Occupational health and safety risk assessment in hospitals: A case study using two-stage fuzzy multi criteria approach

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ABSTRACT

Occupational Health and Safety (OHS) is a basis to reduce occupational accidents in an acceptable level and covers employee health, safety and welfare in the workplaces. Hospitals as the largest employer group in health care industry in Turkey are faced with major hazards categorized as chemical, biological, physical, ergonomic and psychosocial risks. Although Turkey demonstrates rapid economic growth, OHS practices have not been fully put into practice and necessary attention has not shown for the health industry. For this reason, this paper aims to assess risks for health staff, contribute for planning of health services and enhance regulations. A case study is carried out in a leading hospital in Turkey using a two-stage fuzzy multi-criteria approach which provides more consistency in decision process and gives an appropriate final rank of hazard types. Fuzzy Analytic Hierarchy Process (FAHP) is used in weighting five risk parameters which are severity, occurrence, undetectability, sensitivity to maintenance non-execution and sensitivity to personal protective equipment (PPE) non-utilization. The fuzzy

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VIKOR (FVIKOR) approach is then applied for prioritization of hazard types in each department of the hospital. On conclusion of the hazard control hierarchy, measures are overtaken for the hazards and areas open for improvement are presented.

Key words

Occupational Health and Safety, Risk Assessment, Hospitals, FAHP, FVIKOR

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1. INTRODUCTION

World Health Organization (WHO) describes the concept of Occupational Health and Safety (OHS) as a multi-disciplinary activity aimed at four basic issues as follows: (1) the protection and promotion of the health of workers by preventing and controlling occupational accidents and diseases; (2) the development and promotion of healthy and safe work, work environments and work organizations; (3) enhancement of physical, mental and social well-being of workers; and (4) enabling workers to conduct socially and economically productive lives (Kenya Ministries of Health and Intra Health International 2013). OHS covers employee health, safety and welfare in the workplaces of various industries (Victorian Auditor-General's Report 2013). Health care industry which is one of the most affected industries due to poorly management of OHS aims at improving health and safety standards in health institutions over the globe and as well in Turkey. Hospitals have many unique hazards that can potentially affect the health of employees throughout their departments (Gorman *et al.* 2013). These hazards result in increasing accidents at work, antagonistically influence security of both patients and health staff and decreasing efficiency and work performance. Although Turkey shows significant improvements and demonstrate rapid economic growth recently, OHS practices have not been fully put into practice and necessary attention has not shown for the health industry. Therefore, in order to have a clearer picture of implementation of OSH policy and compliance in the health industry, it is obligated carrying risk assessment with the new OHS Law with number 6331 in Turkey (Gul and Guneri 2016). For this reason, this paper aims to present a hospital based OSH risk assessment for health staff and contribute for planning of health services.

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In the literature, many quantitative and qualitative risk assessment tools are available in order to find causes and characteristics of accidents and workplace conditions of various sectors. One of the most important methods is applying a MCDM based method (Gul and Guneri 2016). In MCDM methods, decision makers have often difficulty in evaluation of giving a precise rating to a hazard with respect to the relating risk parameter. Therefore, to carry out probabilistic risk assessment methods cannot give satisfactory results due to the incomplete risk data or availability of high level of uncertainty. In that case, fuzzy sets combined MCDM is adopted to model this situation. Evaluating the relative importance of risk parameters using fuzzy numbers instead of crisp numbers is one of the important advantages of fuzzy MCDM methods. In this paper, we apply FAHP in assessment of five significant risk parameters. Table 1 shows a comparative summary about a number of recent studies for MCDM approaches in OHS risk assessment.

On the other hand, various approaches have been applied in OHS risk assessment, planning and management of healthcare industry. Liu *et al.* (2012) proposed a fuzzy FMEA based on fuzzy set theory and VIKOR method for prioritization of failure modes in general anesthesia process risk evaluation. Three parameters of FMEA were weighted by fuzzy set theory and risk priorities of the failure modes were determined by the extended VIKOR method. Liu *et al.* (2015) applied a novel FMEA approach in combination with FAHP, entropy and FVIKOR methods in general anaesthesia process of a hospital. Jamshidi *et al.* (2015) proposed a three step risk-based prioritization framework for selecting the best maintenance strategy for prioritization of medical devices. First, fuzzy FMEA was applied by considering several risk assessment factors. Second, seven dimensions such as use-related hazards, age, and utilization were applied to consider all

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aspects of hazards and risks. Finally, a simple method was used to determine the most suitable maintenance strategy for each device according to the scores of the previous two steps. Liu *et al.* (2014) proposed a new risk priority model for evaluating the risk of failure modes based on fuzzy set theory and MULTIMOORA method. A case study about preventing infant abduction was also presented in their study.

