10.051103/OMMS.260605112
Vol.5 Iss.1 pp.121-132 **Journal of Operational Management & Marketing Strategies (OMMS)**

A LOPA-based Approach To Risk Assessment and Management

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Abstract—**This article proposes an improved approach to risk criticality assessment by integrating fuzzy logic into Conventional Criticality Matrices (CCM) through a fuzzy inference system. Although conventional criticality matrices are widely used across various industrial sectors, they exhibit inherent limitations due to the subjectivity of expert judgments and the uncertainties associated with risk assessment data. The results highlight the potential of the rule-based fuzzy inference system to enhance conventional criticality matrices by flexibly representing and processing expert knowledge through the Fuzzy Criticality Matrix (FCM), thereby providing a better representation of uncertainties and improving the management of inherent risks. Furthermore, in order to reduce an unacceptable risk to an acceptable, or at least tolerable, level, the application of the conventional Layer of Protection Analysis (LOPA) method made it possible to assess risk reduction by analyzing the contribution of the different protection layers, verifying the adequacy of the existing independent protection layers, and identifying situations requiring the implementation of additional safety barriers. To conduct an inductive analysis, the use of the HAZOP method is essential, as it enables the accurate identification of possible causes and all potential observable consequences. The proposed approach, combining HAZOP, conventional LOPA, and fuzzy logic, was applied to a real industrial case study at SAROST S.A., demonstrating its effectiveness in supporting a more robust risk assessment and management process in industrial environments. Finally, as a perspective, a comparison between the two proposed fuzzy models namely the Fuzzy Criticality Matrix (FCM) and Fuzzy LOPA would be valuable to further improve the achieved level of risk criticality assessment.**

Keywords— **Criticality Index, Conventional Criticality Matrice, LOPA, HAZOP.**

I. INTRODUCTION

Commonly associated with a negative connotation, risk-taking can also be measured and reasoned and may therefore reflect the possibility of a positive consequence [13]. [9] specifies that the risk can be seen as positive or negative, [17, 13]. To illustrate this richness, [20] tries to improve business and business performance in order to make risks become opportunities that can create value. Towards a broader approach than the latter, risk is no longer considered as synonymous with losses, but as a driver for innovation and the creation of new values of which it can be qualified by its positive aspect, especially when it generates profits and not losses [4]. In this regard, the awareness that risk is part of the company's activity is trained and no longer considered as a simple exercise to meet regulatory requirements.

For a risk assessment, which is a mandatory step in the risk management process, it is necessary to make clear all the relevant scenarios. For each of the scenarios, it is reasonable to specify the probability (or frequency) of occurrence and the potential impact (or severity) of its consequences. In order to do this, the risk mapping taking into account the combination of the two risk parameters, frequency (F) and gravity (G) as input variables, and the criticality risk index (R) Output will be used. Since a certain number of these risks cannot be reduced to zero, the idea that «zero risk did not exist» is widely spread. So, it is necessary that the non-compressible part of these risks become «acceptable» and easily controllable [3, 18], and this through risk mapping. This combination will be used to express the acceptance criteria used for the evaluation, which will then be used to prioritize the identified risks in order to better identify those that require improvement as a priority.

However, the knowledge actually available in the risk assessment process is largely characterized by imperfection [12]. The affinity of the results of the evaluation depends on whether the imperfection of the knowledge used is fully or partially taken into account. To remedy these shortcomings, three main problems have to be solved:

1. The first concerns the scoring of frequency, severity and criticality scales. These scales are defined by an ordinal numerical classification, which contrasts with the uncertain and imprecise nature of information on the

ISSN: 2961-662X

10.051103/OMMS.260605112
Vol.5 Iss.1 pp.121-132 Journal of Operational Management & Marketing Strategies (OMMS)

frequency and severity of concrete situations, in particular the existence of rare events or recent systems at the time Design.

2. The following is due to a discontinuous categorization of the scales used which results in difficulties in interpreting the results of the evaluation.

