REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF INDUSTRIAL ENGINEERING

ACTION SELECTION VIA WEIGHTED TOPSIS METHOD BASED ON FUZZY FINE KINNEY RISK ANALYSIS FOR GAS PLANT

BAHAR DOĞAN

MASTER OF SCIENCE

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ADANA 2022

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.

[Signature]

Bahar DOĞAN

ABSTRACT

ACTION SELECTION VIA WEIGHTED TOPSIS METHOD BASED ON FUZZY FINE KINNEY RISK ANALYSIS FOR A GAS PLANT

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Risk analysis is of great importance as it ensures that the necessary measures are taken by predetermining the hazards that may cause work accidents and occupational diseases. The most widely used risk analysis method in practice is the Fine Kinney method. In this thesis, the hazards occurring in a medium-sized gas filling facility were defined and the risk scores of these hazards were determined by the expert team according to the Fine Kinney risk analysis method. However, since the same risk significance level is obtained in different combinations of scale values in the classical Fine Kinney risk analysis method and the characteristics of the company applied in the risk analysis are not taken into account, the hazards were evaluated using Fuzzy Fine Kinney risk analysis and the most critical hazards were determined. Action plans are defined for critical hazards determined as a result of Fuzzy Fine Kinney risk analysis. Among the actions that require labor and/or budget, the action selection was made with the TOPSIS method, taking into account their relationship with the hazards. While applying the TOPSIS method, the importance levels of the groups affected by the hazards were determined by AHP and these AHP weights were reflected in the TOPSIS method and actions were determined.

Keywords: Action selection, AHP, Fuzzy Fine Kinney, TOPSIS

ÖZET

BİR GAZ TESİSİ İÇİN BULANIK FINE KINNEY RİSK ANALİZİNE DAYALI AĞIRLIKLI TOPSIS YÖNTEMİYLE AKSİYON SEÇİMİ

Bahar DOĞAN
Endüstri Mühendisliği Anabilim Dalı
Danışman: Doç. Dr. Murat OTURAKÇI

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İşletmelerin iş kazası ve meslek hastalığına sebebiyet verecek tehlikeleri önceden belirleyerek gerekli önlemlerin alınmasını sağladığı için risk analizinin büyük bir önemi vardır. Risk analizi yöntemlerinden uygulamada yaygın olarak kullanılanı Fine Kinney yöntemidir. Bu tez çalışmasında orta ölçekli bir gaz dolum tesisinde gerçekleşen tehlikeler tanımlanmış ve uzman ekip tarafından bu tehlikelerin risk puanları Fine Kinney risk analiz yöntemine göre belirlenmiştir. Ancak klasik Fine Kinney risk analiz yönteminde skala değerlerinin farklı kombinasyonlarında aynı risk önem seviyesinin elde edilmesinden ve risk analizinde uygulama yapılan firmanın özelliklerinin dikkate alınmamasına sebep olmasından dolayı Fuzzy Fine Kinney risk analizi kullanılarak tehlikeler değerledirilmiş ve en kritik tehlikeler belirlenmiştir. Fuzzy Fine Kinney risk analizi sonucunda belirlenen kritik tehlikeler için aksiyon planları tanımlanmıştır. İşgücü ve/veya bütçe gerektiren aksiyonlar arasından tehlikeler ile olan ilişkileri dikkate alınarak TOPSIS yöntemi ile aksiyon seçimi gerçekleştirilmiştir. TOPSIS yöntemi uygulanırken tehlikelerin etki ettiği grupların önem seviyeleri AHP ile belirlenmiş ve bu AHP ağırlıkları da TOPSIS yöntemine yansıtılarak aksiyonlar belirlenmiştir.

Anahtar Kelimeler: Aksiyon seçimi, AHP, Fuzzy Fine Kinney, TOPSIS

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NOMENCLATURE

FMEA	: Failure Modes and Impact Analysis
PHA	: Preliminary Hazard Analysis
FTA	: Fault Tee Analysis
HAZOP	: Hazard and Operational Analysis
ETA	: Event Tree Analysis
JSA	: Job Safety Analysis
RPN	: Risk Priority Number
AHP	: Analytic Hierarchy Process
TOPSIS	: The Technique for Order of Preference by Similarity to Ideal Solution
FAHP	: Fuzzy Analytical Hierarchy Process
MSDS	: Material Safety Data Sheet
MCDM	: Multi-Criteria Decision Making
GIS	: Geographic Information Systems
ERA	: Ecological Risk Assessment
PSC	: Pharmaceutical Supply Chain
MOGA	: Multi-Objective Genetic Algorithm
ALARP	: As Low As Reasonably Practicable
CRE	: Collaborative Risk Evaluator
EMT	: Electromagnetic Topology
BN	: Bayes Networks
IEME	: Intentional Electromagnetic Environment
RAMCAP	: Risk Analysis and Management for Critical Asset Protection
SD	: System Dynamics

1. INTRODUCTION

1.1. Risk Analysis

Risk analysis is the whole of the studies carried out to determine the hazards that may arise or may occur during the activities of the enterprises. By determining the methods for the measures to be taken against the risks, it is ensured that the risks are eliminated or minimized. Risk analysis is the process of identifying security risks for a system and determining their probability of occurrence, their impact, and measures to mitigate this impact (Syalim et al, 2009).

Conducting risk analysis in every business is a necessity in terms of occupational health and safety. The OHSAS 18001 standard is an effective tool that can be applied to all organizations showing all kinds of business sectors and activities, and is used to systematically address occupational health and safety activities in accordance with the general strategies of the organizations and to analyze them within the framework of a continuous improvement approach. Risk analyzes to be made according to the type of business are determined. Risks in businesses can be predicted with risk analysis. The effects of the foreseen risks can be calculated. It can be known who or how many people may be affected by the risks. Thus, occupational accidents in the workplace are largely prevented, and health problems such as illness, injury, disability and death can be prevented. Unnecessary money and time costs can be reduced and the uninterrupted continuation of activities is ensured.

In risk analysis studies, hazards and risks are determined within the scope of possibilities. It is determined who, what and how these risks will be affected, and how severely they will be harmed. Risks; considering the unique characteristics of the enterprise, the appropriate one of the quantitative and qualitative methods listed below are selected and analyzed based on international standards.

- L Type Matrix Analysis Method
- X Type Matrix Analysis
- Fine-Kinney Method
- Failure Modes and Impact Analysis (FMEA)

- Preliminary Hazard Analysis (PHA)
- Fault tree analysis (FTA)
- Hazard and Operational Analysis (HAZOP)
- Event Tree Analysis (ETA)
- Cause and Effect Analysis
- What If?
- Job Safety Analysis (JSA)

It is important to eliminate the risks, starting with the one with the highest risk level. However, in cases where this cannot be achieved, it is possible to reduce the risks to an acceptable level with control measures. For this, our priority when deciding on risk control measures is the elimination of danger or sources of danger. It is then replacing the hazard with non-hazardous or less dangerous sources. The continuity of the measures taken for the risks that have been reduced to an acceptable level is monitored.

1.2. Risk Analysis Methods

There are two risk assessment models: the qualitative model and the quantitative model. Qualitative risk analysis is the process of evaluating the impact of identified risk factors. In this process, priorities are set to address potential risk factors based on the impact they may have. Through quantitative risk analysis, some numerical results are sought that express the probability of each risk factor and its consequences on the objectives of the project, as well as the risk at the whole project level (Mazareanu, V. P., 2010).

1.2.1. L Type matrix analysis method

The L-type matrix is used to evaluate cause-effect relationships. It is also called the 5x5 Matrix. In this method, two parameters are used, namely probability and severity. Values between 1 and 5 are given for the probability and severity parameters. The risk score is obtained by multiplying the probability and severity values. According to the size of the risk score, it is decided whether the risk will be acceptable or not. In this area, Ozfirat et al. (2017) carried out an L-matrix analysis study to analyze hazards and predict risks in natural stone plants.

1.2.2. X type matrix analysis

This method defines factors and parameters that participate in the problem or event or affect the problem or event and determines the relationship between them. To apply the X-Type Matrix method, first of all, the section where the risk analysis will be done should be selected, and then a 5-year accident investigation should be carried out with this section. To be able to evaluate the risk with the X-Type Matrix, the probability and severity value of a determined dangerous situation, the degree of control of the hazard and the results of previous accidents should be calculated using 5x5 matrices. X-Type Decision Matrix is obtained by assigning these determined values to the relevant variables in the matrix criteria. With the help of the X-Type Decision Matrix created, the degree of importance of the risks is determined. The scores obtained are ordered from high to low and it is decided which dangerous situation should be given priority and corrective-preventive actions should be taken.

1.2.3. Fine-Kinney method

The Fine Kinney method is a quantitative risk assessment method developed by Kinney and Wiruth in 1976 (Kinney and Wiruth., 1976). This method has three parameters as likelihood, exposure and possible consequences.

1.2.4. Failure modes and impact analysis (FMEA)

Failure mode and effects analysis (FMEA) is an easy-to-use and powerful proactive engineering quality method that helps identify and counter weak points at the early concept stage of products and processes (Chang and Paul, 2009).

FMEA prioritizes the potential failure mode by setting a risk priority number (RPN) to take corrective actions. A numerical scale from 1 to 10 is used to rank the severity (S), the probability that the fault mode will occur (O), and the probability that the fault will be detected (D). The RPN is calculated by multiplying the severity (S), probability of occurrence (O) and probability of detection (D) to determine the risk level of a process (Sawhney et al, 2010). The risk with the highest RPN is usually of the highest importance. FMEA method is used in many fields. For example, Arabian et al.(2010) applied the FMEA method to a wind turbine system.

1.2.5. Preliminary hazard analysis (PHA)

PHA is a qualitative risk analysis method. It is used before the design, construction and manufacture of the system, as an effective method to analyze the potential hazard of the system. Then the occurrence of the accidents and the consequences of the accidents can be determined and analyzed. Therefore, losses caused by unsafe technical measures, use of hazardous materials, technology, or devices, and inattention of the system will be prevented by PHA (Yan and Xu, 2019). Gowen et al.(1992), in their study, created a methodology for developing security-critical software systems using the PHA method.

1.2.6. Fault tree analysis (FTA)

Fault tree analysis (FTA) is a logical and diagrammatic method for assessing the probability of an accident resulting from sequences and combinations of fault and fault events (Tanaka et al,1983). FTA is used in conjunction with reliability and probability theorems to schematize possible sub-events with a logical diagram. The root causes are then examined in the FMEA table.Hyun et al. (2015) performed a risk analysis based on fault tree analysis (FTA) and analytical hierarchy process (AHP), which can systematically assess the potential risk and overall risk levels of adverse events occurring during tunneling procedures.

1.2.7. Hazard and operational analysis (HAZOP)

HAZOP is a highly disciplined procedure for determining how a process might deviate from its design intent (Dunjó et al,2010). HAZOP analysis is carried out in a brainstorming led by experts from different disciplines and the HAZOP team leader.

