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An Application of Fuzzy Inference System to MIMOSA

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MIMOSA is the acronym for: Methodology for the Implementation and Monitoring of Occupational SAfety, and it is a new model for evaluating performances in health and safety in workplace, through the use of check-lists and indicators. In this work a first proposal of the application of Fuzzy Logic to the Mimosa methodology is described. It is worth noting that the application of fuzzy logic set theory to the field of occupational safety is legitimate by the presence of typical uncertainty in the collection of data related to the human behavior. The aim is to obtain a quantification of a theme through the fuzzyfication of the checklists, whose scores are vague for definition, and of the indicators. One among the 27 themes of the whole methodology is selected, in order to show in a simple way how fuzzy logic can be applied and which are the results obtained. This is a preliminary approach but it shows that the method can be extended to all the themes and interesting considerations can result for the uncertainties characterizing the final result of Mimosa.

1. Introduction

MIMOSA is a semi-quantitative methodology that allows to evaluate the performance of a company concerning Health & Safety in the workplace through specific key elements and themes (Saracino et al., 2012). This kind of hybrid technique is based both on an analytical assessment and on the safety manager ability. Effectively, “safety level” can be considered as a quantity, which can be estimated and expressed by a mathematical relationship (based on a weighted sum), with the help of historical data recorded in a work site concerning safety culture (as leadership, human factor, risk analysis, maintenance, organization, training, etc.). MIMOSA methodology takes advantages of checklists and key performance indicators (KPI), which are used to calculate a number that could be representative of health and safety level of a large, medium or small enterprise. Literature shows (Marhavilas et al., 2011) that methods based only on checklists have 2 important limitations:

1. The structure of checklist analysis relies exclusively on the knowledge built into the checklist to identify potential problems.
2. Most checklists reviews produce only qualitative results.

This is the reason why MIMOSA methodology uses checklists and key performance indicators side by side. With the data collected with the aim to establish the indicators system, the analysis become more complete and the quality of the “final safety score” is improved.

1.1 MIMOSA methodology and IPESHE calculation

The methodology is structured into 6 key elements, arranged in a list that defines a hierarchy of priorities. The six elements are:

1- Leadership and coherence with targets;
2- Orientation to risk reduction and people protection, in compliance with the law;
3- Involvement, learning and development of personal education;
4- Continuous improvement and innovation;
5- Formal and general compliance;
6- Social responsibility.

Each key element is detailed in specific themes and each theme has been developed by means of two types of checklists, planning and implementation, and performance indicators have been created for each

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theme. All these elements are arranged in a tree structure, where key elements are on the top, followed by their themes and checklists and KPIs are the leaves of the tree system.

The calculation of an index, named IPESHE (Index of PErformance for Safety and HEalth), for the self-assessment aim, is possible thanks to check-list and indicators. In general a check-list collects information on compliance requirements, business risk knowledge, presence of critical points, etc., these elements have been divided considering the difference between planning and implementing questions, and positive answers to the questions of the second type (implementation) assume a higher importance in their quantification. Whereas easily measurable KPIs are referred to specific issues and allow to assess the result of what was planned and what has been actually implemented. The final score is obtained by summing the scores of each checklist and each indicator, with different weights, as shown in the following equation (1):

$$IPESHE = \left[\sum_{i=1,\dots,N_{ke}} \omega_i \sum_{j=1,\dots,N_t(i)} t_j \sum_{k=1,..,n_{kpi-ckl}(j)} p_k \, I_k\right] \quad (1)$$

where N_{ke} is the number of key elements, $N_t(i)$ is the number of themes that contribute to key element i and t_j the relative weight of the theme within the key element; $n_{kpi\text{-}ckl}(j)$ is the number of KPIs and/or checklists belonging to theme j; p_k is the weight of the KPI or of the indicator k and I_k the measured value of KPI or of the checklist ($0<I_k<1$). For more details see publication of MIMOSA (MIMOSA, 2012). As a first attempt, MIMOSA methodology considered two criteria for the calculation of IPESHE, named priority-criterion and equality-criterion respectively, representing two different ways of evaluation. In the equality-criterion all indicators and check-lists give the same contribution to IPESHE, on the other hand in the second criterion, the priority-criterion, different weights (ω_i) can be assumed for each key element, but equal weights for each theme of a key element (t_j) and also equal weights for each indicator/checklist of the theme (p_k) are considered; their importance is calculated starting from the weights fixed in Saracino et al. (2012).

