Allocation and optimization approach for safety barriers in hydrocarbons storage stations:

Case of PSBM station

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Abstract : The complexity of systems in the current process industry is conducive to the concerns of industrialists about the risks that may be inherent in these systems. Risk reduction measures should be considered and implemented to reduce the initial risk to an acceptable level. This is usually achieved by using a combination of systems that provide security, inter alia, Safety Instrumented Systems (SIS). The implementation of a SIS requires the determination of its Safety Integrity Level (SIL) which it must have in order to attain the tolerable risk. The standards IEC 61508 and 61511 provide a framework for the determination of SIL and propose different methods.

The objective of this work consists in proposing an approach of allocation and optimization of the security barriers, using the methods of risk graph and LOPA (Layer Of Protection Analysis) In order to evaluate the performance of the safety measures put in place for the control of risks in a hydrocarbon storage station. A cost benefit analysis (CBA), as a decision support tool, is carried out to improve the safety level of the process studied.

Keywords: Safety Instrumented System, safety integrity level, SIL Allocation, Risk Graph, LOPA, CBA.

1. Introduction

Developments in terms of technical improvements have recently been found in the process industry, in terms of the company objectives, leading to the expansion of facilities and augmentation of their complexities. And lead in turn to increase the concerns of industrials regarding the risks that may be present. So the risk reduction measures should be implemented when the risk is considered unacceptable. Reduce the initial risk to an acceptable level is usually achieved using a combination of safety systems, among which we find the Safety Instrumented Systems (SIS) [1]. The SIS, which often represent an integral part of the safety management systems [17], are designed to maintain the process in a safe state when there is a situation with a real risk for personnel and the environment. They are composed of one or more Safety Instrumented Functions (SIF) which are specified to ensure that risks are maintained to acceptable levels with regards to specific hazardous events. This is usually ensured by making a partial or total shutdown of the process to prevent the dangerous event or to mitigate its consequences.

The implementation of a SIS requires the determination of its Safety Integrity Level (SIL). The international standards IEC 61508 [6] and IEC 61511[7] have addressed the SIF recommendations which are widely recognized as the basis for the requirements related to the specification, design and operation of the SIS. Each SIF is specified in terms of the required action to achieve and the probability of failure on demand (PFD). This latter defines the safety integrity level (SIL) of a SIF. The IEC standards provide a framework for determining the SIL and offer different methods to determine the PFD [15].

The objective of this work lies in this context and consists of proposing an approach for the allocation and optimization of safety barriers, following the analysis phase of the safety lifecycle, as defined in IEC 61508 IEC 61511-1 and -2. These standards have defined an approach for the analysis of the integrity level of a safety system. They help in defining the required safety integrity level (SIL) for a Safety Instrumented Function with regards to the risk analysis. There are no rules imposed by these standards but SIL allocation methods [6], [7], more or less adapted to the level of detail of the previously conducted risk analyses as well as the type and detail of available information [1].

As part of this work, the choice fell on the Risk Graph and Layer Of Protection Analysis (LOPA) methods to assess the performance of the safety barriers used to control the risks in a hydrocarbons storage station. A cost-benefit analysis (CBA) is performed in order to help manufacturers in the decision making. If new risk reduction measures should be added, choosing the most profitable and this for improving the safety of the studied process.

To meet these objectives, our work is organized as follows: section 2 is reserved for the presentation of the approach and the SIL allocation methods, specifically the risk graph and LOPA methods chosen as analytical tools. In Section 3, we present a general approach for the cost-benefit analysis (CBA). The last section is devoted to a case study to illustrate our approach.

2. SIL Allocation Methods

The IEC 61508-5 and IEC 61511-3 describe three types of SIL allocation methods: qualitative, semi-quantitative and quantitative.

- Qualitative methods :

Qualitative methods are based on the verification of the conformity of the safety level with the specifications of regulations and standards [13]. These rules refer to independent means that represent the minimum requirements that must be met to achieve an acceptable level of safety [5]. Among these methods, the risk graph, and hazardous events severity matrix. These methods consider the contribution of risk factors such as the criticality of the consequence, the frequency of dangerous events, the occupation of personnel and the possibility of avoiding the dangerous event [11].

