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Influence of HOT Factors on Risk Assessment Level Based on Fuzzy Set Theory

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Introducing human, organizational and technical/technological factors in a risk assessment model represents a significant step forward in the occupational health and safety field. The best known problems of risk assessment models are their inability to cope with the uncertainties, subjectivity and static nature of the process. The improvements in the risk assessment model presented relate to these problems. Three groups of factors are introduced and their hierarchical structures are defined. The relative importance of the factors and sub-factors and values of the sub-factors are described by predefined linguistic expressions. Fuzzy set theory is used for the modeling of existing uncertainties. The risk assessment model is based on quantitative risk assessment and reducing the risk level is possible through changing the initial values of the sub-factors identified. Varying the values allows the reduction of the risk level between two regular risk assessment processes or permits planning of proactive actions and activities in order to eliminate hazards or reduce risk level in the period considered. The proposed model is tested with real data from one production company.

1. Introduction

Nowadays, risk management and risk assessment have become very popular and much used terms. However, it is worth bearing in mind that the very use of these terms to solve all problems related to risks in business and production systems can lead to the possibility of improper and wrong focus on the problems. Additionally, the major misconception in the occupational health and safety (OHS) field is that the implementation of the risk assessment process is just one great duty, the limiting factor in the functioning of the system and another reason for spending financial resources. Nevertheless, considering all the objectives into account it is stated that reducing the number of accidents is one of the most important goals of reducing the number of unwanted and unplanned events in the workplace (Sawacha et al., 1999). Whether it is about companies that provide services or which are based on the production of certain types of products, the goals need to be defined (relating to production and safety) within acceptable risk levels. This should imply an important balance between production and the concept of safety. The risks themselves are very complex. The complexity is reflected during the risk assessment process in which risks are identified, analyzed and evaluated for the whole system, not individually. According to Bischoff (2008) risks are within normal limits or deemed acceptable if they meet certain conditions, like low uncertainty related to the probability of the occurrence of consequences; fairly low overall probability of injury; low or intermediate probability of the hazard; low consistency; impossibility of occurrence of repeated unwanted and unplanned events; small deviation between the assumed potential harm and the probability of occurrence and low level of risk that is related to social anxiety and potential dissatisfaction. This paper continues work of Djapan et al. (2013) and proposes a model as a supplement of the existing risk assessment process or as a model to decrease the identified risks between two risk assessments. This model is based on the identification of HOT (human, organizational and technical/technological) factors, its implementation and role in risk assessment based on fuzzy set theory. A management team describes each uncertainty in the relative importance of the identified factors and sub-factors, the sub-factor values and the risk level potential. They do this using linguistic

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expressions, which reflects the human way of thinking. Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. Hence, applying the fuzzy approach all uncertainties and imprecisions, which emerge due to lack of good evidence, are managed. These linguistic expressions are modeled by triangular fuzzy numbers (Zimmermann, 2001). The proposed model, bearing in mind the whole concept of health and safety at work and the risk assessment process, can be used to solve the following problems in a production system: 1) prioritization of factors that affect workplace safety, whereby a factor that is rank first has the most impact on it, 2) determining how changes in one or more sub-factors affect the risk level and 3) workplace risk assessment.

2. Literature review

Considering the fact that risks appear in all spheres of life, the term risk is widely used and explained in different ways. Aven (2011) and Leitch (2010) consider that there is a terminological inconsistency within the standards and concepts from different areas where risk is considered, covering the economy/industry, management structure and financial resources. They state that there is a very vague and inconclusive meaning and understanding of the fundamental terms - risk and probability. What significantly complicates risk assessment is how to choose the right tools and methods for conducting this process. Making this choice is especially difficult taking into account that the wrong choice leads to bad decisions, and later to reduced confidence in the whole risk assessment process (Lootsma, 1997). Risk assessment is burdened with subjectivity and there is a tendency for certain risks not to be taken into consideration. The situation becomes even worse if some risks are underestimated. This leads to the conclusion that subjective risk assessment is potentially dangerous and can lead to significant unwanted consequences (Reid, 1992). If the findings of the probabilities and consequences of accidents are not at a high and acceptable level, the risk assessment can be classified as irrational, without unscientific character and with the high potential that it will not be conducted in an appropriate manner (Stirling, 1998). Risk identification, assessment and management should not only be based on an analysis of the technical risks leading to unidimensionality of the risk assessment, neglecting other aspects of business and manufacturing systems (Renn, 1999), such as human and organisational factors (as in Demichela et al., 2014; Monferini et al. 2013) and maintenance management, where the above cited aspects are mostly important (e.g. Todorović et al., 2014). Analogous to the overview of the tools and methods for risk assessment in standard ISO/IEC 31010 (ISO, 2009), in the contemporary scientific literature, there are different opinions on the general division of tools and methods for risk assessment. According to Arunraj and Maiti (2007) and Tixier et al. (2002) there are two main groups of tools and methods, classified according to the nature of use, while according to Marhavilas (2011) there are three groups: a) quantitative, b) qualitative and c) hybrid. The research in the past decade in the occupational health and safety field has concluded that the percentage of the most common group of tools and methods for risk assessment is a quantitative method, app. 65,63% Marhavilas (2011). These data informally accept the quantitative method for the risk assessment process as a the most suitable, as also discussed in Demichela & Camuncoli (2014). The authors of this paper's improved model relies on quantitative risk assessment (McDonald, 2004) and makes a basis for implementing identified HOT factors using fuzzy set theory. Confirmation of the necessity of making such a structure and this type of classification arises from industry, which was at a particular moment of history considered as the riskiest field. The history of aviation safety can be divided into three eras that progressively include three unavoidable factors (ICAO, 2012). In this way, this principle and classification has been adopted and applied to other industries. The authors are of the opinion that this approach has a real scientific basis for the improvement of the risk assessment model and its implementation in other industries.