3. The last one is due to the rule of crossing of the information on the parameters F and G in order to associate a classification of the criticality (index of risk). The product R = F x G is generally used, yet its meaning is strongly rejected for ordinal scales.

By accepting this observation, which is characterized by uncertainty and vagueness in the information available, and taking into account the limitations of numerical models in the face of complex models, our approach naturally involves a process using fuzzy logic, which proves to be more efficient than The digital models.

Indeed, the theory of fuzzy sets due to [10] proceeds essentially from the notion of linguistic variables. This type of variable is used to model imprecise or incomplete knowledge. It seems to offer a very adequate framework for the assessment of criticality (risk index), as long as it is defined as the set of formalisms and techniques that make it possible to represent and manipulate the inaccurate or uncertain information present in the Knowledge base of an expert system. [14] find that a large number of studies have prompted the introduction of fuzzy models to qualitative or semi-quantitative evaluation methods. The use of semi-quantitative evaluation seems to be a choice being proposed such as criticality matrix, calibrated risk graph [1], analysis of protective layers (LOPA), etc. as they are characterized [5], [19].

The choice of the LOPA method (Layer Of Protection Analysis) has been used to assess the reduction of risks deemed unacceptable to an acceptable or at least tolerable level by analyzing the contribution of different layers of protection that encompass the whole Safety barriers, from the design of the process to the emergency measures in the event of an accident, in order to calculate the residual risk expressed in accident frequency per year, which requires quantifying the frequencies of occurrence of the initiating events and The probabilities of failure of each layer.

A key role in the LOPA approach is to control the threat or vulnerability to limit the cause of the risk either on the impact to limit the consequence of the risk in real time.

To be able to protect such a scenario, we incite the combination of several independent and redundant protection layers to arrive at the compensation of potential failures that they are technical, organizational or human nature [2].

Based on this observation, the aim of this work is to integrate itself in this spirit and aims to propose a Conventional LOPA allowing the evaluation of the elements of an accident scenario and the measures of control of risks (safety barriers).

After a modest description of some key definitions related to the mapping of the inherent risks, we present there after matrix obtained residual risks. To explain the possible causes of a drift of the process and describe its consequences, we come to an inductive analysis by the HAZOP (HAZard and OPerability) method, during the phase of the risk qualitative analysis phase as presented by [11], in order to develop potential accident scenarios that may expose the LDE (Logistics Division for Energy) division. Finally, we develop the proposed LOPA approach as well as a discussion of the obtained results.

II. Litterature Review

A. Inherent Risk and Residual Risk

Uncertainty in potential events uses an estimate of the probability and impact of inherent risks to determine risk characteristics. During the execution of our mission, we are assigned as internal auditor (Interviewer) to provide assistance to managers in order to determine the residual risks related to the audited activities after taking into account an analysis of the implemented controls and to develop recommendations for a continuous improvement of the internal control of the LDE division.

[1] defines the Inherent risk as being "an entity is exposed in the absence of corrective actions taken by management to modify the probability of occurrence or impact".

To measure the inherent risk, we need:

Break society into a coherent whole process;

Define measurement scales of the likelihood and impact of identified inherent risks.

ISSN: 2961-662X

The inherent risks are evaluated at first then, once the management responses (responsible for the division LDE) are defined, the evaluation focuses on residual risks.

Calculation of the Score of Concentration of the Risks. To have the matrix of the inherent risks, we refer to the calculation of the score of concentration of the risks by multiplying the notes of the frequency (F) and the severity (S) of all the risks by using the following formula:

Score of concentration of the inherent risk (Criticality Score) = F*S (1)

The description of the frequency, severity and criticality scales refer and are presented in the following manner:

1) Frequency Scale : The probability of contingency is examined through five levels and estimated based on a listed frequency 10^{-n}/year. The occurrence probability classes on your scales are defined qualitatively and quantitatively, with a language designation for each class and a numerical ordinal ranking of 1 to 5 [15].

