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ORIGINAL

# Risk assessment for the liquefied petroleum gas filling industry using fuzzy logic and hazard and operability

## Evaluación de riesgos para la industria de llenado de gas licuado de petróleo utilizando lógica difusa y análisis de peligros y operabilidad

Oubellouch Hicham[1], Soulhi Aziz[1]

[1]National Higher School of Mines. Rabat, Morocco.

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**ABSTRACT**

The object of this study is to integrate Hazard and Operability (HAZOP) analysis and Fuzzy Logic to improve risk assessment in the Liquefied Petroleum Gas (LPG) filling industry. the research introduces a new approach to resolve the uncertainties and imprecise information inherent in traditional risk evaluation methods. Using HAZOP, a qualitative analysis conducted by the experts of industry identifies potential process deviations and hazards, categorized by impact type such as fire, explosion, and environmental damage. Fuzzy Logic, quantifies these risks by evaluating the likelihood and consequences of accidents using linguistic variables like “high,” “medium,” and “low.” The simulation of different parameters considers various scenarios, including the interplay of consequence severity, event frequency, and detection capability on overall risk using model fuzzy-Hazop. The results provide more precision and actionable risk assessments, showing the potential of the combination of Hazop and fuzzy logic for safety measurement in the LPG filling process. The study concludes HAZOP with fuzzy logic evaluates risks in uncertain conditions, offering an alternative for clearer, decision-making in risk-based design processes.

**Keywords:** Risk Assessment; Fuzzy Logic; Gas and Oil Industry; Hazard Control; Decision-Making.

**RESUMEN**

El objeto de este estudio es integrar el análisis de Peligros y Operabilidad (HAZOP) y la Lógica Difusa para mejorar la evaluación de riesgos en la industria de llenado de Gas Licuado de Petróleo (GLP). La investigación introduce un nuevo enfoque para resolver las incertidumbres y la información imprecisa inherente en los métodos tradicionales de evaluación de riesgos. Utilizando HAZOP, un análisis cualitativo realizado por los expertos de la industria identifica posibles desviaciones del proceso y peligros, categorizados por tipo de impacto como incendio, explosión y daño ambiental. La Lógica Difusa cuantifica estos riesgos evaluando la probabilidad y las consecuencias de los accidentes usando variables lingüísticas como “alto”, “medio” y “bajo”. La simulación de diferentes parámetros considera varios escenarios, incluyendo la interacción de la severidad de las consecuencias, la frecuencia del evento y la capacidad de detección sobre el riesgo total usando el modelo fuzzy-Hazop. Los resultados proporcionan evaluaciones de riesgo más precisas y accionables, mostrando el potencial de la combinación de Hazop y lógica difusa para la medición de seguridad en el proceso de llenado de GLP. El estudio concluye que HAZOP con lógica difusa evalúa riesgos en condiciones inciertas, ofreciendo una alternativa para una toma de decisiones más clara en procesos de diseño basados en riesgos.

**Palabras clave:** Evaluación de Riesgos; Lógica Difusa; Industria del Gas y Petróleo; Control de Riesgos; Toma de Decisiones.

## INTRODUCTION

The Liquefied Petroleum Gas (LPG) industry plays a crucial role in meeting the energy needs of many countries. LPG is a highly flammable and explosive gas, which makes it a high-risk industry. Accidents in the LPG filling industry can have severe consequences, including loss of life, property damage, and environmental damage. Therefore, risk assessment is essential for ensuring the safety and reliability of LPG filling processes.

Hazard and Operability (HAZOP) and Fuzzy Logic are two commonly used methods for risk assessment in the LPG industry.[1] HAZOP is a qualitative method that involves a team of experts analyzing the process and identifying potential deviations from the intended design. Fuzzy Logic, on the other hand, is a mathematical method that allows for the representation of uncertain and imprecise information.[2] The need for improved safety and risk assessments in process industries utilizing the HAZOP technique is the scientific issue that motivates this research. Accurate risk assessment is complicated by the inherent uncertainties of processing systems, which may pose safety risks. This work uses fuzzy logic, which can handle process system uncertainty, to get around standard HAZOP constraints. The fuzzy-based HAZOP approach aims to provide risk levels with less uncertainty by addressing both random and epistemic uncertainties, which will increase the accuracy of risk assessment in process industries.

