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Integrated Multi-Model Risk Assessment of an Aging Gas Pipeline Using Fuzzy AHP and 3D Uncertainty Matrix

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The expansion of gas transmission lines in Iran involves numerous risks, requiring regular assessments to ensure safe and efficient transport. This study examines six kilometers of Iran's oldest gas pipeline, located in Tonekabon, a densely populated and touristic city. The pipeline was divided into six zones, considering pipeline class, population density, and intersections. In each zone, three events—leakage, rupture, and explosion—were assessed using four methods: simple matrix, weighted matrix, fuzzy weighted matrix, and a 3D uncertainty-based matrix. Four experts evaluated the probability and severity of consequences, categorized as technical, safety, environmental, and cost impacts. The consequences enabled risk calculation across all categories. Standard deviation was used to compute a three-dimensional uncertainty-based risk, incorporating uncertainty in both probability and consequence estimation. Risk management levels were then adjusted accordingly. Chang's fuzzy AHP method and Mamdani's fuzzy logic in MATLAB were applied to handle inherent uncertainties. Results showed discrepancies between simple and fuzzy matrices due to the exclusion of cost impacts, given the state-owned nature of the company. The 3D matrix further indicated that most risk cells require only preliminary review, attributed to the company's regular inspections and access to reliable data.

Keywords: *fuzzy risk assessment, fuzzy risk matrix, gas transmission lines, fuzzy hierarchical analysis*

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1. Introduction

Lowrance [21] defined risk based on measuring the probability and severity of hazardous effects. Many researchers have defined risk as the probability of a multiplied by the severity of the consequences, and have solved engineering problems based on it. Among these, we can refer to Kerzner [16], Duzgun and Einstein [9], Šotić and Rajić [30], and Aven [2]. The risk, in this paper, is defined as the probability of the occurrence of an event multiplied by the severity of the event.

Oil and gas are the main sources of fuel consumed in the world. The transfer of oil, gas and petrochemical materials through land, sea and air transport has shown that these methods of transfer, in addition to their own obstacles and problems and the existence of many financial and life risks, are not economical from an economic point of view, and transfer through pipelines is a suitable solution to solve this problem. For this reason, the use of this method of transmission shows significant growth in the last decade [4].

On the other hand, many risks such as pipeline leakage, rupture and explosion may result in various consequences. In recent years, many studies have been conducted on the risk assessment of

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pipelines. Among them, one can mention Zhua et al. [36] who evaluated the factors that cause leakage. Zhou et al. [35] presented a theoretical system for risk assessment along gas pipelines.

Shan et al. [29] modeled the leakage risk in the gas pipeline using the fuzzy bowtie method. Various other methods were also used to assess the risk of pipelines, e.g. Selvan and Siddqui [28] used the Hazard and Operability (HAZOP) method to study pipeline risk. Pontiggiaa et al. [25] adopted the Event Tree Analysis method for risk assessment. Fang et al. [10] defined a quantitative method for pipeline risk assessment. Jianxing et al. [14] with the FMEA method, Liang et al. [20] with the fuzzy TOPSIS method and Hassan et al. [12] with the Bayesian network method have performed pipeline risk assessment. Li et al. [19] presented a new quantitative method to assess the risk of pipeline explosion.

In addition to being complex and time-demanding, quantitative risk assessment also faces many uncertainties. This requires detailed knowledge and a vast study to make an accurate quantitative assessment. The method used in this paper is the risk fuzzy matrix and the use of the AHP-FUZZY method for weighting. Bertuccio and Moraleda [3] presented the assessment of corrosion risk in gas pipelines using fuzzy logic. Regarding the use of fuzzy logic for risk assessment of pipelines, the interested reader is encouraged to refer to Li et al. [18] and the AHP–TOPSIS method introduced by Wang [32].

The risk assessment method has been incorporated in various fields, e.g. the studies of Keneti [15], Lane [17], and Reznikov [26].

Regarding the risk matrix method, which is a common method for semi-quantitative evaluations, we can refer to studies that have used this method in the risk assessment of gas transmission pipelines. Among them are the works by Henselwooda and Phillips [13], Lu et al. [22], and Ashton et al. [1].

2. Methodology

The concept of risk has changed significantly in recent centuries, and various evaluation methods have been defined based on scientific fields and the needs. In this paper, the risk matrix evaluation method is adopted. This is a simple method that evaluates the status of risks in the system by spending a short time. Therefore, risk assessment includes determining the probability of occurrence of a risk as well as the severity of its consequence [33].

2.1. Decision Matrix Risk-Assessment (DMRA) Technique

As stated previously, in this paper, risk (R) is defined as the product of the probability of occurrence of the event (P) by the severity of the event (S):

$$R=P\times S$$

Initially, the probability measurement and severity ranking are determined by this method (Tables 1, 2). Then, the risk matrix is constructed based on Table 3. In this method, the weight of experts and that of all types of events are considered identical, which is called a simple risk matrix in this study. Table 4 lists the different levels of risk. Next, based on the weight of experts and events, the weighted risk matrix was formed, and finally, in this paper, a fuzzy approach is proposed with two purposes: 1) to enable experts to use linguistic variables for evaluating two factors that are the parameters of a decision matrix risk-assessment technique to deal with shortcomings of a crisp risk score calculation, and 2) to decrease the inconsistency in decision making [11].

Table 1. Likelihood rankings (P).

Hazard likelihood rankings (P)

Ranking category	Description	Cris p	Fuzzy numerical
RARE	Hardly ever	1	(0,1,2)
UNLIKELY	Remote (Once a year), only in abnormal conditions Possible	2	(1,2,3)
POSSIBLE	Occasional (A few events in a year)	3	(2,3,4)
LIKELY	Frequent (Monthly)	4	(3,4,5)
CERTAIN	Very frequent (Once a week, every day)	5	(4,5,5)

Table 2. Severity rankings (s).

Type of Consequence	Severity	Fuzzy	Sign	Severity rankings (s)
				Event description
TECHNICAL	INSIGNIFICANT 1	(0,1,2)	VL	It does not stop.
	MINOR 2	(1,2,3)	L	It does stop for three days.
	INTERMEDIATE 3	(2,3,4)	M	It does stop for five days.
	SIGNIFICANT 4	(3,4,5)	H	It does stop for one week.
	INTOLERABLE 5	(4,5,5)	VH	It does stop for more than one week.
SAFETY	INSIGNIFICANT 1	(0,1,2)	VL	There is no or little damage (no need for first aid), no loss of work day
	MINOR 2	(1,2,3)	L	Need for first aid or outpatient treatment, loss of a work day (for personnel)
	INTERMEDIATE 3	(2,3,4)	M	Serious injury requiring hospitalization, temporary inability to return to work (for personnel), moderate damage to people
	SIGNIFICANT 4	(3,4,5)	H	Serious injury and termination of membership, permanent inability to return to work (for personnel), serious injury to the public
	INTOLERABLE 5	(4,5,5)	VH	It causes the death of one or more people.
ENVIRONMENTAL	INSIGNIFICANT 1	(0,1,2)	VL	It has negligible effect.
	MINOR 2	(1,2,3)	L	Pollution of water, air, soil, etc. in a small amount that can be compensated in one day. The contamination will only be around the equipment.
	INTERMEDIATE 3	(2,3,4)	M	Pollution of water, air, soil, etc. to an average amount that can be

				compensated in one week. There will be pollution around the equipment.
	SIGNIFICANT 4	(3,4,5)	H	The pollution created is difficult to compensate. The production and spread of pollution is high around the equipment and outside of it.
	INTOLERABLE 5	(4,5,5)	VH	Irreparable pollution around the equipment and outside of it, defects in environmental laws, consumption of resources are very high.
COST	INSIGNIFICANT 1	(0,1,2)	VL	It does not cost much, it does not disturb the main process.
	MINOR 2	(1,2,3)	L	It imposes a cost of up to 45 million Tomans. The damage is to the extent that it has a minor effect on the main process.
	INTERMEDIATE 3	(2,3,4)	M	The cost is between 45 million and 450 million Tomans. The damage is to the extent that it affects the main process.
	SIGNIFICANT 4	(3,4,5)	H	It will cost between 450 million and 4.5 billion Tomans. It seriously affects the main process.
	INTOLERABLE 5	(4,5,5)	VH	It imposes a cost of more than 4.5 billion Tomans. It causes the complete stop of the gas transfer process and the destruction of the equipment.

