6	Strongly important	(5,6,7)
7	Very important	(6,7,8)
8	Very strongly important	(7,8,9)
9	Absolutely important	(8,9,9)

Step – 3: Calculation of Normalized Weights

The formula given Equation (3.11) is used to calculate the normalized weights. This formula is applied for each criterion. As a result, the weights of the fuzzy comparison values are normalized (Vinogradova et al. 2021).

$$r_i = \left(\prod_{j=i}^{n} d_{ij} \right)^{\frac{1}{n}} \tag{3.11}$$

Step – 4: Relative Fuzzy Weight

In this step, taking into account the values calculated in the third step. For each criterion, the relative fuzzy weight is calculated. Then, normalization is performed for each criterion (Oturakçı and Yıldırım, 2021).

3.2.5. Binary Programming

Many techniques and methods are used in the field of Operations Research. One of the frequently used methods among these techniques is binary programming. Binary programming is also a type of mathematical model. In mathematical models, the components are the objective function and the constraints. Binary programming is quite similar to linear programming. In the mathematical model in binary programming, the values that the variables will take are integers. In linear programming, variables can take different values. In binary programming, values often take the value of one or zero (Tamer et al, 2018). The reason why the variables are expressed in this way means that the work is done or not done. The general display of binary model is presented as below;

$$Maximum\ or\ Minimum\ Z = \sum_{j=1}^{n} C_j X_j$$

$$\sum_{j=1}^{n} a_{ij} X_j \ (\leq, \geq, =)\ b_i \qquad i = 1, \ldots..m\ ; (j = 1, \ldots..n)$$

$$X_j \geq 0\ \ and\ integer\ (0-1)$$

In general display of the model Z is presented as objective function and X_j is presented as decision variable. In objective function C_j is defined as the constants of the decision variables while a_{ij} is defined as the constant in the constraints.

The model used in the study was formed as follows.

<u>Indices and Inputs</u>

i= action i= 1,2,…
M_i = Needed Manpower for i^{th} action
T_i = Needed time for i^{th} action
C_i = Needed cost for i^{th} action
w_i = Weight of action
MP= Total reserved manpower (manhour)
TT: Total reserved time (day)
CT= Total reserved cost (Turkish Lira)

<u>Decision Variable</u>

$$\boldsymbol{X_i} = \begin{cases} 1 & \mathrm{i}^{th} \text{ action is taken} \\ 0 & otherwise \end{cases}$$

<u>Objective Function</u>

The objective function is given in Equation (3.12). w_i represents the weight of an action; $X(i)$ represents whether or not actions are implemented. It is aimed to maximize the value of the multiplication in Equation 1. (Z: value of the objective function)

$$\text{Maximum Z} = \sum_i w_i * X_i \qquad (3.12)$$

Constraints

Manpower, time and budget constraints are given in Equation (3.13), Equation (3.14) and (3.15) respectively. Equation (3.13) represents the constraint of “total manpower of the actions to be taken should not exceed reserved manpower (MP); Equation (3.14) represents the constraint of “the total time of the actions to be taken should not exceed the reserved time (TT)” and Equation (3.15) represents the constraint of “the total cost of the actions to be taken should not exceed the total reserved cost (CT)”.

$$\sum_i M_i * X_i \le MP \tag{3.13}$$

$$\sum_i T_i * X_i \le TT \tag{3.14}$$

$$\sum_i C_i * X_i \le CT \tag{3.15}$$

$$X_j \ge 0 \;\; and\ integer\ (0-1) \tag{3.16}$$

4. RESULTS AND DISCUSSIONS

This part of the study consists of 10 steps. These steps include the identification of hazards and risks arising from these hazards, their integrated evaluation within the framework of classical and fuzzy logic, the determination of action plans and action selection in a medium-sized company.

Step 1: Identification of Hazards

In the first step of the study, the hazards that may prevent the effective execution of all processes in the medium-sized company were determined. While determining these hazards the opinions of experienced engineers who have been working in the company for many years and the Occupational Health and Safety expert were taken. One of these engineers is a Mechanical Engineer. He has 10 years of experience in the current company and 14 years in total. He is responsible for steel construction in the production department of the company. The other engineer is an Industrial Engineer. He has 15 years of experience in the current company and in total. He is responsible for machining in the production department of the company. The occupational health and safety specialist has 4 years of experience in the current company and 10 years in total. In this respect, potential hazards and risks that may directly or indirectly affect the work flows in the company are presented in Table 4.1.

Table 4.1. Hazards and risks identification

Number of Hazard	Hazards	Risks
H1	Not using labels for raw materials and semi-finished products.	Lack of traceability
H2	Failure to receive revision information from the purchasing unit to the warehouse unit.	Job delay
H3	The warehouse department does the checks unaware of the revision information.	Job delay

H4	Making production planning according to outdated measures.	Job delay
H5	Lack of space in the warehouse for the quarantine area.	Lack of traceability
H6	Failure to test incoming materials.	Lack of quality Loss of reputation
H7	There is no record of the project for which the material came out of the warehouse.	Lack of traceability
H8	Waiting of packaging materials in different areas in the warehouse.	Injury
H9	Insufficient control of welded manufacturing.	Lack of traceability
H10	The interior of the shelves in the Assembly/Welding area is not tidy.	Lack of traceability
H11	Lack of specific area of assembly materials.	Injury
H12	Failure to record the measurements made in the Assembly/Welding area.	Lack of traceability
H13	Irregularity of the shelves in the machining area.	Lack of traceability
H14	Incorrect drawing in the technical drawing.	Job delay
H15	The lack of measurement controls in the machining area.	Lack of traceability
H16	Irregularity around the machines in the machining area.	Injury
H17	Not wearing protective equipment.	Injury/Death
H18	There are materials on the walkway.	Injury
H19	The production area is unhygienic.	Unhygienic environment

H20	Lack of clear walking path lines.	Injury
H21	Insufficent lightining.	Injury
H22	Full of waste bin in the machining area.	Unhygienic environment
H23	Painting operations are not done indoors.	Poisoning

In Table 4.1, the hazards and risks identified in the medium-sized company are determined. The detailed description of the identified hazards is given below;

H1: Promotional labels are not used for raw materials and semi-finished products delivered to the company on order. Therefore, it is not clear for which project these materials/parts came and traceability cannot be ensured.

H2: The order of the materials to be used in the project is given by the purchasing department at the company. In line with the customer's request, sometimes the dimensions of these materials can be changed after the order. The purchasing department communicates with the supplier company and reports that there is a change in the order and orders the material accordingly. However, the purchasing department does not always communicate the revision information with the warehouse department. As a result, various negative aspects are experienced.

H3: Since the purchasing department does not share the revision information with the warehouse department, the warehouse staff takes the old measurements as reference when checking the input of the incoming material. As a result, it is reported that the material received is incorrect due to the inconsistency of the dimensions during the control and it is rejected as a result of the control. Therefore, there is a waste of time. In some cases, production is delayed. Customer dissatisfaction is increasing.

H4: The purchasing unit sometimes does not share the revision information that occurs in the projects with the production planning officers in a timely manner. Therefore, production planning is done according to old measures. After the revision information, all the plans for the project have to be updated again. As a result, there is a loss of time, an increase in costs and workload and the completion time of the project can be delayed.

