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A fuzzy multi criteria risk assessment based on decision matrix technique: A case study for aluminum industry

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ABSTRACT

Decision matrix risk-assessment (DMRA) technique is a systematic approach widely used in the Occupational Health and Safety (OHS) risk assessment. In a typical matrix method approach, a measure of risk value is obtained by evaluating two risk factors as the likelihood of a hazard and the severity of the hazard when it arises. In this paper, a fuzzy approach enabling experts to use linguistic variables for evaluating two factors which are the parameters of matrix method is proposed to deal with shortcomings of a crisp risk score calculation and to decrease the inconsistency in decision making. The parameters *likelihood* and *severity* related to the hazards in an aluminum plate manufacturing plant are weighted by using Fuzzy Analytic Hierarchy Process (FAHP), then the orders of priority of 23 various hazard groups are determined by using Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. As a follow-up study of the case application, the proposed risk assessment methodology is applied for hazard types in each department of the plant. Depending on the hazard control hierarchy, control measures are overtaken for the hazards that are placed at first of intra-department rankings.

1. Introduction

Risk is defined as the combination of the severity of the harm and the occurrence probability of this harm (Guneri and Gul, 2013; Guneri et al. 2015). Risk assessment is an essential tool for the safety policy of a company (Marhavilas and Koulouriotis, 2008). It includes identifying and evaluating all possible risks, reducing them and documenting the results, respectively (Main, 2012). The plentifulness in risk-assessment methods is such that there are many appropriate methods for any circumstance and the selection of the right is essential. Several methods are developed to assess risks in the literature. These methods are classified into two main groups as qualitative and quantitative in most sources (Tixier et al. 2002; Reniers et al. 2005; Marhavilas et al. 2011; Marhavilas and Koulouriotis, 2008). Multi criteria decision making (MCDM) base methods are used as quantitative risk assessment methods in the literature.

MCDM is a discipline that makes the decision maker's preferences explicit in decision making environments of multiple criteria. It can simultaneously evaluate the multiple and conflicting criteria. A MCDM method should have the following characteristics (Amaral and Costa, 2014): (1) the alternatives to be evaluated, (2) the criteria which the alternatives are evaluated depending on, (3) scores that reflect the value of an alternative's expected performance on the criteria, and (4) weights of criteria that represent relative importance of each one as compared in pair-wise manner. However in some conditions, crisp data based MCDM methods are inadequate to model real-life problems, these methods used in fuzzy environment (Ebrahimnejad et al. 2010).

Fuzzy MCDM is used to model the vagueness. Since, many real-world systems include incomplete and imprecise information (Karsak and Dursun, 2015). Also, in MCDM methods, it is often a difficult evaluation for decision makers to give a precise rating to an alternative with respect to the criteria. Giving the relative importance of criteria using fuzzy numbers instead of crisp numbers is one of the advantages of fuzzy MCDM methods. So, in this paper we prefer fuzzy MCDM methods in assessment of potential hazards in aluminum industry.

This paper presents a combined fuzzy AHP-fuzzy TOPSIS risk

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assessment methodology based on DMRA technique. In weighting the risk parameters *likelihood* and *severity* derived from DMRA, Buckley's FAHP is utilized. In evaluating the ranking orders of 23 various hazard groups and 84 hazard types for each department of the factory, fuzzy TOPSIS is utilized. The combined method considering linguistic variables in evaluation of criteria and alternatives has capability in managing uncertainties, simultaneous consideration of the positive and the negative ideal solutions, simple computations and logical concept (Mahdevari et al. 2014). The proposed methodology aims to reveal the important hazards and suggest control measures for managing them.

Due to the obligation of carrying risk assessment with the new Occupational Health and Safety Law with number 6331 in Turkey, the employers have met a problematic which risk assessment method they should select for applying. Workplace conditions, characteristics of the employees and financial constraints may affect the selection. As one of the growing sectors, aluminum industry in Turkey has faced probably new hazards. International Aluminum Institute (IAI) carries out road map projects to manage the identified hazards and risks. They suggest improved process control, positive technological changes, and better planning in order to lower potential risks (Wesdock and Arnold, 2014). In order to manage risks, companies need comprehensive and apparent risk assessment methods that eliminate occupational hazards or reduce them to an acceptable level in work places systematically, benefit from the experiences of employees with a better teamwork, and making the same study in each department.

In this paper, we propose a fuzzy multi criteria risk assessment based on a quantitative risk assessment technique "*the decision matrix technique*" and apply them on an aluminum industry's plant, which is situated in Tekirdag, Turkey. The rest of the paper is organized as follows: Next section presents the related literature with recent studies. In Section 3, methodologies used in our proposed method are described. Section 4 gives application of the proposed methodology in an aluminum plate manufacturing factory in Turkey. The conclusions of the study and some future remarks are mentioned in the last section.

2. Literature review

Risk assessment is important in almost all manufacturing and service industries. So that, it is a sector with high risk operations, much attention is paid to risk assessment process. Several studies have been done with different risk assessment approaches. Marhavilas and Koulouriotis (2008) explained two new quantitative risk assessment techniques called *proportional technique* and *decision matrix technique* and presented an application of these techniques on an aluminum extrusion industry in Greece. They used real data of potential sources of hazards, recorded by safety managers, during the 5.5-year time period of 1999–2004. They compared the results and reached that the two methods are compatible.

MCDM methods in the field of risk assessment are reviewed. They are mentioned as follows considering aims, methodologies and concluding remarks: Kang et al. (2014) presented the risk evaluation model for oil storage tank zones based on the theory of two types of hazards (inherent hazards, controllable hazards). Inherent hazards are evaluated by the major hazards method, which is based on the likelihood and severity of accidents. The risk factors of controllable hazards are identified by Fault Tree Analysis (FTA). These weights of factors are determined by AHP. After that, fuzzy comprehensive evaluation mode for controllable hazards is established. 5X5 risk-matrix method was applied to determine the risk rank of the oil storage tank zone. The proposed model combines major hazards method, AHP, fuzzy comprehensive evaluation and 5X5 risk matrix. Grassi et al. (2009) proposed a multi-attribute model for risk evaluation in a mortadella (a typical Italian sausage) production company in Italy. They applied fuzzy TOPSIS to determine risk index of hazardous activities. The main contribution of the study is that contributions produced by undetectability, sensitivity to non-execution of maintenance and sensitivity to non-utilization of personal protective equipment (PPE) are also taken into account in the model as well as injury magnitude and occurrence probability. However, while evaluating the five factors' weights they did not use a pair-wise comparison manner between risk factors. Additionally, they weighted the five criteria by the judgment of only one analyst. This may cause a really subjective evaluation. In our study, three OS experts make a group decision by pair wise comparison of the risk parameters of obtained from risk matrix method considering Buckley's FAHP algorithm. Mahdevari et al. (2014) identified and ranked 86 hazards at the Kerman coal deposit, Iran using fuzzy TOPSIS. They classified the risks into twelve different groups with respect to the risk index from fuzzy method. They also represent the control measures at the end of their study. Hu et al. (2009) performed a risk evaluation of green components to hazardous substance using FMEA and FAHP. They used the parameters of FMEA as criteria and weighted them with FAHP. Then a green component risk priority number was calculated for each one of the components by multiplying the weighs and FMEA scores of two managers. Ebrahimnejad et al. (2010) used fuzzy TOPSIS and Fuzzy Linear Programming Technique for Multidimensional Analysis of Preference (FLINMAP) methods based risk assessment model for build–operate–transfer (BOT) projects. They proposed the model for identifying and assessing risks in Iran BOT power plant project. John et al. (2014) proposed a fuzzy risk assessment methodology in seaport operations using FAHP, evidential reasoning (ER) approach, fuzzy set theory and expected utility. They apply FAHP to weight the risk factors while ER to synthesize them. Liu and Tsai (2012) proposed Quality Function Deployment (QFD), fuzzy analytic network process (ANP) and FMEA based risk assessment method in a construction company in Taiwan. They used QFD in order to represent the relationships among construction items, hazard types and hazard causes, fuzzy ANP method to identify important hazard types and hazard causes, FMEA to assess the risk value of hazard.

