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An integrated intuitionistic fuzzy set and mathematical programming approach for an occupational health and safety policy

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Abstract

This paper aims to establish an occupational health and safety policy for three firms. This paper provides to overcome the drawbacks of traditional FMEA (failure mode and effects analysis) by using an integrated intuitionistic fuzzy multi-criteria decision making method and a linear programming. Priority value of criteria has been defined by utilizing intuitionistic fuzzy analytic hierarchy process method and the highest risky failure mode among failure modes has been found by utilizing intuitionistic fuzzy VIKOR (VIsekriterijumska optimizacija i KOm-promisno Resenje). The application of risk evaluation is conducted to show the effectiveness of the proposed method in three firms. The reliability of the risk ranking is verified by helping of a sensitivity analysis and the advantages of the proposed approach are shown by comparing with the other methods. The managers of the firm present some limitations for the occupational health and safety policy so that these constraints are solved by helping of a linear programming. The results show that destroying of the existing steel ropes during production of plaster, risks that caused from work equipment and electric shock during cutting were determined the highest risky failure modes for construction, textile and metal firms, respectively.

1. INTRODUCTION

Failure mode and effects analysis (FMEA) was first developed as a systematic analysis for the aerospace industry in the 1960s (Bowles and Peláez, 1995). FMEA has proven to be a useful and powerful tool in assessing potential failures and preventing them from occurring (Sankar and Prabhu, 2001). The main aim of FMEA implementation is to define, identify, and eliminate the potential failures of the system components before they reach the customer. FMEA is an extensively employed risk evaluation tool for identifying and eliminating potential failures in manufacturing and service systems.

FMEA deals with the proactive treatment of the system in order to prevent the failure while the other risk evaluation techniques find a solution after the failure realize. This situation supports to adjust the available programs to the decision makers, increase compensating provisions, employ the recommended actions to reduce the likelihood of failures, reduce the probability of failure rates and avoid hazardous accidents. A system, component etc. could not meet the design requirements so that these situations are defined as failure modes (FM). A failure mode can affect to other failure modes so that it can be the reason of the other failure modes. A FMEA team defines the final effects of the failure modes (Liu et al., 2011)

In conventional FMEA, the risk priorities of failure modes are defined with so-called risk priority numbers (RPNs), which can be achieved by multiplying the scores of risk factors like occurrence (O), severity (S), and non-detection (D). The RPN can be calculated using Eq.(1) mathematically. The terms of O, S, and D are the probability of the failure, the severity of failure, and the non-detectability of the failure, respectively.

$$RPN = O \times S \times D \tag{1}$$

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The traditional FMEA have been widely criticized in the literature due to various reasons (Bowles and Peláez, 1995; Sankar and Prabhu, 2001; Chin et al., 2009; Seyed-Hosseini et al., 2006; Liu et al., 2011; Liu et al., 2012; Mentes and Ozen, 2015):

* The conventional FMEA can't take into consideration the importance degrees of O, S, and D so that it admits them in equal importance degree. This situation can cause the mistaken results when the conventional FMEA implements to the real life problems.

* Different values of O, S, and D can provide the same RPN but hidden risks of them can be different totally. For example, when O, S, D parameters are 2, 4, 1 and 1, 2, 4 for two situations, respectively, both RPNs are 8 and the same. Therefore, less risky failure mode can be determined as the most important failure mode so that this case causes the waste of resource and time.

* It is difficult to define the values of O, S, and D parameters precisely. O, S, and D parameters in FMEA are generally expressed with the linguistic terms such as important, very high.

* O, S, and D parameters of RPN are discrete ordinal scales according to traditional FMEA so that RPN causes meaningless and misleading information due to multiplication of O, S, and D parameters.

* The mathematical formula of RPN is questionable and debatable. There is no rationale the multiplication of O, S and D parameters to produce the RPN.

Various approaches have been proposed in the literature to overcome the above shortcomings. The most popular approach in FMEA literature is fuzzy rule base system, followed by grey theory, cost based model, analytic hierarchy process (AHP)/ analytic network process (ANP) and linear programming. The fuzzy rule-base system is widely applicable because it has the advantages of fuzzy logic and knowledge-based approach (Liu et al., 2013). This study only focuses on the multi-criteria decision making (MCDM) based FMEA studies in the literature. Chang et al. (1999) used the fuzzy linguistic values to evaluate O, S and D risk factors and the grey relational analysis for reprioritization of potential failure modes. Chang, et al. (2001) considered the grey theory for FMEA. Many decision makers interact to achieve a group opinion in group decision making. Seyed-Hosseini et al. (2006) utilized the DEMATEL (DEcision MAking Trial and Evaluation Laboratory) to determine the risk priority of potential failure modes. Chang and Cheng (2010) introduced intuitionistic fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) approach to overcome the shortcomings of RPN. Ekmekçioğlu and Kutlu (2012) suggested the fuzzy AHP to determine O, S and D in FMEA and the fuzzy TOPSIS to rank the potential failure modes. Liu et al. (2012) used the VIKOR (VIsekriterijumska optimizacija i KOm-promisno Resenje) to find a compromise solution in the ranking of failure modes. They also considered the linguistic values to evaluate the ratings and weights for O, S and D risk factors. Liu et al. (2014) presented the intuitionistic fuzzy hybrid weighted Euclidean distance operator to evaluate the risks in FMEA. Liu et al. (2015a) presented intuitionistic fuzzy hybrid TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to rank the failure modes. Liu et al. (2015b) used the combination of fuzzy AHP and entropy method for the weighting of risk factors, and fuzzy VIKOR method to rank the failure modes. Vahdani et al. (2015) proposed a novel method combining belief structure and TOPSIS to cope with the deficiencies of the traditional FMEA. Efe et al. (2016) presented fuzzy PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) to deal with FMEA method in a construction firm. Tooranloo and Sadat Ayatollah (2016) used the intuitionistic fuzzy TOPSIS technique to rank the failure modes. Wang et al. (2016) presented ANP and COPRAS methods under interval-valued intuitionistic fuzzy environments to implement FMEA. Ahmadi et al. (2017) considered a comprehensive risk management using fuzzy FMEA and fuzzy AHP method in highway construction projects. Mohsen and Fereshteh (2017) handled Z numbers based AHP, entropy and VIKOR methods for risk evaluation in FMEA.

Each individual decision maker might have special goals, opinions, and different evaluation process although they aim to select the best alternative. IFWA (intuitionistic fuzzy weighted averaging) operator can be used to aggregate the opinions of each decision maker in group decision making environment. Saaty's consistency method is useful but cannot ameliorate or repair the inconsistency preference relations automatically so that the inconsistency preference relations can be sent back to the decision maker for reevaluation or can be extracted from decision making process. The reevaluation process is time consuming and the decision makers do not sometimes desire to participate to this reevaluation process. Therefore, we will utilize the proposed method by Xu and Liao (2014) to check the consistency of an intuitionistic preference relation. This method will repair the inconsistent intuitionistic preference relations of the decision makers into a consistent one automatically. The literature lacks studies about risk assessment using integrated intuitionistic fuzzy AHP (IFAHP)-intuitionistic fuzzy VIKOR (IFVIKOR) approach. Priority values of criteria have been determined by employing IFAHP method. IFAHP also deals with the perfect multiplicative consistent intuitionistic preference relation in this paper. The solution of the risk evaluation has been found by employing IFVIKOR method. This methodology allows decreasing the uncertainty and the information loss in group decision-making. This study purposes to ensure an analytical tool to determine the highest risky failure mode among possible failure modes for three firms, which are a textile firm, a metal firm and a construction firm. Furthermore, this paper proposes a linear mathematical model to form an occupational health and safety policy unlike the papers in the literature. This suggestion is very important so that FMEA deals with only ranking of failure modes. This situation can't meet the requirements of the firms in the long period due to limited budget, time etc. properties allocated by the firms for an occupational health and safety policy. Firms have a complex system with several sub-systems. When a firm allocates more budget, time etc. properties for a sub-system, the firm can't present a suitable policy for the other sub-systems. The linear mathematical model in this paper handles budget constraint, time constraint and number of correctable risk constraint. Thus, this paper presents a novel perspective in risk assessment area based on FMEA.

This paper consists of five sections. The second section presents a brief definition that consists of IFSs and IFWA operator. The proposed integrated IFAHP-IFVIKOR approach is given in Section three. Section four is related to a textile firm application of the developed decision making approach, a sensitivity analysis, a comparative analysis and a linear programming. Applications of a metal firm and a construction firm are also presented in Section four. The concluding remarks are presented in the last section.

2. PRELIMINARIES

2.1. Intuitionistic fuzzy sets (IFS)

Let X be a fixed set, an IFS *A* in *X* is given by Atanassov (1986) as follows:

$A=\{(x,\mu_A(x),\nu_A(x))\mid x\in X\}$, where the functions $\mu_A(x):X\to[0,1],\ x\in X\to\mu_A(x)\in[0,1]$ and $\nu_A(x):X\to[0,1],\ x\in X\to\nu_A(x)\in[0,1]$ satisfy the condition $0\le\mu_A(x)+\nu_A(x)\le 1$ for all $x\in X$. The numbers $\mu_A(x)$ and $\nu_A(x)$ represent the membership degree and non-membership degree of the element $x\in X$ to the set *A*, respectively. In addition, $\pi_A(x)=1-\mu_A(x)-\nu_A(x),\ \forall x\in X$ is called the degree of indeterminacy of *x* to *A*.

Intuitionistic fuzzy numbers (IFNs) have been extensively implemented in multi criteria decision making problems.

