Action selection in risk assessment with fuzzy Fine–Kinney-based AHP-TOPSIS approach: a case study in gas plant

Bahar Dogan1 · Murat Oturakci1 · Cansu Dagsuyu1

Received: 28 February 2022 / Accepted: 24 April 2022 / Published online: 2 May 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
In this study, 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 score is obtained in different combinations of scale values in the classical Fine–Kinney risk analysis method and the characteristics/constraints 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 company resources, the action selection was performed with the TOPSIS method, taking into account their relationship with the hazards by integrating the weights, which was calculated with the AHP method, of affected groups. The effect of operating constraints is included in the last step of the study to calculate the final weights. Calculating the results by including the risk-affected groups and company constraints and ranking the actions reveals that the study is an original, objective, and applicable study.

Keywords Fine–Kinney method · Fuzzy · AHP · TOPSIS · Action selection

Introduction
Conducting risk analysis in every business is a necessity in terms of occupational health and safety. The OHSAS 18,001 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 by the general strategies of the organizations and to analyze them within the framework of a continuous improvement approach (Hohnen and Hasle 2018). In risk analysis, 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. For risks, considering the unique characteristics of the enterprise, one of the appropriate quantitative and qualitative methods such as L-type matrix analysis, X-type matrix analysis, Fine–Kinney method, failure modes and effect 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 analysis, and job safety analysis (JSA) is selected and analyzed based on international standards (Oturakci et al. 2015). It is important to eliminate the risks by using mentioned methods, starting 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.

In this study, it is aimed to propose a more objective and more sensitive evaluation method for risk analysis and to select an action plan according to the proposed 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 performed to be ignored. In this case, it is not known whether parameters are more important than other. In this study, a more precise evaluation is realized 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 hazard in the company can be ignored. In some cases, the hazard with a lower risk importance score may be of greater importance for the company. 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 makes the action selection problems more complex. In this study, an integrated multi-criteria decision (MCDM) method for action selection is used to solve to overcome complexity.

In this study, first, 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. Then, an action plan was created by specifying many actions with the same team to eliminate the hazards and the risks arising from these hazards and/or minimize their effects. In the next step of the study, the action selection was performed 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 prioritized. In the last step, after the action priority was realized, the company constraints were identified, the importance weights of these constraints were determined, and a new action weight result was calculated by evaluating the relations of the determined constraints with the actions. In this way, both groups affected by hazards and operational constraints are included in the action selection.

The main motivation of the study is that the risk assessment methods are subjective and the action plans based on these assessments are not realistic. This study is original in terms of its objective and realistic evaluation and application in terms of including fuzzy logic perspective in risk assessment, including groups affected by hazards in action selection and then the impact of operational constraints. In addition to the stated theoretical contributions, the contribution of the study to practice has also been revealed.

The organization of the study is as follows: after the introduction part, a literature study is presented. In the next part, the materials and methods of the study are stated, and in the fourth part, the results and discussion part is presented in detail. In the fifth and last part of the study, the conclusion is given.

**Literature review**

The literature review part of the study is divided into 3 main parts. First, the literature on the Fine–Kinney method, which was also used in this study, was examined. Then, the studies that made risk assessments by using multi-criteria decision-making methods were examined. Finally, fuzzy logic-based studies used in risk assessment studies were included in the literature review.

First, studies using the Fine–Kinney method were examined. Oturakci et al. (2015) proposed a new approach for the Fine–Kinney method. Alternative scales have been constructed by using interpolation methods for the probability and frequency scales. The results of the application show that the classical method is insufficient at certain points and those 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. 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. Gul and Celik (2018) presented the application of a new occupational health and safety risk assessment approach that includes the Fine–Kinney method and a fuzzy rule-based expert system. This approach includes a combination of the Fine–Kinney method and fuzzy rule-based expert system. 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. Zhang et al. (2020) 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 prevent risks from occurring. Tang et al. (2021) 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. 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 risks. Kuleshov et al. (2021) used the Fine–Kinney method to evaluate the severity of the results of an accident as one of the occupational risk components. Derse (2021) aimed to propose a risk assessment for natural disasters by using the Fine–Kinney method.