## METHODS

### Hazop

A team of experts who had extensive experience in the LPG industry conducted the HAZOP study. The team analyzed the LPG filling process and identified potential deviations from the intended design. The deviations s categorized on the type of hazard, such as fire, explosion, toxic release, and environmental impact.[2]

To calculate the risks associated with recognized hazards and their effects, HAZOP needs risk acceptance criteria.

The criteria used to assess the magnitude and acceptability of risks know as risk acceptance criteria.

The current design will be offering if the risks to people, property, and the environment are reasonable considering the risk acceptance criteria. It is hard to articulate precisely what is or is not acceptable for employees, assets, and the environment because the dangers vary.[1,2] Negligible, ALARP (as-low-as reasonably practical), and unacceptable are the typical three zones for these criteria. If a danger is small, further safety precautions are not necessary. When a risk is managing by existing or extra measures, the risk is in the ALARP. The unacceptable zone denotes a hazard that cannot be tolerated by the current design, necessitating design changes.

The three criteria[2] are mostly used to determine priorities:

- Rating the impacts' severity is the initial ranking that will enable us to balance your reaction in accordance with the outcomes envisioned for each mentioned possible concern.
- Probability: To determine if and how frequently the probable failure mode is likely to occur, the probability of occurrence rating, also known as occurrence, is utilized.
- Detection: The listing of non-detection will help you to gauge the likelihood and ability of the outlined control measures to identify problems as they emerge.[3]

HAZOP is an analytical technique for locating both static and moving risks for industrial operations. An independent leader with expertise makes some suggestions regarding. The following keywords are used as guidelines: no, less, low, more, high, reversal, fluctuation, and early. They are chosen in accordance with the process parameters and operational conditions.[1] The HAZOP participants thoroughly go through process systems utilizing the guidelines. All these individuals are specialists with a range of system-related expertise and experience. A standardized form should be used to document the risks, hazards, and recommendations that have been identified.[1,4]

### Fuzzy Logic

The notion of fuzzy sets introduced by Zadeh[5] serves as the foundation for fuzzy logic. It is a broadening of the traditional set theory. This method allows for flexible thinking and takes subjectivity, subjectivity, ambiguity, and ambiguity.[4]

Fuzzy logic defines rules and membership functions in sets termed "fuzzy sets," which provide up a variety of possibilities for working with imprecise linguistic data.[4]

For evaluating indicators for which there is no traditional model for estimation, fuzzy sets theory is useful. If the model is too complicated and measuring. Zadeh[5] claims that this theory is the best formalism for qualitatively describing linguistic variables.

Fuzzy logic is used for dependability and risk evaluation, in fact.[6] The benefit of using fuzzy theory for risk assessment is that the system evaluation that results is qualitative and that it can work with language variables because certain occurrences cannot be quantified mathematically. Fuzzy logic, on the other hand, works with subjective, imperfect, or unreliable knowledge sources.

A suitable method to identify the crucial system components quickly and precisely is fuzzy logic. To determine how each risk factor level contributes to the operational risk indicator, it concurrently assesses each degree of risk. They can aid in developing and putting into practice remedial actions for lowering risks.

The fuzzy inference is a formulation method that applies fuzzy logic to the input data and the output data. It has all the following episodes: fuzzy logic operators, if-then statements, and membership functions.[4,7]

While creating the membership functions and decision matrix for a fuzzy system, for example, the designer relies heavily on statistical data or expert opinion.[7,8] The procedures shown in Figure 1[1] are used to create a fuzzy logic system:

- Choose the main factors that have an impact on the dependent variables.
- Build fuzzy sets for both independent and dependent variables, and then use membership functions to describe the degree of truth that each variable belongs to a certain fuzzy set.
- Set the system's inference guidelines.
- Based on the independent variables and the inference rules, create the output fuzzy set of the dependent variable, after which the defuzzification process calculates the output fuzzy set's numerical value.
- Make a choice based on the model's findings.