The operation laws in Eqs.(2)-(5) are available for two IFNs $\alpha_1=\left(\mu_{\alpha_1},v_{\alpha_1}\right)$ and $\alpha_2=\left(\mu_{\alpha_2},v_{\alpha_2}\right)$:

$$\alpha_1\oplus\alpha_2=\left(\mu_{\alpha_1}+\mu_{\alpha_2}-\mu_{\alpha_1}\mu_{\alpha_2},v_{\alpha_1}v_{\alpha_2}\right) \tag{2}$$

$$\alpha_1\otimes\alpha_2=\left(\mu_{\alpha_1}\mu_{\alpha_2},v_{\alpha_1}+v_{\alpha_2}-v_{\alpha_1}v_{\alpha_2}\right) \tag{3}$$

$$\lambda\alpha=\left(1-(1-\mu_\alpha)^\lambda,(v\alpha)^\lambda\right),\lambda>0 \tag{4}$$

$$\alpha^\lambda=\left(\mu_\alpha^\lambda,1-(1-v_\alpha)^\lambda\right),\lambda>0 \tag{5}$$

Eq. (2) shows the sum of two IFNs. Eq. (3) shows the multiplication of two IFNs. Eq. (4) shows the multiplication of an IFN and a crisp number (λ). Eq. (5) shows the exponential of an IFN. Exponential value is a crisp number. In this paper, we used the crisp numbers for the weights of the decision makers. The judgments of the decision makers are IFNs. Eq. (5) is useful due to this reason. Eqs. (2)-(5) are necessary for the proposed integrated IFAHP-IFVIKOR approach.

Let $\alpha = (\mu_\alpha, v_\alpha)$ be an IFN. The score function S of IFN α can be defined in Eq.(6) (Xu and Yager, 2006):

$$S(\alpha) = \mu_\alpha - v_\alpha, S(\alpha) \in [-1,1] \tag{6}$$

The accuracy function H of IFN α can be expressed in Eq.(7):

$$H(\alpha) = \mu_\alpha + v_\alpha, H(\alpha) \in [0,1] \tag{7}$$

The score function and accuracy function can be proposed to compare any two IFNs $\alpha_1 = (\mu_{\alpha_1}, v_{\alpha_1})$ and $\alpha_2 = (\mu_{\alpha_2}, v_{\alpha_2})$.

If $S(\alpha_1) < S(\alpha_2)$ then α_1 is smaller than α_2, shown by $\alpha_1 < \alpha_2$; if $S(\alpha_1) = S(\alpha_2)$ and

(1) if $H(\alpha_1) = H(\alpha_2)$, then $\alpha_1 = \alpha_2$;

(2) if $H(\alpha_1) < H(\alpha_2)$, then $\alpha_1 < \alpha_2$

This paper obtained IFNs of failure modes for S and R values after intuitionistic fuzzy VIKOR is applied. This paper used Eqs. (6)-(7) to rank the failure modes according to S and R values.

2.1. IFWA operator

IFWA operator, which is called an intuitionistic fuzzy weighted averaging, can be utilized to aggregate the opinions of experts based on intuitionistic fuzzy decision matrix (Boran et al., 2009). In the group decision-making process, the judgments of all decision makers must be aggregated to obtain the aggregated decision matrix as a group judgment without loss of knowledge. Thus, this paper used IFWA operator in Eq.(8). IFWA operator handles the weights of the decision makers λ_k, the membership degree of the IFN of preference relation on j of i according to kth decision maker $\mu_{ij}^{(k)}$, the non-membership degree of the IFN of preference relation on j of i according to kth decision maker$\left(v_{ij}^{(k)}\right)$. $R^{(k)} = \left(r_{ij}^{(k)}\right)_{m\times n}$ be an intuitionistic fuzzy decision matrix of the kth expert. Let $\lambda = \{\lambda_1, \lambda_2, ..., \lambda_t\}$ be the importance degree of all experts where $\sum_{k=1}^{t} \lambda_k = 1,\ \lambda_k \in [0,1]$. IFWA operator, which is presented by Xu (2007), is used in order to aggregate the opinions of all experts. IFWA operator is presented in Eq.(8):

$$r_{ij} = IFWA_\lambda\left(r_{ij}^{(1)}, r_{ij}^{(2)}, ..., r_{ij}^{(t)}\right) = \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus ... \oplus \lambda_t r_{ij}^{(t)} = \left(1 - \prod_{k=1}^{t}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{t}\left(\left(v_{ij}^{(k)}\right)^{\lambda_k}\right), \prod_{k=1}^{t}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{t}\left(\left(v_{ij}^{(k)}\right)^{\lambda_k}\right)\right) \tag{8}$$

The aggregated intuitionistic fuzzy decision matrix (R) is indicated in Eq.(9):

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{9}$$

where $r_{ij} = \left(\mu_{ij}, v_{ij}, \pi_{ij}\right), \mu_{ij} = 1 - \prod_{k=1}^{t}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, v_{ij} = \prod_{k=1}^{t}\left(\left(v_{ij}^{(k)}\right)^{\lambda_k}\right), \pi_{ij} = \prod_{k=1}^{t}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{t}\left(\left(v_{ij}^{(k)}\right)^{\lambda_k}\right), i \in M,\ j \in N.$

r_{ij} shows the preference relation on j of i. *R* shows the group judgment in decision making process. Each decision maker has a judgment about the preference relation on j of i. The judgment of each decision maker must be aggregated for a general evaluation. *R* is acquired by aggregating the judgments of the decision makers (Efe et al., 2015).

3. The Proposed approach

3.1. Intuitionistic fuzzy analytic hierarchy process method

AHP suggested by Saaty (1980) is a method that constructs both qualitative and quantitative data in a multi criteria decision making problem hierarchically. There are many case studies showing that large firms use AHP to achieve better results in their strategic decisions. AHP ensures intuitive and easy to use. AHP allows making a decision handling conflicts between criteria into a hierarchy. AHP provides to validate the consistency of the judgments so that it helps to eliminate the inconsistent judgments. AHP is widely used in different areas such as constructing a mental workload expert system (Şeker, 2014) and architecture design (Arpacioğlu and Ersoy, 2013). IFAHP method develops Saaty's AHP by integrating intuitionistic fuzzy set theory to make a decision in uncertain environment. IFNs are characterized by a membership function, a non-membership function, and a hesitancy function. IFAHP method is employed to compute the weights of criteria in a risk evaluation systematically in a vagueness environment.

The consistency ratio (CR) of the pair-wise comparison matrix must be considered whether bigger or smaller than 0.1 before acquiring the priorities of the criteria. The preference relations may cause to misleading solutions without CR. Xu and Liao (2014) suggested an algorithm to establish a perfect multiplicative consistent intuitionistic preference relation $\bar{R} = (\bar{r}_{ik})_{n\times n}$ and it is presented in Eqs.(10)-(15):

Step 1: For $k > i+1$, let $\bar{r}_{ik} = (\bar{\mu}_{ik}, \bar{v}_{ik})$, where

$$\bar{\mu}_{ik} = \frac{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1}\mu_{it}\mu_{tk}}}{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1}\mu_{it}\mu_{tk}} + \sqrt[k-i-1]{\prod_{t=i+1}^{k-1}(1-\mu_{it})(1-\mu_{tk})}}, k > i+1 \tag{10}$$

$$\bar{v}_{ik} = \frac{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1}v_{it}v_{tk}}}{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1}v_{it}v_{tk}} + \sqrt[k-i-1]{\prod_{t=i+1}^{k-1}(1-v_{it})(1-v_{tk})}}, k > i+1 \tag{11}$$

Step 2: For $k = i+1$, let $\bar{r}_{ik} = r_{ik}$.
Step 3: For $k < i+1$, let $\bar{r}_{ik} = (\bar{v}_{ki}, \bar{\mu}_{ki})$.
Step 4: It means that R is an acceptable multiplicative consistent intuitionistic preference relation, if

$$d\left(R^{(p)}, \bar{R}\right) < \tau \tag{12}$$

where

$$d\left(R^{(p)}, \bar{R}\right) = \frac{1}{2(n-1)(n-2)}\sum_{i=1}^{n}\sum_{k=1}^{n}\left(\left|\bar{\mu}_{ik} - \mu_{ik}^{(p)}\right| + \left|\bar{v}_{ik} - v_{ik}^{(p)}\right| + \left|\bar{\pi}_{ik} - \pi_{ik}^{(p)}\right|\right) \tag{13}$$

and τ is the consistency threshold and p is the number of iterations.

Step 5: If $\tau > 0.1$, a new intuitionistic preference relation must be determined as follows:

$$\tilde{\mu}_{ik} = \frac{\left(\mu_{ik}^{(p)}\right)^{1-\sigma}(\bar{\mu}_{ik})^{\sigma}}{\left(\mu_{ik}^{(p)}\right)^{1-\sigma}(\bar{\mu}_{ik})^{\sigma} + \left(1-\mu_{ik}^{(p)}\right)^{1-\sigma}(1-\bar{\mu}_{ik})^{\sigma}}, \ i,k = 1,2...,n \tag{14}$$

$$\tilde{v}_{ik} = \frac{\left(v_{ik}^{(p)}\right)^{1-\sigma}(\bar{v}_{ik})^{\sigma}}{\left(v_{ik}^{(p)}\right)^{1-\sigma}(\bar{v}_{ik})^{\sigma} + \left(1-v_{ik}^{(p)}\right)^{1-\sigma}(1-\bar{v}_{ik})^{\sigma}}, \ i,k = 1,2...,n \tag{15}$$

where σ is a controlling parameter and is determined by the decision maker.