- Semi-quantitative methods

The semi-quantitative methods quantify the risk associated with the process and determine the required contribution of the SIS to reduce the risk [14]. These methods are used to determine the frequency of the hazardous events that will be compared to a predefined tolerable frequency. Any insufficiency is expressed in terms of SIL and this value will be taken into account for the development of a new protective layer [9], [18]. The most common method is the risk matrix, which has the particularity of giving the SIL level according to the severity of the risk and its frequency of occurrence.

- Quantitative methods

These are the methods by which the PFD of SIS can be calculated from the failure probabilities of their components. Among the most widely used quantitative methods we find the fault trees and Markov models. Thus, the calculated performance makes it possible to qualify the SIL level of the SIS according to the levels defined in the standards IEC 61508 and IEC 61511.

It should be noted at this level that qualitative and semi-qualitative methods are generally less costly than the quantitative ones. They are technologically less demanding, relatively intuitive for operators since they do not require qualification training in risk assessment, and do not require extensive use of historical data related to failures as a basis for estimating the failure probabilities.

2.1 Risk graph

The risk graph as described in IEC 61508 is a qualitative method that is the most commonly used to describe a hazardous situation in the absence of safety-related systems.

On the basis of the relationship: $R = f.C$, where R is the risk in the absence of safety-related systems, f is the frequency of the hazardous event and C is the consequence of this hazardous event, the risk graph uses four risk parameters. In fact, since the frequency (f) of the hazardous event is assumed to be the result of three factors: the frequency and duration of exposure in a hazardous area, the possibility of avoiding the hazardous event, and the occurrence probability (or demand rate) of the hazardous event, the following four risk parameters are then obtained:

- Consequence of the dangerous event (C) ;
- Frequency and duration of exposure to hazard (F) ;
- Possibility of avoiding the dangerous event (P) ;
- Probability of the undesired occurrence (W).

From the data of Table I, the parameters C, F, P are selected, one of six outputs is selected, each of these outputs being matched to one of the three scales (W1, W2, W3), their intersection on the risk graph presented in Figure 1, indicates the minimum risk reduction to which the safety-related system must comply.

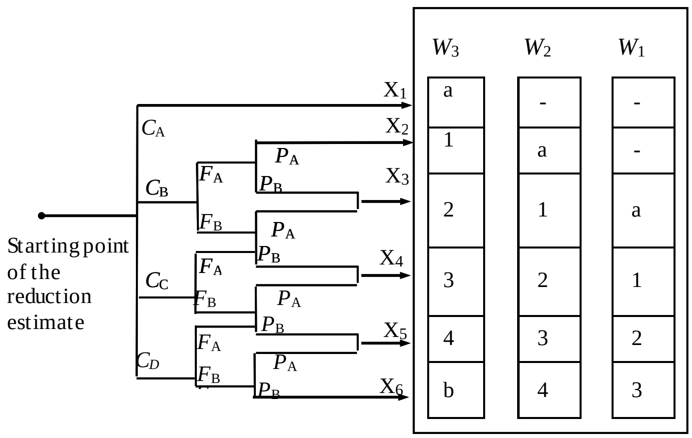

Figure 1. Graph example [6].

The risk graph, as a qualitative method of determining or allocating SIL, is relatively easy to apply and allows a rapid assessment of the safety integrity levels.

Table 1. Example of classification of the risk parameters [6].

Parameter		**Classification**
Consquence	C_A C_B C_C C_D	Minor injury Serious permanent injury to one or more persons; death to one person Death to several people Very many people killed
Exposure time (occupation)	F_A F_B	Rare Frequent
Possibility of avoiding the dangerous event	P_A P_B	Possible Almost impossible
Probability of the unwanted occurrence	W_1 W_2 W_3	A very slight probability Slight probability High probability

2.2Layer Of Protection Analysis (LOPA)

LOPA method, described in the standard IEC 61511[7] and developed by the Center for Chemical Process Safety (CCPS) [3], is a semi-quantitative method of risk evaluation. Its main purpose is to determine if there are sufficient layers of protection against an accident scenario, that is, if the risk is reduced to a tolerable level. A scenario may require one or more layers of protection depending on the complexity of the process and the potential severity of the consequence. LOPA is not a fully quantitative approach of risk assessment, but rather a simplified method for evaluating the effectiveness of protective layers for a well-defined accident scenario [3], [4]. LOPA is

only interested in Independent Protection Layer (IPL). An IPL must be efficient to perform the safety function for which it was chosen [13], independent of the initiating event and other layers of protection and testable to ensure its effectiveness. At each IPL, a probability of failure on demand (PFD) is assigned [3].
The procedure for developing LOPA for a given scenario identified during a qualitative analysis such as HAZOP consists of:

- Choose an accident scenario describing a single couple (cause - consequence).
- Identify the initiating event of the scenario and estimate its frequency. The initiating event must lead to the consequence giving rise to the failure of all the protective layers.
- Identify the independent protection layers (IPLs) and estimate the probability of failure on demand (PFD) of each layer. Certain accident scenarios require only one IPL, while others require several IPLs or IPLs with low PFD, to get a tolerable risk level of the scenario.
- Calculate the frequency of the reduced consequence by combining the frequency of the initiating event, the PFD of IPLs using the following equation :

$$f_i^C = f_i^I \times \prod_{j=1}^{J} PFD_{ij} \qquad (1)$$

where f_i^C is the frequency of the consequence C for the initiating event i ; f_i^I is the frequency of the initiating event i and PFD_{ij} is the probability of failure on demand of the jth IPL which protects against the consequence C of the initiating event i.

- Estimate the risk of the scenario by combining the frequency and the severity of the consequence.
- Assess the risk to make a decision on the acceptability of the scenario by comparing it to the risk acceptability criteria.
- Analyze all the significant scenarios.

For the determination of SIL by the LOPA method, the frequency of the reduced consequence is calculated by combining the frequency of the initiator event with the PFD of the IPLs using equation (1). If f_i^C is greater than the maximum frequency of the tolerable risk *(f_{Tr})*, adding a supplementary protection layer, such as a SIS is required.

$$f_i^C = f_{IE} \times \prod_{i \neq SIS}^{I} PFD_{moy}^{i} \times \mathrm{PFD}_{\mathrm{moy}}^{SIS} \le f_{Tr} \qquad (2)$$

Equation (1) becomes:

$$\mathrm{PFD}_{\mathrm{moy}}^{SIS} \le \frac{f_{Tr}}{f_{IE} \times \prod_{i \neq SIS}^{I} PFD_{moy}^{i}} \qquad (3)$$

3. Cost benefit analysis approach for risk prevention

The approach proposed by the two standards IEC 61508 and IEC 61511 illustrates how process risks can be determined and how the requirements in terms of risk reduction are achieved. However, further efforts are needed to further reduce the risk and continue until risk reduction is profitable [12]. A cost-benefit analysis (CBA) is therefore essential.

The CBA aims to realize all decisions whose benefits are greater than costs. In terms of prevention, in the benefits section, we can include the consequences of a reduction in pollution, a decrease in the incidence of a disease, or a better safety of a plant. In the cost part, one can include the costs of depollution, change of technology, and the costs of investment in safety [19].

In the context of risk analysis and prevention, after identifying all the possible safety measures to reduce the studied risk, we must estimate the cost of these measures. The measures envisaged must then be compared with each other in order to retain the most profitable ones. Finally, for each remaining measure at the end of the second stage, the benefits associated with its implementation are compared with its estimated cost in the first step. The analysis of the results of this comparison makes it possible to orient the decision of the user in favor of the implementation or not of the studied measures.

The sources of cost estimates for the various elements are multiple, therefore the units used are of various monetary values: Algerian Dinar (AD), Euro (€) and Dollar ($). So we kept the homogeneity of the Euro unit (€). The INERIS guide [19] proposed a simple comparison of the annualized costs of measurements; the proposed scale is as follows (Table 2):

TABLE 2. PROPOSAL FOR QUALITATIVE SCALE OF COSTS [19]

Cost Level	Annualized cost
1	Less than 10 000 €
2	Between 10 000 € and 50 000 €
3	Between 50 000 € and 250 000
4	Between 250 000 € and 1 000 000 €
5	Greater than 1 000 000 €

To estimate this annualized cost, we can use various sources such as modeling, feedback, expert opinions, etc. A detailed approach can be based on the following expression of the annualized costs of a new safety measure [19]:

$$Coût\ \text{anualisé} = \sum_{t=1}^{n} \frac{(Tc + \text{TCO})}{(1+\text{r})^{\text{t}-1}} \text{ x } \left[\frac{\text{r}(1+\text{r})^{\text{n}-1}}{(1+\text{r})^{\text{n}} - 1} \right] \qquad (4)$$

where:

n : Estimated life of the measure in question; In our case we take it for 30 years.

t: Index varying from 1 year, of implementation of the measure, to n ;

Tc : Total investment costs of the safety measure over the year t ;

TCO: Total net Cost of Operation and maintenance of the safety measure over the year t;

r : Discount rate =10%.

