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Software for Occupational Health and Safety Risk Analysis Based on a Fuzzy Model

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Risk and safety management are very important issues in healthcare systems. Those are complex systems with many entities, hazards and uncertainties. In such an environment, it is very hard to introduce a system for evaluating and simulating significant hazards. In this paper, we analyzed different types of hazards in healthcare systems and we introduced a new fuzzy model for evaluating and ranking hazards. Finally, we presented a developed software solution, based on the suggested fuzzy model for evaluating and monitoring risk.

risk assessment uncertainty fuzzy model software simulation occupational health and safety

1. INTRODUCTION

It is predicted that the changes in healthcare in the near future will far outweigh the changes made in last 150 years [1]. In the complex environment like healthcare, safety depends greatly on the efforts of everyone in the system [2]. It is necessary for all levels to co-operate with patients as well as other customers. Occupational health and safety (OHS) represents a most important factor in the well-being of modern society. Because of that, occupational accidents are a major source of risk today [3]. A worker's, patient's and third party's safety has become a highest profile risk in the healthcare setting. Hardly a week goes by without a tragic healthcare accident hitting the headlines [4]. That is so because ~10% of workers in the European Union (EU) are employed in the health and welfare sector, with a significant proportion employed in hospitals [5]. This makes healthcare, keeping in mind construction, a major employment sector in Europe. According to EU data the work-related accident rate in the healthcare sector is 34% higher than the EU average [5]. This makes risk management in healthcare systems a necessary tool, which should be supported with an adequate information system. The importance of safety management has dramatically increased in recent years [6]. Society needs to realize and cope with that. Statistical reports emphasize that [7].

In many national healthcare systems, clinics (or outpatient clinics) are important in the first line of providing medical services. In this paper, we will treat a clinic as a small private or public health facility dedicated to the care of outpatients. An outpatient is a patient who is not hospitalized overnight but who visits a hospital, clinic or associated facility for a diagnosis or treatment. The treatment provided in this way is called ambulatory care. When an important issue such as occupational safety arises, different institutions and entities in a healthcare system have very different positions.

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Large hospitals and medical institutions (university clinics) have safety and health management offices or centers. Small clinics usually have a limited number of employees and they do not have enough resources to address issues of OHS.

The initial aim of this paper is to develop a theoretical understanding of risks which appear in a clinical setting, so small clinics (including private ones) would have a quality tool for evaluating OHS. Of course, there is the need to comply with European regulations and standards, such as Standard No. ISO 31000:2009 [8]. Risks can be understood in many ways [9]. However, when we talk about safety and health at work, risks need to be understood as uncertainty. The nature of risk changes over time [10]. That is important for understanding the risk. Some authors presented a method for constructing risk assessment with linguistic terms [11], others presented methods for ranking generalized fuzzy numbers [12]. We made an effort to combine both qualitative and quantitative values of hazards as well as their importance with a fuzzy set.

The advantages of the fuzzy approach in modeling uncertainties over other techniques and methods are numerous. The most important one is a possibility to present expert knowledge with a natural language, which represents the most advanced form of communication (in accordance with the long history of optimization). In a mathematical sense, experts' knowledge can be expressed with a linguistic variable, which can be modeled with a fuzzy set [13]. Fuzzy set theory can provide a valuable tool to cope with three major problematic areas of different selection problems: imprecision, randomness and ambiguity. Fuzzy logic enables us to emulate the process of human reasoning and make a decision based on vague or imprecise data [14].

This paper intends to present a method of analyzing and evaluating occupational risk at medical clinics with fuzzy sets. It presents a software solution for evaluating and modeling quantitative risk assessment with the developed fuzzy model. This software is based on the developed fuzzy model for evaluating risk, which should contribute to reliability and safety in healthcare systems. The model is flexible and can be tested on specific examples.