The multiplicative consistent intuitionistic preference relation can be ameliorated automatically by using these steps. Xu and Liao (2014) presented a new method to obtain the weights of the criteria in IFS and it is shown in Eq.(16):

$$\omega_i = \left(\frac{\sum_{k=1}^{n} \mu_{ik}}{\sum_{i=1}^{n} \sum_{k=1}^{n} (1 - v_{ik})}, 1 - \frac{\sum_{k=1}^{n} (1 - v_{ik})}{\sum_{i=1}^{n} \sum_{k=1}^{n} \mu_{ik}} \right),\ i = 1, 2, ..., n \tag{16}$$

3.2. Intuitionistic fuzzy VIKOR method

The VIKOR method was developed by Opricovic (1998) and Opricovic and Tzeng (2004) for multi-criteria decision making problems. VIKOR method focuses to rank and to select a set of alternatives. It also defines a compromise solution, which is the closest to the ideal solution, for a complex problem so that the decision makers obtain a final decision. VIKOR method calculates positive and negative ideal solutions as ratio. Nevertheless, VIKOR method provides a compromise solution in an advantageous ratio. The compromise solution means reaching agreement with a common consensus in a decision making problem involving conflicting criteria. The IFVIKOR method, which integrates VIKOR method and IFS, is employed to rank the alternatives for a risk evaluation in an uncertain environment in this paper. The IFVIKOR method can be presented in Eqs. (17)-(24) (Chatterjee et al., 2013):

Step 1: Define the intuitionistic fuzzy positive ideal solution $f_j^* = \left(\mu_j^*, v_j^*\right)$ and the intuitionistic fuzzy negative ideal solution $f_j^- = \left(\mu_j^-, v_j^-\right)$ values of all criteria ratings, $j=1,2,\ldots,n$. This step is realized by using Eqs.(17) - (18):

$$f_j^* = \begin{cases} \max\limits_i r_{ij} & \text{for benefit criteria} \\ \min\limits_i r_{ij} & \text{for cost criteria} \end{cases} \quad i = 1, 2, ..., m \tag{17}$$

$$f_j^- = \begin{cases} \min\limits_i r_{ij} & \text{for benefit criteria} \\ \max\limits_i r_{ij} & \text{for cost criteria} \end{cases} \quad i = 1, 2, ..., m \tag{18}$$

Step 2: Calculate the normalized intuitionistic fuzzy difference $\bar{d}_{ij}$ using Euclidean distance in Eqs.(19) - (21):

$$\bar{d}_{ij} = \frac{d\left(f_j^*, r_{ij}\right)}{d\left(f_j^*, f_j^-\right)} \tag{19}$$

$$d\left(f_j^*, r_{ij}\right) = \sqrt{\frac{1}{2}\left(\left(\mu_j^* - \mu_{ij}\right)^2 + \left(v_j^* - v_{ij}\right)^2 + \left(\pi_j^* - \pi_{ij}\right)^2\right)} \tag{20}$$

$$d\left(f_j^*, f_j^-\right) = \sqrt{\frac{1}{2}\left(\left(\mu_j^* - \mu_j^-\right)^2 + \left(v_j^* - v_j^-\right)^2 + \left(\pi_j^* - \pi_j^-\right)^2\right)} \tag{21}$$

Step 3: Calculate the values S_i and R_i and Q_i, i=1,2,…,m. This step is realized by using Eqs.(22) -(24):

$$S_i = \sum_{j=1}^{n} w_j \times \bar{d}_{ij} \tag{22}$$

$$R_i = \max_j \left(w_j \times \bar{d}_{ij}\right) \tag{23}$$

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1 - v) \frac{R_i - R^*}{R^- - R^*} \tag{24}$$

where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$, w_j is the weight of j^{th} criterion and v is presented as a weight for the strategy of maximum group utility, whereas 1-v is the weight of the minimum individual regret. The value of v is handled to 0.5 in this paper. The first part maximum group utility and the second part minimum individual regret of Eq.(24) are calculated by using Eqs.(19)-(21).
Step 4: Rank the alternatives sorting by the values S, R and Q, which are three ranking lists.

Step 5: Propose a compromise solution of the alternative *(a^1)*, which is the best ranked by the measure Q (minimum), if the following two conditions are satisfied (Opricovic and Tzeng; 2007):
(1) *Acceptable advantage*: $Q(a^2)- Q(a^1)\geq DQ$, where *(a^2)* is the alternative with the second position in the ranking list by Q; $DQ=1/(m-1)$; m is the number of alternative.
(2) *Acceptable stability in decision making*: Alternative *(a^1)* must also be the best ranked by S or/and R. The best alternative, ranked by Q, is the one with minimum value of Q.
Fig. 1 presents a systematic approach for risk evaluation. An integrated intuitionistic fuzzy multi-criteria decision making method is used for FMEA. This paper deals with the perfect multiplicative consistent intuitionistic preference relation. If the judgments of decision makers are inconsistent, these judgments are repaired by helping of an algorithm automatically. All judgments of decision makers are aggregated in group decision making environment by using IFWA operator. The consistency of aggregation matrix is checked. If it is inconsistent, it is repaired by helping of the algorithm of Xu and Liao (2014) automatically. The weights of criteria have been calculated by employing IFAHP method. All judgments of decision makers for criteria based alternatives are aggregated in group decision making environment by using IFWA operator. The solution of the risk evaluation has been found by employing IFVIKOR method. The failure modes are ranked after S, R, and Q values are calculated. A mathematical programming is presented to find an optimum solution to overcome the limitations of the firm. The proposed approach includes an integrated multi criteria decision making method and a mathematical programming to apply FMEA method in the firms, which are a textile firm, a metal firm and a construction firm. The proposed paper handles IFNs, which provide an advantage due to considering indeterminacy of the decision maker. The decision maker can present their judgments about a preference relation defining his hesitation. The proposed method wants decision makers, who have much knowledge, experience in risk evaluation field. Finding these decision makers is very difficult and time consuming so that this situation is a disadvantage of the proposed method. Furthermore, the proposed method considers a linear mathematical model to form an occupational health and safety policy. Thus, the capacities of the firm can be handled thanks to this advantage. Defining the time and cost of the risk is very difficult as a disadvantage. The firm presented budget, time and number of correctable risk constraints according to its occupational health and safety policy. The firm can need different capacity constraints in risk evaluation process. This situation must be taken into account as a disadvantage while risk evaluation is implemented.

4. APPLICATIONS FOR RISK EVALUATION

Risk assessment process includes defining of decision makers to make risk assessment, determining failure modes, determining criteria that examined in evaluation phases, weighting the criteria and evaluation of failure modes phases. Three real life applications in three firms, which are a textile firm, a construction firm and a metal firm, are presented in order to provide the better understanding of the proposed approach. The characteristics of a firm are important for the experts' judgments. These characteristics are historical data, experience, manufacturer's data, testing. Experts evaluated occurrence, severity, and non-detection criteria of each failure mode according to these characteristics. The occurrence criterion defines frequency of a failure mode in a period such as a day, a week, a month. Experts present their judgments about the probability of each failure mode in the firm by using linguistic values in Table 1. The severity criterion defines the level of impact to the worker when a failure mode occurred. The failure mode can be caused injury, loss of limb, death of workers. Experts present their judgments about the severity of each failure mode in the firm by using linguistic values in Table 1. The non-detection criterion defines the level of incapability of the reasons of a failure mode in a firm. The reasons of each failure mode can be detected after a control is realized in the firm. This criterion deals with non-detection of the reasons of each failure mode after a control. Experts present their judgments about the non-detection of each failure mode in the firm by using linguistic values in Table 1.

Occupational accidents lead to serious problems in Turkey and in many other countries. The outcomes of occupational accidents can be divided into two categories-social costs and economic costs (Ceylan, 2012). Firms are obliged to provide a safe environment for their employees due to law requirements. Employees can work more comfortably when firms establish a safe working environment. Thus, productivity can be increased. It is highly probable that an occupational accident occurs in an unsafe business environment. The occupational accidents can result in injury or death. This situation can lead to loss of labor force, loss of productivity, pay compensation. For these reasons, firms must take all necessary precautions. Risk assessment is needed to establish a safe working environment. FMEA is a widely used risk assessment method. In this paper, a new method is suggested by eliminating FMEA deficiencies. The managers and all employees must attend to the implementation. The important result of this paper is that the failure modes of the related process in the firm are ranked according to risk level. If these failure modes are considered correctly, the working environment could be improved in terms of occupational safety. This paper significantly ensured the awareness among the employees and managers toward the implementation of FMEA.

4.1. An application in a textile firm

The textile firm wants to eliminate failure modes associated with occupational health and safety in manufacturing system so the managers assign the six experts committee comprising of experts in occupational health and safety domain. After initial elimination, six failure modes have been remained for further assessment. An expert team of six decision makers E1, E2, E3, E4, E5 and E6 were asked to fill a questionnaire in order to define the highest risky failure mode for a textile firm. E1, E2, E3 are occupational health and safety experts while E4 and E5 are academic experts and E6 is a foreman. They worked in different textile firms for least ten years so that they have enough knowledge and experience about risk evaluation. Six failure modes are determined as risks that caused from work equipment (FM_1), noise (FM_2), non-ergonomic working posture (FM_3), fire (FM_4), increasing of work pace depending on the demand (FM_5), bullying and victimization (FM_6) according to the company database. Fig. 2 shows the hierarchy process of the problem. Many failure modes can be found in the firm but they are neglected. They can occur rarely or in little severity. Workers do not complain about this failure mode. Above six failure modes create a problem for the worker. FM_1 relates to sewing, overlook, buttonhole, button sewing machines. They are working with the needle system. The broken needles can puncture the fingers of the worker. It can also cause loss of vision if it reaches the face. FM_2 relates to the sound. Many machines are used in the firm so they can result in loud noise. The workers might not understand the work order exactly due to high sound. FM_3 relates to the non-appropriate line design. The workers have different anthropometric measurements such as length of arm, hand, leg. The line is not appropriate for anthropometric measures of the workers. This situation can cause to the muscle-skeleton disorders for the workers. FM_4 relates to likelihood of fire. There are many fabric parts in the firm so that smoking or electrical malfunctions may cause fire. FM_5 relates to unreasonable speed of work. The workers have to realize more production due to more demand. This situation triggers more failure in the production. FM_6 relates to rude definitions of foreman to the workers. The foreman tells the work orders to the workers by using rude and hard definitions. This situation causes to the dispirited of the workers and decreases the productivity of the workers. Three criteria that affecting risk assessment are the probability of the failure, the severity of failure, and the non-detectability of the failure. Six failures modes have to be categorized based on these criteria. The importance degree of decision makers are assigned in order to show their differences in the group decision making problem so that the importance degrees of E1, E2, E3, E4, E5 and E6 decision makers can be defined as (0.25, 0.15, 0.10, 0.20, 0.10, 0.20), respectively. IFAHP method is utilized to determine the weights of criteria and then IFVIKOR method is employed to rank failure modes based on criteria so that assessment process is completed. The preference relations of specialists' opinions are established to obtain priorities of criteria and to evaluate the ratings of the failure modes by employing the linguistic scale, which is demonstrated in Table 1. The six experts construct the preference relations of criteria as showing in Table 2.