TABLE I. FREQUENCY SCALE

Level	Designations	Qualitative Descriptions
1	Unlikely	Extremely Unlikely over time of life of the installation
2	Rare	Very unlikely over time of life of the installation
3	Occasional	Unlikely over time of life of the installation
4	Frequent	possible over time of life of the installation
5	Very Frequent	Likely over time of life of the installation

2) Severity Scale: Estimation of severity is based on the consequences of a proposed scenario from an ordinal scale with five levels (1 to 5) [15].

TABLE III. SEVERITY SCALE

Level	Consequences	Significations
1	Negligible	Some minor injuries Damage weak and reversible
2	Marginal	Numerous minor injuries and some injuries with disabilities Significant and reversible damage or low and irreversible
3	Severe	Severe injuries Unit shut
4	Critical	Many injured with disabilities Significan and irreversible damage
5	Catastrophic	Death of occupants Plant shutdown

3) Criticality Scale: The multiplication of severity levels by those frequencies completes the risk assessment. However, the criticality risk characterized by a number corresponding to each grid cell, this number varies between 1 (minimum acceptable risk) to 25 (maximum unacceptable risk) [15].

TABLE III. CRITICALITY SCALE

Level	Consequences	Significations	Score
1	Acceptable (Green area)	Reduced risk, no necessary dispositions: preventive measures already in place seem sufficient	1,2,3
2	Tolerable (Yellow area)	medium risk, verify the need for risk reduction: preventive measures are desirable and a review of the position must be achieved	4,5
3	Critical (Orange area)	high risk, provisions for reducing: preventive measures are required with emphasis on collective protection	6,8,9,10
4	Unacceptable (Red area)	unacceptable risk, emergency provisions for the reductions: preventive measures must be applied immediately	12,15,16,20,25

ISSN: 2961-662X

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Vol.5 Iss.1 pp.121-132 **Journal of Operational Management & Marketing Strategies (OMMS)**

- Assigning an Internal Control Rating

After calculating the inherent risk, internal control rating measures the efficiency of an established control within the company in the face of a given risk. It is rated from 1 to 5 based on a judgment of the internal audit of responsible SAROST.
while taking the opinion of the responsible of the LDE division.

The latter may be:

- Effective;
- Effective but with possibility of improvement;
- Medium;
- Low; or
- Non-existent or very low.

This note must be assigned according to the following assessment grid (Table 4):

TABLE IV: THE ADEQUACY OF CONTROL (CONTROL SCORE)

Score	Note	Qualification Control	Description
5	Very high	Effective	The controls are properly designed and implemented. They help to achieve the desired objectives.
4	High	Effective but with possibility of improvement	The controls are properly designed and implemented but minimal improvements remain to be made.
3	Moderate	Medium	Controls are put in place and enforced but considerable improvements remain to be made.
2	Low	Low	The controls put in place are limited and a high level of risk still exists (inappropriate or faulty controls).
1	Very low	Not-existing or Very low	The controls are not existing (or assimilated to not existing). They do not reduce the level of risk.

- Calculation of the Residual Risk Score

The residual risk is calculated by dividing the score of concentration of inherent risk by the note of internal control:

$$\text{Residual Risk Score} = \text{Inherent Risk Score} \times (1-(\text{control score}/5)) + 0.2\times \text{Inherent Risk Score} \quad (2)$$

At this stage, we can develop an internal audit plan based on the risk based on:

- Important risks positioned on the mapping
- Scores of the obtained residual risks

We can establish a list of the operating divisions or the directions according to a decreasing order of residual risk scores to attack areas of major risks.

The matrix of the residual risks can be used in the unfolding process of the audit engagement in knowledge-making phase to better plan its missions.

B. Residual Risk Matrix

The primary objective of any risk assessment is to reduce risks considered unacceptable to an acceptable, or at least tolerable, level. Accordingly, for each identified risk, the working group defines the preventive measures that can be implemented to better plan its activities. As a priority, attention should be focused on scenarios with the most severe consequences. This prioritization is based on the color-coded risk matrix presented in the technical document entitled "Risk Assessment Matrix." This grid has 4 arees namely [16]:

1) Control Improvement: A high risk of exposure with weak controls in place. Priority area for the establishment or strengthening of adequate controls.