2. RISK ANALYSIS IN HEALTHCARE SYSTEMS

The systems for OHS services were mainly oriented towards the requirements of large institutions in healthcare systems. Little attention was paid initially to the particular situation of small clinics and ambulance settings. Therefore, for a variety of reasons, it seems that the implementation of an effective system of OHS services for clinics has different patterns than the usually implemented procedures in large healthcare institutions. The major differences between clinics and large healthcare institutions are limited financial resources of clinics compared to large systems and a low level of knowledge or no knowledge at all of health and safety requirements among the personnel employed in small clinics. Implementing a safe and healthy environment into the clinic setting with a system approach is a method to achieve the desired results.

A medical clinic is a service-based industry. Many studies focus on only one or two specific themes, e.g., exposure to the human immunodeficiency virus (HIV), hepatitis B, hepatitis C [15, 16], needle stick and sharp injuries [17, 18], facility design [19] or workplace violence [20].

According to Standard No. ISO 31000:2009, risk management should be an integral part of management, embedded in culture and practice [8]. Risk analysis is the main part of risk management. According to one definition, risk analysis deals with uncertain situations [21]. Dealing with uncertainty means that we need some methodology to prevent adverse events. Hence, there are many risk analysis methodologies, but each has, more or less, the same steps of which three can be identified as the main [22, 23].

According to one case study, it is clear that the OHS risk factor has the greatest average impact on a healthcare system [24]. This is the reason we concentrated on the field of OHS. Three major problems characterize the current clinic setting: accessibility, quality and cost [25]. These problems are related in one way or another to OHS. The key of successful risk management is that we need to believe that humans can control hazards and prevent accidents [26]. Risk assessment is undertaken and risk measures implemented in the best way when safety officers work at that same institution. That is essential because they will have information valuable for risk management, e.g., related to the location and the severity of hazard. There are many useful checklists that make hazard identification easier [27, 28]. These checklists have both advantages and disadvantages. We chose a checklist of the European Agency for Safety and Health [29]. There were two reasons: (a) it completely covers all known hazards, which helps in further research and (b) the European Agency for Safety and Health at Work is the main EU reference point for safety and health at work.

3. A NEW FUZZY MODEL

3.1. Basic Assumptions

The developed model for evaluating risk is based on the following assumptions:

- hazards are defined according to the European Agency for Health and Safety at Work;
- an organized pair (relative importance and value) is assigned to each defined hazard;
- the relative importance of the identified hazards is different and determined by knowledge and experience of the risk management team. In this paper, they are described with linguistic expressions modeled with triangular fuzzy numbers; and
- values of hazards which can cause accidents or occupational injuries in clinics can be crisp or uncertain.

3.2. Notation

h—identified hazard, h = 1, … , H
H—total number of identified hazards
H'—total number of cardinal hazards
$\tilde{W}_h$—triangular fuzzy number representing relative importance of hazards which can cause accidents or occupational injuries, h = 1, … , H
v_h—parameter of crisp hazard h, h = 1, … , H'
v_h^{max}—maximum value of crisp parameter h, h = 1, … , H'
v_h^n—normalized value of v_h, h = 1, … , H'
$\tilde{v}_h$—parameter of uncertain hazard h, h = H' + 1, … , H
$\tilde{v}^{max}$—maximum value of $\tilde{v}_h^n$, h = H' + 1, … , H
$\tilde{v}_h^n$—normalized value of $\tilde{v}_h^n$, h = H' + 1, … , H
r_h—representative scalar of fuzzy number $\tilde{v}_h^n$, h = H' + 1, … , H
$\tilde{c}_h$—fuzzy portrait of hazard h, h = 1, … , H

3.3. Modeling Uncertainty

The fuzzy approach to treating uncertainties can be used (a) in continuously changing preconditions so that treated variables can not be modeled with probability theory, and (b) if the amount of relevant data for statistical analysis is insufficient. What is probable must be possible but not vice versa, so we may only require grades of probability to act as lower bounds on grades on possibility [30]. We give the number and type of linguistic expressions with which the relative importance of identified hazards leading to adverse events is described. Also, the risk management team determines the values of uncertain hazards.