1.2.8. Event tree analysis (ETA)

The Event Tree Analysis (ETA) shows the sequences of events related to the success or failure of management (Raiyan et al,2017). It is a quantitative analysis system.

1.2.9. Cause and effect analysis

Its purpose is to define the chain between events and to determine what the undesired consequences are. A detailed cause and effect diagram is in the form of a fishbone. Hence it is also called Fishbone Diagram.

1.2.10. What if?

It starts with "What if?". It is based on the answers given to the questions. Possible consequences of failures are identified and recommendations for each situation are identified by the responsible persons.

1.2.11. Job safety analysis (JSA)

The purpose of the JSA is to identify and evaluate all risk elements associated with a task so that measures can be implemented to eliminate and/or control hazards (Albrechtsen et al, 2019). Focuses on work tasks performed by individuals or groups. It is appropriate if the jobs and tasks in a business or factory are well defined.

1.3. Description Of The Problem

This study, it is aimed to reveal a more objective and more sensitive evaluation method for risk analysis and to select an action plan according to this risk analysis method. There are many methods used in risk analysis studies in the literature and practice. In these methods, hazards are defined and the risk importance score of the hazards is determined according to the scales included in the risk analysis method considered. In these studies, the scales of the risk analysis method are considered equally important. This causes the same risk significance level to be obtained in different combinations of scale values. This situation causes the characteristics of the company whose risk analysis is made to be ignored. In this case, it is not known whether probability or frequency is more important. In this study, a more precise evaluation is made by combining the fine kinney method and fuzzy logic. In addition, risk importance scores determined according to scale values in risk analysis methods are based on mathematical processing and the dimensions of danger in the company can be ignored. In some cases, the hazard with a lower risk importance score may be of greater importance for the firm. This situation cannot be taken into account in the classical risk analysis method, and it is aimed to solve this problem with the fuzzy logic approach.

Another issue considered within the scope of the study is the choice of action. As a result of risk analysis studies, companies determine actions for hazards and aim to eliminate hazards if possible or to reduce risk importance levels to an acceptable risk level with these actions. However, the limited resources of the companies do not make it possible to implement an action plan for all hazards. In these cases, companies need to choose an action that will maximize their benefits. Actions determined for hazards are not always effective in solving a single hazard, they may affect more than one hazard with different severity levels. This situation makes the action selection problems more complex. In this study, the TOPSIS method, one of the multi-criteria decision-making methods, was used to solve this problem. While choosing an action, the level of importance also varies according to the group affected by the hazards. For a precise action selection, these weights should be reflected in the action selection problem. The group affected by each hazard changes. And groups affected by hazards; can be classified as employees, customers, residents of the environment. This makes it important to reflect the determination of the weights of the importance levels of the groups in the action selection. It is aimed to use the company's resources effectively, to minimize the dangers in the companies, and to reduce the labor and time losses as much as possible by choosing the action that will maximize the benefits of the companies by choosing the action according to the weighted scores.

1.4. Purpose Of The Study

The main purpose of risk assessment is to predict the risks in our environment, as well as to classify the risks in order of priority and to implement prevention plans.

With this thesis;

- With Fuzzy Fine Kinney risk analysis, more sensitive risk analysis than Classic Fine Kinney risk analysis,
- Identification of critical hazards for the gas filling facility,
- Taking action plans for hazards,
- Reflecting on the groups affected by the hazards to the action plans,
- Effective use of company resources,
- It is aimed to reduce possible work accidents in the company.

Risk analysis is of great importance as it ensures that the necessary measures are taken by predetermining the hazards that may cause work accidents and occupational diseases. The most widely used risk analysis method in practice is the Fine Kinney method. In this thesis, the hazards occurring in a medium-sized gas filling facility were defined and the risk scores of these hazards were determined by the expert team according to the Fine Kinney risk analysis method. However, since the same risk significance level is obtained in different combinations of scale values in the classical Fine Kinney risk analysis method and the characteristics of the company applied in the risk analysis are not taken into account, the hazards were evaluated using Fuzzy Fine Kinney risk analysis and the most critical hazards were determined. Action plans are defined for critical hazards determined as a result of Fuzzy Fine Kinney risk analysis. Among the actions that require labor and/or budget, the action selection was made with the TOPSIS method, taking into account their relationship with the hazards. While applying the TOPSIS method, the importance levels of the groups affected by the hazards were determined by AHP and these AHP weights were reflected the TOPSIS method and actions were determined.

2. LITERATURE REVIEW

2.1. Fine Kinney Risk Analysis

Oturakci et al.(2015) examined a new approach for the Fine Kinney method. Alternative scales have been constructed for the probability and frequency scales used in the previous method in this new approach. At an application in a medium-sized business, the results of the traditional method and the new approach were compared. Risks with higher probability and frequency had their scores updated, and their priority degrees were raised. As a result, people were more conscious of the dangers. Furthermore, it was discovered during the study's implementation that the results of the old Fine Kinney method had complications in terms of priority, which was resolved with the new methodology. In this way, the action plan of the works has been changed and the risks that are more important for the company have been taken into account. The results of the application show that the classical method is insufficient at certain points and that new approaches bring sensitivity to risk scores.

Kokangul et al.(2017) improved a new approach concerning the usability of class ranges in the Fine Kinney risk analysis method for the results obtained with the AHP method. In an application made in a large manufacturing company, a risk assessment study was executed in which the hazards were determined based on experience, and the defined hazards were categorized for the first time in this study concerning the processes involved in machine manufacturing and the scoring of each. The AHP approach was used to prioritize each category. The Fine Kinney approach was also used to assess the danger of the hazards discovered in the field. The relationship between the Fine Kinney risk assessment technique classes and the AHP scores was examined, and the AHP score class ranges were produced. As a result, the Fine Kinney risk assessment method's risk class ranges could be employed in the AHP method's results. As a result, AHP could be used to estimate both severity levels and hazard classes.

Gul et al.(2018) proposed a new risk assessment method that combines a fuzzy analytical hierarchy process (FAHP) with fuzzy VIKOR (FVIKOR) due to the Fine Kinney method's limitation of providing equal weights for its three parameters. FAHP was used to weigh these risk parameters. Then, the priority order of the hazards was determined with the FVIKOR method. The proposed method allows for group decision-making in hazard assessment by comparing the relative importance of the three risk characteristics using Buckley's FAHP pairwise comparison. Gul et al. (2018) used a case study to examine risk assessment in the arms business. For order preference, the classical method and the fuzzy technique were compared using the similarity of an ideal solution (FTOPSIS). The findings suggest that the proposed method helps assist stakeholders in determining risk control strategies and verifying risk control effectiveness.

Gul and Celik (2018) presented the application of a new OHS risk assessment approach that includes the Fine-Kinney method and a fuzzy rule-based expert system. This approach includes a combination of Fine Kinney method and fuzzy rule-based expert system. Captures nonlinear causal relationships between Fine Kinney parameters. A case study was conducted for a rail transport system in Istanbul/Turkey. A comparison with the classical Fine Kinney method is discussed in the case study. The results of the case study identify the clusters of risks that need to be considered and the associated control measures. The study methodologically contributes to the risk assessment in information, while the case study in a real rail transport system offers an insight into the public transport industry in improving safety.

Wang et al. (2018) propose a new Fine-Kinney-based risk analysis approach that combines triangular fuzzy numbers, MULTIMOORA method and Choquet integral to improve the limitations of classical Fine-Kinney risk analysis. In the Fine-Kinney technique, risk parameters are expressed as fuzzy linguistic variables and assessed using triangular fuzzy numbers rather than precise numerical values. The Choquet integral and the relative preference relation-based ranking approach are used to determine the weights of risk characteristics. Finally, the extended MULTIMOORA technique is used to determine the risk priority of each hazard. In an unpredictable context, this innovative Fine-Kinney-based risk assessment approach generates data for risk analysis with interaction correlations between risk characteristics. A ballast tank maintenance example is offered to example the risk assessment and prioritization procedures of the advanced Fine-Kinney-based risk assessment model.

Zhang et al.(2019) introduce a combination method based on FAHP and Fine Kinney for risk assessment of the airport operating process. By combining the two methods, one can prioritize and categorize hazards, assess their risks, and make important decision-making recommendations to better prevent risks from occurring. To measure the key factors affecting airport operation and to improve airport operating efficiency and service capacity, a state value model has been developed for airport operation. In practice, an independent t-test and Levene-test were performed on the evaluation results. The results show that the combination of FAHP and Fine Kinney has a certain generalization. The research results can be applied to the risk assessment of the airport operating situation and provide a decision-making basis for civil aviation departments.

Tang et al.(2020) aimed to improve a hybrid risk prioritization approach for Fine-Kinney using the generalized TODIM (an acronym in Portuguese of interactive and multi-criteria decision making), best-worst and interval type-2 fuzzy set. They proposed the best-worst technique for determining the relative relevance of risk characteristics and obtaining appropriate risk parameter weights. To evaluate the risk priority ordering of risks, the generalized TODIM technique included intermittent type-2 fuzzy numbers, which can replicate the restricted rational behavior of experts in uncertain circumstances. To demonstrate the implementation of the Fine Kinney framework, a real example of risk analysis, sensitivity, and comparative analysis of ballast tank maintenance is shown.

Dagsuyu et al.(2020) developed a new approach to the classical Fine Kinney risk assessment method. It is possible to reach the same RPN values with different combination calculations made with the three parameters Fine Kinney uses to assess risk. To overcome this situation, new classes were created for the Fine Kinney method by using K-Means clustering algorithms and two different distance functions. Classes were tried to be determined with K-Means and Hierarchical clustering algorithms by using two different distance functions, the new risk level, Euclidean and Manhattan distances. Conventional Fine Kinney and K-Means Algorithms have been applied to the risks of a workshop of a textile company. Risks were prioritized according to the classical Fine Kinney method and new risk levels of classes were determined according to K-Means algorithms. These data were compared in detail. Thanks to clustering techniques, it has been shown that the disadvantages of the classical Fine Kinney method are overcome and it is a new, original and viable way to identify new classes to prioritize risks.

Kuleshov et al.(2021) used the Fine and Kenny assessment method to evaluate the severity of the results of an accident as one of the occupational risk components. An investigation of events and incidents that occurred over three years in one of the coal mining operations was conducted to provide a comprehensive assessment of occupational hazards. The severity of the events of the accidents that occurred in the enterprise was defined as a consequence of the analysis. Conducting such activities ensures that information is generated and used for further monitoring and development of measures that lead to the elimination of occurrences and accidents. During the use of the technical process, this study demonstrates how it contributes to numerous accidents, occurrences, and financial losses.