***Table 1**. Transformation between linguistic values and IFNs.*

Linguistic values	IFNs
Very high (VH)	(0.95,0.05,0.00)
High (H)	(0.75,0.15,0.10)
Equal (E)	(0.50,0.50,0.00)
Medium (M)	(0.50,0.40,0.10)
Low (L)	(0.25,0.65,0.10)
Very low (VL)	(0.05,0.95,0.00)

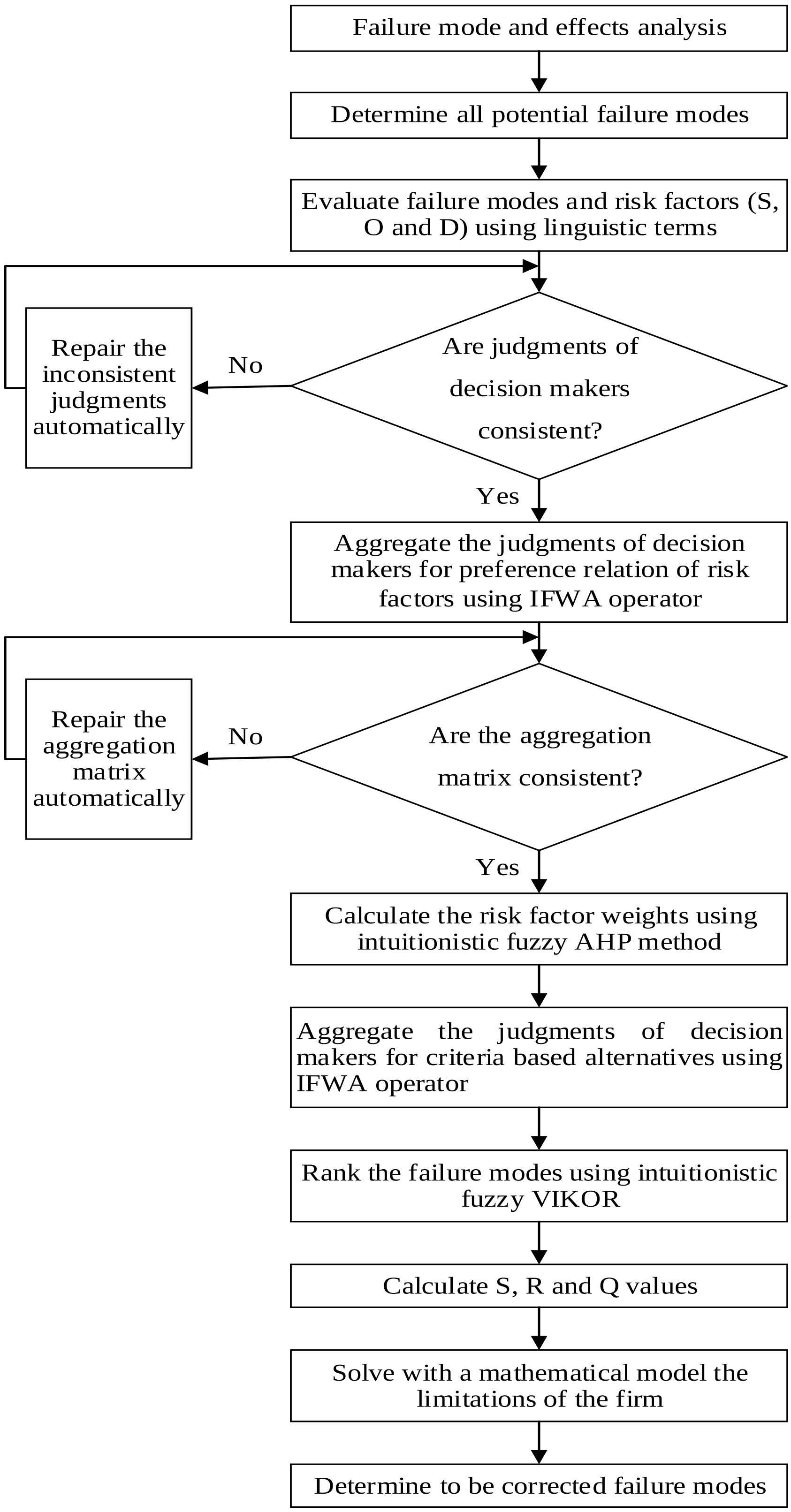

Figure 1. *Flowchart of the proposed approach.*

The judgments of each expert can be checked in terms of consistency. The inconsistent intuitionistic preference relations of the experts can be repaired into a consistent one by helping of an algorithm automatically. A perfect multiplicative consistent intuitionistic preference relation $\bar{R}=(\bar{r}_{ik})_{n\times n}$ can be established for expert 5 as an example. Firstly, the modified intuitionistic preference relation $\bar{R}=(\bar{r}_{ik})_{n\times n}$ is defined and it is shown in Table 3. Here, we indicate $\bar{r}_{13}$ as an example:

$$\bar{\mu}_{15}=\frac{\mu_{12}\times\mu_{23}}{\mu_{12}\times\mu_{23}+(1-\mu_{12})\times(1-\mu_{23})}=\frac{0.5\times 0.5}{0.5\times 0.5+(1-0.5)\times(1-0.5)}=0.50$$

$$\bar{v}_{13}=\frac{v_{12}\times v_{23}}{v_{12}\times v_{23}+(1-v_{12})\times(1-v_{23})}=\frac{0.4\times 0.4}{0.4\times 0.4+(1-0.4)\times(1-0.4)}=0.308$$

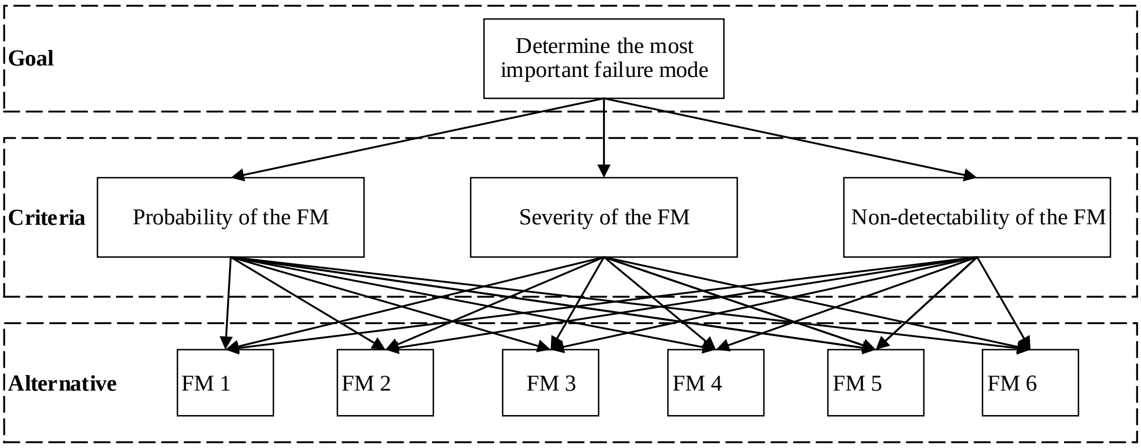

Figure 2. *The hierarchy process of the problem for textile firm*

The deviation $d\left(R^{(p)},\bar{R}\right)$ between $R^{(p)}$ and $\bar{R}$ is calculated and the consistency of intuitionistic preference relation is determined as $d\left(R^{(0)},\bar{R}\right)=0.3423>0.1$ which means the unacceptable consistency so that it needs to repair by using Eqs. (14)-(15) automatically. When σ is 0.8 here, the acceptable consistent intuitionistic preference relation $R^{(1)}$ for expert 5 can be indicated in Table 4. The consistency of intuitionistic preference relation is determined as $d\left(R^{(1)},\bar{R}\right)=0.064<0.1$ which means the acceptable consistency. The consistency checking is realized by using same process for other experts. IFWA operator can be utilized to aggregate the judgments of experts based on importance degree of experts. The judgments of all experts are combined into unique group opinion to aggregate their intuitionistic preference relations. The consistency checking of the combined intuitionistic preference relation is done and it is determined as the unacceptable consistency so that it needs to repair by using Eqs. (14)-(15). After repairing process, the perfect multiplicative consistent intuitionistic preference relation is defined and shown in Table 5.

The weights of criteria with the perfect multiplicative consistent intuitionistic preference relation are obtained by using Eq. (16) and data in Table 5 as follows:

$\omega_O=(0.270,0.613)$, $\omega_S=(0.280,0.621)$, $\omega_D=(0.300,0.590)$

Using Eq.(6), it is acquired $S(\omega_O)=-0.342$, $S(\omega_S)=-0.341$, $S(\omega_D)=-0.290$.