From this brief literature review, we conclude that our study will contribute more to literature on fuzzy MCDM methods related risk assessment models by some aspects: (1) we propose a hybrid fuzzy MCDM method that avoids shortcomings of a crisp risk score calculation and decreases the inconsistency in decision making. (2) The evaluations of risk parameters and hazard rankings are made by three experienced OS experts and a full consensus. (3) Apart from a classic DMRA approach, experts assign criteria weights by pair wise comparison manner of Buckley's FAHP. (4) To the best of authors knowledge, this is the first study in OHS risk assessment of aluminum industry in Turkey that uses FAHP-fuzzy TOPSIS hybrid approach.

3. Methodology

Risk assessment process involves some steps (Main, 2012). The steps are identifying hazards, assessing risks, reducing the identified risks and documenting the results. Risk assessment is a systematic use of available data to determine how often specific events may occur and the magnitude of their likely consequences. The risk assessment is the central part of the risk management process, which purposes to establish a proactive safety strategy by investigating potential risks (Rausand, 2013; Mahdevari et al. 2014). The first step is establishing project parameters and identifying assessment scope. In the second step, hazards are identified through different approaches. The third step is about assessing initial risks. The main focus of this paper is inside this step.

Main (2012) generated four sub-steps to assess initial risks. First, a risk scoring system is selected. Two-parameter (severity and likelihood) based scoring systems are frequently used in the literature as in DMRA method. Second, for each hazard, the severity rating is assessed. Severity is assessed according to the personal injury, the value of property or equipment damaged, the loss of working time and so on factors. Third, the probability of hazard is assessed. It is related to the frequency, duration and extent of exposure, training and awareness, and the characteristics of the hazard. Forth is about deriving initial risk level from the selected risk scoring system. The forth of main steps in risk assessment process is reducing risks. This step enables the process become more efficient so that significant risks are fast eliminated by using hazard control hierarchy (Main, 2012). After the risk reduction is performed, a second assessment is conducted to validate that the selected measures effectively reduce the risks. This is the step of assessing residual risks. The process follows a decision step hereafter. The risk assessment team decides on that the risks are reduced to an acceptable level. The last step includes documentation of the results (Marhavilas et al. 2011).

In risk assessment process using an apparent technique has several advantages. First of all it reveals occupational hazards and improvement precautions more efficiently than the conventional safety works. It is required to use a risk assessment technique in order to determine occupational hazards in work places systematically, benefiting from the experiences of employees with a better teamwork, and obtaining the same results at the end of the reviews in each department. Selecting the appropriate risk assessment method among several methods which have different outputs, steps and applications has a vital importance. Outputs of the risk assessment vary depending on the type of method selected. Currently many risk assessment methods are available in the literature in terms of estimating the risks, occurrence probability of the risks and possible effects of risks (Ceylan and Bashelvaci, 2011; Pinto et al. 2011; Tixier et al. 2002; Marhavilas et al. 2011).

In this section, DMRA method and its limitations are emphasized. Hereafter, Buckley's FAHP and fuzzy TOPSIS methodologies are explained.

3.1. Decision matrix risk-assessment (DMRA) technique

The decision matrix risk-assessment technique is a systematic approach which is widely used in OHS risk assessment and incorporating of measuring and categorizing risks on an informed judgment basis with respect to both likelihood and severity (Marhavilas and Koulouriotis, 2008; Marhavilas et al. 2011; Ceylan and Başhelvacı, 2011; Önder et al. 2011). We obtain a measure of risk value (R) by the aid of relation in severity (S) and likelihood (P) as: $R = S^*P$.

Initially, measurement of the severity and likelihood ratings are determined with this method (Tables 1 and 2). Then, the risk matrix and the decision-making table are constructed (Table 3). The acceptability level of the risks are also interpreted according to Table 3.

In this paper, a fuzzy approach enabling experts to use linguistic variables for evaluating two factors which are the parameters of decision matrix risk-assessment technique is proposed (1) to deal with shortcomings of a crisp risk score calculation and (2) to decrease the inconsistency in decision making. The classic DMRA has some limitations. It is based on an equal criteria weight for likelihood and severity. Different evaluations on the criteria may lead to different meanings (Grassi et al. 2009). For example, hazards with high probability and low severity can be classified at the same level as ones with low probability and high severity. The new developed DMRA technique based fuzzy method has some advantages: (1) It enables a group decision-making in assessing risks. (2) It uses relative importance among the two risk parameters by pair wise comparison of FAHP. (3) It is mostly difficult for *S* and *P* to be precisely evaluated. Therefore, linguistic terms are utilized in the developed method.

3.2. Fuzzy AHP

FAHP is one of the extensively used multi-criteria decision-making methods based on fuzzy set theory. AHP cannot still specify the subjective thinking style. So, FAHP is developed to solve hierarchical fuzzy problems. There are many FAHP methods proposed by various authors. Buckley (1985) determines fuzzy priorities of comparison ratios whose membership functions trapezoidal. Chang (1996) introduces a new approach for handling FAHP, with the use of triangular fuzzy numbers for pair wise comparison scale of FAHP, and the use of the extent analysis method for the synthetic

Table 1
Severity ratings (S).

Severity of consequences ratings (*S*)	
Rating category	Description
Insignificant (1)	No loss of working hours and requiring first aid
Minor (2)	No loss of working days, requiring outpatient treatment without a lasting impact and requiring first aid
Moderate (3)	Minor injury, requiring inpatient treatment
Major (4)	Major injury, requiring long-term treatment and therapy, occupational disease
Catastrophic (5)	Death, permanent total disability

Table 2
Likelihood ratings (P).

Hazard likelihood ratings (*P*)	
Rating category	Description
Rare (1)	Hardly ever
Unlikely (2)	Remote (Once a year), only in abnormal conditions
Possible (3)	Occasional (A few events in a year)
Likely (4)	Frequent (Monthly)
Almost certain (5)	Very frequent (Once a week, every day), under normal working conditions

Table 3
The risk-assessment decision matrix.