When comparing the possible measures in order to achieve a first filter of the most effective measures. We compare the most effective measures for each cost level, i.e., those that minimize the risks leading to identical consequences. The consequences in terms of risks can be assessed using different supports. INERIS proposes three types of comparisons, based on the effects distances, on the urbanization control document appropriate to the case study, and on the risk matrix. These comparisons can be used independently or in a complementary manner depending on the envisaged measures (preventive or protective measures, measures to modify the process, etc.). The information resulting from these comparisons is then analyzed in order to proceed to selecting the measurements [19]. Finally, for each measure chosen at the end of the second stage, we propose to evaluate the benefits of its implementation.

4. Case study

In order to illustrate the applicability of the proposed approach and to demonstrate its contribution in improving the safety of industrial processes, our case study focused on one of the hydrocarbon storage stations that could generate, in the case of failure, critical or even catastrophic human, material, and environmental consequences. This is the pumping station PSBM (Pumping station of Beni-Mansour) SONATRACH [16].

The storage section consists of two tanks with a capacity of 12000 m^3 each. These storage tanks serve as standby buffers at the pumping station. The filling of these storage tanks is carried out either from the raw feed network (main network) or from the drain and purge network (secondary network). The tanks can be emptied only through the main network.

A HAZOP (HAZard and Operability) analysis [8] is performed to identify the representative scenarios. The choice between several scenarios was based on the following two scenarios resulting in the shutdown of the storage section and can cause serious damage to people and the environment (Table 3):

Table 3. Retained accident scenario

Scenario	Description
1. High crude oil level in the storage tank	The raising of the level of the crude, causes the overflow of the tank, loss of confinement of the crude oil, and with a presence of a source of ignition, the formed pool ignites (pool fire). The thermal effects generated by the fire around the tank can reach people, equipment and the environment.
2. Too much pressure [High pressure in the storage tank]	The rise in pressure causes a rupture of the dress of the tank and then the loss of confinement with formation of a pool which can ignite in the presence of a source of ignition. Pressure build-up may result in bursting of the tank top or loss of tightness between the roof and the tank top, leading to a formation of a large explosive cloud and leading to a UVCE, the effects of which can affect persons, equipment, and the environment.

4.1 Application of the risk graph method

Once the accident scenarios have been identified, it is then necessary to check whether a reduction is necessary for each retained scenario, using in our case the risk graph method which has the peculiarity of giving results in the form of requirements in terms of SIL.
Referring to the data in Table I, a qualitative and quantitative definition of parameters C, F, P and W is given (Table 4).

Table 4. Determination of the risk graph parameters related to the two scenarios

Parameters	**Scenario 1: Level augmentation**	**Scenario 2: excessive pressure**
Consequences of the hazardous event (C) :	$\mathbf{C_C}$: The irreversible and lethal effects come out of the site. At most one person (1 to 10) exposed, which can cause the death of several people.	$\mathbf{C_C}$: The irreversible and lethal effects come out of the site. At most one person (1 to 10) exposed, which can cause the death of several people.
Frequency of exposure to hazard (F)	$\mathbf{F_B}$: The total duration of work (8h) - The duration of exposure to danger: (1h) - Duration of work : 100% - Duration of exposure: 12.5% ≥10%.	$\mathbf{F_B}$: The total duration of work (8h) - The duration of exposure to danger: (1h) - Duration of work : 100% - Duration of exposure: 12.5% ≥10%.
Possibility of avoiding the risk event (P)	P_A : In the case of a deviation and the absence of SIS, there are places of the following means: - The accident scenario kinetics is slow. - An alarm alarming the operator immediately after the danger is detected; - The danger zone is in an open space that facilitates the evacuation of people to safe areas; - The operator can act quickly just after the alert in the case of the occurrence of the dangerous event.	$\mathbf{P_B}$: In the case of a deviation and the absence of SIS, - The accident scenario kinetics is rapid. - Absence of an alarm which alerts the operator when dealing with this type of hazard.
Probability of occurrence of the unwanted event (W)	**W1**: The occurrence probability is estimated at (<1times/30 years)]. Which corresponds to W1.	**W1**: The occurrence probability is estimated at (<1times/30 years)]. Which corresponds to W1.
Safety Integrity Level (SIL)	**SIL 1**	**SIL 2**

For both scenarios, there are safety implications that can be subject to a necessary risk reduction with functions of level SIL 1 for the first scenario and SIL 2 for the second scenario.

