

Application of LOPA Method in the Assessment and Risk Management

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Abstract— In order to determine the criticality of a risk, an assessment of the probability of occurrence (notion of frequency) and of the impact (notion of severity) are to be estimated. The criticality is the product of the probability of its occurrence and the impact that the risk has on the project, hence on the whole company. So, the practice of matrix or the criticality grid considering these two dimensions is necessary. However, the criticality grid involves the insufficiencies inherent to the subjective behavior of expert judgments and to the imprecise information engaged in the assessment of the risk. Taking into account the problems of the imperfection implied in the Conventional Criticality Matrix (CCM), the objective of this work is to develop a Fuzzy Criticality Matrix (FCM) to overcome these difficulties. The proposed model aims at improving the system of fuzzy inference. To lead an exhaustive analysis, the provision of a method allowing the precise definition of the possible causes and the entire observable consequences will be essential. All these reasons justify the utility of inductive analysis by the HAZOP method, during the phase of the risk qualitative analysis phase, in order to develop accident scenarios and a "barrier" approach using the LOPA method to determine the frequency of the reduced consequence of these scenarios. 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 proposed approach is applied to a test system which is the company SAROST S.A.

Keywords— Criticality, Fuzzy Set Theory, Risk Analysis, LOPA, HAZOP.

I. INTRODUCTION

For a risk assessment, which is a mandatory step in the risk management process, we believe 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 criticality matrices 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. 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 [2]. 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 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 $R = F \times G$ 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 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. A large number of studies have prompted the introduction of fuzzy models to qualitative or semi-quantitative evaluation methods [12]. The use of semi-quantitative evaluation seems to be a choice being proposed such as criticality matrix, calibrated risk graph [7], analysis of protective layers (LOPA), etc, as they are characterized [10], [3].

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 [4]. 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 [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. LITERATURE REVIEW

A. Risk

Risk is defined as the set of hazards likely to affect populations and compromise their physical integrity within a relatively short period of time [5].” Subsequently, [7] associates it with “the effect of uncertainty on objectives. These definitions highlight a dual perspective on risk:

- A pessimistic perspective, viewing risk as a high probability of loss.
- A more optimistic perspective, where risks are undertaken in pursuit of worthwhile and meaningful objectives.

Reference [15] states that risk in our world is essentially nothing more than our uncertainty regarding human decisions and the best ways to respond to them. Risk is therefore commonly defined using what is known as the “risk equation,” which is the most widely recognized and applied concept in the field of risk management. This equation plays a fundamental role in risk identification and assessment.

$$\text{Risk} = \text{Criticality} = \text{Severity} \times \text{Frequency} \\ = \text{Impact} \times \text{Probability}$$

B. Risk Management

Supply chain risk management is carried out collaboratively with partners within an integrated supply chain system through the application of risk management processing tools [16]. Supply Chain Risk Management (SCRM) is not an end in itself, but rather a set of defined methods and tools designed to control and mitigate risks. The primary objective of these methods and tools is not only to identify strategic risks, but also to prioritize them according to their significance in order to support rational and informed policy decisions regarding resource allocation. This approach aims to prevent or reduce the likelihood of a specific strategic risk occurring, as well as minimize its potential consequences should it materialize.

C. Risk Mapping

A Key Element of the Risk Management Process (RMP), Risk mapping is the structured representation of a set of identified and quantified risks within a given scope. It is a visual tool intended to provide the reader with an immediate overview of the situation [1]. Risk mapping, a key component of the risk management process, is a framework in which major risks are identified, categorized, and prioritized according to various

criteria, such as potential impact, probability of occurrence, or the current level of risk control that may affect the company's activities.

In order to better plan its missions, each working group determines the prevention measures that can be implemented for each identified risk. This has the effect of reducing the levels of risk. To determine priorities, it will be based on the color coding of the matrix of the technical document Risk Rating Grid. Referring also to Criticality Score and the table of Score Control, we obtained following the residual risks matrix (e.g. Fig. 1).