	Likelihood (P)				
Severity (S)	Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Almost certain (5)
Insignificant (1)	1	2	3	4	5
Minor (2)	2	4	6	8	10
Moderate (3)	3	6	9	12	15
Major (4)	4	8	12	16	20
Catastrophic (5)	5	10	15	20	25

Intolerable (unacceptable) risks (25)	Work should not be started until the identified risks reach to an acceptable level. If there is an ongoing activity, it should be immediately stopped. Unless it is possible to reduce the risks despite the precautions, activities should be avoided.
Significant risks (15, 16, 20)	Work should not be started until the identified risks should be stopped immediately. If there is an ongoing activity, it should be stopped. If the risk is concerned with the continuation of the work, emergency precautions must be taken.
Intermediate risks (8, 9, 10, 12)	Actions should be initiated to reduce the identified risks. It may take time for risk reduction preventions.
Acceptable risks (2, 3, 4, 5, 6)	There is no need to plan control processes in order to to eliminate the identified risks. However, the existing controls should be maintained and these controls should be monitored.
Insignificant risks (1)	There is no need to plan control processes in order to to eliminate the identified risks and to keep records of the activities to be carried out.

extent values of the pair wise comparisons. In our study we use the method of Buckley's (1985). Because in other methods, there are some limitations. For example, the extent analysis method could not make full use of all the fuzzy comparison matrices information, and might cause an irrational zero weight to the selection criteria (Chan and Wang, 2013). The procedure of the method is defined in four steps in the following (Tzeng and Huang, 2011; Gül et al., 2012).

Step 1: Pair wise comparison matrices are constructed among all the elements/criteria in the dimensions of the hierarchy system. Linguistic terms to the pair wise comparisons are assigned by asking which is the more important of each two elements/criteria, such as.

$$\widetilde{M} = \begin{pmatrix} 1 & \widetilde{a}_{12} & \cdots & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & 1 & \cdots & \widetilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{a}_{n1} & \widetilde{a}_{n2} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} 1 & \widetilde{a}_{12} & \cdots & \widetilde{a}_{1n} \\ 1/\widetilde{a}_{21} & 1 & \cdots & \widetilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\widetilde{a}_{n1} & \widetilde{a}_{n2} & \cdots & 1 \end{pmatrix} \quad (1)$$

$$\widetilde{a}_{ij} = \begin{cases} \widetilde{1}, \widetilde{3}, \widetilde{5}, \widetilde{7}, \widetilde{9} & \text{criterion } i \text{ is of relative importance to criterion } j \\ 1 & i = j \\ \widetilde{1}^{-1}, \widetilde{3}^{-1}, \widetilde{5}^{-1}, \widetilde{7}^{-1}, \widetilde{9}^{-1} & \text{criterion } j \text{ is of relative importance to criterion } i \end{cases} \quad (2)$$

Step 2: Using the geometric mean technique the fuzzy geometric mean matrix is defined.

$$\widetilde{r}_i = (\widetilde{a}_{i1} \otimes \widetilde{a}_{i2} \otimes \cdots \otimes \widetilde{a}_{in})^{1/n} \quad (3)$$

Step 3: Fuzzy weights of each criterion is calculated by the Eq. (4) below.

$$\widetilde{w}_i = \widetilde{r}_i \otimes (\widetilde{r}_1 \oplus \widetilde{r}_2 \oplus \cdots \oplus \widetilde{r}_n)^{-1} \quad (4)$$

Here,$\widetilde{w}_i$ is the fuzzy weight of criterion i. And $\widetilde{w}_i = (lw_i, mw_i, uw_i)$.

Here$lw_i mw_i$, uw_i justify lower, middle and upper value of the fuzzy weight of criterion i.

Step 4: To find the best non-fuzzy performance (BNP), CoA (center of area) method is used as in the Eq. (5)

$$w_i = [(uw_i - lw_i) + (mw_i - lw_i)]/3 + lw_i \quad (5)$$

3.3. Fuzzy TOPSIS

The Technique for Order Preferences by Similarity to an Ideal Solution (TOPSIS) was developed by Hwang and Yoon (1981) to determine the best alternative based on the concepts of the compromise solution. The compromise solution can be regarded as choosing the solution with the shortest distance from the ideal solution and the farthest distance from the negative ideal solution. Since the preferred ratings usually refer to the subjective uncertainty, it is natural to extend TOPSIS to consider the situation of fuzzy numbers (Tzeng and Huang, 2011; Celik et al. 2012).

In our study, we follow the procedure of the FTOPSIS method proposed by Chen (2000). It is defined in step by step in the following (Tzeng and Huang, 2011; Kutlu and Ekmekçioğlu, 2012):

Step 1: Considering a decision making group with K experts, the scores of alternatives with respect to each criterion is calculated by the formula as follows: $\widetilde{x}_{ij} = \frac{1}{K}[\widetilde{x}_{ij}^{1}(+)\widetilde{x}_{ij}^{1}(+)....(+)\widetilde{x}_{ij}^{K}]$. While $A = \{A_i|i = 1, ..., m\}$ shows the set of alternatives, $C = \{C_j|j = 1, ..., n\}$ represent the criteria set. Where $X = \{X_{ij}|i = 1, ..., m; j = 1, ..., n\}$ denotes the set of fuzzy ratings and $\widetilde{w} = \{\widetilde{w}_j|j = 1, ..., n\}$ is the set of fuzzy weights. The linguistic variables are described by triangular fuzzy number as follows: $\widetilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$.

Step 2: Normalized ratings are determined by Eq. (6).

$$\widetilde{r}_{ij} = \begin{cases} \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), & \text{where } c_j^* = \max_i c_{ij} \text{ if } j \in \text{benefit criteria} \\ \left(\frac{a_j^-}{c_{ij}}, \frac{b_j^-}{b_{ij}}, \frac{c_j^-}{a_{ij}}\right), & \text{where } a_j^- = \min_i a_{ij} \text{ if } j \in \text{cost criteria} \end{cases} \tag{6}$$

Step 3: Weighted normalized ratings are determined by Eq. (7).

$$\widetilde{v}_{ij} = \widetilde{w}_j(x)\widetilde{r}_{ij}, \quad i = 1, ..., m; j = 1, ..., n \tag{7}$$

Step 4: The fuzzy positive ideal point (FPIS,A*) and the negative ideal point (FNIS,A$^-$) are derived as in Eqs. (8) and (9). Where J_1 and J_2 are the benefit and the cost attributes, respectively.

$$\text{FPIS} = \text{A}* = \left\{\widetilde{v}_1^*, \widetilde{v}_2^*, ..., \widetilde{v}_n^*\right\} \text{ where } \widetilde{v}_j^* = (1, 1, 1) \tag{8}$$

$$\text{FNIS} = \text{A}^- = \left\{\widetilde{v}_1^-, \widetilde{v}_2^-, ..., \widetilde{v}_n^-\right\} \text{ where } \widetilde{v}_j^- = (0, 0, 0) \tag{9}$$

Step 5: Similar to the crisp situation, the next step is to calculate the separation from the FPIS and the FNIS between the alternatives. The separation values can also be measured using the Euclidean distance as in Eqs. (10) and (11):

$$\widetilde{S}_i^* = \sqrt{\sum_{j=1}^{n}\left[\widetilde{v}_{ij} - \widetilde{v}_j^*\right]^2}, \quad i = 1, ..., m \tag{10}$$

$$\widetilde{S}_i^- = \sqrt{\sum_{j=1}^{n}\left[\widetilde{v}_{ij} - \widetilde{v}_j^-\right]^2}, \quad i = 1, ..., m \tag{11}$$

Step 6: Then, the defuzzified separation values are derived using the CoA (centre of area) defuzzification method, such as, to calculate the similarities to the ideal solution. Next, the similarities to the ideal solution are given as Eq. (12).

$$C_i^* = \widetilde{S}_j^- \Big/ \left(\widetilde{S}_j^* + \widetilde{S}_j^-\right), \quad i = 1, ..., m \tag{12}$$

Finally, the preferred orders are ranked according to C_i^* in descending order to choose the best alternatives.

