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# APPROACH OF FUZZY LOGIC IN THE PRELIMINARY RISK ANALYSIS OF THE UPSTREAM AND DOWNSTREAM LINES OF AN OFFSHORE PETROLEUM PRODUCTION UNIT

Claudio B. Garcia[1], Edson Pinho[2], Luiz Maia Neto[3]



## Abstract

This work consists of the application of a model of qualitative risk assessment based in fuzzy logic for the judgment of criticality of the scenarios of accident identified through the technique of Preliminary Hazard Analysis in the upstream and downstream of an offshore oil production unit already in operation. The model based on fuzzy logic acts as substitute to the traditional Risks Matrix that uses subjective concepts for the categories of expected severity and frequency of the accidents. The structure of the employed model consists of 7 input variables, an internal variable and an output variable, all linked in accordance with the modules of analysis for each type of accident. The developed base of knowledge, that complete the expert system consists of membership functions developed for each one of the variables and a set of 219 distributed inference rules in the 7 different modules. The developed knowledge base, which incorporates the mechanisms of logical reasoning of specialists, assists and guides, with efficiency, the teams that carry through the Preliminary Hazard Analyses with the use of a computer program having previously inserted routines. The employed model incorporates in the knowledge base of the program the existing concepts in the categories of frequency and severity, under the form of membership functions of the linguistic variable and the set of rules. With this, scales subdivided in ranges, defined on the basis of the existing direction present in the risks matrices are used to define the actions to be taken for the analyzed accident scenarios.

## 1. Introduction

Chemical process quantitative risk analysis is a methodology designed to provide management with tool to help overall process safety in chemical process industry. In more recent years, the oil and gas industries has also benefit of this methodology.

Management systems such as engineering codes, checklists and process safety management provide layers of protection against accidents. However, the potential for serious incidents cannot be totally eliminated. Quantitative risk analysis provides a quantitative method to evaluate risk and to identify areas for cost-effective risk reduction.

Chemical process quantitative risk analysis methodology has evolved since the early 1980s from its roots in the nuclear, aerospace and electronic industries. A fundamental part of any such risk analysis is the hazard identification. Process Hazard Analysis has been performed in chemical process industry for more than 40 years. Other less systematic reviews have been performed for even longer.

Although a quantitative risk analysis can, in principle, be conducted for any kind of industrial process, in huge facilities we can be dealing with some thousands of scenarios, which impose limitations on cost effectiveness of the technique. A process hazard analysis gives the opportunity to systematically identify the hazards of the process and some of its techniques, as a Preliminary Hazard Analysis, allow ranking scenarios which enable to choose which ones should be first quantitatively investigated.

[1] MSc, Chemical Engineer – PETROBRAS TRANSPORTE S.A.
[2] PhD, Associate Professor – UFRRJ / Risk, Reliability and Multiphysics Simulation. Consultant – RISCO AMBIENTAL ENGENHARIA
[3] MSc, Electrical & Safety Engineer, Risk and Reliability Consultant

Preliminary Hazard Analysis (PHA) is a well established technique and, usually, is first one to be employed to identify hazards and to rank scenarios according to risk levels. Although it is appropriate for the purposes it was designed, one important limitation of the method is the uncertainties associated with the linguistic variables used to classify the severity and frequency of each accidental scenario. Such uncertainties are responsible for different judgment for the same scenario by two different groups of analysts. As a matter of fact, the same group may well give different interpretation of the same scenario sometime in the future.

One of us (CBG) has proposed the application of the elements of fuzzy set theory and fuzzy logic in the context of preliminary risk analysis conducted in petrochemical industries, as a way to overcome the difficulties associated with this analysis[1]. The success of his results encourages us to apply such technique to offshore industry, particularly to Floating Production, Storage and Offloading Systems (FPSO)[2], that is the purpose of this work.

## 2. Scope of Work

This work comprises the application of elements of fuzzy set theory and fuzzy logic as an alternative to risk ranking matrices that make use of subjective concepts to classify categories of severity and frequency of scenarios, in a qualitative risk analyzes. The methodology that will be presented in this paper will be applied to analyze the scenarios coming from failure of productions' risers of gas. The scope of the work covered:

- Description of risers systems and the aspects of the regions they are localized in FPSO;
- Description of the methodology;
- Results obtained;
- Conclusions and perspectives.