In this paper, five linguistic expressions are used to describe the severity of hazard that leads to accidents and occupational injuries in clinics. They are *very low severity*, *low severity*, *medium severity*, *high severity* and *very high severity.* Also, three vague expressions are used to describe the values of uncertain hazards: *low value*, *medium value* and *high value*. The meanings of those expressions are specified with triangular fuzzy numbers [31]. On that basis, we used the horizontal method of membership estimation.

3.3.1. Estimating the severity of identified hazards

Triangular fuzzy numbers are used to describe the relative importance of causes which lead to accidents and occupational injuries in the following way: *very low severity*, $\tilde{W}_1$ = (x; 1, 1, 6); *low severity*, $\tilde{W}_2$ = (x; 1, 1, 9); *medium severity,* $\tilde{W}_3$ = (x; 1, 5, 9); *high severity*, $\tilde{W}_4$ = (x; 1, 9, 9);

very high severity, $\tilde{W}_5$ = (x; 4, 9, 9). Thus, *low*, *medium* and *high* are three primary terms. Two additional terms with the word *very* are obtained by moving hedges. Figure 1 shows all five terms.

The domain of every triangular fuzzy number is defined on a scale of 1–9. The lowest severity of hazard is indicated with 1, the highest with 9.

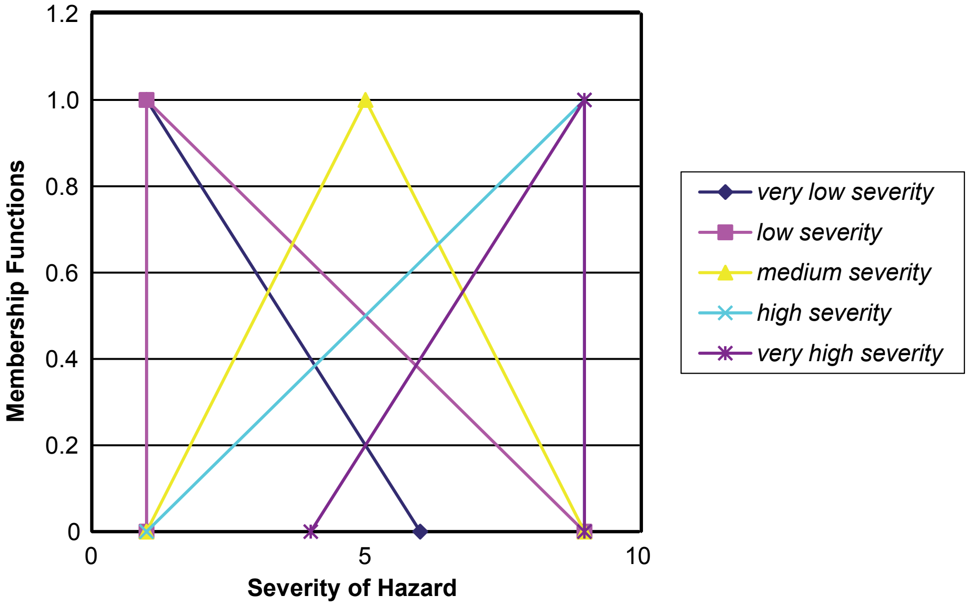

Figure 1. Severity of identified hazards.

