Risk, Reliability and Societal Safety – Aven & Vinnem (eds)
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The safety integrity level as Hazop Risk consistence. The Brazilian risk analysis study case

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ABSTRACT: The HAZOP is the most used risk analyze tool in Brazilian oil industry and it's has been given the high support in project decision to risk reduction regarding layers protection as safeguard implementations or projects modifications. As a matter of fact, the mean focus of Hazop is process deviations nor hazard and environment aspect and it's the first limitation. Moreover, even given a high contribution to increase the safety level plants so many recommendations requires safeguards and it's can lead Plants to unsafe condition regarding in some specific events, so many visual alarms and others safeguards are released in the same time that operator have no condition to pay attention in all of then and it's may happen an accident. So the recommendation consistence is necessary to keep safety level and reduce the layers protections that not contribute to risk reduction.

The SIL analysis has the mean objective to check the reliability level of safety functions and if it's necessary, to propose configuration improvement to increase safety levels. There are qualitative and quantitative SIL analysis methodology, The matrix methodology, Risk graph, Assignment base on frequency and Assignment based on individual and society risk. All of that methodology permit to identify SIL and propose improvements to achieve SIL target that's is defined for specific standards or for company standards. Therefore, that's an important risk analysis to check HAZOP consistence.

The SIL application will be shown in a refinery study case as a consistence analysis of HAZOP analysis to check if the recommendation is enough to achieve the SIL required or not and in which cases it'll be necessary increase or reduce safety levels.

1 INTRODUCTION

The HAZOP means hazard and operability and it's a famous risk analysis in Chemical, Oil and gas industry. That's technique was introduced for ICI Chemical company engineers in 1970 in order to prevent process deviation. Its consist in very structural methodology with specific world which provide a guideline to assess process deviation, causes, consequences and whenever it's possible to propose recommendation to mitigate risk. In Brazil it's usual in project risk analysis in Oil and Gas industry and chemical either.

The SIL analysis is other very important risk analysis technique and means safety integrity level. That application starts in mechanical industry in EUA as process management tool and a OHSAS standard required for that industry to support decision about system emergency control integrity. In EUA, the ISA (Instrumentation, System and Automation Society) published a ANSI/ISA-84.01-1996 and the IEC (International Eletromechanical Commission) made up another standard, IEC 612508 regarding several industries.

The mean idea in SIL analysis is define the safety function protection and check that reliability level. The standard are used to compare the integrity level function with SIL required and if necessary to precise how much that level must to be increased in order to achieve SIL target .

In so many cases in Brazilian risk analysis used to perform HAZOP and after SIL analysis to certify the safety function protection, that reliability and optimize the instrumentation in operational plants.

2 THE HAZOP RISK ANALYSIS IN BRAZIL

The HAZOP RISK ANALYSIS was implemented in 90 decades in Brazilian oil industry. From now on , due the accident around the world, was evident the importance of that analysis in project in order to avoid catastrophic accident . In some case, if that technique were applied in project one layer protection would impede the accident.

Nowadays, nobody question the HAZOP importance but in so many cases in Brazil, so many engineers, project coordinators and manager try to simplify that application reducing the analyze time or gathering another kind of risk analysis to be performed together.

In fact, HAZOP has a process deviations focus and must be performed apart from other analysis.

In Brazil, HAZOP is performed for risk analysis specialist, specific companies and in some cases for safety engineers. Nowadays, the risk analysis is not spread out and in so many cases specific companies are contracted to coordinate that. The bad side that most part of that analysis are performed for little companies and it's not permit to divulge that technique and in some cases that not independent results due to commercial issues involved.

Despite that fact, that kind of risk analysis is being know for engineers and Brazilian Universities are evaluating and perform some risk analysis.

3 THE SIL ANALYZE IN BRASIL

In Brazil, SIL analysis is not usual in most of industries. Even in oil and gas and chemical industries in not common and it's makes difficult to perform that analysis in project.