From the overview of previous related work, it is concluded that current study contributes to the literature about hospital risk assessment by some aspects: (1) A FAHP proposed by Buckley (1985) which avoids shortcomings of a crisp risk parameter calculation and decreases the inconsistency in decision making is used. Unlike classic OHS risk assessment methods, decision makers assign parameter weights by fuzzy linguistic scale and pair wise comparison manner of Buckley's FAHP. (2) In classic OHS risk assessment methods, there are two (e.g. decision matrix method) or three (e.g. Fine-Kinney method, Failure Modes and Effect Analysis-FMEA method) risk parameters. Different from this, this paper takes into account five parameters which are severity, occurrence, undetectability, sensitivity to maintenance non-execution and sensitivity to personal protective equipment (PPE) non-utilization.

(3) To the best of our knowledge, this is the first study in OHS risk assessment in assessing the risks for a Turkish hospital that uses a two-stage fuzzy approach (FAHP-FVIKOR).

The paper is arranged as follows: Section 2 presents the research methods. Section 3 deals with the proposed two-stage fuzzy risk assessment approach. In Section 4, application case study in assessing hazards in a Turkish leading education and research hospital is presented. Some concluding remarks and future recommendations are provided in the last section.

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2. RESEARCH METHODS

2.1. AHP

The AHP was proposed by Thomas L. Saaty as a measurement theory of intangible criteria (Aragonés-Beltrán *et al.* 2009). AHP is based on the hierarchic MCDM problem consisting of a goal, criteria and alternatives. In each hierarchical level, pair wise comparisons are made with judgments using numerical values taken from the Saaty's scale of 1–9. The pair wise comparisons are used to synthesize local principal eigenvector of the matrices of each element of the hierarchy by using the eigenvalue method. These matrices are positive and reciprocal. It gives the relative priority of the element measured in a ratio scale (Saaty 1990). In addition, the AHP also allows decision makers to control the consistency ratio (CR) which is calculated as in the following.

The CR of each judgment is calculated and checked to ensure that it is lower than or equal to 0.1. The calculation of The CR is then calculated as follows (Tzeng and Huang 2011; Guneri *et al.* 2015):

Step 1: Multiply the pairwise comparison matrix by the relative priorities

Step 2: Divide the weighted sum vector elements by the associated priority value

Step 3: Compute the average (denoted λ_{max}) of the values from Step 2

Step 4: Compute the consistency index CI = $(\lambda_{max} - n)/(n - 1)$, where n is the number of items being compared.

Step 5: Compute the consistency ratio CR = CI/RI, where RI is the random index (CI of the randomly generated pairwise comparison matrix) as shown in Table 2.

2.2. Buckley's FAHP

FAHP is one of the common used fuzzy based MCDM methods. Since traditional AHP cannot provide the subjective thinking manner, FAHP is proposed in order to solve hierarchical problems under fuzzy environment. There are more than one FAHP methods proposed in the fuzzy MCDM literature. Buckley (1985) proposed fuzzy priorities of comparison ratios whose membership functions trapezoidal. Chang (1996) introduced an FAHP approach with the use of triangular fuzzy numbers for pair wise comparison manner, and the use of the extent analysis method for the synthetic extent values of the pair wise comparisons. Buckley's (1985) method was used in the case application of this paper. However, other methods have some limitations. For instance, 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 steps of Buckley's FAHP method followed in this study was given as below (Tzeng and Huang 2011; Gul and Guneri 2016):

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

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

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

Step 2: Fuzzy geometric mean matrix is defined using the geometric mean technique.

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

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

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n \right)^{-1}$$

(4)

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

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

Step 4: Center of area (CoA) method is used to find the best non-fuzzy performance (BNP), as in the equation (5)

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

2.3. FVIKOR

VIKOR (the VlseKriterijumska Optimizacija I Kompromisno Resenje) is one of the MCDM methods developed by Opricovic (1998) for multi-criteria optimization problems and compromise solutions. It ranks alternatives and determines the compromise solution that is the closest to the “ideal”. The fuzzy version of this method FVIKOR involves fuzzy assessments of criteria and alternatives in VIKOR. For a recent literature review on VIKOR based applications and their fuzzy extensions see Gul et al. (2016). The steps of FVIKOR method can be described as the following.

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Step 1: Defuzzification of the elements of fuzzy decision matrix for the criteria weights and the alternatives into crisp values are carried out. A fuzzy number $\tilde{a} = (a_1, a_2, a_3)$ can be converted into a crisp number *a* by the equation (1):

$$a = \frac{a_1 + 4a_2 + a_3}{6} \quad (6)$$

Step 2: The best and worst values of all criteria ratings (j=1,2,.., n) and alternatives (i=1,2,.., m) are determined using Eqs (7)-(8).

$$f_j^* = \max_i \{x_{ij}\};\ f_j^- = \min_i \{x_{ij}\} (Benefit\ criteria) \quad (7)$$

$$f_j^* = \min_i \{x_{ij}\};\ f_j^- = \max_i \{x_{ij}\} (\mathrm{Cos}t\ criteria) \quad (8)$$

Step 3: S_i and R_i values are calculated using Eqs (9)-(10).