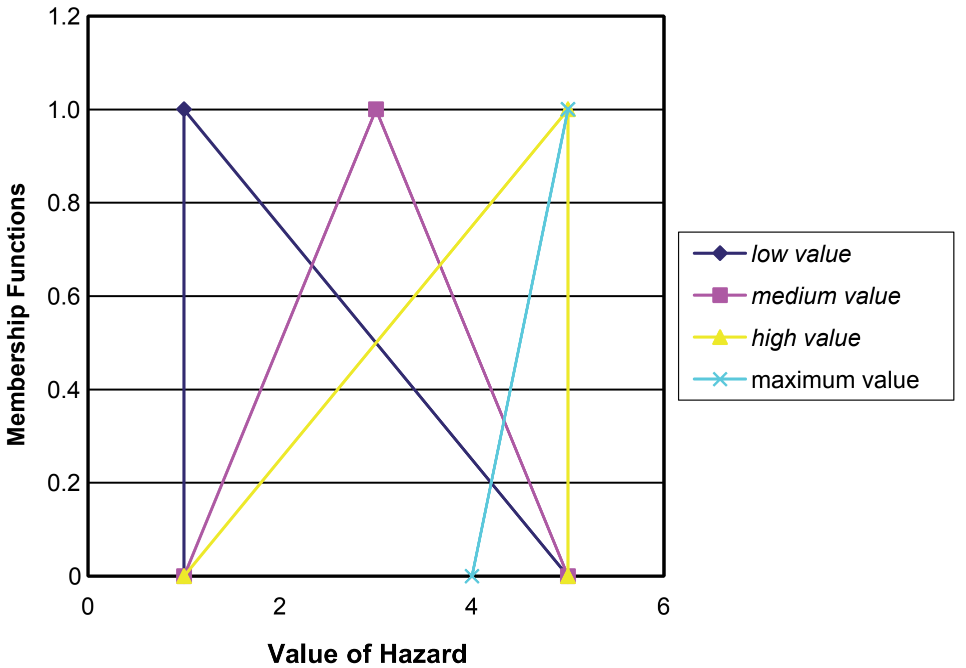

Figure 2. Value of uncertain hazards.

3.3.2. Estimating values of uncertain hazards

Values of the remaining hazards which cannot be determined analytically are determined on the basis of experts' subjective assessment, which is usually based on evidence data, their experiences and knowledge. The membership functions of the corresponding triangular fuzzy numbers are given on a scale of 1–5: *low value*, $\tilde{v}_1$ = (y; 1, 1, 5); *medium value*, $\tilde{v}_2$ = (y; 1, 3, 5); *high value*, $\tilde{v}_3$ = (x; 1, 5, 5); *maximum value*, $\tilde{v}_4$ = (y; 4, 5, 5) (Figure 2).

3.4. Preliminaries

Hazards are indexed with h = 1, … , H. They have different degrees of seriousness and heaviness. According to the experience of the risk management team, some have a strong influence on the health and safety of the employees in every clinic and of the patients in that clinic. The hazards, which may lead to a deterioration in OHS at work, have different importance and their causal significance can not be precisely described. As given in section 3, the severity of each identified hazard h = 1, … , H will be described in this paper with a triangular fuzzy number $\tilde{W}_h$ = (x; x_L, x_M, x_R) with the lower and upper bounds x_L, x_R, respectively, and modal value x_M. Further, it is supposed that each crisp uncertain hazard h = 1, … , H is measurable and determined with one deterministic numerical parameter v_h, which has its unit of measurement. The value of parameter v_h usually differs from the corresponding maximum value of the same parameter, denoted with v_h^{max}. By applying the concept of maximum values [32], the normalization of parameter v_h, h = 1, … , H' is performed in a way that each v_h is divided by the corresponding v_h^{max} and thus normalized, dimensionless parameters v_h^n, h = 1, … , H' are obtained.

As it is supposed, the values of uncertain hazards are described with three primary value expressions modeled with triangular fuzzy numbers $\tilde{v}_h$ = (y; y_{hL}, y_{hM}, y_{hR}), h = H' + 1, … , H. The lower and upper bounds and modal value of triangular fuzzy number are denoted as y_{hL}, y_{hR} and y_{hM}, respectively. The maximum allowed value of hazard h, H' + 1, … , H is determined by the risk management team. In this paper, it is supposed that this value is described with the triangular fuzzy number $\tilde{v}_h$ = (y; y_L^{max}, y_M^{max}, y_R^{max}) with the lower and upper bounds y_L^{max}, y_R^{max} and modal value y_M^{max}, respectively. The normalized value of each uncertain hazard h, h = H' + 1, … , H, $\tilde{v}_h^n$ is obtained when $\tilde{v}_h$ is divided by $\tilde{v}^{max}$. The normalized values of uncertain parameters are presented with fuzzy numbers according to fuzzy algebra rules [13, 31, 33], $\tilde{v}_h^n$ = (r; r_{hL}, r_{hM}, r_{hR}) with the lower and upper bounds r_{hL}, r_{hR} and modal value r_{hM}, respectively. By using the maximum method, a representative scalar r_h of each fuzzy number $\tilde{v}_h^n$, h = H' + 1, … , H is calculated.