Table 3. The risk-assessment decision matrix.

	LIKELIHOOD				
SEVERITY	RARE	UNLIKELY	POSSIBLE	LIKELY	CERTAIN
INSIGNIFICANT	1	2	3	4	5
MINOR	2	4	6	8	10
INTERMEDIATE	3	6	9	12	15
SIGNIFICANT	4	8	12	16	20
Catastrophic	5	10	15	20	25
	LIKELIHOOD				
SEVERITY	RARE	UNLIKELY	POSSIBLE	LIKELY	CERTAIN
INSIGNIFICANT	VL	L	L	L	L
MINOR	L	L	L	M	M
INTERMEDIATE	L	L	M	M	H
SIGNIFICANT	L	M	M	H	H

Catastrophic	L	M	H	H	VH

Table 4. Acceptability level of the risks.

Risk number	Sign	Risk definition	Risk management description
1	VL	Insignificant	The risk is insignificant and does not matter. Only the factors that may cause risk are recorded in the risk book.
2,3,4,5,6	L	Acceptable	The risk is acceptable. The results of the cathodic protection system are updated and checked.
8,9,10,12	M	Intermediate	Smart pigging is carried out in smaller time intervals (every three years). Leak detection is done at small frequent intervals (four times a year). The cathodic protection system is upgraded and the results are carefully monitored.
15,16,20	H	Significant	Smart pigging is done in fewer time intervals (every two years). Leak detection is done at less frequent intervals (four times a year). The cathodic protection system is upgraded and the results are carefully monitored. The way of passing the pipe through the intersections is inspected and revised.
25	VH	Intolerable (unacceptable)	Changing classes or constructing parallel pipelines is considered. The before and after the valve is closed immediately. The gas in the line is drained, and upon discovering the cause of the error, appropriate remedial measures are put on the agenda. Changing the class and constructing a parallel line are seriously on the agenda.

2.2. Fuzzy AHP

For the first time, Zadeh [34] introduced a novel mathematical approach with respect to crisp numbers, providing a new horizon for calculations under uncertainty. In classical, or crisp, sets the transition for an element in the universe between membership and non-membership in a given set is abrupt and well-defined (said to be crisp).

FAHP is one of the widely-used multi-criteria decision-making methods based on fuzzy set theory. Many FAHP methods have been proposed in the literature. Buckley [5] determines the fuzzy priorities of comparison ratios that are trapezoidal membership functions. Chang introduces a new approach to FAHP management using triangular fuzzy numbers for the pairwise comparison scale [7].

2.2.1. Triangular fuzzy numbers

Definition 1. Let $M \in F(R)$ be called a fuzzy number if [7]:

1) There exists $x_0 \in$ R such that $\mu_M(x_0) = 1$.

2) For any $\alpha \in [0, 1]$, $A_\alpha = [x, \mu_{A\alpha}(x) \geq a]$ is a closed interval. Here, *F(R)* represents all fuzzy sets, and R is the set of real numbers.

Definition 2. We define a fuzzy number *M* on *R* to be a triangular fuzzy number if its membership function $\mu_M(x)$: $R \rightarrow [0, 1]$ is equal to:

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x \in [l, m], \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in [m, u], \\ 0, & \text{otherwise}, \end{cases}$$

Where $l \leq m \leq u$, and l and u stand for the lower and upper value of the support of M respectively, and m is the modal value. The triangular fuzzy number can be denoted by (l, m, u). The support of M is the set of elements { ∈ R |$l<x<u$}. When $l = m = u$, it is a no fuzzy number by convention.

Definition 3. Let M_{g1}^{1}, M_{g1}^{2}, ... M_{g1}^{m}, be values of extent analysis of the ith object for$m$ goals. Then the value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{g1}^{j} \odot \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g1}^{j}\right]^{-1}$$

2.2.2. Presentation method of fuzzy numbers for the pairwise comparison scale

The first task of the FAHP method is to decide on the relative importance of each pair of factors in the same hierarchy. By using triangular fuzzy numbers, via pairwise comparison, the fuzzy evaluation matrix $A = (a_{ij})_{n\times m}$ is constructed. For example, essential or strong importance of element i over element j under a certain criterion: then $a_{ij}=(l, 5, u)$, where l and u represent a fuzzy degree of judgment. The greater u - l, the fuzzier the degree; when u - $l = 0$, the judgment is a no fuzzy number. This stays the same to scale 5 under general meaning. If the strong importance of element j over element i holds, then the pairwise comparison scale can be represented by the fuzzy number a_{ij}^{-l} = *(1/u, 1/m, 1/l).*

2.2.3. Calculation of priority vectors of the Fuzzy AHP

Let $A=(a_{ij})_{n\times m}$ be a fuzzy pairwise comparison matrix, where $a_{ij} = (l_{ij}, m_{ij}. u_{ij})$, which is satisfied with

$$l_{ij} = \frac{1}{l_{ji}} m_{ij} = \frac{1}{m_{ji}} u_{ij} = \frac{1}{u_{ji}}$$

To obtain the estimates for the vectors of weights under each criterion, we need to consider a principle of comparison for fuzzy numbers. In fact, two questions may arise:

1) What is the fuzzy value of the least or greatest number from a family of fuzzy numbers?

2) Which is the greatest or the least among several fuzzy numbers?

The answer to the first question is given by the use of the operation max and min. However, the answer to the second question requires effort. We must evaluate the degree of possibility for $x \in R$ fuzzily restricted to belong to M, to be greater than $y \in R$ fuzzily restricted to belong to M. Thus, we define as follows:

Definition 4. The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V (M_1 \geq M_2) = \sup [\min (\mu_{M_1}(x), \mu_{M_2}(y))].$$

When a pair (x, y) exists such that $x \geq y$ and $\mu_{M_1}(x) = \mu_{M_2}(y) = 1$, then we have $V (M_1 \geq M_2) = 1$. Since M_1 and M_2 are convex fuzzy numbers, we have:

$$V (M_1 \geq M_2) = 1 \text{ if } m_1 \geq m_2$$
$$V (M_2 \geq M_1) = \text{hgt } (M_1 \cap M_2) = \mu_{M_1}(d),$$

Where *'d* is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}

When $M_1 = (l_1, m_l, u_l)$ and $M_2 = (l_2, m_2, u_2)$, the ordinate of D is given by:

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}$$

To compare M_1 and M_2, we need both values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

1- Assessment Methodology in Indonesia
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18- Sensitivity Analysis of Gas Distribution Pipeline Risk
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37- Assessment Methodology in Indonesia
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Definition 5. The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i ($i = 1, 2, . . .,k$) can be defined by

$V(M \geq M_1, M_2, ..., M_k) = V[(M \geq M_1)$ and $(M \geq M_2)$ and

… and $(M \geq M_k)] = \min V(M \geq M_i), \quad i=1, 2 ... k$

Assume that

$d(A_i) = \min V(S_i \geq S_k)$,

For $k = 1, 2, …,n$; $k \neq i$. Then the weight vector is given by $W' = (d'(A_1), d'(A_2) … d'(A_n))^T$,

Where Ai $(i = 1, 2, ...,n)$ are elements. Via normalization, we find the normalized weight vectors $W = (d(A_1), d(A_2), …, d(A_n))^T$.