H5: The quarantine area is not specified in the warehouse layout plan. The quarantine area is the area reserved for unsuitable/wrongly sent raw materials and products produced as a result of faulty/wrong production. Since the quarantine areas are not specified, such raw materials and products are kept in any free area, not in their own area. Therefore, both the warehouse area cannot be used efficiently and the materials/parts in the warehouse cannot be tracked effectively.

H6: Chemical and mechanical test certificates are requested from the supplier company for some raw materials that come to the company. However, the company does not make these tests itself. Therefore, the company cannot obtain any data to compare the test results it receives from the supplier company. For this reason, the quality controls of the incoming materials cannot be ensured precisely. In the future, these materials may show poor quality in the production area and the entire production process may be affected by this error. There is a high probability of loss of time and cost. In addition, after the product is delivered to the customer, much more serious consequences may occur as a result of an error in the product and the company may face a legal process.

H7: While the material is being issued from the warehouse area, it is recorded to which employee the material was given. However, no record is kept of which project the material was given for. As a result, the traceability of the parts in the production area cannot be ensured.

H8: The materials coming to the warehouse are not positioned in the areas each allocated to itself. Air bubble wraps coming for packaging are also randomly placed in the warehouse area. Leaving these heavy materials in the middle could cause an accident and result in injury.

H9: After welding operations in the company, control operations are carried out only by eye. There is no detailed control. In addition, these controls are not recorded. In such a case, the error to be made may cause irreparable results in the future. In addition, it is not possible to provide retrospective traceability in this way.

H10: Shelves in the Assembly/Welding area are not organized. It is not known how much of which material is inside the shelves. For this reason, the factory may order again, thinking that it does not have the materials it has. This causes unnecessary expense. In addition, irregular and old shelves prevent a good appearance in the working environment.

H11: In the assembly area, the materials coming for assembly are placed randomly. No space is reserved for the materials to wait. This restricts the movement environment of the employees and may cause injury as a result of an accident.

H12: After the operations in the assembly/welding area, the necessary measurements are not made in detail. Failure to provide continuous controls leads to lack of traceability in the production process. Since controls are not carried out continuously, an error cannot be intervened immediately. In such a case, the effects of the error will emerge in the following processes and will cause both serious loss of time and serious cost increase.

H13: Shelves in the machining area are not regular. It is not known how much of which material is inside the shelves. Therefore, the company may place an order again considering that it does not have the materials it has. This causes unnecessary expense. In addition, irregular and old shelves prevent a good appearance in the working environment.

H14: If the production will be done for the customer in the company, the technical drawings are given by the customer. However, if production will be made for the company, the technical drawings are drawn by the draftsman. The technical draftsman can draw incorrectly while preparing the drawings. In such a case, the part produced is produced using the wrong dimensions. Extra time and money is spent on corrections after the error is noticed.

H15: After the operations in the machining area, the necessary measurements are not made in detail. Failure to provide continuous controls leads to lack of traceability in the production process. Since controls are not carried out continuously, an error cannot be intervened immediately. In such a case, the effects of the error will emerge in the following processes and will cause both serious loss of time and serious cost increase.

H16: In the machining area, various equipments are scattered around the machines. A scattering of equipment can both restrict movement in the work area and cause injury from an accident.

H17: Persons working in the production area do not wear hard hats, safety glasses and earplugs used for noisy environments. Therefore, any work accident that may occur may result in serious injury and death for employees.

H18: There are materials in some parts of the walking path in the production area. Therefore, the walking area is narrowed. Therefore, people using the walking path pass through the production area and may face the possibility of an accident. In addition, the appearance of the walking path for the people who visit the company in this way may cause a bad image for the company.

H19: People working in the production area throw used wastes such as plastic tea cups and snack packages around instead of trash cans. This causes pollution of the production area and creates an unhygienic environment.

H20: In some parts of the walkway in the production area, the lines are blurred. Walkway lines are not clearly visible. This causes both the blurring of the walking path and a bad appearance. In addition, people using the walking path cannot see the walking area clearly, so they pass through the production area and may face the possibility of an accident.

H21: Lighting is insufficient in some parts of the production area in the company. Lighting is not provided enough and a dark environment is formed. Work accidents may occur as a result of working in a dark environment, and these accidents may result in serious injury or death.

H22: Metal shavings spilled on the ground due to the fullness of the garbage cans in the machining area. Spilled sawdust can cause various injuries to workers working in that area.

H23: Due to the fact that the dyeing processes are carried out in the open area, the smell of various chemicals used for dyeing spreads around. Workers who work around the painting area but not in the painting section may be affected by this odor and may be at risk of poisoning.

Step 2: Identification of Affected Departments by Risks

As a result of Step 1, 23 hazards and risks were determined in the medium-sized company. In this step, the departments that are directly affected by the 23 hazards identified in the company have been identified.

Identified Hazards and the departments affected by these hazards are presented in Table 4.2. According to this table, departments that hazards directly affect are identified in 7 groups in total: manufacturing, warehouse, production planning, sales and marketing, quality control, purchasing, human resources.

Table 4.2. Hazards and affected departments by risks

Number of Hazard	**Affected Departments by Risks**	**Number of Hazard**	**Affected Departments by Risks**
H1	Manufacturing, Production Planning	H13	Manufacturing, Quality Control
H2	Warehouse, Manufacturing, Production Planning	H14	Manufacturing
H3	Warehouse, Manufacturing, Production Planning, Purchasing	H15	Manufacturing, Production Planning
H4	Manufacturing	H16	Manufacturing
H5	Manufacturing, Warehouse, Purchasing	H17	Manufacturing, Human Resources
H6	Manufacturing, Sales and Marketing	H18	Manufacturing, Human Resources
H7	Production Planning	H19	Manufacturing, Human Resources
H8	Warehouse, Manufacturing, Production Planning, Purchasing	H20	Manufacturing, Human Resources
H9	Manufacturing, Quality Control	H21	Manufacturing, Human Resources
H10	Warehouse, Manufacturing, Production Planning	H22	Manufacturing, Human Resources

H11	Manufacturing	H23	Manufacturing, Warehouse
H12	Manufacturing, Quality Control		

Step 3: Integrated Risk Analysis Results of FMEA & AHP

In the steps prior to Step 3, the hazards in a medium-sized company, the risks arising from the hazards and the departments affected by the emergence of these risks were determined. In Step 3, these risks were evaluated using Failure Mode and Effect Analysis (FMEA) and Analytic Hierarchy Process (AHP).

Failure Mode and Effect Analysis (FMEA) is a risk analysis method that has a wide range of uses, is easy to implement and is just as effective. While evaluating with the FMEA method, the severity (S), probability of occurrence (P) and detectability (D) value of a hazard are taken into account. It is determined by using the scales in Table 3.2, 3.3, 3.4. By multiplying the determined values, the Risk Priority Number (RPN) is determined for the hazards. The priority status of the hazard is determined by using the scale in Table 3.4. In line with this information, the hazards in Table 4.1. were evaluated by FMEA method. The result of this assessment and the priority status of the hazards are given in Table 4.3.

