CHEMICAL ENGINEERING TRANSACTIONS
VOL. 33, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Enrico Zio, Piero Baraldi

ISBN 978-88-95608-24-2; **ISSN** 1974-9791
DOI: 10.3303/CET1333078

A New Model for Evaluation of Safety Grade of Indicators based on a Fuzzy Logic

Marko Djapan*, Danijela Tadic, Ivan Macuzic, Branislav Jeremic, Eva Giagloglou

Faculty of Engineering, University of Kragujevac, Sestre Janjic 6, 34000 Serbia
djapan@kg.ac.rs

Further researching and development in the field of health and safety at work should be looking beyond traditional principles, on a quite new, innovative and contemporary approach. Changing the approach is natural, obvious and necessary regarding frequent technology improvement on all fields, emerging industrial facilities, big social, economical and demographic changes, as well as changes of workforce that is constantly circulating with various different education, profiles, ages and gender. The necessity of frequent monitoring of the changes in a workplace comes in the foreground in order to identify all the changes that could be the potential safety problems. Every risk assessment is specific and needs to take into account a number of indicators which affect whole assessment process. Complexity of business/production systems and changing dynamics are at much higher and greater level, therefore dictate implementation of new models. Also, limits complying with the requirements of existing risk assessment models are significantly overstrained. By using multi-criteria analysis Analytical Hierarchy Process (AHP), the decision making process could be improved through determination of indicators priority. The contributions of this paper are as follows: it proposes fuzzy safety grades of all indicators and sub-indicators, it handles uncertainty, which is performed by using fuzzy sets and the given results can be used to analyze the safety grade of each indicator and sub-indicator over time.

1. Introduction

The concept of life and therefore the concept of work are dramatically changed and are changing at much faster pace at the moment. The pace of changes is continuously growing which has direct, as well as indirect, influence on the working conditions and workplace generally (EASHW, 2002). Usually these questions are focused on the reorganization and structuring of employees, changes to employment contracts, the number of working hours during week, use of advanced technology, the necessity of developing skills and ability to cover a larger number of work activities or work from home, etc and have influence on occupational safety and health (Storrie, 2002). Regarding this fact, the risk assessment is drastically changed, too (Cacciabue, 2000). The need for new risk assessment models and models for preservation of safety and health at work is obvious and necessary. The methods, principles and ways of working as well as design and construction of modern business/production systems are significantly different than those from the previous millennium. Complexity and dynamics of business/production systems are on a much higher level. Therefore, boundaries complying requirements of existing occupational safety and health models are significantly overstrained. Leveson (2004) recognized the key elements which represent basis and necessary reasons for introduction of new models. The new models need to focus not only the technical, but the human and organizational aspects. This means, if we want to gain full understanding of safety condition in a specific situation, then it's necessary to consider all of the aspects through systemic approach (Ren et al, 2008). The major challenge is to obtain valid indicators and adequate scientific or practical coverage by set of sub-indicators (Øien et al, 2011).
Our research will be based on the triangle of indicators, human, organizational and technological that makes appearing as necessary for improving safety (Dağdeviren and Yüksel, 2008). Risk assessment is characterized by the presence of uncertainty and impreciseness, implicit in the parameters and due to subjective evaluations. In order to avoid greater subjectivity, uncertainties, vagueness and ambiguities can adequately be described by linguistic expressions called linguistic variables. According to Zadeh (1977),

Please cite this article as: Djapan M., Tadic D., Macuzic I., Jeremic B., Giagloglou E., 2013, A new model for evaluation of safety grade of indicators based on a fuzzy logic, Chemical Engineering Transactions, 33, 463-468 DOI: 10.3303/CET1333078

the words of natural language, not numbers, are allowed values of a linguistic variable. In a phase of access to treating/handling uncertainties, linguistic expressions are modelled by fuzzy sets (Pedrycz and Gomide 1998). Linguistic expressions are the best way to describe the uncertainties (Zimmermann, 2001). It should be emphasized that the fuzzy approach in treating uncertainties can be used: (a) when there are not a lot of relevant data from the evidence, (b) when uncertainty can be adequately described by linguistic expressions.