The basic idea in analyzing risk in clinics caused by the action of identified hazards is to calculate the normalized value for each identified hazard h, h = 1, … , H multiplied by their fuzzy severity. Since the severity of hazards is described with triangular fuzzy numbers, the values $\tilde{c}_h$, h = 1, … , H are triangular fuzzy numbers, too, with the lower and upper bounds α_{hL}, β_{hR}, respectively, and modal values μ_h. In this way $\tilde{c}_h = \alpha_{hL}$, μ_h, β_{hR} represents a fuzzy portrait hazard h, h = 1, … , H, with respect to its severity. This risk analysis is based on a comparison of triangular fuzzy numbers , h = 1, … , H. In this paper, a simple procedure for comparing fuzzy numbers is used [24].

Specific case: 22 hazards

The results of theory and practice in OHS indicate that the next 22 hazards have an influence on accidents and occupational injuries. Those hazards are at the highest level of abstraction, i.e., each defined hazard can be precisely defined for a specific work place. These hazards are (1) high pressure; (2) chemical substances; (3) noise; (4) hand-arm vibration; (5) whole-body vibration; (6) lighting; (7) ultraviolet, infrared, laser and microwave radiation; (8) electromagnetic fields; (9) hot or cold climate; (10) uneven or slippery surfaces; (11) moving vehicles and machines; (12) moving parts of machines; (13) objects and parts with dangerous surfaces; (14) hot or cold surfaces, materials, etc.; (15) hand tools; (16) electrical installations and equipment; (17) fire; (18) explosion; (19) lifting and carrying loads; (20) work involving poor posture; (21) biological hazards; and (22) stress, violence, harassment.

Reference values of cardinal parameters are $v_1^{max} = 1$ bar; $v_2^{max} = 200$ ml/kg; $v_3^{max} = 85$ dB; $v_4^{max} = 5$ m/s^2; $v_5^{max} = 1.15$ m/s^2; $v_6^{max} = 2000$ lx; $v_7^{max} = 4$ mSv; $v_8^{max} = 4$ mG and $v_9^{max} = 45$ °C.

3.5. Developed Algorithm

The algorithm outlined in this section describes, in a more formal way, the problem of reducing OHS injuries in clinics due to identified hazards through steps.

Step 1. Calculation of normalized values for crisp hazards: $v_h^n = \frac{v_h}{v_h^{max}}$, h = 1, … , H'.

Step 2. Calculation of normalized values for uncertain hazards: $\tilde{v}_h^n = \frac{\tilde{v}_h}{\tilde{v}^{max}}$, h = H' + 1, … , H.

Step 3. Representative scalar of each fuzzy number, $\tilde{v}_h^n$, r_h, h = H' + 1, … , H is determined with the maximum method: $\mu_{\tilde{v}_h^n}(r_h) \geq \mu_{\tilde{v}_h^n}(r_h)$ for $(\forall r_h)$, $r_h \in [r_{hL}, r_{hR}]$.

Step 4. Calculation of a fuzzy portrait of each identified hazard: $\tilde{c}_h = \tilde{W}_h \cdot v_h^n$ for all cardinal hazards, h = 1, … , H', and $\tilde{c}_h = \tilde{W}_h \cdot r_h$ for all linguistic hazards, h = H' + 1, … , H.

Step 5. Rank of hazards is based on the comparison method of fuzzy numbers [24].

4. SOFTWARE FOR RISK AND SAFETY ANALYSIS

4.1. Modules of Application

Using the previously presented model, the software solution is developed for risk and safety analysis. The procedure of risk and safety analysis can be performed through several phases.