Where W is a no fuzzy number.

2.3. The Proposed Fuzzy Rule-Based Risk Assessment Method

The simple risk matrix was developed using crisp numbers, and the fuzzy matrix was formed using fuzzy numbers. The experts of the risk assessment team compared the risk in different zones by employing the available information, experience, knowledge, engineering judgments and observations with the help of linguistic terms (instead of assigning a clear and specific value).

The advantages of employing the fuzzy approach in risk assessment are two-fold: it allows failure risk evaluation, ranking, and prioritization to be conducted based on experts' knowledge, experiences, and opinions; and it allows the failure risk evaluation function to be customized based on the nature of a process [31]. The five steps in FIS for risk assessment in the fuzzy logic toolbox of MATLAB version 2020 include: 'fuzzification' of input variables, application of 'fuzzy operator' in the antecedent, 'implication' from antecedent to consequent, 'aggregation' of consequent across the rules and the 'defuzzification' process (Figures 1, 2).

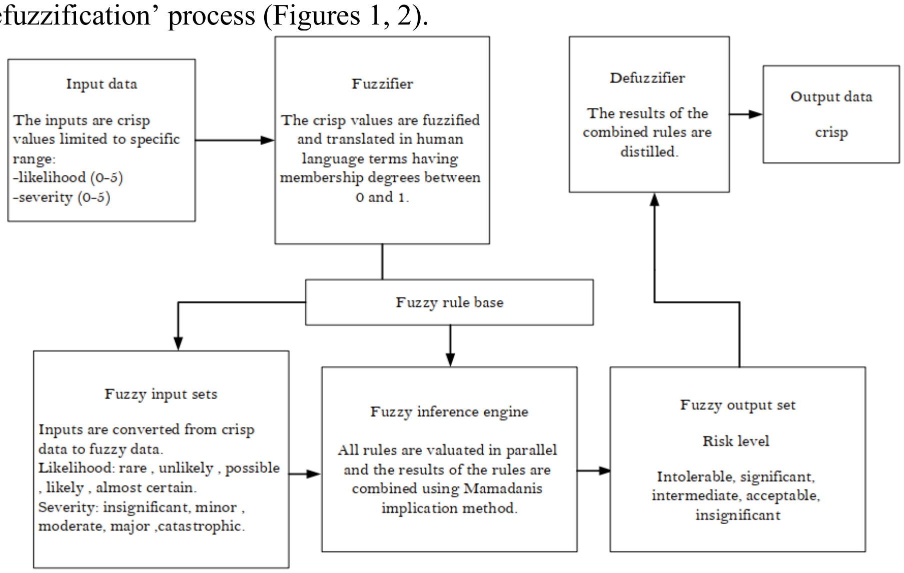

Figure 1. Fuzzy inference process for risk assessment

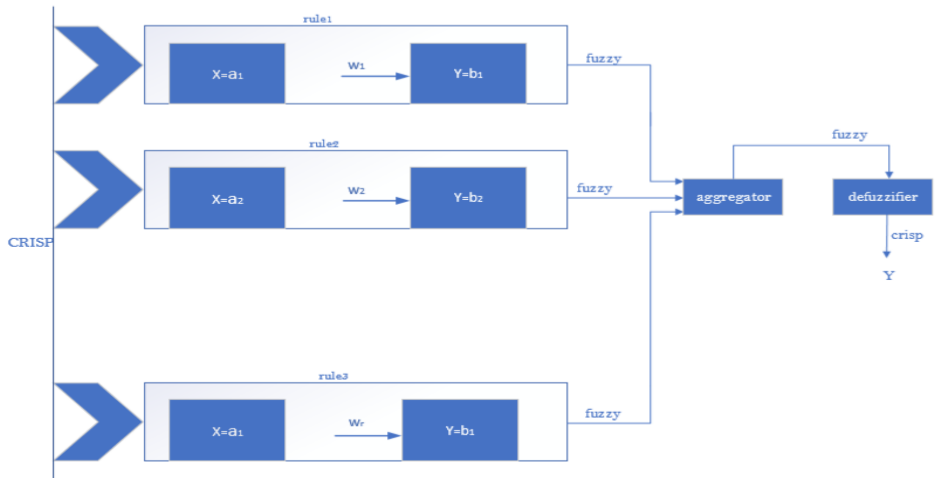

Figure 2. Block diagram of a fuzzy inference system

In the proposed model, two inputs of severity (S) or probability (P) are defined from 1 to 5, and fuzzy risk (R) is defined as an output in the range of 1 to 25 (Figure 3).

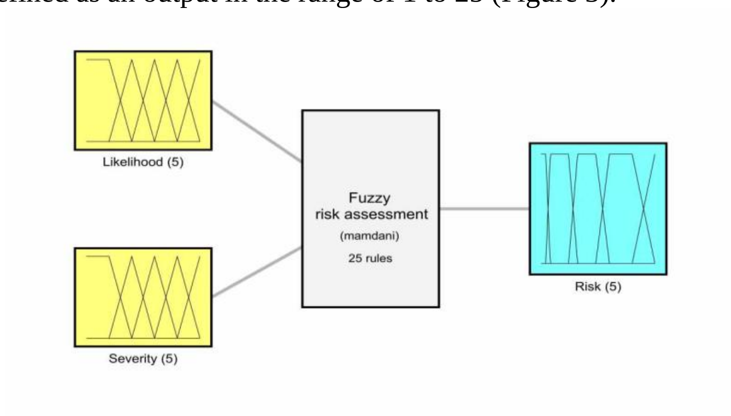

Figure 3. Structure of the constructed fuzzy model

In the current fuzzy model, triangular and trapezoidal membership functions, which are more common, have been used. The input parameters are fuzzified with the opinion of experts and using linguistic tags (Tables 1, 2; Figures 4, 5). The results obtained for risk are classified according to Fig. 6, the range of which corresponds to the linguistic terms presented in Table 4.

