

Integrated approach for HAZOP, LOPA and Alarm Rationalisation Reviews

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Abstract

The Oil and Gas Industry is constantly evolving and increasing in complexity. The inherent nature of operations within the industry means that temperature, pressure, flammable and toxic hazards pose a continual risk. There is therefore a requirement to perform a systematic, auditable approach to plant design and operation with the aim to maintaining a high standard of safety. This is essential to maintain the confidence of both the public and stake holders.

Operators are seeking new strategies to increase profitability and efficiencies. The LNG market is enjoying an upsurge in global demand, due to it being a greener and more efficient alternative to other hydrocarbons. LNG facilities are typically complex and inherently hazardous to operate due to the large volume of flammable inventory present.

Process Hazard Analysis (PHA) is widely accepted as a comprehensive, multi-disciplinary exercise to identify potential hazards arising from process / operating deviations within an engineered design. HAZOP, LOPA and Alarm Rationalisation analyses are generally executed during the design phase (during Concept Stage, FEED and Detail Design Phase) and are subsequently revalidated periodically throughout the operational life of the facility.

Currently, there is a drive to integrate safety analyses such as HAZOP and LOPA, however there are still cases where other PHA analyses are performed in isolation and by differing disciplines. This results in variations in assumptions, methodologies and outcomes. Differing disciplines may use differing data, have differing philosophies and may provide contradictory recommendations to decision makers. Erroneous decisions can be made, with a subsequent impact on construction schedules due to late changes. Significantly, there is also a potential impact to the safety of any project.

Due to the repeated analysis of the same data by differing disciplines, workshop schedules may be wastefully extended.

To address the potential issues of performing typical PHA analyses in isolation and to ensure the safe design of LNG plants, a formal, systematic and integrated system of performing HAZOP, LOPA and Alarm Rationalisation was developed and executed. The methodology ensures that all three analyses are executed in the most efficient way, by cross referencing data from each study and minimising repetition and inconsistencies. This methodology results in a highly efficient and auditable workflow minimising the time spent for workshop based analysis, also, significantly improving the quality of the findings of these analyses.

This paper discusses how the methodology was applied to an LNG project. The example facility is comprised of an LNG export facility with several trains fed with feed gas from offshore production facilities. The technique will demonstrate how to ensure an integrated approach to HAZOP, LOPA and Alarm Rationalisation whilst following the international standards namely IEC 61882 (Cenelec, 2016) , IEC 61511 (International Electrotechnical Commission,2016) and IEC 62682 (International Electrotechnical Commission,2014).

Key Words: Hazard and Operability (HAZOP) Analyses, Layers of Protection Analysis (LOPA), Alarm Rationalisation, Liquefied Natural Gas (LNG), Big Data, Integration

Introduction

This paper focuses on the performance of Process Hazard Analysis analyses such as HAZOP, LOPA and Alarm Rationalisation in determining Operating Envelopes and ensuring these are reflected in design analyses and future operation of the facility. These analyses are typically performed by differing disciplines i.e. process, instrumentation and potentially safety disciplines. However due to the overlap in their scopes and being typically performed in isolation, the findings of each of these analyses may contradict each other i.e. HAZOP contradicts LOPA and Alarm Rationalisation Study findings. This paper describes a methodology which links these analyses in a simple manner to avoid contradictions, resulting in study recommendations that avoid errors/ and or resultant rework. The focus of this paper is the detailed design project phase.

In order to illustrate how the methodology has been used in industry, this paper details examples from a study conducted on an onshore LNG export facility. This facility is comprised of several LNG trains, LNG storage tanks and LNG export facilities.

Background Principles

For safe and efficient operation of hydrocarbon facilities, the operation should be within the normal operating window. Any excursions outside the normal operating window should be avoided and documented. Mitigative measures should be taken to ensure any excursions outside this window are rectified in a timely fashion. The integrity operating window as discussed in API 754 is used to establish safe operating limits for a facility. Figure 1 highlights the operating and design limits. The roles of HAZOP, LOPA and Alarm Rationalisation are discussed in the following sections.