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad (9)$$

$$R_i = \max_j w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad (10)$$

Step 4: Q_i values are calculated using Eq. (11).

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1-v) \frac{R_i - R^*}{R^- - R^*} \quad (11)$$

where $S^* = \min_i S_i; S^- = \max_i S_i; R^* = \min_i R_i; R^- = \max_i R_i$. And *v* is the weight for the strategy of maximum group utility and *1-v* is the weight of the individual regret.

Step 5: Alternatives are ranked sorting by the values S, R and Q in ascending order.

Step 6: As a compromise solution the alternative ($A^{(1)}$) which is the best ranked by the measure Q(minimum) is proposed if the following two conditions are satisfied.

Condition 1: "Acceptable advantage": Adv ≥ DQ

where $Adv = [Q(A^{(2)}) - Q(A^{(1)})] / [Q(A^{(J)}) - Q(A^{(1)})]$ is the advantage rate of the alternative $A^{(1)}$ ranked first, $A^{(2)}$ is the alternative with second position in $\{A\}_Q$, and the threshold $DQ = 1/(J-1)$.

Condition 2: "Acceptable stability in decision making":

The alternative $A^{(1)}$ must also be the best ranked by S or/and R. The compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or ''by consensus $v \cong 0.5$'', or ''with veto'' ($v < 0.5$). Please note that v is the weight of the decision making strategy of maximum group utility. If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition 2 is not satisfied or
- Alternatives $A^{(1)}$; $A^{(2)}$; . . . ; $A^{(M)}$ if the condition 1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the position of these alternatives are in closeness).

3. THE PROPOSED TWO-STAGE FUZZY RISK ASSESSMENT APPROACH

A common risk assessment framework includes seven main steps (Main 2012). The first step is identifying scope of risk assessment. In the second step, hazards or hazard groups are described. The third step is about assessing the hazards. The specific focus of this paper is inside this step. In this step, Buckley's FAHP is used in weighting five risk parameters by taking into consideration pair wise comparison and fuzzy linguistic ratings. In the literature, classic OHS risk assessment methods especially consider two (e.g. probability and severity in decision matrix method) or three (e.g. probability, severity and frequency in Fine-Kinney method and occurrence, severity and detection in FMEA method) risk parameters. Although this is simple and easily applicable, it includes some shortcomings as expressed by Grassi *et al.* (2009). First, weights of these two or three parameters are mostly not taken into account. Second, different combinations of judgments on the parameters may lead to a completely different meaning. For example, hazards with high probability and low severity could be classified at the same level as hazards with low probability and high severity. Third, the risk value considers only two or three evaluation parameter and neglects other parameters, such as working environment and human factors. So, this paper deals with five parameters which are severity, occurrence, undetectability, sensitivity to maintenance non-execution and sensitivity to personal protective equipment (PPE) non-utilization. The priority orders of hazards with respect to these parameters are then determined by using FVIKOR (see Figure 1).

The forth step 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

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reduction is carried out, a second assessment is carried out to validate that the selected measures reduce the risks effectively. This is the step of assessing residual risks. The overall 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 results and documentation.

4. CASE STUDY IN A LEADING HOSPITAL

To show the applicability of the proposed approach, a real-world application in a leading education and research hospital in Turkey is employed in this section. The steps and analysis of this application example are given below.

4.1. Implementation of the Proposed Approach

The hospital seeks to identify several most important hazard types in its health care processes to take required measures in advance and prevent the incidence of medical accidents. A team of ten decision makers, (DM1 to DM10), has been set up in the hospital in order to evaluate the hazard types in six departments of the hospital as well as the whole hospital system. The decision makers includes ten physicians. Twelve hazard types have been identified by the DM team which are related to infection (H1), allergens (H2), dangerous substance (H3), medical waste (H4), radiation (H5), sound (H6), ergonomics (H7), ventilation and air conditioning (H8), violence (H9), communication (H10), electricity (H11) and fire and other emergency situations (H12). The risk parameters, occurrence (O), severity (S), sensitivity to personal protective equipment non-utilization (PPE), sensitivity to maintenance non-execution (M) and undetectability (U) have been defined according to the related literature (Grassi *et al.* 2009).

The ten decision makers use the linguistic variables shown in Table 3 to assess the subjective importance of the risk parameters. Also the decision makers use the linguistic rating variables shown in Table 4 to evaluate the ratings of hazard types with respect to each risk parameter.

According to the Buckley's FAHP method, evaluations of the physicians in linguistic variables are used to calculate the subjective weights of risk parameters by pairwise comparisons, and the results are given in Table 5. In this study, the consistency ratio calculated is lower than 0.1 according to the results of experts' evaluations. Thus, the pairwise comparison matrix can be considered as consistent and the questionnaire is valid in terms of FAHP.