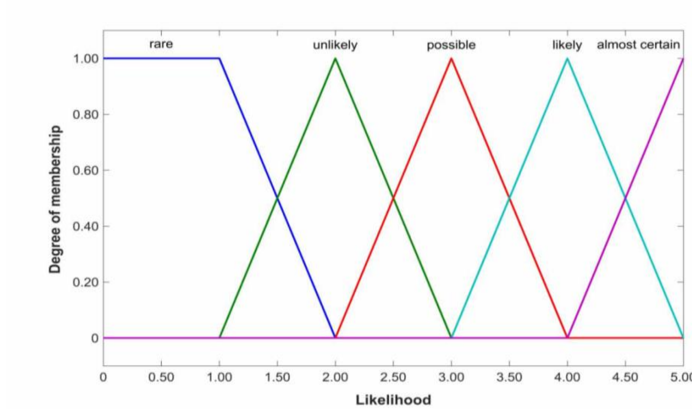

Figure 4. Membership functions representing the likelihood

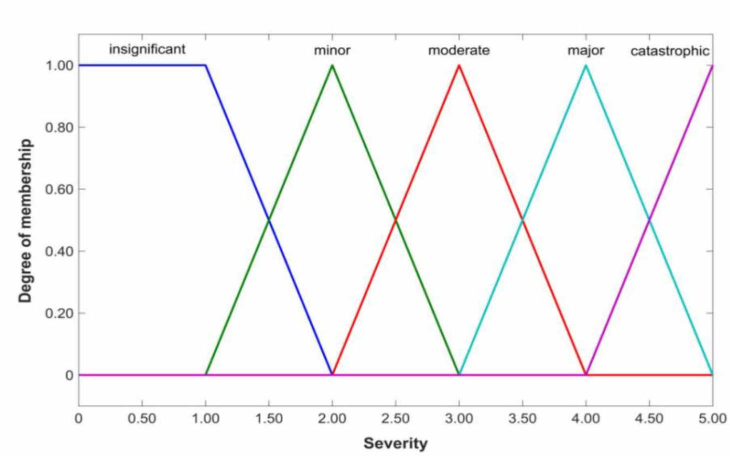

Figure 5. Membership functions representing the severity

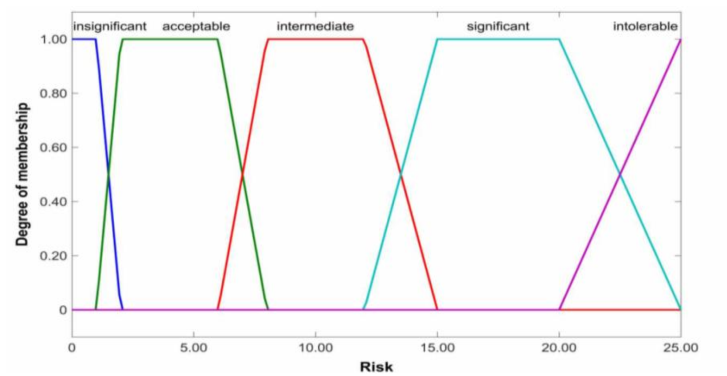

Figure 6. A membership function representing the risk output in the fuzzy model

The final step in building a fuzzy risk assessment model is to determine if-then rules. Fuzzy if-then rules are the backbone of a fuzzy inference system (FIS). If-then rules (Table 5) are extracted based on expert knowledge, safety analysis and risk score obtained from the traditional risk matrix method in Table 3. Since five membership functions are assigned for both two inputs and two inputs, the number of fuzzy if-then output rules is 25. These fuzzy rules form the basis of the fuzzy rules (Figure 3) of the constructed model. The numbers given in parentheses at the end of each rule in Table 5 indicate the weight of the rule (w). The results of the rules are combined using the Mamdani algorithm. To obtain the final risk score from the constructed FIS, Eq. (1) is used to fuzzily the accumulated fuzzy set resulting from the Mamdani algorithm.

Table 5. Fuzzy if-then rules.

Rule no.	**Fuzzy rule and rule weight**
1	If (likelihood is rare) and (severity is insignificant) then (risk is insignificant) (1.00)
2	If (likelihood is rare) and (severity is minor) then (risk is acceptable) (0.40)
3	If (likelihood is rare) and (severity is moderate) then (risk is acceptable) (0.40)
4	If (likelihood is rare) and (severity is major) then (risk is acceptable) (0.40)
5	If (likelihood is rare) and (severity is catastrophic) then (risk is acceptable) (0.40)
6	If (likelihood is unlikely) and (severity is insignificant) then (risk is acceptable) (1.00)
7	If (likelihood is unlikely) and (severity is minor) then (risk is acceptable) (1.00)

8	If (likelihood is unlikely) and (severity is moderate) then (risk is acceptable) (0.40)
9	If (likelihood is unlikely) and (severity is major) then (risk is intermediate) (0.40)
10	If (likelihood is unlikely) and (severity is catastrophic) then (risk is intermediate) (0.40)
11	If (likelihood is possible) and (severity is insignificant) then (risk is acceptable) (1.00)
12	If (likelihood is possible) and (severity is minor) then (risk is acceptable) (1.00)
13	If (likelihood is possible) and (severity is moderate) then (risk is intermediate) (1.00)
14	If (likelihood is possible) and (severity is major) then (risk is intermediate) (0.40)
15	If (likelihood is possible) and (severity is catastrophic) then (risk is significant) (0.40)
16	If (likelihood is likely) and (severity is insignificant) then (risk is acceptable) (1.00)
17	If (likelihood is likely) and (severity is minor) then (risk is intermediate) (1.00)
18	If (likelihood is likely) and (severity is moderate) then (risk is intermediate) (1.00)
19	If (likelihood is likely) and (severity is major) then (risk is significant) (1.00)
20	If (likelihood is likely) and (severity is catastrophic) then (risk is significant) (0.40)
21	If (likelihood is almost certain) and (severity is insignificant) then (risk is acceptable) (1.00)
22	If (likelihood is almost certain) and (severity is minor) then (risk is intermediate) (1.00)
23	If (likelihood is almost certain) and (severity is moderate) then (risk is significant) (1.00)
24	If (likelihood is almost certain) and (severity is major) then (risk is significant) (1.00)
25	If (likelihood is almost certain) and (severity is catastrophic) then (risk is intolerable) (1.00)

Table 6. Event definition.

EVENT	SIGN	DESCRIPTION
LEAKAGE	E1	A gas leak refers to an unintended leak of natural gas from a pipeline.
RUPTURE	E2	If the piping design pressure is exceeded, pipe rupture may occur.
EXPLOSION	E3	Gas explosion is an explosion resulting from mixing gas, typically from a gas leak, with air in the presence of an ignition source.

In this research, six kilometers of the first nationwide gas transmission pipeline, which is the oldest pipeline in Iran, is studied. The selected six kilometers are divided into six zones: A to E, based on the thickness of the pipe, population density, equipment passage and similar things. In each zone, it is assumed that possible events are limited to leakage, rupture and explosion. In each zone and according to the defined consequences s, the technical, safety, environmental and cost consequences were defined. Technical consequences are scored based on the time required for repair, safety based on the severity of damage to the workforce and people, environmental based on the emission and sustainability of pollution, and cost based on the company's financial situation. Fuzzy numbers listed in Table 7 were used for weighting. In order to get the opinion of the experts, four people were asked for their opinion and based on Table 8, points were given to each expert, and the weight of the experts was calculated based on this.

Table 7. The fuzzy number to compare the events and consequences.

Description	Fuzzy number
Absolutely equal	(1,1,1)
Very negligible and less important	(1,1,3)
Somehow important	(1,3,5)
Important in average	(3,5,7)
Very important	(5,7,9)
Absolutely important	(7,9,9)

Table 8. Experts' scores to weigh the received comments.

Work experience	Education	Score
25-30 yrs	Doctoral degree (Ph.D.)	5
20-25 yrs	Master's degree (M.Sc.)	4
15-20 yrs	Bachelor's degree (B.Sc.)	3
10-15 yrs	Associate degree	2
Less than 10 yrs	Diploma (High school)	1

In this paper, the first nationwide gas transmission line is studied. Iran Gas Transmission Company ranks first in Asia and The Middle East in terms of the volume of pipelines and facilities under operation (more than 36 thousand kilometers of pipelines and 81 gas pressure boosting stations) and it ranks fourth in the world after the US, Russia and Canada. In addition, this company has the potential to transfer more than 280 billion cubic meters of gas per year. The reason for choosing the first national pipeline is the age of this line, which is more than forty years old. A six-kilometer section of this line that passes through the touristic and dense city of Tonekaben has been studied. In Table 9, the characteristics of the studied line are mentioned.