When risk analysis studies based on multi-criteria decision-making methods are examined; Khadam and Kaluarachchi (2003) utilized risk assessment and multi-criteria decision analysis for the management of contaminated groundwater resources. 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. Catrinu and Nordgård (2011) examined integrating multi-criteria decision support and risk analysis under uncertainty in electricity distribution system asset management. Tamošaitienė 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. Malekmohammadi and Rahimi Blouchi (2014) investigated an ecological risk assessment (ERA) process to identify stress factors and responses within an ecosystem-based approach. Bentaleb et al. (2015) wanted to analyze and evaluate risk factors within the dry port–seaport system using a multi-criteria approach. 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). Senthil et al. (2017) investigated the risks involved in reverse logistics using hybrid multi-criteria decision-making methods in a plastic recycling company. Srinivasan and Kamalakannan (2018) considered risk assessment in financial institutions as a multi-criteria decision-making problem. They proposed a multi-objective genetic algorithm (MOGA) to analyze financial data for risk analysis and forecasting. 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. Shariat et al. (2019) applied a risk analysis study in urban stormwater systems. They proposed multi-criteria decision-making (MCDM), geographic information systems (GIS), and fuzzy set theory to identify criteria influencing risk analyze data and information and formulate problem uncertainty. 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.

When fuzzy logic-based risk analysis studies are examined, De Ru and Elof (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. 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. Tah and Carr (2000) presented a study aiming to develop knowledge-based robust system techniques by using fuzzy logic that can improve risk analysis and management processes for the sustainability of the construction industry. Gallego et al. (2004) proposed a risk assessment methodology using fuzzy logic for lightning risk assessment. 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. Wulan and Petrovic (2012) present a fuzzy logic-based system for risk analysis and assessment within their corporate collaboration. Alidoosti et al. (2012) developed a method to analyze critical risk elements in pipeline systems by using fuzzy logic. Shi et al. (2014) examined the analysis of delivery methods on how to reduce the risk of a construction program with the help of fuzzy sets. 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. Chen and Kezunovic (2016) presented a new method of fuzzy risk-based decision-making using weather effects. Peikert et al. (2017) present a method based on fuzzy logic and set theory that analyzes the risk of an IT System and around a facility. 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. In addition to fuzzy logic-based studies, Gul et al. (2021) have made significant contributions to the Fine–Kinney literature under the integration of fuzzy logic.
and MCDM with their book of *Fine–Kinney-Based Fuzzy Multi-criteria Occupational Risk Assessment* that includes Fine–Kinney-based occupational risk assessment using fuzzy best and worst method (F-BWM) and fuzzy MAIRCA; interval type-2 fuzzy TOPSIS; interval-valued Pythagorean fuzzy VIKOR; intuitionistic fuzzy TODIM; hexagonal fuzzy MULTIMOORA; single-valued neutrosophic TOPSIS; interval type-2 fuzzy QUALIFLEX; and interval type-2 fuzzy VIKOR in separate chapters. Gul et al. (2022) have studied the prioritization of control measures in Fine–Kinney-based risk assessment by using Bayesian best–worst method (BBWM) and Fuzzy VIKOR method. The model of the study has been applied to a liquid fuel tank area of a gas station. In recent years, it has been observed that risk assessment studies involving machine learning, fuzzy set-based MCDM, and studies evaluated with the effects of COVID-19 have been carried out (Hegde and Rokseth 2020; Lyu et al. 2020; Kaikkonen et al. 2021; Chen et al. 2021; Rathore and Gupta 2021; Sari and Tüysüz 2022).