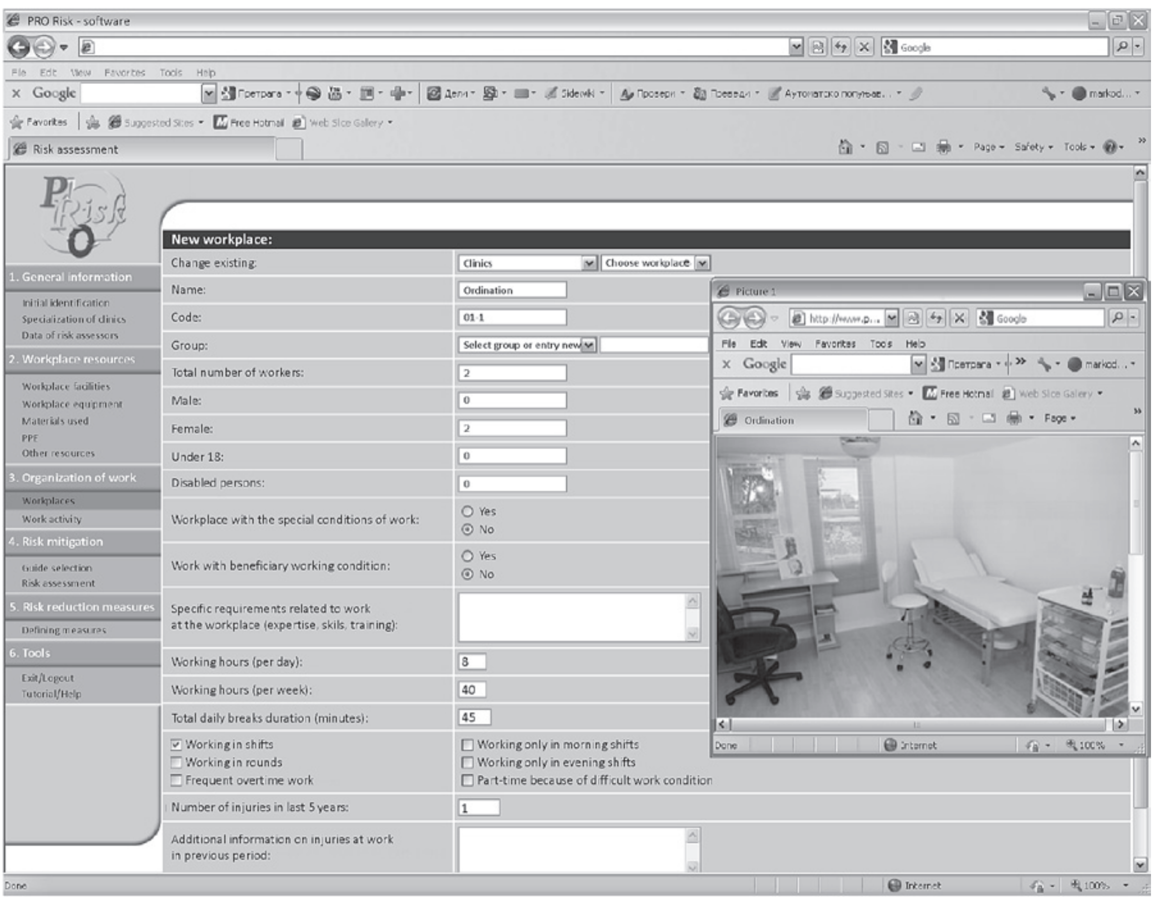

Figure 3. Input parameters for defining workplaces and identifying hazards.

The first phase in the procedure of risk assessment with this software is the preparation of documentation and information for the risk evaluation and initialization of the developed databases. This phase covers defining a set of entities that have vital importance for risk assessment (workplaces, equipment, etc.). Within this step, a number of items of information should be set on information on institution safety and regulations in the whole system (organization of the working process, duration of work, systematization of workplaces, activities, etc.).

The next phase covers identifying of hazards for specific workplaces. By using the developed wizard system and the initial base of potential risks users, we set a list of hazards. Each detected hazard is evaluated and ranked with the described fuzzy model. This approach ensures optimal diversification and ranking of the hazards by using the calculated representative scalar. Figure 3 represents identification of hazards for one workplace in a healthcare institution. Actual values of hazards are used in the previous example of the fuzzy model.

