A Fuzzy Model for Assessing Impacts of Natural Gas Pipeline Systems on Environment

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***Abstract*— Notwithstanding that the transport of natural gas by pipeline system represents the safest way for the on land gas transfer, the failure in pipelines can happen and thus cause massive human, ecological, material, and social damages. Being long linear systems, sometimes comprising thousands of kilometers of pipes, various factors can inflict damages in pipelines. Identification of these factors and reliable risk assessment are among the key elements for preventing the damages. Accordingly, integration of highly developed information and communications technology systems represents a necessary paradigm for the successful planning, monitoring, and controlling of this infrastructure system. The main goal of this paper is to propose a model based on type-2 fuzzy sets to assess the impacts of these systems on the environment using modern technologies: Geographic Information System (GIS) and Information Building Modeling (BIM). In this way, the proposed model enables more adequate risk assessment because of the capacity of interval type-2 fuzzy sets to convey higher degrees of uncertainty along with fuzzy inference system potentiality to incorporate expert judgments, experience, and engineering knowledge thus providing more accurate and robust results. On the other hand, application of BIM and GIS technology can enable optimal planning, installation, monitoring, and maintenance of the natural gas pipeline systems together with the identification of various types of factors that cause their damages. Also, these advanced technologies allow complex analysis and 3D visualization of the impacts of a large number of different factors and parameters for all the pipeline life cycle phases. Guidelines for the future development of this model are also given.**

***Index Terms*—Natural gas pipeline system (GPLS), Geographic Information System (GIS), Building Information Modeling (BIM), Environmental impact, Risk assessment, Type-2 Fuzzy sets**

I. Introduction

An adequate risk assessment and a proper management of the natural gas pipeline system (GPLS) are the key elements to prevent their failure. However, there is still a lack of consensus among academic researchers on how to model and assess the risk associated with transportation of hazardous substances [1]. The GPLS are usually installed underground for greater security but still many factors can cause deterioration and induce damages. Among the most important are corrosion, interference from the third party, material defects, malfunction and natural hazard [1], [2].

The risk assessment of gas pipeline systems is a complex problem because it is associated with a large number of uncertain factors that are mutually dependent and changeable in time. Nevertheless, as stated in [3] many companies are still applying deterministic techniques to provide safe operation of the pipeline facilities, without employing risk assessment approaches which take into consideration the uncertainties and multiple dimensions that the impacts of accidents can have [4].

In particular, the assessment of soil and groundwater risk, which may be subjected to a significant damage in cases of accidental spillage of chemicals has not been adequately addressed [5]. Besides the accidental spills, which can bring to significant release rates and to the scenarios affecting both people and environment, very small leaks such as those resulting from corrosion and not immediately detectable in case of buried pipelines, could be very harmful to the soil and groundwater as well. They can last for a long time before being discovered, inducing in depth soil contamination of extended areas [5]. This possibility is always present in case of non-flammable liquids, harmful for the environment.

In case of flammable substances, a pool leaking into the soil will be present only if the substance does not immediately ignite. In case of ignition, the fire will burn the substance due to high burning rate causing various damages depending on the location characteristics. In case of an enduring pool, the liquid will move from the surface into the soil. Therefore, the extension of the contaminated zone need to be evaluated as a function of the pool dimensions and environmental conditions characterizing the impacted soil area [5], [6].

This paper proposes a model for the risk assessment based on fuzzy sets theory in order to more appropriately encompass uncertainties regarding the factors affecting the pipeline failure together with application of GIS and BIM technologies. These technologies serve for a more accurate incorporation of the geographic parameters and for a more precise probability calculation of the pipeline failure allowing also 3D visualization of any design and risk parameter at any point of the pipeline route. The methodology for the risk assessment based on type-2

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fuzzy sets and fuzzy logic is described in the following chapter (chapter II). A proposed model for the integration of GIS and BIM technology with its graphical representation is introduced in the chapter III, while the future development of the proposed model is discussed in the chapter IV.

II. Description of the Methodology

For linear systems, such as GPLS, which are extended over significant geographical areas, including agricultural and other types of land with diverse characteristics, identifying and understanding all factors involved in risk assessment is an especially demanding problem.

A traditional procedure for risk evaluation based on failure of pipeline system is performed through the relative risk score (RRS). Apart from pipeline inspection, maintenance and replacement, its results are also important for the risk management of the petrochemical feed and product pipelines [7]. The RRS model indices are introduced in [8] and the paper gives a comprehensive reference on determining the factors for assessing the pipeline risk. The indices of pipeline failure are grouped into eight parameters: 1) corrosion (C), 2) design (D), 3) third-party damage (TPD), 4) incorrect operation (IO), 5) product hazard (PH), 6) leak volume (LV), 7) dispersion (DI), and 8) receptors (RE). These eight parameters, for the purpose of evaluation characteristics, are grouped into two categories: the index sum and leak impact factor, as graphically presented in Fig. 1.