Table 9. Technical characteristics of the gas transmission pipeline under study.

Name of pipeline	The first national gas transmission pipeline in Iran
Construction year	1969
Place	Tonekabon city
Origin	1032 km
Destination	1038 km
Diameter	30 inches
Length	6 km

According to parameters such as population density, different thicknesses of the pipe, crossing the width of the raging Cheshmeh Kileh river and also the intersection with the road, these six kilometers are divided into six zones A to E, and the risk assessment in each zone is studied for three E1 to E3 consequences.

The risk matrix formed for this study includes the probability of occurrence of each of the E1-E3 events described in Table 1. In Table 2, possible consequences s are divided into four types of technical, safety, environmental and economic consequences s. As it is clear from the events, in the technical consequence, the severity of the damage and the possibility of repair in the shortest possible time has been considered. In the safety consequence, the amount of damage to humans, in the environmental consequence, the duration of the damage, and in the economic consequence, the amount of Rial (currency of Iran) costs are considered. In the following, the weight of each of these events compared to each other was calculated using the hierarchical analysis method. The weight of the consequences s, experts and different events was shown in Tables 10-12.

Table 13 reports the equipment of each zone. To calculate the risk in the simple matrix, the opinion of the experts regarding the probability of occurrence and the event was received, and by averaging the values (neglecting the weight of the experts and the weight of the events and occurrences), the risk was calculated. In the weighted matrix and the fuzzy matrix...

PT was calculated by multiplying the weight of each expert by the assigned probability, which indicates the probability of each event occurring in the desired zone. Then, considering the weight of each expert in the assigned numbers for the severity of events, W_{CT},W_{CS}, W_{CE} and W_{CC} are calculated. Now, the product of probability in each of the above parameters determines the risk of that type of event for the consequence determined in that specific zone. For example, the product of probability and incident of the environmental consequence of the second consequence shows the environmental risk of a pipeline rupture in the first zone. Experts' numbers are fuzzified with the help of MATLAB software, and then the risk number is determined by the defuzzification operation.

In the following, considering the weight of the consequences s that are presented in Table 12, CT is calculated in each of the four mentioned events. The result of multiplying the probability number by the events number determines the risk of each event in that zone, which is shown by $RISK_{EVENT}$. Finally, by taking into account the weight of each of the consequences s listed in the table, the risk is determined in five zones, which is shown by $RISK_{ZONE}$.

Table 10. Comparison of weights of the defined events.

E_1	E_2	E_3
0	0.25	0.75

Table 11. Comparison of expert weights.

D_1	D_2	D_3	D_4
0.28	0.25	0.25	0.22

Table 12. Comparison of weight of the considered consequences.

W_{CT}	W_{CS}	W_{CE}	W_{CC}
0.29	0.66	0.05	0

Table 13. Pipeline Zone Classification by Congestion and Intersection Characteristics

ZONE	Km	Pipeline class	Length(Km)	Description
A	1031-1032	C	1	Low congestion-There is no intersection with the road and river.
B	1032-1034	C	2	High congestion-There is an intersection with the road.
C	1034-1035	D	1	Low congestion-There is an intersection with the road and river.
D	1035-1036	C	1	Low congestion-There is an intersection with the road.
E	1036-1037	C	1	Very low congestion-There is no intersection with the road and river.

2.4. Three-Dimensional Risk Matrix of Uncertainty

In this study, risk is defined as the product of the probability of occurrence and the severity of the consequence. In another definition, risk is equivalent to uncertainty. This study attempts to structure a model with the aim of enhancing confidence. Accordingly, a new model is proposed under the title "Three-Dimensional Uncertainty Matrix" to better account for ambiguity in expert-based assessments. In this model, in addition to the main components of risk—namely the probability of occurrence (P) and consequence severity (C)—a third dimension is considered as expert uncertainty. The results derived from expert judgment are included in the model so that differences in individual assessments can be reflected quantitatively in the final decision-making process.

In this method, initially, for each event, four experts provide scores for the probability and consequence severity on a scale of 1 to 5. From these scores, the average and standard deviation for each component is calculated. The standard deviations are then converted into discrete uncertainty multipliers based on a predefined classification table, as shown in Table 14:

Table 14. Classification of standard deviation into uncertainty coefficient (U)

Standard Deviation	**Uncertainty Coefficient**
σ≤0.4	1
0.4≤σ<0.8	1.25
0.8≤σ<1.2	1.5
1.2≤σ<1.6	1.75
σ≥1.6	2

Using the above coefficients, the uncertainty multipliers for both probability and consequence are determined separately. Their product is then entered into the final risk formula as the combined uncertainty coefficient:

R = P × C × U
U = U_P× U_C

This model gives a three-dimensional structure to the risk matrix. Then, a composite decision matrix is used based on two variables: the risk value and the level of uncertainty (U), to propose an appropriate management strategy. Using the above coefficients, the uncertainty multiplier for probability and consequence is determined separately, and their product is then included in the risk formula.

To classify the combined uncertainty, the product U_P×U_C is divided into five bands:

Table 15. Classification of U ranges into uncertainty levels.

Combined Uncertainty (U)	**Uncertainty Level**
U≤1/2	Very Low
1/6≤ U<1/2	Low
2/2≤U<1.6	Moderate
3≤U<2/2	High
U≥3	Very High

Figure 17 illustrates the three-dimensional risk matrix, where the probability of occurrence ranges from 1 to 5, the consequence severity ranges from 1 to 5, and the uncertainty ranges from 1 to 4.”

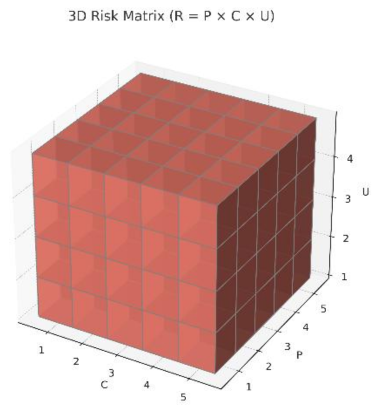

Figure 7 .3D Risk Matrix

3. Results and Discussion

As described, six kilometers of the first national line were selected for study, as shown in Figure 8.

Figure 8. Aerial map of the pipeline under study

In Table 16, the opinion of all four experts is stated. If we pay attention to the probability of occurrence of each of the events, it can be understood that in the gas transmission industry, in compliance with safety issues, the probability of occurrence of failure in each of the described events is not very high.

In this table, P_E indicates the probability of occurrence of each consequence in each zone. Each expert's opinion is marked with D_1 to D_4. The numbers related to the severity of technical, safety, environmental and economic consequences s are denoted by *CT*, *CS*, *CE* and CC are specified in the table. The events defined in Table 6 are shown with E_1 to E_3 in Table 14.

In the four Consequences defined, the lowest numbers are assigned to leaks and the highest numbers are assigned to explosions. However, it is obvious that the possibility of leakage in pipelines is more than an explosion.

Leakage in gas pipes is somewhat normal. The leakage itself may not pose much of a risk, but it may lead to larger events with more significant risks. Therefore, leakage detection in gas transmission lines is done regularly and accurately. This care made it possible to control the severity of the events resulting from this event.

Table 16. Experts' opinions about the probability of occurrence and severity of events.