After determining the weights of five risk parameters by Buckley's FAHP, the fuzzy evaluations of each risk parameter with respect to hazard types in each of six departments of the observed hospital, FVIKOR is applied. In the paper, the evaluations of the physicians in linguistic variables for the risk parameters with respect to 12 different hazard types are obtained for all employees (in other words for "the whole system"), radiology department, laboratory, community mental health center, domestic and medical waste department, outpatient clinics and emergency department. Subsequently, the linguistic evaluations obtained are converted into triangular fuzzy numbers. Then the aggregated fuzzy ratings of hazard types are calculated to determine the fuzzy decision matrix. For example, the fuzzy decision matrix for emergency department (ED) is given as in Table 6.

In the next step, the fuzzy best f^*_j and fuzzy worst f^-_j values of all risk parameter ratings are determined by Eqs. (7) and (8). The normalized fuzzy distance are calculated for each risk parameter of the hazard types in the ED, as shown in Table 7.

Then, the values of S, R and Q are calculated for all hazard types as in Table 8. Finally, the risk priority orders of the hazard types by S, R and Q in decreasing order are obtained. Figure 2 shows the values of S, R and Q for each department. The minimum values are ranked highest risk, while risks having S, R and Q values closest from 1 is ranked lowest risk. Results show that the most important hazard types in the whole system of the observed hospital are stemmed from H11, H1 and H12. In radiology department, H5, H11 and H3 are most important hazard types. The hazard types of H12, H11 and H3 are placed at the first three rankings in the laboratory of the observed hospital. Instead of the hazard type "H3" in the laboratory, in community mental health center, ventilation and air conditioning based hazards (H8) is a tertiary significant hazard type. H3, H4 and H5 are determined as the most important hazard types in domestic and medical waste department of the hospital. Analysis on outpatient and emergency department show that H11 is the most significant hazard type in the observed hospital. These hazards are followed by H8 and H1 in outpatient clinic and by H12 and H2 in emergency department of the hospital.

The compromised rankings for each department are also presented in Figure 3. In the case of risk prioritization of all employees, the compromised rank 1 (H11) represents the hazard value closest to the ideal solution which means it has the most risk compared to others, and similarly the highest rank 5 (H9 and H10) represents those hazards which are having least risk associated with them. In total 5 clusters are formed which are shown in Figure 3. Cluster 1, consisting of H11, represents the hazard with highest amount of risk. If we look upon the other clusters formed we can see that cluster 2 consists of H12, H1, H5 & H3; cluster 3 has hazards H2, H8, H7 & H4; cluster 4 has H6; and lastly the cluster 5 has hazards H9 & H10 with the least amount of relative risk associated with it. Similar analysis to form clusters for the remained six department of the

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observed hospital is performed in order to show compromised rankings for the hazard types using FVIKOR.

4.2. Risk control measures

The premise of the vision regarding better and healthier workplaces is to create a corporate culture where managers and employees discuss work processes together in a continuous improvement manner including all hospital/department related risks and possible measures for improvements. After determination of the risk priorities and ranking of hazard types in six departments, we have proposed compromise solution in the following fields: improvement in particular of the working environment to protect employee's health and safety, working conditions, informing and consulting employees. Employers are required to take practical measures to protect the health and safety of their workers, keep accident records, provide information and training, consult employees and cooperate and coordinate measures with contractors. In this paper, risk control measures are divided in two categories with the advice of ten decision makers; protective measures and preventive measures. The main aim of distinguishing the two categories is stemmed from elimination of the hazards, control of the hazards at their sources, minimization of the hazards and providing of suitable PPE.

After the main strategy has been determined to deal with and avoid hazards we have presented protective and preventive measures for each of six department and the whole system. Determination of control measures can help to manage effectively the risks in the hospital. For all employees category, we have found that H11, H9, H10 are the highest risks. For each of six

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department, protective measures are recommended considering required activities, tests and follow-up period.

Same analysis system has been put into practice for the remained six departments of the observed hospital. For all employees, following protective measures should be taken into account: (1) Regarding the activities of staff training and vaccines (hepatitis B, tetanus, diphtheria, pertussis, influenza, meningococcal, and chickenpox), Anti HBs test is required for the first stage of recruitment. (2) For the activities of usage of PPE and sound insulation, the same test is required in times of injuries. (3) In times of an accident occurrence, stab injuries and contacting with blood and body fluid, Anti HBs test is required for adequate use of auxiliary tools (wheelchairs, stretchers). The preventive measures can be summarized as follows: (1) Powdered gloves should be used. (2) Data sheets regarding health hazards of chemicals on the material safety should be provided and explained to employees. (3) Cleaning chemicals should be purchased considering allergic effect on employees. (4) Elevators must be adapted to the elevator regulations and requirements should be periodically checked. (5) Hospital stretchers should be periodically checked. (6) The sufficient number of employees should be hired according to the department requirements and workload. (7) Considering the working environment, the number of employees and patient narrow areas should be expanded. (8) Safety-walk steps should be used in stairs. (9) An adequate rest area and breaks must be provided to hospital employees. (10) Hospital cleaning checklist should be used in order to keep patients and visitors healthier. (11) Adequate mechanical ventilation system should be provided. Air conditioning system should be checked periodically. Natural ventilation must be considered as a second option. (12) Employee's thermal comfort should be provided according to the seasonal

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conditions. (13) A sufficient number of isolation rooms should be available for each department. (14) Hospital managers should provide extension cords policies and procedures. Earth leakage circuit breakers should be used. Insulating mat should be available in each of the electrical panel. (15) Periodic maintenance and checks must be made by experts. (16) Waste collection policy should be tackled and be followed by hospital executive with the aid of all employees.