Figure 1: Facility Design and Operating Limits

		Design Margin/ Known to be unsafe	Formally Investigate Exceedance

Safe Design Envelope		Upper Buffer Zone	Formally Report Exceedance. Predetermined action should be taken to restore parameters within the normal operating envelope.
	Safe Operating Envelope	Troubleshooting Zone	Troubleshoot utilising documented Alarm Response
		Normal Operating Window	
		Troubleshooting Zone	Troubleshoot utilising documented Alarm Response
		Lower Buffer Zone	Formally Report Exceedance. Predetermined action should be taken to restore parameters within the normal operating envelope.
		Design Margin/ Known to be unsafe	Formally Investigate Exceedance

Hazard and Operability Study (HAZOP)

HAZOP is a workshop analysis which is utilised to identify shortfalls in the design that could lead to safety, environmental or economic impact. HAZOP is a structured brain-storming exercise where Process and Instrumentation Diagrams (P&IDs) and other design documents are reviewed with the objective of identifying possible hazard cause consequence pairs.

As per IEC 61882 - HAZOP (Cenelec, 2016) is a structured and systematic technique for examining a defined system, with the objectives of:

- identifying risks associated with the operation and maintenance of the system. ;
- identifying potential operability problems with the system and in particular identifying causes of operational disturbances and production deviations likely to lead to nonconforming products.

Layer Of Protection Analysis (LOPA)

LOPA is a method that uses the findings of hazard identification such as HAZOP, and accounts for each identified hazard by documenting the initiating cause and the protection layers that prevent or mitigate the hazard. As per IEC 61511 (International Electrotechnical Commission,2016), the methodology cumulatively identifies the required total risk reduction for each identified scenario leading to a recommendation if risk targets have not been met. As per the IEC 61511 lifecycle, this papers focus on the aspects deemed as "hazard and risk assessments, and allocation of safety function for protection layers".

Alarm Rationalisation

For safe and efficient operation of a facility, an alarm system is required to support the operator in maintaining the facility within safe operating limits. The primary function within the alarm system is to notify operators of abnormal process conditions and/or equipment malfunctions and support the response. The performance of alarm systems can have significant safety, environmental and economic impact" (The Engineering Equipment and Materials User'Association, 2013).

Alarm Rationalisation is a tool that uses the findings of hazard identification, such as HAZOP, LOPA, Design review etc, to establish the requirement of particular alarms as per agreed alarm philosophy. The rationalisation process includes documenting the reason for retaining an alarm. The process also produces a document that ascertains the basis for the alarm setpoints, the consequence of not responding to the alarm, and any required corrective action that can be taken by the operator.

Identification of alarms is typically done during Hazard Identification e.g. HAZOP, LOPA,.

Similarities between HAZOP, LOPA and Alarm Rationalisation

HAZOP, LOPA and Alarm rationalisation have many similarities, see Figure 2.

Figure 2 A Comparison Of Data Required for HAZOP, LOPA and Alarm Rationalisation

HAZOP required information	**LOPA required information**	**Alarm Rationalisation required information**
Initiating Cause	Initiating Cause	Initiating Cause (See safeguards)
Cause Frequency	Initiating Likelihood	The most likely initiating causes are typically identified first in Alarm Response Documentation.
Consequence	Impact Event	Consequence of Inaction
Consequence Severity Determining the Maximum Expected Excursion of the parameter allowed for a better definition of Consequence.	Severity Level	Consequence classification
Safeguards	Protection Layers	Identification of Safeguards and Protection Layers along with their set points allows for Team to identify true causes of Alarms assuming all safe guards operate as intended.
Identification of process safety time can enable screening of alarms as satisfactory safeguards	Process Safety Time	Time to Event

Applied Methodology

Liquefied Natural Gas

The emergence of Liquefied Natural Gas (LNG) as an energy source has resulted in a fuel source that can be economically transportable over large distances worldwide, has wide range of potential uses, both domestically and industrially, and is more environmentally friendly than conventional hydrocarbons as it generates less CO2 per unit of energy. The LNG market is likely to grow steadily in future due to its undoubted benefits coupled with the rise in demand from the developing far east nations.

LNG facilities are typically complex and handle a large volume of hydrocarbons while utilising innovative cryogenic technologies. Although LNG facilities are usually located away from the general public, loss of containment events and subsequent fires from these facilities have potential to cause loss of life, impact the environment and lead to a significant financial impact. A good facility design can enable a safe, operable and reliable facility.