Based on crisp concepts of the traditional RRS technique, relative risk score (RRS) is calculated by the intersection of the index sum (IS) and leak impact factor (LIF) [10], i.e.,

$$RRS = \frac{IS}{LIF} = \frac{score\ of\ IS}{score\ of\ LIF}, \quad (1)$$

where:

$$IS = TPD + C + D + IO, \quad (2)$$

$$LIF = PH \times LV \times DI \times RE, \quad (3)$$

The methodology presented in [2], [9], for the evaluation of social and environmental risk, consists of several phases. Some phases are common for both social and environmental risk assessment while others are specific for one of them. The first phase is common and describes the modes a pipeline can break, Fig. 2. Usually two or three loss of containment events (LOCs) (i.e. a "pinhole", a medium hole and a full-bore rupture, etc.) are chosen as a function of the pipeline diameter. For these events, data regarding the occurrence frequencies are derived from a historical data set [2]. For each LOC the source term has to be evaluated through the well-defined consequence analysis models as a function of the whole diameter, pressure conditions inside the pipeline, and properties of the substance [5]. Duration of the release and totally spilled mass can also be assessed. Subsequently, through the post-release event trees, different final outcomes (pool-fires, toxic plumes or puffs, fireballs, flash-fires, vapor cloud explosions, non-ignited pools, etc.) can be related to each LOC and the occurrence frequency for each final scenario can be determined [5].

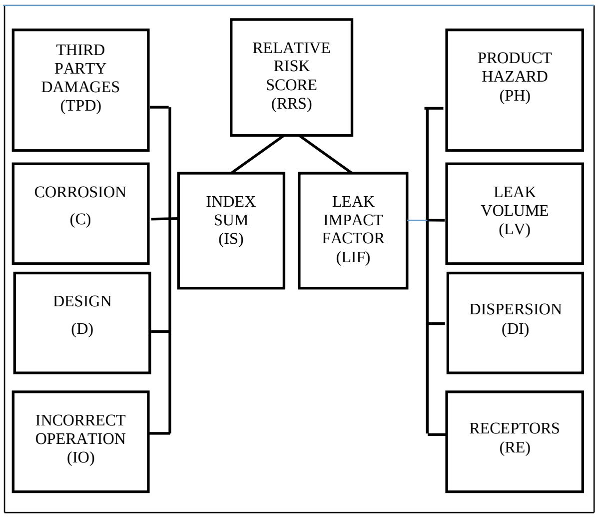

Figure 1. Graphical representation of pipeline failure indices [10]

Integration of GIS and BIM technologies as a decision-support system can facilitate this process to a large degree. BIM technology can enable incorporation of all relevant information both from geometric and semantic point of view. For example, BIM can provide detailed design of the pipeline network and its three dimensional visualization (3D) together with the detailed characteristics of each item in the pipeline system. However, it does not include surrounding information [10] affecting the pipeline integrity state. The drawbacks of BIM technology in spatial planning for construction is in detail described in [11].

On the other side, GIS technology enables spatial analysis based on the functional and physical spatial relationship of outdoor environment at large spatial scale, while it lacks detailed and comprehensive digital storage of information regarding the facility characteristics [12]. Therefore, integrating these technologies as a support decision-making system could be advantageous throughout the entire pipeline lifecycle phases: planning, design, construction, operation, maintenance, facility removal, and recycling along with the pipeline monitoring and risk management. For example, topographic information and soil characteristics, essential for the pipeline routing and risk assessment, can only be provided by GIS technology, while 3D visualization of the facility, various parametric changes, safety and hazard simulations, etc., are possible by implementing the BIM technology. Similarly, optimization of equipment and material allocation on construction sites and detection of their spatial-temporal conflicts is another example where integration of the GIS and BIM technology can be useful as well [13].

In addition to spatial information, many other attributes related to the pipeline location can be included in GIS technology and used for supplementary spatial or temporal analysis [14]. The key research topics of GIS are the following: locations, conditions, trends, patterns and models [15]. Furthermore, application of BIM and GIS technology enables an effective information management throughout the entire pipeline lifecycle and this information can be available for different applications at any spatial and temporal scale as well [15]. Furthermore, detailed information of components in a predesigned BIM system, can also be beneficial in decision-making during planning stage [16], while GIS can provide the spatial context view of the site and the quantitative assessment of the environmental impacts [17].