Table 4.3. FMEA result

Hazards	Severity	Probability	Detectability	RPN (SxPxD)	RESULT
H1	6	10	10	600	Precaution must be taken
H2	5	10	9	450	Precaution must be taken
H3	5	10	9	450	Precaution must be taken
H4	7	10	9	630	Precaution must be taken
H5	5	10	8	400	Precaution must be taken
H6	10	10	7	700	Precaution must be taken
H7	5	10	9	450	Precaution must be taken
H8	4	5	1	20	No need to take precautions

H9	7	10	9	630	Precaution must be taken
H10	5	10	5	250	Precaution must be taken
H11	4	5	3	60	It is useful to take precautions
H12	7	10	9	630	Precaution must be taken
H13	7	5	6	210	Precaution must be taken
H14	5	3	4	60	It is useful to take precautions
H15	9	10	10	900	Precaution must be taken
H16	4	4	3	48	It is useful to take precautions
H17	10	10	1	100	It is useful to take precautions
H18	3	5	2	30	No need to take precautions
H19	2	5	3	30	No need to take precautions
H20	4	3	1	12	No need to take precautions
H21	3	4	2	24	No need to take precautions
H22	2	4	4	32	No need to take precautions
H23	4	5	2	40	No need to take precautions

According to the FMEA risk analysis result, 12 risks are in the important hazards category. When the FMEA result is examined, the hazard with the highest RPN score is H15. The other hazards in the top five ranks are respectively H6, H4, H9 and H12. Hazrads in this category should be included in the priority group in the action plan and must be eliminated or their effects reduced. However, it was concluded that FMEA alone is not sufficient when determining the groups and priority situations of hazards, since FMEA is a subjective method. In other words, the RPN value of a hazard may vary according to the assessor. For example, the severity of a hazard may take different values according to evaluator A and evaluator B. This situation causes the hazards that should be included in the priority group not be determined precisely. As a result, the productivity of the work decreases. Accordingly, the hazards in Table 4.1 have been weighted with Analytic Hierarchy Process (AHP). While applying the weighting process, the hazards were evaluated among themselves and a pairwise comparison matrix was created. While creating the pairwise comparison matrix, the Saaty Scale in Table 3.5. was used. The results of weighting the hazards with AHP are given in Table 4.4.

Table 4.4. AHP result

Number of Hazards	Wi	Number of Hazards	Wi
H1	0,0848	H13	0,0105
H2	0,0611	H14	0,0177
H3	0,0908	H15	0,1539
H4	0,0497	H16	0,0289
H5	0,0401	H17	0,0381
H6	0,096	H18	0,0248
H7	0,0929	H19	0,0067
H8	0,0212	H20	0,0143
H9	0,0386	H21	0,0073
H10	0,0329	H22	0,0083
H11	0,0142	H23	0,0059
H12	0,0613		

The consistency ratio (CR) of the AHP study performed was 0.09 and was consistent. According to the AHP results, the highest weighted hazard is H15. Other hazards in the top five are H6, H7, H3, and H1, respectively. When the AHP results are compared with the FMEA results, it is seen that there are differences in the hazard order except for H15. In other words, since AHP is a subjective method like FMEA, the values taken during the evaluation of the hazards among themselves in the pairwise comparison matrix vary according to the evaluator. This situation directly affects the values of the hazards and creates differences in the weights of the hazards. As a result, an objective assessment cannot be truly performed. Considering this information, FMEA and AHP methods were integrated in order to obtain a more objective result by using two subjective methods. The integration process was carried out by multiplying the RPN scores obtained as a result of FMEA and the W_i weights obtained as a result of AHP. The integrated risk scores obtained as a result of the integration process and the hazards ranking according to these scores are presented in Table 4.5.

Table 4.5. FMEA&AHP integration result

Number of Hazards	RPN	Wi	RPN*Wi	Rank	Number of Hazards	RPN	Wi	RPN*Wi	Rank
H1	600	0,0848	50,8615	3	H13	210	0,0105	2,2102	13
H2	450	0,0611	27,4786	8	H14	60	0,0177	1,0642	15
H3	450	0,0908	40,8751	5	H15	900	0,1539	138,496	1
H4	630	0,0497	31,3067	7	H16	48	0,0289	1,3872	14
H5	400	0,0401	16,0596	10	H17	100	0,0381	3,808	12
H6	700	0,096	67,1999	2	H18	30	0,0248	0,7441	17
H7	450	0,0929	41,7919	4	H19	30	0,0067	0,2012	21
H8	20	0,0212	0,4247	18	H20	12	0,0143	0,1721	23
H9	630	0,0386	24,3357	9	H21	24	0,0073	0,1754	22
H10	250	0,0329	8,2215	11	H22	32	0,0083	0,265	19
H11	60	0,0142	0,8497	16	H23	40	0,0059	0,2353	20
H12	630	0,0613	38,5923	6					

According to the FMEA & AHP integrated results, it is seen that among the hazards, H15 is the most important hazard with the highest score. Other hazards in the top five are H6, H1, H7 and H3, respectively. Among these hazards;

- H6 ranks second in risk ranking according to both FMEA result, AHP result and integrated result.
- H1 is in sixth place according to FMEA result; In the fifth place according to the AHP result; It ranks third in the risk ranking according to the integrated result.
- H7 is in ninth place according to FMEA result; In the third place according to the AHP result; It ranks fourth in the risk ranking according to the integrated result.
- H3, in eighth place according to FMEA result; In the fourth place according to the AHP result; It ranks fifth in the risk ranking according to the integrated result.

It is clear that making a common priority order as a result of integration is an accurate intermediate result for these hazards that are in different priority ordering in different methods and the risks arising from these hazards.

Step 4: Integrated Risk Analysis Results of Fuzzy FMEA (F-FMEA) & Fuzzy AHP (F-AHP)

In traditional methods, a precise language is used by the decision makers while making the decision. Uncertainties are not taken into account. Fuzzy logic is closer to human thought than classical logic. The concept of verbal variable takes place in fuzzy logic. This allows calculations with words and allows uncertainty to be expressed. In line with this information, the hazards and risks arising from these hazards determined in a medium-sized company were evaluated using fuzzy logic. A more objective evaluation was considered according to the fuzzy approach. It is thought that the hazards parameters will be determined more accurately with the verbal expressions of the fuzzy logic approach.

In this step, the methods used in step 3 were evaluated with the fuzzy logic approach. First, the classical FMEA method and then the classical AHP method were formed with the fuzzy logic approach and the application results were recalculated.

The fuzzy FMEA (F-FMEA) scale for the company was prepared the risk analysis with experts and the F-FMEA Risk analysis was coded in MATLAB 18b Fuzzy Logic Designer Tool. Probability, Severity, and Detectability parameters in the F-FMEA risk analysis scale are taken as an input; the RPN is taken as output. The fuzzy design of the study is presented in Figure 4.1 and as it can be seen from the figure, the 'Mamdani min max' method was used in the design.

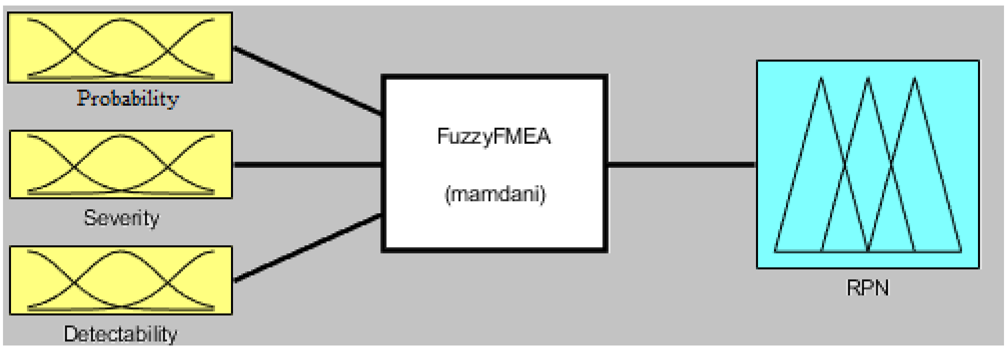

Figure 4.1. Fuzzy FMEA Design

In the F- FMEA risk analysis used and designed in the study, three inputs and one output consist of five levels (Very Low, Low, Medium, High, Very High). The values of membership functions created for all inputs and output are given in Table 4.6, and their figures are given in Figures 4.2, 4.3, 4.4, and 4.5.