In some cases, some companies made up specific procedures to implement that analysis and engineer arte responsible to coordinate that analysis in their companies.

The interesting fact is that most of cases, a qualitative analyze is chosen as standard what is not the best decision but is clear that as another risk analysis applications the SIL analysis will evaluate and must be spread out to safety professionals and engineers.

4 THE HAZOP METHODOLOGY

The HAZOP methodology consist in define which are the consequence of process deviation and try to mitigate the risk implement recommendations as layers protection. That is a well structural analysis which specific process deviation, guide world and concepts.

The first step in HAZOP analysis is define the system, subsystems and in each subsystem is necessary to define nodes. That nodes will limit the consequence process deviations and include a group of equipment, alarms, valves and so on. Depends on coordinator it's been considered the causes and safe guard into the nodes, out of node or both of then.

In fact, if it's been considered the process deviation consequence into the nodes and causes and safeguards in anywhere, the focus is on node without forgetting any important issues out of that.

The second step is to ask for group about process deviation as pressure, level, temperature, flow and contamination but to do that some guide words is necessary. The mean guide words terminology is shown in table 1 below.

Based in that words is asked to group about low pressure and high pressure, low temperature and high temperature and so on. After that the causes, consequence are assessed and it's check if there are safeguards or not and if it's necessary. The safe guard is considered the equipment which function is alarm independently in case of unsafe condition. By that way, if any action as read a instrumentation is necessary that instrument is not considered a safe guard. So safeguards works automatically in any unsafe condition. The HAZOP steps can be summarized in figure 1 above.

Table 1. Words guide.

Word guide	Mean
None	There's no parameter
Less	Quantitative Reduction
More	Quantitative increase
Part of	Qualitative reduction
Either	Qualitative increase
Reverse	Opposite flow than usual
Other	Complete substitute

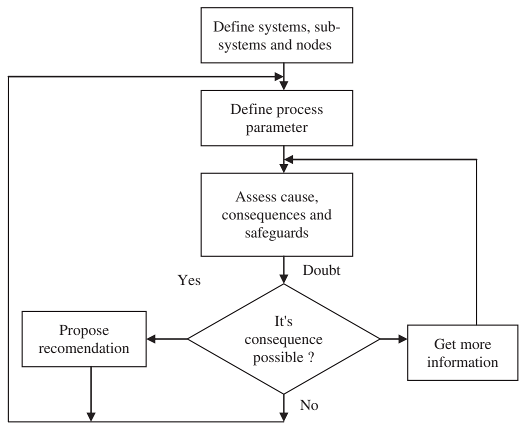

Figure 1. HAZOP steps.
Source: Moraes, 2003.

5 THE SIL METHODOLOGY

The SIL risk analysis has the mean objective to define integrity safety functions in terms of reliability.The four methods define the SIL required but is necessary to check the layer protection PFD in order to compare with PFD related with SIL target in selection. The Layer protection PFD must be lesser than SIL target, otherwise some improvement is necessary to safety function achieve SIL target. As mentioned

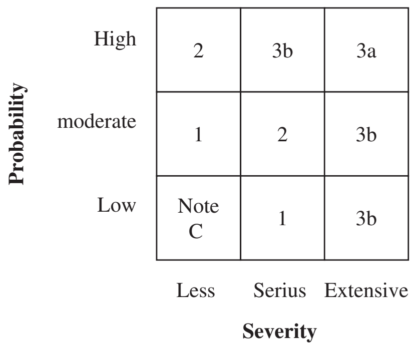

Figure 2. Risk matrix.
Source: Schartz, 2002.

a) In level 3 the SIF not provide a RRF necessary. Modification are required.
b) In level 3 the SIF not provide a RRF necessary. Is necessary assess carefully.
c) SIF probability not require layer protection.
d) That not enough to SIL 4 condition.

before, there are some international standard to check if the SIL is enough to guarantee reliability necessary or if necessary to modify safety function in order to obtain SIL target.