In risk assessment studies, it has been observed that there are almost no action selection and prioritization studies, except for the application of risk prioritization with integrated models, the creation of new risk assessment methods, and method development under fuzzy logic and MCDM theories. Among the studies that can be reached by action selection and prioritization; Dagsuyu et al. (2021) proposed an integrated model with AHP, FMEA, and a mathematical model to select actions in a 3 PL provider in a cold chain. For this reason, this study provides both fuzzy logic and MCDM integration; it is unique in that the action choices are performed by including the business constraints. Thus, it aimed to contribute to the literature both theoretically and practically.

**Materials and methods**

**Materials**

The study was carried out in a medium-sized company operating in the industrial gas sector, supplying liquid oxygen, and filling oxygen gas. Within the scope of the study, the hazards experienced during the gas filling process and the risks arising from these hazards are discussed. The evaluation team consists of the business manager, occupational health and safety specialist, technicians, and foremen.

**Methods**

**Fine–Kinney method**

The Fine–Kinney method was published in G. F. Kinney’s 1976 article *Practical Risk Analysis for Safety Management* (Kinney and Wiruth 1976). 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. Table 1 presents the three different parameter scales. In Table 2, the RPN interpretation is presented.

**Analytic hierarchy process (AHP)**

As one of the most popular MCDM methods, AHP was proposed and developed by Professor Thomas Lorie Saaty (Saaty 1980). AHP represents judgments as pairwise comparisons and provides a basic scale of relative magnitudes expressed in units of dominance (Saaty 1987). AHP implementation steps start by creating the hierarchical structure in the first step. In step

| Table 1 Scales of Fine–Kinney method (Kinney and Wiruth 1976) |
|----------------------------------|------------------|------------------|
| Likelihood of a hazardous event | Probability       | 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              |
| Exposure factor                  | Frequency        | Value |
| “Continuous”                     | 10               |
| “Frequent (daily)”               | 6                |
| “Occasional (weekly)”            | 3                |
| “Unusual (monthly)”              | 2                |
| “Rare (a few per year)”          | 1                |
| “Very rare (yearly)”            | 0.5              |
| Possible consequences            | Severity         | Value |
| “Catastrophe (many fatalities)”  | 100              |
| “Disaster (few fatalities)”      | 40               |
| “Very serious (fatality)”        | 15               |
| “Serious (serious injury)”       | 7                |
| “Important (disability)”         | 3                |
| “Noticeable (minor first aid accident)” | 1            |
2, pairwise comparison matrices are formed to compare each criterion over another. Scoring from 1 to 9 is used for comparison. A score of 9 means “extreme importance of one over another,” while a score of 1 means “equal importance.” After relative importance values are determined in the next step, the consistency ratio (CR) needs to be calculated in the next step. CR is calculated by the division of consistency index to random index, where the random index is dependent on the number of criteria \(n\) and consistency index is calculated by deducting \(n\) from the largest “eigenvalue of the matrix (\(\lambda_{\text{max}}\)) and divided by \((n - 1)\) (Saaty 1980). If the consistency ratio is below 0.1, the solution is considered consistent; otherwise, a re-evaluation is required. Final weights are calculated with the integration of individual judgments after applying the geometric rule of Saaty (Saaty 1980).

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

The TOPSIS method is a frequently used method among MCDM methods. The steps of this method developed by Hwang and Yoon (1981) can be summarized as follows: first, the decision matrix is formed by the decision-makers, and decision scores between 1 to 10 are given under certain determined criteria for all alternatives. In the second step, the matrix is normalized, and in the third step, the weighted normalization matrix is formed. In this method, the weighted normalization matrix is a step involving subjectivity. To reduce subjectivity, criterion weights are integrated with the AHP method in this study. In the next steps, ideal and negative ideal solution sets are prepared and ideal, and negative ideal distance values are calculated. As the last step of this method, ideal solving relative proximity is calculated, and the weights of the alternatives are determined (Hwang and Yoon 1981).

Methodology of the study

The methodology of this study includes 7 steps, and the steps are presented in Fig. 1.

