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Fuzzy Risk Assessment and Management in Process Industries-Case Study: Gas Pipelines

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Abstract

Risk assessment is the heart of ISO and OHSAS auditions and also is vital demand for any industry to characterize hazards and their risks for personnel, environment and loss of money. Traditionally, Risk matrix was a very useful tool to estimate the risk of process or equipment or acts that helps decision-making processes. Establishment and development of soft set theory and its applications are used in recent years and are extended in combined forecasting, decision-making, information science and so on. Fuzzy modeling is one of the most powerful tools to estimate relation between input-output of nonlinear systems. In this method, fuzzy numbers are referred to variables that express uncertainties. A fuzzy number expresses relation between an imprecise or uncertain number, X and a membership function, ì that is between (0,1). In other words, the fuzzy logic tool provides a technique to deal with imprecision and information, the fuzzy theory provides a mechanism for representing linguistic constructs such as “many”, “low”, “medium”, “few”, etc. In the new view of analysts and decision makers, risk analysis is being done with great uncertainties because risk assessment requires detail information about damage frequency rate of particular processes and equipment components. This data usually are imprecise and uncertain. One of the advantages of fuzzy logic in the field of risk assessment is dealing with these problems.

Keywords: Fuzzy Logic, Risk Assessment, Uncertainties

1. Introduction

Currently, the importance of hazard perception is increasingly considered as a part of risk assessment and with the various models in the workplaces or society. Along with emerging of technologies, the related safety issues are developing. In recent years, recognizing the importance of behavioral and cultural aspects of the organization's safety management and HSE are increased widely, because researches on major accidents indicate that in spite of all engineering factors and extreme conservations, there is a potential for accidents to occur in a form of defect behavioral culture. Hence for planning and implementation of safety plans, it is required to consider various factors, otherwise it could result in resources be wasted, lower efficiency and motivation of personnel [1].

In addition, researchers have recently concluded that the industry systems are of social, organizational and environmental components in addition to technical and technological elements and all of them should be integrally considered in modelling of events [2]. Process and chemical industries that use and store huge volume of chemicals are exposed any type of risks ranged from process hazards to intentional accidents and sabotages, so the potential hazards and their consequences should be identified and analyzed in an analysis process of risk assessments[3] . Hazardous product transmission such as gas through pipelines are categorized as such industries, they have high risks and may impose severe damages which are occurring after hazard elements' releasing. The damages, human casualties, economic and environmental adverse effects introduced by accidents such as oil leakage of British multinational oil and gas company in Gulf of Mexico indicate importance of increasingly importance of more efficient and effective systems to identify the hazards[4].

Due to the importance and the necessity to increase the efficiency of the gas transmission industry, it is vital to obtain better and more accurate results than the results of traditional Kent Muhlbauer method. Thus to overcome the ambiguity of Kent Muhlbauer method, fuzzy logic is applied in this method and the more accurate results are obtained. This process caused better and more accurate results. In this paper, fuzzification process is performed using Fuzzy Inference System toolbox in MATLAB software which is the most well-known and the best software in solving mathematical problems. In this model, FIS toolbox and expert opinions are used to fuzzify the indexes of Kent Muhlbauer method.

2. Risk assessment methods

Currently, more than 90 applied methodology of risk assessment has been developed. These techniques are classified in three general categories including quantitative, qualitative and semi quantitative. Some of the methods that are used in the pipeline risk assessments are listed in the following and some of them are described:

1- What-If analysis
2- HAZOP
3- Failure Mode and Effects Analysis (FMEA)
4- Fault Tree Analysis (FTA)
5- Event Tree Analysis (ETA)
6- Risk-Consequence Analysis (RCA)

General information of the methods are available in the references number[5-8] for researchers so they are not explained anymore but for pipeline risk assessment, Kent Muhlbauer method is applied in most of cases. The method is the most important and well known method for risk assessment of pipelines.