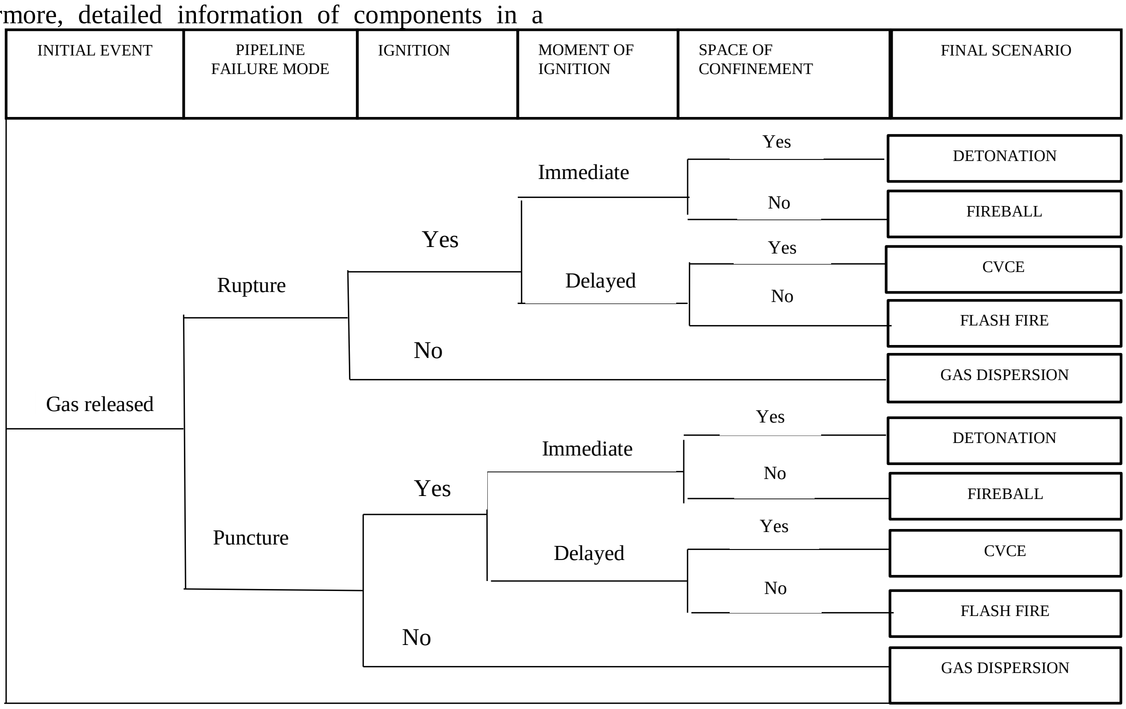

Figure 2. Simplified event tree for leakages from GPLS [2]

A. *Fuzzy Inference System Based on Type-2 Fuzzy Sets*

Fuzzy set theory provides a sophisticated inference structure for dealing with complex problems where complete data set is not possible to gather or/and where uncertainty regarding the data accuracy is present. The variables involved can have both quantitative and qualitative form. A typical fuzzy inference system (FIS) includes four main parts: (1) Fuzzification process, (2) Knowledge base, (3) Fuzzy base inference system, and (4) Defuzzification process. It is also called Mamdani fuzzy logic system, or fuzzy-rule based system, fuzzy expert system, fuzzy model or fuzzy linear controller [17], [18], [19].

To compute the output by the FIS given the inputs several steps has to be done. The first step is the fuzzyfication process, which comprises the process of transforming the linguistic variables into fuzzy sets. The membership functions of type-2 fuzzy sets can have different types of linear and nonlinear shapes. In general, the type of the membership function depends on the modeled problem, experts' knowledge and contexts [20]. Membership functions of the data base are applied in "IF-THEN" fuzzy rules forming rule base. Data base and rule base create the knowledge base. Fuzzy "IF-THEN" rules are extracted from experts judgments, engineering knowledge and experience [21]. The input-output relationships are defined through fuzzy "IF-THEN" rules, and therefore they are also called "conditional functions". For example "IF x is powerful (premise) THEN y is high (consequent)". The terms "powerful" and "high" can be represented by membership functions [22].

The fuzzy rules are aggregated in the fuzzy inference block, by a composition operator in order to derive an output [23]. This is the main part of a fuzzy inference system, which aggregates the facts derived from the fuzzification process by the rule base generated in the previous step.