As can be seen in Fig. 1, the methodology consists of seven steps. In the first step, hazards are needed to be defined by the expert team then perform the classic Fine–Kinney method to the defined hazards and the risks that arise from those hazards in step 2. To objectify the evaluation, parameters that constitute the classic method are fuzzified, and the priority of the hazards is determined in step 3. To determine the action plans, importance levels of the groups affected by the risks are needed to be revealed, and their weights are calculated with the AHP method in step 4. After determining the action plans in step 5, the most appropriate action selection is performed with the weighted TOPSIS method in step 6. In step 7, action weights are re-calculated with the integrative effect of company constraints.

Results and discussion

Step 1: identifying hazards

The hazards in the gas filling facility were determined with the company’s occupational health and safety experts.

![Fig. 1 Methodology of the study](image-url)
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 risks arise from with hazards are given in Table 3.

**Step 2: performing the risk analysis**

The team determined the probability, severity, and frequency values in the classical Fine–Kinney risk analysis for the hazards defined in step 1, using the tables in the Methods and parameters used in logistics route planning section (Tables 1 and 2), and the RPN values were calculated. Results are presented in Table 4.

According to Table 4, where the classical Fine–Kinney results are given, urgent action is required for only 2 hazards in the very high-risk group within the enterprise’s constraints and limited resources. Especially since the H8 has the highest RPN value, it should be considered to take action to eliminate this hazard. 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 instance, H11 and H17 hazards are at the same level of importance according to the classical

| # of hazard | 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 braking 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                                       | A 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                         | A 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                                   | A 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                                   |
Fine–Kinney method since they have the same RPN value with different P, S, and F parameters. Although those hazards have the same 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: Classical Fine–Kinney risk analysis for gas filling plant

| # 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

The fuzzy Fine–Kinney scale for the gas filling facility was prepared with the risk analysis expert team of the company, and the analysis was conducted and coded in MATLAB 18b fuzzy logic designer tool. In the design phase probability, severity and frequency parameters in the Fuzzy Fine–Kinney risk analysis scale are selected as input; the RPN value is considered as output by using “Mamdani min–max” method, which is presented in Fig. 2.

In fuzzy Fine–Kinney risk analysis, inputs of probability and severity include 5 levels, while frequency includes 6 levels. Hence, membership function values are created for each input and output as presented in Table 5 and illustrated in Fig. 3.

Considering the membership functions of probability, severity, and frequency inputs, 150 decision rules (6*5*5) specific to the gas filling facility were defined. According to the decision rules created, fuzzy Fine–Kinney values were calculated for the hazards evaluated with the classical method in the previous step, and the comparative results are presented in Table 6.

The results were updated with the fuzzy method, which was carried out due to the insufficient separation and objectivity of the results obtained in the classical method. Thus, with a more objective approach, it has been revealed which hazards and the order in which action should be taken for the risks arising from these hazards.

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

The hazards identified and evaluated by the expert team of the enterprise and the risks arising from these hazards affect different groups at different levels. Including these impact levels in action plans shows that risk assessment studies are more realistic and objective. It was decided that the groups affected by the risks in the enterprise where the application study was carried out were employee, visitor, customer, and a resident of the environment, and the importance levels of these groups were determined by AHP. As it is presented...
in Table 7, 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. 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 than visitors can be seen in 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 7, 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 next step of the study.

Step 5: determination of action plans

To eliminate the hazards in the highest risk group or to minimize their effects, the company needs to determine an action plan, which depends on the company’s constraints such as time, budget, cost, and employees. As can be seen from Table 6, when the fuzzy RPN values calculated for the hazards are examined, the hazard groups can be divided into four main groups. 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. These hazards are followed by H3, H9, H16, H20, H21, H23, H24, and H26 hazards with the same fuzzy RPN (283). 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 8.