3. Traditional Kent Muhlbauer method

Indexing model of Kent Muhlbauer is used in the process of risk assessment. In this method two stages is considered, first, risk estimation including identification, analysis and risk prioritization and second, risk control including planning and risk management, planning of risk monitoring and corrective measures. Kent Muhlbauer indexing is a systematic method and assist to extract the 6 main indexes through data gathering from documents, operator interviews and field observations. The 6 main indexes are as follow:

1- Third party damage index
2- Corrosion index
3- Design index
4- Incorrect operation index
5- Dispersion factor
6- Product hazard

To compute the relative risk scores after extraction of these indexes, sum of the four indexes is divided into impact factor of leakage that is sum of the dispersion factor and Product hazard and indicate acute and chronic consequences resulting from risk of product releasing from pipeline. It is noticeable that in this paper we applied localized model used in 4th district of Iranian gas transfer operations. This model is simplified and two parameters including leak volume and receptors are not considered. The schematic overview of the model is presented in Fig. 1.

This method is a subjective scoring technique for each section, it means that all of the elements and parameters are scored relatively and then final scores are obtained from combining them. The strength of this method is its intuitive nature and in the other words, intellect and judgment are of the most importance in the method. The concept and presentation of the technique for a certain example, damages resulting from third party, is presented in Fig. 2. This diagram indicates occurring an event as an input of the system and probability of consequent events, antagonistic effects, their role in reducing the consequences and finally possible consequences. This simple diagram indicates how extreme events and incidents may be originated from an event apparently inconsiderable, especially when the probabilities are taken into account.

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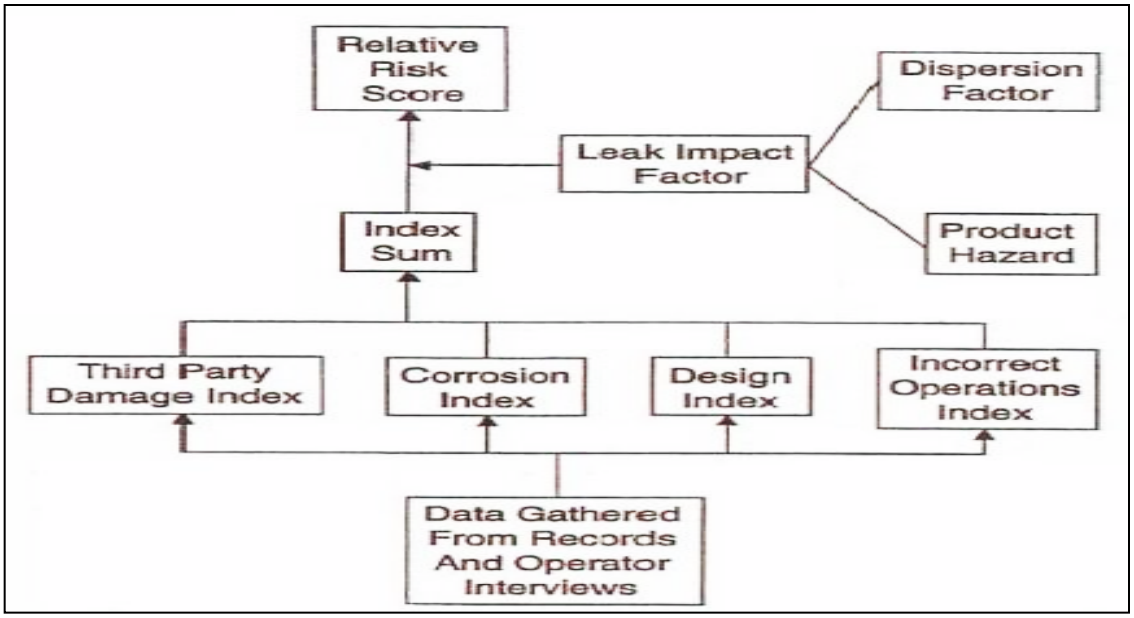

Figure 1. Schematic overview of Kent Muhlbauer method.