There are several types of fuzzy inference systems that have been applied in different aspects of science and engineering applications. Mamdani fuzzy model is one of the most popular algorithms. It uses the concepts of fuzzy sets and fuzzy logic to translate an entirely unstructured set of linguistic heuristics into an algorithm [24]. It is described by p inputs, $x_1 \in X_1, x_2 \in X_2, \ldots, x_p \in X_p$, one output $y \in Y$, and by M rules, where the i^{th} rule has the form:

$$R^i\!: IF\ x_1\ is\ \tilde{\tilde{A}}_1^i\ and\ x_2\ is\ \tilde{\tilde{A}}_2^i\ and\ \ldots, x_p\ is\ \tilde{\tilde{A}}_p^i \quad THEN\ y\ is\ B^i\ \ i = 1,2,\ldots,M, \tag{4}$$

where x_i is the input variable, $\tilde{\tilde{A}}_i^l$ and $\tilde{\tilde{B}}_i^l$ are type-2 fuzzy sets representing appropriate linguistic terms, y is output variable, and M is the number of rules. The general "IF-THEN" rule structure of Mamdani algorithm is schematically presented in Fig. 3.

III. THE PROPOSED MODEL

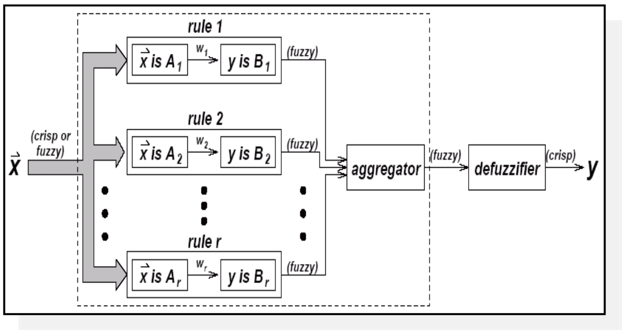

Figure 3. Mamdani "IF-THEN" type fuzzy rules [25]

The proposed model for fuzzy risk analysis consists of four phases: 1) the pipeline sectioning, 2) the IS assessment, 3) the LIF evaluation, and 4) the risk analysis. The framework of the proposed model is schematically presented in Fig. 5. Both the qualitative and quantitative variables can be included, which gives more flexibility and robustness to the model. Taking into account that pipelines are long linear system, consisting sometimes of thousands of kilometers of pipes, passing over different types of land,

failure rates in a pipeline vary along its route depending on the length of the pipeline section, local soil characteristics, pipeline age, polymeric coating, pressure, pipeline diameter, quality of the cathodic protection, etc. [26]. Therefore, to assess risk in pipelines, it is necessary to divide them into smaller sections s_i $i=1,2,\ldots,n,$ as their conditions differ along their routes. Furthermore, the appropriate strategies can be more easily applied to reduce the risk in each section separately, based on the risk level and the local conditions of the section. It is an iterative process and it is also related to the process of the optimal route selection along with the identification of the hazard scenario of the pipeline system.

The second phase in this process is concerned with the IS assessment. It determines the overall failure probability, which is caused by corrosion, third-party damage, design or incorrect operation. This phase calculates the potential for a particular failure mechanism to happen and it is different from the likelihood of failure [27]. By using a FIS model, the IS assessment can be calculated as a consequent of the overall failure probability, Fig. 4.

In the third phase, the overall consequence of a pipeline failure, including product hazard, leak volume, dispersion, and receptors is calculated by applying also Mamdani FIS model, similarly to the IS assessment. The LIF evaluation is derived from the overall potential consequences of pipeline failure.

In the final phase, the relative risks score is computed to evaluate the risk level. It is done by combining the index sum (IS), calculated in the second phase, with the leak impact factor (LIF) derived from the third phase. This step is then repeated for each pipeline section s_i $i=1,2,\ldots,n$. After computing the risk values for all pipeline sections, they are ranked in descending order and the riskier sections are individuated to be alleviated by

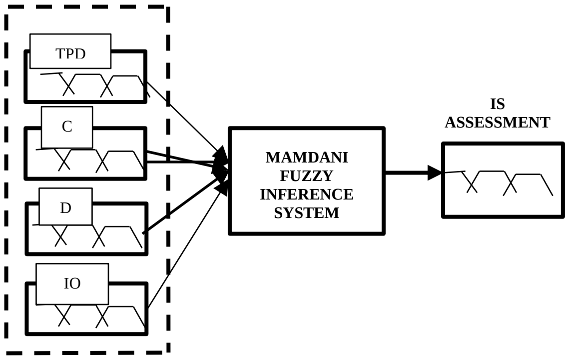

Figure 4. Graphical representation of the model for IS determination

appropriate strategies or by changing the section route, etc. The input and output variables in the Mamdani FIS model are fuzzified into trapezoidal type-2 fuzzy membership functions as presented in Table 1.