Derse (2021) aimed to make a risk assessment for natural disasters. For this, data from 8 different provinces in the Aegean region of Turkey between 1990 and 2020 were used. By using the Fine Kinney risk assessment method, natural disasters were revised and a risk score was obtained for each province. Then, the AHP-based ELECTRE I method was applied to these provinces and the criteria weighted by AHP were used as input in the ELECTRE I method. As a result of this method, the riskiest province is obtained. The establishment of a crisis center in the riskiest province should offer effective solutions to the regions affected by the consequences of disasters. Thus, the problem of choosing the most suitable place in the crisis center is handled with the goal programming approach.

2.2. Risk Analysis With Multi-Criteria Decision Making

Khaadam and Kaluarachchi (2003) utilized risk assessment and multi-criteria decision analysis for the management of contaminated groundwater resources. In their methodology, they present important concepts and definitions such as the trade-off between population risk and individual risk that arise in decision analysis regarding groundwater pollution, the trade-off between residual risk and the cost of risk reduction and cost-effectiveness as a rationale for improvement. The proposed decision analysis framework integrates a probabilistic health risk assessment cost-based multi-criteria decision analysis framework. And a numerical example is presented for the proposed methodology. The results proved the importance of using an integrated approach to decision making, considering both costs and risks.

Linkov et al.(2007) presented demonstrates how MCDA administration can balance societal benefits against undesirable side effects and risks, as well as how multiple pieces of evidence can be combined to predict the possible toxicity and risk of nanomaterials given limited information on physical and chemical properties. The main contribution of the MCDA is that it allows quantifying the trade-offs involved in the decision-making process by correlating this performance information with decision criteria and weights derived from scientists and managers. The study given illustrates the use of the MCDA for policy decisions that balance the societal benefits and health risks arising from various nanomaterials and end with the choice of a nanomaterial with an optimal combination of benefits and risks.

Catrinu and Nordgard (2011) examined integrating multi-criteria decision support and risk analysis under uncertainty in electricity distribution system asset management. It provides an example of decision support based on maintenance and reinvestment strategies using multi-criteria decision analysis. Existing theoretical methods for multi-criteria decision analysis under uncertainty are discussed, and their use in decision support is shown based on the information available in distribution companies. This study is presented that addresses the process of establishing a maintenance and reinvestment strategy for air-insulated switch-disconnectors. The study shows how simplified risk assessment combined with quantitative economic data can be used in a multi-criteria decision support process. It also relies on expert opinions and qualitative multi-criteria assessments to analyze and classify security risk.

Risk assessment is very important in construction projects as the risk factor is very high in the construction busines. Tamosaitiene et al.(2013) present a risk assessment of construction objects for a construction project. They used multi-criteria decision-making methods with fuzzy information for risk assessment. Risk assessment criteria were selected by considering the macro, mezzo and micro levels of a construction project and the variables determined to contribute to the risk level were divided into groups. The ordering of the objects and determination of their optimality were determined by applying the TOPSIS-F method with the criteria values containing fuzzy information.

Malekmohammadi and Blouchi (2014) investigated an ecological risk assessment (ERA) process to identify stress factors and responses within an ecosystem-based approach. All potential environmental factors have been studied in a physical, chemical and biological context. They presented a systematic methodology for risk assessment and zoning of wetland ecosystems. By identifying the most important risks threatening wetlands, endpoint assessments were defined according to wetland values and functions, and ecological risks associated with these endpoints were determined. Risks; analyzed according to severity, probability, and various outcomes. Multi-Criteria Decision Making (MCDM) and Geographic Information System (GIS) methods are used to prioritize these risks in line with expert opinions and to develop a zoning map with a combination of risk layers according to their importance. The proposed management strategies methodology to deal with the risks was applied to the Shadegan International Wetland located in southwestern Iran. Based on the results obtained for this area, which is currently threatened by various risks, areas with high degree of potential risks and different risk levels and management strategies are proposed.

Bentaleb et al.(2015) wanted to analyze and evaluate risk factors within the dry port-seaport system using a multi-criteria approach. A list of the main risk factors was created by identifying and determining the risk factors. In this way, it is easier for managers to understand the risk theory in the dry port seaport system. Identified risk factors were analyzed using multi-criteria analysis. The relative importance of risk families and process stages has been evaluated to rank the risk factors in each risk family or in each stage process. Also, each risk factor has a relative judgment value, but in our framework, it can inherit the relative importance of family and relationship stage, this way we assess the global value of risk. This study has been applied in the Moroccan dry port-seaport system, the approach can be adapted to any dry port-seaport system and provides a proactive method to support decision-making regarding dry port-seaport system risk. In this way, they emphasized the strategic importance that should be given to the choice of dry port-seaport location in order to master this critical stage in the process.

Vishwakarma et al.(2016) present a multi-criteria decision-making (MCDM) methodology based on the FAHP approach to prioritize and rank risks in the pharmaceutical supply chain (PSC). Successful implementation of the PSC; production and commercial activities are difficult due to the different risks involved. Identification of risks and subsequent PSC analysis are therefore crucial to ensure that drug supply and the efficiency of the health system are not interrupted. The proposed methodology is suitable for analyzing the judgments and uncertainty of the expert involved in the risk assessment process. The study identifies 24 risks under five main risk measures of Indian PSC through relevant literature and expert opinions. The identified risks were primarily analyzed using the fuzzy AHP approach. The analysis of the data by fuzzy AHP enabled managers to overcome the problem of human subjectivity in analyzing PSC risks. It will help provide a measure of the relative concerns of the risk categories recognized in the PSC and of particular risks.

Senthil et al.(2017) investigated the risks involved in reverse logistics using hybrid multi-criteria decision-making methods in a plastics recycling company. The proposed methodology deals with the different risks that hinder the reverse logistics application and the hierarchy of actions to be taken for the risks is determined. In addition, the weights assigned to the attributes can be varied so that the priorities for the attributes change at any point. Once the risks in reverse logistics are prioritized, response-based risk mitigation strategies can be selected, taking into account the risk-return balance. Links between various functions in reverse logistics have been developed. In this way, it has helped decision-makers make important decisions by considering not only economic benefits but also environmental and social benefits. Considering the potential risk factors, it has been an important study in terms of shedding light on the risk perception of the plastic recycling industry. It has been observed that the social concern for the protection of the environment is generally based on cooperation.

Srinivasan and Kamalakannan (2017) considered risk assessment in financial institutions as a multi-criteria decision-making problem. They explored the latest developments in the use of data analytics or data mining techniques for financial risk analysis. Risk analysis obtained from financial data is a multi-criteria decision problem as it depends on various factors, both objective and subjective. They proposed a multi-objective genetic algorithm (MOGA) to analyze financial data for risk analysis and forecasting. The algorithm is applied to benchmark datasets to predict the decision on credit card and loan applications. The preliminary results are encouraging and shed light on better decision-making in reducing risks.

Luu and Meding (2018) conducted a study using spatial multi-criteria decision analysis to assess flood risk in Quang Nam province of Vietnam. The study offers a new approach to local flood risk assessment mapping that combines historical flood traces with exposure and vulnerability data. It is intended to integrate AHP with Geographic Information System (GIS) mapping to create a flood risk assessment map. Thanks to the flood risk map output, it can guide the decision-makers in undertaking flood risk management activities in the province. A flood risk assessment model has been developed that can quickly simulate a flood risk map. A comprehensive flood risk assessment map has been produced in Quang Nam province that can be used by practitioners to develop flood risk mitigation measures. In this way, a methodology for the creation of flood risk assessment maps that can be applied to other provinces in Vietnam is presented.

Shariat et al.(2019) applied a risk analysis study in urban storm water systems. They proposed Multi-Criteria Decision Making (MCDM), geographic information systems (GIS), and fuzzy sets theory to identify criteria influencing risk, analyze data and information, and formulate problem uncertainty. They used a Fuzzy Analytical Hierarchy Process (FAHP) to determine the weights of criteria affecting risk such as Hydrological and Hydraulic, Traffic, Social, Economic, Environmental, Structural and Green space. They received support from Autodesk Storm and Sanitary Analysis model for Hydrological and Hydraulic simulations. In addition, FSAW and FTOPSIS methods were used to provide a risk map that presents a level of risk for each channel in the network. Based on the risk analysis you presented, a real case study was implemented in the 11th District of Tehran, the capital city of Iran. The resulting risk maps show a high or very high flood risk for the 17.07 to 41.95 km of storm water channels in the study area, covering approximately 10.5 to 26% of the total length of the channels. The method applied in this way has proven to be a suitable risk analysis tool in urban stormwater systems.

Syed and Lawryshyn (2020) created a method for risk-informed decision-making in the context of physical asset management with risk assessment and cost-benefit analysis. It uses risk tolerance criteria, cost-benefit analysis, uncertainty reduction metrics, methodology, quantitative risk measures for loss of life, loss of production, and property loss. They presented a methodology for the quantitative prioritization of risk-informed asset management projects using the MCDA. A risk matrix is used to classify the risk as unacceptable, As Low As Reasonably Practicable (ALARP) or generally tolerable. Risk handling options are created for risks in the intolerable and ALARP region. Applicable projects, which are determined by the values calculated in the cost-benefit analysis, are then prioritized with the AHP and

TOPSIS MCDM/A methods. AHP is used to obtain weights for prioritization criteria based on decision-maker preferences. The usefulness of the methodology for improved decision-making is demonstrated using a numerical example.

2.3. Fuzzy Logic Risk Analysis

De Ru and Eloff (1996) explore the inherent weaknesses of traditional computational risk analysis models and also examine how fuzzy logic risk analysis techniques can successfully address these weaknesses. They established a methodology for modeling the risk analysis process within a computing facility. They dealt more effectively by discussing some aspects of risk analysis for accurate risk assessments. The aspects discussed were modeled using fuzzy logic techniques to address some observations as well as further investigation. The realistic and precise applicability of fuzzy logic risk analysis modeling techniques is demonstrated.

Bonvicini et al.(1998) have presented a new methodology for assessing uncertainty in risk assessment based on fuzzy logic by estimating risk for the transport of toxic materials, both by road and pipeline. To assess this uncertainty, they considered applying traditional statistical analysis based on the Monte Carlo method. However, they decided that a simpler and less computational procedure, such as uncertain logic, would be more useful for measuring uncertainty intervals, as dangerous goods transport often has very little input data in risk analysis. In fuzzy logic, uncertain input parameters are defined with fuzzy numbers and calculations are done using fuzzy arithmetic; the outputs will be fuzzy numbers. To show what effect each uncertain input has on output uncertainty, they present and discuss the test results of the combined uncertainty and sensitivity analysis in the risk assessment of a toxic gas release.

Tah and Carr (2000) presented a study aiming to develop knowledge-based robust system techniques that can improve risk analysis and management processes for the sustainability of the construction industry. They created a scheme to classify risks. By developing a formal model for qualitative risk assessment, a common language is provided for describing risks to achieve consistent quantification. The relationships between risk factors, risks, and their consequences are shown in cause-effect diagrams. By applying fuzzy logic to these diagrams, descriptive linguistic variables are used to describe risks and their consequences. Based on fuzzy estimates of risk components, a methodology for assessing risk exposure is presented that considers the consequences of the entire project in terms of time, cost, quality and safety performance measures. This methodology was implemented and tested in a prototype risk management software package to test the ideas developed.