Table 2. *Preference relations of criteria for six experts.*

		O	S	D			O	S	D
E1	O	(0.5,0.5,0)	(0.5,0.4,0. 1)	(0.5,0.4,0.1)	E4	O	(0.5,0.5,0)	(0.25,0.65,0.1)	(0.25,0.65,0.1)
	S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.25,0.65,0.1)		S	(0.65,0.25,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
	D	(0.4,0.5,0.1)	(0.65,0.25,0.1)	(0.5,0.5,0)		D	(0.65,0.25,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)
E2	O	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.25,0.65,0.1)	E5	O	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.25,0.65,0.1)
	S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.25,0.65,0.1)		S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
	D	(0.65,0.25,0.1)	(0.65,0.25,0. 1)	(0.5,0.5,0)		D	(0.65,0.25,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)
E3	O	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.25,0.65,0.1)	E6	O	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.5,0.4,0.1)
	S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.75,0.15,0.1)		S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
	D	(0.65,0.25,0.1)	(0.15,0.75,0.1)	(0.5,0.5,0)		D	(0.4,0.5,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)

***Table 3**. Transformed preference relation of criteria for expert 5.*

	O	S	D
O	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.5,0.308,0.192)
S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
D	(0.308,0.5,0.192)	(0.4,0.5,0.1)	(0.5,0.5,0)

***Table 4.** Acceptable consistent preference relation of criteria for expert 5.*

	O	S	D
O	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.445,0.372,0.183)
S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
D	(0.372,0.445,0.183)	(0.4,0.5,0.1)	(0.5,0.5,0)

***Table 5**. Preference relation of criteria for the combining result of six experts.*

	O	S	D
O	(0.500,0.500,0.000)	(0.458,0.441,0.101)	(0.406,0.398,0.196)
S	(0.461,0.435,0.104)	(0.500,0.500,0.000)	(0.451,0.441,0.108)
D	(0.513,0.349,0.138)	(0.499,0.395,0.106)	(0.500,0.500,0.000)

The ranking of criteria is D>S>O, since $S(\omega_D) > S(\omega_S) > S(\omega_O)$ so that D is the most important criteria for risk assessment of the specified textile firm.

IFVIKOR method is proposed to evaluate the failure modes under an intuitionistic fuzzy environment. Six experts utilize the linguistic rating values indicated in Table 1 to determine the rating of failure modes based on each criteria. The rating of the six failure modes by the six experts based on the three criteria are presented in Table 6. The linguistic evaluations indicated in Table 6 are converted into intuitionistic fuzzy numbers by using Table 1. Decision makers presented their judgments about criteria based alternative in Table 6. The weights of criteria are necessary for IFVIKOR method. The above weights of the criteria are used to evaluate the criteria based alternative. The group decision of six experts based on their importance is obtained with using IFWA operator and the aggregated intuitionistic fuzzy rating of failure modes under three criteria is shown in Table 7. This paper used IFWA operator to aggregate the judgments of the decision makers. The calculations of S criterion based FM1 according to six decision makers are presented as follows:

E1, E2, E3, E4, E5 and E6 presented their judgments (0.5,0.4), (0.5,0.4), (0.95,0.05), (0.95,0.05), (0.5,0.4) and (0.75,0.15) for S criterion based FM1, respectively.

$$(0.4)^{0.25} \times (0.4)^{0.15} \times (0.05)^{0.10} \times (0.05)^{0.20} \times (0.4)^{0.10} \times (0.15)^{0.20} = 0.176\ (v)$$
$$1-(1-0.5)^{0.25} \times (1-0.5)^{0.15} \times (1-0.5)^{0.10} \times (1-0.5)^{0.20} \times (1-0.5)^{0.10} \times (1-0.5)^{0.20} = 0.782\ (\mu)$$

The best f_j^* and the worst f_j^- values of all criteria are defined by using Eqs. (17)-(18) and Eqs. (6)-(7) as follows:

$$f_O^* = (0.288, 0.644),\ f_S^* = (0.322, 0.576),\ f_D^* = (0.400, 0.498)$$

$$f_O^- = (0.750, 0.150),\ f_S^- = (0.782, 0.176),\ f_D^- = (0.836, 0.130)$$

This paper obtained the normalized intuitionistic fuzzy difference $\bar{d}_{ij}$ using Euclidean distance in Eqs. (19) -(21). The calculations of O criterion based FM1 are presented as follows:

$$d\left(f_O^*, r_{1O}\right) = \sqrt{\frac{1}{2}\left((0.288-0.5)^2 + (0.644-0.4)^2 + (0.068-0.1)^2\right)} = 0.229$$
$$d\left(f_O^*, f_O^-\right) = \sqrt{\frac{1}{2}\left((0.288-0.75)^2 + (0.644-0.15)^2 + (0.068-0.1)^2\right)} = 0.478$$
$$\bar{d}_{1O} = \frac{0.229}{0.478} = 0.479$$

S, R and Q values of FM1 are determined by using Eqs. (22)-(24) as follows:

$$S_1 = (0.479)\times(0.140, 0.791) + (1.0)\times(0.280, 0.621) + (1.0)\times(0.300, 0.590) = (0.567, 0.290, 0.143)$$

$$R_1 = \max\left((0.479)\times(0.140, 0.791), (1.0)\times(0.280, 0.621), (1.0)\times(0.300, 0.590)\right) = (0.300, 0.590, 0.110)$$

$$Q_1 = 0.5\times\frac{\sqrt{\frac{1}{2}\left((0.567-0.146)^2+(0.290-0.785)^2+(0.143-0.069)^2\right)}}{\sqrt{\frac{1}{2}\left((0.567-0.146)^2+(0.290-0.785)^2+(0.143-0.069)^2\right)}}+$$

$$0.5\times\frac{\sqrt{\frac{1}{2}\left((0.300-0.108)^2+(0.590-0.837)^2+(0.110-0.055)^2\right)}}{\sqrt{\frac{1}{2}\left((0.300-0.108)^2+(0.590-0.837)^2+(0.110-0.055)^2\right)}}=1.000$$

Table 6. *Evaluation data for alternatives in the textile firm*

	E1			E2			E3			E4			E5			E6		
	O	S	D	O	S	D	O	S	D	O	S	D	O	S	D	O	S	D
FM_1	M	M	H	M	M	H	M	VH	VH	M	VH	VH	M	M	VH	M	H	L
FM_2	H	H	L	H	H	M	H	H	L	H	H	M	H	H	L	H	H	M
FM_3	M	M	M	M	M	M	M	M	M	H	M	H	M	M	M	H	VH	H
FM_4	L	M	L	M	L	M	M	L	M	M	L	M	M	L	M	M	L	M
FM_5	H	H	M	L	L	M	L	VL	L	L	VL	L	L	VL	L	L	L	M
FM_6	M	L	M	VL	M	VH	VL	M	VH	VL	M	VH	VL	M	VH	M	VH	VL

Table 7. *Evaluation data for alternatives for the combining result of six experts.*

	O	S	D
FM_1	(0.500,0.400,0.100)	(0.782,0.176,0.042)	(0.836,0.130,0.034)
FM_2	(0.750,0.150,0.100)	(0.750,0.150,0.100)	(0.400,0.498,0.102)
FM_3	(0.621,0.270,0.109)	(0.685,0.264,0.052)	(0.621,0.270, 0.109)
FM_4	(0.447,0.452,0.102)	(0.322,0.576,0.102)	(0.447,0.452,0.102)
FM_5	(0.430,0.451,0.119)	(0.374,0.524,0.102)	(0.412,0.486,0.102)
FM_6	(0.288,0.644,0.068)	(0.651,0.207,0.143)	(0.840,0.152,0.009)

The values of S, R, and Q are computed by using Eqs. (19)-(24) for the six failure modes and are presented in Table 8. S and R are determined as IFNs and the six failure modes are ranked by using Eqs. (6)-(7). Since values of S and R are IFNs, value of Q is calculated by using Eqs. (19)-(21) and Eq. (24). The rankings of the six failure modes by values of S, R, and Q are indicated in Table 9.

Table 8. *The values of S, R and Q for alternatives.*

	S	R	Q
FM_1	(0.567,0.290,0.143)	(0.304,0.589,0.107)	1.000
FM_2	(0.472,0.383,0.144)	(0.280,0.624,0.096)	0.830
FM_3	(0.498,0.358,0.144)	(0.231,0.687,0.082)	0.735
FM_4	(0.146,0.785,0.069)	(0.110,0.840,0.050)	0.007
FM_5	(0.151,0.779,0.070)	(0.108,0.844,0.048)	0.006
FM_6	(0.461,0.404,0.135)	(0.300,0.593,0.107)	0.877

Table 9. *The ranking orders of alternatives by S, R and Q.*

	FM_1	FM_2	FM_3	FM_4	FM_5	FM_6
S	1	3	2	6	5	4
R	1	3	4	5	6	2
Q	1	3	4	5	6	2

FM1 is obviously the highest risky failure mode for the textile firm according to value of Q and should be eliminated by the textile firm. The ranking will be followed by failure modes FM*6, FM2, FM3, FM4, FM5*.

4.1.1. Sensitivity analysis

A sensitivity analysis can be realized to test the quality of the proposed methodology under different conditions. The sensitivity analysis is implemented to define the effect of the parameter v on the final ranking of the failure modes. The parameter v has been presented as weight of the maximum group utility in VIKOR method. The compromise solution combines the maximum group utility and the minimum individual regret by helping of the parameter v and it ensures to rank the failure modes. The value of v begins as 0 value and ends as 1 value with increasing 0.1 value. The exchanging of v value is shown in Fig. 3. As it can be seen in Fig. 3, the ranking orders of FM1 and FM2 don't change at all values of v so that the ranking orders of these two failure modes are the same according to the compromise solution. FM1 is obviously the highest risky failure mode for all values of v. This means that the proposed approach presents robust and accurate results. On the other hand, the ranking orders of FM4 and FM6 were high when the value of v was small because the minimum individual regret was handled to be important due to reduce of the value of v. The ranking orders of FM3 and FM5 were higher level when the value of v was big because the maximum group utility was handled to be important due to increase of the value of v.