3. Framework of the model

Since, in practice, none of workplaces has the same characteristics and each is specific in its own way, and risk assessment process should be viewed as separate and unique problem. According to this assumption, in this paper, we set limits on defined factors, while the total number of sub-factors could vary depending on the observed workplace. The starting point of the proposed model is workplace risk assessment. This type of risk assessment (McDonald, 2004) belongs to the group of quantitative methods and tools. In addition, this risk assessment method is the maximally applicable in practice and the results obtained by using this method proved to be acceptable and relevant. This type of form covers all essential elements that have an impact on risk level. It includes four elements: the probability of injury, the severity of injury (because of manifestation of dangerous situations), the frequency of exposure to hazards and the number of people exposed to the identified hazards. The focus of the proposed model is on the probability of injury. The expert team is consisted of licensed OSH persons, professors from universities, OSH engineers, members of OSH council on national level and engineers who work in observed types of companies. All factors are classified into different groups by expert team based on data from the literature and the results of good practice. Groups of factors are formally represent set of indices I={1,...,i,...,I}, where i represents the index for the group of factors, and I is the total number of defined groups of factors. Sub-factor being represented by a set of indices J={1,...,j,...J_i}. The total number of sub-factors defined by the factor i, i=1,..,I is referred to as Y_i. Index which indicates the sub-factor, any factor is j, j=1,...,J. It should be noted that, in general, the number of sub-factors might be different. In our specific case, since the research is about a group of similar production companies, the number of factors is three and each factor contains five sub-factors (Table 1).

Table 1: HOT factors

Human factors	Organizational factors	Technical/technological factors
Personal characteristics (HF1)	Work pace (OF1)	Technical characteristics of equipment (TTF1)
Experience (HF2)	Organizational and schedule of work tasks (OF2)	Level of automatization (TTF2)
Training level (HF3)	Informations, procedures and documentation (OF3)	Characteristics of safety equipment and devices (TTF3)
Behavior (HF4)	Workplace ergonomy (OF4)	Maintenance level of equipment (TTF4)
Relations (HF5)	OHS system (OF5)	Characteristics of personal protective equipment (TTF5)

Identifying and assessing the risks of the workplace is one of the most important tasks of management at the level of each company. This paper considers a group of similar companies. Based on these assumptions, we can consider that the relative importance of the factors and the relative importance of sub-factors were determined at the level of a given group of companies. The expert team defines and determines the relative importance of the factors and sub-factors and it is formally presented a set of indices decision makers E={1,...,e,...E}, where e represents the index for decision-makers, and E is the total number of members of the expert team. Each member of the management team estimates the relative importance of the factors. They expressed their estimates using five predefined linguistic expressions. Modeling of linguistic expressions is based on the theory of fuzzy sets (Zimmermann, 2001). In other words, determining the relative importance is set as a problem of group decision making. Aggregating individual assessment in group consensus is obtained by applying the method of fuzzy mean value. Weight of factors w_i, i=1,..,I and weight of sub-factors, w_{ji}, j=1,..,J_i; i=1,..,I are obtained from fuzzy analytic hierarchy process (FAHP) that was developed in (Chang, 1996).

4. Modeling uncertainties

Workplace risk assessment depends on the relative importance of the factors, sub-factors and their current values. It can be assumed that it is closer to the human way of thinking if the management team's evaluations, attitudes, knowledge and experience are expressed by linguistic expressions. In this section, the relative importance of the factors, sub-factors and their values are described with predefined linguistic expressions. The number and type of the linguistic expressions defines the management team. In this paper, the modeling of linguistic expressions is based on the fuzzy sets theory, which is a useful tool to handle imprecision, vagueness and randomness. It can be considered that the fuzzy set theory supports the human way of thinking because it uses approximate information and uncertainty to generate decisions (Kahraman, 2009). In this paper it is assumed that the relative importance of the factors and sub-factors is equal. The values of the relative importance do not change over time. Each member of the expert team assesses the relative importance of the defined factors and sub-factors. Assessing the relative importance aims to establish a practical basis for the introduction of improved risk assessment models.