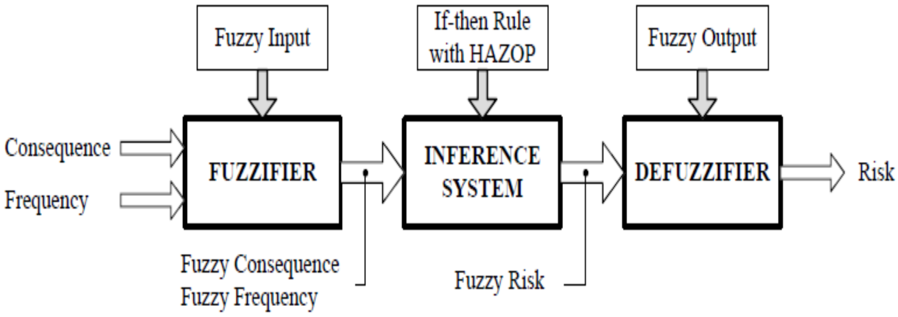


**Figure 1.** Modelling Of Risk Indices By Fuzzification

The Fuzzy Logic model was then developed using the results of the HAZOP study and expert knowledge to assess the likelihood of an accident occurring and the severity of the consequences. The Fuzzy Logic model used linguistic variables, such as "high," "medium," and "low," to represent uncertain and imprecise information.

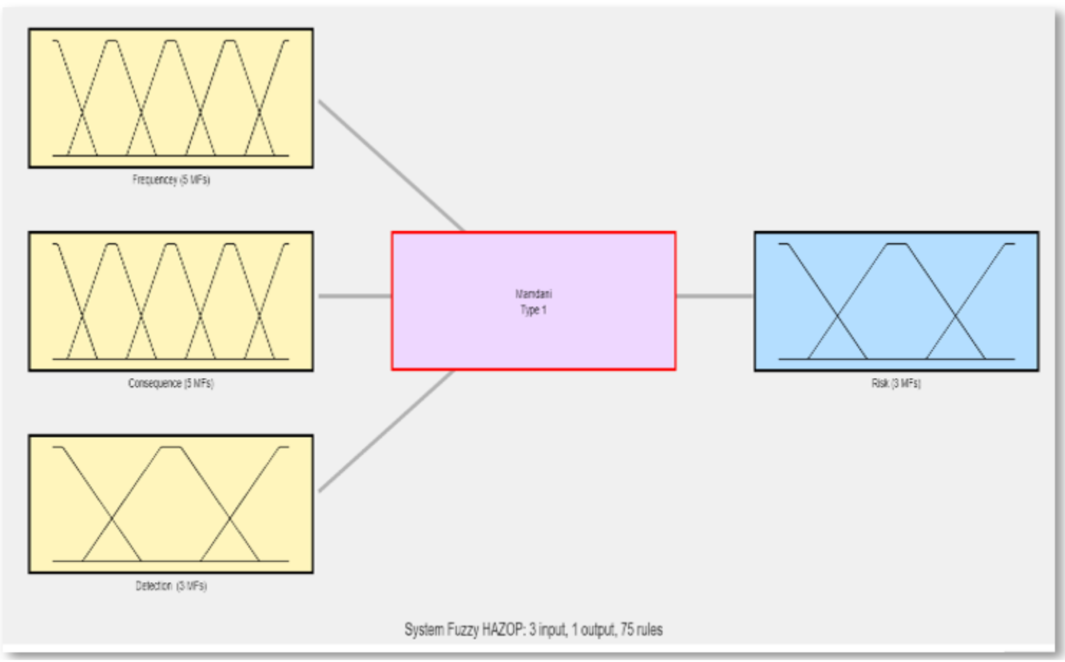


**Figure 2.** Fuzzy Model

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The Fuzzy Logic model was validated using data from previous accidents in the LPG filling industry. The data included the process parameters and the severity of the consequences. The model was calibrated using the data to improve its accuracy and reliability.[1,7]