4.1.2. Comparisons and discussion

The traditional FMEA model, fuzzy VIKOR, fuzzy TOPSIS, and IFAHP- intuitionistic fuzzy grey relational analysis (IFGRA) methods are considered in order to illustrate the effectiveness of the proposed method. The ranking orders results of six failure modes are acquired by utilizing these methods and the results are shown in Table 10.

Table 10. *Ranking orders comparisons.*

	FM_1	FM_2	FM_3	FM_4	FM_5	FM_6
Proposed approach	1	3	4	5	6	2
IFAHP-IFGRA	1	3	4	5	6	2
FTOPSIS	2	1	3	5	6	4
FVIKOR	1	2	3	5	6	4
Traditional FMEA	1	2	3	4	6	5

Based on the ranking orders results in Table 10, the advantages of the proposed approach according to the other methods can be summarized as follows:

* The results of the proposed approach and the traditional FMEA are rather different. Except for FM1 and FM5, the ranking orders of the other failure modes are the different for these two methods. The proposed approach can be defined the weights of the risk factors, which are O, S, D. For example, FM4 is ranked in front of FM6 in result of the traditional FMEA because of big O rating of FM4 in comparison with FM6. The traditional FMEA considers that the weights of the risk factors are equal but the proposed approach determines the weights of the risk factors using IFAHP so that the risk factor O has less weighting than the other risk factors S and D.

* The results of the proposed approach and IFAHP-IFGRA are the same. GRA method provides to measure the grey relational grade between an alternative and the reference sequence and then the best alternative is selected according to the grey relational grades. The parameter ρ in GRA plays key role in the ranking orders of failure modes. If these parameters change, the ranking orders can change so that it can be seen in Fig. 3.

* The results of the proposed approach and the fuzzy VIKOR are rather different. VIKOR method considers the minimum individual regret and the maximum group utility, and presents the compromise solution using the parameter v. The parameter v in VIKOR plays key role in the ranking orders of failure modes. If these parameters change, the ranking orders can change so that it can be seen in Fig. 3. IFVIKOR takes into account the non-membership degree and hesitation degree. When problem with big size is used, the ranking orders of fuzzy VIKOR can significantly be different from that of IFVIKOR.

* Except for FM4 and FM5, the ranking orders of the other failure modes acquired by the fuzzy TOPSIS are remarkably different from that acquired by the proposed method. TOPSIS method simultaneously deals

to find the shortest distance from positive ideal solution and the farthest from negative ideal solution. The failure mode *FM2* is obviously the highest risky failure mode according to the result of fuzzy TOPSIS method. The proposed method and the other comparison methods determined the FM1 as the highest risky failure mode.

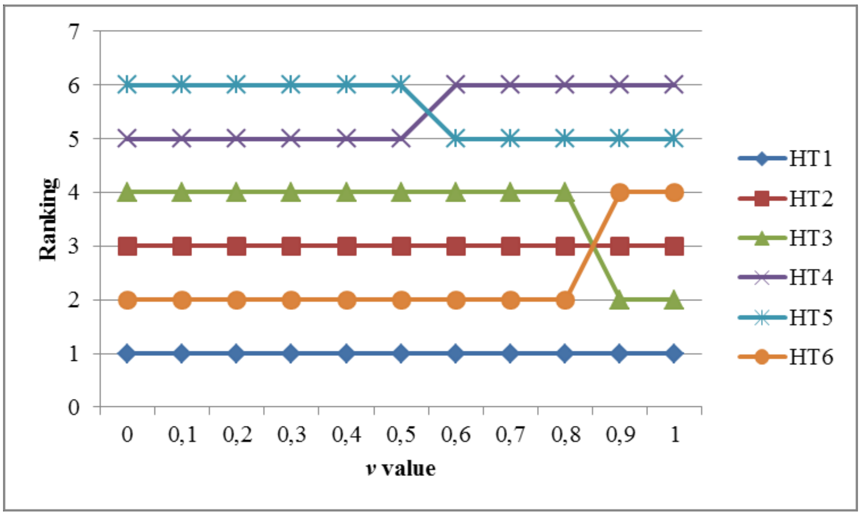

Figure. 3. Sensitivity analysis due to exchanging of *v* value.

4.1.3. Linear programming

The managers of the firm determined an occupational health and safety policy that includes some conditions. They stated that the results of FMEA are insufficient since FMEA method ignores the capacity of the firm and this situation causes some problems in long term. We proposed a linear programming to overcome this limitation. The firm presented budget, time and number of correctable risk constraints according to its occupational health and safety policy. The firm planned to allocate 17500 Turkish Liras (TL), 6-12 months, 3-6 correctable risks as constraints. We defined 3 different times, which are 6, 9 and 12 months. We presented 3, 4, 5 and 6 values for number of correctable risk. We calculated 12 different situations that the firm could select the most appropriate situation according to its conditions. Linear programming based on S, R and Q values in Table 8 is solved in BARON, which is available under GAMS software program, as a solver of the mathematical model. The mathematical model is presented below along with the notations used.

Notations

x_i : Binary variable, equal to 1 when failure mode i is corrected

f^* : Intuitionistic fuzzy value of failure mode, which has the lowest score value for S and R values in Table 8

f_i : Intuitionistic fuzzy value of failure mode i for S and R values in Table 8

c_i : Total cost after corrective action

b_i : Total cost without corrective action

t_i : Necessary time to correct failure mode i

q^* : Value of failure mode, which has the lowest value for Q value in Table 8

q_i : Value of failure mode i for Q value in Table 8

$$\max \sum_{i=1}^{n} d\left(f^*, f_i \right).x_i \tag{25}$$

Eq. (25) shows the objective function for linear programming based on S and R values in Table 8. $d\left(f^*, f_i \right)$ indicates distance between f^* and f_i intuitionistic fuzzy values. Eq. (26) is used to calculate the distance between them. f^* shows intuitionistic fuzzy value of failure mode, which has the lowest score value defined by using Eq. (6).

$$d\left(f_i^*, f_i \right) = \sqrt{\frac{1}{2}\left(\left(\mu_i^* - \mu_i \right)^2 + \left(v_i^* - v_i \right)^2 + \left(\pi_i^* - \pi_i \right)^2 \right)} \tag{26}$$

As it can be seen in Table 8, Q is not an intuitionistic fuzzy value. Eq. (27) is utilized to calculate the objective function based on Q value instead of Eq. (25).

$|q_i - q^*|$ defines the absolute value of difference between q_i and q^* values. Eqs. (25) and (27) aim to maximize the impact values of corrected risks as possible.

$$\max \sum_{i=1}^{n} |q_i - q^*| . x_i \tag{27}$$

st.

$$\sum_{i=1}^{n} (c_i . x_i + b_i .(1 - x_i)) \leq budget \tag{28}$$

$$\sum_{i=1}^{n} t_i . x_i \leq time \tag{29}$$

$$\sum_{i=1}^{n} x_i \leq number\ of\ correctable\ risk \tag{30}$$

$$x_2 - x_5 \leq 0 \tag{31}$$

$$x_1 - x_3 \leq 0 \tag{32}$$

$$x_i = 0 - 1 \tag{33}$$

Eq. (28) explains that firm limits the budget for corrective actions. The firm meets with several risk in work environment but the managers can not correct all of them due to some limitations. Risk can be reduced or eliminated after corrective action is realized. If the firm continues without corrective actions it can meet some problems in long term and this situation causes higher cost to the firm. Eq. (29) presents the time constraint of the firm to deal with the risks. Eq. (30) shows maximum number of correctable risk by the firm so that the firm can deal with certain risks due to its ability. Eqs.(31)-(32) show associated constraints between correctable risks. Eq.(31) means that failure mode 5 must be corrected when failure mode 2 corrected. Eq.(32) means that failure mode 3 must be corrected when failure mode 1 corrected. Eq.(33) shows binary variable. It equals to 1 when failure mode i is corrected. Cost and time data of failure modes in the textile firm are presented in Table 11.

Table 11. *Additional data in the textile firm*

Failure modes	c_i (TL)	b_i (TL)	t_i (Months)
FM1	1000	2500	2
FM2	1500	3000	1,5
FM3	2500	5000	1,5
FM4	2000	4500	1
FM5	2000	3500	2
FM6	1500	2500	1

After the mathematical model is solved the obtained results are presented in Table 12. The firm can realize the most appropriate occupational health and safety policy for its own sake by helping of the results in Table 12. Though failure mode 2 is always one of the first three failures according to the result of VIKOR method, this situation is invalid for the half of occupational health and safety policies according to the results of mathematical model. Failure mode 1 is the most important failure mode for the results of integrated intuitionistic fuzzy AHP-VIKOR method and mathematical model.

Table 12. *The results of linear programming based on S, R and Q values for the textile firm*

Budget	Time	NOCR	CR (S)	CR (R)	CR (Q)
17500	6	3	136	136	136
17500	6	4	136	1346	1346
17500	6	5	136	1346	1346
17500	6	6	136	1346	1346
17500	9	3	136	136	136
17500	9	4	1235	1346	1346
17500	9	5	12356	12356	12356
17500	9	6	123456	123456	123456

17500	12	3	136	136	136
17500	12	4	1235	1346	1346

* Corrected risks: CR, Number of correctable risk: NOCR

4.2. An application in a metal firm

After initial elimination, fourteen failure modes in Table 13 have been remained for further assessment. An expert team of five decision makers E1, E2, E3, E4, and E5 were asked to fill a questionnaire in order to define the highest risky failure mode for a metal firm. E1, E2, E3 are occupational health and safety experts while E4 is an academic expert and E5 is a foreman. They worked in different metal firms for least ten years so that they have enough knowledge and experience about risk evaluation. The importance degrees of E1, E2, E3, E4 and E5 decision makers can be defined as (0.15, 0.15, 0.25, 0.25, 0.20), respectively. Integrated IFAHP-IFVIKOR method is utilized to evaluate fourteen failure modes in a metal firm.