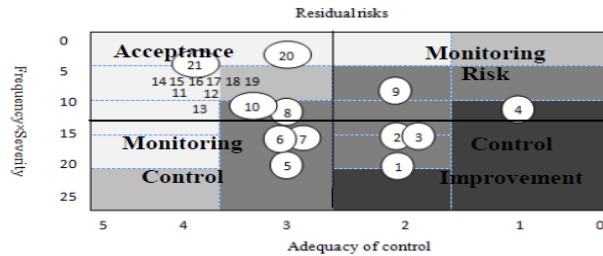


Fig. 1 Residual risks matrix

III. METHODOLOGIE

In this study, we adopted a mixed-methods approach, combining both qualitative and semi-quantitative methods to address the research objectives. The LOPA method is defined [9] as a semi-quantitative method, because it is based on levels determined by powers of 10 to indicate the likelihood, frequency and severity levels, developed in the optics of to assess the reduction of risk by analyzing the contribution of the different which include the set of barriers, from process design to the emergency measures in case of accident to reach a tolerable or acceptable level. In this regard, the definition of tolerable risk [6], "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. It presents an approach for assessing barriers to eliminate the subjective aspect of qualitative methods, with a cost-effective better than a purely quantitative approach.

This 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 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 [4]. All these reasons justify the utility of inductive analysis by the HAZOP method, during the phase of the risk qualitative analysis phase [8], in order to develop accident scenarios and a "barrier" approach using the LOPA method to determine the frequency of the reduced consequence of these scenarios. The subsequent section will, in fact, devote to the implementation of the LOPA model.

A. Realization of a HAZOP study within the division LDE

The HAZOP method [14], 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 description of the different causes, consequences and barriers persistent security within the LDE division of SAROST Company. Two selection criteria scenarios obtained for further analyses were selected thorough analysis are retained according to the company SAROST are shown in Table 1.

- All scenarios whose criticality scores below 15 are excluded.
- Any event whose control score is greater than 2 (3, 4 and 5) is excluded (e.g. Fig. 1).

TABLE I. 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 (e.g. 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 is interested in the more serious consequences of a scenario. Relying on the results provided by the HAZOP (Table 1), the identification of these scenarios is an essential step is shown in Table 2.

TABLE II. 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

3) *Step 3: Estimation of the Initiators Events (IE) Frequency:* A mark that the estimate of the frequency of occurrence of the (IE) is performed sitting on an estimate relied on the judgment of experts present on site by making recourse to their acquired experiences in the domain in which is the study (their own knowledge as well as on the return to experiences, analysis of potential hazards ...), are shown in Table 3.

TABLE III. INITIATORS EVENTS FREQUENCY

Scenario	Initiator Event (IE)	Code	Frequency (/year)
1	incompatible chemical	IE_1	3,16E-01
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):* To assess the Probability of Failure on Demand (PFD) an IPL, the data can be arise from databases of return to experiences industrial sector concerned (that of the LDE division) or data of the entrepreneur. The Probability of Failure on Demand (PFD) of these layers of protection is shown in Table 4.

TABLE IV. PROBABILITY OF FAILURE ON DEMAND OF THE IPL

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

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

Identification of the Scenario

Fig. 3 shows an example of a dimension to the consequences of undesirable events using the Event Tree Analysis (ETA) of the first scenario.

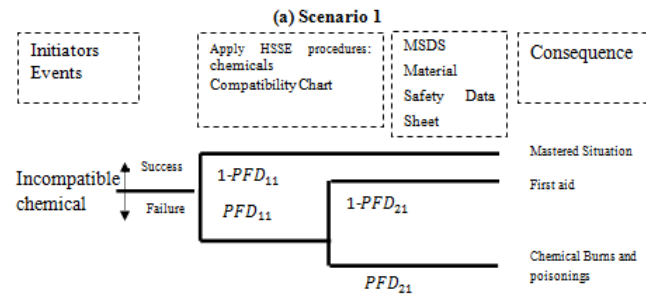


Fig. 3 Layers of protection and conduct of accident scenarios Retained : Scenario 1