Gallego et al.(2004) proposed a risk assessment methodology using fuzzy logic for lightning risk assessment. Fuzzy logic was used to measure the uncertainties in lightning risk assessment. Fuzzy logic is a powerful tool with the ability to combine linguistic and numerical variables to predict the subjectivity involved in risk analysis and to determine whether a level of risk is acceptable. The methodology establishes a direct relationship between a lightning parameter and a harmful event as a powerful tool to more accurately predict damage probabilities. Proposed probability estimation requires modeling uncertainties through fuzzy probability. The methodology proposed the analysis of the risk of damage from lightning. In this study, specially Tropical Regions where parameters such as ground flash density and lightning current peak value is taken into.

Managing risks is very important for the success of a construction project. Nasirzadeh et al. (2008) presented a fuzzy-based system dynamics approach to realize an integrated risk management process for the complex nature, dynamic behavior and uncertain nature of construction risks. Risk sizes are defined by a fuzzy logic-based risk size estimation system. The system dynamics (SD) simulation model uses Zadeh's extension principle and interval arithmetic to present system results taking into account uncertainties in the magnitude of risks. The impact of a risk is quantified and the effectiveness of different alternative responses evaluated. The proposed approach supports different phases of the risk management process, taking into account both the systemic and uncertain nature of risks.

Wulan and Petrovic (2012) present a fuzzy logic-based system for risk analysis and assessment within their corporate collaboration. Potential risk factors related to institutional collaborations were identified through the literature review. A fuzzy logic-based algorithm has been developed to evaluate these risk factors. Risks are defined by a risk probability and a risk effect. It is specified in imprecise linguistic terms and modeled with fuzzy sets. The algorithm is then applied to the Collaborative Risk Evaluator (CRE) prototype web service implemented to identify risks, provide fuzzy risk assessment, and facilitate control of risk spillover in enterprise collaboration. It has also been demonstrated to test and use the CRE in real-life industrial applications.

For developing pipeline systems, it is very important to identify the potential risks that practitioners may face. Therefore, risk analysis can identify critical risk elements to allocate limited resources and time. Alidoosti et al. (2012) developed a method to analyze critical risk elements in pipeline systems. They aimed to explore the main security risk elements to allocate limited resources and time using fuzzy set theory through Fuzzy Risk Analysis and Management for Critical Asset Protection (RAMCAP). Thus, Fuzzy RAMCAP was introduced for risk analysis and management for pipeline systems. Fuzzy RAMCAP considers the relative importance between vulnerability, threat, and outcome. The application of linguistic terms in input and output information can be more realistic and flexible with fuzzy RAMCAP. Fuzzy RAMCAP can provide more accurate risk analysis for the protection of critical assets in pipeline systems. A conceptual example application from pipeline systems for the proposed methodology is shown in the article.

Selecting and using an appropriate delivery method is critical to a construction project. Many factors influence the choice of delivery methods and many methods for evaluating these methods. Among these methods, risk assessment plays an important role in choosing the delivery method for construction projects. Shi et al.(2014) examined the analysis of delivery methods on how to reduce the risk of a construction program. A case study of the 2010 Guangzhou Asian Games was conducted as an example to apply and validate a risk assessment approach in the selection of delivery methods. In this case study, a mixed approach combining qualitative and quantitative methods is designed to assess the risk of each delivery method using the construction program. With the qualitative method, program managers were enabled to develop the basic risk structure. In the quantitative method, using fuzzy logic theory and DEA, the magnitude of the specific risk and the efficiency of the intervention plan were calculated. As a result of the case study, it was understood that the separate contract delivery method planned to be used according to the mixed analysis of delivery risk management at the 2010 Guangzhou Asian Games is not the best choice. Its principles can be considered incorporated into the delivery method of a large construction schedule as there are better-performing contracts.

Petrović et al.(2014) present a model of risk assessment of technical system failures in mining based on fuzzy set theory, fuzzy logic and minimum-maximum composition. Fuzzy sets theory and fuzzy logic based on the expert judgment of risk indicators as a model for technical system failure risk assessment in mining is a new approach. The advantage of the fuzzy logic approach lies in the possibility of working with imprecise and insufficient data and avoiding working with numerical values. The fuzzy logic theory includes linguistic variables as input values and gives a result that can also be defined as a fully definable linguistic variable. The presented model was applied to assess the failure risk level of belt conveyor elements operating under severe conditions in a coal mine. Also, this article demonstrates the advantages of this model in FMEA method of risk assessment compared to a standard RPN calculation procedure.

Weather effects are very important in distribution outage management. Chen and Kezunovic (2016) presented a new way of risk-based decision-making using weather effects. They applied a new approach to the weather-based risk framework to produce risk maps. They created a fuzzy logic system to mitigate weather effects. This allowed utility operators to make more accurate outage forecasts and achieve optimal maintenance planning. Reducing downtime, which is a significant performance improvement in outage management, has been demonstrated using weather data.

Peikert et al.(2017) present a method based on fuzzy logic and set theory that analyzes the risk of an IT System in and around a facility. EMT(electromagnetic topology), FTA(fault tree analysis) and BN(Bayes networks) are introduced to fuzzy set theory. The susceptibility of an electronic system to intentional electromagnetic interference is analyzed and classified into its intentional electromagnetic environment (IEME). In addition, subjective information, uncertain data, intangible quantities, crossing boundaries and expert opinions are added to the risk assessment, which can be simulated with a numerical or analytical mathematical program. In this way, fault tree analysis, electromagnetic topology and Bayesian networks (BN) models are extended. The critical scenarios that can be used to increase the level of protection and the most contributing factors and location to the risk have been identified.

Gallab et al.(2019) focused on measuring the risks and failures that may arise while performing maintenance activities in the LPG supply chain using fuzzy sets theory. They aimed to calculate the qualitative values of the risk level. The Risk Priority Number (RPN) was digitized with the parameters of frequency, detectability and severity. But, results are often subjective and do not offer absolute value. Also, combinations of these parameters with different scores can have the same RPN with fuzzy logic, even if the risks are not of equal importance. A model based on fuzzy sets theory is proposed to assess the risk level of errors in maintenance activities in the LPG supply chain. The proposed model for measuring maintenance failure risk is considered a new approach compared to the traditional approach. The obtained results confirm the applicability of the proposed model.

3. MATERIAL AND METHOD

3.1. Material

The medium-sized company operating in the industrial gas sector entered the sector by supplying liquid oxygen and filling oxygen gas. By obtaining a medical gas filling license, it met the medical gas needs of many public and private hospitals without any problems. In addition to filling argon, nitrogen and mixture gases, it increased its supply power by commissioning the acetylene gas production facility. The company, which has a tube test and control maintenance authorization certificate approved by the Ministry of Science, Technology and Industry, has an advanced inspection station. The company, whose main field of activity is gas filling and distribution, also provides supply and consultancy services to its customers on gas equipment. It also performs feasibility, project design, assembly and test controls regarding central gas distribution systems.

Occupational Health and Safety system is applied in the company, which is in the very dangerous class, in order to protect both the business and the health of workers. For this, it receives services from an occupational physician, occupational safety specialist and other health personnel. They carry out services such as occupational safety training, risk assessment, preparation of the emergency action plan, preparation of the explosion protection document, preparation of the annual work plan, design of the annual training plan, writing the final evaluation report, and continuous field surveillance.

The company has previously served in the field of construction. In this process, the expert team used the Fine Kinney risk analysis method for risk assessment. After the company moved to the gas filling sector, they adopted the risk analysis method they used before. Therefore, they used the Fine Kinney risk analysis method for the gas filling plant.

Gas filling process is carried out by trained and experienced personnel by taking all precautions. In the gas filling facility, the gas filling process begins when the liquid products are brought to the company by tankers. The liquid in the tankers is transferred to the fixed tanks by the authorized personnel. There are separate tankers and fixed tanks for each gas. The tubes to be filled are physically checked and the tubes that are suitable for filling are fixed with chains and placed on the filling ramps. The tubes are connected to the ramp with whips from their valves and the filling process is started with the valves in the tanks. All ramps have manometers for pressure control. The filling time and pressure differ for each gas. During the filling, the temperature, pressure and leakage control of the tube is carried out by authorized personnel. After the filling process is completed, the tubes are carefully separated from the ramps and the leakage is checked with foam or spray. The valves of the tubes without leakage problem are covered with heating packaging and caps are attached. The filled tube information is processed into the relevant forms. Full tubes are transported to the storage area. When the shipping time comes, the tubes are placed in vehicles suitable for tube transportation and the tubes are safely delivered to the customer. The gas filling flow diagram is given in the Figure 3.1 below.

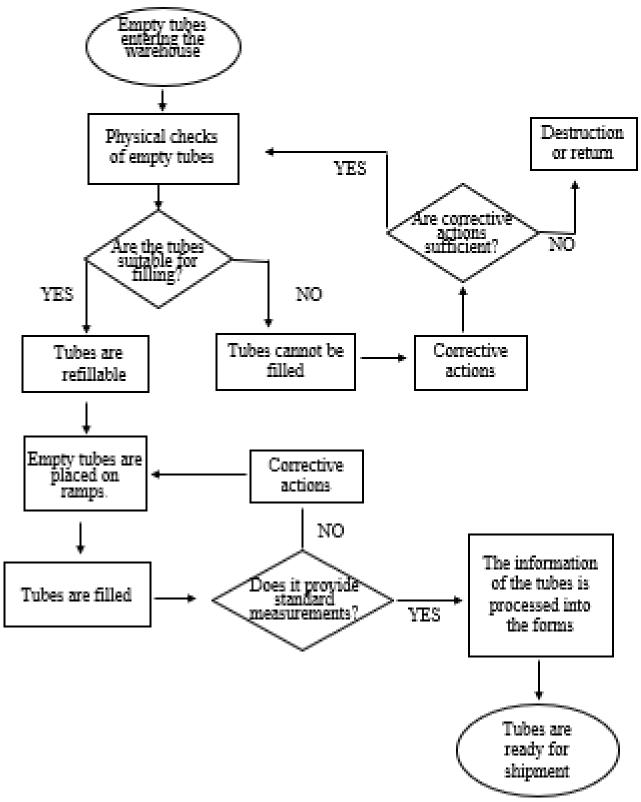

Figure 3.1. Gas filling process flow diagram

3.2. Method

This thesis consists of three steps and the methodology in the thesis is given in Figure 3.2. In the first step, the hazards in the gas filling facility are determined by using the literature and expert opinion, and the RPN value and risk classes of the hazards are determined with the Fine Kinney risk analysis method.