1.2 General application of fuzzy logic to occupational safety

The occupational safety field can be studied with different approaches and different mathematical tools. The collected of answers to checklists is characterized by the presence of uncertainty, because judgment is a subjective parameter, so it is often difficult to answer with only two options (like yes or not). The randomness inherent in nature is the reason why an approach focused on fuzzy logic is required. Fuzzy logic allows working with imprecision and real-world vague engineering problems that would be otherwise rejected by the traditional statistical methodologies (Gentile et al., 2003). However, the quantification of valuable knowledge to estimate the uncertainties is not an easy task. The fuzzy set theory is a convenient mathematical tool that can process these linguistic terms (Beriha et al., 2012). Thus, the fuzzy approach is utilized to propose an efficient and systematic uncertainty modeling in this work. Qualitative, imprecise and uncertain information are processed through linguistic variables in fuzzy system. Linguistic variables are extensions of numerical variables in the sense that they are able to represent the condition of an attribute at a given interval by taking fuzzy sets at their values (Zadeh, 1965). Fuzzy logic technique is widely applied in the field of risk analysis, like the assessment of the accident consequences arising due to frequency of dangerous substances transport (Marseguerra et al., 2004).

2. Fuzzy evaluation model

As previously described, key elements and themes of MIMOSA methodology are quantified through 2 tools. Whereas a KPI is a ratio between two units (like the number of “performed checks” to the number of “planned checks” to respect the law), a checklist is a set of some information. We can apply the fuzzy logic theory both to assess checklists and KPIs. The idea is to blur the boundary of the sets, to give much more prominence to a personal judgment. So, for what concerns a checklist, the possible answers are not only yes or not, but there are also the options to be partially in agree or in disagree with the sentence. Thus four levels of answer have been introduced, which are going to be summed with the score of KPIs, with the adopted criteria chosen for the calculation of the final index. Also for the value of indicators, fuzzy approach is required, thus their crisp values are turned into 3 fuzzy classes of safety level. Finally the assessment of both tools will be carried out by means of the degree of membership to tree levels: low, medium or high compliance/safety. To show the result of this first application to MIMOSA methodology, a theme belonging to the second key element has been selected. The selected theme, named

“Emergencies”, is quantified through two indicators and two checklists, shown in Table 1a and 1b and in table 2a and 2b respectively, which have been developed within MIMOSA project.

Table 1a: KPI for emergency simulations

INDICATOR 1	Number of emergency simulations		
Definition of indicator	Number of realized emergency simulations divided by the total number of emergency simulation expected in the annual plan.		
Target of indicator	Practical exercise to prepare the workers to emergency conditions.		
Belonging to theme and key element	Theme: Emergencies Key element: Orientation to risk reduction and people protection in compliance with the law.		
Quantification methodology	A = total number of realized simulations B = total number of expected simulations		
Reference indicator values	Safety threshold	1	$I_{Safety} = \frac{A}{B}$
Law, rules and other references	Art. 18 and Section VI EMERGENCIES MANAGEMENT Chapter I, Legislative Decree 81/08		
Type of company	Large and medium companies		

Table 1b: KPI for implemented improvements for safety

INDICATOR 2	Number of opportunities for improvement identified and implemented		
Definition of indicator	Number of identified and implemented "opportunities for improvement" during emergency simulations divided by the total number of registered opportunities.		
Target of indicator	Systematic elimination of monitored and recorded criticalities derived from the emergency simulations.		
Belonging to theme and key element	Theme: Emergencies Key element: Orientation to risk reduction and people protection in compliance with the law.		
Quantification methodology	A = total number of implemented opportunities of improvement B = total number of recorded opportunities of improvement		
Reference indicator values	Safety threshold	0.75	$I_{Safety} = \frac{A}{B}$
Law, rules and other references	Art. 18 and Section VI EMERGENCIES MANAGEMENT Chapter I, Legislative Decree 81/08		
Type of company	Large and medium companies		

Table 2a: P-checklists (or planning-checklist)

“Planning questions”	Answers: yes, partially yes, partially not, not
1. Is the emergency plan expected?	(1, 0.75, 0.25, 0)
2. Is the emergency plan adequate on the basis of the assessment of its effectiveness?	….
	….
3. Has the frequency of emergency simulation been planned?	….
4. Have any necessary relationships with the in charge public services that are responsible for first aid, rescue, fire fighting and emergency management been foreseen?	….
5. Have the workers involved in emergencies and fire risk been appointed?	
6. Is the information to the workers about the measures and behaviors to adopt in case of emergencies expected?	
7. Is there a plan of actions and measures in case of danger to ensure that workers stop their activities?	

8. Is a report about the emergencies simulation trend expected?
9. Have the updating, the integration and the improvement of the emergency plan in the provided cases by law and in any case of structural, educational, information and training deficiencies been planned?