Table 4.6 Membership functions for inputs and output

Probability	Severity	Detectability	RPN
Zmf(0, 2)	Zmf(0, 2)	Zmf(0, 2)	Zmf(0, 200)
Tria(1, 3, 5)	Tria(1, 3, 5)	Tria(1, 3, 5)	Tria(100, 300, 500)
Tria(3, 5,7)	Tria(3, 5,7)	Tria(3, 5,7)	Tria(300,500,700)
Tria(5, 7, 9)	Tria(5, 7, 9)	Tria(5, 7, 9)	Tria(500, 700, 900)
Smf(7, 10)	Smf(7, 10)	Smf(7, 10)	Smf (700, 1000)

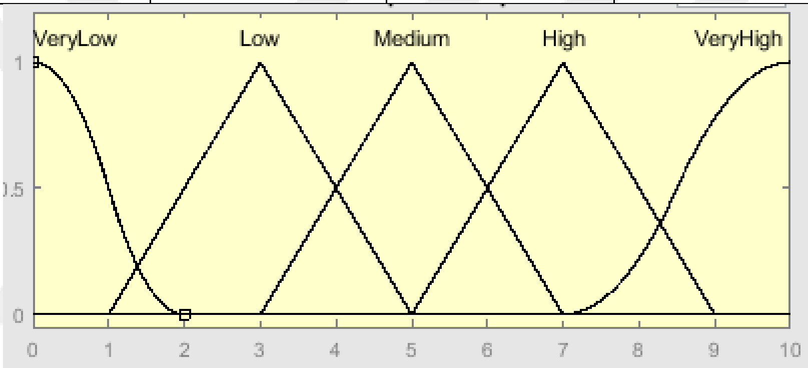

Figure 4.2. Membership function plots for Probability

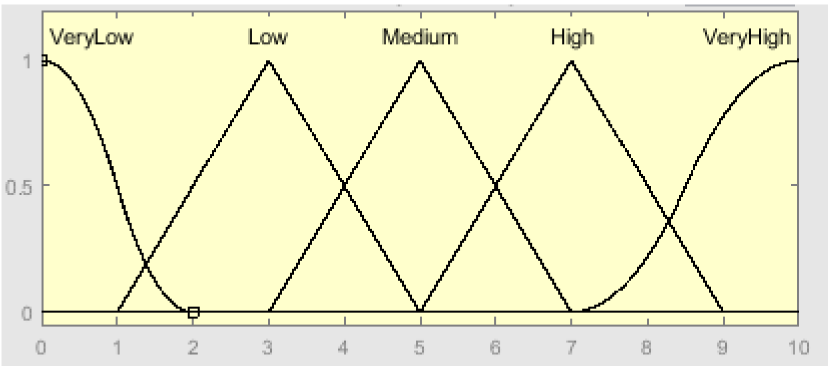

Figure 4.3. Membership function plots for Severity

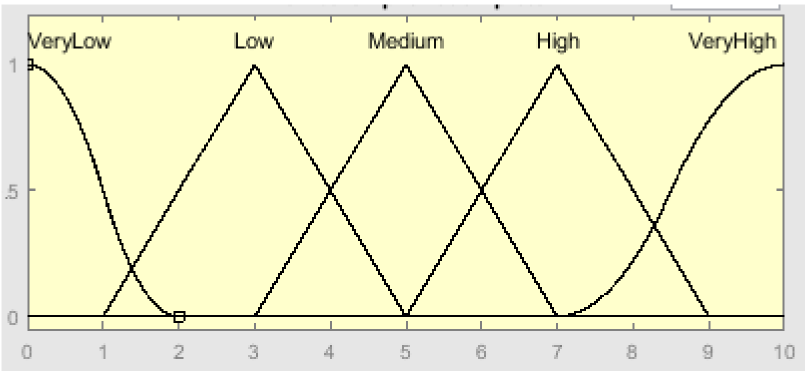

Figure 4.4. Membership function plots for Detectability

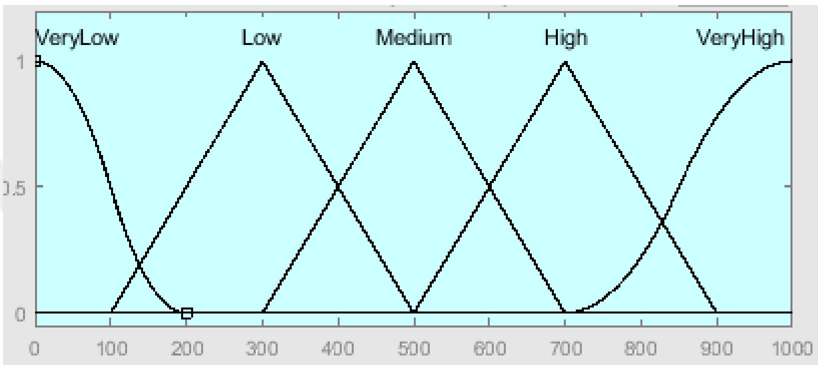

Figure 4.5. Membership function plots for the RPN

Taking into account the membership functions of the probability, severity, and detectability inputs, 125 business-specific decision rules were defined. The scores calculated according to the developed decision rules are presented in Table 4.7 in comparison with the classical results.

Table 4.7. Fuzzy FMEA results

Number of Hazard	**Fuzzy FMEA Result**
H1	899
H2	910
H3	910
H4	910
H5	738
H6	915
H7	910

H8	400
H9	910
H10	700
H11	400
H12	910
H13	600
H14	400
H15	910
H16	300
H17	500
H18	300
H19	300
H20	229
H21	300
H22	400
H23	400

Considering the results of F-FMEA and traditional FMEA (Table 4.3.) methods; According to the traditional FMEA result, the top five risks with the highest RPN are H15, H6, H4, H9 and H12, respectively. According to the F-FMEA result, the first 5 hazards with the highest RPN are H6, H2, H3, H4 and H15, respectively.

Integrating fuzzy logic with AHP provides great convenience. Uncertainties arise when constructing the pairwise comparison matrix in traditional AHP. However, this situation disappears when fuzzy logic is used. Results of the F-AHP are presented in Table 4.8.

Table 4.8. F-AHP result

Number of Hazards	F-AHP Results (Ni)	Number of Hazards	F-AHP Results (Ni)
H1	0,0846	H13	0,0107
H2	0,0614	H14	0,0181
H3	0,0901	H15	0,1502

H4	0,0502	H16	0,0294
H5	0,0409	H17	0,0387
H6	0,0961	H18	0,0254
H7	0,0919	H19	0,0067
H8	0,0215	H20	0,0146
H9	0,0387	H21	0,0073
H10	0,0327	H22	0,0084
H11	0,0145	H23	0,0061
H12	0,0616		

According to the F-AHP method, the first five hazards with the highest weight are H15, H6, H7, H3, and H1 same as in classical AHP results (from Step 3). However, even if there is no change in the ranking, the slightest change in the AHP weight may change the hazard ranking in the integration process. For this reason, it is a more accurate approach to use the results of the F-AHP method.