In step 2, the fuzzy logic approach is integrated into the risk analysis. Fine Kinney risk analysis scale values and membership functions of RPN value are defined. Since the rule-based fuzzy logic approach was used in the study, decision rules specific to the gas filling facility were developed and defined in this step.
In step 3, action selection is made for hazards with high fuzzy RPN values. Action plans are implemented to eliminate or minimize the effects of hazards. Each of the action plans requires manpower and a budget. This turns the problem into a decision problem. In this step, TOPSIS method, which is one of the multi-criteria decision-making approaches, is used to solve the decision problem. Action selection was carried out with the weighted TOPSIS approach by reflecting the importance of the hazards to the action selection.

Step 1. Performing Risk Analysis

- Identifying hazards
- Determination of Probability, Severity and Frequency values of hazards
- Determining the RPN value (Fine Kinney method)

Step 2. Performing fuzzy logic risk analysis

- Defining membership functions for Probability, Severity and Frequency and RPN value
- Determination of decision rules
- Determination of fuzzy RPN values

Step3. Choosing the action plan

- Weighting of hazards according to the group they affect with AHP
- Determination of actions
- Action selection with multi-criteria decision making method by considering weights (Weighted TOPSIS)

Figure 3.2. Flow diagram in the thesis

3.2.1. Fine-Kinney risk analysis

The Fine Kinney method was published in G. F. Kinney's 1976 article Practical Risk Analysis for Safety Management. The method was published under the name of practical risk analysis in occupational safety management at the time it was published. Later, it was named after Fine Kinney, who was the first person to propose the method by the world of science.

The Fine-Kinney method is a method that shows which jobs should be prioritized and where resources should be allocated according to the results of risk grading. By calculating the weight ratios of the risks, the rating is made and it is decided whether to take the precautions. The method gives more realistic results in line with the opportunity to use the statistics of the workplace.

The Fine Kinney risk analysis method is a qualitative method that allows the enterprise to use it together with its historical data and forecasts. In other words, if the risk analysis made with this method consists of confirmed accident and near-term data instead of just prediction, much more accurate results can be obtained. The Kinney method also takes into account not only the probability and frequency of accidents, but also the frequency with which persons at risk are exposed to hazards.

In this method, three parameters (likelihood, exposure and possible consequences) are considered for each hazard. And, a ‘‘Risk Priority Number (RPN)” is obtained by multiplying these parameters, as given in Equation (3.1).

Risk Priority Number = Likelihood of Hazardous Event x The Exposure Factor x Possible

Consequence (3.1)

In Fine-Kinney method has three parameters. And they state that; i)Likelihood is the probability of damage occurring over time; ii)Exposure factor indicates the frequency of hazard exposure; iii) Possible consequences is the amount of harm or damage to people, the workplace and the environment if a hazard occurs (Kinney and Wiruth, 1976).

The assessment tables for the concepts used to calculate the risk score are shown in Tables 3.1, 3.2 and 3.3, and the risk score itself is shown in Table 3.4 (Kinney and Wiruth, 1976)

Table 3.1. The values for the likelihood of a hazardous event (Kinney and Wiruth, 1976)

Likelihood	Value
Might well be expected	10
Quite possible	6
Unusual but possible	3
Only remotely possible	1
Conceivable but very unlikely	0.5
Practically impossible	0.2
Virtually impossible	0.1

Table 3.2. The values for the exposure factor (Kinney and Wiruth, 1976)

Exposure	Value
Continuous	10
Frequent (daily)	6
Occasional (weekly)	3
Unusual (monthly)	2
Rare (a few per year)	1
Very rare (yearly)	0.5

Table 3.3.The values for possible consequences (Kinney and Wiruth, 1976)

Possible Consequence	Value
Catastrophe (many fatalities, or > $\$10^7$ damage)	100
Disaster (few fatalities, or > $\$10^6$ damage)	40
Very serious (fatality, or> $\$10^5$ damage)	15
Serious (serious injury, or $\$10^4$ damage)	7
Important (disability, or $\$10^3$ damage)	3
Noticeable (minor first aid accident, or >$100 damage)	1

Table 3.4. The risk score definitions (Kinney and Wiruth, 1976)

Risk Score	Risk Situation
>400	Very high risk; consider discontinuing operation
200 to 400	High risk; immediate correction required
70 to 200	Substantial risk; correction needed
20 to 70	Possible risk; attention indicated
>20	Risk; perhaps acceptable

3.2.2. Fuzzy logic

The concept of Fuzzy Logic was first introduced by Lotfi A. Zadeh in an article titled "The Theory of Fuzzy Logic and Fuzzy Sets" published in 1965. However, it was used as a more frequently used term in the 1970s. It became much more popular in the 1980s when the Japanese used fuzzy logic principles in their production. Fuzzy logic applications are computer-assisted artificial intelligence systems that reason in a way that imitates human behavior and the functioning of nature.

Fuzzy logic principles do not work like classical logic principles. There are no completely true or completely false values in fuzzy logic principles. Instead, uncertain options such as partially correct or partially incorrect are considered in the variable range. It can process data and turn it into meaningful information. By using meaningful information, they can create control and decision-making processes with models close to human thought. However, when enriched with algorithms, it can simultaneously process data and control or decision-making processes.

3.2.3. Analytic hierarchy process (AHP)

The Analytical Hierarchy Process was first introduced by the Myers and Alpert duo in 1968 and was developed as a model by Professor Thomas Lorie Saaty in 1977 and made it usable in solving decision-making problems.

AHP is a decision-making and estimation method used when the decision hierarchy can be defined, giving the percentage distributions of decision points in terms of factors affecting the decision.

AHP represents judgments as pairwise comparisons and provides a basic scale of relative magnitudes expressed in units of dominance. A ratio scale of relative magnitudes expressed in priority units is then derived from each set of comparisons. An overall priority scale is then synthesized to obtain a ranking of the alternatives. From its axioms to its procedures, AHP has emerged as an independent decision-making theory, historically and theoretically different from utility theory (Staay, 1990).

AHP is based on one-to-one comparisons on a decision hierarchy, using a predefined comparison scale, in terms of the factors affecting the decision and the importance values of decision points in terms of these factors. As a result, the differences in importance translate into percentage distributions over the decision points.

AHP implementation steps (Saaty, 1987; Vaidya and Kumar,2006):

Step 1: Creating the hierarchical structure: At this stage, first of all, the main purpose of the decision problem should be determined.

Step 2: Creating pairwise comparison matrices: At this stage, each criterion is compared with each other. While making the comparison, the decision-maker evaluates by making use of Table 3.5.

Table 3.5. The 1-9 scales for pairwise comparisons in the AHP

Importance Intensity	Definition
1	Equal importance
3	Moderate importance of one over another
5	Strong importance of one over another
7	Very strong importance of one over another
9	Extreme importance of one over another
2,4,6,8	Intermediate values
Reciprocals	Reciprocals for inverse comparison

When evaluating with AHP in a decision problem with n criteria, As a result of the pairwise comparisons of the ith criterion and the jth criterion; where i=j is aij=1, otherwise aij=1/ aij; the matrix (A) given by equation 3.2 is formed.

$$A = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \cdots & \cdots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \cdots & \cdots & \alpha_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \alpha_{n1} & \alpha_{n2} & \cdots & \cdots & \alpha_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \alpha_{12} & \cdots & \cdots & \alpha_{1n} \\ \alpha_{21} & 1 & & & \alpha_{2n} \\ \cdots & \cdots & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & 1 & \cdots \\ \alpha_{n1} & \alpha_{n2} & & & 1 \end{bmatrix} \tag{3.2}$$

Step 3: Determination of relative importance values: Equation (3.3) is applied by making use of the column elements of matrix A and the vector B given in Equation (3.4) is obtained.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{3.3}$$

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix} \tag{3.4}$$

By combining n times B column vectors, the n x n-dimensional C matrix given in Equation (3.5) is formed.

$$C = \begin{bmatrix} c_{11} & c_{12} & \dots & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & \dots & c_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ c_{n1} & c_{n2} & \dots & \dots & c_{nn} \end{bmatrix} \tag{3.5}$$

Considering the row components of the C matrix, the priorities vector, in other words, the W vector showing the percent importance distributions, is obtained with Equations (3.6) and (3.7).

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{3.6}$$

$$W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} \tag{3.7}$$

Step 4: Consistency ratio: While calculating the importance or priority values of the criteria with the AHP method, inconsistencies may occur due to subjectivity. To measure this situation, the Consistency ratio is calculated and it is concluded that if this ratio is below 0.1, the solution is consistent, otherwise, a re-evaluation is required. Steps to be followed when calculating the consistency ratio;

1. As shown in Equation (3.8), matrix A is multiplied by the priority vector W.

$$D = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \cdots & \cdots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \cdots & \cdots & \alpha_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \alpha_{n1} & \alpha_{n2} & \cdots & \cdots & \alpha_{nn} \end{bmatrix} X \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ \vdots \\ w_n \end{bmatrix} \tag{3.8}$$

2. As given in Equation (3.9), each element of the D vector is divided into the corresponding elements in the priorities vector.

$$E_i = \frac{d_i}{w_i} \qquad i = 1, 2, \ldots\ldots\ldots, n \tag{3.9}$$

3. λ_{max} is calculated by equation (3.10).

$$\lambda_{max} = \frac{\sum_{i=1}^{n} g_i}{n} \tag{3.10}$$

4. Taking into account λ_{max}, Equation (3.11) calculates the Consistency Index (CI), which shows the degree of deviation.

$$CI = {(\lambda_{max} - n)} \big/ {(n-1)} \tag{3.11}$$

5.After finding the Consistency Index (CI), Equation (3.12) and Consistency Ratio (CR) are calculated with the help of Random Consistency Index (RI).

$$CR = CI / RI \tag{3.12}$$

RI varies according to the number of criteria considered in the AHP, and RI values depending on the number of criteria are given in Table 3.6.

Table 3.6. RI values

N	1	2	3	4	5	6	7
RI	0	0	0,52	0,89	1,11	1,25	1,35

3.2.4. The technique for order of preference by similarity to ideal solution (TOPSIS)

The TOPSIS method was introduced by Chen and Hwang (1992) regarding the work of Hwang and Yoon (1981). TOPSIS method is one of the multi-criteria decision-making methods.

Evaluation of decision options is based on two main points: positive ideal solution and negative ideal solution. The TOPSIS method, it is aimed to determine the decision option with the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. The TOPSIS method reveals the distances from the positive and negative ideal solutions, and also reveals the ideal and non-ideal solutions. The positive-ideal solution is the one that maximizes the benefit criteria and minimizes the cost criteria. The negative-ideal solution maximizes the cost criteria while minimizing the benefit criteria. In summary, the positive-ideal solution consists of all the best attainable values of the criteria, and the negative-ideal solution consists of all the worst attainable values of the criteria (Krohling and Pacheco, 2015).

The TOPSIS process is performed as follows (Krohling and Pacheco, 2015):

Step 1

Build an evaluation matrix of m alternatives and n criteria, with the intersection of each alternative and the criteria given as x_{ij}, so we have a $(x_{ij})_{mxn}$ matrix.