TABLE I. REPRESENTATION OF LINGUISTIC TERMS BY TRAPEZOIDAL TYPE-2 FUZZY SETS

Linguistic term	Trapezoidal type-2 fuzzy sets
Very Low (VL)	((0;0;0;0.1;1;1),(0;0;0;0.05;0.9;0.9))
Low (L)	((0;0.1;0.1;0.3.1;1;1),(0.05;0.1;0.1;0.2;0.9;0.9))
Medium low (ML)	((0.1; 0.3; 0.3; 0.5;1;1),(0.2; 0.3; 0.3; 0.4;0.9;0.9))
Medium (M)	((0.3; 0.5; 0.5; 0.7;1;1),(0.4; 0.5; 0.5; 0.6;0.9;0.9))
Medium high (MH)	((0.5; 0.7; 0.7; 0.9;1;1),(0.6; 0.7; 0.7; 0.8;0.9;0.9))
High (H)	((0.7; 0.9; 0.9; 1.0;1;1),(0.8; 0.9; 0.9; 0.95;0.9;0.9))
Very high (VH)	((0.9;1;1;1;1;1),(0.95;1;1;1;0.9;0.9))

The trapezoidal membership functions of type-2 fuzzy sets are characterized by the following parameters:

$$\tilde{\tilde{A}}_1 = \left(\tilde{A}_1^U, \tilde{A}_1^L\right)^2 = \\ = \begin{pmatrix} \left(a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(A_1^U), H_2(A_1^U)\right), \\ (a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(A_1^L), H_2(A_1^L)) \end{pmatrix}. \quad (5)$$

In general, it is recommended to adjust these parameters so that every membership function has 50% overlapping with the neighboring membership functions, when applying them in FIS model. In this way the "holes" in the input domain are removed [28]. Regarding the Mamdani model, both input and output variables are fuzzy propositions in the IF-THEN rule structure. These rules represent the fuzzy relations between input and output variables and they are formed on the basis of experts' and engineering knowledge. A sample of the fuzzy IF-THEN rules for the IS assessment is listed below:

1. *IF (C is VL) and (TPD is VL) and (D is VL) and (IO is VL) THEN (IS is VL),*
2. *IF (C is L) and (TDP is L) and (D is L) and (IO is L) THEN (IS is L),*
3. *IF (C is M) and (TDP is M) and (D is M) and (IO is M) THEN (IS is M),*

4. *IF (C is H) and (TDP is H) and (D is H) and (IO is H) THEN (IS is H),*
5. *IF (C is VH) and (TDP is VH) and (D is VH) and (IO is VH) THEN (IS is VH),*
6. *IF (C is L) and (TDP is M) and (D is M) and (IO is M) THEN (IS is M).*
7. *IF (C is H) and (TDP is H) and (D is VH) and (IO is H) THEN (IS is H),*
8. *IF (C is VL) and (TDP is L) and (D is M) and (IO is H) THEN (IS is M),*

The risk assessment is performed by combining the calculated values IS and LIF according to (6) as well.

After the aggregation of the fuzzy rules is completed, defuzzification is used to transfer the derived fuzzy value into crisp value. The Centroid of area (COA), is one of the most frequently used methods for defuzzification process [19]. The advantage of the COA method is that all activated membership functions of the conclusions (all active rules) participate in the defuzzification process [30].