2) Monitoring Controls: A high risk of exposure but mastered by the company through the adequate controls in place. The company must always ensure that these controls are working correctly.

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3) Monitoring Risks: A risk of low exposure with weak controls in place. The company must always ensure that the risk level has not increased.

4) Acceptance: A low exposure to risk with high controls in place, these risks is accepted by the company which must always ensure that these controls are operating correctly.

«Referring also to Criticality Score and the table of Score Control of the (Appendix), we obtained following the residual risks matrix (Figure 1):

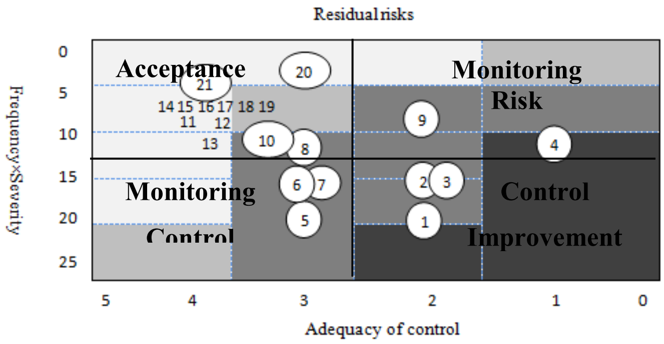

Fig 1. Residual risks matrix

When the identified hazardous events (Events 1, 2, and 3) fall within the priority zone (Improvement Controls), immediate investment in additional risk reduction measures, particularly safety barriers, is essential for the DLE division to prevent and/or mitigate their potential consequences.

These barriers enable the assessment of risk reduction by evaluating the contribution of the different Independent Protection Layers (IPLs), encompassing all protective measures from process design to emergency response provisions. To ensure a comprehensive analysis, it is essential to employ a method capable of accurately identifying the possible initiating causes and the full range of potential consequences.

These considerations justify the use of an inductive HAZOP analysis to develop accident scenarios [6], followed by a barrier-based approach using the LOPA method to determine the mitigated consequence frequency of the identified scenarios.

Accordingly, the following section is devoted to the application of the conventional LOPA mode [15].

III. Methodologie

In this study, a mixed-methods approach combining qualitative and semi-quantitative techniques was adopted to achieve the research objectives. Among the available semi-quantitative risk assessment methods, Layer of Protection Analysis (LOPA) is widely recognized as an effective tool for evaluating risk reduction through the analysis of multiple independent protection layers. According to [19], LOPA relies on order-of-magnitude estimates, typically based on powers of ten, to characterize the likelihood of initiating events, the effectiveness of protection layers, and the frequency of hazardous consequences. The method evaluates the contribution of safety barriers, ranging from process design features to emergency response measures, in reducing risks to acceptable or tolerable levels. In this regard, the definition of tolerable risk by the [8], Risk accepted in a certain context and based on the values admitted by the company, let's show through the difficulty of retaining goals and fixed criteria for risk acceptance.

The LOPA method can be a method capable of ensuring that the level of risk is mastered to an acceptable level. This is a reasonable methodology, based on a reasoned approach allowing a rapid identification of protection levels reducing the frequency and / or consequence dreaded initiating events.

LOPA offers a practical compromise between qualitative and fully quantitative approaches. It reduces the subjectivity inherent in purely qualitative assessments while avoiding the complexity, data requirements, and cost associated with detailed quantitative risk analyses. By systematically evaluating the performance of independent protection layers, LOPA method has for the end to value all the protective layers implemented to reduce risk to show whether the number of existing layers of protection are sufficient to ensure that the level of risk is at least tolerable or if new layers of protection must be added. It may also be adapted well to study complex processes which have multiple barriers of protection or emergency procedures in place to react to a specific initiating event that we cannot be reassured of a judgment relied exclusively on a qualitative

ISSN: 2961-662X

judgment. The LOPA method allows to complete the analysis conducted during the HAZOP (conducted after the HAZOP) if the working group considers the scenario too complex or that the consequences are too important [2]. The following section presents the implementation of the proposed LOPA model.