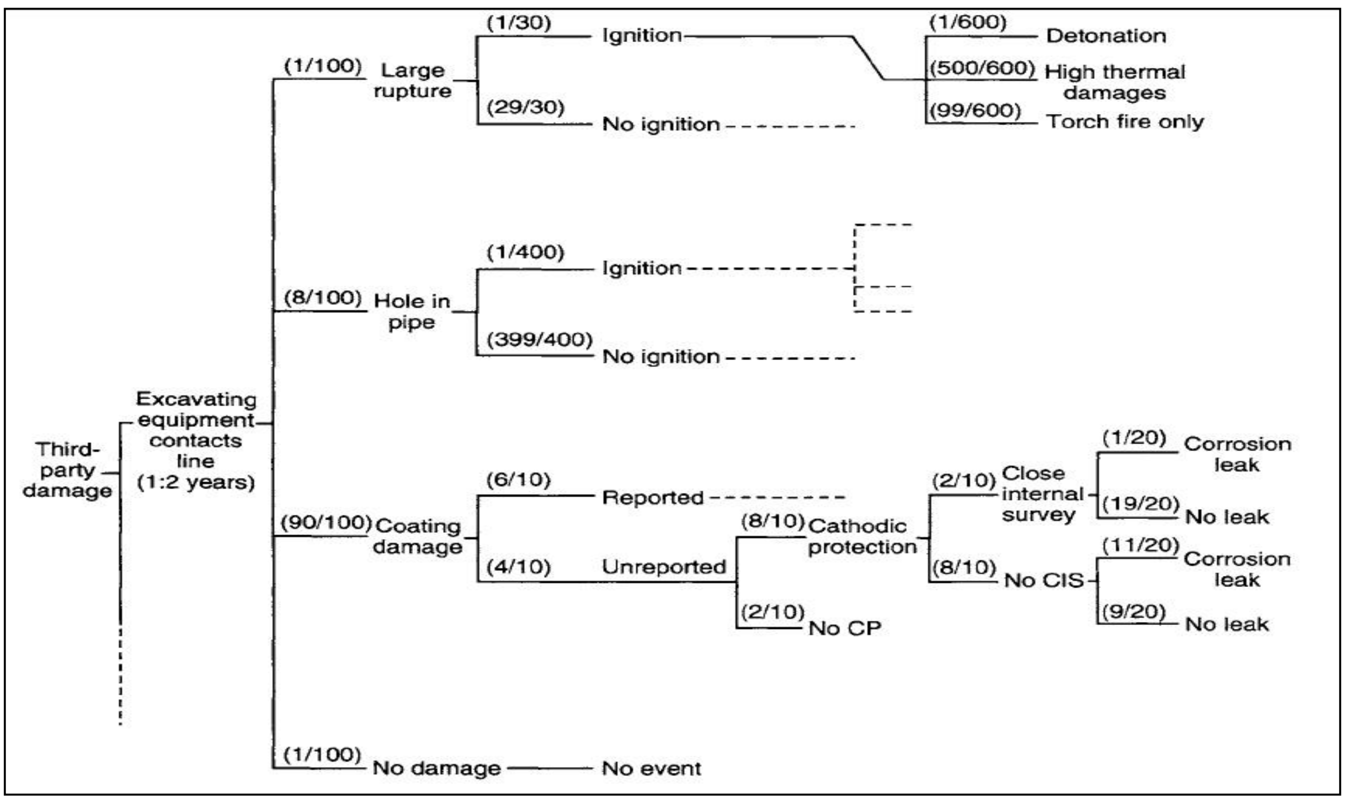

Figure 2. Schematic overview of indexing technique for a certain index, Third party index[9].

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4. Fuzzy logic

Evaluators encounter insufficient or uncertain data in problems of real world, so the ambiguity and uncertainty are inherent in the engineering issues. Fuzzy logic introduced by Lotfi A. Zadeh is the solution for these problems[10]. Linguistic Terms are applied to develop a deductive structure for modeling complicated problems. A base model of fuzzy logic is comprised of 4 main elements as follow:

1- Fuzzification
2- Knowledge Base
3- Fuzzy Inference System(FIS)
4- Defuzzification

These elements schematically are presented in Fig.3.