**Table 1.** Frequency Level Description

| Linguistic Term | Description |
|---|---|
| Improbable | So unlikely it can be assumed that occurrence may not be experienced |
| Remote | Unlikely but possible to occur in the life of an item |
| Occasional | Likely to occur sometime in the life of an item |
| Probable | Will occur several times in the life of an item |
| Frequent | Likely to occur frequently |

**Table 2.** Consequence Category Description

| Linguistic Term | Definition |
|---|---|
| Negligible | Very minor or no injury; less than minor component or environment damage |
| Marginal | Single injury with minor health effects; minor system or environment damage |
| Moderate | Single injury with disability; major system or environment damage |
| Critical | Multiple and serious injuries; system loss or severe environment damage |
| Catastrophic | Fatality; system loss or severe environment damage |

**Fuzzy Inference**

HAZOP linguistically expresses the system participants' viewpoints. Tables 1 and 2 provide an overview of accident frequency and consequences. Combining these conveys the accident. With regard to technological failures or human errors, it is useful to methodically separate causes from outcomes. Nevertheless, the facilitation of a HAZOP leader and the expertise of the participants determine how thorough the linguistic descriptions are.[9] It might be challenging to define the system circumstances correctly at times.[10]

the "linguistic variables are linked together by rules and allow us to draw inferences".[4] Thus, the inference engine is a step consisting of defining the decision rules (If. Then) established by the experts to the input variables using the fuzzy operators OR or AND or both.[7,8]

Rules
If F= improbable and S=Negligible and D=High then RPN is Low Risk
If F=
…..
However, we have 75 rules because there are 5 levels in severity and probability and 3 in non-detection.

**The defuzzification**

The fuzzification is the linguistic-to-numerical translation of several factors defining overall effectiveness. The center of gravity approach is the one employed in this situation. This approach considers all information at hand.[8]

$$Y_0 = \frac{\int_y y \times \mu(y)\,dy}{\int_y \mu(y)\,dy}$$

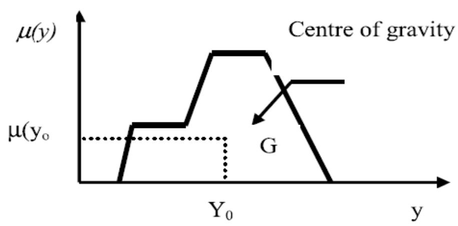


**Figure 3.** Centre Of Gravity

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We will use the membership functions, making by the experts like filling plant managers HSSE Manager, Maintenance Manager Technical engineer and HAZOP Lead , to demonstrate the corresponding level of validity of each variable. The indicators are described by a trapezoidal membership function using language phrases relevant to each indicator.