A. Realization of a HAZOP study within the division LDE

The LOPA method begins with data developed during the HAZOP study and takes into account each identified hazard by documenting the initiating cause and the protective which avoid or limit the danger.

The HAZOP method, mentioned in the International Electro technical Commission [7], considers the potential drift (or deviations) of the main functioning parameters of the system related to the operation of the installation. For each of these drifts, we must seek to determine the causes and potential consequences of accident scenarios. She even admits distinguishing different safety barriers that can avoid these accidents. The analysis led during the HAZOP can be completed by the LOPA method.

To focus on the most significant hazardous scenarios, a selection process was applied based on criteria established by SAROST. The selected scenarios retained for further analysis are presented in Table 5. The selection criteria were defined as follows:

• Scenarios with a criticality score lower than 15 were excluded from further analysis.
• Scenarios associated with a control score greater than 2 (i.e., scores of 3, 4, or 5) were excluded, as they were considered adequately controlled by existing safety measures (Fig. 1).

The remaining scenarios were subjected to a detailed LOPA analysis in order to evaluate the effectiveness of the existing protection layers and estimate the residual risk levels.

TABLE V. PRESENTATION OF THE SHEET HAZOP : ACCIDENT SCENARIOS OF THE LDE DIVISION

N°	Word guide	Element	Deviation	Possible causes	Consequence	Protections
1	less	chemical	less compatibility	incompatibility chemical	chemicals burns and poisonings	apply HSSE procedures (display and application compatibility of the table Chemicals, FDS)
2	do not do / less	retention tank	no/less tank	lack of retention tank»	spill of Chemical and environment contamination	apply HSSE procedures (spill kit) prevention of fire and eliminate ignition source
3	less	air flow	less flow	explosive atmosphere with air	fire or explosion	apply HSSE procedures (anti explosion wall) prevention of fire and eliminate ignition source (gas detector)

B. LOPA method Application

The analysis carried out during HAZOP can be complemented by the LOPA method. The phases of the LOPA method are explained in detail in the following.

1) Step 1: Establishment of the Acceptance Criteria: By the referring to the criticality grid (Fig. 2), In case of occurrence of undesirable events (1, 2 and 3) in the priority area (improving controls), member of the LDE division are called to put in place risk control measures to anticipate and / or mitigate its consequences.

2) Step 2: Analysis of Scenarios: The LOPA method focuses on scenarios associated with the most severe consequences. Based on the results obtained from the HAZOP study (Table 5), the identification of these scenarios constitutes a fundamental step in the analysis, (Table 6).

TABLE VI. SCENARIOS OF RETAINED ACCIDENTS

Scenario	Initiator Event (IE)	Consequence
1	incompatible chemical	chemicals burns and poisonings
2	lack of retention tanks	spill of Chemical and environment contamination
3	explosive atmosphere	fire or explosion

ISSN: 2961-662X

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3) Step 3: Estimation of the Initiators Events (IE) Frequency: The estimation of the Initiating Event (IE) frequencies was carried out based on expert judgment. This assessment relied on the expertise of on-site specialists, drawing upon their accumulated experience in the field under investigation, including their professional knowledge, operational feedback, and potential hazard analyses. The resulting estimated frequencies are presented in Table 7.

TABLE VII. INITIATORS EVENTS FREQUENCY

Scenario	Initiator Event (IE)	Code	Frequency (/year)
1	incompatible chemical	IE_1	3,16E-02
2	lack of retention tanks	IE_2	1,00E-01
3	explosive atmosphere	IE_3	2,24E-02

4) Step 4: Identification of the Independent Protection Layers (IPL): The Independent Protection Layers (IPLs) considered in this study are as follows:

- Implementation of HSSE procedures;
- Fire prevention through the elimination and control of ignition sources;