Hazards were evaluated by integrating FMEA and AHP methods with fuzzy logic. The F-RPN and Ni values of the hazards were calculated. In addition, F-FMEA and F-AHP methods integrated with fuzzy logic are integrated with each other. The integration process was realized by multiplying the F-RPN obtained as a result of F-FMEA and the Ni weights obtained as a result of F-AHP. F-FMEA and F-AHP integration are presented in Table 4.9.

Table 4.9. F-FMEA&F-AHP Integration result

Number of Hazards	F-FMEA	F-AHP	INTEGRATION	Rank
	F-RPN	Ni	F-RPN*Ni	
H1	899	0,085	76,415	5
H2	910	0,061	55,51	7
H3	910	0,09	81,9	4
H4	910	0,05	45,5	8
H5	738	0,041	30,258	10
H6	915	0,096	87,84	2
H7	910	0,092	83,72	3
H8	400	0,022	8,8	13
H9	910	0,039	35,49	9
H10	700	0,033	23,1	11
H11	400	0,015	6	18

H12	910	0,062	56,42	6
H13	600	0,011	6,6	17
H14	400	0,018	7,2	16
H15	910	0,15	136,5	1
H16	300	0,029	8,7	14
H17	500	0,039	19,5	12
H18	300	0,025	7,5	15
H19	300	0,007	2,1	22
H20	229	0,015	3,435	19
H21	300	0,007	2,1	23
H22	400	0,008	3,2	20
H23	400	0,006	2,4	21

Considering the weights of the hazards as a result of the fuzzy integrated process, the hazard with the highest weight is H15. The top five hazards with the highest scores are H15, H6, H7, H3, and H1, respectively.

Step 5: Calculating the Weights of Affected Departments with Fuzzy AHP

As a result of the study carried out in a medium-sized company, 23 risks that hinder the work flow throughout the enterprise were identified and these risks were evaluated using comparatively classical and fuzzy methods. While identifying the risks, the departments that will be adversely affected as a result of the realization of these risks are also determined. These designated departments are divided into 7 groups. These; manufacturing, warehouse, production planning, sales and marketing, quality control, purchasing, human resources. Determining the priority status of these departments affected by risks is important for the action plan to be prepared as a result of the risk analysis. Accordingly, these departments that will be affected by the realization of risks have been weighted using the Fuzzy AHP (F-AHP) method and their priority order has been determined. The result of F-AHP applied for the departments is given in Table 4.10. According to this result, the department with the highest weight is manufacturing. The department with the lowest weight in the sales and marketing.

Table 4.10. F-AHP for affected departments

Departments	Ni
Production Planning	0,1458
Purchasing	0,0476
Warehouse	0,2406
Quality Control	0,1025
Manufacturing	0,4055
Human Resources	0,0394
Sales and Marketing	0,0187

Step – 6: Final Risk Score Calculation

In Step-6, F-RPNs are obtained as a result of F-FMEA of the hazards, N_{i1}'s are obtained as a result of F-AHP and N_{i2}'s of the departments obtained as a result of F-AHP applied to the departments affected by the hazards were used. The "Final Risk Score" was obtained by multiplying the values of these three groups obtained for each hazard. During these processes, if the emergence of a hazard affects more than one department, the sum of the N_i values of these departments is taken. Final risk scores and its components are presented in Table 4.11.

Table 4.11. Final risk score calculation

HAZARDS	F-RPN	F-AHP (N_{i1})	Weights of Affected Department's (N_{i2})	Final Risk Score
H1	899	0,085	0,5512	42,1229
H2	910	0,061	0,7918	43,9542
H3	910	0,09	0,8394	68,7489
H4	910	0,05	0,4055	18,4490
H5	738	0,041	0,6937	20,9887
H6	915	0,096	0,4241	37,2565
H7	910	0,092	0,1458	12,2036
H8	400	0,022	0,8394	7,3869
H9	910	0,039	0,5080	18,0275
H10	700	0,033	0,6937	16,0235

H11	400	0,015	0,4055	2,4328
H12	910	0,062	0,5080	28,6590
H13	600	0,011	0,5080	3,3525
H14	400	0,018	0,4055	2,9194
H15	910	0,15	0,5512	75,2441
H16	300	0,029	0,4055	3,5276
H17	500	0,039	0,4449	8,6754
H18	300	0,025	0,4449	3,3367
H19	300	0,007	0,4449	0,9343
H20	229	0,015	0,4449	1,5282
H21	300	0,007	0,4449	0,9343
H22	400	0,008	0,4449	1,4237
H23	400	0,006	0,6461	1,5505

Integrated scores of hazards were calculated according to the "Final Risk Score" calculation above in Table 4.11. As a result of these calculations, the prioritization of the hazards from the highest score to the lowest score is given in the Table 4.12.

Table 4.12. Prioritization of hazards

HAZARDS	Final Risk Score
H15	75,2441
H3	68,7489
H2	43,9542
H1	42,1229
H6	37,2565
H12	28,6590
H5	20,9887
H4	18,4490
H9	18,0275
H10	16,0235
H7	12,2036
H17	8,6754
H8	7,3869
H16	3,5276
H13	3,3525
H18	3,3367

H14	2,9194
H11	2,4328
H23	1,5505
H20	1,5282
H22	1,4237
H19	0,9343
H21	0,9343

When the Table 4.12. is examined, the hazard with the highest score was determined as H15. It has been observed that the hazards that make up the first five rows are H3, H2, H1 and H6, respectively. H12, H5, H4 and H9 are other hazards that are not in the first places but do not have a significant difference in their scores. H21 and H19 hazards have the same score and are in last place. Considering these results, it is necessary to determine the hazards that need to be taken care of. Then, preventive actions should be established for these hazards.

Step – 7: Pareto Analysis for Determining Important Hazards

The Final Risk Scores of the hazards identified as a result of the analyzes were determined. It is planned to take preventive actions for the hazards that represent the important group among these hazards. However, it is a difficult problem to identify the hazards that represent the important group among the hazards. In order to determine these hazards correctly, it is necessary to make an objective and logical selection. Any mistake that will occur during the selection of hazards will cause negative consequences for the companies. Therefore, it has been decided to apply the Pareto Analysis to determine the hazards that represent the important group among the hazards. According to Pareto Analysis, 80% of problems arise from 20% of causes. However, within the scope of this study, it was decided to take into account 90% of the problems as a result of the interviews with the experts in the company. In this way, it was concluded that both the effectiveness and scope of the study would increase and better results would be obtained for the company. In this direction, the study carried out to determine the hazards representing the important group among the hazards is given in Table 4.13.