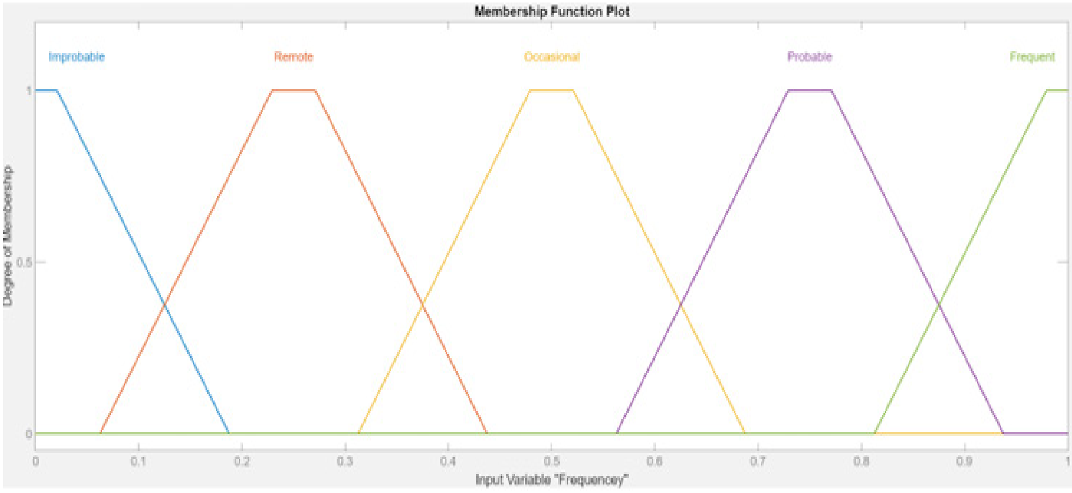


**Figure 4.** Frequency Membre Ship Function

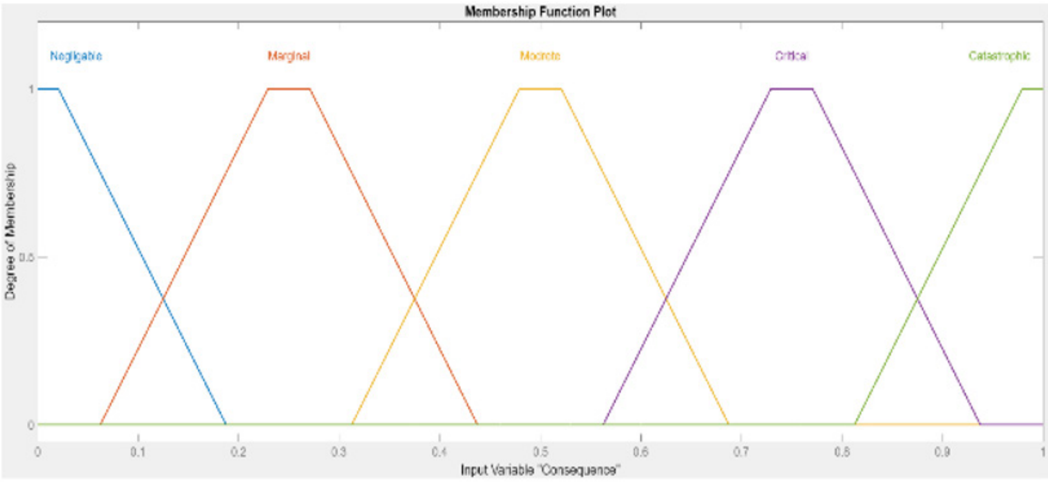


**Figure 5.** Consequency Membre ship Function

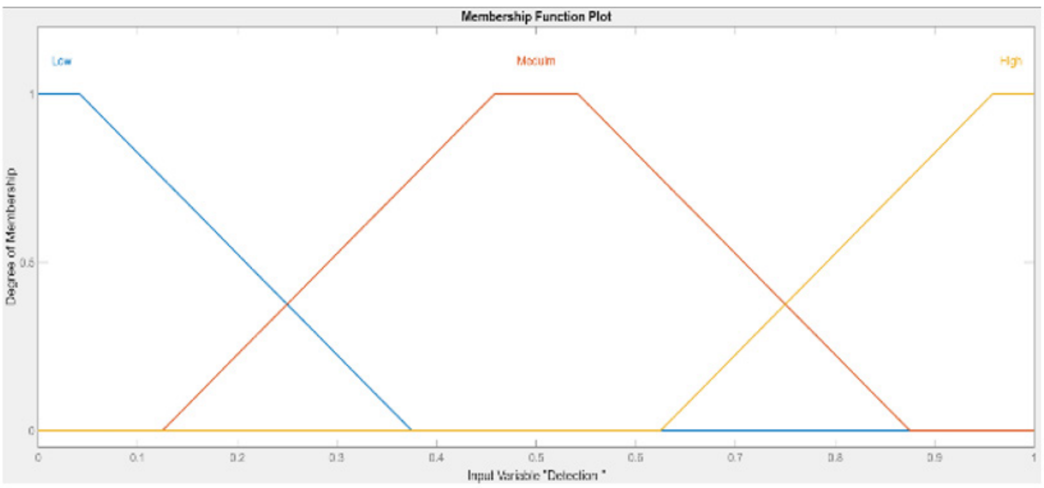


**Figure 6.** Detection Membre ship Function

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## RESULT

*Case N°1 : [Input1 = Consequency ; Input2 = Frequency]*

The index of detection is fixed in advance in Medium.