3.4. The proposed methodology

Fuzzy logic is the way of transforming the vagueness of human feeling and its decision-making ability into a mathematical formula (Kutlu and Ekmekçioğlu, 2012). In this paper, a fuzzy approach enabling OS experts to use linguistic variables for evaluating two factors which are the parameters of decision matrix risk-assessment technique is proposed (1) to deal with shortcomings of a crisp risk score calculation and (2) to decrease the inconsistency in decision making for aluminum industry. First, a group of OS experts identifies the potential hazards. Second, a pair-wise comparison matrix for two risk parameters is constructed, and Buckley's FAHP is utilized to determine the weights of these risk factors. Then, experts' linguistic evaluations of each hazards with respect to risk parameters are aggregated to get a mean value. By the aid of obtained fuzzy decision matrix, implementation of fuzzy TOPSIS is carried out. In fuzzy TOPSIS process, by using the weights of risk parameters and the fuzzy decision matrix, weighted normalized fuzzy decision matrix is constructed. Subsequently, FPIS and FNIS and the distance of each hazards from FPIS and FNIS are calculated, respectively. In final step, fuzzy TOPSIS closeness coefficients of processes are obtained. According to the closeness coefficients, the ranking order of all hazard groups is determined. Also the ranking of hazards for each department of the factory are obtained. Fig. 1 represents proposed fuzzy multi criteria risk assessment model based on decision matrix risk assessment method.

4. Application of the proposed methodology

The proposed methodology is applied to an aluminum facility. The facility in our study is located in Tekirdag, Turkey. The firm is founded as the first flat product manufacturer in Turkey. By the year of 2011, it has reached a total export ratio of 50%. The firm is placed 350th among the largest 500 companies in Turkey. In its machinery park, it has casting lines, cold rolling mills, slitting lines, cut-to-length line, annealing furnaces and tension leveling & degreasing lines. The products are plain coils and strips, stucco embossed coils and strips, cast coils, and plain and stucco embossed sheets.

Main hazard list is identified by a group of OS experts within 23 items as falling from the height (H1), falling on the same level (H2), falling of objects (H3), collision (H4), getting hit (H5), slipping (H6), being dragged along (H7), strain (H8), getting an electric shock (H9), flammable destruction (H10), explosive destruction (H11), exposure to chemicals (H12), popping out materials (H13), blowing materials (H14), sinking materials (H15), fire (H16), getting drowned (H17), suffocation from gas (H18), exposure to welding beam (H19), poisoning (H20), exposure of the eyes to burrs (H21), touch hot surfaces (high or low temperature, boiling water) (H22), and panic and disturbance (H23).

After the identification of the hazards, by utilizing Buckley's FAHP method, evaluations of three OS experts in linguistic variables are used to determine the importance of two risk parameter (S, and P) by pair-wise comparison. In this paper, the OS experts use the linguistic variables to evaluate the risk parameters' weights in Table 4 (Kutlu and Ekmekçioğlu, 2012). The evaluation in linguistic form is presented in Table 5. For instance, when comparing the risk parameter likelihood and severity, the responses of three experts are fairly weak (FW), very weak (VW), and very weak (VW), respectively. After applying FAHP the weights of risk parameters are obtained as (0.639, 0.361) for S and P, respectively.

Then, by using the risk parameters' weights from Buckley's FAHP, and the fuzzy evaluations of each risk parameter with respect to hazard groups, fuzzy TOPSIS is applied. In the paper, the OS experts make the evaluation of hazard groups using linguistic variables as shown in Table 6. The evaluations of the OS experts in linguistic variables for the risk parameters with respect to 23 different hazard group are expressed as in Table 7. For example, the three OS experts evaluated the hazard (H1)-falling from the height as medium good (MG), fair (F), medium good (MG) respectively for severity (S), and medium poor (MP), medium poor (MP), and poor (P) respectively for likelihood (P).

The fuzzy linguistic variables in Table 7 is then transformed into

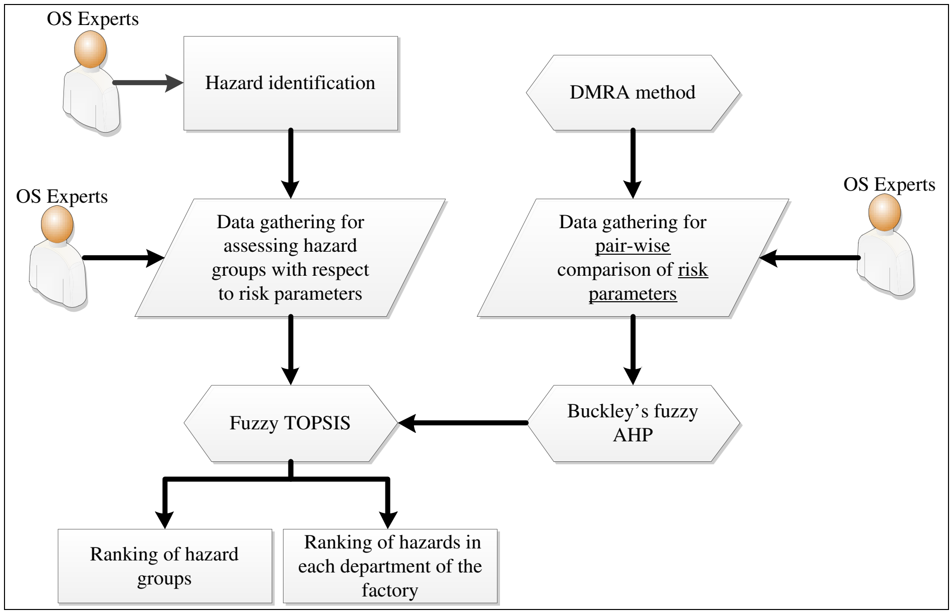

Fig. 1. Proposed fuzzy multi criteria risk assessment method.

Table 4
Linguistic terms and related fuzzy values for weight evaluation.

Linguistic terms	Fuzzy values
Absolutely strong (AS)	(2, 5/2, 3)
Very strong (VS)	(3/2, 2, 5/2)
Fairly strong (FS)	(1, 3/2, 2)
Slightly strong (SS)	(1, 1, 3/2)
Equal (E)	(1, 1, 1)
Slightly weak (SW)	(2/3, 1, 1)
Fairly weak (FW)	(1/2, 2/3, 1)
Very weak (VW)	(2/5, 1/2, 2/3)
Absolutely weak (AW)	(1/3, 2/5, 1/2)

Table 5
Evaluations of OS experts in linguistic variables and weights of the risk parameters.

OS experts 1-2-3	Likelihood	Severity	Weight
Likelihood	E,E,E	FW,VW,VW	0.361
Severity	–	E,E,E	0.639

Table 6
Linguistic terms and related fuzzy values for hazard ranking.

Linguistic terms	Fuzzy values
Very poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very good (VG)	(9, 10, 10)

Table 7
Evaluations of OS experts in linguistic variables for the two risk parameters with respect to 23 hazard groups.