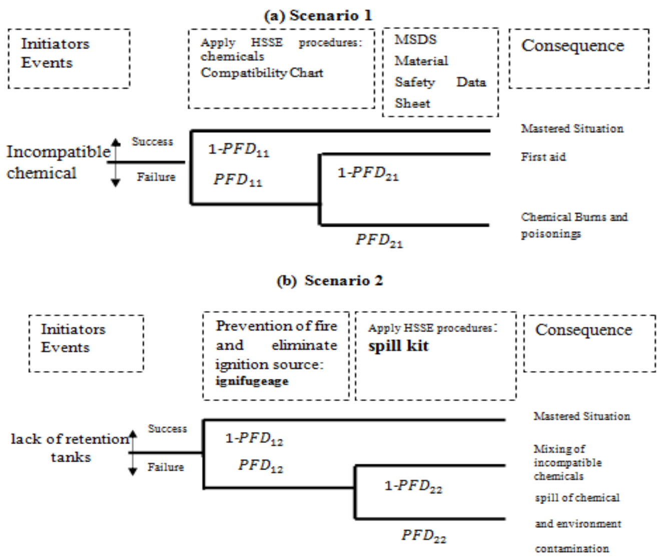
To evaluate the Probability of Failure on Demand (PFD) of an IPL, the required data may be obtained from reliability databases, operational feedback from the relevant industrial sector (the DLE division), or data provided by the contractor. The Probability of Failure on Demand (PFD) values of these Independent Protection Layers are presented in Table 8.

TABLE VIII. PROBABILITY OF FAILURE ON DEMAND OF THE IPL

Scenario	IPL	Code	PFD
1	apply HSSE procedures	PFD_{11} PFD_{21}	3,16E-01 1,00E-01
2	prevention of fire and eliminate ignition source apply HSSE procedures	PFD_{12} PFD_{22}	3,16E-01 3,16E-01
3	prevention of fire and eliminate ignition source apply HSSE procedures	PFD_{13} PFD_{23}	3,16E-04 3,16E-02

5) Step 5: Development of the Scenarios of Accidents and Determination of their Frequencies: Identification of the Scenario

Fig. 2 shows an example of a dimension to the consequences of undesirable events using the Event Tree Analysis (ETA) of the first scenario.



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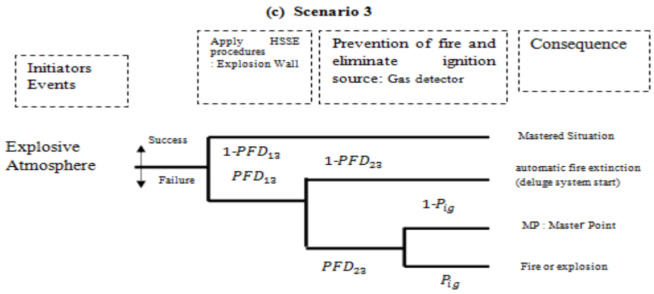

Fig. 2 Layers of protection and conduct of accident scenarios Retained : (a) Scenario 1, (b) Scenario 2 and (c) Scenario 3

Calculation of the Frequency of Reduced Consequence

The calculation of the frequency of the reduced consequence of the accident scenarios 1 and 2 is obtained by means of this equation $f_C = f_i \times [PFD_1 \times \ldots \times PFD_n]$ and that of the scenario 3 is obtained by means of this equation $f_C^{feu} = f_i \times [PFD_1 \times \ldots \times PFD_n] \times P^{ignition}$, we obtain:

$f_1^c = IE_1 . PFD_{11} . PFD_{21}$= 3,16E-03/an.

$f_2^c = IE_2 . PFD_{12} . PFD_{22}$= 1,00E-02/an.

$f_3^c = IE_3 . PFD_{13} . PFD_{23} . Pr_{ig}$= 2, 12E-08/an.