In this paper, the authors' attention focuses on the development of procedure for improvement of safety conditions. According to the safety grades, current situation can be analyzed and appropriate measurement can be implemented. Hence, each treated indicators and sub-indicators will always influence on increasing/decreasing risk. With respect to this fact, safety grade of each indicator and sub-indicator can be calculated by using the fuzzy logic approach. The paper is organized in the following way - the modelling of all uncertainties is given in Section 2; Section 3 describes the proposed fuzzy method for determining the safety grades of indicators and sub-indicators; in Section 4, an illustrative example offering real-life data used to verify the developed fuzzy model is presented; conclusions are presented in Section 5.

2. The modelling of uncertainties

In this Section, the modelling of uncertainties in indicators and sub-indicators are described by management team. The uncertainties are described by the linguistic expression modelled by fuzzy sets (Klir and Folger, 1988). The fuzzy set is represented by its membership function. Creating the membership function is a very important decision problem. It can be said that determining of the membership function can be defined as the task itself. The membership function of fuzzy sets can be obtained by using different ways (Zimmermann, 1978). In our research, the determining of the membership functions is based on subjective belief and the experiences of decision makers. However, subjectivity in determining the membership function has been considered as the weakest point in the fuzzy sets theory. Jointly used shapes of triangular and trapezoidal functions offer a good compromise between descriptive power and computational simplicificity. The fuzzy sets of higher types and levels have not as yet played a significant role in the applications of the fuzzy sets theory (Klir and Yuan, 1995). Granularity is defined as the number of fuzzy numbers assigned to the relative importance of indicators and sub-indicators. Human being can have only seven categories at the most (Lootsma, 1997). Therefore, in this paper, the authors used five linguistic expressions at the most assigned to the existing linguistic variables.

2.1 Modelling of relative importance of indicators and sub-indicators

All of the indicators and sub-indicators are not commonly of the same relative importance. Also, they can be considered as unchangeable during the considered period of time. Determining weights of the indicators and sub-indicators can be stated as a problem itself. They involve a high degree of subjective judgment and the individual preferences of decision makers. We think that the judgment of each pair of treated hazards best suits human-decision nature (analogously to the AHP method) (Saaty, 1990). The use of the discrete scale of AHP is simple and easy, but it is not sufficient to take into account the uncertainty associated with the mapping of one's number perception (Kwong and Bai, 2003). Decision makers express their judgments far better by using linguistic expressions than by representing them in the terms of precise numbers.

In this paper, the fuzzy rating of management team is described by the linguistic expressions that can be represented as a triangular fuzzy number $\tilde{W}_{ii'} = \left(x; l_{ii'}, m_{ii'}, u_{ii'}\right)$, $\tilde{W}^{i}_{jj'} = \left(x; l^{i}_{jj'}, m^{i}_{jj'}, u^{i}_{jj'}\right)$, $i = 1,...,I; j = 1,..,J_i$ with the lower and upper bounds $l_{ii'}, l^{i}_{jj'}, u_{ii'}, u^{i}_{jj'}$ and modal value $m_{ii'}, m^{i}_{jj'}$, respectively.

The value in the domain of each of these fuzzy numbers is defined by a real set of numbers that belongs to the interval [1-5]. The value 1 means that indicator i, actually sub-indicator j and indicator i', actually sub-indicator j' have the equal relative importance. The value 5 means that indicator i, actually sub-indicator j has a very strong relative importance over indicator i', actually sub-indicator j', $i = 1,..,I; j = 1,..,J_i$.

If strong relative importance of indicator $i^{'}$ over indicator i holds, then the pairwise comparison scale can be represented by the fuzzy number $\tilde{W}_{ii'} = \left(\tilde{W}_{i'i}\right)^{-1} = \left(\frac{1}{u_{ii'}}, \frac{1}{m_{ii'}}, \frac{1}{l_{i'i}}\right)$. If $i = i^{'}$, $i = 1,..,I$ then relative importance of indicator i over indicator $i^{'}$ is represented by single point 1 that is a triangular fuzzy number (1,1,1). On the exact same way, the problem of determining relative importance of sub-indicator $j^{'}$ over sub-indicator j, $j, j^{'} = 1,..,J_i$.