When designing and engineering an LNG facility, differing disciplines are required to contribute such as Process, Safety, Piping, Mechanical, electrical and instrumentation disciplines from the Operator and the Engineering Contractor. And since the impact of the design is felt mostly during the operational phase, experienced operations personnel from the Operator are also typically required to participate in finalising the design. The multi-disciplinary process can however present its own problems, decisions from one discipline may affect the design of another discipline to a small or large extent. Correct interfaces between the different disciplines can reduce reworks/delays due to clashes and ensures that designed equipment will work in harmony with minimal errors. Errors in the design can lead to an unsafe and inoperable facility with the associated financial impact.

Description of Methodology

Prior to commencing the analyses, the importance of consistency should be emphasized to the team.

The methodology involves aligning the risk matrix between the three analyses (HAZOP, LOPA and Alarm Rationalisation) to ensure similar risk ranking/outcomes via:

- Aligning the frequency of causes.
- Aligning the consequence classification.
- Aligning the HAZOP risk matrix, the target mitigated event likelihood for LOPA and Alarm Rationalisation.

The first step was to ensure an alignment in the interpretation of risk between the three analyses techniques. Risk matrices determine the risk reduction requirements for any given scenario identified in an analysis. The aim of this step is to ensure that HAZOP and LOPA will give the same required extent of risk reduction when considering comparable risks.

The LOPA tolerability target table (See Figure 4) was aligned to with the blue section of the HAZOP risk matrix (Figure 3) i.e. areas signifying tolerable risk.

For the Alarm Rationalisation, the severity and acceptable response time are utilised to determine the priority of the alarm (See Figure 5). The definition of events consequence was aligned with the HAZOP and LOPA matrices.

Figure 3: HAZOP Risk Matrix

	1 Less than 1 in 1,000,000 years	**2** 1 in 1,000,000 years	**3** 1 in 100,000 years	**4** 1 in 10,000 years	**5** 1 in 1000 years	**6** 1 in 100 years	**7** 1 in 10 years	**8** 1 in 1 year or more
A								
B					High Risk: Mandatory Risk Reduction			
C								
D								
E	Negligible Risk: Risk Reduction not mandatory			Medium Risk: Risk Reduction Required				
F					Low Risk: Risk Reduction Required			
G								
H								

Figure 4: LOPA Tolerability Targets

Severity Level		**Target Frequency for Tolerability Per Year**
A to B	LOPA is not appropriate due to the large consequence. A more appropriate risk assessment should be utilised.	
C	Above 10 fatalities	1E-6
D	Above 3 fatalities	1E-5
E	1 to 3 fatalities	1E-4
F	Permanent injury	1E-3
G	Minor injury	1E-2
H	Negligible injury	1E-1

Figure 5: Alarm Rationalisation Urgency Table

	Event consequence		
Urgency	**Large (F or above)**	**Medium (G)**	**Small (H)**
Immediate	High Priority	High Priority	Medium Priority
Prompt	High Priority	Medium Priority	Medium Priority
Soon	High Priority	Medium Priority	Low Priority

Initiating Cause Alignment

Rulesets regarding documentation of potential initiating causes were aligned to ensure a consistent approach across all analyses. The aim was to ensure that as per the risk matrices, the same cause of failure will generate similar risk reduction requirements in the HAZOP and LOPA reports. Failure frequency from the LOPA guide (Centre for Chemical Process Safety, 2015), which are based on failure rate data and human reliability were mapped to the HAZOP analysis.

For the alarm rationalisation, the emphasis was placed on listing causes for the operator in order of likelihood of occurrence, this allows operators to identify the most credible source of failure during the workshop.