6) Step 6: Assessment of Accident Scenarios against the Criteria of Acceptability: To support decision-making regarding the acceptability criterion of the accident scenarios under study, the calculated probability value, representing the frequency of the mitigated consequence, is compared with the tolerable risk frequency adopted by the company. Based on the application of the conventional LOPA method and the comparison between the frequencies of the mitigated consequences for the three accident scenarios and the company's maximum tolerable risk frequency (10^{-5}), it can be observed that the mitigated consequence frequencies f_1^c and f_2^c, corresponding to the first and second scenarios, respectively, are considered unacceptable. In contrast, the mitigated consequence frequency f_3^c, associated with the third scenario, is considered acceptable.

III. Results and Discussion

The estimated frequency of each of the three accident scenarios is used as an input to the fuzzy inference system. Because the fuzzy severity scale is continuous, the critical fuzzy set is explored by assigning severity values of 3.5, 3.75, and 4 to the three scenarios, respectively. The fuzzy inference is executed by means of "Fuzzy Logic Toolbooks" under Matlab. The figure 3 shows an example of the fuzzy inference process concerning the S1 scenario.

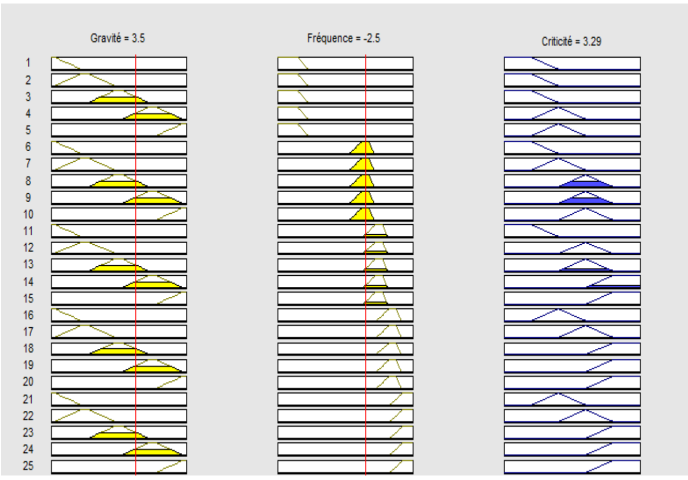

Fig. 3 Fuzzy rule-based inference progress : Case Scenario S1

ISSN: 2961-662X

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The criticality assessment results for the three studied scenarios are summarized in the table 9.

TABLE IX. RESULTS COMPARED A BOTH APPROACHES AS TO THE EVALUATION OF CRITICALITY

Scenario	Inputs		Outputs (criticality index)		Interpretation
	F	G	CCM	FCM	
S1	3,16E-03	3.5	C(3)	3.29 (C-71%,NA-29%)	under estimation
		3.75	C(3)	3.24 (C-76%,NA-24%)	under estimation
		4	C(3)	3.23 (C-77%,NA-23%)	under estimation
S2	1,00E-02	3.5	C(3)	3.63 (C-37%,NA-63%)	under estimation
		3.75	C(3)	3.82 (C-18%,NA-82%)	under estimation
		4	C(3)	3.82 (C-18%,NA-82%)	under estimation
S3	2,12E-08	3.5	T(2)	1.37 (A-63%,T-37%)	overestimation
		3.75	T(2)	1.74 (A-26%,T-74%)	overestimation
		4	T(2)	2 (T-100%)"	-

By comparing the results obtained from the two criticality assessment approaches, namely the Conventional Criticality Matrix (CCM) and the Fuzzy Criticality Matrix (FCM), several key conclusions can be drawn:
The above table highlights a clear distinction between the two approaches, reflected by the overestimation or underestimation of the criticality levels of the studied scenarios. Specifically, the CCM classified the first two scenarios as Critical (C), whereas the FCM identified the second scenario as belonging to the Not Acceptable (NA) category, with a membership degree exceeding 63%. This finding indicates the need to revise the existing prevention and protection measures in order to achieve more effective risk management for these two scenarios. From a practical perspective, the managers of the DLE division should take immediate action to reduce the identified risks. For the three studied scenarios, the fuzzy criticality index is characterized by gradual membership in more than one criticality category, each associated with a distinct membership degree. For the first scenario, the criticality value mainly belongs to the Critical (C) category, as the fuzzy criticality index of 3.29 belongs to the Critical (C) and Not Acceptable (NA) categories with membership degrees of 0.71 and 0.29, respectively. In contrast, for the second scenario, the CCM assigns the scenario exclusively to the Critical (C) category, whereas the fuzzy criticality index of 3.63 belongs to the Critical (C) category with a membership degree of 37% and to the Not Acceptable (NA) category with a membership degree of 63%.