Table 2b: A-checklists (or acting-checklist),

"Implementation questions"	Answers: yes, partially yes, partially not, not
1. Is there the emergency plan?	(1, 0.75, 0.25, 0)
2. Has the adequacy of the emergency plan, through the assessment of its effectiveness been checked?	…. ….
3. Has the frequency of exodus test (at least once a year) been implemented?	….
4. Have the necessary relationships with the in charge public services that are responsible for first aid, rescue, fire fighting and emergency management been set up?	….
5. Has the training of the workers involved in emergencies and fire risk been activated?	
6.Has the workers information about the measures and behaviors to adopt in case of emergencies been implemented?	
7. Has the planning of actions and measures to be taken into account to ensure that workers stop their activities in case of danger been implemented?	
8. Has the report about the exodus tests trend been implemented?	
9. Has the emergency plan in the provided cases by law and in any case of structural, educational, information and training deficiencies been updated, integrated and improved?	

2.1 Fuzzification of variables

The solution of the problem through the fuzzy logic approach can be broken into the following operations (Dubois and Prade, 1980):

- Fuzzifier: the real world input to the fuzzy system is applied to fuzzifier. The fuzzifier converts precise quantity to the form of imprecise quantity like 'low', 'medium', 'high' etc. with a degree of belongingness to it.
- Knowledge base: the main part of the fuzzy system is the knowledge base in which both rule base and database are jointly referred. The database defines the membership functions of the fuzzy sets used in the fuzzy rules where as the rule base contains a number of fuzzy IF-THEN rules.
- Infercence engine: the inference system or the decision-making unit performs the inference operations on the rules. It handles the way in which the rules are combined.
- Defuzzifier: the output generated by the inference block is always fuzzy in nature. A real world system will always require the output of the fuzzy system to the crisp or in the form of real world input. The job of defuzzifier is to receive the fuzzy input and provide real world output. In operation, it works opposite to the input block.

The input parameters, in our case study, are 4 (2 values for the checklists and 2 values for the indicators) all in the range between 0 and 1. To reduce the number of fuzzy rules, which must be defined to obtain the relationship between inputs and outputs data, the values of the two checklist are summed together with different weights. Thus the 9 questions that compose each checklist are the same, but the second set of questions tests if something in the management of the emergencies has been actually done, and not if it has been only planned. Therefore the second set of questions, in the "implementation-checklist", is more important than the first one, due to its major impact on the risk reduction, on the basis of opinions by members involved in the project a weight of 0.33 has been applied to planning items (and 0.67 to implementation items). In this way the first value of the planning-checklist (that belongs to the interval 0-9) has been normalized (simply dividing by 9) and multiplied by a weight of 0.33. In the same way also the score of the "implementing-checklist" has been divided by 9 and multiplied by 0.67. In the same way the first indicator is most important than the second, hence a weight of 0.67 has been assigned to the first and

0.33 to the second, in order to respect the hierarchy of importance between them. A final value representing the two checklists and a final value for the indicators are the inputs to the FIS (Fuzzy Inference System), so they must be fuzzyfied. The output of the FIS is called “safety index”, it ranges between 0 and 1 and represents the safety level of the theme ‘emergencies’, which could be fuzzified too. The membership functions chosen for the inputs and for the outputs are triangular functions in both cases. Hence, each function is identified by a triplet (a, b, c) of t values defining the three vertex of the triangle (see panel a of Figure 1), and the function $\mu_x(t)$ represents the degree of membership of the value t to the fuzzy class x. The values chosen for the linguist variable are shown in Table 3 below:

Table 3: Input membership function

Linguistic variables for checklists or KPIs	Fuzzy vertex of MF (a, b, c)
Low compliance/safety	(0, 0, 0.25)
Medium compliance/safety	(0.25, 0.5, 0.75)
High compliance/safety	(0.5, 0.75, 1)

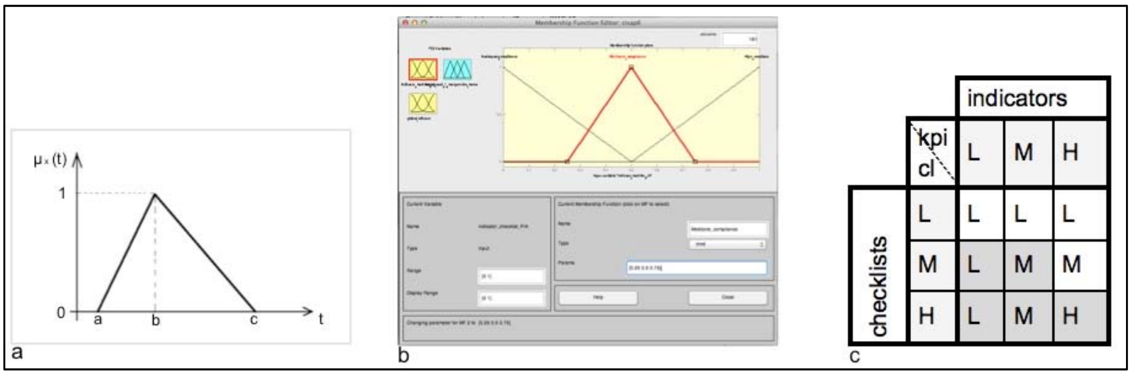

Figure 1: General application of fuzzy rules (a-generic triangular MF (membership function), b-fuzzy triangular MF for KPIs, c-fuzzy rules matrix: L=low, M=medium, H=high)