Table 4.13. Pareto Analysis

Hazards	Final Risk Score	Cumulative	Cumulative Ratio
H15	75,2441	75,2441	17,93%
H3	68,7489	143,9930	34,31%

H2	43,9542	187,9472	44,78%
H1	42,1229	230,0702	54,82%
H6	37,2565	267,3266	63,70%
H12	28,6590	295,9857	70,53%
H5	20,9887	316,9743	75,53%
H4	18,4490	335,4233	79,92%
H9	18,0275	353,4508	84,22%
H10	16,0235	369,4742	88,04%
H7	12,2036	381,6779	90,94%
H17	8,6754	390,3533	93,01%
H8	7,3869	397,7402	94,77%
H16	3,5276	401,2678	95,61%
H13	3,3525	404,6203	96,41%
H18	3,3367	407,9570	97,21%
H14	2,9194	410,8764	97,90%
H11	2,4328	413,3092	98,48%
H23	1,5505	414,8598	98,85%
H20	1,5282	416,3880	99,22%
H22	1,4237	417,8116	99,55%
H19	0,9343	418,7459	99,78%
H21	0,9343	419,6802	100,00%

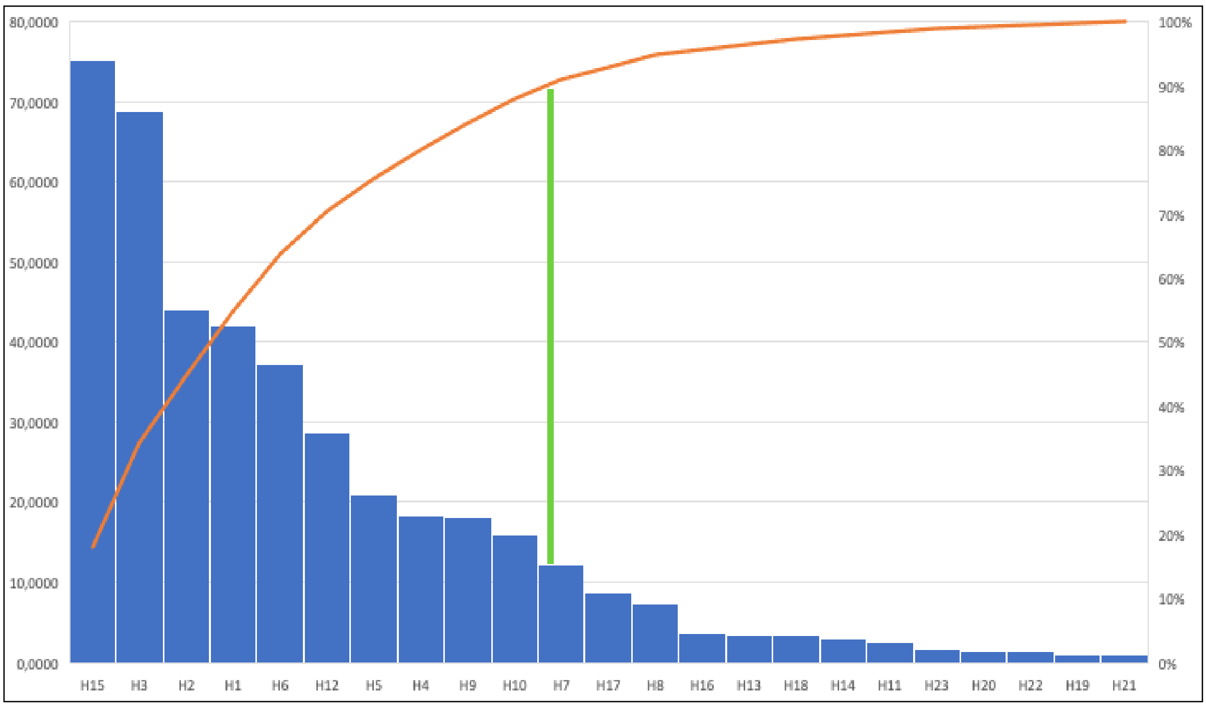

Figure 4.6. Pareto Analysis Graph

As a result of the Pareto Analysis, it was decided that the hazards, which form 90% of the problems, represent the significant group. Accordingly, the hazards in this group are H15, H3, H2, H1, H6, H12, H5, H4, H9, H10, and H7, in descending order of importance. These hazards need to be completely eliminated or their effects must be reduced. In this way, it was thought that the company would have a more efficient work flow. In addition, the occurrence of negative consequences within the scope of occupational health and safety will be prevented.

Step – 8: Determination of Actions

After the Pareto Analysis applied in Step 7, among the hazards determined throughout the company, the hazards representing the important group were determined. In terms of the effectiveness of the study, it is necessary to eliminate these hazards or reduce their effects. In this direction, first of all, actions should be determined for these hazards. While determining the actions, interviews were held with various experts working at the company. As a result of these interviews, actions were determined for the selected hazards. While determining the actions, the maximum benefit and maximum impact for the company were taken into consideration. In line with this information, hazards and actions are given in Table 4.14.

Table 4.14. Hazards and actions

Number of Hazards	Hazards	Number of Actions	Actions
H15	While the material is sent to another workbench after the work is finished, the form for the measurement controls is not kept.	A15	Measurement controls should be made after each operation. For this, an Internal Process Control Form should be created for intermediate controls during the production period. These operations should be added to the Production Quality Plan. Calibration and maintenance of measuring devices should be done at regular intervals.
H3	Since the purchasing unit does not transmit the revised information of the material size for the order to the warehouse, the warehouse evaluates the incoming material according to the old size and takes it to the quarantine zone.	A3	The warehouse should perform the input control processes in line with the revision information from the purchasing department. A communication channel should be established for faster information exchange.
H2	When the size of the material ordered by the purchasing unit is revised later, revision information is not sent to the warehouse.	A2	Purchasing department should notify the necessary units immediately and in writing when the revision process related to the ordered material takes place.

H1	It is not clear which craftsman/workbench will process the incoming materials/parts.	A1	At the material exit from the warehouse, a Warehouse Material Request and Delivery Receipt Form must be created to indicate to which employee or machine the material will be given. Transactions should be recorded in this way.
H6	Incoming materials are not sent for testing	A6	An agreement should be made with an accredited laboratory. Incoming materials should be sent for testing regularly. In the Input Quality Control Form and Input Quality Plan, the tests planned to be carried out in accordance with the incoming materials should be included. Raw material entry should not be approved without tests.
H12	Measurements/controls are made after the operation is performed, but there is no record of the controls.	A12	Measurement controls should be made after each operation. For this, an Internal Process Control Form should be created for intermediate controls during the production period. These operations should be added to the Production Quality Plan. Calibration and maintenance of measuring devices should be done at regular intervals.
H5	There is no quarantine area. Inappropriate raw materials, wrong/faulty productions are kept in different places. A complete follow-up is not possible. There are no records of unsuitable raw materials, wrong/faulty productions.	A5	Warehouse Layout Plan should be prepared. Warehouse arrangement should be made according to this plan. Existing warehouse space should be expanded. An Inappropriate Product/Part Form should be created regarding unsuitable products, raw materials and faulty productions.
H4	While production planning is being done, planning is done according to the old dimensions, since the revision information of the material dimensions is not received. Therefore, errors are encountered in production.	A4	Purchasing department should give information about revision in a timely manner. Production Planning department should carry out the planning processes in line with the revision information coming from the purchasing unit. A communication channel should be established for information exchange.
H9	Weld control is done by eye only. No form is kept.	A9	Welded Manufacturing Control Form should be kept for the control of welding processes. Acceptance criteria and tolerances should be included in the Production Quality Plan.
H10	Shelves are not tidy. There is no record of how much of which material in which section.	A10	Arrangements should be made for the shelves in the Welding / Assembly area. Worn shelves need to be replaced. Counting has to be done. How much of which part/material should be recorded.
H7	While the material is given to the master from the warehouse, it is clear to which master the material was given, but it is not recorded for which project it was given.	A7	Warehouse Material Request and Delivery Slip should be prepared while assigning materials from the warehouse to the master/machine. This form, which should be kept, should include "project no/order no". These records should be transferred to the computer environment. Market research should be done for stock records and software should be purchased.