There are four methodologies to perform SIL analysis that are:

- Risk matrix;
- Graph methodology;
- Target Frequency;
- Individual risk;

The risk matrix is a first qualitative SIL methodology which considers a qualitative risk matrix to define SIL of specific safety function. So frequency and consequence is took into consideration. The combination of safety function failure frequency and consequence severity is SIL. In figure 2 above is shown the risk matrix.

The graph methodology is second qualitative methodology and it's takes consideration so many facts as the frequency that safety function is required to avoid accident, human exposure, safety function failure and the possibility to avoid accident. Each criterion has one score which results in specific SIL depends on scores results combination. The graph guide is shown in figure 3 below.

So, for instance the combination W3, S4 and A2 require safety class X, but what does it means. In fact each safety class SIL is related with one specific SIL and safety function demand failure as shown in table 2 below.

So the safety class X means that it's necessary high reliability level due to catastrophic consequences and high probability to happen.

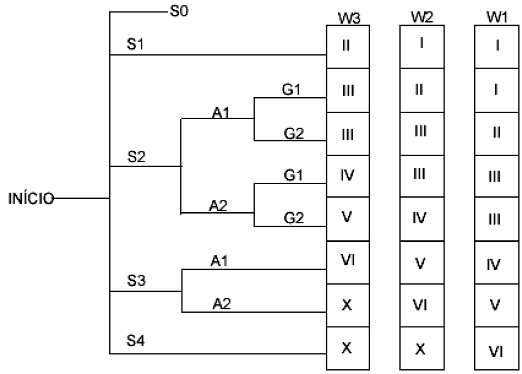

Figure 3. Graph methodology.
S represent individual health disturb so:
S0 = none
S1 = lost time injures
S2 = disability or death of one individual
S3 = disability or death of several individuals
S4 = Catastrophic
A represent level of individual presence in risk area:
A1 = rarely
A2 = frequent
G represent possibility to avoid risk exposure:
G1 = Under certain conditions
G2 = hardly possible
W represent safety function requirement:
W1 = 0.03 per year
W2 = between 0.03 and 0.3 per year
W3 = between 0.3 and 3 per year

Table 2. SIL classification.

Safety class	PFD	SIL	AK Class
I	≥10 – 1	0	–
II	≥10 – 1	0	1
III	≥10 – 2 – <10 – 1	1	2–3
IV	≥10 – 3 – <10 – 2	2	4
V	≥10 – 4 – <10 – 3	3	5
VI	≥10 – 4 – <10 – 3	3	6
X	≥10 – 5 – <10 – 4	4	7–8

Source: Schartz, 2002.

The target frequency methodology is based in risk reduction that means RRF = Fac/Falvo. RRF = risk reduction factor, Fac = fatalities and Ftg = frequency target. So RRF is based in fatalities frequency and probability of accident occur. The table 3 below show the RRF and SIL required.

One example would consider the toxic liberation which cause 75.6 f/ev losses of life per event with probability of 1 in each 862 years (1.2×10^{-3}). In this case is necessary to qualify the consequence as shown in table 4 below as extensive (1×10^{-6}). So:

RRF = Fac/Falvo = (1/862) / (1x10-6) = 1121.

Table 3. SIL × RRF.

SIL	RRF
4	1000 > RRF
3	1000 > RRF > 10000
2	100 > RRF > 1000
1	10 > RRF > 100

Source: Schartz, 2002.

Table 4. Target frequency.

Severity rank	Impact	Target frequency
Less	Low health disturb and environment impact. No process losses.	1.0×10^{-3}
Serius	Equipement damages. Process shutdown. High environment impact.	1.0×10^{-4}
Extensive	High equipment damage. Long process shutdown and catastrophic health and environment impact	1.0×10^{-6}

Source: Schartz, 2002.

We verify that the SIL related with that RRF value is 4 because we must consider one level above.