4.2 Application of LOPA method

In order to reduce the risks generated by the two scenarios identified above, several safety barriers are implemented. These are identified in advance by the HAZOP method.

The frequency of the reduced consequence of the two scenarios is calculated using equation (1). We find 4.00E-06/year for S1 and 1.01E-04/year for S2 (Table 5). The values of the calculated frequencies will be compared with the frequency of the tolerable risk (1.00E-05) adopted by the company for a decision on the acceptability of these scenarios.

Table 5. SIL determination using LOPA method

Title of the study : Storage tank R561 **Group composition :** End-of-cycle students IHSI-Batna Master MRI, Engineer MN, Instrumentation and Operators								**N° of (P&ID) : not available** **N° de Revision : not available** **Date : 06 April to 04 May 2016.**			
reference	Unwanted Event		Initiating event (IE)		Protection layer (IPL)						
	Description	Catégorie de gravité	Initaiting event (IE)	Frequency of the IE ($/h^{-1}$)	Alarm/HO	ESD	Retention bowl	Probability of the inermediate ing event	Maximum tolérable risqk	Required PFD SIS	Required Safety Integrity Level (SIL)
Sc.1	High level causes overflow and loss of containment	G4	Human error (over filling).	2.00E-01	1.00E-01	1.00E-03	1.00E-01	2.00E-06	1.00E-05	/	none
			Failure of the tank level detection system during filling.	1.00E-01	1.00E-01	1.00E-03	1.00E-01	1.00E-06			
			Failure of the valve MOV 08 of input / output tank when filling (blocked open).	1.00E-01	1.00E-01	1.00E-03	1.00E-01	1.00 E-06			
Sc.2	Overflow and loss of containment due to overpressure	G4	Excessive opening of valve MOV 08 (High filling rate).	1.00 E-01	1.00 E-01	1.00E-03	1.00 E-01	1.00 E-06	1.00E-05	1.11E10-2	SIL1
			Failure of the roof of the tank (jamming, gluing ...).	9.00 E-03	/	/	1.00 E-01	9.00 E-04			

4.3 Results discussion and recommendations

Following the application of the LOPA method (Table V) and comparing the frequencies of the reduced consequences of the studied scenarios with the maximum tolerable risk frequency (1.00E-05), we find that scenario 1 has no requirement in terms of risk reduction. However, scenario 2 has safety implications that can be subject to a necessary risk reduction with a function (SIF) whose PFD is determined using equation (3). The SIS PFD to implement in order to reduce the frequency of scenario 2 is 1.11E-2, which corresponds to SIL1.

The application of the two approaches, qualitative with the risk graph and semi-quantitative with LOPA, yielded different results. The difference was observed in the two scenarios where an overestimation of the SIL level was obtained by the qualitative approach compared to the result obtained by the semi-quantitative approach, which is more precise. Indeed, the evaluation of the parameters of the risk graph is made based, on the one hand, on the judgment of experts and on the other hand on the use of data derived from the literature. Therefore, the use of qualitative definitions for risk parameters is very subjective and their meaning can be misunderstood. Thus, the estimation of the parameters of the graph is an important source of uncertainty and may be the origin of the results' inconsistencies and possibly of the conservatism which can result in an under or overestimation of the SIL.

Moreover, in order to mitigate the consequences that can be generated by the second scenario, a review of the means of prevention and protection put in place for the management of these risks is essential.

5. Improvement and optimization of the safety level

Some recommendations are made for the improvement and optimization of the safety level of the PSBM. For the necessary risk reduction, the IEC 61511 standard [7] recommended the use of (independent) protective layers from other technologies before defining the need for an safety instrumented function implemented in a SIS to comply with the target safety requirement (tolerable risk).

In our case, for scenario 2 no protection layer based on other technologies or external means of risk reduction are considered to reduce the risk to a target safety level. Therefore, a new safety instrumented function with SIL 1 incorporated in a SIS must be used to achieve the target safety level. In view of this, the SBM station is equipped with a safety instrumented system having a SIL 1 of emergency shutdown (ESD), thus the new function is an emergency shutdown function.