Below highlights the initiating frequency for some typical causes that can lead to excursions outside the operating envelope:

Figure 6 Failure rates for causes that can leading to excursions outside the operating window

	Description **(Centre for Chemical Process Safety, 2015),**	**Unmitigated failure rate as per LOPA guidebook (Centre for Chemical Process Safety, 2015),**
BPCS control loop failure:	A BPCS control loop typically consists of a pneumatic, electrical, electronic, or programmable electronic system (PES). They are used to control process or systems to ensure they remain within the normal operating window.	0.1 per year i.e. 6 frequency (1 failure in 10 years) for HAZOP risk matrix
Pump Trip:	An electric or steam-powered pump fails and stops due to causes such as shaft/coupling failure, motor failure, or impeller failure.	0.1 per year i.e. a 6 frequency (1 failure in 10 years) for HAZOP.
Spurious Operation of SIS e.g. spurious closure of ESD valve:	Instrumented safeguards that take action to achieve or maintain a safe state of the process in response to a specified process condition	0.1 per year i.e. a 6 frequency (1 failure in 10 years) for HAZOP. Although, specific failure rate data can be assumed to avoid conservatism.
Human error during a task that is performed more than once per Week.	This initiating event is a human error in overlooking a step or performing a step incorrectly on a task that is performed less than once per week but at least once per month	1 per year i.e. 7 frequency (1 failure in 1 years) for HAZOP.
Human error during a task that is performed between once per month and once per week:	This initiating event is a human error in overlooking a step or performing a step incorrectly on a task that is performed less than once per week but at least once per month.	0.1 per year i.e. a 6 frequency (1 failure in 10 years) for HAZOP.

Human error, Task performed less than once per month	This initiating event is a human error in overlooking a step or performing a step incorrectly on a task that is performed infrequently, less than once per month	0.01 per year i.e. a 5 frequency (1 failure in 100 years) for HAZOP. Although, specific failure rate data can be assumed to avoid conservatism

Alignment of Consequence Development Criterion

The primary requirement for the HAZOP is to identify hazards and their causes. The consequences and causes identified and developed within the HAZOP are then utilised as the basis for LOPA and Alarm Rationalisation.. The classification of consequences and their severity is also therefore, required to be aligned between the analyses. This ensures that the risk reduction requirements are aligned.

Once HAZOP has determined the consequences and severities for identified hazard scenarios , appropriate safeguards are identified. Event that were considered able to cause fatalities were analysed in more detail using the LOPA methodology, this ensured that any coarse approach to determine risks within the HAZOP were refined for severe consequences.

To determine the unmitigated risk within HAZOP, the values from Figure 6 above were compared against the severity ranking (Figure 4) to determine the unmitigated risk.

To determine the unmitigated risk from the scenario, the probability of failure on demand of the safeguard was then used as a basis (See Figure 7). The frequency of the identified scenario was reduced by 1, if the probability of failure on demand (PFD) was 0.1, and by 2 if the PFD is 0.01. This simple technique was applied to all scenarios, with the risk reduction from multiple safeguards summed together to provide the total reduction in scenario frequency. The new value was then compared against Figure 3 to determine the required risk reduction.

For any scenarios that did not result in a fatality, the risk analysis ended at the HAZOP stage. Recommendations were made to ensure that either an inherent safe recommendations as detailed in (Matiti, 2014) or additional safeguards are added to reduce risks to ALARP. Any alarm safeguards utilised within HAZOP and LOPA were then passed to the Alarm Rationalisation for further analysis.

For Alarm Rationalisation, the philosophy to establish credible initiating causes differs slightly from HAZOP and LOPA in that all safeguards are assumed not to fail. Therefore, a certain amount of analysis was required to align with the initiating causes from HAZOP and LOPA. Careful consideration was given to the way the HAZOP and LOPA were documented to ensure that scenarios could be easily aligned.

Figure 7 Failure rates for safeguards and protection layers

Protection Layer	**Description**: **(Centre for Chemical Process Safety, 2015),**	**PFD** **(Centre for Chemical Process Safety, 2015),**
BPCS control loop failure:	A BPCS control loop typically consists of a pneumatic, electrical, electronic, or programmable electronic system (PES). They are used to control process or systems to ensure they remain within the normal operating window.	0.1 per year i.e. reduce initial frequency by 1 order of magnitude
Spurious Operation of SIS e.g. spurious closure of ESD valve:	Instrumented safeguards that take action to achieve or maintain a safe state of the process in response to a specified process condition	0.1 per year (SIL 1 ESD loop) 0.01 per year (SIL 2 ESD loop) 0.001 per year (SIL 3 ESD loop) i.e. reduce initial frequency by 1,2 or 3 orders of magnitude based on the SIL classification of the loop
Human response to an alarm	Requires time to be sufficient for the operator to receive alarm, diagnose alarm and perform the action to prevent the event	0.1 per year i.e. reduce initial frequency by 1 order of magnitude