Item	Hazard description	Severity	Likelihood
H1	Falling from the height	MG,F,MG	MP,MP,P
H2	Falling on the same level	MP,F,F	P,P,MP
H3	Falling of objects	MG,G,G	MP,P,MP
H4	Collision	P,MP,MP	F,MP,MG
H5	Getting hit	F,F,MG	P,MP,P
H6	Slipping	MG,G,G	P,MP,MP
H7	Being dragged along	G,G,MG	P,MP,MP
H8	Strain	MG,MG,MG	MP,P,P
H9	Getting an electric shock	VG,VG,G	P,MP,MP
H10	Flammable destruction	MG,MG,G	MP,MP,P
H11	Explosive destruction	G,VG,VG	VP,P,VP
H12	Exposure to chemicals	F,MG,MG	F,MP,MG
H13	Popping out materials	MG,MG,F	P,MP,P
H14	Blowing materials	F,F,MP	MG,MG,G
H15	Sinking materials	F,MP,F	P,P,MP
H16	Fire	F,MG,MG	P,P,MP
H17	Getting drowned	VG,VG,G	VP,P,P
H18	Suffocation from gas	VG,VG,G	P,P,MP
H19	Exposure to welding beam	F,MG,MG	P,P,P
H20	Poisoning	MP,F,MG	MP,MP,F
H21	Exposure of the eyes to burrs	F,F,MG	MP,MP,F
H22	Touch hot surfaces (high or low temperature, boiling water)	F,F,MG	P,P,MP
H23	Panic and disturbance	G,VG,G	VP,P,P

a fuzzy triangular values as shown in Table 8. This is the first stage of the fuzzy TOPSIS analysis. The fuzzy risk parameter weights are added into the calculation in fuzzy TOPSIS analysis. The next step is to generate the weighted fuzzy decision matrix using. Using Eq. (7) fuzzy weighted decision matrix is obtained as in Table 8. According to Table 8, we reach the FPIS and the FNIS values as: (1, 1, 1) and (0, 0, 0). For the next step, the distance of each alternative from S_k^+ and S_k^- are calculated using Eqs. (10) and (11). The next step presents the similarities to an ideal solution by Eq. (12). The resulting fuzzy TOPSIS analyses are summarized in Table 9. According to the fuzzy TOPSIS method, the highest hazard group is the one which has the shortest distance from the fuzzy positive ideal solution and farthest distance from the fuzzy negative ideal solution. Related to the results, the ranking of the hazards are determined by giving C_i^* value closest to 1 is ranked highest risk, while risks having C_i^* value farthest from 1 is ranked lowest risk (Mahdevari et al. 2014; Kutlu and Ekmekçioğlu, 2012; Guneri and Gul, 2013).

Finally, as shown in Table 9, the scores are ranked and results show that the most important three hazard groups for the factory is *H18-Suffocation from gas*, *H9-Getting an electric shock* and *H3-*

Table 8
Fuzzy decision matrix and weighted fuzzy decision matrix.

	Fuzzy decision matrix						Weighted fuzzy decision matrix					
Item	Likelihood (P)			Severity (S)			Likelihood (P)			Severity (S)		
H1	0.67	2.33	4.33	4.33	6.33	8.33	0.02	0.09	0.23	0.21	0.41	0.7
H2	0.33	1.67	3.67	2.33	4.33	6.33	0.01	0.06	0.19	0.11	0.28	0.54
H3	0.67	2.33	4.33	6.33	8.33	9.67	0.02	0.09	0.23	0.3	0.54	0.82
H4	3	5	7	0.67	2.33	4.33	0.09	0.19	0.36	0.03	0.15	0.37
H5	0.33	1.67	3.67	3.67	5.67	7.67	0.01	0.06	0.19	0.18	0.37	0.65
H6	0.67	2.33	4.33	6.33	8.33	9.67	0.02	0.09	0.23	0.3	0.54	0.82
H7	0.67	2.33	4.33	6.33	8.33	9.67	0.02	0.09	0.23	0.3	0.54	0.82
H8	0.33	1.67	3.67	5	7	9	0.01	0.06	0.19	0.24	0.45	0.76
H9	0.67	2.33	4.33	7	9	10	0.02	0.09	0.23	0.33	0.58	0.85
H10	0.67	2.33	4.33	5.67	7.67	9.33	0.02	0.09	0.23	0.27	0.49	0.79
H11	0	0.33	1.67	8.33	9.67	10	0	0.01	0.09	0.4	0.62	0.85
H12	3	5	7	4.33	6.33	8.33	0.09	0.19	0.36	0.21	0.41	0.7
H13	0.33	1.67	3.67	4.33	6.33	8.33	0.01	0.06	0.19	0.21	0.41	0.7
H14	5.67	7.67	9.33	2.33	4.33	6.33	0.17	0.29	0.49	0.11	0.28	0.54
H15	0.33	1.67	3.67	2.33	4.33	6.33	0.01	0.06	0.19	0.11	0.28	0.54
H16	0.33	1.67	3.67	4.33	6.33	8.33	0.01	0.06	0.19	0.21	0.41	0.7
H17	0	0.67	2.33	8.33	9.67	10	0	0.03	0.12	0.4	0.62	0.85
H18	0.33	1.67	3.67	8.33	9.67	10	0.01	0.06	0.19	0.4	0.62	0.85
H19	0	1	3	4.33	6.33	8.33	0	0.04	0.16	0.21	0.41	0.7
H20	1.67	3.67	5.67	3	5	7	0.05	0.14	0.29	0.14	0.32	0.59
H21	1.67	3.67	5.67	3.67	5.67	7.67	0.05	0.14	0.29	0.18	0.37	0.65
H22	0.33	1.67	3.67	3.67	5.67	7.67	0.01	0.06	0.19	0.18	0.37	0.65
H23	0	0.67	2.33	7.67	9.33	10	0	0.03	0.12	0.37	0.6	0.85
W	*0.27*		*0.35*		*0.48*		*0.48*		*0.65*		*0.85*	

Falling of objects, respectively.

Risk management cannot eliminate risks altogether but can only propose appropriate strategies to manage. Therefore, after identifying, analyzing and assessing the risks, each should be controlled or eliminated. Unless this is possible, they should be reduced to the acceptable level (Mahdevari et al. 2014).

In our application study, fuzzy TOPSIS results are discussed by the company management. It is conclude that these hazards are arisen from rolling oil vapor that compose during processing of rolled aluminum in cold rolling facility, workings in electrical panels and generator room during maintenance and repairing, and high stacking shelves in finished goods inventory hall, respectively.

As a follow-up study of the application, the proposed risk assessment methodology is applied for each department of the factory. In relation to OHS operations in the aluminum plate manufacturing factory, the hazard types for each department are categorized in twelve groups: casting lines' hazards (CL), type room hazards (TR), carpenter's area hazards (C), finished goods inventory hall hazards (FIH), component production hall hazards (CPH), packing area hazards (P), slitting line hazards (SL), cut-to-length line hazards (CTL), washing & tensioning line hazards (WTL), cold rolling hazards (CR), maintenance hall hazards (MH), and production hall hazards (PH). Altogether 84 hazard types are identified based on OS experts' identification. The definitions of the hazards for each department are summarized and codified in Table 10.

Table 9
Fuzzy TOPSIS final ranking.