In the radiology department, results show that H5, H11and H3 have the highest risk level. Therefore, in order to eliminate these risks some protective measures should be followed in a specific period. Full blood count test and hematological examination are required at least one time examination a year and investigation in the first recruitment for staff training and vaccines. For basic safety standards for protection against radiation and effective usage and control of PPE against radiation, peripheral blood smear examination is required in times of injuries. For sound insulation activity, (1) dermatological skin examination is required in times of an accident occurrence, stab injuries and contacting with blood and body fluid; (2) comprehensive eye examination and cardiovascular dosimetry follow bimonthly are required. Regarding preventive measures in radiology department the following measures apart from those mentioned above for all employees must be taken: (1) identifying and providing appropriate PPE against radiation should be performed. (2) 24-hour security should be available. (3) Skin and hair rashes should be examined in detail.

For the laboratory department, some crucial additional measures should be taken into consider. Initially, laboratory staff must get experienced disposing and separating nonhazardous waste from hazardous waste. Second, a person should be assigned to the sealing process, if economically feasible. Laboratory staff should be periodically checked and practically examined. Third, the sufficient number of employees should be hired according to the department requirements and workload. Finally, puncture-resistant gloves and containers should be preferred.

In the community mental health center, results show that H12, H11 and H8 have the highest amount of risk. In order to reduce the risks to an acceptable level, some new preventions must be taken apart from other observed units. One of is regarding availability of psychological assistance. In the domestic and medical waste department, results show that H5, H4 and H3 have the highest risk. Therefore, weekly, monthly, quarterly and annual fire alarm system maintenance, fire drill documentation and staff training must be carried out. Additionally, periodic monitoring of electrical equipment and humidity level log for all potential locations should be made. Hazardous healthcare waste management should be planned. Cytotoxic waste should be collected in strong, leak-proof containers. Chemical or pharmaceutical waste should be collected together with infectious waste. In the outpatient and emergency department of the observed hospital, mandatory control measures that must be taken are the same with all employees. Since risk assessment process should be realized as a continuing process and the adequacy of control measures should also be subject to continual review, executives of the hospital must have strong suggestions in terms of providing of required revision if necessary.

5. CONCLUSION AND FUTURE REMARKS

In this paper, a two stage fuzzy multi-criteria framework which provides more consistency in decision making process and gives an appropriate final rank of hazard types is proposed. The

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proposed method is applied through a leading education and research hospital in Turkey in order to determine hazardousness of the departments of the hospital and suggest potential control measures. First, Buckley's FAHP was used in weighting five risk parameters which are severity, occurrence, undetectability, sensitivity to maintenance non-execution and sensitivity to personal protective equipment (PPE) non-utilization. Then, risk prioritization of hazard types in each department of the hospital were determined by using FVIKOR method. Results of the case study show that the most important hazard types in the whole system of the observed hospital are stemmed from electricity, infection, and fire and other emergency situations. In other departments of the hospital, control measures are overtaken for the hazards and areas open for improvement are presented.

This study contributes to the context of risk assessment from two sides. From methodological point of view; (1) a FAHP based method that avoids shortcomings of a crisp risk parameter calculation and decreases the inconsistency in decision making is proposed. Apart from classical OHS risk assessment methods, decision makers assign criteria weights by pair wise comparison manner of Buckley's FAHP. (2) Different from classic OHS risk assessment methods (e.g. 2 parameters in decision matrix method, 3 parameters in Fine-Kinney method and FMEA method), this paper considers five parameters which are severity, occurrence, undetectability, sensitivity to maintenance non-execution and sensitivity to personal protective equipment (PPE) non-utilization. From application point of view, this study is expected to provide a basis for decisions and policies that must be taken by hospitals in their healthcare process. This study is the first study in OHS risk assessment in assessing the risks for a whole hospital that uses a two stage

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(FAHP-FVIKOR) approach. This will further lead the stakeholders in determination of national and macro-scale health care risk control policies.

It should be acknowledged that the study has some limitations. Particularly, in the second stage of the methodology presented in this paper-*prioritization of hazard types*, it is important to keep in mind that the other multi criteria decision methods (fuzzy TOPSIS, fuzzy ELECTRE etc.) and/or their combinations can also be used as effective solutions. Carrying out a sensitivity analysis of the presented two stage fuzzy multi criteria methodology can also be considered as part for future research context. In times of a potential difficultness in capturing the decision maker's judgment with respect to the risk parameters using a single set of fuzzy linguistic terms, one can considered the application of various versions of fuzzy sets theory for resolving this issue.