## 3. Description of The Riser of Gas

At this work the Riser of gas is one of the flexible risers mounted inside an internal turret mooring system. A turret mooring system is defined as a mooring system where lines are connected to the turret via bearings allows the vessel to rotate around the anchor legs. This turret can be mounted in the ship either internally or externally. An external turret is fixed, with appropriate reinforcements, to bow or stern of the ship. In the internal case the turret is placed within the hull, in a so called moon pool. The chain table, connecting the mooring lines to the turret, can be either above or below the waterline.

External turret systems are less expensive than internal turret designs and can be delivered in a shorter period of time, but have a limitation in terms of capacity of risers and water depth.

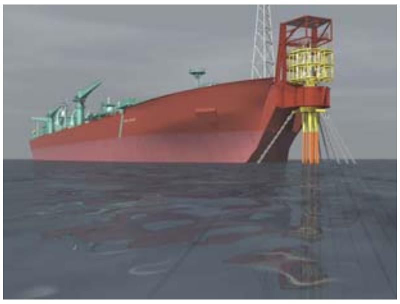

Figure 3.1 – An Example of External Turret
Source: http://www.offshoremoorings.org

We present now an example of internal turret. Internal turret mooring systems may be built with permanent and disconnectable design; it is applicable in a moderate to harsh environment and deep water systems and provides more fluid transfer capabilities than external turret system. Internal systems can accommodate up to 100 or more risers in water depths ranging between 100 to 10,000 feet or more.

Figure 3.2 – An Example of Internal Turret and Other Details
Source: offshore-technology.com

The flexible risers are produced by overlapping of several layers of metallic and non metallic materials, to form a structure that combines flexibility and resistance to traction, collapse, internal pressure and attack of chemicals. Flexible Pipes are manufactured for a long life term (not less than twenty years) and have been a successful solution for deep water risers and flowline systems worldwide. In such applications, flexible pipes section may be used along the entire riser length or limited to short dynamic sections such as jumpers.

## 4. Methodology Employed

Fuzzy means something not clearly defined or vague. Such terms usually occurs in daily conversations, for example when we refer to “a good quality control system”, to “catastrophic consequences of accidental scenario” or “negligible frequency”.

In the classical set theory, an element belongs or not to a particular set. In such theory, there is no way for an intermediate belonging to a condition between the belonging and not belonging to it. So, the classifications such as “good quality control system”, “catastrophic consequences of accidental scenario” or “negligible frequency of accidental scenario”, cannot be considered as elements of a classical set theory.

On the other hand, the Fuzzy Set Theory is nowadays a well established subject[3] and a whole bunch of applications followed such a set theory[4]. The concept of Fuzzy Logic was conceived by Lotfi Zadeh, a professor at the University of California at Berkley, and presented as a way of processing data by allowing the use of the concept of linguistic or "fuzzy" variables. These variables are linguistic objects or words, rather than numbers. The input is a noun, e.g. "temperature", "displacement", "velocity", "flow", "pressure", etc. The fuzzy variables themselves are adjectives that modify the variable (e.g. "large positive" velocity, "small positive" error, "zero" flow, "small negative" temperature).

To create a Fuzzy Logic System is necessary to define firstly the analytical objectives, criteria and responses. Secondly, determine the input and output relationships and choose the variables for input to the system. After that, the analytic problem is broken down into a series of simple, plain-language IF X AND Y THEN Z rules that define the output response for the input conditions. These rules are associated to linguistic variables rather than mathematical formulas.

Then, fuzzy membership functions that define the values of input and output terms used in the rules are created. Finally, system is tested, results are evaluated, and the rules and membership functions are tuned until satisfactory results are obtained.

For each input parameter, there is a unique membership function that associates a weighting factor with values of each input and the effective rules. These weighting factors determine the degree of influence or degree of membership each active rule has. By computing the logical product of the membership weights for each active rule, a set of fuzzy output response magnitudes are produced. All that remains is to combine these logical sums in a defuzzification process to produce the crisp output.

The application of Fuzzy Set Theory to a Preliminary Risk Analysis of Chemical and Petrochemical Industries were already pointed out by one of us (CBG, Ref. [1]). In a PHA, the team responsible for the analysis has to classify qualitatively the scenarios accordingly previously established risk categories. Such risk categories are defined through risk matrices composed of categories of frequency and severity for scenarios. These categories have very imprecise and vague character whose judgment strongly depends on the team, and even for the same team it may vary from time to time. Also, the judgment is strongly dependent of the experience of the team involved.