The company aims to manage its limited resources most effectively and to minimize the negative effects of hazards by affecting more than one hazard with the action plan.
implemented. In this context, taking into account the relationship between actions and hazards, action selection was performed with the TOPSIS approach, one of the multi-criteria decision-making methods. The relationship between the identified actions and hazards and which action will eliminate which hazard or minimize their effects is discussed in the TOPSIS evaluation. The group weights affected by the hazards are also taken into account in the weight calculation for the action selection.

**Step 6: choosing the most appropriate action with the weighted TOPSIS method**

The action selection that maximizes the benefit of the company is conducted with the weighted TOPSIS method. The weight score of the group affected by each hazard is also taken into account in the TOPSIS evaluation in this study. In Table 9, the groups affected by these hazards and the sum of the AHP weight scores of these groups are presented. In the study, it has been determined that there are four groups affected by hazards and risks arising from hazards (customer, resident of the environment, visitor, employee). The importance levels of these groups were determined in step 4. In this step, we can see the calculated values of the group members affected by the hazard. If a group is affected by a hazard, the calculated value of that group is taken into account, and if more than one group is affected, the total values of those groups are taken into account. If the hazard affects all groups, the weight sum will be “1.”

As the first step in the implementation of the TOPSIS method, the relationship level between the action plans and hazards was scored with the TOPSIS scale (1–10). Scoring was carried out by the expert team who performed the risk analysis. Then calculations have been carried out with the group weights as an importance level to calculate the final weights of the actions. In Table 10, the final weight scores of actions are presented.

As can be seen from Table 10, 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.

**Step 7: choosing the most appropriate action based on company constraints**

After the action selection, calculations including the hazards and the groups affected by the risks arising from these hazards are performed; it should be inevitable that the constraints of the company should be included in the choice of action.

It was determined by the managers and the evaluation team that the main constraints of the company are labor,
cost, material and resources, and time. The necessity of re-evaluating the weighted TOPSIS results according to these constraints is an important condition on the objectivity and reality of the study. For this reason, first, the importance levels of these constraints for the enterprise were determined. In this evaluation, which was given out of 5 points, 4 points were given to the cost constraint, 3 points to the labor constraint, 2 points to the time constraint, and 1 point to the material and resource constraint. Thus, the importance levels of the constraints were calculated over the given score/total constraint score and were calculated as 0.4, 0.3, 0.2, and 0.1, respectively.

According to Table 11, the relations of the actions with the operational constraints are scored between 1 and 5. Then, the constraint-related scores of the actions were multiplied by the constraint weights, and the total weighted scores of the actions were calculated by multiplying weight scores from step 6 to weighted action-constraint scores.

Table 12 shows the importance of the change in the order of action preference, including the company constraints. As can be seen from Table 12, the priority order of the A9 coded action “Sufficient number and type of fire extinguishers should be available in the working area” has not changed. Since it is an easy action for the business to implement, it is a prediction that is likely to receive low scores in the action-constraint evaluation. However, when the second action is examined, it is seen that the order has changed. Considering the constraints, it was determined that the A7 coded “Technological developments should be used in the process” action can be performed in the second place in the weight calculation. This action, which ranks eighth in the evaluation without including constraints, is an action that includes updates that are vital for the company. When the A8 coded action “A new closed area should be created for fabrication work near the test area” is examined, it is seen that this action has also increased from the ninth to the fifth rank. Actions coded A11 and A12 were calculated as actions that should be taken into the lower ranks considering the constraints.