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TABLE 1 Comparison of the previous studies that have used MCDM methods for OHS risk assessment

Study	**Objectives**	**Methods used**	**Approach used**
Grassi *et al.* (2009)	Rank of hazardous activities in production process of a well-known Italian sausage	FTOPSIS	Used FTOPSIS method for ranking hazards considering effects of human behavior and environment on risk level, other than the classical magnitude an probability factors
Gul and Guneri (2016)	Prioritization of the hazard groups in an aluminum plate manufacturing factory	Buckley's FAHP, FTOPSIS	Used FAHP to determine weights of two criteria derived from Decision matrix method and the FTOPSIS method for ranking hazard types of each department in the plant

Mahdevari *et al.* (2014)	Investigate risks associated with health and safety in underground coal mines	FTOPSIS	Used FTOPSIS method for arranging hazards in the mines in Iran
Liu and Tsai (2012)	Provide risk assessment values of hazard causes in construction industry	Quality function deployment (QFD), Fuzzy analytic network process (FANP), Fuzzy FMEA	Used QFD to represent the relationships among construction items, hazard types and hazard causes, FANP to identify hazard types and hazard causes, Fuzzy FMEA to assess the risk value of hazard causes based on the fuzzy inference approach
John *et al.* (2014)	Propose a novel fuzzy risk assessment approach to facilitating the	FAHP, Evidential reasoning (ER)	Used FAHP to analyze the complex structure of seaport operations and determine the

	treatment of uncertainties in seaport operations		weights of risk factors, ER to synthesize them
Hu *et al.* (2009)	Risk evaluation of green components to hazardous substance	FAHP, FMEA	Used FAHP to determine the relative weightings of four factors (three in FMEA and frequency of green component), FMEA to calculate risk priority number
Ebrahimnejad *et al.* (2010)	Risk identification and assessment for build-operate-transfer (BOT) projects	FTOPSIS, Fuzzy Linear Programming Technique for Multidimensional Analysis of Preference (FLINMAP)	Used FTOPSIS and FLINMAP for comparatively to rank high risks in BOT projects

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Djapan *et al.* (2015)	Determination of risk levels on the workplaces in a central Serbian manufacturing small and medium enterprise	FAHP	Used FAHP to define hierarchical structures and describe relative importance of factors, sub-factors and values of sub-factors
Vahdani *et al.* (2015	Preference of cause failures of steel production process	FMEA, TOPSIS	Used parameters of FMEA with fuzzy belief TOPSIS to determine the preference of cause failures

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TABLE 2 The random consistency index (RI) for different size matrices

Size of matrices (n)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51

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TABLE 3 Linguistic terms and corresponding fuzzy values for evaluation of risk parameters

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)

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TABLE 4 Linguistic terms and corresponding fuzzy values for hazard ranking (Chen, 2000)

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)

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TABLE 5 Weights of risk parameters obtained from Buckley's FAHP method

Risk parameter	O	S	PPE	M	U	**w**
O	(1,1,1)	(0.50,0.68,0.83)	(0.50,0.66,0.89)	(0.65,0.96,1)	(0.69,0.89,1.13)	0.16
S	(1.21,1.46,1.98)	(1,1,1)	(0.89,1,1.33)	(0.89,1.33,1.62)	(0.81,1.18,1.62)	0.24
PPE	(1.13,1.51,2.02)	(0.75,1,1.13)	(1,1,1)	(1,1.04,1.54)	(1,1.13,1.64)	0.23
M	(1,1.04,1.54)	(0.62,0.75,1.13)	(0.65,0.96,1)	(1,1,1)	(0.85,1,1.28)	0.19
U	(0.89,1.130,1.45)	(0.62,0.85,1.23)	(0.61,0.89,1)	(0.78,1,1.18)	(1,1,1)	0.19

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TABLE 6 Fuzzy decision matrix of hazard types in the observed hospital ED

Hazard types	O	S	PPE	M	U
H1	(1,4.2,7)	(1,5.2,9)	(0,3.4,7)	(0,2.4,5)	(1,4.8,9)
H2	(3,5,7)	(1,5,9)	(0,4,7)	(0,2.6,7)	(1,4.6,7)
H3	(0,1.6,5)	(3,6.8,9)	(0,2.6,7)	(0,2.4,5)	(1,4.8,7)
H4	(1,3.8,7)	(1,4.4,9)	(0,3.4,7)	(0,2.4,7)	(1,4.6,7)
H5	(0,1.4,5)	(1,4.8,9)	(0,2.9,7)	(0,2.6,5)	(0,3.5,7)
H6	(3,5.4,9)	(1,3.8,7)	(0,1.8,5)	(0,2.2,7)	(0,3.4,7)
H7	(0,5.6,9)	(1,4.6,7)	(0,2.7,7)	(0,2.1,7)	(0,4.8,9)
H8	(0,5.4,9)	(0,3.8,9)	(0,2.7,7)	(3,5.4,9)	(0,4.6,9)
H9	(1,6.8,10)	(5,7,9)	(0,0.6,3)	(0,0.1,3)	(0,4,9)
H10	(1,4.2,7)	(1,4,9)	(0,1,5)	(0,1.6,5)	(0,3,7)
H11	(1,3.8,7)	(3,6,9)	(1,4.6,9)	(1,4.4,7)	(1,5,9)
H12	(0,1.9,5)	(5,8.8,10)	(0,4.1,9)	(3,6.4,9)	(3,6.4,9)