The basic idea developed in the Ref. [1], and that will be applied here for offshore scenarios, is contained in a developed software (FURIA – Fuzzy Risk Analyst), that uses direct numerical known data or that can be easily calculate, instead of linguistic variable. The numerical data used, that are considered numerical variables, are those that keeps straight relationship to an expected damage levels in an accidental scenario or the chance of its occurrence. The list of such variables is:

- Distance from the initiating event to nearest population;
- Maximum inventory leakage of the substance;
- Expected frequency of initiating event;
- Inflammability of the substance expressed as its LFL;
- Toxicity of the substance expressed as its IDLH;
- Vaporization indices of the substance expressed as the difference between vaporization and system temperature;
- Molecular weight of the substance.

The basic structure of the software is contained in the following procedures, for each variable considered:

a) Fuzzification procedure;
b) Checking to the attendance of the fuzzy logic rules;
c) Inference procedure;
d) Defuzzification procedure;
e) Output results.

The procedures from “a” to “d” makes use of knowledge basis that comprises membership functions of the fuzzy variable that inform the degree of membership of each element of the set. Also, a whole set of protocol fuzzy logic rules take part in the knowledge basis used for inference.

In this study, we used the characteristics functions proposed in the Ref. [1]. The set of protocol fuzzy logic rules and the range that defines the output risk scales also follows that used in the same above mentioned reference.

## 5. Input Data and Premises

For the purposes of this study, we considered an export riser of gas that leaves FPSO going to a submarine mesh of gas. We also considered only the superficial segment of the riser, with the properties given by Table 5.1.

Table 5.1 – Operational and Constitutive Properties of The Considered Riser

| VARIABLES | EXPORTATION RISER OF GAS |
|---|---|
| Flow Rate ($m^3/h$) | $7.70 \times 10^5$ |
| Operational Pressure ($Kgf/cm^2$) | 145.03 |
| Operational Temperature (º C) | 30 |
| Diameter (in) | 10” |
| Material | API 5LGR B |
| Extension (m) | 50 |

In Table 5.2 we present a typical natural gas composition in the riser.

Table 5.2 – Composition of The Considered Gas

| COMPONENT | % MOLAR |
|---|---|
| $C_1$ Methane | 86.3 |
| $C_2$ Ethane | 5.6 |
| $C_3$ Propane | 3.4 |
| Other HC | 4.7 |

The initiating events that we are considering in this study are:

I. Five minutes leakage of inflammable gas caused by catastrophic rupture (100% diameter of the line) of exportation riser at connector region;
II. Five minutes leakage of inflammable gas caused by a hole (20% diameter of the line) on the exportation riser at connector region;
III. Five minutes leakage of inflammable gas caused by a puncture (5% diameter of the line) on the exportation riser at connector region.

For each initiating event considered, we obtain its frequency consulting the OREDA data bank[5]. The probability associated with the intermediate events was obtained consulting the Purple Book[6]. In order to evaluate the frequency of each scenario, we draw an event tree and the corresponding frequency was obtained multiplying the initiating event frequency by the probability of each intermediate event, as usual. All these information are presented in the Figures 5.1 to 5.3.