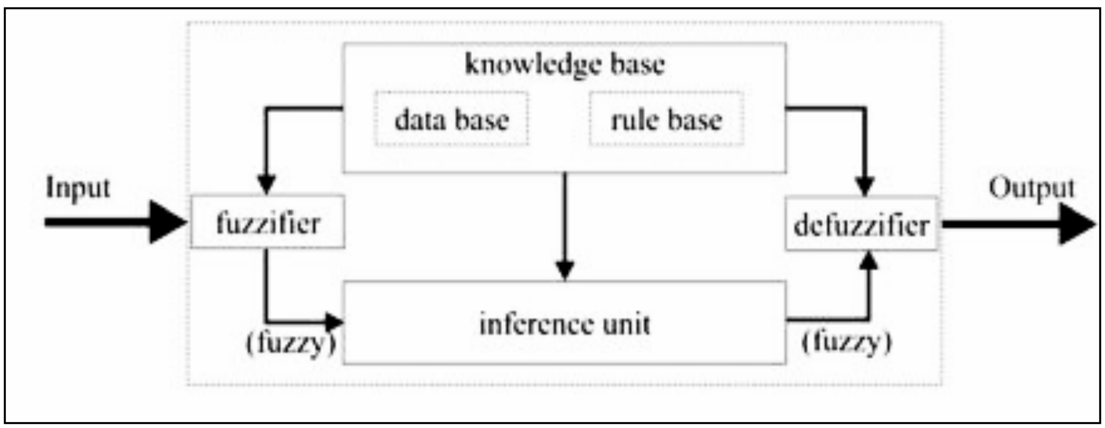

Figure 3. Overview of a Fuzzy Inference System

Contrary to traditional method, assigning numbers to indexes is not only limited to integers even it is possible to assign the real numbers($x \in R$) ,the superior of this method compared to the traditional method for determining the indexes is the assignment of real numbers and not merely dealing with integers.

This advantage can reduce the uncertainty of common risk assessment methods and it is possible to rank indexes which can improve the process of decision making because it allow decision makers to control the risk based on the necessity[6].

The first stage to construct a fuzzy system is to reach a set of "If-Then" fuzzy rules from expert knowledge or related science. The next stage include combining the rules in a unit system. The various fuzzy systems apply different principles and methods to combine the rules. 3 types of fuzzy systems are mainly used in engineering science including:

1- pure fuzzy system
2- Takagi and Sugeno's fuzzy system
3- fuzzy logic systems with fuzzifier and defuzzifier

The general structure of a pure fuzzy system is shown in Figure 4.