***Table 13**. Failure modes in the metal firm*

Abbreviations	Failure modes
FM1	Unsuitability of moving parts
FM2	To be closed the front of the emergency exit door
FM3	Inappropriate equipment
FM4	Inward opening of the emergency exit door
FM5	Absence of barriers on the upper floor
FM6	Electric shock during cutting
FM7	Noise after cutting
FM8	Absence of hook safety latch
FM9	Unfixed pressure tubes
FM10	Absence of periodic maintenance
FM11	Explosion of compressed air tank
FM12	Falling of load
FM13	Impacting of load to staff
FM14	Moving of load

The preference relations of criteria is determined by using Table 1 and is shown in Table 14. The weights of criteria in the metal firm are presented in Table 15. The rating of the fourteen failure modes by the five experts based on the three criteria are presented in Table 16. The linguistic evaluations indicated in Table 16 are converted into intuitionistic fuzzy numbers by using Table 1.

***Table 14**. Preference relations of criteria in the metal firm*

		C1	C2	C3			C1	C2	C3
E1	C1	(0.5,0.5,0)	(0.25,0.65,0.1)	(0.5,0.4,0.1)	E4	C1	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.75,0.15,0.1)
	C2	(0.65,0.25,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)		C2	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
	C3	(0.4,0.5,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)		C3	(0.15,0.75,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)
E2	C1	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.25,0.65,0.1)	E5	C1	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.25,0.65,0.1)
	C2	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)		C2	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
	C3	(0.65,0.25,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)		C3	(0.65,0.25,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)
E3	C1	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.25,0.65,0.1)					
	C2	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.75,0.15,0.1)					
	C3	(0.65,0.25,0.1)	(0.15,0.75,0.1)	(0.5,0.5,0)					

***Table 15**. Weights of the criteria in the metal firm*

Criteria	Weights
O	(0.299,0.577,0.124)
S	(0.307,0.585,0.108)
D	(0.236,0.652,0.112)

The values of S, R, and Q are computed by using Eqs. (19)-(24) for the fourteen failure modes and are presented in Table 17. The rankings of the fourteen failure modes by values of S, R, and Q are indicated in Table 18. The managers of the firm determined an occupational health and safety policy that includes some conditions. The firm presented budget, time and number of correctable risk constraints according to its occupational health and safety policy. The firm planned to allocate 15000 TL, 14-18 weeks, 6-8 correctable risks as constraints. We defined 3 different times, which are 14, 16 and 18 weeks. We presented 6, 7 and 8 values for number of correctable risk. We calculated 9 different situations that the firm could select the most appropriate situation according to its conditions. S, R and Q values based linear programming is solved in BARON, which is available under GAMS software program, as a solver of the mathematical model. Eq. (25) shows the objective function for linear programming based on S and R values in Table 17. Eq. (27) is utilized to calculate the objective function based on Q value in Table 17. Eqs. (28)-(30) and (33) are consider as constraints of the firm. Cost and time data of failure modes in the metal firm are presented in Table 19. After the mathematical model is solved the obtained results are presented in Table 20.

Table 16. *Evaluation data for alternatives in the metal firm.*

	E1			E2			E3			E4			E5		
	O	S	D	O	S	D	O	S	D	O	S	D	O	S	D
FM1	M	H	L	H	M	L	H	M	VL	M	M	M	H	VH	M
FM2	M	H	L	M	M	L	M	M	M	L	VH	M	M	M	M
FM3	M	L	H	L	L	M	L	L	H	VL	VL	M	L	L	VH
FM4	M	M	VL	L	L	VL	M	M	VL	M	L	L	M	L	L
FM5	H	L	H	H	L	M	M	L	M	H	M	M	M	M	M
FM6	M	H	M	M	M	M	H	VH	M	VH	H	H	H	VH	L
FM7	H	L	H	H	L	H	L	L	VH	M	M	H	VH	M	H
FM8	H	L	H	M	L	H	H	L	H	M	M	M	M	VL	M
FM9	H	L	H	H	L	H	M	M	VH	M	L	VH	H	M	H
FM10	M	M	M	L	M	M	M	M	L	M	H	L	L	H	M
FM11	M	L	H	L	L	M	L	L	M	M	L	M	L	L	M
FM12	M	M	M	H	M	M	H	M	M	H	H	L	M	M	M
FM13	L	L	H	L	L	L	M	VL	H	L	L	L	L	VL	H
FM14	H	L	H	L	L	M	L	L	M	M	M	H	H	VL	H

Table 17. *The values of S, R and Q for alternatives in the metal firm.*

	S	R	Q
FM1	(0.484,0.367,0.149)	(0.252,0.638,0.110)	0.726
FM2	(0.431,0.428,0.142)	(0.265,0.638,0.097)	0.664
FM3	(0.226,0.668,0.106)	(0.205,0.695,0.100)	0.236
FM4	(0.237,0.665,0.098)	(0.141,0.790,0.069)	0.026
FM5	(0.433,0.418,0.150)	(0.246,0.645,0.108)	0.645
FM6	(0.586,0.262,0.152)	(0.299,0.577,0.124)	1.000
FM7	(0.496,0.347,0.158)	(0.264,0.623,0.114)	0.783
FM8	(0.413,0.437,0.150)	(0.227,0.671,0.102)	0.561
FM9	(0.488,0.355,0.157)	(0.240,0.653,0.106)	0.700
FM10	(0.386,0.480,0.135)	(0.232,0.680,0.088)	0.504
FM11	(0.259,0.628,0.113)	(0.148,0.776,0.077)	0.096
FM12	(0.480,0.369,0.151)	(0.257,0.631,0.112)	0.740
FM13	(0.214,0.684,0.102)	(0.169,0.744,0.087)	0.103
FM14	(0.384,0.471,0.145)	(0.185,0.722,0.093)	0.399

Table 18. *The ranking orders of alternatives by S, R and Q in the metal firm.*

	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11	FM12	FM13	FM14
S	4	7	13	12	6	1	2	8	3	10	11	5	14	9
R	5	3	10	14	6	1	2	8	7	9	13	4	12	11
Q	4	6	11	14	7	1	2	8	5	9	13	3	12	10

The firm can realize the most appropriate occupational health and safety policy for its own sake by helping of the results in Table 20. Failure mode 6 is the most important failure mode for the results of integrated intuitionistic fuzzy AHP-VIKOR method and mathematical model.

Table 19. *Additional data in the metal firm*

Failure modes	c_i (TL)	b_i (TL)	t_i (Weeks)
FM1	1500	2500	2
FM2	1250	2000	2
FM3	250	450	2

FM4	1250	2000	2
FM5	2500	3500	3
FM6	1750	4000	3
FM7	1000	1500	2
FM8	300	750	1
FM9	200	600	1
FM10	250	500	1
FM11	200	500	1
FM12	1000	2000	2
FM13	350	800	2
FM14	200	300	1

Table 20. *The results of linear programming based on S, R and Q values for the metal firm*

Budget	Time	NOCR	CR (S)	CR (R)	CR (Q)
15000	14	6	1,2,5,6,7,12	1,2,5,6,7,12	1,2,5,6,7,12
15000	14	7	1,5,6,7,8,9,12	1,5,6,7,8,9,12	1,5,6,7,8,9,12
15000	14	8	1,2,6,7,8,9,12,14	1,2,6,7,8,9,10,12	1,2,6,7,8,9,10,12
15000	16	6	1,2,5,6,7,12	1,2,5,6,7,12	1,2,5,6,7,12
15000	16	7	1,2,5,6,7,9,12	1,2,5,6,7,9,12	1,2,5,6,7,9,12
15000	16	8	1,2,5,6,7,8,9,12	1,2,5,6,7,8,9,12	1,2,5,6,7,8,9,12
15000	18	6	1,2,5,6,7,12	1,2,5,6,7,12	1,2,5,6,7,12
15000	18	7	1,2,5,6,7,9,12	1,2,5,6,7,9,12	1,2,5,6,7,9,12
15000	18	8	1,2,5,6,7,8,9,12	1,2,5,6,7,8,9,12	1,2,5,6,7,8,9,12

* Corrected risks: CR, Number of correctable risk: NOCR

4.3. An application in a construction firm

After initial elimination, eleven failure modes in Table 21 have been remained for further assessment. An expert team of five decision makers E1, E2, E3, E4, and E5 were asked to fill a questionnaire in order to define the highest risky failure mode for a construction firm. An expert team of five decision makers E1, E2, E3, E4, and E5 were asked to fill a questionnaire in order to define the highest risky failure mode for a metal firm. E1 and E2 are occupational health and safety experts while E3 and E4 are academic experts and E5 is a building site chief. They worked in different construction firms for least ten years so that they have enough knowledge and experience about risk evaluation. The importance degrees of E1, E2, E3, E4 and E5 decision makers can be defined as (0.30, 0.20, 0.25, 0.15, 0.10), respectively. Integrated IFAHP - IFVIKOR method is utilized to evaluate eleven failure modes in a construction firm.

Table 21. *Failure modes in the construction firm*

Abbreviations	Failure modes
FM1	Injuring the foot of sharp materials in places
FM2	Entering plaster to eye
FM3	Unsuitability of the ladder platform used in high working
FM4	Absence of parachute type safety belt in high working
FM5	Electrical leakage in the plaster machine
FM6	Absence of the control of the plaster machine
FM7	Manual handling
FM8	Overturning of load during moving of load with pallet jack
FM9	Connections problems in handcuffs of the hose of plaster machine
FM10	Destroying of the existing steel ropes during production of plaster
FM11	Overtaken limbs during cleaning of plaster machine

The preference relations of criteria are determined by using Table 1 and are shown in Table 22. The weights of criteria in the construction firm are presented in Table 23. The rating of the fourteen failure modes by the five experts based on the three criteria are presented in Table 24. The linguistic evaluations indicated in Table 24 are converted into intuitionistic fuzzy numbers by using Table 1. The values of S, R, and Q are computed by using Eqs. (19)-(24) for the eleven failure modes and are presented in Table 25. The rankings of the eleven failure modes by values of S, R, and Q are indicated in Table 26.