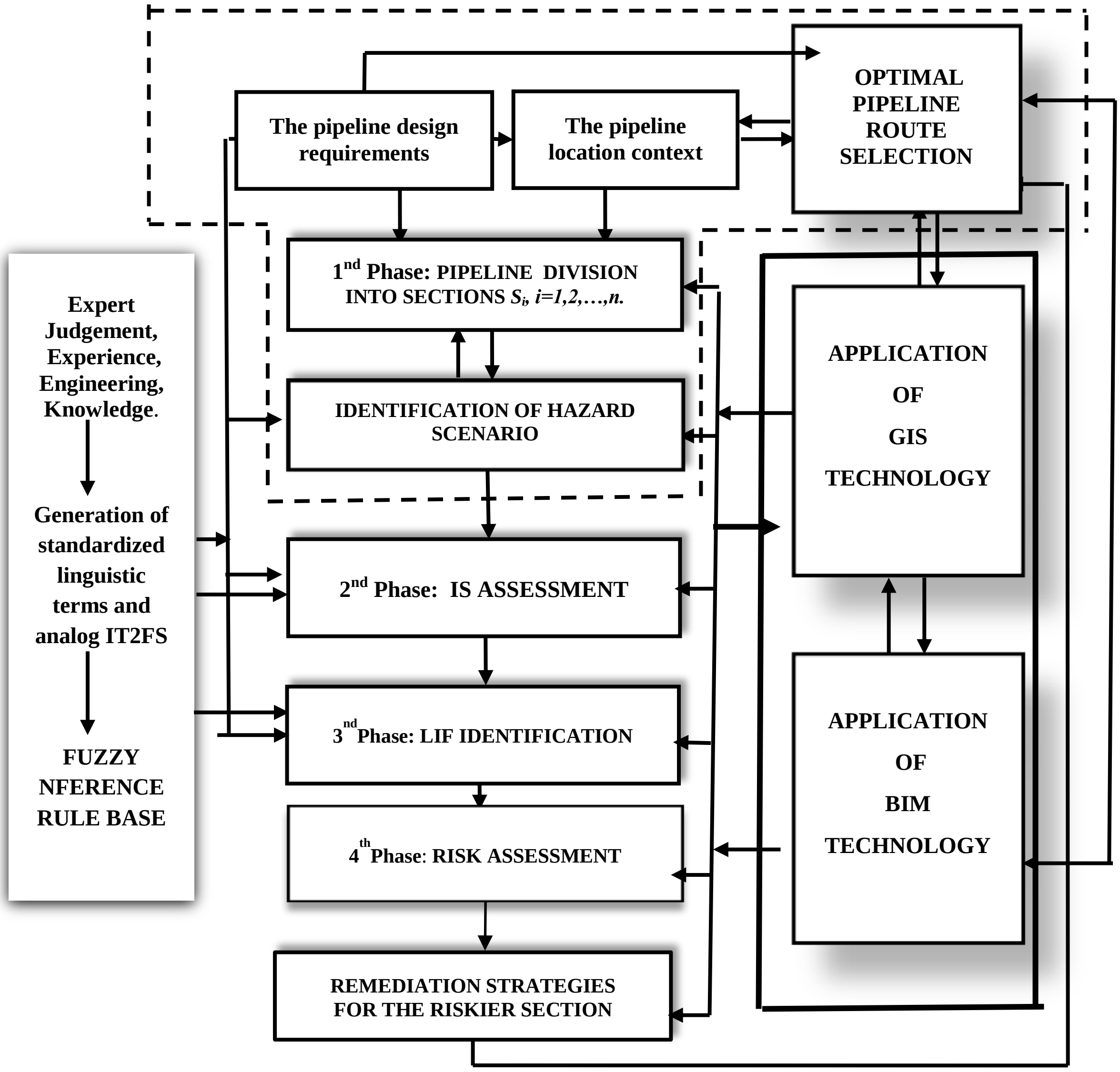

Figure 5. The proposed model for the risk assessment

and so on following equation (4). The aggregation process for IS and LIF assessment is done by applying the max-min composition, i.e.,

$$\mu_{C_k}\left(\tilde{\tilde{Z}}\right) = max\left[min\left[\mu_{\tilde{\tilde{A}}_k}\left(input(x)\right), \mu_{\tilde{\tilde{B}}_k}\left(input(y)\right)\right]\right], \quad (6)$$

where $\mu_{C_k}, \mu_{A_k}, \mu_{B_k}$ are the membership functions of output "z" for rule "k", input "x", and "y" respectively.

The COA method for transferring interval type-2 fuzzy values into a crisp value is defined as follows [29]:

$$Defuzzified\left(\tilde{\tilde{Z}}\right) = \frac{1}{2}\left(\begin{array}{c} \frac{\left(z^U_{ij4}-z^U_{ij1}\right)+\left(H_1\left(\tilde{Z}^U_{ij}\right)*z^U_{ij2}-z^U_{ij1}\right)+\left(H_2\left(\tilde{Z}^U_{ij}\right)*z^U_{ij3}-z^U_{ij1}\right)}{4} \\ +z^U_{ij1} + \\ \frac{\left(z^L_{ij4}-z^L_{ij1}\right)+\left(H_1\left(\tilde{Z}^L_{ij}\right)*z^L_{ij2}-z^L_{ij1}\right)+\left(H_2\left(\tilde{Z}^L_{ij}\right)*z^L_{ij3}-z^L_{ij1}\right)}{4} \\ + \\ z^L_{ij1} \end{array}\right), \quad (7)$$

where type-2 fuzzy set $\tilde{\tilde{Z}}$ represents the aggregated ouput of the max-min composition given by (6).

In the last step of this phase, defuzzification process of the calculated fuzzy RRS values is performed in order to get the corresponding crisp values by using the COA method defined by (7). This process is done for each pipeline section *i*, $i=1,2,\ldots,n$. The proposed framework for the pipeline risk assessment by integrating BIM and GIS technology as a decision-support system is schematically presented in Figure 5.