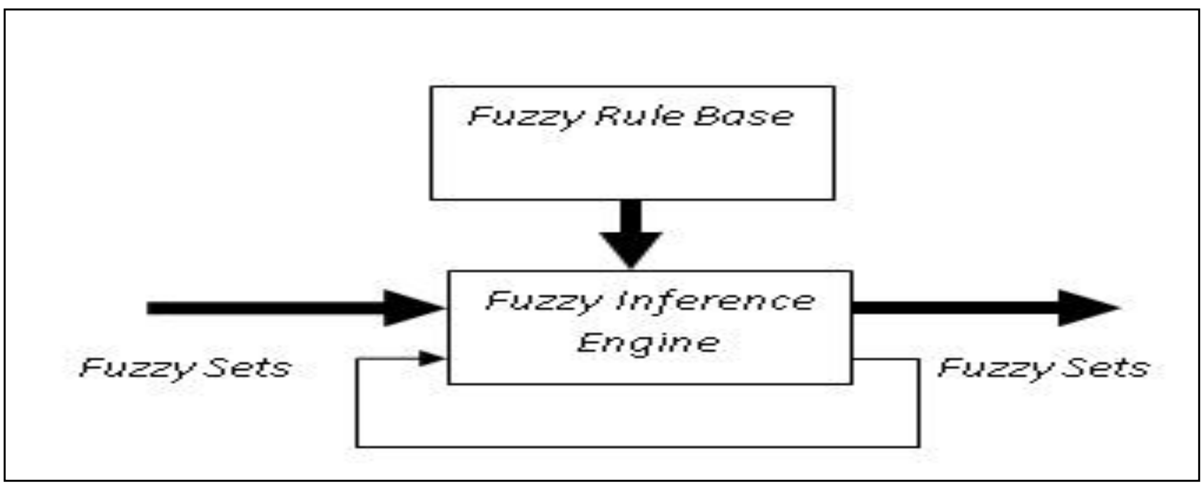

Figure 4. The general structure of a pure fuzzy system

Fuzzy rule bases indicate a rule set of If-Then. The fuzzy inference engine combines these rules to mapping from fuzzy sets in the input, into the fuzzy sets in the output based on fuzzy logic principles. The main problem of the pure fuzzy systems is that their inputs and outputs are fuzzy sets (universe of discourse), while the inputs and outputs are real valued variables in engineering systems. To solve this problem, Takagi, Sugeno and Kang introduced another fuzzy system that their

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input and output are real valued variables. This system converts "Then" fuzzy rules into a simple mathematical formulation using a descriptor with linguistic terms. This converting simplify the fuzzy rule combination. In fact, the fuzzy system is weighted average from "Then" rules. The general structure of the fuzzy system is shown in Fig. 5.

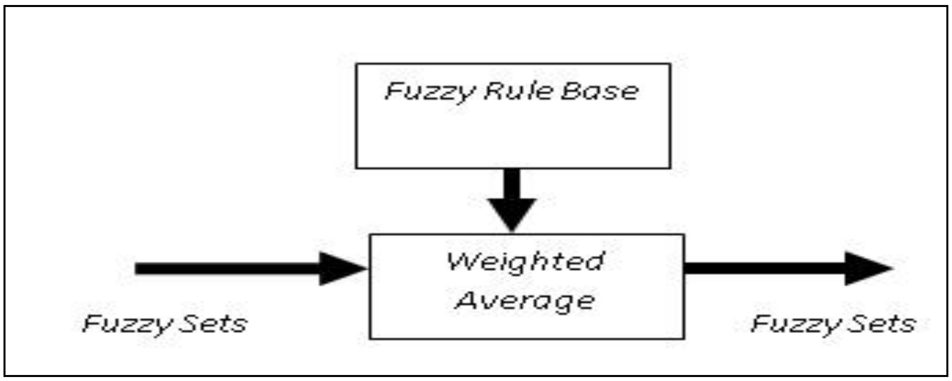

Figure 5. The general structure of Takagi, Sugeno and Kang's fuzzy system

The main problems of this fuzzy system are as follows:

1- Then fuzzy rule is a mathematical formulation and so it does not provide a framework to indicate expert opinion and human knowledge
2- This system is not of the fuzzy systems' flexibility and has a limitations to apply various fuzzy logic principles.

To solve this problems, the third fuzzy system as fuzzy logic systems with fuzzifier and defuzzifier are used. To apply the pure fuzzy logic system in engineering systems a fuzzifier is added to the input, to convert real-valued variables into fuzzy sets, and a defuzzifier to the output of the pure fuzzy logic system, to convert fuzzy sets into real-valued variables. The results and main structure of fuzzy systems with fuzzifier and defuzzifier is shown in Fig. 6.