Item	S_i^+	S_i^-	C_i^*	Rank
H1	2.579	1.083	0.296	14
H2	2.82	0.815	0.224	22
H3	2.403	1.267	0.345	3
H4	2.811	0.817	0.225	21
H5	2.684	0.966	0.265	19
H6	2.403	1.267	0.345	4
H7	2.403	1.267	0.345	5
H8	2.553	1.118	0.304	12
H9	2.348	1.322	0.36	2
H10	2.459	1.213	0.33	10
H11	2.403	1.211	0.335	9
H12	2.408	1.26	0.344	7
H13	2.618	1.042	0.285	15
H14	2.444	1.204	0.33	11
H15	2.82	0.815	0.224	23
H16	2.618	1.042	0.285	16
H17	2.376	1.248	0.344	6
H18	2.312	1.325	0.364	1
H19	2.657	1.001	0.274	18
H20	2.63	1.019	0.279	17
H21	2.562	1.094	0.299	13
H22	2.684	0.966	0.265	20
H23	2.414	1.225	0.337	8

The evaluations of the OS experts in linguistic variables for the risk parameters with respect to 84 different hazard types within 12 department are expressed as in Table 11. For example, the three OS experts evaluated the hazard type coded as (CL1)-Molten aluminum splash as medium poor (MP), poor (P), and medium poor (MP) for likelihood (P), good (G), good (G), and medium good (MG) for severity (S), respectively.

For evaluating and ranking hazard types for each department on the basis of the C_i^* value, the results of calculation are also presented in Table 11. It additionally, makes an intra-department and overall ranking. According to the intra-department ranking results of the risk assessment, the hazards CL5, TR3, TR4, C3, FIH3, CPH6, P4, SL4, CTL4, WTL5, WTL6, CR1, MH1, MH2, MH12, and PH6 are high-risk hazards (the first ranks of each department) and need the most attention, while CL2, CL4, TR2, C8, FIH2, CPH1, CPH2, P3, SL2, CTL1, WTL3, CR6, CR7, MH9 and PH2 have the least risks (the last ranks of each department). An overall ranking is obtained related to the C_i^* values of each hazard. By doing this arrangement, a grouping can be proposed with respect to C_i^* value in order to manage hazards and suggest appropriate control measures. According to the principles of risk-assessment decision matrix method, a five interval based grouping between the lowest and highest value of C_i^* of the hazards can be proposed.

A sensitivity analysis is conducted to validate the results performance of the proposed FAHP and fuzzy TOPSIS combined methodology. For this reason, the weights gained from FAHP are changed. Three cases are realized during the sensitivity analysis as

Table 10
Classification of various types of the hazards affecting OHS operations of departments in the aluminum plate manufacturing company.

Department	Code	Definition of the hazard
Casting lines	CL1	Molten aluminum splash
	CL2	Stack materials falling
	CL3	Intervene as a result of the overflow of liquid aluminum
	CL4	Cause to fire of spilled aluminum
	CL5	Exposure to excessive temperature in front of the furnaces & Inhalation of slag powder & Skin burns caused by hot material
	CL6	Accidents related to the slowing of reflex, sleepiness and signs of physical and mental fatigue
Type room	TR1	Inhalation of dust
	TR2	Explosion risk related to the armatures
	TR3	Fire as a result of overheating inside the cabinets
	TR4	Loss of limbs as a result of finger jamming in radial sections
	TR5	Excessive dust of environment when working with materials
	TR6	Opening the room door right into the factory not outside during emergency cases
Carpenter's area	C1	Fire and its damages to the employees
	C2	Injuries as a result of hand or finger jamming into the operations area
	C3	Hearing loss as a result of excessive noise during operations
	C4	Respiratory tract diseases due to the exposure to dust during material cutting
	C5	Eye injury as a result of exposure of the eyes to wood burrs during material cutting
	C6	Injury as a result of nail sinking
	C7	Burn injuries as a result of touching hot surfaces
	C8	Getting an electric shock
	C9	Injuries as a result of falling from pallets
Finished goods inventory hall	FIH1	Fire as a result of smoking of transport vehicle drivers in this area
	FIH2	Hitting of forklifts to the pedestrian in this area
	FIH3	Falling of materials
Component production hall	CPH1	Injuries as a result of jamming in radial sections
	CPH2	Finger jamming and breaking inside the space of press
	CPH3	Hand-finger breaking as a result of touching operations area (Protective covers are available in front of the guillotine shears)
	CPH4	Hand-finger breaking as a result of touching operations area (Protective covers in front of the guillotine shears are inserted)
	CPH5	Hand-finger breaking while passing of coil-coated sheet inside the straightening machine
	CPH6	Cutting of the material in the guillotine shears following the passing from straightening machine
Packing area	P1	Explosion as a result of throwing the tubes
	P2	Leaking of the tubes where they are stored
	P3	Touching hot nylon material
	P4	Gas leaking in LPG tubes
	P5	Injury due to the forklift crash
	P6	Waist and spine diseases
	P7	Injury by the knife used for cutting
	P8	Foot crushing while working with cranes
	P9	Injury as a result of overthrowing of the strips during packaging
Slitting line	SL1	Jamming in the moving rolls
	SL2	Loss of limbs as a result of hand-finger breaking in the guillotine shears
	SL3	Injury due to the dropping down of the iron material during an operation
	SL4	Hearing loss due to the excessive noise during cutting operation
Cut-to-length line	CTL1	Tripping on and wounding due to the scrap pieces
	CTL2	Waist and spine diseases during laying
	CTL3	Hand-finger jamming and wounding in the operation area
	CTL4	Hearing loss due to the excessive noise during cutting operation
Washing & Tensioning line	WTL1	Uncontrolled movement of the coils and rolling
	WTL2	Crushing as a result of throwing of the steel core
	WTL3	Skin and eye irritation and injury as a result of contact with detergents
	WTL4	Jamming between plates and rollers and crashing
	WTL5	Hand-finger jamming and wounding in the operation area
	WTL6	High noise levels arising from gear motors during operation
Cold rolling	CR1	Respiratory tract diseases due to the inhaling rolling oil vapor
	CR2	Causing wet floors of rolling oils accumulated on the roller
	CR3	Falling down the spaces as a result of loss of balance and wounding
	CR4	Sharp corner caused cutting during transportation and wounding
	CR5	Suffocation from CO_2 discharge of the fire detector system tubes into the workplace
	CR6	Injury as a result of the rupture of the strip during the tightening procedure
	CR7	Remaining between the steel core and crushing
	CR8	Falling down the space without floor plates and wounding
	CR9	Injury as a result of touching hot coils
	CR10	Working in coil car maneuvering area
Maintenance hall	MH1	Injuries as a result of limbs jamming inside the radial sections
	MH2	Eye injuries as a result of burr jumping from the lathed material
	MH3	Hand or finger jamming during cleaning of accumulated burrs
	MH4	Falling down the spaces during cleaning filter pits
	MH5	Injuries as a result of jamming in radial sections
	MH6	Wet floors as a result of pouring the oily substance during roll changes
	MH7	Using steel and cloth ropes in transporting rollers with cranes
	MH8	Exposure of the operator to welding gas
	MH9	Exposure of the operator to welding beam
	MH10	Tube exploiting
	MH11	Finger jamming inside the spaces in operation area

Table 10 (*continued*)

Department	Code	Definition of the hazard
	MH12	Exposure of the eyes to burrs during working
	MH13	Falling from the height
	MH14	Severe injuries and death as a result of electric shock
Production hall	PH1	Injury due to hitting of the forklifts to the pedestrian
	PH2	Throwing the materials from forklifts because of a breakdown
	PH3	Throwing the heavy material from the crane and braking to fail
	PH4	Collision of moving cranes
	PH5	Explosion and throwing the tubes
	PH6	Loss of limbs in the operation area and wounding
	PH7	Tripping on and wounding

in Table 12. More different weight changes can be applied to expand the sensitivity analysis. Thus the methodology result changes can be seen, and this helps the decision maker to determine the priorities and make the evaluation process easier. The results of the sensitivity analysis can be seen from Fig. 2.