The time from an appropriate alarm to the end consequence was determined during the HAZOP. Performing this task at this stage ensured that the discussions were not repeated during the LOPA and Alarm Rationalisation. Both LOPA and Alarm rationalisation utilise the estimated time to determine the ability for the operator to react to the scenario. If there is sufficient time for an operator to react from alarm activation, to prevent the end consequence, the alarm can be taken as an IPL in LOPA, depending on the independence of the cause and the alarm. Alarm Rationalisation utilises the time to event to establish the urgency (see Figure 8 and 9) and priority of the Alarm (see Figure 3). This step ensures alignment between the studies and also ensures that there is ample opportunity for operations to determine the adequacy of alarm safeguards during both the LOPA and alarm rationalisation.

Figure 8 Alarm Rationalisation Urgency Table

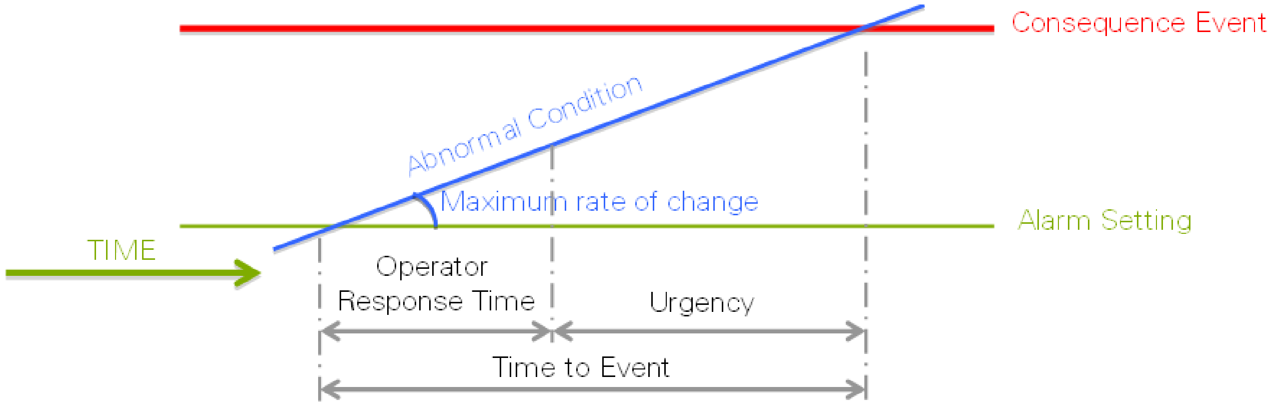

Figure 9 Alarm Rationalisation Urgency Table

Urgency Category	Time to Event – Operator Response Time
Immediate	<= 10 minutes
Prompt	10 minutes to 30 minutes
Soon	> 30 minutes to a shift

Additionally, an assumption based on underlying shift handover procedures present at the site was developed. This assumption addressed slow developing events and their credibility. Based on these procedures, scenarios considered as slow to develop (i.e. time to development crosses several shifts) were considered as unlikely to occur. The premise was functioning shift handover procedures which can be engaged to identify sustained operation outside the desired operating window (See Figure 1). Within HAZOP, these scenarios were deemed not credible as long as independent alerts which measure the process parameters were present. These alerts were then rationalised in alignment with HAZOP findings during alarm rationalisation. This approach led to a unified approach between the studies, and also ensured that the number of alarms was decreased drastically and systematically during the Alarm Rationalisation Process. These scenarios would require the failure of the shift change over systems to occur.

When establishing the consequence during HAZOP, the maximum expected excursion of the parameter during the scenario was recorded to ascertain the impact of the event. An example is when considering the excursion of pressure, if process team determine that the pressure is below 1.3x the design pressure (hydrotest pressure), then loss of containment was discredited. Excursions above 1.3 x the design pressure could lead to loss of containment, and excursions above 3 would lead to rupture. For LOPA, this overpressure ratio value was also utilised to establish the likelihood of ignition i.e. any events that caused a rupture were deemed to ignite at all times, while leak applied a probability of ignition as a modification factor. This technique ensured consistency of approach throughout the HAZOP and LOPA. Consequently, it also allowed documented set points within the alarm documents to be verified against the process parameter excursion identified during the HAZOP and LOPA.