In our case, the five linguistic expressions are used and they are modelled by triangular fuzzy numbers given in the following way:

moderately low important-$\tilde{R}_1 = (x;1,1,2)$, *moderately important*-$\tilde{R}_2 = (x;1,2,3)$, *moderately high important*-$\tilde{R}_3 = (x;2,3,4)$, *strongly important*-$\tilde{R}_4 = (x;3,4,5)$, and *very strongly important*-$\tilde{R}_5 = (x;4,5,5)$

Weight vector of the considered indicators and sub-indicators is calculated applying the concept of extent analysis (Chang, 1996).

2.2 Modelling of safety grade

From the viewpoint of process management, the task of determining the indicator and sub-indicators weights is in order to conduct safety evaluation. In this paper, the safety grades are defined by management team. They are described by five predefined linguistic terms which are modelled by the triangular fuzzy numbers whose domains belong to the interval [0-1]. The value 0 denotes that the safety grade is very poor, means risk is the highest. The value 1 indicates a very good safety situation, which means that influence of indicators and/or sub-indicators is very low, almost negligible.

The triangular fuzzy numbers for modelling the safety grades are:

very poor (VP) - $(y;0,0.05,0.2)$, *poor (P)* - $(y;0.1,0.3,0.5)$, *medium (M)* - $(y;0.3.0.5,0.7)$, *good (G)* - $(y;0.5,0.7,0.9)$, *very good (VG)* - $(y;0.8.1,1)$

Since the overlap from one triangular fuzzy number to the other is very high, it obviously indicates that there is a lack of knowledge about the safety values or a lack of sufficient partitioning. The triangular fuzzy numbers derived for the selected linguistic terms, such as very poor, poor, medium, good and very good are based on the assumption: if the weight indicator and/or sub-indicator, $w_i, i = 1,,.,I$ and/or $w_j^i, j = 1,..,J_i$ for any process is smaller than 0.5, it is then considered that the process is located in the unsafe region. It follows that considered indicator and sub-indicator have high influence on increasing risk and vice versa.

3. The fuzzy proposed model for risk assessment of uncertainties

In a general case, the relative importance of indicators and sub-indicators existing in any processes is different. The relative importance of indicators and sub-indicators are stated by pairwise comparison matrix which elements are predefined linguistic expressions. Using the method developed in Chang (1996), the weight vector can be calculated. The elements of weight vector are crisp and belong to the interval [0-1]. The safety grades are ranked into five levels: very poor, poor, medium, good, and very good. In this case, the fuzzy IF-THEN rules must describe the influence indicators and sub-indicators on risk assessment. In general, there are a number ways for determining the IF-THEN rules, for instance: a fuzzy-based evidential reasoning approach (Liu, et al, 2004), Adaptive Network Fuzzy Interference (Mathworks, 2000), etc. In this paper, the rules are built from the management team's knowledge, experience and from data.

The most effective principle for organizing and tracking information in the business/production systems of different types, levels of organization and complexity is the introduction of a hierarchical structure. Our proposed model has the hierarchical structure, where the output of one interference system is used as an input, with other variables for each next interference step. For instance, the output of the first interference system is indicator and sub-indicators weights which are crisp. In the following interference systems based on crisp values, using fuzzy rules, the safety grade for each indicator and sub-indicator is calculated. The algorithm of the proposed fuzzy model is presented as follows.

Step 1. Set up a pairwise comparison matrix of relative importance of identified indicator and sub-indicator $\left[\tilde{w}_{i'}\right]$, $\left[\tilde{w}^{i}_{jj'}\right]$, $i, i' = 1,...,I; j = 1,..,J_i$ The weight vector of indicators is $\left[w_i\right]_{1xI}$ and the weight vector of sub-indicators is $\left[w^i_j\right]_{1xJ_i}$. They are calculated using the extent method (Chang, 1996).