Thus, in order to mitigate the high pressure and prevent the rupture and loss of crude oil containment and ultimately limit the spreading of oil beyond the storage section, the safety function must be implemented by a SIS consisting of three elements (Figure 2):

- A pressure transmitter at each tank foot (R561 and R562) downstream of the valves (MOV08 and MOV 512) (respectively). (PT1, PT2).
- Logical unit: of emergency shutdown (ESD); (Available at the PSBM station);

- The two emergency shutdown valves MOV08 and MOV 562 installed at the tank feet R561 and R562, which interrupt the filling of the tanks when the downstream pressure exceeds a pre-set trigger level. (Available).

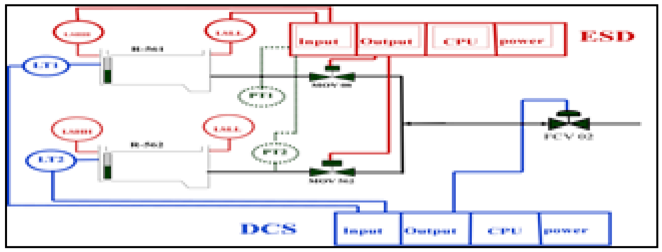

Figure 2: Illustrative diagram of the allocated function and other safety functions.

The new safety instrumented function, having a SIL 1, is used to minimize the frequency of an overpressure at the crude oil storage tank at the collector and then the reduction of the frequency of occurrence of the rupture and loss of crude confinement. The overpressure frequency was reduced to 1.11E-2 /year, which is below the target safety level of 10 E-5 /year.
Therefore the determination of the SIS architecture is essential. According to IEC 61508-2 (§7.4.2.2) the design of SIS shall comply with the equipment safety integrity requirements which shall include:

- Architectural constraints related to hardware safety integrity.
- The requirements concerning the SIS probability of failure.

Concerning the architectural constraints: according to IEC 61508-2 "in the context of hardware safety integrity, the highest level of integrity (SIL) that can be announced for the given safety function is limited by the hardware fault tolerance of the equipment and the safe failure fraction (SFF) of the subsystems that perform the safety function ".
The evaluation of the architectural performance requires to previously identify the type, namely, A or B of each subsystem [2], for our case the subsystem: logical unit (ESD) has a SIL 3 with a 1oo2 architecture, and the actuators (MOV 08 and MOV 562) have an SIL 2 each with an architecture of 1oo1. Therefore, it remains for us to determine the architecture of the sensor (pressure transmitter) which in this case must have a SIL 1.
Since failure modes of the transmitter are not well defined, and there is not enough reliable feedback data, the pressure transmitter to be installed must therefore be considered of type B.
For a pressure transmitter of SIL 1 and type B, the architectural possibilities can be (1oo1, 2oo2, 3oo3 ...) or (1oo2, 2oo3 ...).

Using the on-line software for calculating the SIL of SIS [10], the architectures that can be most claimed in our case are: 1oo1 or 1oo2, which are shown in Figure 3.

Figure 3: The proposed configurations for the new SIS.

So the choice between these two cases is subject to a company decision depending on the performance of the purchased pressure transmitters and the estimated cost. So a cost-benefit analysis is essential to prioritize the architectures in order to help the company in making a decision.

6. Cost-benefit analysis (CBA):

It is necessary to recall that the requirements in terms of risk reduction involves the implementation of measures having safety functions which contribute by the high pressure attenuation, then avoiding the equipment failure and the loss of petroleum confinement Crude and ultimately the spread of the petrol beyond the storage section.

a) Identification of measures and their annualized cost.

After a preliminary study based on the consultation of the PSBM hazard study, we identified the safety measures whose annualized costs are estimated using equation (4) and given in Table 6.

Table 6. Identification of the annualized cost measures

Category	Risk reduction measures	Annualized cost	Cost level
Measures that make the scenario physically impossible and replace it with other one or more.	M1: Make the wall and the bottom of the bowl in concrete.	10020.669 €	2
Preventative measures	Emergency shutdown system (ESD) : 1.M2: first configuration (1oo1): one single sensor. 2. M3: second configuration (1oo2): two sensors.	115200.86 €	3

For the reinforced concrete of the bowl, the volume of concrete has: 128 m^3 and 811.80 €/m^3 given by LIVIOS therefore the total cost of reinforced concrete is: 103910.4 €.

- Total investment costs of the safety measure is 103910.4 € in year ;
- Estimated lifetime of the safety measure equals : 30 years;
- Retained discount rate: 10% ;
- Total net cost of operation and maintenance of the safety measure: 0€.