The next phase represents evaluating risks. Risk at the workplace is evaluated on the following scale: *negligible risk* (no corrective actions are recommended) in green; *small risk* (monitoring risk status) in light green; *moderate risk* (there is risk, corrective actions are needed) in yellow; *high risk* (there is risk, corrective actions are mandatory, immediately) in orange and *unacceptable risk* (working at this level of risk is unacceptable) in red.

The final phase consists in defining corrective actions to reduce the calculated risk level. In this phase, users can select a corrective action from a predefined list of corrective actions or define corrective actions on their own. Users can comment or add multimedia files attached to each risk, and use this in developing their report. The function for developing a document on performed risk evaluation at workplaces is a very important part of this software.

This system is very flexible and users can customize it according to their needs and the real situation. Users can develop existing templates and wizards as well as the knowledge base according to their needs. Additionally, modeling all uncertainties is based on the fuzzy set theory and the developed model evaluates and ranks hazards with the exact method, making it possible for expert knowledge to be expressed in a linguistic form and transformed to an exact set of value.

5. ILLUSTRATIVE EXAMPLE

The procedure is illustrated with an example of determining the degree of belief that one or more identified hazards cause accidents or occupational injuries in a clinic in Kragujevac, Serbia. Values of input data (Table 1) are based on evidence data and judgments of the risk management team (general practitioners, mechanical engineers, electrical engineers and protection engineers at work) of this clinic. Data used for developing and testing the model are collected from clinics in central Serbia, a region with a population of 2.5 million. One hundred and twenty-eight medical experts were involved in this study.

TABLE 1. Values of Identified Hazards and the Estimation of Their Severity

Hazard	Value	Relative Importance
h = 1	0.94	*moderate*
h = 2	0.01	*very high*
h = 3	85	*high*
h = 4	0.12	*very low*
h = 5	0.005	*very low*
h = 6	320	*high*
h = 7	0.15	*moderate*
h = 8	0.4	*low*
h = 9	27	*high*
h = 10	*high*	*high*
h = 11	*medium*	*moderate*
h = 12	*medium*	*high*
h = 13	*medium*	*moderate*
h = 14	*medium*	*moderate*
h = 15	*low*	*low*
h = 16	*high*	*high*
h = 17	*high*	*very high*
h = 18	*high*	*very high*
h = 19	*medium*	*moderate*
h = 20	*medium*	*moderate*
h = 21	*high*	*very high*
h = 22	*high*	*very high*

The procedure in steps 1–3 (see section 3.5.) provides values for normalized crisp hazards as well as normalized values of uncertain hazards and their representative scalar (Table 2). Normalized values of crisp hazards h = 1 to h = 9 have normalized values 0.94, 0.00005, 1, 0.024, 0.0435, 0.16, 0.0375, 0.08 and 0.6, respectively.

TABLE 2. Normalized Values of Uncertain Hazards and Their Representative Scalar

Hazard	Normalized Values of Uncertain Hazards	Representative Scalar of Normalized Values of Uncertain Hazards
h = 10	(0.2, 1, 1.25)	1
h = 11	(0.2, 0.6, 1.25)	0.6
h = 12	(0.2, 0.6, 1.25)	0.6
h = 13	(0.2, 0.6, 1.25)	0.6
h = 14	(0.2, 0.6, 1.25)	0.6
h = 15	(0.2, 0.2, 1.25)	0.2
h = 16	(0.2, 1, 1.25)	1
h = 17	(0.2, 1, 1.25)	1
h = 18	(0.2, 1, 1.25)	1
h = 19	(0.2, 0.6, 1.25)	0.6
h = 20	(0.2, 0.6, 1.25)	0.6
h = 21	(0.2, 1, 1.25)	1
h = 22	(0.2, 1, 1.25)	1

The algorithm (steps 4–5) provides a fuzzy portrait of each identified hazard and its rank (Table 3).