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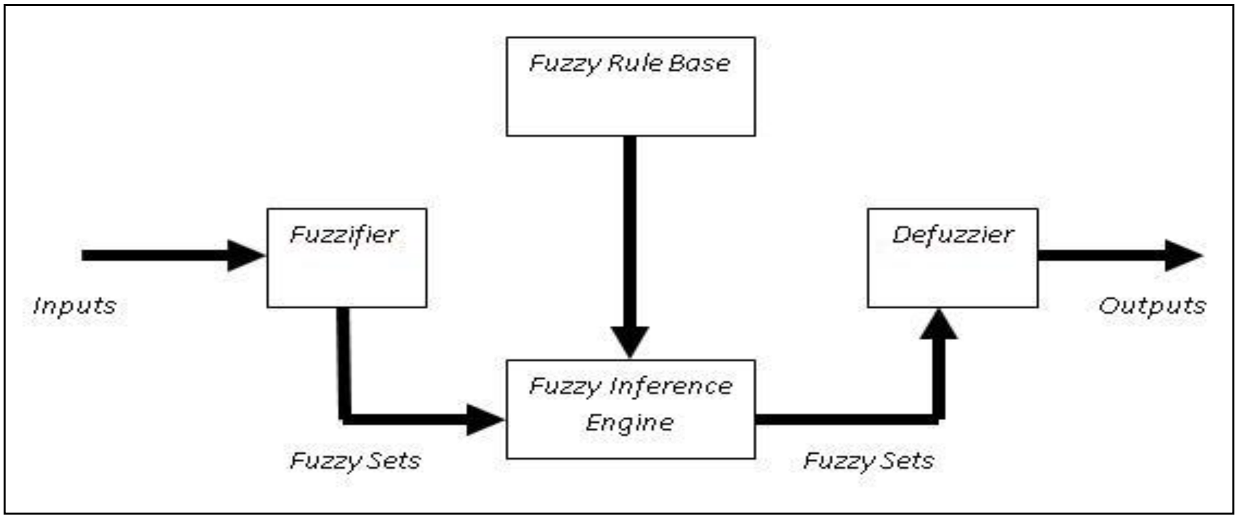

Figure 6. General structure of fuzzy systems with fuzzifier and defuzzifier

Applying this system eliminates the deficiencies of pure and Takagi's fuzzy system. Fuzzy systems with fuzzifier and defuzzifier is used in this paper. In general, it can be said that on the one hand fuzzy systems are mapping in the form of some inputs and one output from one vector with real value to one scalar with real value (mapping of some outputs may be obtained with combining some mapping of one output), and the precise mathematical formulation of the mapping is obtainable, on the other hand, fuzzy systems are based on knowledge in form of "If-Then" rules.

5. Fuzzy model of risk assessment

Due to the importance and the necessity to enhance the efficiency of the gas transmission industry, it is essential to obtain better and more accurate results than the results of traditional Kent Muhlbauer method. Hence to overcome ambiguity of Kent Muhlbauer method, fuzzy logic is used and consequently the more accurate results are obtained. This process cause to reach better and more accurate results. In this paper, fuzzification process is performed using Fuzzy Inference System toolbox in MATLAB software which is the most well-known and the best software in solving mathematical problems. In this model, FIS toolbox and expert opinions

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are used to fuzzify the indexes of Kent Muhlbauer method. Fuzzy risk assessment include three phases including:

1- Assessment
2- Indexing
3- Risk analysis

Assessment and indexing are based on fuzzy logic to eliminate ambiguity in modelling process. The schematic overview of this method is presented in Fig. 7.

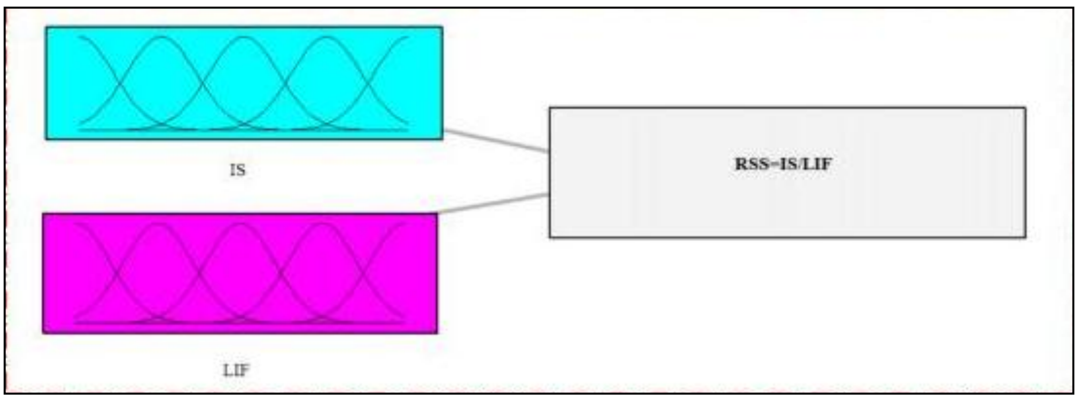

Figure 7. the basic model of pipeline risk assessment

In the first phase, the probability of main failures is considered. The failures are as a result of following:

1- Damage resulting from third party
2- Corrosion
3- Design
4- Improper operation

The potential of special failure mechanism is examined and computed in this phase, while it is completely different from failure probability [9]. The index of a failure mechanism is computed and two parameters are considered in the indexing phase.