Step 2

The matrix $(x_{ij})_{mxn}$ is then normalized to form the matrix

$R = (r_{ij})_{mxn}$, using the normalisation method

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k-1}^{m} x_{kj}^2}}, \qquad (3.13)$$

İ = 1, 2,..., m, j = 1, 2,...,n

Step 3

Calculate the weighted normalized decision matrix

$T_{ij} = r_{ij} . w_j$, i = 1, 2,...,m, j = 1, 2,...,n (3.14)

Where

$w_j = W_j \Big/ \sum_{k=1}^{n} W_k,$ j = 1, 2,...,n so that $\sum_{i-1}^{n} w_i = 1$ and (3.15)

W_j is the original weight given to the indicator v_j , j = 1, 2,...,n.

Step 4

Determine the worst alternative (A_w) and the best alternative (A_b):

A_w = {(max(t_{ij} I i = 1, 2,...,m) I j ∈ J_), (min(t_{ij} I i= 1,2,...,m) I j ∈ J_+)} = { t_{wj} I j = 1,2,...,n}, (3.16)

A_b = {(min(t_{ij} I i = 1, 2,...,m) I j ∈ J_), (max(t_{ij} I i= 1,2,...,m) I j ∈ J_+)} = { t_{bj} I j = 1,2,...,n}, (3.17)

Where,

J_+ = { j = 1,2,...,n I j } associated with the criteria having a positive impact, and

$J\_ = \{ j = 1,2,...,n \ I \ j \}$ associated with the criteria having a negative impact.

Step 5

Calculate the L^2-distance between the target alternative i and the worst condition A_w

$$d_{iw} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{wj})^2}, \quad i = 1, 2, \ldots, m, \tag{3.18}$$

and the distance between the alternative i and the best condition A_b

$$d_{ib} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{bj})^2}, \quad i = 1, 2, \ldots, m \tag{3.19}$$

Where d_{iw} and d_{ib} are L^2-norm distances from the target alternative i to the worst and best conditions, respectively.

Step 6

Calculate the similarity to the worst condition:

$$S_{iw} = d_{iw} / (d_{iw} + d_{ib}), \ 0 \leq s_{iw} \leq 1, \ i = 1, 2,...,m. \tag{3.20}$$

$S_{iw} = 1$ if and only if the alternative solution has the best condition;

And

$s_{iw} = 0$ if and only if the alternative solution has the worst condition.

Step 7

Rank the alternatives according to s_{iw} (i = 1, 2,...,m).

4. RESULTS AND DISCUSSION

Step 1: Identifying Hazards

The hazards in the gas filling facility were determined as a result of the company's Occupational Health and Safety experts and literature review. While determining the hazards, the filling facility, production area, stock and transportation processes, quality control department and general hazards that may be encountered in the whole company were taken into consideration. Hazards and possible risks associated with hazards are given in Table 4.1.

Table 4.1. Gas filling plant hazards and risks

Number of hazards	Hazards	Risk
H1	Sparking from contact with gratings on the ground during the transportation of the tubes	Fire
H2	Falling of tubes as a result of not being securely fixed	Explosion
H3	Heating of the tubes during filling	Combustion, explosion
H4	Gas leakage during filling	Suffocating environment, fire
H5	Incorrect gas filling into the wrong tube	Explosion, danger to human health
H6	Leakage in the tube filling hose	Rapid breaking and striking of copper whip, death, injury
H7	The inability of whips to fix during filling	Injury due to ejection of the filling gun, death
H8	Working with oily gloves and oily materials in filling pump maintenance	Fire
H9	Tubes tipping over during shipping	Work accident, injury, traffic accident
H10	The pressure rise in cryogenic liquid tanks	The explosion of the tank and the spread of the cryogenic liquid

H11	Splashing of the product while delivering the product from the cryogenic liquid tank to the liquid tanker	Cold burning
H12	Drying and cleaning the tubes improper operation	Work accident, injury, death
H13	Insufficient grounding of construction equipment and steel construction roof used in the field	Work accident, injury, death
H14	Painting the tubes while under pressure	Work accident, injury, death
H15	Failure to record the details of the experiment performed by the personnel	Non-prosecution
H16	Unsuitable valves	Work accident, injury, death
H17	Failure to check the tightness after installing the valve	Work accident, fire, injury, death
H18	Inappropriate tube muff	Work accident, injury, death
H19	Keeping the protection covers open during the test	Work accident, injury, death
H20	Operation by sparking in the test area	Work accident, injury, death
H21	Not having the proper type of fire extinguisher	Injury as a result of not being able to intervene immediately in a fire that may break out, death, fire
H22	Absence of emergency exit signs	Difficulty in emergency evacuation
H23	Not using personal protective equipment (PPE)	Work accident, occupational diseases
H24	Storing flammable, combustible materials near electrical installations	Work accident
H25	Absence or failure of residual current relays in electrical panels	Electric shock, combustion, injury, death

H26	The doors of the electrical panels are not locked	Electric shock, combustion, injury, death
H27	No warning signs	Injury

Step 2: Performing the risk analysis

The Fine Kinney risk analysis method parameters, Probability, Severity and Frequency values for each hazard were determined by the team identifying the hazards in Step 1, using Table 3.1, 3.2, 3.3. P, S and F values; RPN values obtained according to Equation (3.1) and the explanation of risk according to these RPN values according to Table 3.4 are given in Table 4.2. According to the results obtained in Table 4.2, 2 of the 27 hazards are at Very High Risk, 8 of them are High Risk, 4 of them are Medium Risk, 10 of them are Low risk, and the remaining 3 hazards are in the Very Low Risk class. Although the first group to take action within the framework of the limited resources of the company is those in the Very High risks class, H8, which has the highest RPN value according to the classical Fine Kinney assessment, seems to be the first hazard to be taken action. However, in this evaluation, no distinction is made between probability, frequency and severity scales, and the characteristics of the environment in which the danger occurs are not taken into account. For example, H5 is in third place from the last in terms of RPN, and in case of this danger, multiple casualties will occur according to the information obtained from the Severity value. In addition, H11, H12 and H17 hazards are at the same level of importance according to the classical Fine Kinney method since they have the same RPN value with different P, S and F parameters. Although it has RPN values, the importance of each of the P, S and F scales in different combinations on the hazard may differ, making it necessary to evaluate the different combinations of P, S and F parameters separately by the expert team. Therefore, in the study, hazards were evaluated with rule-based fuzzy logic risk analysis.

Table 4.2. Fine Kinney Risk analysis for Gas filling plant

Number of hazard	Probability (P)	Frequency (F)	Severity (S)	RPN	Risk Category
H1	3	2	15	90	Medium risk
H2	1	1	40	40	Low risk
H3	3	6	40	720	Very high risk
H4	0,5	1	100	50	Low risk
H5	0,2	2	40	16	Very low risk
H6	1	1	15	15	Very low risk
H7	0,5	3	15	22,5	Low risk
H8	3	3	100	900	Very high risk
H9	1	6	40	240	High risk
H10	1	3	100	300	High risk
H11	1	3	15	45	Low risk
H12	1	3	15	45	Low risk
H13	3	3	15	135	Medium risk
H14	3	3	15	135	Medium risk
H15	3	1	7	21	Low risk
H16	3	6	15	270	Low risk
H17	0,5	6	15	45	Low risk
H18	3	3	15	135	Medium risk
H19	0,2	3	15	9	Very low risk
H20	3	3	40	360	High risk
H21	1	6	40	240	High risk
H22	3	3	7	63	Low risk
H23	3	6	15	270	High risk

H24	3	3	40	360	High risk
H25	1	3	100	300	High risk
H26	3	3	40	360	High risk
H27	1	3	15	45	Low risk

Step 3: Performing the Fuzzy Fine Kinney Risk Analysis

Based on the classical Fine Kinney risk analysis scale, the fuzzy Fine Kinney scale for the gas filling facility was prepared with risk analysis experts and the resulting fuzzy Fine Kinney Risk analysis was coded in MATLAB 18b Fuzzy Logic Designer Tool.

Probability, severity and frequency parameters in the Fuzzy Fine Kinney risk analysis scale are input; the risk score was taken as output. Figure 4.1 shows the fuzzy design created in this study according to the input and output. As seen in Figure 4.1, the 'mamdani min max' method was used.

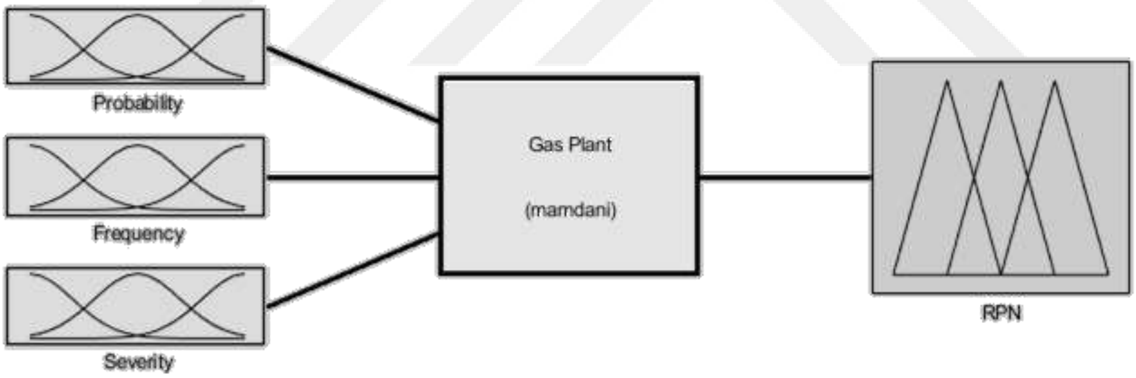

Figure 4.1. Fuzzy Fine Kinney design

In fuzzy Fine Kinney risk analysis, which includes 3 inputs and a single output, probability, severity inputs and output consist of 5 levels, and the frequency input value consists of 6 levels. Membership function values created for input and output are given in Table 4.3. Membership functions created for each input and output are given in Figure 4.2, 4.3, 4.4 and 4.5.

Table 4.3. Membership functions for inputs and output

Probability	Frequency	Severity	RPN
Zmf(0,1)	Zmf(0,1)	Zmf(0,7)	Zmf(0,70)
Tria(0.5,1,3)	Tria(0.5, 1, 2)	Tria(3, 7,15)	Tria(20, 70, 150)
Tria(1,3,6)	Tria(1, 2, 3)	Tria(7, 15, 40)	Tria(100,200,250)
Tria(4,6,8)	Trai(2, 3, 6)	Tria(20,40,70)	Tria(200, 300, 350)
Smf(6,10)	Trai(4,6,8)	Smf(50, 100)	Smf (300,400)
	Smf(6, 10)		

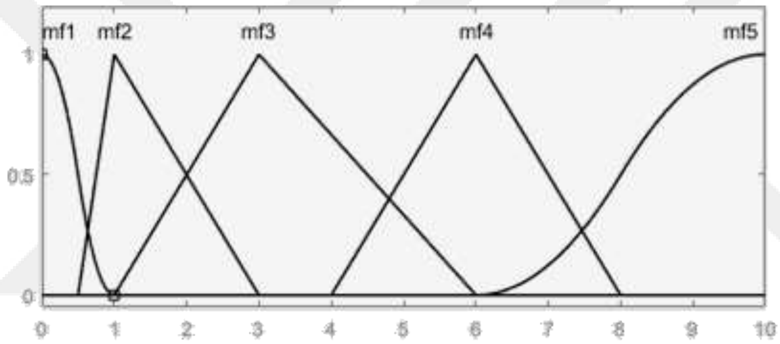

Figure 4.2. Membership function plots of Probability variable.