4.1 Modeling of relative importance of factors and sub-factors

The members of the expert team used five predefined linguistic expressions for factors that are modeled by triangular fuzzy numbers and seven predefined linguistic expressions for sub-factors that are modeled by triangular fuzzy numbers. These triangular fuzzy numbers for factors and sub-factors are presented in Table 2. Relative importance of factors *i* related to factor *i'*, *i=1,...,I', i≠i'* is modeled using triangular fuzzy number $\widetilde{W}^e_{ii'i} = (x; l^e_{ii'}, m^e_{ii'}, u^e_{ii'})$. Upper and lower bounds of these fuzzy numbers are represent as $l^e_{ii'}$ and $u^e_{ii'}$, while $m^e_{ii'}$ represents modal value. Domain of these triangular fuzzy numbers is in interval [1-5].

Table 2: Relative importance of factors and sub-factors modeled by triangular fuzzy numbers

Factors	Sub-factors
very low importance – $\tilde{R}_1 = (x; 1,1,3.5)$	*very low importance* – $\tilde{R}_1 = (x; 1,1,2.5)$
low importance – $\tilde{R}_2 = (x; 1,2.5,4)$	*low importance* – $\tilde{R}_2 = (x; 1,2,3)$
medium importance – $\tilde{R}_3 = (x; 1,3,5)$	*medium low importance* – $\tilde{R}_3 = (x; 2,3.5,5)$
high importance - $\tilde{R}_4 = (x; 2,3.5,5)$	*medium importance* – $\tilde{R}_4 = (x; 3.5,5,6.5)$
extremely importance - $\tilde{R}_5 = (x; 2.5,5,5)$	*medium high importance* - $\tilde{R}_5 = (x; 5,6.5,8)$
	high importance - $\tilde{R}_6 = (x; 7,8,9)$
	extremely importance - $\tilde{R}_7 = (x; 7.5,9,9)$

Value 1 means that factor *i* has almost equal importance and value 5 has extreme importance, regarding to factor *i'*. Relative importance of sub-factors *j*, related to sub-factor *j'*, *j=1,…,J$_i$, j≠j'* is modeled using triangular fuzzy number $\widetilde{W}^e_{jj'i} = (x; l^e_{jj'i}, m^e_{jj'i}, u^e_{jj'i})$. Upper and lower bounds of these fuzzy numbers are represent as $l^e_{jj'i}$ and $u^e_{jj'i}$, while $m^e_{jj'i}$ represents modal value. Domain of these triangular fuzzy numbers is in interval [1-7]. Value 1 means that sub-factor *j* has almost equal importance and value 7 has extreme importance, regarding to sub-factor *j'*.

4.2 Modeling of factors' values

The management team consists of a person responsible for health and safety at work, managers of all the sectors observed and external experts (if management considers them necessary). The management team uses the five predefined linguistic expressions for their assessment which are modeled by triangular fuzzy numbers $\tilde{V}_{ji} = (y; L_{ji}, M_{ji}, U_{ji})$, where L_{ji} and U_{ji} are lower and upper boundaries respectively, and M_{ji} is modal value. These triangular fuzzy numbers are defined in Table 3. The domain of these triangular fuzzy numbers is in interval [0-1]. Value 0 means that the value of the factor is negligibly low and value 1 represents the extreme value of the factor.

Table 3: Relative importance of factor values

Factor values
very low importance – $\tilde{V}_1 = (y; 0,0,0.2)$
low importance – $\tilde{V}_2 = (y; 0.15,0.3,0.45)$
medium importance – $\tilde{V}_3 = (y; 0.35,0.5,0.65)$
high importance - $\tilde{V}_4 = (y; 0.55,0.7,0.85)$
extreme importance - $\tilde{V}_5 = (y; 0.8,1,1)$

5. Developed algorithm

The probability of injury is determined for each workplace respecting the importance of the factors, sub-factors and the importance of the current value of the sub-factors. The value of the probability of injury is described by triangular fuzzy number $\tilde{d}_{ji}$. The determination of this value is presented as equation Eq(1).

$$\tilde{d}_{ji} = w_i \cdot \widetilde{w}_{ji} \qquad i = 1, \dots, I; j = 1, \dots, J; \; J = \sum_{i=1}^{I} J_i \tag{1}$$

Prioritization of the factor is determined based on calculation of the probabilities of injury. The factor which is associated the greatest possibility of injury $\tilde{d}_{ji}$ has the greatest impact on workplace safety, and vice versa.