1- Dispersion factor
2- Product hazard

In this phase, similar to the previous phase, indexes are obtained by applying the model made in MATLAB from the potential of consequences' failure of the pipeline. In the last phase, the final risk scores are computed which the appropriate strategies can be based on them. The results of these phase could be considered as input for risk management process. There is two stage in this phase, sum of the indexes obtained in phase 1 are combined with the consequences of leakage obtained from phase 2 to compute an index for every part of pipeline.

To construct a fuzzy member function, Gaussian membership functions were used because they are more natural and closer to the reality whilst the function is not zero at any part and it is always soft[12].

Gaussian membership are defined based on 2 parameters.

$$Gaussion(x\,; c, \sigma) = e^{-\frac{1}{2}\left(\frac{x-c}{\sigma}\right)^{2}}$$

Where c is central value of membership function and σ is width of the membership function.

In this paper, the situation of first parameter is precisely define so that every membership function have 50% overlapped with others. This type of definition cause reducing risk resulting from a hole in dominant of inputs [13].

An example of designing a fuzzy system is shown in Fig 8 and designing total indexes are presented in the figure.

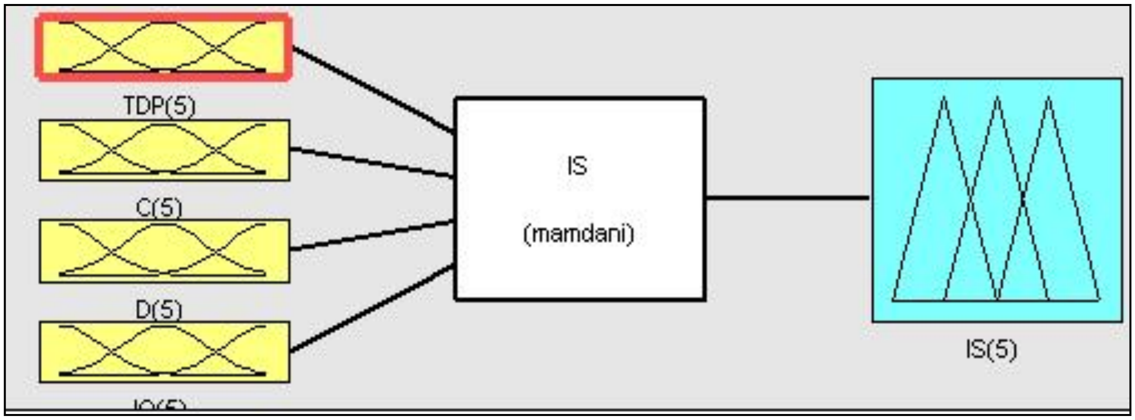

Figure 8. An example of simulation process in MATLAB

Next phase is constructing the If-Then rules that equal to 220 made in MATLAB. The rules indicate the fuzzy relations between the input and output variables and are based on expert opinions. Set of the rules for index of hazards are presented in fig. 9.