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 $f_c = f_i \times [PFD_1 \times \dots \times PFD_n]$ and that of the scenario 3 is obtained by means of this equation $f_c^{feu} = f_i \times [PFD_1 \times \dots \times PFD_n] \times p_{ignition}$, we obtain:

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

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

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

6) Step 6: Assessment of Accident Scenarios against the Criteria of Acceptability

Starting from the application of the conventional method LOPA, and referring to the frequencies of reduced consequences of the scenarios studied compared to the frequency of the maximum tolerable risk (10^{-5}), we note that the frequency of the consequence reduced f_1^c and f_2^c relatives simultaneously on the first and second scenario are considered unacceptable. However, the frequency of the reduced consequence f_3^c relative on the last scenario is considered acceptable.

IV. RESULTS AND DISCUSSION

The estimated frequency of each of three accidental scenarios will be introduced in the fuzzy inference system as an input value. As fuzzy severity scale is continuous, we come to a scan all critical fuzzy set by giving each scenario the following severity values : 3.5, 3.75 and 4. A summary of the results of the evaluation of the criticality of three scenarios studied are shown in Table 5.

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

Scenario	Inputs		Outputs (criticality index)		Interpretation
	F	G	CCM	FCM	
1	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%)	-

The results obtained prove distinctions between a both approaches explained by an over / underestimate the criticality of the scenarios studied. Indeed , the Conventional Criticality Matrix (CCM) has provided absolutely critical indices of criticality (C) for the first two scenarios while the FCM (Fuzzy Criticality Matrix) shows the appearance of unacceptable level (NA) especially for the second scenario, with degrees of membership > 63%.

This requires a rectification methods of prevention and protection applied to ensure risk management of these two scenarios. Practically speaking, the responsible of the LDE division are expected to quickly seek to reduce the detected risks. The fuzzy criticality index obtained for scenarios studied is characterized by a gradual membership in more than one category with distinct degrees of membership. Concerning the first scenario, the conventional criticality index absolutely belongs in the critical category, as the fuzzy criticality index value of 3.29 belongs simultaneously to the critical categories (C) and unacceptable (NA) with

respective degrees of membership 0.71 and 0.29. Regarding the second scenario, the CCM shows only a total membership in a single category, that of the critical category (C), while the fuzzy criticality index value of 3.63 belongs to the critical category (C) with a degree of membership of 37% and belongs to the category unacceptable (NA) with a degree of membership of 63%. This comparison thus proves an underestimation of the criticality index in the case of the first two scenarios to master the optimistic choice.

- As these first two scenarios belong to the unacceptable category (NA) with some degree of membership, a finer assessment of severity remains indispensable.
- However, the conservative approach requires that the risk should be overestimated to represent the unfavorable situations in order to compensate for uncertainty. This conservative approach requires that the risk is overestimated assuming unfavorable conditions to master the pessimistic choice (case of the latter scenario: S3).
- At the end of the membership function generated for criticality of Tolerable category (T), we can see only 1 to 2, the value of the criticality index passes progressively from 0 to 100% in the Tolerable category (T), coinciding in the value 2, the value of the criticality index belongs to the Tolerable category (T) with 100% certainty (membership rate equal to 1), and between 2 and 3, the value of the criticality index passes gradually from 100 to 0%.

V. CONCLUSION

An application to the studied process was used to support the use of a fuzzy rule-based system for determining the value of the criticality index. The results of the practical study of this approach validate the proposed methodology and show its scope in assessing the criticality of risk and risk acceptability occurred specifically studied process and industrial risks generally. The criticality assessment risk based on the FCM as an alternative to the CCM, exhibits several advantages. Therefore, it allows us:

- To address the need to represent imprecise knowledge such as those expressed in natural language (linguistic variables) aggregated fuzzy intervals cannot be described by quantitative terms;
- To reveal the continuity of categories via a gradual membership;
- To rely on continuity of fuzzy scales used, which can remedy the problem of interpreting the results of the evaluation.

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