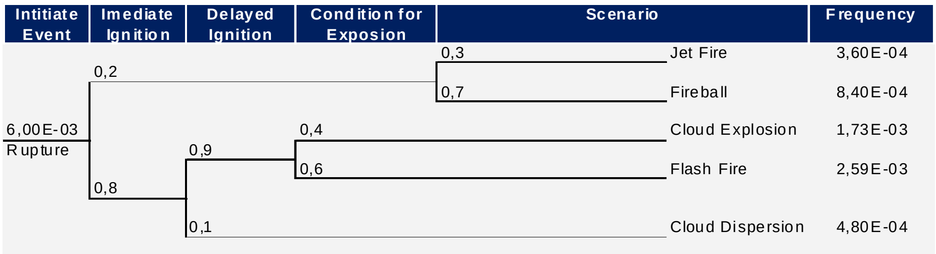


Figure 5.1 – Event Tree for The Catastrophic Rupture Initiating Event

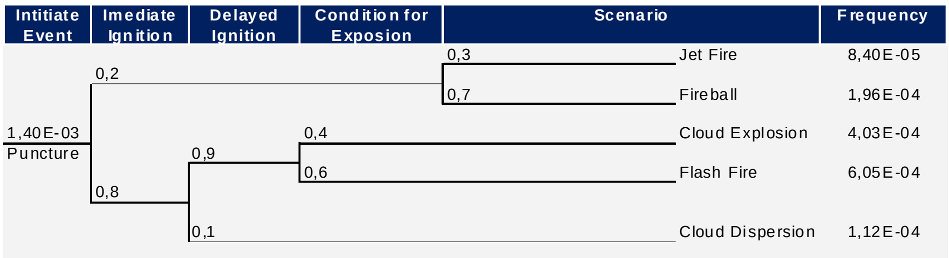


Figure 5.2 – Event Tree for The Leak Initiating Event

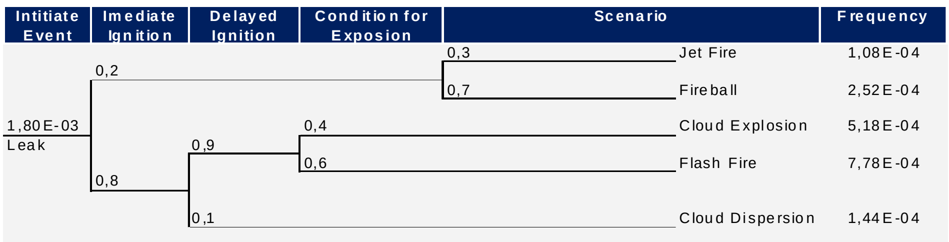


Figure 5.3 – Event Tree for The Puncture Initiating Event

The inventory associated with each initiating event were calculated with using the software PHAST® v.5.4, the premises, operational and process conditions and gas constitution given above. These results are given in Table 5.4.

Table 5.4 – Inventory Associated with Each Initiating Event

| INITIATING EVENT | DESCRITION OF THE EVENT | INVENTORY LEAKAGE (ton) |
|---|---|---|
| I | Five minutes leakage of inflammable gas caused by catastrophic rupture (100% diameter of the line) of exportation riser at connector region; | 536.4 |
| II | Five minutes leakage of inflammable gas caused by a hole (20% diameter of the line) on the exportation riser at connector region; | 21 |
| III | Five minutes leakage of inflammable gas caused by a puncture (5% diameter of the line) on the exportation riser at connector region; | 1.3 |

PHAST® also provides us with the results for the boiling temperature (-160.40C) and inferior limit of inflammability – ILI (3.8 %) for the natural gas mixture assumed.

## 6. Results

In what follows, we present the results for the risk variable. The inference and defuzzification methods chosen were Inference from Composition Max-Dot and Dufuzification from Centroid. We observe in Figures 6.1 to 6.3 that the risk grows with the possible inventory to leak. Also, we observe, in general, that the risk decreases with the distances to the nearest population.

The fireball and flash fire have essentially the same modulus of calculation in the FURIA, the fuzzy routine developed for calculation. The results for vapor cloud explosion and flash fire although similar for the conditions used for the calculations, are not the same.