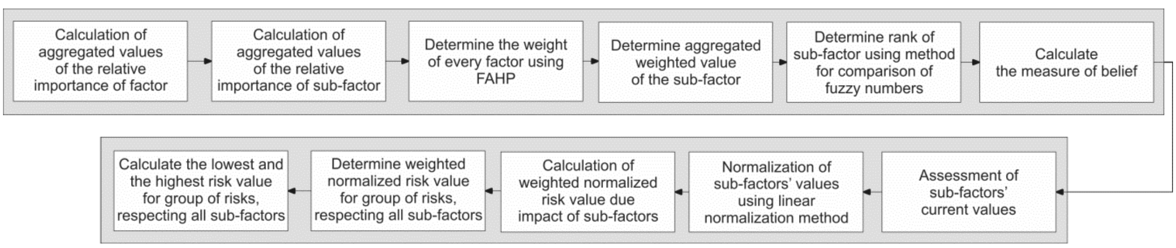

Figure 1. Developed algorithm

Based on the measure of belief calculated this factor can be ranked in first place and the management team gets the necessary input data to take appropriate actions. These actions should lead to a reduction in the value of the probability of injury. Consequently, decreasing this element, the overall risk level is reduced. The developed algorithm of the proposed model is presented in Figure 1.

6. Case study

For the purposes of this research and paper we used the most general list of possible risks which can be found in a workplace. The list consists of 25 risks (EASHW, 2007). The case study was carried out for one SME in the production sector. The characteristics of this company are production processes in operation for less than a year; a significant number of new employees; the current workload requiring only one shift; the prevailing of manual operation; internal transportation; the use of improvised hand tools; the use of the simplest form of gloves as personal protective equipment; the workplace location in the same bigger space where the rest of the equipment is located with no physical isolation from the influence of microclimate, such as noise, vibration, dust and temperature. The authors will show what type of input data needs to be available for this model, the improvement in the percentage of sub-factors according to the financial status of the company and the determined output. The case study is presented in Table 4.

Table 4: Current value (as a percentage) of sub-factors and sub-factor improvement (as a percentage)

Sub-factors	Current Value	Planned improvements
HF1	70 %	-
HF2	20 %	10 %
HF3	20 %	20 %
HF4	50 %	10 %
HF5	60 %	-
OF1	30 %	60 %
OF2	40 %	-
OF3	25 %	15 %
OF4	10 %	25 %
OF5	30 %	-
TTF1	20%	20 %
TTF2	10 %	-
TTF3	20 %	-
TTF4	50 %	-
TTF5	30 %	20 %

Taking into account the projection of the production increase, that the work is mostly performed manually and the costs/benefit analysis conducted, three risks R7, R14 and R22 were taken into consideration. The improvement of these risks needed to be implemented within 12 months. The improvements were possible because the sub-factors selected did not require capital financial resources. The human sub-factors changed continuously. The improvements were mostly based on intensive training and individual work with employees. The improvement of the organizational sub-factors was based on introducing the safest way to work and creating procedures for a certain number of workplaces. The technical/technological sub-factors depended on the financial investments and needed to be planned according to the financial state of the company. The results of the quantitative risk levels and new determined risk levels after implementation of the planned improvements of the sub-factors using the proposed model are shown in Table 5.

Table 5: Current value (as a percentage) of sub-factors and sub-factor improvement (as a percentage)

Risk	Risk level	New risk level	Percentage
R7	175	153	-13 %
R14	150	136	-9.5 %
R22	200	179	-10.5 %

7. Conclusions

The modification of the value of one or more sub-factors leads to changes in risk level. The risk assessment model developed is not intended to replace the existing risk assessment tools, methods and techniques. The main contribution of the paper is to help OHS managers to reduce risks as much as possible. Another contribution is to proactively plan and prepare activities for OHS improvement. Based on the future financial

and organizational status of their company, OHS managers could make relevant calculations in advance about which area can be covered and which activities are the most cost-effective.
The general limitations of the model are that a significant increase in some sub-factors does not reduce the risk to an extent that would be expected and the sub-factors have an influence on the group of similar risks, not on specific hazards. The first limitation could be solved by introducing an enhanced way to assess relative importance, because each sub-factor has a certain minimal impact which does not have to be the case in practice. The second limitation could be solved by making minor model changes, providing a choice for the risk assessment process for specific hazards. The main advantages of the model presented are an easy to use methodology and that the ranking of sub-factors and level of risk can be obtained in an exact way. The proposed method is flexible with regard to the changing in the number of factors and sub-factors and the changes in their relative importance. Future work on this issue will be to design an appropriate and user-friendly interface for better and faster calculations. Moreover, an additional improvement for determining the best package of actions and measures for improving the chosen sub-factors will be considered.

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