Sample Assessment

HAZOP Worksheets

HAZOP was used as the primary source to identify causes and the safeguards. The discussions in this example concentrate on safety impact only to simplify the example, although environmental impact and business impact are also typically considered (Figure 10).

The causes that had potential to generate unmitigated consequences with the ability to cause fatalities were passed to LOPA (there were exceptions to this rule however for simplicity this will not be discussed in this paper).

All safeguards were assessed for their auditability, effectiveness and independence from the scenario. Which is aligned with the LOPA approach. This includes documenting the set point, actions and assessing whether there are any common factors that could lead to the cause of the scenario disabling the identified protection layer. If any of these factors were not available, the safety layer was not claimed in HAZOP.

Using Figure 3, Figure 4 and Figure 6 the HAZOP identified that the unmitigated scenario requires risk reduction, however, considering the safeguards (Figure 7), the mitigated risk should be negligible. As the scenario was considered a fatality, the seriousness of the scenario required LOPA (See Figure 11) to be undertaken to ensure that the scenario is addressed in sufficient detail. However, as discussed, the tolerability of the scenario aligns between the HAZOP (Figure 3) and LOPA (Figure 4) risk matrices, which means the 2 studies would arrive at the same decision making outcome.

Where as the HAZOP will discuss the scenarios one by one, in isolation to determine their impact against the Risk Matrix. The LOPA will discuss the scenario cumulatively when establishing the demand rate on a SIS function i.e. the calculated frequency of a single scenario is added to other identified scenarios leading to the same consequence. Alignment between the HAZOP and LOPA discussions will ensure that the process of determining SIL classification requirements is aligned between the HAZOP and the LOPA process.

During the HAZOP, the modes of operation and their frequency was discussed and all initiating events and consequences were also discussed. LOPA quantified the discussions in the HAZOP to establish a more refined analysis against the target, and if required, would discuss the ignition probability based on the scenario, and also the occupancy of personnel. The LOPA analysis highlighted that the alarms identified in the HAZOP is not critical for safeguarding the scenario. Therefore, there is no requirement to classify the alarm as critical to safety. However, operationally, the alarm was still assessed during the alarm rationalisation study.

The alarm rationalisation study (See Figure 12) highlights the required corrective actions from an operator when an alarm annunciates. In this scenario, it was identified that the alarm was not critical (as per LOPA findings), however, an assessment of the alarm requirements was still required. Assessing the HAZOP and LOPA, it was identified, that in the event of operator error, the flow control valve would control the flow and maintain the pressure, therefore, this was defined as the consequence of interest within the alarm rationalisation.

In the event that only the bursting disk was identified as a cause for the alarm in HAZOP, then only the rupture of the bursting disk would be considered the final consequence. Additionally, in the event that the alarm was considered safety critical in the LOPA analysis (i.e. an IPL), then the consequence of interest would align with the LOPA.

When identifying the initiating causes, all causes identified for the scenario are listed as per the likelihood highlighted in Figure 6. This ensures that when operators hear the alarm, the Human Machine Interface will highlight the most likely causes of failure first.

For the example scenario, based on the set points of the safeguards it was determined that in the event that the pressure high alarm annunciates, the pressure control valve will divert the flow and maintain the pressure within the system.

As the consequence has changed, the alarm rationalisation study, reclassifies the consequence based on the impact on not responding to the alarm annunciation. In this case, the impact was negligible impact to operations ie. H category in terms of business impact.

With an operator response time of 15 minutes, and time to event of 2 hours, Figure 9 and Figure 8 were used to determine the urgency as “soon”. Using the Figure 5 it was determined that the priority of the alarm is “Low”.