- This comparison demonstrates that the conventional approach underestimates the criticality level of the first two scenarios, thereby promoting an overly optimistic decision-making process. Since the first two scenarios exhibit a certain degree of membership in the Not Acceptable (NA) category, a more detailed assessment of their severity is required to support more reliable risk management decisions.
- Conversely, the conservative approach intentionally overestimates the risk level in order to account for unfavorable situations, compensate for uncertainty, and support pessimistic decision-making, as illustrated by the third scenario (S3).
- The output of the membership function associated with the Tolerable (T) criticality category shows that, for criticality index values ranging from 1 to 2, the membership degree increases continuously from 0% to 100%. At a criticality index of 2, the value belongs entirely to the Tolerable (T) category, with a membership degree equal to 1 (100%). Between 2 and 3, the membership degree decreases continuously from 100% to 0%, reflecting the gradual transition from the Tolerable (T) category to the adjacent criticality category.»

IV. CONCLUSION

This study proposed an improvement to risk criticality assessment by integrating fuzzy logic into Conventional Criticality Matrices (CCM) through a fuzzy inference system. The results demonstrate that this approach provides a better representation of the imprecision and uncertainties associated with risk parameters while offering a more gradual, consistent, and realistic assessment than conventional criticality matrices. The Fuzzy Criticality Matrix (FCM) therefore constitutes an effective decision-support tool capable of improving the reliability of industrial risk assessment. Furthermore, the application of the conventional Layer of Protection Analysis (LOPA) method made it possible to verify the adequacy of the existing protection layers and to identify situations requiring the implementation of additional safety barriers in order to reduce the risk

ISSN: 2961-662X

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to an acceptable, or at least tolerable, level. To conduct a comprehensive analysis, the availability of a method capable of accurately identifying the possible causes and the full range of observable consequences is essential. For this reason, the use of the HAZOP method for inductive analysis is fully justified. The combination of the Fuzzy Criticality Matrix with the conventional LOPA method therefore provides a complementary framework that enhances the overall process of risk analysis and management. The obtained results confirm the relevance of the proposed approach for improving the accuracy and reliability of criticality assessments, particularly in situations where the available data are imprecise or uncertain. As a future perspective, it would be worthwhile to extend this research by developing a Fuzzy LOPA approach to incorporate uncertainty not only into criticality assessment but also into the parameters specific to the LOPA method. A comparative study between the proposed Fuzzy Criticality Matrix and a future Fuzzy LOPA approach would also enable the evaluation of their respective performances and the identification of their most suitable application domains.

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ISSN: 2961-662X

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APPENDIX

Risk Department SIMP

Risk N°	Wording	Criticality Score	Control Score
1	Risk of fire or explosion	20	2
2	chemical burns and poisonings	16	2
3	Spill Risk	16	2
4	Search logistics partners unsuccessful	12	1
5	Lack of information about potential customers	20	3
6	uncompetitive delivery offers	16	3
7	Risk stand-by periods	16	3
8	risk of night work	12	3
9	Risk management Chemicals	8	2
10	Risk of expired product: deterioration of the composition chemical	10	3
11	Risk of falling objects	12	4
12	Risk of falling (personal)	12	4
13	Equipment failure	10	4
14	Risk when cleaning the equipment with chemicals	8	4
15	Risks associated with manual handling of loads	8	4
16	Risks related to mechanical handling	8	4
17	Risk of painful postures	8	4
18	Temperature extremes: heat / cold	8	4
19	risks clashes between machines and pedestrians	8	4
20	hazardous chemicals	4	3
21	Lack of comparative grid supplier deals	6	4

ISSN: 2961-662X