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TABLE 7 Normalized fuzzy distances of hazard types in the observed hospital ED

Hazard types	O	S	PPE	M	U
H1	4.13	5.13	3.43	2.43	4.87
H2	5.00	5.00	3.83	2.90	4.40
H3	1.90	6.53	2.90	2.43	4.53
H4	3.87	4.60	3.43	2.77	4.40
H5	1.77	4.87	3.10	2.57	3.50
H6	5.60	3.87	2.03	2.63	3.43
H7	5.23	4.40	2.97	2.57	4.70
H8	5.10	4.03	2.97	5.60	4.57
H9	6.37	7.00	0.90	0.57	4.17
H10	4.13	4.33	1.50	1.90	3.17
H11	3.87	6.00	4.73	4.27	5.00
H12	2.10	8.37	4.23	6.27	6.27

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TABLE 8 Values of S, R and Q for all hazard types in the observed hospital ED

Hazard types	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
S_i	0.38	0.34	0.43	0.41	0.50	0.49	0.40	0.32	0.48	0.57	0.23	0.13
R_i	0.12	0.10	0.12	0.11	0.12	0.14	0.12	0.13	0.19	0.16	0.07	0.11
Q_i	0.48	0.38	0.54	0.48	0.61	0.68	0.49	0.45	0.89	0.88	0.12	0.16

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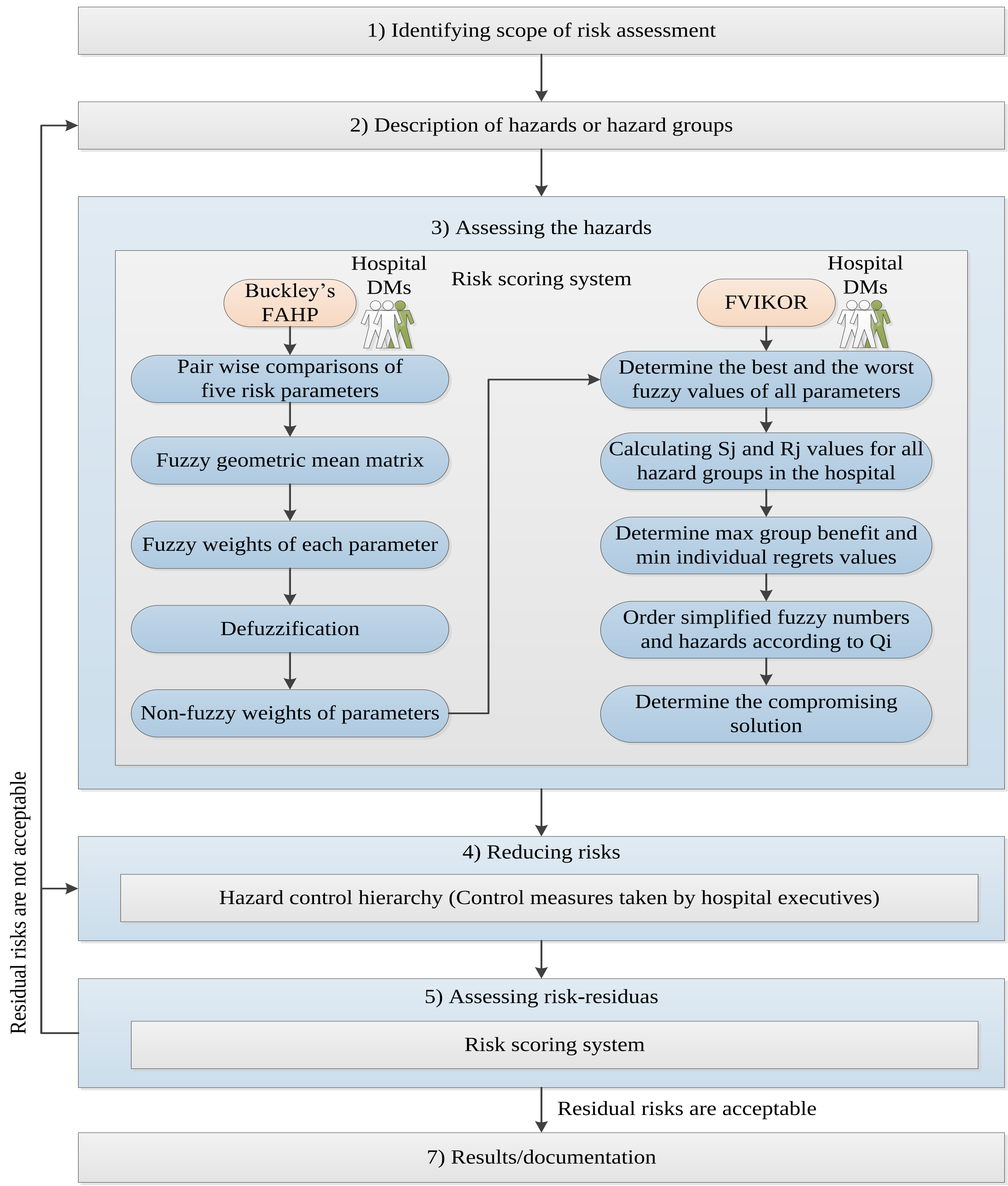