ZONE		**D1**	**D2**	**D3**	**D4**	**D1**	**D2**	**D3**	**D4**	**D1**	**D2**	**D3**	**D4**	**D1**	**D2**	**D3**	**D4**	**D1**	**D2**	**D3**	**D4**
	EVENT	PE	PE	PE	PE	CT	CT	CT	CT	CS	CS	CS	CS	CE	CE	CE	CE	CC	CC	CC	CC
A	E1	2	2	3	2	1	1	2	2	1	1	1	1	1	2	2	2	1	2	2	2
	E2	1	2	2	1	2	2	2	2	3	3	3	4	3	5	3	3	1	1	1	2
	E3	1	1	2	1	2	3	2	2	4	5	4	5	4	5	3	3	1	2	1	2
B	E1	3	2	3	2	1	1	2	2	2	1	1	1	2	2	2	2	2	2	2	2
	E2	2	2	2	2	3	2	3	3	4	3	3	4	4	5	3	3	4	5	5	4
	E3	2	2	2	2	3	2	2	3	5	5	5	5	4	5	3	3	5	5	5	5
C	E1	3	2	2	2	1	2	2	5	2	2	1	1	2	3	2	2	2	1	1	2
	E2	2	2	2	2	4	5	5	4	3	3	3	3	4	5	3	3	3	3	3	2
	E3	2	3	2	2	5	5	5	5	3	3	3	4	4	5	3	3	2	2	3	2
D	E1	2	2	3	2	1	1	2	2	1	1	1	1	1	2	2	2	1	1	1	2
	E2	1	2	2	1	2	2	3	3	2	3	3	4	3	5	3	3	3	2	3	3
	E3	1	2	2	1	3	2	2	3	4	4	4	5	4	5	3	3	1	1	1	2
E	E1	2	2	3	2	1	1	2	2	1	1	1	1	1	2	2	2	1	1	1	2
	E2	1	2	2	1	1	1	2	2	2	2	3	4	3	5	3	3	1	1	1	1
	E3	1	1	2	1	2	1	2	2	4	2	4	5	4	5	3	3	1	1	1	1

In Table 17, the risk in different consequences has been calculated by four methods: simple matrix, weighted matrix, fuzzy weighted matrix and three-dimensional uncertainty matrix. In the simple matrix, the average score of experts is used to calculate the probability and the severity of each consequence. In the weight matrix method, the weight of each expert is included to calculate the probability and the severity of each event. In the last column, fuzzy numbers are used to calculate risk. Considering that the four selected experts did not differ much in terms of education and experience, the results of the matrices are almost similar. At this stage, considering that the risk has been calculated in each consequence, it was only necessary to consider the weight of the experts. In the table, technical risk is shown with R_T, safety risk with R_S, environmental risk with R_E and economic risk with R_S. As it is known, economic risk and safety risk are higher in zone B. The reason for this is the large number of residential units located in the pipeline route in this zone. On the other hand, the technical and environmental risk in zone C is higher than other zones. The gas pipe passes through the river in this zone, and if a problem occurs, more time is needed to establish the gas flow. Regarding event E3, the risk value R_S is higher in zone B than in zone C in all methods except the three-dimensional uncertainty matrix. This indicates that, according to the experts, the likelihood or severity of this event in zone C is greater than in zone B

Table 17. Risk of the four consequences for each event in each zone.

		SIMPLE MATRIX				**WEIGHT MATRIX**				**FUZZY MATRIX**				**3D MATRIX**			
ZONE	**EVENT**	R_T	R_S	R_E	R_C	R_T	R_S	R_E	R_C	R_T	R_S	R_E	R_C	R_T	R_S	R_E	R_C
A	**E1**	**3.38**	**2.25**	**3.94**	**3.94**	**3.02**	**2.25**	**4.01**	**4.01**	**4.37**	**4.32**	**4.32**	**4.32**	**5.27**	**2.81**	**6.15**	**6.15**
	E2	**3.00**	**4.88**	**5.25**	**1.88**	**4.34**	**4.92**	**5.25**	**1.83**	**4.38**	**6.99**	**7.91**	**3.69**	**3.75**	**7.62**	**9.84**	**2.93**
	E3	**2.81**	**5.63**	**4.69**	**1.88**	**4.51**	**5.66**	**4.65**	**1.84**	**4.43**	**6.73**	**6.3**	**3.21**	**4.39**	**8.79**	**8.79**	**2.93**
B	**E1**	**3.75**	**3.13**	**5.00**	**5.00**	**3.67**	**3.01**	**4.94**	**4.94**	**4.37**	**4.37**	**4.37**	**4.37**	**5.86**	**4.88**	**6.25**	**6.25**
	E2	**5.50**	**7.00**	**7.50**	**9.00**	**6.61**	**7.00**	**7.44**	**9.00**	**4.43**	**7.91**	**9.13**	**10.5**	**6.88**	**8.75**	**11.25**	**11.25**
	E3	**5.00**	**10.0**	**7.50**	**10.0**	**7.84**	**10.0**	**7.44**	**10.0**	**4.38**	**10.4**	**9.13**	**10.4**	**6.25**	**10.00**	**11.25**	**10.00**
C	**E1**	**5.63**	**3.38**	**5.06**	**3.38**	**5.04**	**3.63**	**5.56**	**3.71**	**8.09**	**4.37**	**6.72**	**4.38**	**14.06**	**5.27**	**7.91**	**5.27**
	E2	**9.00**	**6.00**	**7.50**	**5.50**	**7.84**	**6.94**	**7.44**	**5.56**	**10.5**	**7.71**	**9.13**	**4.43**	**11.25**	**6.00**	**11.25**	**6.88**

	E3	**11.25**	**7.31**	**8.44**	**5.06**	**8.99**	**7.31**	**8.37**	**5.06**	**13.1**	**7.59**	**9.13**	**6.25**	**14.06**	**11.43**	**15.82**	**7.91**
D	**E1**	**3.38**	**2.25**	**3.94**	**2.81**	**3.02**	**2.25**	**4.01**	**2.88**	**4.37**	**4.32**	**4.32**	**4.33**	**5.27**	**2.81**	**6.15**	**4.39**
	E2	**3.75**	**4.50**	**5.25**	**4.13**	**4.30**	**4.59**	**5.25**	**4.13**	**4.38**	**5.23**	**7.91**	**4.44**	**5.86**	**8.44**	**9.84**	**6.45**
	E3	**3.75**	**6.38**	**5.63**	**1.88**	**5.37**	**6.42**	**5.58**	**1.83**	**4.38**	**7.91**	**7.91**	**3.69**	**5.86**	**9.96**	**10.55**	**2.93**
E	**E1**	**3.38**	**2.25**	**3.94**	**2.81**	**3.02**	**2.25**	**4.01**	**2.88**	**4.37**	**4.32**	**4.32**	**4.33**	**5.27**	**2.81**	**6.15**	**4.39**
	E2	**2.25**	**4.13**	**5.25**	**1.50**	**3.72**	**4.22**	**5.25**	**1.50**	**3.69**	**4.45**	**7.91**	**3.69**	**3.52**	**7.73**	**9.84**	**1.88**
	E3	**2.19**	**4.69**	**4.69**	**1.25**	**3.85**	**4.73**	**4.65**	**1.25**	**3.89**	**6.25**	**6.3**	**2.9**	**3.42**	**10.25**	**8.79**	**1.56**

In Table 18, taking into account the weight of consequences (Table 12), the risk of each event is determined (R_{EVENT}). The severity of the event was calculated in a simple matrix with the average of technical, safety, environmental and economic consequence. As the weight of the economic consequence in this assessment is zero as per the experts' opinions (Table 10), the economic consequence was not considered in the weight matrix and the rest of the consequences s were calculated based on the weight of each consequence. In the fuzzy matrix, while considering the weight of the consequences s, fuzzy numbers are used to calculate the risk in each consequence. In the simple matrix, due to the high economic risk in zone B, the explosion risk in this zone has a higher rank than that in zone C; an issue that differs in the weighted and fuzzy matrix when considering the weight of each consequence. As it is clear in the table, the explosion risk is higher in zone C. What matters in the risk matrix is not the risk priority number. Rather, based on the level of risk that is given in Table 4, suitable reactions are selected under the title of risk management. Considering that this study does not define a risk management table for the three-dimensional uncertainty matrix, such a table has not been included.