Sensitivity analysis shows that the ranking among the hazards is quite sensitive to the changes considering the weights of the two risk parameters. In two cases (Case 1 and Case 2), the most

Table 11
Evaluations of OS experts in fuzzy TOPSIS, C_i^* values and rank orders of the hazard types for each department.

Department	Code	Likelihood (P)	Severity (S)	S_i^+	S_i^-	C_i^*	Intra-department rank	Overall rank
Casting lines	CL1	MP,P,MP	G,G,MG	2.385	1.294	0.352	3	29
	CL2	MP,P,MP	F,MP,F	2.772	0.870	0.239	5	6
	CL3	F,MP,F	F,MP,F	2.649	0.997	0.273	4	14
	CL4	MP,P,MP	MP,F,F	2.772	0.870	0.239	5	6
	CL5	G,G,MG	G,G,MG	2.024	1.660	0.451	1	54
	CL6	MP,F,F	G,G,MG	2.262	1.421	0.386	2	41
Type room	TR1	F,F,MG	F,MP,MG	2.511	1.139	0.312	4	19
	TR2	MP,P,MP	P,MP,P	3.050	0.563	0.156	5	1
	TR3	F,MG,F	G,G,MG	2.201	1.474	0.401	1	45
	TR4	F,F,MG	MG,G,G	2.201	1.474	0.401	1	45
	TR5	MG,G,G	F,MG,F	2.290	1.366	0.374	2	37
	TR6	P,P,MP	G,VG,VG	2.317	1.318	0.363	3	34
Carpenter's area	C1	MP,MP,P	MG,G,G	2.379	1.302	0.354	4	30
	C2	MP,P,MP	G,G,MG	2.379	1.302	0.354	4	30
	C3	MG,F,F	G,G,MG	2.164	1.525	0.413	1	48
	C4	MG,G,MG	F,F,F	2.358	1.303	0.356	2	32
	C5	MG,MG,F	F,MG,F	2.368	1.303	0.355	3	31
	C6	MP,P,MP	G,G,MG	2.379	1.302	0.354	4	30
	C7	MP,P,MP	F,MP,F	2.766	0.878	0.241	5	8
	C8	P,P,MP	F,MP,F	2.805	0.837	0.230	6	4
	C9	MP,MP,P	F,F,MP	2.766	0.878	0.241	5	8
Finished goods inventory hall	FIH1	MP,P,MP	F,MP,F	2.415	1.401	0.367	2	35
	FIH2	P,P,MP	F,MP,F	2.492	1.311	0.345	3	27
	FIH3	MP,MP,P	F,F,F	2.329	1.508	0.393	1	43
Component production hall	CPH1	VP,P,VP	VG,G,G	2.379	1.289	0.351	5	28
	CPH2	VP,VP,P	G,G,VG	2.379	1.289	0.351	5	28
	CPH3	P,VP,P	MG,VG,VG	2.344	1.334	0.363	4	34
	CPH4	P,P,MP	G,G,VG	2.196	1.534	0.411	3	47
	CPH5	MP,MP,P	G,VG,VG	2.082	1.647	0.442	2	52
	CPH6	F,P,P	G,VG,VG	2.067	1.649	0.444	1	53
Packing area	P1	VP,P,VP	VG,G,G	2.436	1.195	0.329	3	22
	P2	VP,VP,P	G,G,VG	2.436	1.195	0.329	3	22
	P3	MP,P,MP	F,MP,F	2.768	0.876	0.240	7	7
	P4	F,P,P	G,VG,VG	2.253	1.386	0.381	1	40
	P5	F,F,MG	F,MP,MG	2.469	1.191	0.325	4	21
	P6	MG,F,G	MP,MP,F	2.522	1.126	0.309	5	18
	P7	F,F,MG	F,MP,MG	2.469	1.191	0.325	4	21
	P8	MP,MP,P	G,VG,VG	2.260	1.385	0.380	2	39
	P9	MP,MP,P	F,F,F	2.699	0.951	0.261	6	11
Slitting line	SL1	MP,F,F	G,G,MG	2.188	1.515	0.409	2	46
	SL2	P,P,MP	F,MP,F	2.774	0.880	0.241	4	8
	SL3	MP,P,MP	F,MP,F	2.728	0.931	0.254	3	10
	SL4	F,MG,F	G,G,MG	2.083	1.626	0.438	1	51
Cut-to-length line	CTL1	F,F,MG	P,P,MP	2.740	0.907	0.249	4	9
	CTL2	F,MP,F	F,MP,F	2.575	1.091	0.298	3	17
	CTL3	MP,F,F	G,G,MG	2.188	1.515	0.409	2	46
	CTL4	F,MG,F	G,G,MG	2.083	1.626	0.438	1	51
Washing & Tensioning line	WTL1	MP,MP,P	F,F,F	2.657	1.009	0.275	3	15
	WTL2	MP,F,F	G,G,MG	2.188	1.515	0.409	2	46

(*continued on next page*)

Table 11 (*continued*)

Department	Code	Likelihood (P)	Severity (S)	S_i^+	S_i^-	C_i^*	Intra-department rank	Overall rank
	WTL3	MP,P,MP	G,G,MG	2.341	1.355	0.367	4	35
	WTL4	MP,F,F	G,G,MG	2.188	1.515	0.409	2	46
	WTL5	F,MG,F	G,G,MG	2.083	1.626	0.438	1	51
	WTL6	MG,F,F	G,G,MG	2.083	1.626	0.438	1	51
Cold rolling	CR1	G,G,MG	G,G,MG	2.048	1.625	0.442	1	52
	CR2	MG,MG,F	F,MG,F	2.401	1.259	0.344	3	26
	CR3	MP,P,MP	F,MP,F	2.787	0.849	0.233	5	5
	CR4	MP,P,MP	F,MP,F	2.787	0.849	0.233	5	5
	CR5	MP,MP,P	G,VG,VG	2.279	1.358	0.373	2	36
	CR6	MP,P,MP	F,MP,F	2.894	0.734	0.202	6	2
	CR7	MP,P,MP	F,MP,F	2.894	0.734	0.202	6	2
	CR8	F,MP,F	F,MP,F	2.665	0.976	0.268	4	12
	CR9	MP,P,MP	F,MP,F	2.787	0.849	0.233	5	5
	CR10	P,P,MP	F,MP,F	2.825	0.809	0.223	5	3
Maintenance hall	MH1	F,MG,F	G,G,MG	2.107	1.591	0.430	1	50
	MH2	F,F,MG	MG,G,G	2.107	1.591	0.430	1	50
	MH3	MP,F,F	G,G,MG	2.212	1.480	0.401	2	45
	MH4	F,F,MG	F,MP,MG	2.417	1.256	0.342	6	25
	MH5	F,P,P	G,VG,VG	2.227	1.420	0.389	3	42
	MH6	MP,F,F	G,G,MG	2.212	1.480	0.401	2	45
	MH7	MP,MP,P	MG,G,G	2.365	1.320	0.358	5	33
	MH8	MP,P,MP	G,G,MG	2.365	1.320	0.358	5	33
	MH9	MP,MP,P	F,F,MP	2.743	0.910	0.249	9	9
	MH10	VP,VP,P	G,G,VG	2.428	1.207	0.332	7	23
	MH11	MP,F,F	G,G,MG	2.212	1.480	0.401	2	45
	MH12	F,MG,F	G,G,MG	2.107	1.591	0.430	1	50
	MH13	MP,MP,P	F,F,F	2.674	0.985	0.269	8	13
	MH14	P,P,MP	G,VG,VG	2.282	1.368	0.375	4	38
Production hall	PH1	P,MP,P	G,F,MG	2.515	1.161	0.316	5	20
	PH2	VP,VP,P	MG,MG,G	2.570	1.087	0.297	6	16
	PH3	P,MP,MP	G,G,G	2.290	1.403	0.380	3	39
	PH4	P,P,MP	MG,MG,G	2.451	1.238	0.336	4	24
	PH5	MP,P,MP	G,VG,VG	2.215	1.447	0.395	2	44
	PH6	F,F,F	MG,G,G	2.122	1.584	0.427	1	49
	PH7	P,P,MP	G,F,MG	2.515	1.161	0.316	5	20