TABLE 3. Fuzzy Portraits and Rank of Identified Hazards

Identified Hazard	Fuzzy Portrait	Rank
h = 1	(0.94, 4.7, 8.46)	3
h = 2	(0.0002, 0.00045, 0.00045)	11
h = 3	(1, 9, 9)	1
h = 4	(0.024, 0.024, 0.144)	10
h = 5	(0.0435, 0.0435, 0.261)	9
h = 6	(0.16, 1.44, 1.44)	5
h = 7	(0.0375, 0.189, 0.337)	7
h = 8	(0.08, 0.08, 0.48)	8
h = 9	(0.6, 5.4, 5.4)	2
h = 10	(1, 9, 9)	1
h = 11	(0.6, 3, 5.4)	4
h = 12	(0.6, 3, 5.4)	4
h = 13	(0.6, 3, 5.4)	4
h = 14	(0.6, 3, 5.4)	4
h = 15	(0.2, 0.2, 1.8)	6
h = 16	(1, 9, 9)	1
h = 17	(4, 9, 9)	1
h = 18	(4, 9, 9)	1
h = 19	(0.6, 3, 5.4)	4
h = 20	(0.6, 3, 5.4)	4
h = 21	(4, 9, 9)	1
h = 22	(4, 9, 9)	1

The model makes it possible to rank identified hazards with respect to their values and importance. Thus, hazards most likely to lead to adverse events are in the first place, whereas those least likely to do so are last. Using the obtained result of ranking, the risk management team defines a plan for developing a procedure. It is clear that procedures for hazards ranked at the top will be developed first. The results show that the risk management team first develops procedures for reducing risk of undesirable consequences caused by actions of the following hazards: h = 3, h = 10, h = 16, h = 17, h = 18, h = 21, h = 22.

6. CONCLUSION

Clinics as small entities in a healthcare system are important factors in such systems in many countries. Since clinics employ a relatively small number of employees and do not possess sufficient financial resources or trained experts in OHS, it is clear that they can benefit from a method and software support that would give them some level of knowledge and service in occupational safety that large systems already have. In this paper, we presented a method for ranking potential hazards and a software solution.

The proposed fuzzy model contributes to ranking identified hazards with respect to their severity that leads to a decrease in OHS. Values of hazards can be either crisp or uncertain. It is shown that fuzzy sets are suitable for modeling uncertain input data, subjectively estimated, in the considered risk analysis problem. The developed fuzzy models are flexible: (a) they include and operate with both precisely and imprecisely specific data, (b) all changes can be easily incorporated into the model, (c) the fuzzy model can be modified for solving different but similar risk analysis problems and (d) the software solution based on the suggested method is presented. The developed fuzzy model is valuable, primarily because the rank of identified hazards is determined with an exact method. On the basis of the rank, a risk management team implements adequate preventive measures to minimize or eliminate the negative impact of identified hazards, which can cause accidents or occupational injuries.

The presented fuzzy model, which is used in developing a software application, is a valuable contribution of this paper. It is important to state that a significant advantage of this software consists in both defining hazard scalars and ranking potential hazards and risk. This software translates expert knowledge and its linguistic formulation of risk into a mathematical model. Besides, this software is flexible and open to all; end users can further develop and customize templates, wizards and the knowledge base. In addition to the part for risk assessment and corrective actions, our software has an important module for integrating occupational safety and risk management in an integrated management system; this is done by incorporating occupational safety into a quality management system. Finally, users can model risk in the form of event sequence diagrams. This software solution can be further developed with additional modules for risk modeling. It is obvious that even with its advantages, this system can not be the only option in providing occupational safety; however, it can be a very useful tool for clinics.

The benefits of the developed model and the corresponding software can be expressed thus: (a) in the matter of safety, all employees of the considered organizations and people who receive medical services in their organization are less likely to get injured due to identified hazards, so the number of undesirable outcomes is reduced, as is absenteeism; (b) in the economic sense, the developed procedure offers the possibility to significantly reduce the cost of medical treatment and the cost related to absenteeism.

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