The company officials thought that the action plan, which included the restrictions, could be more sheltered in terms of both occupational health and safety, and they predicted that they could progress their activities more safely and efficiently.

| # of action | Actions                                                                 |
|------------|------------------------------------------------------------------------|
| A1         | Periodic maintenance of cryogenic liquid tanks should be done by an accredited institution |
| A2         | The calibration of the pressure gauge of cryogenic liquid tanks should be done regularly |
| 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 |
| A4         | A suitable leakage current relay must be installed in the electrical panels |
| A5         | Procurement and use of insulating mats                                  |
| A6         | Supply of tube transport vehicles                                       |
| A7         | Technological developments should be used in the process               |
| A8         | A new closed area should be created for fabrication work near the test area |
| A9         | A sufficient number and type of fire extinguishers should be available in the working area |
| A10        | Fire training should be given to the personnel, and emergency teams should be formed |
| A11        | A locked storage area should be created where flammable and explosive materials will be stored |
| A12        | Maintenance repair of electrical panels is done only by an electrician |

| # of hazard | Affected group | Sum of the AHP weight of groups |
|-------------|----------------|-------------------------------|
| H8          | Employees, visitors | 0.751                        |
| H10         | All groups        | 1                             |
| H25         | Employees, visitors | 0.751                        |
| H3          | All groups        | 1                             |
| H9          | Employees, environment | 0.708                      |
| H16         | Employees         | 0.65                          |
| H20         | Employees, visitors | 0.751                        |
| H21         | Employees, visitors | 0.751                        |
| H23         | Employees, visitors | 0.751                        |
| H24         | All groups        | 1                             |
| H26         | Employees         | 0.65                          |

| # of action | Weight scores | # of action | Weight scores |
|------------|---------------|------------|---------------|
| A1         | 0.2883        | A7         | 0.2462        |
| A2         | 0.2883        | A8         | 0.2340        |
| A3         | 0.3508        | A9         | 0.6332        |
| A4         | 0.1949        | A10        | 0.2693        |
| A5         | 0.2228        | A11        | 0.3002        |
| A6         | 0.2161        | A12        | 0.2900        |
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 study, 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. Since no distinction is defined among the probability, frequency, and severity parameters in the classical Fine–Kinney scale and the characteristics/constraints and affected groups of the applied firm are not taken into account, in this study, the hazards were evaluated with the Fuzzy Fine–Kinney risk analysis. In the next phase of the study, action plans were defined for critical hazards as a result of fuzzy Fine–Kinney risk analysis. To select or decide the priority of actions, the TOPSIS method was applied to calculate action weights. When performing 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 method. At the last phase of the study, the effect of operating constraints was included in the action weights calculated with the integration of the affected groups. By including the weights of labor, cost, material and resources, and time constraints and their effects on actions, action weight calculations were performed again, and the final result was reached.

In future studies, it is planned to include more operating constraints

---

### Table 11 Weighted action-constraint and final score of actions

| Company constraints | Number of action | Weight points (step 6) (a) | Labor (b) | Cost (c) | Material & resources (d) | Time (e) | Weighted action-constraint scores (f) = (0.3*b + 0.4*c + 0.1*d + 0.2*e) | Final score of actions (a)* (f) | Final rank of the action |
|---------------------|-----------------|---------------------------|-----------|---------|--------------------------|---------|---------------------------------------------------------------------------------|-----------------------------|
|                      | A1              | 0.2883                    | 1         | 4       | 3                        | 1       | 2.4                                                                              | 0.6919                      | 6                          |
|                      | A2              | 0.2883                    | 3         | 2       | 2                        | 3       | 2.5                                                                              | 0.7208                      | 4                          |
|                      | A3              | 0.3508                    | 1         | 3       | 2                        | 2       | 2.1                                                                              | 0.7366                      | 3                          |
|                      | A4              | 0.1949                    | 2         | 2       | 2                        | 2       | 2                                                                                | 0.3898                      | 12                         |
|                      | A5              | 0.2228                    | 1         | 3       | 2                        | 1       | 1.9                                                                              | 0.4234                      | 11                         |
|                      | A6              | 0.2161                    | 1         | 4       | 2                        | 1       | 2.3                                                                              | 0.4971                      | 10                         |
|                      | A7              | 0.2462                    | 3         | 3       | 3                        | 3       | 3                                                                                | 0.7387                      | 2                          |
|                      | A8              | 0.2340                    | 2         | 3       | 4                        | 4       | 4                                                                                | 0.7020                      | 5                          |
|                      | A9              | 0.6332                    | 1         | 3       | 3                        | 1       | 2                                                                                | 1.2664                      | 1                          |
|                      | A10             | 0.2693                    | 4         | 2       | 1                        | 2       | 2.5                                                                              | 0.6731                      | 7                          |
|                      | A11             | 0.3002                    | 2         | 2       | 3                        | 2       | 2.1                                                                              | 0.6304                      | 8                          |
|                      | A12             | 0.2900                    | 3         | 1       | 1                        | 2       | 1.8                                                                              | 0.5221                      | 9                          |