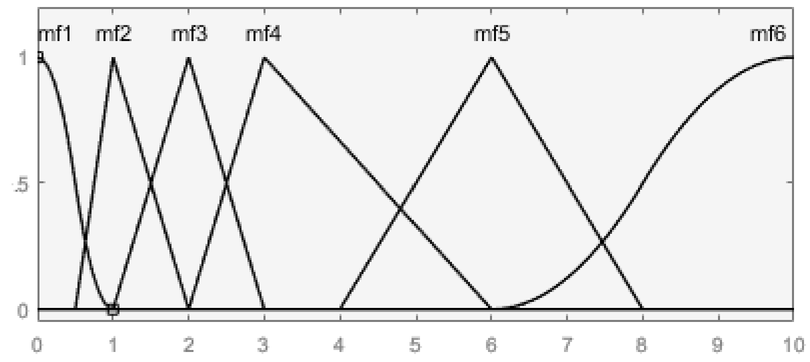

Figure 4.3. Membership function plots of Frequency variable.

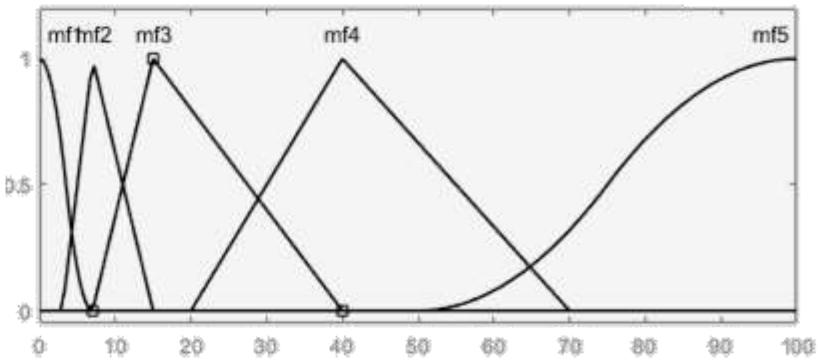

Figure 4.4. Membership function plots of Severity variable.

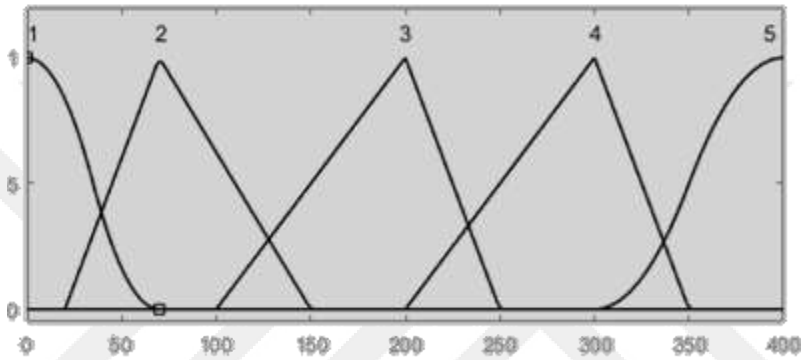

Figure 4.5. Membership function plots of RPN variable.

Considering the membership functions of probability, severity and frequency inputs, 150 decision rules specific to the gas filling facility were created. According to the developed decision rules, gas filling facility risks calculated with classical Fine Kinney risk analysis, Classic Fine Kinney and Fuzzy Fine Kinney risk scores and risk classes are given in Table 4.4.

Table 4.4. Fuzzy Fine Kinney Risk Analysis

Number of Hazard	Probability	Frequency	Severity	Classic-RPN	Fuzzy RPN
H1	3	2	15	90	183
H2	1	1	40	40	80
H3	3	6	40	720	283
H4	0,5	1	100	50	181
H5	0,2	2	40	16	183

H6	1	1	15	15	80
H7	0,5	3	15	22,5	81,7
H8	3	3	100	900	372
H9	1	6	40	240	283
H10	1	3	100	300	372
H11	1	3	15	45	183
H12	1	3	15	45	183
H13	3	3	15	135	183
H14	3	3	15	135	183
H15	3	1	7	21	80
H16	3	6	15	270	283
H17	0,5	6	15	45	181
H18	3	3	15	135	183
H19	0,2	3	15	9	80,1
H20	3	3	40	360	283
H21	1	6	40	240	283
H22	3	3	7	63	80
H23	3	6	15	270	283
H24	3	3	40	360	283
H25	1	3	100	300	372
H26	3	3	40	360	283
H27	1	3	15	45	183

Step 4: Determining the importance levels of the groups affected by the risks

The groups affected by the hazards occurring in the enterprises may be different. When the hazards in the company where the application is made are examined, it is seen that the hazards affect the customers, residents of the environment, visitors and employees. While grouping, grouping was made by taking into account the exposure time of the groups to possible dangers and the rate of exposure to the danger in case of danger. For example, if an explosion event occurs while filling the tubes, it is expected that this danger will affect the employee, resident of the environment, and the visitor if any. However, since the proximity to this explosion point will be different in each group, the rates of being affected by the hazard will also differ. For this, when determining the importance level of the hazard, it can be ensured that the hazard and the affected group/groups are taken into account at the same time by taking the sum of the importance levels of the groups it affects. While determining the importance level of groups that may be affected by the hazard, the Analytical Hierarchy Process method (Table 3.5), which is a pairwise comparison matrix, was used. The comparison chart made with AHP is given in Table 4.5.

Table 4.5. AHP Comparison

	Employee	**Visitor**	**Customer**	**A resident of the environment**
Employee	1	7	5	7
Visitor	0,14285	1	0,33	3
Customer	0,2	3	1	3
Resident of the environment	0,14285	0,333	0,333	1

The comparison given in Table 4.5 was evaluated with Equation (3.2)-(3.7) and the weight values in Table 4.6 were obtained. As seen in Table 4.6, the highest impact of the hazards occurring in the gas filling facility, according to the expert opinion, is on the employees. The fact that the activities in the gas filling facility are manual and the physical workers are in the production area for a long time bring about the dangers that may occur have a greater impact on the employees. According to Table 4.6, employees are followed by customers, visitors and residents of the environment with the lowest level of importance. The effect of being in the customer group company more frequently and for a longer period of time than visitors can be seen on the evaluation results. Although the residents of the environment will be affected by possible hazards, their distance to the danger point will be low within the company. Thus, it will be an expected result that the impact of the hazard on the resident of the environment will be lower than other groups. As a result of the evaluation in Table 4.6, the consistency index was obtained as 0.07. Since this value is less than 0.10, the AHP weight values were taken into account in the TOPSIS evaluation.

Table 4.6. AHP values

Groups	**AHP value**
Customer	0,190
Resident of the environment	0,058
Visitor	0,101
Employee	0,650

Step 5: Determination of action plans

H8, H10 and H25 hazards have the same fuzzy RPN (372) level of importance and constitute the most critical hazards in a gas filling facility (in Table 4.4). These hazards are followed by H3, H9, H16, H20, H21, H23, H24 and H26 hazards with the same fuzzy RPN (283). Actions are taken in companies to eliminate hazards if possible, and if not, to reduce their impact, RPN value. Considering these hazards, the actions that can be taken in the company have been determined by the team performing the risk analysis and are given in Table 4.7. As seen in Table 4.7, the actions were classified into two groups. In these actions, the first group can be implemented in the current situation and the company will not need to allocate limited resources such as workforce and budget to realize these actions. However, the second group, which should be prioritized within the constraints, and the company's limited resources of labor and budget resources are needed to carry out the actions in its class. The company aims to manage its limited resources most effectively and to minimize the negative effects of hazards by affecting more than one danger with the action plan implemented. In this context, taking into account the relationship between actions and hazards, action selection was made with the TOPSIS approach, one of the multi-criteria decision-making methods.

Table 4.7. Action plans

	Can be done in a short time	Should be prioritized within constraints
Written assignments should be made during the maintenance-repair of the filling pump.	+	
Filling instructions must be observed.	+	
Cryogenic liquid tanks should be constantly checked and the controls should be reported.	+	
Periodic maintenance of cryogenic liquid tanks should be done by accredited institution.		+
The calibration of the pressure gauge of cryogenic liquid tanks should be done regularly.		+
Receiving a warning as a result of the increase in the temperature of the tubes by installing a technological mechanism on the filling ramp		+
Filling should be done by experienced personnel.	+	
A suitable leakage current relay must be installed in the electrical panels.		+
Procurement and use of insulating mats		+
Supply of tube transport vehicles		+
Technological developments should be used in the process.		+
It is checked whether there is a pi sign on the valves. Valves without the pi mark are scrapped.	+	
All threads are checked with bell gauges to ensure that the thread diameters, shape, length and taper of the valves are appropriate.	+	
Operations that generate sparks should be	+	

started on site with written permission.		
Gas measurement is made before working with spark.	+	
A new closed area should be created for fabrication work near the test area.		+
Sufficient number and type of fire extinguisher should be available in the working area.		+
Fire training should be given to the personnel and emergency teams should be formed.		+
A warning sign should be placed around the fire extinguisher.	+	
PPE should be used.	+	
A locked storage area should be created where flammable and explosive materials will be stored.		+
Chemicals should be stored in accordance with their MSDS.	+	
Care should be taken to keep the electrical covers closed.	+	
Maintenance-repair of electrical panels is done only by an electrician.		+

Step 6: Choosing the most appropriate action with the weighted-TOPSIS method

Taking into account the hazards of H8, H10, H25, H3, H9, H16, H20, H21, H23, H24 and H26, which are in the first two groups according to the fuzzy RPN values, the action selection that maximizes the benefit of the company will be realized with the weighted-TOPSIS method. The weight score of the group affected by each hazard will also be taken into account in the TOPSIS evaluation in this study. In Table 4.8, the groups affected by these hazards and the sum of the AHP weight scores of these groups are given.