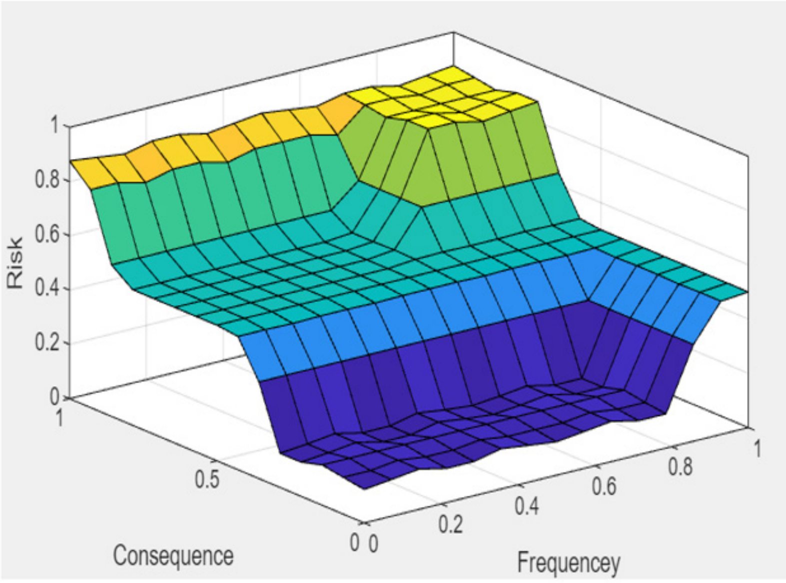


**Figure 7.** The Curve Of The Case N°1

**Interpretation:** it is found that the combination of consequence and frequency has a significant impact on the severity of high rates.

For frequent frequency with marginal consequence, they give medium risk for medium detection that can explain the importance of fuzzification to give us more detail for the risk assessment.

*Case N°2 : [Input1 = Consequences ; Input2 = Detection]*

The index of Frequency is fixed in advance in Occasional.

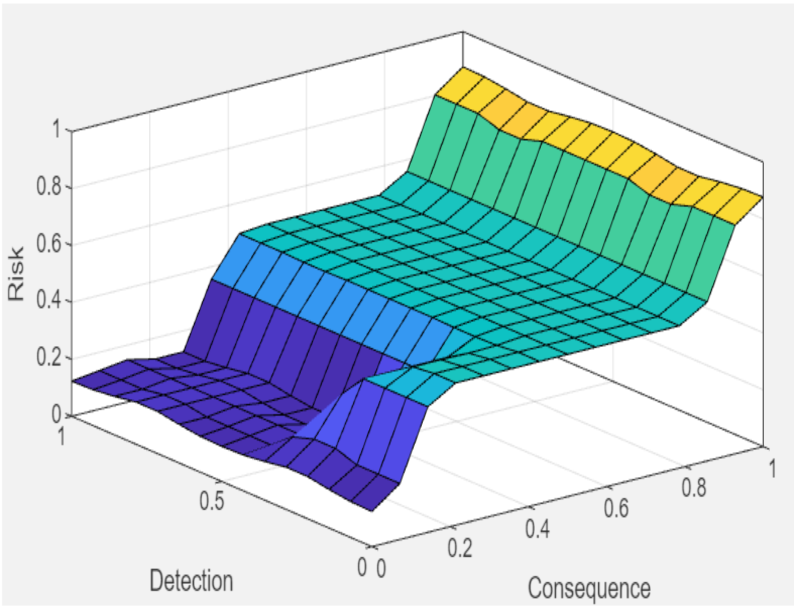


**Figure 8.** The curve case N°2

**Interpretation:** the curve below shows that the consequence affects the severity regardless of detection level. Also, for low detection independent of consequence the have a severe impact in the risk which mean the function of detection have a potential role in the risk assessment to avoid a hid of risk major.