Step – 9: Determination of Constraints for Actions

Actions for hazards are determined in step-8. Another problem for the company is which of these actions will be selected and applied. Because, like every company, the company where this study is carried out does not have infinite resources. Therefore, the company has to use its resources in the optimum way for the determined actions. This situation emerges as a decision problem. In this direction, as a result of the exchange of ideas with various experts in the company, the constraints of the company were determined into three groups as cost (TL), time (day) and manpower. Considering this information, the manpower, time and costs needed to perform the actions for the decision problem are given in the Table 4.15.

Table 4.15. Action's constraints values

Number of Actions	**Constraints**		
	Manpower	**Time (day)**	**Cost (TL)**
A15	6	16	5000 TL
A3	3	10	7500 TL
A2	2	3	3250 TL
A1	4	8	3750 TL
A6	4	10	15000 TL
A12	6	16	5000 TL
A5	12	21	45000 TL
A4	3	3	10500 TL
A9	7	5	3500 TL
A10	4	10	11000 TL
A7	3	14	15000 TL

After determining the values of the constraints of the actions, another important component of the decision problems is to determine the values of the company constraints. Because the company does not have unlimited resources. The company has to make the best use of its available resources. Accordingly, the values of company constraints are given in Table 4.16.

Table 4.16. Company constraints and values

Company Constraints		
Total Manpower Constraint	**Total Time (day) Constraint**	**Total Budget (TL) Constraint**
20	25	75000 TL

Step – 10: Binary Programming Model For Choosing Hazards

In Step-9, the values needed to perform the actions were determined in three groups. Then, the constraints of the factory for these actions were determined. In step-10, considering these constraints, a binary programming model was created and its solution was made.

In the objective function of the created binary mathematical model, each decision variable has weight. For the weights of the decision variables, the final risk scores of each hazard obtained as a result of Step-6 were used. As a result of the Pareto Analysis applied in Step-7, the final risk scores of the hazards in the important risk group were normalized. In this way, the weights in the objective function of the binary mathematical model were reached. The weights used in the mathematical model are given in Table 4.17.

Table 4.17. Weights of decision variables

HAZARDS	Final Risk Score	Weights of Decision Variables
H15	75,24	0,20
H3	68,75	0,18
H2	43,95	0,12
H1	42,12	0,11
H6	37,26	0,10
H12	28,66	0,08
H5	20,99	0,05
H4	18,45	0,05
H9	18,03	0,05
H10	16,02	0,04
H7	12,20	0,03

The use of weights in the binary mathematical model enabled the importance of hazards to be taken into account and offered a more objective approach.

In the mathematical model created, decision variable numbers are assigned for the important group hazards selected as a result of Pareto Analysis. The hazards represented by the decision variables used in the model to avoid any confusion are given in Table 4.18.

Table 4.18. Actions and decision variables number

Actions	Decision Variable No
A15	X1
A3	X2
A2	X3
A1	X4
A6	X5
A12	X6
A5	X7
A4	X8
A9	X9
A10	X10
A7	X11

Considering this information, the binary mathematical model and its constraints are given below;

<u>Objective Function</u>

Z_{max}=0.20x1+0.18x2+0.12x3+0.11x4+0.10x5+0.08x6+0.05x7+0.05x8+0.05x9+0.04x10+0.0x 11

<u>Constraints</u>

6x1+3x2+2x3+4x4+4x5+6x6+12x7+3x8+7x9+4x10+3x11<=20 → *Manpower Constraint*

16x1+10x2+3x3+8x4+10x5+16x6+21x7+3x8+5x9+10x10+14x11<=25 → *Time Constraint*

5000x1+7500x2+3250x3+3750x4+15000x5+5000x6+45000x7+10500x8+3500x9+11000x10 +15000x11<=75000 → *Cost Constraint*

This mathematical model was created using the LINGO 19.0 package program. The codes of the given model in the LINGO 19.0 program and the solution result are given in Figure 4.7. and Figure 4.8.

```
!Objective Function;
Max=0.20*x1+0.18*x2+0.12*x3+0.11*x4+0.10*x5+0.08*x6+0.05*x7+0.05*x8+0.05*x9+0.04*x10+0.03*x11;

!Manpower Constraints;
6*x1+3*x2+2*x3+4*x4+4*x5+6*x6+12*x7+3*x8+7*x9+4*x10+3*x11<=20;

!Time Constraints;
16*x1+10*x2+3*x3+8*x4+10*x5+16*x6+21*x7+3*x8+5*x9+10*x10+14*x11<=25;

!Cost Constraints;
5000*x1+7500*x2+3250*x3+3750*x4+15000*x5+5000*x6+45000*x7+10500*x8+3500*x9+11000*x10+15000*x11<=75000;

@BIN(x1);
@BIN(x2);
@BIN(x3);
@BIN(x4);
@BIN(x5);
@BIN(x6);
@BIN(x7);
@BIN(x8);
@BIN(x9);
@BIN(x10);
@BIN(x11);
```

Figure 4.7. LINGO codes for action selection

```
Global optimal solution found.
Objective value:                              0.4600000
Objective bound:                              0.4600000
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              0
Elapsed runtime seconds:                           0.16

Model Class:                                       PILP

Total variables:                    11
Nonlinear variables:                 0
Integer variables:                  11

Total constraints:                   4
Nonlinear constraints:               0

Total nonzeros:                     44
Nonlinear nonzeros:                  0



                              Variable           Value        Reduced Cost
                                    X1        0.000000          -0.2000000
                                    X2        1.000000          -0.1800000
                                    X3        1.000000          -0.1200000
                                    X4        1.000000          -0.1100000
                                    X5        0.000000          -0.1000000
                                    X6        0.000000          -0.8000000E-01
                                    X7        0.000000          -0.5000000E-01
                                    X8        1.000000          -0.5000000E-01
                                    X9        0.000000          -0.5000000E-01
                                   X10        0.000000          -0.4000000E-01
                                   X11        0.000000          -0.3000000E-01
```

Figure 4.8 LINGO result of action selection

According to the LINGO 19.0 results, the decision variables X_2 X_3 X_4 and X_8 took the value "1" as a result of solving the mathematical model. In other words, the implementation of the recommended actions for the hazards represented by these decision variables will be the best decision for the company. The decision variables selected as a result of the solution of the model and the actions it represents are given in Table 4.19.

Table 4.19. Choosed actions and decision variables

Actions	**Decision Variable No**
A3	X2
A2	X3
A1	X4
A4	X8

The constraints of the company for actions are determined as manpower, time (day) and budget (TL). These constraints can be directly or indirectly affected by the actions of the company. This means that the values determined for the constraints may change. For example, if the company takes the due date of a project earlier, it means allocating more labor and time to that project. In addition, the values of the constraints can also be affected by environmental conditions, independent of the company. For example, sudden changes in exchange rates may affect the company in terms of budget or an epidemic in the company affects the workforce. Therefore, a sensitivity analysis was conducted to see how a change in constraints would affect the solution. As a result of interviews with company experts, the company's constraints for sensitivity analysis were changed to +5%, -5%, +10% and -10%. The values calculated as a result of changing the constraints at the determined rates are given in Table 4.20.

Table 4.20. New constraints and values for sensitivity analysis

Changed Constraints Rate	**Constraints**		
	Manpower	**Time (day)**	**Budget (TL)**
+%5	21	26.25	78750
-%5	19	23.75	71250
+%10	22	27.50	82500
-%10	18	22.50	67500

According to the information of the constraints given in Table 4.20, new mathematical models were created. A program of mathematical models created according to the new constraints was written and the program was run 4 more times. The comparison of the actions selected according to the results obtained from each model and the actions selected according to the first model are given in Table 4.21.