Step 2. The safety grade for all indicators and sub-indicators can be defined according to the rule:

IF the weight indicator and sub-indicator, w_i, w^i_j THEN the safety grade of treated indicator and sub-indicator is described by linguistic expression where $\max_{q=1,..,Q} \mu_{\tilde{s}_q}\left(y = w_i\left(w^i_j\right)\right) = \mu_{\tilde{s}_{q^*}}$.

4. Illustrative Example

The general criteria level involved three major groups of indicators: human (i=1), technological (i=2) and organizational (i=3) indicators. Each of these three indicators needed further decomposition into specific sub-indicators. Literature provides different groups of indicators as well as different number of sub-indicators, human, technological, organizational and environmental factors (Shrivastava, 1994), human and organizational factors (Daniellou et al., 2011), organizational and management, job and individual (HSE, 1999), organizational factors (Øien, 2001), human factors (Cacciabue, 2000), human, technological and organizational factors (Berglund and Karltun, 2005), organizational, personal, environmental and job related factors (Dağdeviren and Yüksel, 2008). The list of sub-indicators depends on workplace conditions and current situation. The illustrative example offering real-life data obtained from chosen small and medium enterprise from the production sector in central region in Serbia. The sub-indicators are listed by management team (assistant of manager, production supervisor, safety manager, one employee from each production sector observed). The sub-indicators of all three indicators are represented in Table 1.

Table 1: Defined sub-indicators

Human (i=1)	Technological (i=2)	Organizational (i=3)
fatigue (w_{11})	equipment (w_{21})	work pressure (w_{31})
age (w_{12})	procedures (w_{22})	shifts (w_{32})
skills (w_{13})	design (w_{23})	tasks (w_{33})
	maintenance (w_{24})	

The pairwise matrix of relative importance of indicators have been derived by the management team judgment: $\begin{bmatrix} 1,1,1 & 1/\tilde{R}_1 & \tilde{R}_3 \\ \tilde{R}_1 & 1,1,1 & \tilde{R}_2 \\ 1/\tilde{R}_3 & 1/\tilde{R}_2 & 1,1,1 \end{bmatrix}$.

The pairwise comparison matrix of sub-indicators under indicator i=1, i=2 and i=3, respectively are given:

$$\begin{bmatrix} 1,1,1 & \tilde{R}_3 & 1/\tilde{R}_2 \\ 1/\tilde{R}_3 & 1,1,1 & \tilde{R}_4 \\ \tilde{R}_2 & 1/\tilde{R}_4 & 1,1,1 \end{bmatrix}, \begin{bmatrix} 1,1,1 & \tilde{R}_1 & \tilde{R}_3 & \tilde{R}_4 \\ 1/\tilde{R}_1 & 1,1,1 & \tilde{R}_3 & 1/\tilde{R}_5 \\ 1/\tilde{R}_3 & 1/\tilde{R}_3 & 1,1,1 & \tilde{R}_4 \\ 1/\tilde{R}_4 & \tilde{R}_5 & 1/\tilde{R}_4 & 1,1,1 \end{bmatrix} \text{ and } \begin{bmatrix} 1,1,1 & 1/\tilde{R}_5 & \tilde{R}_3 \\ \tilde{R}_5 & 1,1,1 & 1/\tilde{R}_4 \\ 1/\tilde{R}_3 & \tilde{R}_4 & 1,1,1 \end{bmatrix}$$

The vector weights of indicators is determined by extent analysis method (Chang, 1996): $\tilde{S}_1 = (0.14, 0.29, 0.57)$, $\tilde{S}_2 = (0.25, 0.49, 1.14)$ $\tilde{S}_3 = (0.13, 0.22, 0.57)$.