FIGURE 1 Flowchart of the proposed two-stage approach

FIGURE 2 Risk priorities of the hazard types by S, R and Q values in each department of the observed hospital

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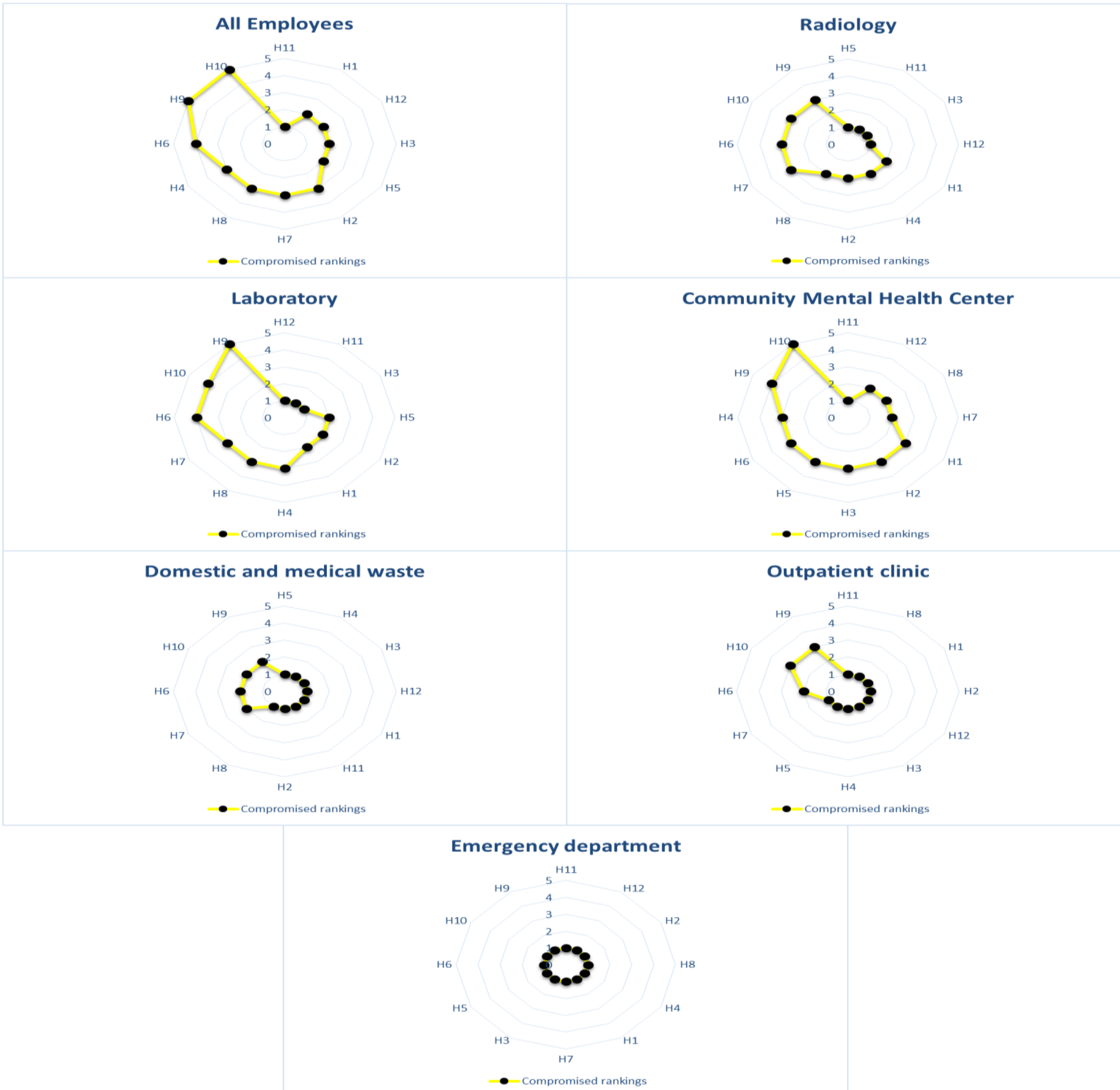

FIGURE 3 Compromised rankings for the hazard types in each department of the observed hospita