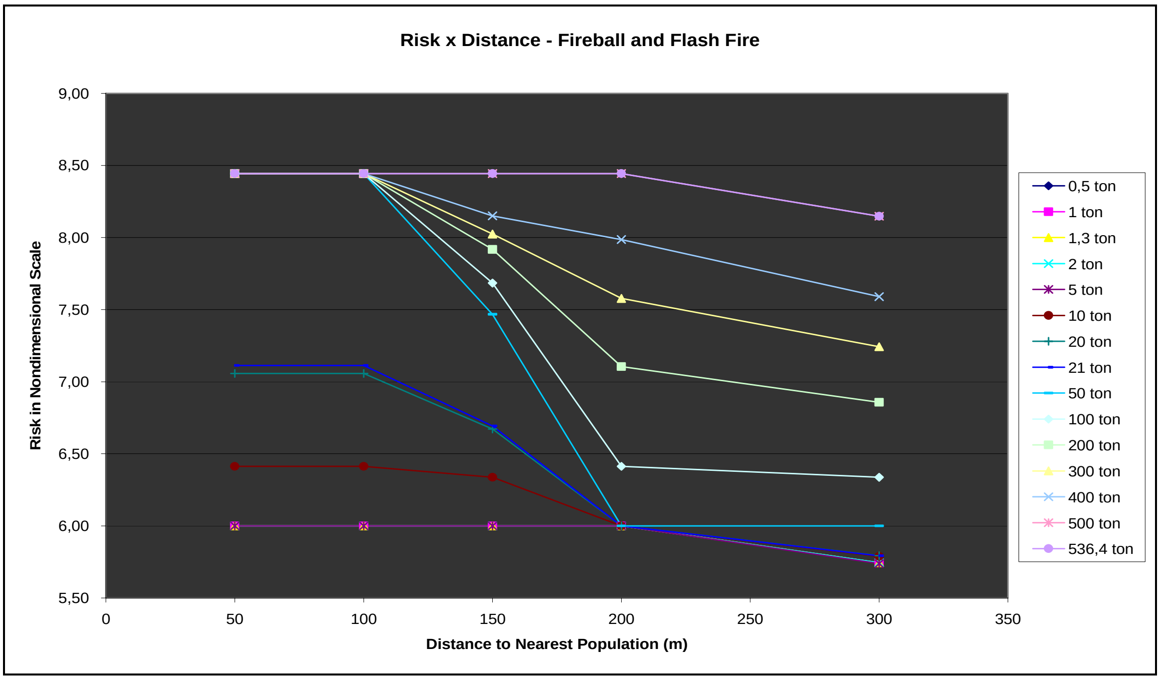


Figure 6.1 - The Fireball and Flash Fire Risk Versus Distance Curves for Various Inventories