Using the procedure for comparing the fuzzy numbers (Dubois and Prade, 1979), it is obtained:

$$Bel\left(\tilde{S}_1 \geq \tilde{S}_2 \wedge \tilde{S}_1 \geq \tilde{S}_3\right) = 0.62,\ Bel\left(\tilde{S}_2 \geq \tilde{S}_1 \wedge \tilde{S}_2 \geq \tilde{S}_3\right) = 1,\ Bel\left(\tilde{S}_3 \geq \tilde{S}_1 \wedge \tilde{S}_3 \geq \tilde{S}_2\right) = 0.54$$

After normalization, weight vectors of identified hazards are: $W = (0.29, 0.46, 0.25)$. Values of sub-indicator weights are defined in a similar way.
Applying the IF-THEN rules (Step 2 of the proposed Algorithm), the safety grade of indicator i=2 is defined for the dividing process: μ_P=0.2, μ_M=0.8, so that, max (0.2, 0.8)=0.8. It follows that the safety grade of indicator (i=2) is medium. The values of safety grade for the rest of the indicators and sub-indicators are calculated applying the proposed algorithm and they are presented in Table 2.

Table 2: The vector weights and safety grade of indicators and sub-indicators

Indicators and sub-indicators	The weights of indicators and sub-indicators	Safety grade	Indicators and sub-indicators	The weights of indicators and sub-indicators	Safety grade
w_1	0.29	poor	w_{22}	0.2	poor
w_2	0.46	medium	w_{23}	0.23	poor
w_3	0.25	poor	w_{24}	0.23	poor
w_{11}	0.35	poor	w_{31}	0.27	poor
w_{12}	0.4	poor/medium	w_{32}	0.47	medium
w_{13}	0.24	poor	w_{33}	0.33	poor
w_{21}	0.34	poor			

According to Table 2 the safety grades of indicators and sub-indicators can be analyzed. The difference between the first and third indicator is very small. Therefore, both indicators have very high influence on increasing risk. But, for a management team and for implementing appropriate measures, it is necessary to make decision which indicator needs in order to be analyzed and improved. Firstly, from Table 2, the organizational indicator has the highest influence on increasing risk in considered enterprise. In order to improve safety condition and increase safety level at considered workplace, a management team need to implement significant improvements predominantly regarding workplace organization in the broadest sense. The improvements are reflected through properly defining type and characteristics of workplace, better job organization, resources management, communication and coordination through all levels of organization, as well as individual and group roles and responsibilities. The technological indicator has safety grade denoted as medium. This indicator has the smallest influence on risk compared to other two indicators. Thus, it isn't possible to conclude that this indicator can't have an influence on risk, because as stated earlier, every indicator smaller than 0.5 have higher influence on results. This situation is specific where one of the indicators is very near to margin value and there is a need to observe and monitor the equipment status, scheduled maintenance processes and procedures. On the exact same way, all listed sub-indicators could be analysed.

5. Conclusion

Contemporary business/production systems have high demands for flexibility, a need to deal with high degree of uncertainty, problem-solving and performing parallel activities. Development of existing and establishing new markets require necessary development of technologies and skills related to the use of the same. Therefore, it comes to significant adaptation, integration and reconfiguration of their skills, knowledge and capabilities. Because of the frequent advances in all fields of technology, new industrial plants, large-scale changes in the social, economic and demographic fields and a diverse workforce profile, age and sex, which is constantly circulating, changing approaches of risk assessment implementation compared to the traditional approach is natural and necessary.
A new approach and a new model helps to identify areas critical for the safety and health area in order to prevent unplanned events and accidents, and to improve the understanding of the possible causes of accidents and their relative significance in the context of risk, in the terms of achieving zero accident goal. It is necessary to identify type of possible organizational, technological and human errors firstly, and then to specify sub-indicators for current situation and condition. Successful implementation and further understanding of safety in the complex business/production systems is conditioned by the introduction of all three components. Often, one of the components is omitted or interlaced depending on how the system is observed. The contributions of this paper are as follows: (1) it proposes fuzzy safety grades of all indicators and sub-indicators, (2) it handles uncertainty, which is performed by using fuzzy sets and (3) the given results can be used to analyze the safety of each indicator and sub-indicator over time and, based on results of safety grade, quickly take appropriate measures which enhance indicators and reduce the negative influence on the occupational safety and health. Another trend in the safety research community

is striving to proactive approaches, i.e., that the indicators should be able to provide signals before the event, which would be the future part of research.