Table 22*. Preference relations of criteria in the construction firm*

		O	S	D
E1	O	(0.5,0.5,0)	(0.75,0.15,0.1)	(0.5,0.4,0.1)
	S	(0.15,0.75,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
	D	(0.4,0.5,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)
E2	O	(0.5,0.5,0)	(0.25,0.65,0.1)	(0.25,0.65,0.1)
	S	(0.65,0.25,0.1)	(0.5,0.5,0)	(0.5,0.4,0.1)
	D	(0.65,0.25,0.1)	(0.4,0.5,0.1)	(0.5,0.5,0)
E3	O	(0.5,0.5,0)	(0.25,0.65,0.1)	(0.5,0.4,0. 1)
	S	(0.65,0.25,0.1)	(0.5,0.5,0)	(0.75,0.15,0.1)
	D	(0.4,0.5,0.1)	(0.15,0.75,0.1)	(0.5,0.5,0)
E4	O	(0.5,0.5,0)	(0.75,0.15,0.1)	(0.75,0.15,0.1)
	S	(0.15,0.75,0.1)	(0.5,0.5,0)	(0.25,0.65,0.1)
	D	(0.15,0.75,0.1)	(0.65,0.25,0.1)	(0.5,0.5,0)
E5	O	(0.5,0.5,0)	(0.5,0.4,0.1)	(0.5,0.4,0.1)
	S	(0.4,0.5,0.1)	(0.5,0.5,0)	(0.25,0.65,0.1)
	D	(0.4,0.5,0.1)	(0.65,0.25,0.1)	(0.5,0.5,0)

Table 23. *Weights of the criteria in the construction firm*

Criteria	Weights
O	(0.320,0.542,0.138)
S	(0.289,0.602,0.109)
D	(0.226,0.658,0.116)

Table 24. *Evaluation data for alternatives in the construction firm.*

		FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11
E1	O	L	H	L	L	H	VH	M	M	H	VH	H
	S	M	VL	M	M	VH	H	M	VL	L	H	H
	D	L	VH	M	M	VL	H	M	M	VH	H	H
E2	O	M	M	L	L	L	VH	VH	M	H	VH	M
	S	L	H	M	M	VH	H	M	H	H	H	H
	D	L	VH	H	H	H	H	M	H	M	M	M
E3	O	M	M	M	L	M	M	M	L	M	H	M
	S	L	L	M	M	VH	H	VH	H	M	H	H
	D	M	H	H	H	VH	H	H	H	H	VH	H
E4	O	H	L	M	VL	M	M	M	H	VH	H	H
	S	H	L	M	VL	L	M	L	L	M	M	H
	D	H	M	M	VL	VH	H	VH	H	VH	VH	VH
E5	O	L	M	VL	VL	M	L	VL	VL	H	VH	M
	S	H	H	M	M	H	M	H	M	M	H	H
	D	VH	L	VH	VH	VH	VH	VH	VH	VH	VH	VH

The managers of the firm determined an occupational health and safety policy that includes some conditions. The firm presented budget, time and number of correctable risk constraints according to its occupational health and safety policy. The firm planned to allocate 15000 TL, 12-20 weeks, 4-6 correctable risks as constraints. We defined 3 different times, which are 12, 16 and 20 weeks. We presented 4, 5 and 6 values for number of correctable risk. We calculated 9 different situations that the firm could select the most appropriate situation according to its conditions. S, R and Q values based linear programming is solved in BARON, which is available under GAMS software program, as a solver of the mathematical model.

Table 25. *The values of S, R and Q for alternatives in the construction firm.*

	S	R	Q
FM1	(0.198,0.709,0.093)	(0.149,0.773,0.077)	0.214
FM2	(0.368,0.478,0.155)	(0.213,0.676,0.111)	0.571

FM3	(0.239,0.648,0.113)	(0.121,0.810,0.069)	0.204
FM4	(0.115,0.821,0.064)	(0.098,0.844,0.057)	0.000
FM5	(0.536,0.302,0.162)	(0.289,0.602,0.109)	0.867
FM6	(0.529,0.306,0.165)	(0.292,0.578,0.130)	0.895
FM7	(0.466,0.374,0.160)	(0.225,0.667,0.108)	0.684
FM8	(0.327,0.533,0.139)	(0.147,0.776,0.076)	0.360
FM9	(0.474,0.358,0.167)	(0.274,0.602,0.125)	0.805
FM10	(0.577,0.257,0.165)	(0.320,0.542,0.138)	1.000
FM11	(0.506,0.331,0.163)	(0.225,0.667,0.108)	0.723

Table 26. *The ranking orders of alternatives by S, R and Q in the metal firm*

	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11
S	10	7	9	11	2	3	6	8	5	1	4
R	8	7	10	11	3	2	6	9	4	1	5
Q	9	7	10	11	3	2	6	8	4	1	5

Eq. (25) shows the objective function for linear programming based on S and R values in Table 25. Eq. (27) is utilized to calculate the objective function based on Q value in Table 25. Eqs. (28)-(30) and (33) are consider as constraints of the firm. Cost and time data of failure modes in the construction firm are presented in Table 27.

Table 27. *Additional data in the construction firm*

Failure modes	c_i (TL)	b_i (TL)	t_i (Weeks)
FM1	350	750	1
FM2	500	800	1
FM3	500	1200	1
FM4	500	100	1
FM5	1200	2000	2
FM6	1500	3000	3
FM7	1200	2000	2
FM8	400	800	1
FM9	500	750	2
FM10	2500	4500	4
FM11	500	750	2

After the mathematical model is solved the obtained results are presented in Table 28. The firm can realize the most appropriate occupational health and safety policy for its own sake by helping of the results in Table 28. Failure mode 10 is the most important failure mode for the results of integrated intuitionistic fuzzy AHP-VIKOR method and mathematical model.

Table 28. *The results of linear programming based on S, R and Q values for the construction firm.*

Budget	Time	NOCR	CR (S)	CR (R)	CR (Q)
15000	12	4	5,6,10,11	5,6,9,10	5,6,9,10
15000	12	5	5,7,9,10,11	2,5,6,9,10	5,7,9,10,11
15000	12	6	2,5,6,7,9,11	2,5,6,7,9,11	2,5,6,7,9,11
15000	16	4	5,6,10,11	5,6,9,10	5,6,9,10
15000	16	5	5,6,9,10,11	5,6,9,10,11	5,6,9,10,11
15000	16	6	5,6,7,9,10,11	5,6,7,9,10,11	5,6,7,9,10,11
15000	20	4	5,6,10,11	5,6,9,10	5,6,9,10
15000	20	5	5,6,9,10,11	5,6,9,10,11	5,6,9,10,11
15000	20	6	5,6,7,9,10,11	5,6,7,9,10,11	5,6,7,9,10,11

* Corrected risks: CR, Number of correctable risk: NOCR

5. CONCLUSIONS

Risk evaluation associated with occupational health and safety is very vital for an organization's performance in growing competitive environment. This paper provides an integrated IFAHP-IFVIKOR approach for risk evaluation under group decision making. All judgments of experts are characterized based on linguistic values by intuitionistic fuzzy numbers, which deals with uncertainty. IFWA operator is used to aggregate the individual opinions of experts into a group opinion. IFAHP is utilized to determine the weights of criteria. IFVIKOR method is proposed to evaluate the failure modes based on three criteria under an intuitionistic fuzzy environment.

The suggested model is implemented within a textile firm, a metal firm and a construction firm. The results show that the suggested model can be efficiently utilized in risk evaluation problem. The results of the proposed method were compared with four comparable methods in FMEA application for the textile firm. Furthermore, the exchanging of *v* value is used for a sensitivity analysis of the proposed approach. Furthermore, this paper proposes a linear mathematical model to form an occupational health and safety policy unlike the papers in the literature. Thus, this paper presents a novel perspective in risk assessment area based on FMEA. The managers of the construction, metal and textile firms determined an occupational health and safety policy that includes some conditions. The firms presented budget, time and number of correctable risk constraints according to its occupational health and safety policy. The construction firm planned to allocate 15000 TL, 12-20 weeks, 4-6 correctable risks as constraints. The metal firm planned to allocate 15000 TL, 14-18 weeks, 6-8 correctable risks as constraints. The textile firm planned to allocate 17500 TL, 6-12 months, 3-6 correctable risks as constraints. The proposed method shows that destroying of the existing steel ropes during production of plaster, risks that caused from work equipment and electric shock during cutting were defined the most important failure modes for construction, textile and metal firms, respectively.

The results showed that the proposed approach provided a more accurate and robust risk ranking in FMEA. The proposed method can be used simply by the firms after the proposed method is transformed to risk evaluation software program. The managers define the decision makers in risk evaluation field. The decision makers only enter their judgments about criteria and criteria based alternative to the software program. Thus, the managers of firm can obtain the results from the software program, which implements IFAHP, IFVIKOR, linear programming methods.

The proposed method used Xu and Liao (2014)'s method to repair the inconsistent intuitionistic preference relations of the decision makers into a consistent one automatically. Thus, the proposed method overcomes to time consuming of the reevaluation process. The literature lacks studies about risk assessment using integrated IFAHP - IFVIKOR approach. The linear mathematical model in this paper handles budget constraint, time constraint and number of correctable risk constraint. Thus, this paper presents a novel perspective in risk assessment area based on FMEA. This paper simultaneously considered the ranking of the risks and capacities of the firms so that the established occupational health and safety policy for the firms can be valid in long term.

An integrated MCDM method with intuitionistic fuzzy set has big chance of success for risk evaluation problem since it also handles uncertain judgments of experts. In future papers, this integrated approach can be utilized for dealing with vagueness under intuitionistic fuzzy environment in different applications such as personnel selection, software selection, and supplier selection.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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