Figure 10 Sample HAZOP worksheet

Deviation	Cause	Consequences	Safeguards/IPLs	Risk Ranking
Misdirect Flow	Human error during a task that is performed between once per month and once per week: Operation is 100% of the time	Misdirected flow of seawater from upstream Hydrocyclone Filter through the brine header leading to reduced flow of sea water to the Evaporator This will lead to rise in temperature (due to heating from Electrical Heater, Vapour Compressor) and pressure within the evaporator with potential loss of containment of steam and brine to environment. Safety : Potential for 1 - 2 fatalities due to hot steam Maximum expected pressure is above 1.3 kg/cm2(g) DP of evaporator is 0.5 kg/cm2 (g). Overpressure ratio is 1.54x Maximum expected temperature in this scenario is 125°C	1. High Pressure Alarm (set at 0.1 kg/cm2(g)) will alarm on high pressure and allow operator to troubleshoot. Scenario takes more than 12 hours from set point to event (2 hours to set point of flow control) 2. Pressure Controller (set at 0.3 kg/cm2(g)) will regulate flow to evaporator by restricting flow via independent Flow Valve 3. Bursting disk (set at 0.5kg/cm2(g)) will open and mitigate the scenario	Starting likelihood: 6 (Human error, task performed weekly) Unmitigated Risk: 6E (Yellow: Risk Medium Risk: Risk Reduction Required Mitigated risk: Bursting Disk (Credit :2) BPCS (Credit : 1) Alarm (Credit : 1) 6-4 = 2 Unmitigated risk: 2E (Green: Negligible Risk: Risk Reduction not mandatory)

Figure 11 Sample LOPA worksheet

Consequence Category		Initiating Cause	Failure frequency per year	Frequency Modifier	Probability	IPL	Probability of Failure on Demand	Target Frequency	Mitigated Event Frequency
Safety	E Potential for 1 to 2 fatalities due to steam exposure	Human error during a task that is performed between once per month and once per week:	0.1	No modifier is applied as the operation is continuous i.e. 100% probability of operation	1	PAH (set at - 0.1 kg/cm2(g)) (Alarm) Alarm was not taken as an IPL as there is sufficient safeguards in place.	1	1E-4	1E-4
						Pressure transmitter opening pressure Control Valve Opening to divert flow to drain (set at 0.3 kg/cm2(g)) (Alarm))	0.1		
						Bursting disk ((set at 0.5kg/cm2(g))	0.01		

Figure 12 Sample Alarm Rationalisation Worksheet

Alarm	Initiating Cause	Consequence Description	Operator Response And Corrective Action	Operator Response Time
Pressure Alarm High	1) Human error during a task 1 (valve1 opened in error) that is performed between once per month and once per week from control room 2) Human error during a task 2 (valve2 opened in error) that is performed between once per year from control room (Verify via nearby Pressure and Temperature Indicators))	1) In efficient operation of evaporator due to opening of pressure Control Valve and diverting divert flow drains rm to event) (2 hours from alarm to activation of high pressure and valve and divertion to drain)	1),2) Ask field technician to close valve E) Inform line manager	(HAZOP Cause 1) 1) Operator Response Time -15 mins a) Control Room Technician (CRT) -5 mins (ask Field Technician) b) Field Technician (FT) - 5 mins (To travel to location) c) Field Technician (FT) - 5mins (To analyse local conditions and take appropriate response).

Conclusion

Organisations are integrating HAZOP and LOPA more these days, however the integration of HAZOP, LOPA and Alarm rationalisation is rare.

The integrated methodology ensures that consistent application of data from one study to another. The analyses includes the participation of differing disciplines, consistent application of philosophies to ensure that the findings of the analyses were consistent.

Figure 2 highlights the duplication of data between, HAZOP, LOPA and Alarm Rationalisation. The approach negates the need to "re-invent the wheel" during each HAZOP, LOPA and Alarm Rationalisation workshop as the base line for each analysis is set by the previous analysis. Additionally, using the base line data, allows for personnel to interrogate the data for correctness, and therefore any obvious errors can be identified.

This paper describes a simple and efficient way to integrate the analyses. The simplified case study used in this paper demonstrates how the auditable and consistent methodology has been used in practice

- identifying all hazard scenarios in HAZOP,
- Performing a high level risk analysis-to determine the risks of the scenarios
- Analysing high risk scenarios in more detail within using LOPA
- Utilising discussions within HAZOP and LOPA to rationalise alarms and eliminate or elevate alarms based on identified risks.

For a complex and large facility such as an LNG facility it is crucial to maintain consistency when performing the analyses. The benefits of integration are clear, especially, at a time when smart use of data and digitalisation is a key cornerstone for the future of industry.

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