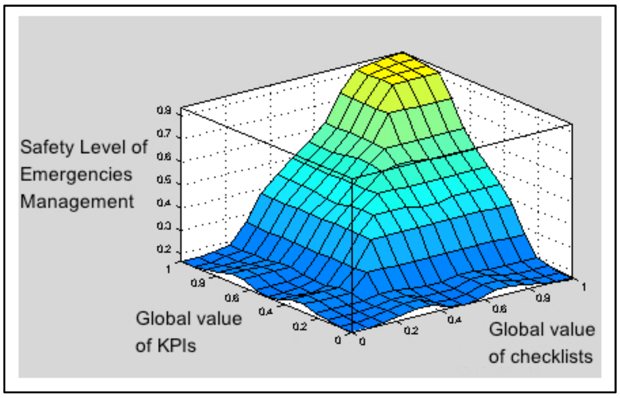

Figure 2: Fuzzy results for the Safety Level of Emergency Management.

Once that the scores of the checklists and of the indicators are obtained, each value allows to obtain a class of membership to “Compliance with law” for checklists and to “safety level” for KPIs (see panel b of figure 1), which can be entered in the rules’ matrix (see panel c of Figure 1) and give back a final safety class index (low, medium or high), which reflects the company status regarding the emergencies management. The matrix is only a manner for visualization of fuzzy rules. Fuzzy rules are of decisional type “if…then”, and they are deduced from past data and from the experience of the analyst. In this work the quantitative solution of the fuzzy system is obtained using the Matlab fuzzy toolbox. In figure 2 are shown the results, each point of the graph represents a level of safety concerning emergencies management, obtained through the application of the proposed FIS in the whole range of the global value of checklists and of the global value of KPIs.

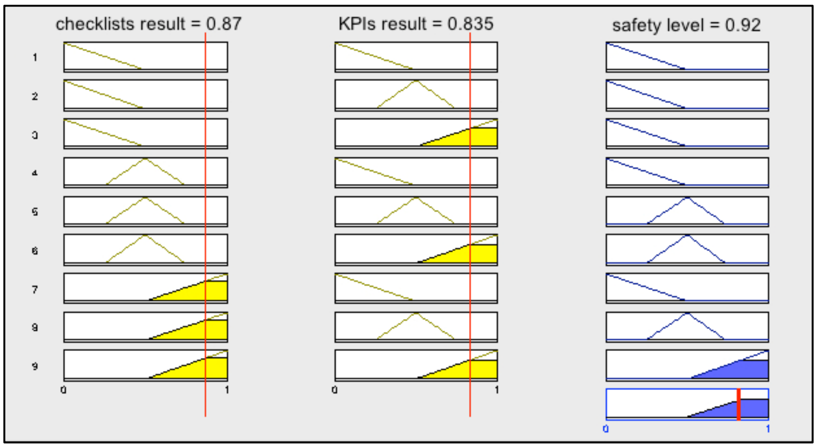

Figure 3: Results of application to an engineering faculty.

2.2 FIS application to emergency plan of an engineering faculty

A first application to an engineering faculty of the University of Bologna is briefly presented. About 10 lecture halls, some chemical laboratories and some administration offices compose the interested structure. The test was carried out through an interview to the deputy responsible for the implementation and application of the emergency plan. The responsible has filled in the two sheets of checklists and evaluated the indicators with their own quantification methodology, using the 2011-2012 data. The normalized scores obtained for the KPIs result and the checklists result (Figure 3) were then entered in MATLAB fuzzy tool. These are 0.87 for the first input variable and 0.835 for the second. With these values the software returns as an output of 'emergencies management measure' the 0.92 value, as is shown in Figure 3. This means that the 'safety level of emergencies management' belong to the class "high safety" class with a degree of membership of 0.92.

3. Conclusion

This work shows a first attempt to application of fuzzy logic to MIMOSA methodology. The future goal is to extend the fuzzy logic to whole MIMOSA system, with the aim to improve the significance of study paying more attention to the sensitivity of recorded data, which represent the personal judgment of the analyst.

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