Table 4.21. Comparision of action selection results

Comparision of Results									
Initial Model		**Increased %5 Model**		**Decreased %5 Model**		**Increased %10 Model**		**Decreased %10 Model**	
Actions	**Decision Variable No**	**Actions**	**Decision Variable No**	**Actions**	**Decision Variable No**	**Actions**	**Decision Variable No**	**Actions**	**Decision Variable No**
A3	X2	A3	X2	A3	X2	A3	X2	A3	X2
A2	X3	A2	X3	A2	X3	A2	X3	A2	X3

A1	X4	A1	X4	A1	X4	A1	X4	A1	X4
A4	X8	A4	X8	--	--	A4	X8	--	--

When the Table 4.21. was examined, various inferences were made. These are;

- When the model was solved with the constraints determined as a result of the interviews with the experts in the company, A3, A2, A1 and A4 were selected among the actions. The selection and implementation of these actions will provide maximum benefit for the company in terms of manpower, time (day) and budget (TL).
- When the model created by increasing the values of the constraints determined as a result of the interviews with the experts in the company was solved by 5%, A3, A2, A1 and A4 were selected among the actions. This model has been found to have the same result as the initial model. In other words, if the company increases its resources by 5%, choosing the same actions will provide maximum benefit for the company in terms of manpower, time (day) and budget (TL).
- When the model created by reducing the values of the constraints determined as a result of the interviews with the experts in the company was solved by 5%, A3, A2 and A1 were selected among the actions. The result of this model is different from the model in which the initial model and constraints are increased by 5%. If the company's resources are reduced by 5%, the company will not be able to implement the A4 action. It is understood that company does not have enough resources for this.
- When the model created by increasing the values of the constraints determined as a result of the interviews with the experts in the company was solved by 10%, A3, A2, A1 and A4 were selected among the actions. This result has the same result as the initial model and the model where resources are increased by 5%.
- When the model created by reducing the values of the constraints determined as a result of the interviews with the experts in the company was solved by 10%, A3, A2 and A1 were selected among the actions. This result has the same result as the model where resources are reduced by 5%.
- When the results are examined, the initial model, the models in which the resources are increased by 5% and 10% have the same results. In this direction, the company can take the same actions without increasing the resource up to 10%.

- When the results are examined, the models in which the resources are reduced by 5% and 10% have the same result. However, it has different results with the initial model. When these models are compared with the initial model, it is seen that the A4 action is not included in the solution. In this direction, if the company realizes a decrease in its resources up to 10%, only A4 cannot perform the action.

5. CONCLUSIONS

It is one of the requirements of the age that companies are always ready for unexpected situations. For this, companies should have a strong system, manage their resources and processes in the best way and prevent situations that may harm the company. In this way, companies can increase the quality of their products, increase customer satisfaction and reach a healthier living space by eliminating situations that will harm the company. In order to meet these conditions, there are many methods and studies related to these methods in the literature.

Risk analyzes are vital for companies when applied correctly. When the concept of risk and risk analysis is mentioned, occupational health and safety comes to mind first. However, from a wider perspective, risk study is an effective method that can be used not only in terms of occupational health and safety, but also in improving processes in companies. However, the risk study will yield effective results if the appropriate actions are determined after the identified hazards are evaluated and the selection is made considering the resources of the companies and the benefits of these actions to the companies. Another important point is that the applied analyzes are carried out objectively.

Within the scope of this study, an application including risk analysis and decision problem was made in order to improve existing processes and eliminate various problems in a medium-sized company. First of all, the hazards were determined in the company in question. Then, the identified hazards were evaluated using the Failure Mode and Effect Analysis (FMEA) method and the Analytic Hierarchy Process (AHP) method, and the scores were calculated. Then, these scores were multiplied with each other to obtain an integrated score. The purpose of the integration process is to get rid of the subjectivity of FMEA and AHP methods and try to provide objectivity. According to this procedure, the top 5 hazards with the highest scores were H15, H6, H1, H7 and H3, respectively.

While making evaluations using FMEA and AHP, final judgments are used by the decision maker(s). Therefore, a danger that should be important can be ignored and undesirable consequences may occur. Therefore, the methods used in the evaluation process are integrated with fuzzy logic. With the use of fuzzy logic, it is aimed to expand the evaluation range and to eliminate the uncertainties. In this way, it was thought that a more objective evaluation would be made and more accurate results would be achieved. The hazards identified in this direction were re-evaluated with Fuzzy FMEA and Fuzzy AHP. The integration process was performed for the scores calculated as a result of the application of both methods. According to the operations performed, the top 5 hazards with the highest scores as a result of including fuzzy logic were H15, H6, H7, H3, and H1, respectively.

After the evaluation of the hazards, the departments that are directly or indirectly affected by the hazards are also included in the evaluation process. In this way, it has been tried to make a comprehensive evaluation by taking into account the hazards, the consequences of the hazards and the environments in which the hazards take place. The departments affected by the hazards were evaluated using the Fuzzy AHP method. As a result of the evaluation, 7 departments affected by the hazards were determined. Among these departments, "Manufacturing" is the most affected; It has been determined that "Sales and Marketing" is the department that is least exposed to the impact.

In order to get rid of subjectivity in the evaluation processes and to obtain a common result, the weights obtained as a result of the Fuzzy FMEA & Fuzzy AHP integration of the hazards and the evaluation of the departments with the Fuzzy AHP were multiplied with each other and "Final Scores" were obtained. According to the Final Score, the 5 hazards with the highest scores were H15, H3, H2, H1 and H6, respectively.

Pareto Analysis was applied considering the determined Final Scores. Thanks to the Pareto Analysis, it is thought that the hazards that will be included in the action plan among the hazards are evaluated objectively. As a result of the Pareto Analysis, the 9 hazards with the highest score were included in the action plan and actions were determined for these hazards. The question of which of these actions will be implemented constituted the decision problem part of the study. binary programming is used to solve this decision problem. In this way, it is aimed to use the company's resources in an optimum way by including the company's constraints in the problem. The mathematical model created was solved by the LINGO 19.0 package program. As a result of the solved model, the actions A3, A2, A1 and A4 were selected to be applied. As a result of the analyzes applied, H15 was the hazard with the highest score. The action of H15 is expressed by A15. However, A15 was not chosen in the solution of the mathematical model. According to the traditional risk analysis approach, the hazard or risk with the highest score should always be in the action plan. However, in this study, a new approach has been proposed and a departure from the traditional risk analysis approach. In addition, company resources were taken into account in the selection of actions. Considering the result of the mathematical model created for the action selection, choosing A15 will prevent the optimum use of company resources. In line with this information, A15 was not included in the action plan. Finally, sensitivity analysis was carried out to determine the limits of the mathematical model and to increase the effective use of company resources.

6. RECOMMENDATIONS

In future studies, more methods and techniques can be used in the assessment process by increasing the number of hazards. The company's constraints for actions can be increased. In this way, it is possible to use resources more accurately, taking into account more constraints in the selection process for the actions to be taken for hazards. For the solution of the decision problem, comparisons can be made with the results obtained by using various optimization methods such as metaheuristic methods, decision tree analysis, apart from the mathematical model. With the proof of the effectiveness of the study, all these processes can be transferred to the decision support system and a standard can be established for certain sectors to improve their processes.

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