The individual risk methodology requires the probability of losses of life in a specific accident together individual risk, that results in Target frequency (Ftg = Find/PLL). The reduction factor is the frequency accident with target frequency. RRF = Fac/Falvo, so in last example if:

Falvo = Find / PLL = 1x10-4 / 75,6 = 1,32 x 10-6.

RRF = 1/892 /1,32 x 10-6 = 849

That results in SIL 3.

Summarizing the SIL analysis, is performed a qualitative analysis to find out the probability of safety function failure and based in consequence is defined a SIL level required. The figure 4 below shows the safety life Cicle which describe The phases as analyze, realization and operation, regarding all actions necessary to achieve SIL target.

Important to say that after select SIL to specific SIF is necessary to check if layer protection PFD is lesser than SIL target defined in SIL selection. So regarding

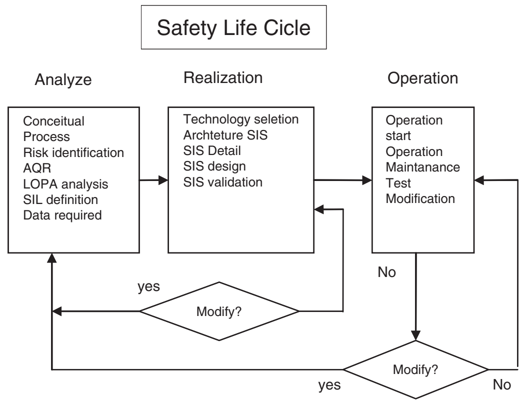

Figure 4. Safety life cicle.

a layer protection with two layers with 0.1 of PFD each one the layer protection PFD is

PFDlp = total layer protection PFD
PFD1 = layer protection PFD1
PFD2 = total layer protection PFD2

PFDlp = PFD1 x PFD2
PFDlp = 0.1 x 0.1 = 0.01

If SIL target is 4, PFD required is 0.0001 so it's necessary to implement one SIF in order to achieve the SIL 4 and it has to be PFDsif = 0.01 . After SIF implemented the new PFDlp is

PFDlp = PFD1 x PFD2 x PFDsif

PFDsif = safety function PFD

So, the PFDlp will be.

PFDlp = 0.1 × 0.1 × 0.01 = 0.0001

So the SIL 4 is achieved.

6 THE SIL ANALYSIS AS HAZOP CONSISTENCE STUDY CASE

The SIL analysis in Brazil is used as a HAZOP consistence assessment in order to validate the safety functions reliability. In fact, due to qualitative HAZOP features and process focus, it's difficult to Know if some recommendation improve the safety level or make up one unsafe condition regarding that in some cases, so many alarms will not permit operator to have the best decision and that alarms must be ignored.

The study case is assess a refinery plant (UGH). The Hydrogen Generation Unit has the mean objective to send hydrogen to other refinery plant as

Hydro desulfurization Units. That process comprise tree sub-systems as:

- Feed Desulphurization;
- Reforming and Steam Generation;
- Purification;

In Hydrogen Generation Units based on catalytic steam reforming process the removal of sulphur compounds from the feed is extremely important to avoid the poisoning of the reformer catalyst. In Feed Desulphurization sub-system, the most common poison present in natural gas feedstock is sulphur. The feed desulphurization is done in two stages. In the first one the organic sulphur compounds are hydrogenated forming hydrogen sulfide (H2S). In the second stage the H2S is removed by a high-porosity catalyst.

In Reforming and Steam Generation sub-system hydrogen is produced in the reforming section by the reaction of hydrocarbons (from natural gas or naphtha) with steam, in presence of a catalyst. As the reforming reaction is strongly endothermic and the heat requirement is very high, the reforming catalyst is placed in vertical tubes installed inside the radiant section of the Reformer. The main limitation of the reforming process is carbon formation over the catalyst by hydrocarbon decomposition. This secondary reaction always occurs and must be minimized in order to avoid catalyst deactivation, tube overheating and tubes blockage. Ensuring an excess of steam for the reforming reactions can prevent the carbon formation over the catalyst.