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*Case N°3 : [Input1 = Frequency ; Input2 = Detection]*

The index of Consequence is fixed in advance in Moderate.

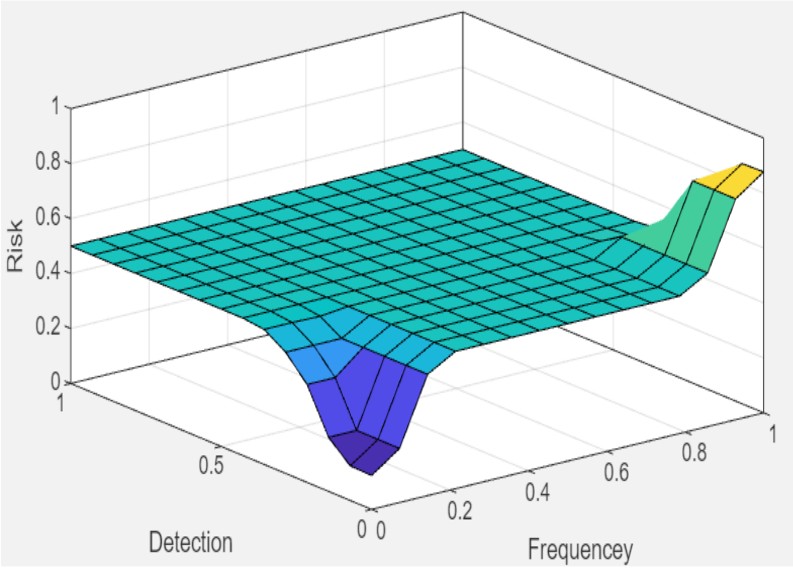


**Figure 9.** The curve case N°3

**Interpretation:** the curve below shows the crucial role of detection in managing risks within industrial processes. It quantitatively confirms the necessity for high detection capabilities to maintain safety and highlights the areas where improvements can significantly reduce risks. This visual representation provides a compelling argument for the prioritization of enhancements in detection technology and methodologies in the risk assessment of LPG industry.

## CONCLUSION

In this study, we have introduced an innovative approach to enhance traditional HAZOP analysis by incorporating fuzzy logic, specifically designed to address the inherent uncertainties associated with process deviations in the LNG industry. This methodology, grounded in the principles of fuzzy set theory, offers a robust framework for quantifying the vagueness and imprecision that often characterize linguistic descriptions in risk assessments.

This approach is an alternative to overcoming uncertainties in the HAZOP design review stage for risk-based design. It helps the designer to make scientific decisions by using a blurred set of theory. Vague modeling is used to express the risks related to the frequency and consequences of process deviations. The blurred logic quantifies the ambiguity and inaccuracy of language descriptions and calculates the risks based on the degree of adherence. The expected average value is introduced to blur language variables. This is to provide the number of language variables with less uncertainty.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

## AUTHORSHIP CONTRIBUTION

*Conceptualization:* Hicham OUBELLOUCH.
*Data curation:* Hicham OUBELLOUCH.
*Formal analysis:* Hicham OUBELLOUCH.
*Acquisition of funds:* Hicham OUBELLOUCH.
*Research:* Hicham OUBELLOUCH.
*Methodology:* Aziz SOULHI.
*Project management:* Hicham OUBELLOUCH.
*Resources:* Hicham OUBELLOUCH.
*Software:* Hicham OUBELLOUCH.
*Supervision:* Hicham OUBELLOUCH.
*Validation:* Aziz SOULHI.
*Display:* Hicham OUBELLOUCH.
*Drafting - original draft:* Hicham OUBELLOUCH.
*Writing - proofreading and editing:* Hicham OUBELLOUCH.