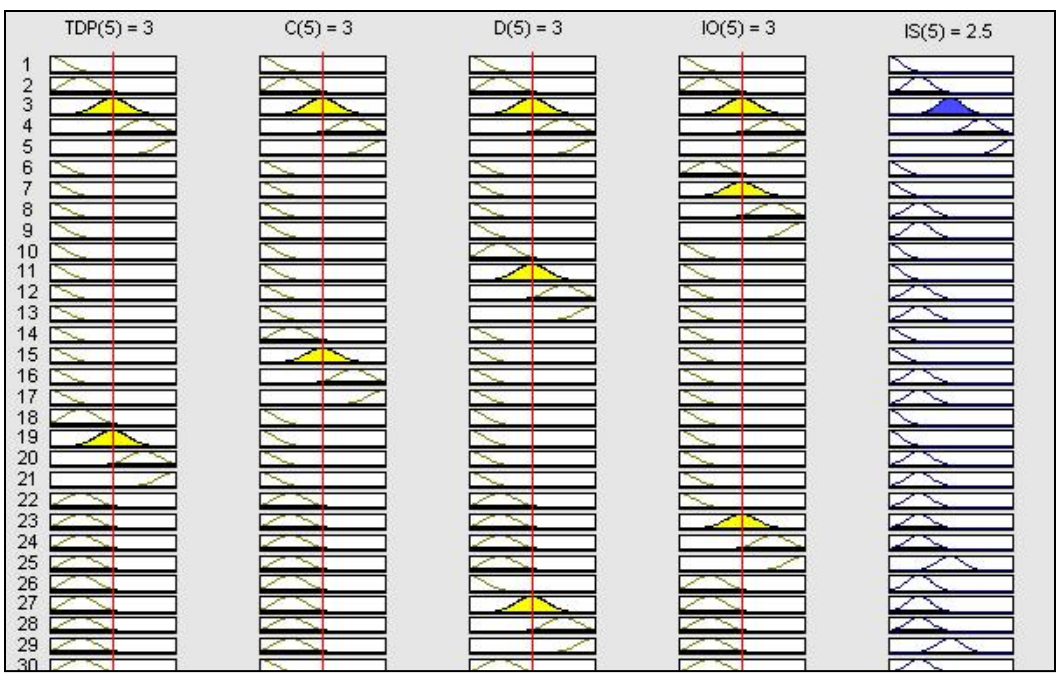

Figure 9. Set of the rules constructed with fuzzy logic

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In this definition and considering the available data, it is possible to plot the parameters in three-dimensional surface by MATLAB's fuzzifier, for example, relation between sum index based on parameter C and D is represented in Fig. 9. Similarly, it is possible to plot each parameter in three-dimensional surface. After making the primary structure of model, the rules are developed based on expert opinions. In the final part of the phase, center of area is applied for defuzzification to obtain crisp values.

6. Results

Based on obtained data and applying them in fuzzification process, a table is provided to compare the results of risk assessment using traditional Kent Muhlbauer method with fuzzy Kent Muhlbauer method. It is worth mentioning that numbers of table 1 are taken in certain scale.

Table 1. Results of traditional Kent Muhlbauer method and fuzzy Kent Muhlbauer method for comparing

section	Traditional RRS						Fuzzy model					
	IS	Rank	LIF	Rank	RRS	Rank	IS	Rank	LIF	Rank	RRS	Rank
1	297	2	10.5	3	28.3	2	285.4	2	9.95	1	28.7	6
2	304	4	9.31	2	32.7	5	294.9	5	11.27	3	26.2	4
3	297	2	10.5	3	28.3	2	287.3	3	11.55	4	24.9	3
4	304	4	10.5	3	28.9	4	294.45	4	12.81	5	23	2
5	310	6	14	6	22.1	1	299.3	6	13.72	6	21.8	1
6	293	1	7	1	41.1	6	283.3	1	10.57	2	26.8	5

Conclusion

According to the results of Fuzzy Inference System toolbox in MATLAB software, it could be concluded that fuzzy Kent Muhlbauer method may provide the better solution to eliminate the uncertainty of risk assessments, because it allows to experts and assessors to assign real values to each index, but in traditional Kent

Muhlbauer method assessors are forced to assign default values of Kent Muhlbauer system to each index. And therefore useful numbers for ranking is formed to categorized and ranked type, that enables decision-makers to adapt necessary decides simply.

For ranking in fuzzy systems, assessor is forced to use all of available data and consider even negligible components and numbers to obtain precise number for each parameter, but in traditional method, there is not any interval and assessor or safety expert are forced to guess and extract one scale, number, from some scales, numbers, determined in traditional Kent Muhlbauer method so it may cause uncertainty that could be eliminated by using fuzzy logic.

7. Acknowledgments

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