As described, the obtained numbers were calculated in the fuzzy form in MATLAB software, and then the risk number was calculated in AutoCAD. Figure 9 is mentioned as an example to calculate the risk number. Figure 9, which is the output of MATLAB software, shows the risk levels.

Table 18. Risk of the three consequences s in different zones.

		SIMPLE MATRIX			WEIGHT MATRIX			FUZZY MATRIX		
ZO	EV	R_{EVENT}	*RPN*	*RISK LEVEL*	R_{EVENT}	*RPN*	*RISK LEVEL*	R_{EVENT}	*RPN*	*RISK LEVEL*
A	E1	3.38	3	Acceptable	3.02	3	Acceptable	4.35	3	Acceptable
B	E1	4.22	2	Acceptable	3.67	2	Acceptable	4.38	2	Acceptable
C	E1	4.36	1	Acceptable	5.04	1	Acceptable	4.92	1	Acceptable
D	E1	3.09	4	Acceptable	3.02	3	Acceptable	4.35	3	Acceptable
E	E1	3.09	4	Acceptable	3.02	3	Acceptable	4.35	3	Acceptable
A	E2	3.75	4	Acceptable	4.34	3	Acceptable	4.45	3	Acceptable
B	E2	7.25	1	Acceptable	6.61	2	Acceptable	6.58	2	Acceptable
C	E2	7	2	Acceptable	7.84	1	Acceptable	10.01	1	Intermediate
D	E2	4.41	3	Acceptable	4.30	4	Acceptable	4.45	3	Acceptable
E	E2	3.28	5	Acceptable	3.72	5	Acceptable	4.38	4	Acceptable
A	E3	3.75	4	Acceptable	4.51	4	Acceptable	6.52	4	Acceptable
B	E3	8.13	1	Intermediate	7.84	2	Acceptable	10.01	2	Intermediate
C	E3	8.02	2	Intermediate	8.99	1	Intermediate	10.40	1	Intermediate
D	E3	4.41	3	Acceptable	5.37	3	Acceptable	7.91	3	0.05 0.95
E	E3	3.20	5	Acceptable	3.85	5	Acceptable	5.14	5	Acceptable

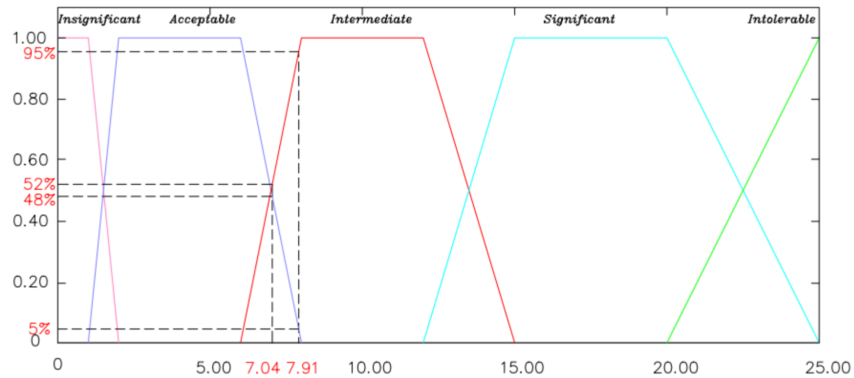

Figure 8. Obtaining fuzzy risk score.

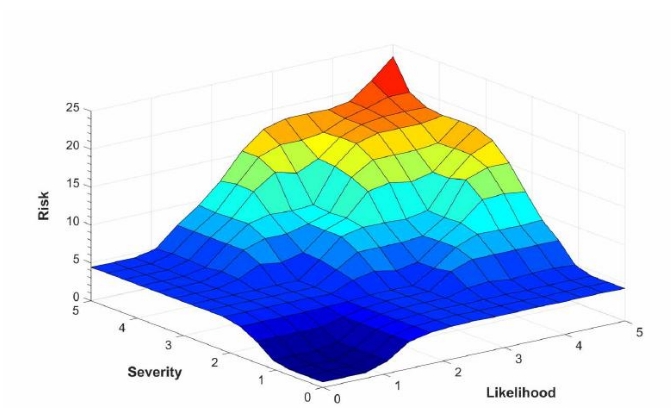

Figure 9. Risk management.

Table 19 presents the risk ranking in each zone. As shown, in all methods except the simple matrix, the risk in zone C is higher than in zone B, due to the impact of economic risk in zone B caused by the presence of building density. In the weighted and fuzzy weighted matrices, the economic parameter weight is zero; however, in the three-dimensional uncertainty matrix, the risk in zone C is higher than in zone B. This is because the economic risk weight has not been applied, and also due to greater uncertainty in zone C, as noted by the experts.

Table 19. Risk priority number.

	SIMPLE MATRIX		**WEIGHT MATRIX**		**FUZZY MATRIX**		**3D MARTIX**	
ZONE	$RISK_{ZONE}$	RPN	$RISK_{ZONE}$	RPN	$RISK_{ZONE}$	RPN	$RISK_{ZONE}$	RPN
A	3.63	4	4.47	4	6	4	6.30	4
B	6.53	1	7.53	2	9.15	2	8.40	2
C	6.46	2	8.71	1	10.30	1	9.71	1
D	3.97	3	5.10	3	7.04	3	7.01	3
E	3.19	5	3.81	5	4.94	5	6,18	5

Table 20 reports the risk level in each zone. Based on the assessment using the simple matrix, the risk is acceptable in all zones. When applying the weighted matrix, the risk in zone C is medium and requires corrective measures listed in Table 4. In the fuzzy matrix, the risk is medium in both zones B and C, which is shown in yellow. Also, as shown in Fig. 8, according to the risk number in zone D, it has an average risk of 52%. Due to population density, house and intersection with the road in zone B, the existence of the river and the difficulty of restoring a stable flow of gas, indiscriminate harvesting of river materials that can increase the probability of occurrence in zone C, as well as agricultural land and intersection with the road in zone C, the fuzzy risk matrix has shown the most logical result by considering the weights of events, occurrences and experts.

Table 20. Risk level in five zones understudy.

	SIMPLE MATRIX		WEIGHT MATRIX		FUZZY MATRIX		
Zone	$RISK_{ZONE}$	$RISK\ LEVEL$	$RISK_{ZONE}$	$RISK\ LEVEL$	$RISK_{ZONE}$	$RISK\ LEVEL$	
A	3.63	Acceptable	4.47	Acceptable	6	Acceptable (1)	
B	6.53	Acceptable	7.53	Acceptable	9.15	Intermediate (1)	
C	6.46	Acceptable	8.71	Intermediate	10.30	Intermediate (1)	
D	3.97	Acceptable	5.10	Acceptable	7.04	Acceptable (0.48)	Intermediate (0.52)
E	3.19	Acceptable	3.81	Acceptable	4.94	Acceptable (1)	

In Table 3, the uncertainty-based risk assessment matrix is presented. To model the uncertainty, the evaluation of uncertainty is shown in Table 21.