Table 4.8. Hazards and affected Groups

Number of Hazard	Hazard	Affected group	Sum of AHP weight points
H8	Working with oily gloves and oily materials in filling pump maintenance	Employees, visitors	0,751
H10	The pressure rise in cryogenic liquid tanks	Everyone	1
H25	Absence or failure of residual current relays in electrical panels	Employees, visitors	0,751
H3	Heating of the tubes during filling	Everyone	1
H9	Tubes tipping over during shipping	Employees, environment	0,708
H16	Unsuitable valves	Employees	0,65
H20	Operation by sparking in the test area	Employees, visitors	0,751
H21	Not having the proper type of fire extinguisher	Employees, visitors	0,751
H23	Not using personal protective equipment (PPE)	Employees, visitors	0,751
H24	Storing flammable, combustible materials near electrical installations	Everyone	1
H26	The doors of the electrical panels are not locked	Employees	0,65

As the first step in the implementation of the TOPSIS method, the relationship between the action plans and hazards was scored. Scoring was carried out by the expert team who performed the risk analysis. Table 4.9 shows the relationship between action plans and hazards. For example, although the action of ‘Periodic maintenance of cryogenic liquid tanks should be done by accredited institution’ has a very strong relationship with the H10 hazard, the level of association with other hazards is very low. This shows that the action of 'Periodic maintenance of cryogenic liquid tanks should be done by accredited institution' affects the H10 hazard. Considering the action of 'Sufficient number and type of fire extinguisher should be available in the working area.', it has an impact on the hazards of H8, H10, H25, H3, H9, H20, H21, H24 and H26, although at different levels of importance.

Table 4.9. Relationship between action plans and hazards

	0,751	1	0,751	1	0,708	0,65	0,751	0,751	0,751	1	0,65
Actions	H8	H10	H25	H3	H9	H16	H20	H21	H23	H24	H26
Periodic maintenance of cryogenic liquid tanks should be done by accredited institution.	1	10	1	1	1	1	1	1	1	1	1
The calibration of the pressure gauge of cryogenic liquid tanks should be done regularly.	1	10	1	1	1	1	1	1	1	1	1
Receiving a warning as a result of the increase in the temperature of the tubes by installing a technological mechanism on the filling ramp	1	1	1	10	1	1	1	1	1	1	1
A suitable leakage current relay must be installed in the electrical panels	1	1	10	1	1	1	1	1	1	1	1

Procurement and use of insulating mats	1	1	10	1	1	1	1	1	1	1	5
Supply of tube transport vehicles	1	1	1	1	10	1	1	1	1	1	1
Technological developments should be used in the process.	1	1	1	1	10	1	1	1	1	1	1
A new closed area should be created for fabrication work near the test area.	1	1	1	1	1	1	10	1	1	1	1
Sufficient number and type of fire extinguisher should be available in the working area.	5	5	5	5	5	1	10	10	1	10	5
Fire training should be given to the personnel and emergency teams should be formed.	1	1	1	1	1	1	1	10	1	1	1
A locked storage area should be created where flammable and explosive materials will be stored.	1	1	1	1	1	1	1	1	1	10	1
Maintenance-repair of electrical panels is done only by an electrician.	1	1	10	1	1	1	1	1	1	1	10

In Table 4.9, together with the hazard-action relations, the importance levels are also included, taking into account the groups affected by the hazards. Considering these values, Equation (3.13)-(3.20) was applied and as a result of TOPSIS evaluation, the final weight scores of the actions in Table 4.10 were obtained.

Table 4.10. Weighted TOPSIS value for actions

Number of Action	Actions	d_{iw}	d_{ib}	$d_{iw}+d_{ib}$	Weight points
A1	Periodic maintenance of cryogenic liquid tanks should be done by accredited institution.	1,452342	0,588348	2,04069	0,288309
A2	The calibration of the pressure gauge of cryogenic liquid tanks should be done regularly.	1,452342	0,588348	2,04069	0,288309
A3	Receiving a warning as a result of the increase in the temperature of the tubes by installing a technological mechanism on the filling ramp	1,378643	0,744845	2,123488	0,350765
A4	A suitable leakage current relay must be installed in the electrical panels	1,522986	0,368734	1,891719	0,19492
A5	Procurement and use of insulating mats	1,473323	0,422469	1,895792	0,222846
A6	Supply of tube transport vehicles	1,510608	0,416551	1,927158	0,216148
A7	Technological developments should be used in the process.	1,407114	0,459631	1,866744	0,24622
A8	A new closed area should be created for fabrication work near the test area.	1,498629	0,457777	1,956407	0,233989
A9	Sufficient number and type of fire extinguishers should be available in the working area.	0,66334	1,145164	1,808503	0,633211
A10	Fire training should be given to the personnel and emergency teams should be formed.	1,378737	0,508024	1,886761	0,269257
A11	A locked storage area should be created where flammable and explosive materials will be stored.	1,418683	0,608563	2,027246	0,300192
A12	Maintenance-repair of electrical panels is done only by an electrician.	1,450603	0,592622	2,043225	0,290042

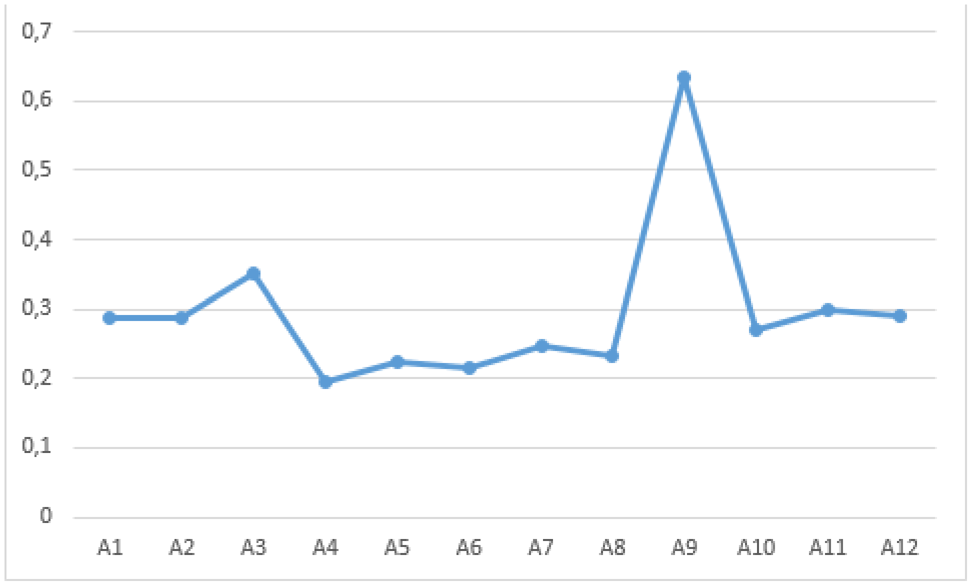

Figure 4.6. Wieghted Topsis value

As can be seen from Table 4.10 and Figure 4.6, the action 'Sufficient number and type of fire extinguisher should be available in the working area.' has the highest weight score. This action is followed by the actions 'Receiving a warning as a result of the increase in the temperature of the tubes by installing a technological mechanism on the filling ramp' and 'A locked storage area should be created where flammable and explosive materials will be stored'. Thus, when it is necessary to choose among 12 possible actions to maximize the expected benefit from limited resources in the company, it is appropriate to take actions in the order of A9, A3, and A11. It is expected to create a positive effect on more than one hazard at the same time and to eliminate or minimize the negativities that will occur due to work accidents that will occur in the company.

5. CONCLUSION

Labor and cost losses due to work accidents and occupational diseases in companies cause the importance of occupational health and safety studies to increase day by day. In addition to the increasing awareness in companies, the legal regulations and obligations of the state in the field of occupational health and safety have led to an increase in the studies on risk analysis due to occupational health and safety. Although there are many methods used in risk analysis studies, the basis of risk analysis studies is to determine the hazards and to create the risk score of the hazards. The criticality levels are determined according to the hazards risk score. In cases where classical risk analyzes are not sensitive enough, hybrid risk analysis methods can be used. In this thesis, the hazards occurring in the gas filling facility were defined and the risk scores of these hazards were determined by the expert team according to the Fine Kinney risk analysis method. According to the classical Fine Kinney risk analysis assessment, the hazards of 'Working with oily gloves and oily materials in filling pump maintenance' and 'Heating of the tubes during filling' have the highest risk score and are in the 'Very High' risk class.

No distinction is made between the Probability, Frequency and Severity parameters in the Classical Fine Kinney scale, and the characteristics of the applied firm are not taken into account. To reduce the effects of these negative effects, in this study, the hazards were evaluated with the Fuzzy Fine Kinney risk analysis. Probability, frequency and severity parameters in Fine Kinney risk analysis are input; RPN value is accepted as output and membership functions are defined. The decision rules determined by considering the gas filling facility hazards were also determined in this step. As a result of fuzzy Fine Kinney risk analysis evaluation, the most critical hazards were determined as 'Working with oily gloves and oily materials in filling pump maintenance', 'Pressure rise in cryogenic liquid tanks' and 'Absence or failure of residual current relays in electrical panels'. Expressing different hazards as critical hazards as a result of Classical and Fuzzy Fine Kinney risk analysis shows the difference between the two methods. The fact that the characteristics of the firm are also reflected in the risk analysis in the Fuzzy Fine Kinney risk analysis enables us to interpret that the results of the Fuzzy Fine Kinney risk analysis are more meaningful for the firm.

After the companies identify the hazards, they create action plans to eliminate the hazards if possible and to reduce the effects if this is not possible. Action plans cannot be implemented for every hazard, as the action plans require labor and budget in addition to the ordinary activities of the companies. For this reason, action plans are implemented starting from hazards with high risk scores. However, when an action plan is effective in reducing the impact of more than one hazard, the choice of action becomes a complex decision problem. This situation enables action selection to be made with multi-criteria decision making methods. In this study, action plans were defined for critical hazards as a result of fuzzy fine kinney risk analysis. These action plans are divided into two groups as those that require labor-budget and those that do not. Action plans that do not require labor and/or budget are not taken into account in the action selection problem. Among the actions that require labor and/or budget, the action selection was made with the TOPSIS method, taking into account the relationships with the hazards. While applying the TOPSIS method, the importance levels of the groups affected by the hazards were determined by AHP and actions were determined by reflecting these AHP weights to the TOPSIS method. The most important action to be taken into account in the gas filling facility has been determined as 'Sufficient number and type of fire extinguisher should be available in the working area'. If other action can be taken within the limited workforce and budget possibilities, 'Receiving a warning as a result of the increase in the temperature of the tubes by installing a technological mechanism on the filling ramp' has been determined as the second action plan. By reflecting the relationship of action plans with hazards and the weights of groups affected by hazards to the action selection problem, it is aimed to use company resources effectively and maximize company benefits.

6. RECOMMENDATIONS

The number of hazards examined in future studies can be increased and the application can be carried out in another sector. In this study, the definitions of membership functions created in fuzzy logic risk analysis can be changed and a different risk analysis method can be considered. In addition to the risk analysis studies of current hazards, hazard score estimations can be made for the future period. When choosing the action plans, a mathematical model can be established by taking into account the constraints such as cost and labor, which are the limited resources of the company. Thus, action selection can be performed with the optimization model. By integrating these estimation results into the action plan selection, the appropriate action plan for the company can be determined.

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