As depicted on the diagram, Fig. 5, the first phase of proposed procedure for the risk assessment is the division of the pipeline into smaller sections with similar external surrounding conditions and analogous internal pipeline characteristics. This is recommended because failure rate in pipeline network differs along its route, depending on the topology and soil characteristics, pipeline age and diameter, polymeric coating, pipeline pressure, quality of the cathodic protection, etc. In this regard, GIS technology can be used for identification and incorporation of the external surrounding conditions along the entire pipeline route in order to get more precise data needed for the optimal pipeline design, routing, and pipeline risk evaluation. On the other side, BIM technology, based on the data gathered by GIS along with previously acquired and stored information, can perform various calculations and simulations to test design and safety requirements, providing also 3D visualization of the desired parameters, at any point of the pipeline route, enabling a better understanding and identification of the potential conflicts or hazardous situations.

In the second and third phase of the risk assessment procedure, the overall failure probability caused by corrosion, third-party damage, erroneous design or incorrect operation together with overall consequence is calculated. In these phases, GIS technology can serve for more precise identification of the external factors affecting the pipeline failure along with their effects while BIM technology can serve for the simulation of the hazard impacts on the pipeline system for more precise evaluation of the consequences.

Similarly, these technologies can be used for design and adequate implementation of remediation strategies (the fifth phase) in case of a failure or merely as a prevention measure.

IV. The Future Reccomandations

The future application of these technologies can be used not only to ensure more accurate risk assessment but also more accurate evaluation of the pipeline state of the art along with real-time prediction of a failure and its consequence impacts. In addition, recommendations for the remediation strategies for each incident type can be provided in real-time. These improvements can be done by implementing appropriate “smart” sensors in situ and connecting them with BIM and GIS technology, in order to get unbiased data, required for real-time risk assessment and design parameters examination. Also, it could be used for real-time failure prediction and its consequence impact assessment regarding the agricultural land, crops, water streams, wildlife, fishery, air pollution, etc. In addition, effective real-time automatic information and calculation management along with real time failure warning and optimal selection of the remediation strategies could be also implemented in the future applications of these technologies integrated in the proposed model, thus providing a “smart” system for risk assessment and risk management across gas pipeline systems lifecycle.

V. Conclusion

This paper proposes a model for the pipeline risk assessment implementing fuzzy inference system based on interval type-2 fuzzy sets along with BIM and GIS technology. The proposed model enables more appropriate risk assessment because of the ability of interval type-2 fuzzy sets to encompass higher degrees of uncertainty along with fuzzy inference system capacity to include expert judgments, experience, and engineering knowledge (as inference rules) thus providing more accurate and robust results. Moreover, integration of GIS technology enables more precise identification and incorporation of the external data: topology, soil characteristics, weather conditions, pipeline age and diameter, quality of cathodic protection, etc., along the entire pipeline route, which are necessary for the optimal pipeline design, routing and pipeline risk evaluation. BIM integration in the proposed model serves to store and manage all relevant facility information, as well as to perform various design calculations, allowing also 3D visualization of any design and risk parameter at any point of the pipeline route, therefore enabling a better understanding and identification of the potential conflict situations or hazard detection. Additionally, BIM technology implementation allows various simulations of the diverse hazard impacts thus enabling more precise design and implementation of the adequate remediation strategies.

References

[1] National Infrastructure Protection Plan (NIPP). Partnering to enhance protection and resiliency. USA: National Infrastructure Protection Plaan, 2009.

[2] D. Yuhua and Y. Datao, “Estimation of failure probability of oil and gas transmission pipelines by fuzzy fault tree analysis,” *Journal of Loss Prevention in the Process Industries*, vol. 18, pp. 83-88, 2005.

[3] G. A. Papadkis, “Assessment of requirements on safety management systems in EU regulations for the control of major hazard pipelines,” *Journal of Hazard. Materials*, vol. 78, pp. 63–89, 2000.

[4] S. Sklavounos and F. Rigas, “Estimation of safety distances in the vicinity of fuel gas pipelines,” *Journal of Loss Prevention in the Process Industries*, vol. 19, pp. 24–31, 2006.

[5] D. Monaci, et al. Quantitative assessment of the risk associated to the transport of hazardous substances by pipeline, Available at: https://www.aidic.it/CISAP3/webpapers/49Monaci.pdf

[6] A. G. Spadoni, *Rischi per l’uomo e l’ambiente nel trasporto di* sostanze *pericolose: il nuovo TRAT, Atti del Convegno VGR2k2*, Eds. M.Carcassi and M.Leonardi, DIMNP Università degli Studi di Pisa, Pisa (I), 2002.