References

Berglund M., Karltun J., 2005, Human, technological and organizational aspects influencing the production scheduling process, 18th International Conference on Production Research, Salerno, Italy, <www.hops-research.org> (accessed: 14.12.2012)

Cacciabue P.C., 2000, Human factors impact on risk analysis of complex systems, Journal of Hazardous Materials, 71, 101–116.

Chang D.Y., 1996, Applications of the extent analysis method on fuzzy AHP, European Journal of Operational Research, 95, 649-655.

Dağdeviren M., Yüksel I., 2008, Developing a fuzzy analytic hierarchy process (AHP) model for behavior-based safety management, Information Sciences, 178, 1717–1733.

Daniellou F., Simard M. and Boissières I., 2011, Human and organizational factors of safety: a state of the art. Number 2011-01 of the Cahiers de la Sécurité Industrielle, Foundation for an Industrial Safety Culture, Toulouse, France <www.foncsi.org/en/cahiers> (accessed: 20.12.2012).

Dubois D., Prade H., 1979, Decision-making under Fuzziness. In: Gupta M.M., Ragade R.K., Yager R.R. (eds). Advances in Fuzzy Set Theory and Applications, Amsterdam, the Nederlands, 279-302.

EASHW (European Agency for Safety and Health at Work), 2002. Research on changing world of work, <www.osha.europa.eu> accessed: 20.12.2012.

HSE (Health and Safety Executive), 1999, Reducing error and influencing behaviour, <www.hseni.gov.uk> (accessed: 20.12.2012).

Klir G., Yuan B., 1995, Fuzzy sets and fuzzy logic, theory and applications, Prentice Hall. New Jersey,USA

Klir G.J., Folger T., 1988, Fuzzy Sets, Uncertainty, and Information, Prentice Hall, Upper Saddle River, New Jersey, USA.

Kwong C.K., Bai H., 2003, Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach, IIE Transactions, 35, 619-625.

Leveson N., 2004, A new accident model for engineering safer systems, Safety Science, 42, pp. 237–270.

Liu J. Yang J.B., Wang J., Sii H.S., Wang Y.M., 2004, Fuzzy rule-based evidential reasoning approach for safety analysis, Int. Journal of General Systems, 33, 183-204.

Lootsma F.A., 1997, Fuzzy Logic for Planning and Decision making, Kluwer Academic, Boston, USA.

Mathworks, 2000, Fuzzy Logic Toolbox, User Manual, <www.mathworks.com> accessed: 20.12.2012.

Øien K., 2001, A framework for the establishment of organizational risk indicators, Reliability Engineering and System Safety, 74, 147-167.

Øien K., Utne I.B., Tinmannsvik R.K., Massaiu S., 2011b, Building Safety indicators: Part 2 – Application, practices and results, Safety Science, 49, 162–171.

Pedrycz W., Gomide F., 1988, An introduction to fuzzy sets, Analysis and Design, MIT-Press: Cambridge Massachusetts, USA.

Ren J., Jenkinson I., Wang J., Xu D.L., Yang J.B., 2008, A methodology to model causal relationships on offshore safety assessment focusing on human and organizational factors, Journal of Safety Research, 39, 87–100.

Saaty T.L., 1990, How to make a decision: The Analytic Hierarchy Process, European Journal of Operational Research, 48, 9-26.

Shrivastava P., 1994, Technological and Organizational Roots of Industrial Crises: Lessons from Exxon Valdez and Bhopal, Technological Forecasting and Social Change, 45, 237-253.

Storrie D., 2002, Temporary agency work in the European Union. European Foundation for the Improvement of Living and Working Conditions, Dublin, <www.eurofound.europa.eu> (accessed: 17.12.2012).

Zadeh L.A., 1977, The Concept of a Linguistic Variable and its Application to Approximate reasoning, Information Scinence, 8, 199-249.

Zimmermann H.J., 1978, Results of empirical studies in fuzzy set theory. In: Klir G.J. (ed). Applied General Systems Research, Plenum Publishing Corporation, 303-311.

Zimmermann H.J., 2001, Fuzzy set Theory and its applications, Kluwer Nijhoff Publising, Boston, USA.