### Table 12 Comparison of action ranks

| Action | Action rank without constraints | Action rank with constraints |
|--------|---------------------------------|-----------------------------|
| A1     | 5                               | 6                           |
| A2     | 6                               | 4                           |
| A3     | 2                               | 3                           |
| A4     | 12                              | 12                          |
| A5     | 10                              | 11                          |
| A6     | 11                              | 10                          |
| A7     | 8                               | 2                           |
| A8     | 9                               | 5                           |
| A9     | 1                               | 1                           |
| A10    | 7                               | 7                           |
| A11    | 3                               | 8                           |
| A12    | 4                               | 9                           |

### 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.
by increasing the hazard quantity and accordingly the action quantity.

**Acknowledgements** This study was produced from the master’s thesis of the first author.

**Author contribution** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Bahar Dogan, Cansu Dagsuyu, and Murat Oturakci. The first draft of the manuscript was written by Murat Oturakci, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**Data availability** All data and materials are available in the manuscript.

**Declarations**

**Ethics approval** Since this study did not recruit any human and/or animal subjects, this section does not apply.

**Consent to participate** Not applicable.

**Consent for publication** The authors confirm that the final version of the manuscript has been reviewed, approved, and consented for publication by all authors.

**Competing interests** The authors declare no competing interests.

**References**

Alidoosti A, Jamshidi A, Haji Yakhchali S, Basiri MH, Azizi R, Yazdani-Chamzini A (2012) Fuzzy logic for pipelines risk assessment. Manag Sci Lett 2(5):1707–1716

Bentaleb F, Mabrouki C, Semma A (2015) A multi-criteria approach for risk assessment of dry port-sea port system. Supply Chain Forum: an International Journal 16(4):32–49

Bonvincini S, Leonelli P, Spadoni G (1998) Risk analysis of hazardous materials transportation: evaluating uncertainty by means of fuzzy logic. J Hazard Mater 62(1):59–74

Catrinu MD, Nordgård DE (2011) Integrating risk analysis and multi-criteria decision support under uncertainty in electricity distribution system asset management. Reliab Eng Syst Saf 96(6):663–670

Chen PC, Kezunovic M (2016) Fuzzy logic approach to predictive risk analysis in distribution outage management. IEEE Transactions on Smart Grid 7(6):2827–2836

Chen Y, Zheng W, Li W, Huang Y (2021) Large group activity security risk assessment and risk early warning based on random forest algorithm. Pattern Recogn Lett 144:1–5

Dagsuyu C, Oturakci M, Essiz ES (2020) A new Fine-Kinney method based on clustering approach. Internat J Uncertain Fuzziness Knowledge-Based Systems 28(03):497–512

Dagsuyu C, Derse O, Oturakci M (2021) Integrated risk prioritization and action selection for cold chain. Environ Sci Pollut Res 28(13):15646–15658

De Ru WG, Eloff JHP (1996) Risk analysis modelling with the use of fuzzy logic. Computers & Security, 15(3):239–248

Derse O (2021) A new approach to the Fine Kinney method with AHP based ELECTRE I and math model on risk assessment for natural disasters. J Geogr 42:42