[7] M. J. Gharabagh et al. “Comprehensive risk assessment and management of petrochemical feed and product transportation

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pipelines," *Journal of Loss Prevention in the Process Industries*, vol. 22, pp. 533-539, 2009.
[8] W. K. Muhlbauer, *Pipeline risk management manual; ideas,* techniques*, an d resources,* 3rd edition, Elsevier Inc. 2004.
[9] A. J. Brito et al. "A multi-criteria model for risk sorting of natural gas pipelines based on ELECTRE TRI integrating Utility Theory," *European Journal of Operation research*, vol. 200, pp. 812–821, 2010.
[10] A. Rafiee et al. *"*From BIM to geo-analysis: View coverage and shadow analysis by BIM/GIS integration"*. Procedia Environ. Science,* vol. 22, pp. 397–402, 2014.
[11] V. Bansal, "Use of GIS and topology in the identification and resolution of space conflicts," *Journal of Computation in Civ. Eng*. vol. 25, pp. 159–171, 2010.
[12] S. Amirebrahimi, "A data model for integrating GIS and BIM for assessment and 3D visualization of flood damage to building. *Locate,* vol. 15, pp. 10–12, 2015.
[13] J. Irizarry and E. P. Karan, *"*Optimizing location of tower cranes on construction sites through GIS and BIM integration"*. Journal of* Inf. *Technol. Construction,* vol. 17, pp. 351–366, 2012.
[14] X. Liu et al. "Spatial and temporal analysis on the distribution of active radio-frequency identification (RFID) tracking accuracy with the kriging method"*. Sensors,* vol. 14, 2014.
[15] S. Virmani et al. "Overview of GIS, GIS application in cropping system analysis-case studies in Asia," *In Proc. International* Workshop *on Harmonization of Databases for GIS Analysis of Cropping Systems in the Asia Region,* India, 1997, pp. 18–29.
[16] H. Li et al. "Optimizing construction planning schedules by virtual prototyping enabled resource analysis" *Autom. Construction,* vol. 18, pp. 912–918, 2009.
[17] M. Sebt, E. P. Karan and M. Delavar, 2008, "Potential application of GIS to layout of construction temporary facilities*"*. International Journal of Civil Engineering,vol. 6, pp. 235–245.
[18] M. A. Grima, P. A. Bruines and P. N. W. Verhoef, "Modelling tunnel boring machine performance by neuro-fuzzy method," *Tunnelling and Underground Space Technology*, vol. 15, pp. 259-269, 2000.
[19] A. Jamshdia et al. "Developing a new fuzzy inference system for pipeline risk assessment*," Journal of Loss Prevention in the Process Industries*, vol. 26, pp. 197-208, 2013.
[20] M. A. Grima et al. „Modelling tunnel boring machine performance by neuro-fuzzy methods," *Tunnelling and* Underground *Space Technology*, vol. 15, pp. 259-269, 2000.
[21] E. Ghasemi and M. Ataei, "Application of fuzzy logic for predicting roof fall rate in coal mines," *Neural Computing and Applications,* vol. 22, pp 311–321, May 2013.
[22] J. S. R. Jang, C. T. Sun and E. Mizutani, *Neural-fuzzy and soft computing.* Englewood Cliffs, NJ: Prentice-Hall, 1997.
[23] Z. Li, *Fuzzy chaotic systems: Modeling, control, and applications.* Berlin Heidelberg: Springer-Verlag. 2006.
[24] Mamdani, E. H., & Assilian, S. (1975). *"An experiment in linguistic synthesis with a fuzzy logic controller"* International Journal of Man e Machine Studies,7(1), 1-13.
[25] T. J. Ross, *Fuzzy Logic with Engineering Applications*, 2nd edition, John Wiley & Sons, 2010.
[26] Y. D. Jo and B. J. Ahn, "A method of quantitative risk assessment for transmission pipeline carrying natural gas," *Journal of Hazardous Materials,* A123, pp. 1-12, 2005.
[27] W. K. Muhlbauer, Pipeline *Risk Management Manual; Ideas,* Techniques, *And Resources*, 3rd edition, Elsevier Inc., 2004.
[28] J. S. R. Jang, C. T. Sun, and E. Mizutani, *Neural-fuzzy and Soft Computing,* Englewood Cliffs, NJ: Prentice-Hall, 1997.
[29] M. Iphar and R. M. Goktan, An application of fuzzy sets to the Diggability Index Rating Method for surface mine equipment selection", *International Journal of Rock Mechanics and Mining Sciences,* vol. 43, pp. 253-266, 2006.
[30] A. Daftaribesheli et al. "Assessment of rock slope stability using the Fuzzy Slope Mass Rating (FSMR) system," *Applied Soft Computing,* vol. 11, pp. 4465-4473, 2011.

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