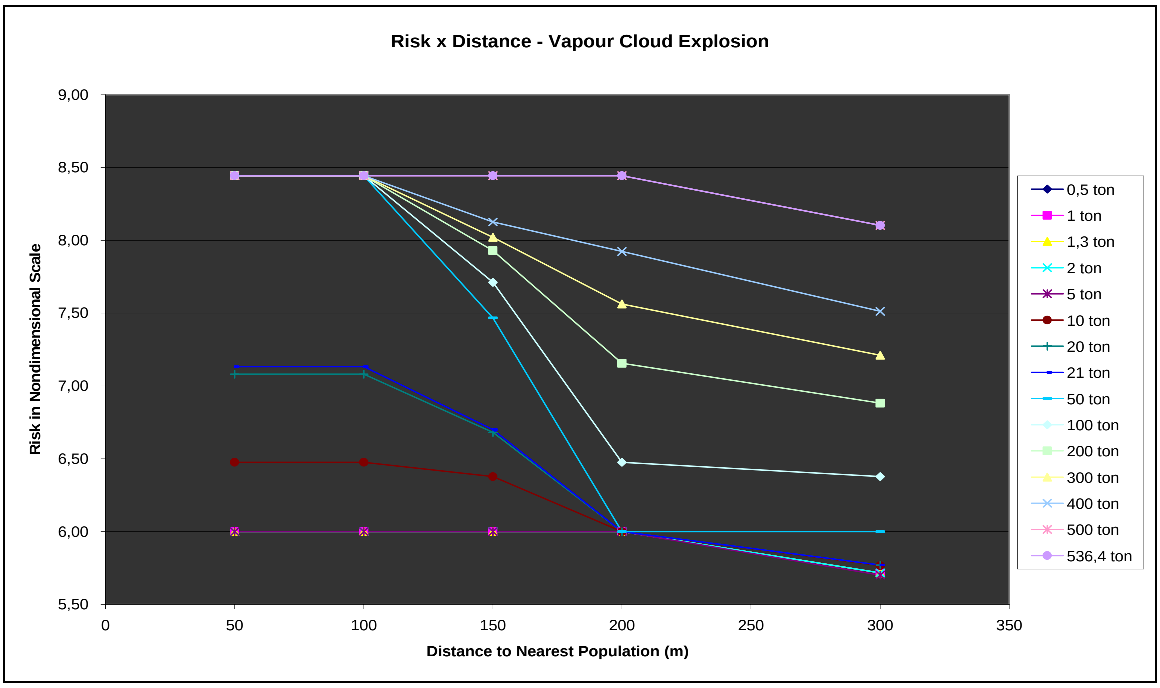


Figure 6.2 - The VCE Risk Versus Distance Curves for Various Inventories

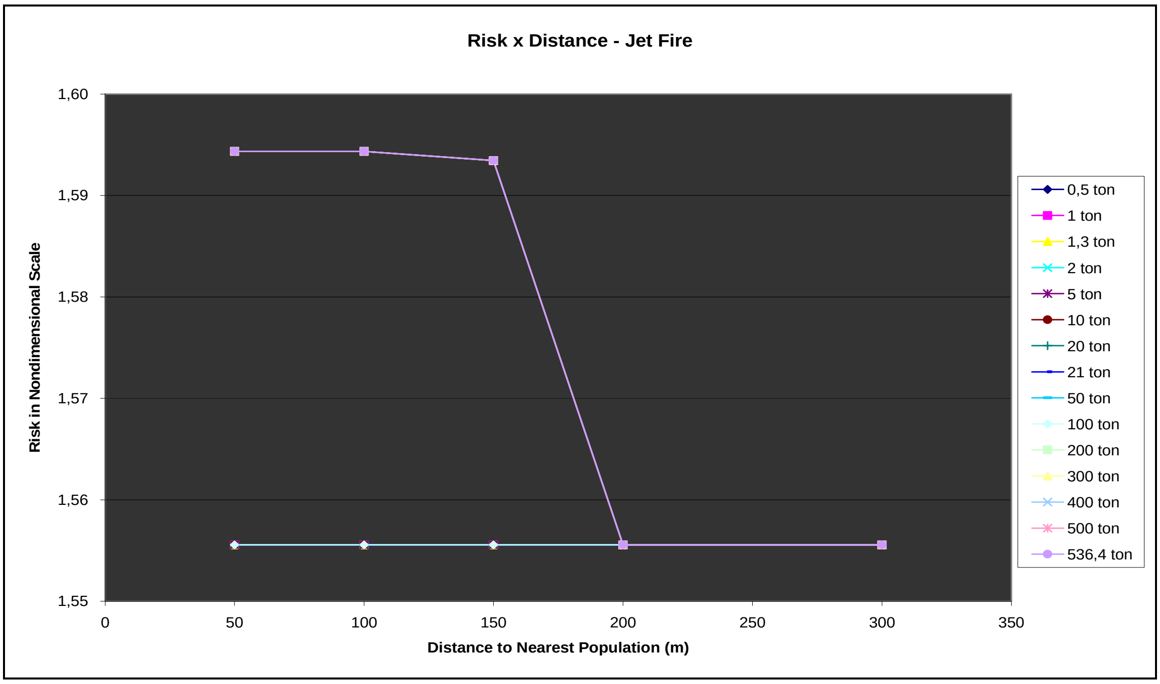


Figure 6.3 - The Jet fire Risk Versus Distance Curves for Various Inventories

## 7. Conclusions and Perspectives

The main conclusions of this study are as follows:

i. The Fuzzy Set Theory and Fuzzy Logic was presented as a new tool for elaborating specialist systems in the field of qualitative risk analysis;

ii. The basic model for a qualitative risk analysis program were developed using fuzzy logic in order to be applied in substitution of the frequency and severity categories as well as the risk matrices used in the PHA studies. The structure of the model consists of 7 input variables, one internal variable and one output variable linked accordingly to each developed, modulus of accident. The knowledge basis consists of the characteristics functions for each of the linguistic variables and a set of logic rules developed for each different modulus of accident;

iii. The behavior of the models in function of the variables leakage inventory, and distance to nearest population present, revealed the coherence between input data and output results;

iv. The results obtained indicated that the present methodology works quite well. It revealed to be a useful tool that can be implemented by personnel without experience in risk analysis, but experienced in the process involved. The knowledge basis, that incorporates the logic mechanisms of the specialists in the field, helps and guide efficiently the team involved in the qualitative risk analysis that, with the methodology presented, will be using software that has the FURIA routines incorporated on it. The models present in such routines eliminates the necessity of the use of the categories of frequency and severity, once those concepts are already present in the knowledge basis, as membership functions of the linguistic variables as well as the whole set of logic rules used. Risk matrices are not used within the presented methodology and are substituted by scales subdivided in ranges that define actions to be taken from those scenarios included in it.

Although the results obtained in this work has shown meaningful behavior, it also revealed the needs for calibration in order to be widely used in offshore industry in substitution to the traditional Risk Matrix in PHA studies. Such calibrations that are in progress for us right now, has to do with the specificities of platforms compared to onshore industrial plants. Some of those are the scale of distances involved, the presence of highly congested and confined areas and the diversity of levels having populations on it – the decks of platforms, which makes distance necessary to be treated in tridimensional space. Also in offshore industry the importance of integrity structure as a safety condition as well as the importance of environmental scenarios has to be properly considered here. We believe that with these calibrations, that is been implement right now by us, a new age in qualitative risk analysis of offshore units can be initiated.

## 8. References

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