important hazard type is H18 and the second most important hazard type is H9. In Case 2, as the weight of severity is the highest, H18 is the most important hazard type. The least important hazard type is H15 except in current case, Case 1 and Case 3. It is also ranked last but one in the Case 2. According to the analysis above, this paper finds that the proposed approach can produce reasonable results and provide suitable information to assist management in the risk assessment problems.

4.1. Control measures of the hazards

We applied FAHP-fuzzy TOPSIS hybrid approach to rank the hazards using fuzzy numbers to be more adapted to the real world cases instead of crisp numbers (Mahdevari et al. 2014). In order to reduce the risks, a hazard control hierarchy is required. The order of hierarchy of control as in (Barnes, 2009) aids the determination of control measures to manage the risks in the factory. This order is the most effective way in controlling measures of a hazard. If the best control measure is not possible, it may use the other measures to reduce them. Some control measures for the hazards that are placed at first of intra-department rankings are recommended in the following.

Exposure to excessive temperature in front of the furnaces, inhalation of slag powder and skin burns caused by hot material are of considerable hazards in the casting lines of the factory in terms of both severity and likelihood. The existing control measures for these hazard types are to make employees use suitable PPE for the work. Additional control measures are (1) to use mechanical systems in attracting slag from the furnaces and (2) to strengthen the slag room vacuum system.

Table 12
Weights of the risk parameters with respect to the considered cases.

Parameters	Current case	Case 1	Case 2	Case 3
Likelihood	0.361	0.400	0.350	0.500
Severity	0.639	0.600	0.650	0.500

For hazards TR3 and TR4, several control measures are taken. However, a sprinkler and alarm system should be installed against a possible fire risk. Protective equipment of the machine should be checked frequently. During material cutting process in milling machines, there will occur an excessive noise. In order to struggle this, suitable earplugs should be used. For regular use of earplugs, employees should be checked. The most important risk in doing high stacking shelves is falling of materials. So, it should be complied with stacking rules as an existing control measure. Then, stacking should be checked. Boundary lines should be drawn up indicating the upper limit of the stack.

In component production hall, guillotine protective equipment is available for the hazard CPH6. However, if it is needed to the protective equipment be installed permanently, a warning signal system should be performed. In order to keep control the gas leaking in LPG tubes in packing area, safety equipment in the tubes should be checked periodically. Preventing hearing loss due to the excessive noise during related operations is the main control measure in slitting line, cut-to-length line and washing & tensioning line of the factory. To success this, employees should be checked whether they use of earplugs regularly. Also, in washing & tensioning line the hazard WTL6 is challenging. In order to prevent hand-finger jamming and wounding in the operation area, there will be more effective to install *emergency stop wires* all around the line environment. To reduce the risks related to the MH1, MH2, and

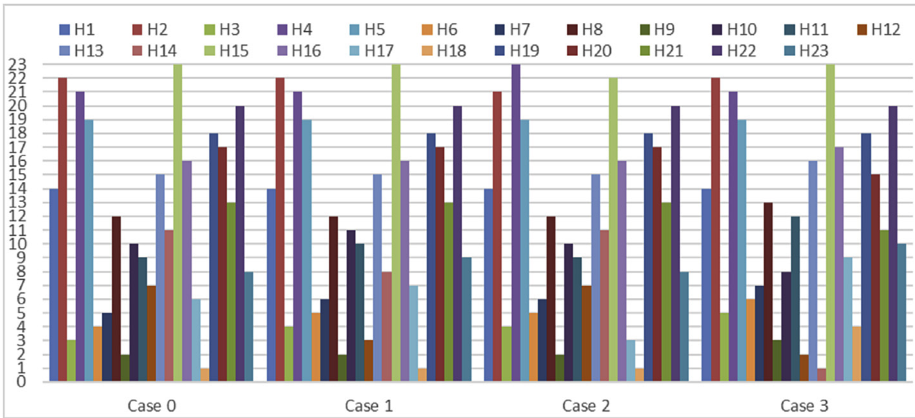

Fig. 2. Result of the rankings based on sensitivity analysis.

MH12, control measures to be taken are as follows: (1) the operator must permanently wear safety goggles while working. (2) Hard protective transparent plate must be installed on the lathes grinders. Insufficient coupling guards must be provided in order to prevent loss of limbs and wounding in the operation area of production hall.

Risk assessment should be realized as a continuing process and the adequacy of control measures should also be subject to continual review and revision if necessary (Mahdevari et al. 2014).

5. Conclusion and future remarks

A fuzzy multi criteria risk assessment methodology enabling OS experts to use linguistic variables for evaluating two criteria which are the parameters of DMRA technique is proposed to deal with shortcomings of a crisp risk score calculation and to decrease the inconsistency in decision making. The parameters likelihood and severity related to the hazards in an aluminum plate manufacturing plant in Turkey are weighted by using FAHP, then the orders of priority of 23 various hazard groups are determined by using fuzzy TOPSIS method. As a follow-up study of the case application, the proposed risk assessment methodology is applied for hazard types of each department in the factory. Results show that the most important three hazard groups for the factory is H18-Suffocation from gas, H9-Getting an electric shock and H3- Falling of objects, respectively. OS experts conclude that these hazards are arisen from rolling oil vapor that compose during processing of rolled aluminum in cold rolling facility, workings in electrical panels and generator room during maintenance and repairing, and high stacking shelves in finished goods inventory hall, respectively.

In our follow-up study, altogether 84 various hazard types within 12 departments are identified and ranked. According to the intra-department ranking results of the risk assessment, the hazards CL5, TR3, TR4, C3, FIH3, CPH6, P4, SL4, CTL4, WTL5, WTL6, CR1, MH1, MH2, MH12, and PH6 are high-risk hazards (the first ranks of each department) and need the most attention, while CL2, CL4, TR2, C8, FIH2, CPH1, CPH2, P3, SL2, CTL1, WTL3, CR6, CR7, MH9 and PH2 have the least risks (the last ranks of each department). An overall ranking is also carried out.

Depending on the hazard control hierarchy, control measures are overtaken for the hazards that are placed at first of intra-department rankings by OS experts. However, risk management is an ongoing review of processes, criteria that may affect the risk score may change over time. So, the OS experts and senior management should monitor risks and control in regular periods.

As a future remark, the development of new hybrid fuzzy multi criteria risk assessment methods, which will combine well-known MCDM methods (including ANP, VIKOR, PROMETHEE and etc.), can enable aluminum industry stakeholders to struggle with hazards more efficiently. Besides, the proposed fuzzy approach can easily be adopted to other manufacturing industries unlike aluminum industry.

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