The annualized cost is 10020.669 €, so of level 2 (Table 2).

To estimate the cost of the emergency shutdown system, in this case we have two configurations to consider. The purchase of a single pressure transmitter for the first configuration and two pressure transmitters for the second configuration.

For the first configuration: measure M2

- The purchase of the sensor is estimated at: 50000$= 44870 €
- Total investment costs of the safety measure: 51340$ = 46073€ at year.
- Estimated lifetime of the safety measure : 30 years ;
- Tc: Total net cost of operation and maintenance of the safety measure: 17 of investment per year.
- TCO: Equal to the sum of maintenance, repair and test costs, it is equivalent to 17% of Ct.

The annualized cost is 115200.86 €, so of level 3 (Table 2).

For the second configuration: measure M3:

Knowing that the two level transmitters are identical, they have the same cost. And therefore the total annualized cost is 230401.72 €, so of level 3 (Table 2).

b) Selection of the most cost-effective measures:

The objective of this step is to compare the measures to carry out a selection of the most effective ones. In our case, the comparisons of measurements are made with identical consequences based on the evaluation by the risk matrix. This makes it possible to deal explicitly with possible new scenarios created by the envisaged measures. For example, in the case of ESD, it contributes to risk reduction through an action on the MOV 08 and MOV 562 valves which will attenuate the high pressure in the storage tank, but this can lead to an increase of pressure in the equipment upstream of the valves. Same thing for the retention bowl, which will retain all of the crude oil spread and with the presence of a source of ignition a bowl fire may be considered. So the two retained measures lead to secondary scenarios that are called residual scenarios [19]. The comparison consists of positioning the studied major accident, and the set of the residual scenarios, on a probability/gravity grid. Then, we count how many boxes each measure has moved the accident in the risk matrix, whether in terms of probability or gravity, in order to compare between the measurements.

The distance-based assessment consists of comparing the advantages obtained before and after the placement of the reinforced concrete retention bowl on the same cartographic support. As part of a hazard study, zoning effects is a suitable tool for this comparison. Indeed, measure M1 leads to the reduction of the distance effect especially the zone of the lethal effects (LET: Lethal Effect Threshold) and irreversible effects (IET: Irreversible Effects Threshold).

The evaluation by the criticality grid revealed that no retained measure was favored with regard to the retention bowl and the emergency shutdown system. Both measures need to be implemented since they have not the same safety functions; the emergency shutdown system is dedicated for prevention and the retention bowl for protection.

The comparison must be made between the two configurations of the envisaged emergency shutdown system (M2 and M3) which have the same consequences with different costs.

c) Comparison of risk reduction measures: Measure M3 could be used but the measurements M2 and M3 have the same advantages because they both prevent the pressure rise. On the other hand, measure M3 is more expensive than the measurement M2 and the comparison of cost levels with the equivalent benefits therefore eliminates it.

Analysis of the results: Measure M1 in fact reduces the number of people exposed in the LET and the IET on the one hand and to protect the environment on the other one.

The measurements M2 and M3 make it possible to completely attenuate the high pressure in the storage tanks. Especially M3, that more on performs its safety function. But this one is costly compared to M2 which can perform the same safety function.

7. General conclusion

The main objective of this work is to evaluate the performance of the safety barriers installed on the storage tanks at the Béni-Mansour pumping station for controlling the risks that can be generated by this installation.

A well-defined approach has guided us in establishing a risk analysis and in identifying the most critical accident scenarios as well as the prevention and protection barriers that have been put in place to deal with these scenarios. The allocation of requirements in terms of risk reduction was done by applying two approaches: qualitative by the risk graph and semi-quantitative by LOPA method for the determination of the safety integrity level (SIL). Indeed, when the issues are high, it is necessary to question the use of one or the other of these proposed approaches in order to opt for the most appropriate according to the available information and the needs of the study and the nature of the consequences in terms of safety of people and/or environment.

We conclude that in the implementation of both approaches, the qualitative evaluation by the risk graph is easier and faster. On the other hand, it may be subjective and could be burdened by a problem of interpretation of the risk parameters. Indeed, the evaluation of the parameters of the risk graph was made on the basis of expert opinions and the data used are derived from the literature. Thus, it can lead to inconsistent results and therefore to pessimistic SIL levels compared to the results obtained by the semi-quantitative evaluation by LOPA method which is more precise.