Gallab M, Bouloiz H, Alaloui YL, Tkiouat M (2019) Risk assessment of maintenance activities using fuzzy logic. Procedia Computer Science 148:226–235

Gallego LE, Duarte O, Torres H, Vargas M, Montaňa J, Pérez E, …. Younes C (2004) Lightning risk assessment using fuzzy logic. J Electrostat 60(2–4):233–239

Gul M, Guven B, Guneri AF (2018) A new Fine-Kinney-based risk assessment framework using FAHP-FVIKOR incorporation. J Loss Prev Process Ind 53:3–16

Gul M, Celik E (2018) Fuzzy rule-based Fine-Kinney risk assessment approach for rail transportation systems. Hum Ecol Risk Assess Int J 24(7):1786–1812

Gul M, Mete S, Serin F, Celik E (2021) Fine–Kinney-based fuzzy multi-criteria occupational risk assessment. Springer, Cham, Switzerland

Gul M, Yucesan M, Ak MF (2022) Control measure prioritization in Fine – Kinney-based risk assessment: a Bayesian BWM-Fuzzy VIKOR combined approach in an oil station. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-19454-x

Hegade J, Rokseth B (2020) Applications of machine learning methods for engineering risk assessment–a review. Saf Sci 122:104492

Hohnen P, Hasle P (2018) Third party audits of the psychosocial work environment in occupational health and safety management systems. Saf Sci 109:76–85

Hwang CL, Yoon K (1981) Methods for multiple attribute decision making. In: Multiple attribute decision making (pp. 58–191). Springer, Berlin, Heidelberg

Kaikkonen L, Parviainen T, Rahikainen M, Uusitalo L, Lebkoisoinen A (2021) Bayesian networks in environmental risk assessment: a review. Integr Environ Assess Manag 17(1):62–78

Khadam IM, Kaluarachchi JJ (2003) Multi-criteria decision analysis with probabilistic risk assessment for the management of contaminated ground water. Environ Impact Assess Rev 23(6):683–721

Kinney GF, Wiruth AD (1976) Practical risk analysis for safety management. Naval Weapons Center, pp 1–20

Kokangul A, Polat U, Dagsuyu C (2017) A new approximation for risk assessment using the AHP and Fine Kinney methodologies. Saf Sci 91:24–32

Kuleshov VV, Yu Skuba P, Ignatovich IA (2021) Assessment of the severity of the last accident based on the Fine-Kinney method. IOP Conf Ser.: Earth Environ Sci 720(1):012094

Linkov I, Satterstrom FK, Steevens J, Ferguson E, Pleus RC (2007) Multi-criteria decision analysis and environmental risk assessment for nanomaterials. J Nanopart Res 9(4):543–554

Luu C, von Meding J (2018) A flood risk assessment of Quang Nam, Vietnam using spatial multicriteria decision analysis. Water 10(4):461

Lyu HM, Sun WJ, Shen SL, Zhou AN (2020) Risk assessment using a new consulting process in fuzzy AHP. J Constr Eng Manag 146(3):04019112

Malekmohammadi B, Rahimi Blouchi L (2014) Ecological risk assessment of wetland ecosystems using multi criteria decision making and geographic information system. Ecol Ind 41:133–144

Nasirzadeh F, Afshar A, Khamzadi M, Howick S (2008) Integrating system dynamics and fuzzy logic modelling for construction risk management. Constr Manag Econ 26(11):1197–1212

Oturakci M, Dagsuyu C, Kокангул А (2015) A new approach to Fine Kinney method and an implementation study. Alphanumeric Journal 3(2):83–92

Peikert T, Garbe H, Potthast S (2017) Fuzzy-based risk analysis for IT-systems and their infrastructure. IEEE Trans Electromagn Comp 59(4):1294–1301

Petrović DV, Tanasijević M, Milić V, Lišić N, Stojadinović S, Srkvić I (2014) Risk assessment model of mining equipment failure based on fuzzy logic. Expert Syst Appl 41(18):8157–8164