Table 21. Uncertainty-Based Risk Assessment Matrix

Severity Uncertainty	**Probability Uncertainty**				
	Very Low	Low	Moderate	High	Very High
Very Low	1	1.25	1.50	1.75	2
Low	1.25	1.56	1.87	2.18	2.50
Moderate	1.5	1.87	2.25	2.62	3
High	1.75	2.18	2.62	3.06	3.50
Very High	2	2.50	3	3.50	4.50

Based on Table 3 and Table 21, the risk levels in the simple, weighted, fuzzy weighted matrices, and the result of the multiplication of probability uncertainty by severity uncertainty are presented. In Table 22, the risk level is shown in a color-coded format.

Table 22. Risk levels of the four-fold consequences (Consequences) for each event (Event) in each zone, shown in color-coded format.

		SIMPLE MATRIX				WEIGHT MATRIX				FUZZY MATRIX				U			
ZONE	**EVENT**	R_T	R_S	R_E	R_C	R_T	R_S	R_E	R_C	R_T	R_S	R_E	R_C	R_{TU}	R_{SU}	R_{EU}	R_{CU}
A	**E1**	3.38	2.25	3.94	3.94	3.02	2.25	4.01	4.01	4.37	4.32	4.32	4.32	1.56	1.25	1.56	1.56
	E2	3.00	4.88	5.25	1.88	4.34	4.92	5.25	1.83	4.38	6.99	7.91	3.69	1.25	1.56	1.88	1.56
	E3	2.81	5.63	4.69	1.88	4.51	5.66	4.65	1.84	4.43	6.73	6.3	3.21	1.56	1.56	1.88	1.56
B	**E1**	3.75	3.13	5.00	5.00	3.67	3.01	4.94	4.94	4.37	4.37	4.37	4.37	1.56	1.56	1.25	1.25
	E2	5.50	7.00	7.50	9.00	6.61	7.00	7.44	9.00	4.43	7.91	9.13	10.5	1.25	1.25	1.50	1.25
	E3	5.00	10.0	7.50	10.0	7.84	10.0	7.44	10.0	4.38	10.4	9.13	10.4	1.25	1.00	1.50	1.00
C	**E1**	5.63	3.38	5.06	3.38	5.04	3.63	5.56	3.71	8.09	4.37	6.72	4.38	2.50	1.56	1.56	1.56
	E2	9.00	6.00	7.50	5.50	7.84	6.94	7.44	5.56	10.5	7.71	9.13	4.43	1.25	1.00	1.50	1.25

	E3	11.25	7.31	8.44	5.06	8.99	7.31	8.37	5.06	13.1	7.59	9.13	6.25	1.25	1.56	1.88	1.56
D	E1	3.38	2.25	3.94	2.81	3.02	2.25	4.01	2.88	4.37	4.32	4.32	4.33	1.56	1.25	1.56	1.56
	E2	3.75	4.50	5.25	4.13	4.30	4.59	5.25	4.13	4.38	5.23	7.91	4.44	1.56	1.88	1.88	1.56
	E3	3.75	6.38	5.63	1.88	5.37	6.42	5.58	1.83	4.38	7.91	7.91	3.69	1.56	1.56	1.88	1.56
E	E1	3.38	2.25	3.94	2.81	3.02	2.25	4.01	2.88	4.37	4.32	4.32	4.33	1.56	1.25	1.56	1.56
	E2	2.25	4.13	5.25	1.50	3.72	4.22	5.25	1.50	3.69	4.45	7.91	3.69	1.56	1.88	1.88	1.25
	E3	2.19	4.69	4.69	1.25	3.85	4.73	4.65	1.25	3.89	6.25	6.3	2.9	1.56	2.19	1.88	1.25

In Table 23, integrated risk management is defined by considering three parameters: probability of occurrence, severity of consequences, and uncertainty.

Table 23. Three-Dimensional Risk Management Table

Risk Level		Uncertainty Level				
Risk Value	Two-Dimensional Risk	$U = 1$ Very Low	$1.2 < U \leq 1.6$ Low	$1.6 < U \leq 2.2$ Medium	$2.2 < U \leq 3$ High	$U \geq 3$ Very High
$R \leq 3$	Very Low	No issue	Monitoring and data should be recorded.	Preliminary inspection should be conducted.	Inspection and information gathering required	Immediate review and analysis required
$3 < R \leq 7$	Low	Acceptable	Preliminary review should be conducted.	Information gathering + preliminary review should be conducted.	Suspension and detailed assessment required	Operational suspension and information gathering
$7 < R \leq 12$	Medium	To be monitored	Information gathering + analysis of potential consequences	Information gathering + corrective action required	Conditional operational shutdown required + consequence modeling with uncertainty	Shutdown + formation of emergency committee
$12 < R \leq 18$	High	Review and corrective action needed	Information gathering + corrective action required	Suspension and detailed assessment required	Operational shutdown required + consequence analysis + sensitivity analysis	Immediate shutdown + off-site crisis management
$18 < R \leq 25$	Very High	Immediate review and analysis required	Immediate corrective action required	Operational shutdown required + corrective action	Complete operational shutdown required + immediate reassessment	Total shutdown + portfolio-level risk management

4. Conclusions

In this research, cost, safety, environment and recovery time are not modeled separately. The initiative was used to define the consequence in the form of technical, safety, environmental and economic consequences. Gas Transmission Company in Iran is a fully state-owned company, which according to the country's policies; it is most important goal is to maintain a stable flow of gas. Mazandaran province, which is studied in this research, is at the end of the gas transmission pipeline starting from the south of the country. Despite the fact that Iran has the second gas reserve in the world, the gas of the northern provinces of the country (including Mazandaran province, Tonekabon city) is supplied from Turkmenistan. In some winter days, when Turkmenistan cuts off gas, the most important challenge for the gas transmission company is the stable supply of gas in the Northern provinces. Therefore, from the perspective of the experts of the company, who have been working and trained in this environment for years, the role of the economic factor was so low that its weight was considered zero. Based on this, the fuzzy matrix of three zones B, C and D needs corrective measures as stated below:

Smart pigging is carried out in smaller time intervals (every three years).

Leak detection is done at small frequent intervals (four times a year).

The cathodic protection system is upgraded and the results are carefully monitored.

In addition, strict compliance with the laws related to the privacy of gas transmission pipelines is very effective. The northern provinces of Iran have dense vegetation. The existence of beautiful nature, fertile land, sufficient rain, river, etc. have led to a high population density, attracting tourists and the high economic value of the land. It is natural that farmers and residents hardly abandon their precious land. This has caused the standard privacy of pipelines in the northern provinces to be ignored more than the rest of the country. If privacy is preserved, the consequences of different events will be significantly reduced.

The three-dimensional uncertainty matrix enhances the accuracy of risk analysis and assists in decision-making by simultaneously considering both risk severity and the level of confidence in its estimation. Thus, in scenarios where the uncertainty is high but the severity of risk is low, instead of taking costly measures such as ‘data acquisition’ or ‘expert reassessment,’ the risk can be managed through alternative policies

The final remark to mention is that gas transmission lines, equipment and stations are old and strained. In many places where the risk is high and there is especially population density, changing the class of pipes will help significantly due to its high impact on reducing the probability of occurrence of events. It is possible to prioritize changing the class of pipes by identifying points with higher risk.

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