In Purification sub-system, the reformed gas has a reasonable amount of carbon oxides (CO_2 and CO), which will be removed in the CO_2 recovery system and in the PSA system. As most of CO_2 is removed in the CO_2 recovery system and as the PSA removes CO_2 more easily than CO, it is important that the CO content in the PSA feed be as small as possible. In the Shift Reactor the CO is converted to CO_2 and hydrogen, by reaction with steam. This reaction reduces the CO content and simultaneously increases the global process yield.

The HAZOP risk analysis was performed in one week with so many different professional back ground. There was in HAZOP team Process engineers, UGH operators, instrumentation specialist and safety specialist. In most of cases, the group implement one layer of protection whenever one unsafe contition is detected ans it's critical. In fact, after two days analysis the number of layer protection was considered to much and the group start to be conservative and avoid to implement recommendation to install layers protection. That is a reality in risk analysis in Brazil and in some cases the group try to avoid to implement recommendation do not affect the project cost. In that specific case, the conservative and pessimist attitude was performed along analysis that required a SIL consistence analysis.

Table 5. HAZOP matrix.

XXXXX	HAZOP - (Hazard Operability Analysis)			XXXXXXXXX
Unit: UGH		System: Feed treatment		Data: 06/04/2006
Subsystem: Pressure control feed treatment Nó 7: From D-03 until out of PSA, passing by D-03, C-4, C-05, C-06, F-05.				Nº Draw:
Deviation	***Causes***	***Efect***	***Safeguard***	***Recommendation***
Low level	-Control failure in do LIC - 012 -Open failure in LV-012	-Send H2 to E -01	-LAL-01 -LSLL-2	1) Install logic control (software) to low flow in FFIC-02. *Ação por XXXX.*

The HAZOP methodology shown above describes the steps and in that case, the deviation consequence was took into consideration into each node and causes and safeguard in anywhere. The words guide are less, more, none and the process deviation are pressure, temperature, level, contamination and flow. The table 5 shows the HAZOP matrix.

In that example a low level deviation in a vessel due to level control failure or open failure valve LV-012 cause H2 liberation. Despite there are two layer protection, one low level alarm and one low level shutdown control, Hazop analyze group thought necessary more one protection and recommended one logic control implementation.

That a kind of situation that increase the number of layer protection not mean to improve safe function or system safety.

In graph methodology SIL analysis, was decided that this layer protection was not necessary due to flow control that indicate indirectly H2 flow .

In whole HAZOP analysis the group analyze propose 63 recommendation and 36 related with safe function. After SIL analysis 3 of 36 recommendations related with safe function was not implemented . To Know if that reduction improve system safety or not is difficult but all 36 recommendation was assess in SIL analysis and it's certify in part that importance as HAZOP consistence analysis.

7 CONCLUSION

The SIL analysis is a good tool to consistence HAZOP assess, in so many cases in Brazil some HAZOP recommendation are not implemented along process due so many factor as cost, time and different point view about system safety. Despite, qualitative feature in that two analysis, is very difficult to have different focus in process and safe function. So is advisable to have that two analysis.

In Brazil SIL analysis is not spread out and start to be used in project risk analysis, it's means that will be necessary to implement that in more project analysis in order to check the advantages and drawbacks but up till now, that analyze shows a great chance to improve systems in terms of safety using a specific tool to assess safe functions.

More than 30 projects were analyzed by SIL methodology and it's clear that some improvement is necessary as:

- Not limit the SIL analysis only to automatically instrumentation;
- Spread out that analysis to several companies, University and professional to a qualitative improvement;
- Make up one Brazilian standard SIL to attend local industries;
- Improve historical datas to permit different SIL methodology application in order to compare which one is better that other in specific cases;

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