The main contribution made through our case study is the SIL allocation required to satisfy the necessary risk reduction requirements in order to mitigate the accident scenario inherent in the system (pressure rise in the storage tank) by applying the two methods: risk graph and LOPA.

This application allowed us to identify the safety functions of each implemented layer of protection as well as their requirements in terms of risk reduction. The obtained results showed that the accident scenario (pressure rise in the storage tank which can cause an overflow or a rupture followed by a loss of confinement of crude oil which risks spreading beyond of the bowl which is in height), is subject to a risk reduction by a safety function of level SIL1 to reduce the risk to the tolerable risk level.

The implementation of these measures can lead to changes in equipment and the production process which can in turn lead to new accident scenarios and lead to cost increases. So these measures need to be justified in terms of cost and benefit to help policy-makers in implementing them. For this purpose, a cost-benefit analysis (CBA) was carried out. The latter consists of four stages, the application of which has led us to choose the economically feasible measures by comparing the advantages of their implementation.

References

1. Adjadj Ahmed et Dominique Charpentier. Allocations de SIL requis des fonctions instrumentées de sécurité d'une installation lorsque l'analyse de risques est incomplète. BENNOUNA.M, EL. HAMI. *Congrès International Qualita*, pp.207-214, Mar 2007.
2. Bradley Allen, *process safebook 1*, sécurité fonctionnelle dans l'industrie de procédé. Mars 2013.
3. Center for Chemical Process Safety (CCPS), Layer of protection analysis (overview of LOPA), *an AIChE Industry technology alliance, American Institute of Chemical Engineers*, 2001, page 14.
4. Chunyang Wei, William J. Rogers and Sam Mannan, Layer of protection analysis for relative chemical risk assessment", *Journal of Hazardous Material*, 159, 2008.
5. Dziubiñski. M., M. Frątczak, A. S. Markowski, « Aspects of risk analysis associated with major failures of fuel pipelines », *Journal of Loss Prevention in the process industries*, vol. 19, pp.399-408, 2006.
6. IEC 61508 Standard, Parts 1-6, Functional safety of electrical/electronic/programmable electronic safety related systems, *International Electro technical Commission* , First edition, 1998.
7. IEC 61511 Standard, Parts 1-3, Functional safety-Safety instrumented systems for the process industry sector-, *International Electro technical Commission* , First edition, 2003.
8. IEC 61882 Standard, Hazard and OPerability studies (HAZOP studies) - Application guide, *International Electro technical Commission*, 2001.
9. *INERIS*, ARAMIS Development of an integrated method of analysis of the risks for the prevention of the major accidents, Final report, 2004.
10. Institute of Regulation and Automation (IRA), *Automatisme.sécurité.pageperso*-orange.fr
11. Kirkwood. D and Tibbs. B, «Developments in SIL determination», *Computers and Control Engineering Journal*, vol. 16, pp. 21-27, 2005.
12. Marengo. C.R., J. Flores, A.L. Molina, R. Román, V. C. Vázquez, M. S. Mannan, «A formulation to optimize the risk reduction process based on LOPA», *J. Loss Prev. Proc. Ind.*, 1-6, 2012.
13. Marszal. E.M., E.W. Scharpf, «Safety Integrity Level selection-Systematic Methods including Layer of Protection Analysis», *Instrumentation Syst. and Automation Society (ISA)*, 2002.
14. Simon. C., Sallak. M and Aubry. J.F., «SIL allocation of SIS by aggregation of experts opinions», *Safety and Reliability Conference*, June 25-27, Stavanger (Norway), 2007.
15. Smith. D.J. and Simpson. K.J.L, Functional safety: A straightforward guide to applying IEC 61508 and related standards, 2nd edition, *Elsevier Butterworth-Heinemann*, 2004.
16. SONATRACH document /Pumping Station Beni-Mansour (PSBM), 2009.
17. Timms. C.R., «IEC 61511-an aid to COMAH and safety case regulations compliance», Measurement & Cont. J., Vol. 37, Part 4, pp. 115-122, 2004.
18. White Paper Report, «SIL Determination Technique », *ACM Facility Safety*, 2006.
19. Yann FLAUW, Clément LENOBLE, Guide mise en œuvre du principe ALARP sur les installations classées pour la protection de l'environnement, *Rapport d'étude, INERIS-DRA-71-opération A*.5, 2014.

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