# Practical Experience of Retrospective HAZOP and LOPA studies for an Offshore Platform

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## Introduction

To achieve continuous improvement in process safety performance on existing facilities a key activity is conducting periodic Retrospective Hazard Reviews, also known as Process Hazard Analysis (PHA) Revalidation. The overall objective is to review the design and performance of the facility, ensuring that adequate safeguards are in place to control risks, and providing assurance that these safeguards are working effectively. Referring to the classic 'Swiss Cheese Model' for barrier management, the reviews ensure sufficient barriers and check that the holes/weakness in barriers are not larger than expected, raising risk justified recommendations for improvement where required.

This paper provides practical experience from a large review on a series of offshore platforms and associated onshore facilities for a major Oil and Gas company. Baseline reviews were carried out on all process and utility systems on the facilities using a structured Hazard and Operability (HAZOP) approach. All hazardous events with potential to cause serious harm to people, the environment, or the business, were then subject to Layer of Protection Analysis (LOPA). The LOPA study had the objective of determining the risk level for the hazardous event, based on the company standard risk matrix, and assessing the required risk reduction from key risk control safeguards, including hardware, instrumented and procedural protection.

The proprietary software system PHA-Pro was used for recording both the HAZOP and LOPA parts of the review. This provided a facility for transferring hazardous events and their associated safeguards between HAZOP and LOPA, with the anticipated benefit of a seamless link. It also includes a number of features that are helpful on very large studies, to ensure that full recording of the study is carried out to a high standard, and that all outstanding queries have been closed before the review is reported.

This paper describes some of the challenges faced during the HAZOP and LOPA studies, from both a technical and organisational perspective. Topics covered include; selection of competent Leaders, availability of knowledgeable team including Operations, provision of up-to-date technical data, and managing multiple parallel teams with changing personnel over a period of several years.

Practical experience is provided on combining HAZOP and LOPA studies, with advice on how this can be done most effectively. This approach provides many potential benefits, including efficiency savings, greater consistency, and an effective way of identifying safety critical equipment and systems in a structured and quantifiable manner. Many challenges arose that are discussed in detail, including the selection of suitable events for LOPA, and how to combine HAZOP initiating causes from many Nodes into a single LOPA scenario.

## Overview of Facilities

This paper relates to retrospective HAZOP and LOPA studies for a large oil field complex that includes many offshore platforms and onshore processing, storage and export systems. The study was carried out over several years with the complex split into several production facilities, each with a separate management team and clearly defined boundaries. First oil was extracted from this field during the 1990's and there has been continued development of the field since this date. All projects have been subject to hazard studies during the process design phase, including Hazard and Operability (HAZOP) studies on the firm Piping and Instrument Diagrams (P&ID).

An offshore platform represents a typical facility included in the scope of the HAZOP and LOPA study. On the process side scope of the study starts at the subsea riser bringing hydrocarbons to the platform, passing through the flow lines to the Production Separators, where 3-phase separation occurs into oil, gas and produced water. Oil passes through further separation to export pumps, and gas passes through a compressions stage, with sub-sea oil and gas export lines to isolation valves at the onshore facilities. Produced water passes through oil and sand separation before being dumped to the sea, or combined with fresh seawater to provide injection water to maintain well pressures. All the Utility systems were also included in the scope, with systems typically including; Flare, Fuel Gas, Diesel, Open and Closed Drains, Chemicals, Seawater, Cooling Water, Firewater, Instrument Air, Nitrogen, Effluent, etc.

## Requirements for Study

The company operating these facilities has a standard to carry out retrospective process safety reviews every 5 years in order to demonstrate continuous improvement. This timescale matches international good practice as driven by OSHA-PSM requirements for PHA Revalidation every 5 years, and the EU Major Accident Hazard (MAH) Directive requirements for reviewing and updating Safety Reports/Cases every 5 years.

The studies needed to comply with company guidance for HAZOP and LOPA studies and be facilitated by company approved competent Leaders. Each facility had a Terms of Reference (ToR) document prepared and agreed with the company, stating the need to comply with the guidance documents and detailing any other aspects to include in the scope of the study. The ToR document was found to be a very valuable source of information on how the study was to be conducted and typically included the following contents;

- Scope of review, list of process and utility systems in scope, plus any exclusions
- Dates, timing and location for studies, including limits on hours per day
- Team composition, including mandatory members
- Methodology, including reference guidance, plus guidewords
- Prioritisation method and choice of risk matrix including calibration
- Consequence severity levels for typical scenarios on facility
- Recording method including choice of software
- Report contents and distribution
- Follow-up responsibility for action close-out

The company was keen to avoid raising an excessive number of recommendations that would be difficult to close out effectively. There was a policy of only raising recommendations for risk-ranked events where the risk was significant and the proposed action would provide genuine risk reduction. To accommodate many minor issues raised by the study teams, a system for raising ‘Observations’ was implemented, where these were given a lower priority for resolution. In addition, any issues where information was not available to the study team was noted as ‘Parking Lot Issues’, with a system to gather the required data and close the issue before the study was completed.

## Outline of Methodology

### HAZOP Study

HAZOP study was originally developed in the 1970’s as a method for a structured review of process designs at the project stage. The objective is to identify potential process hazards caused by deviations from the design intent, normally associated with equipment failures or human errors. Having identified an initiating cause, the team consider the potential escalation of the event, assess the likely unmitigated event severity, in terms of harm to people, the environment or company business/reputation. The team then consider whether the design safeguards are adequate and meet relevant good practice. Actions are raised to improve the safeguards where necessary with the overall objective of reducing process risks to ‘as low as reasonably practicable’ (ALARP).

The key documents for a HAZOP study are the P&ID’s for the facility, which are broken down into manageably sized Nodes. On the type of facility covered by this paper the Nodes are typically lines between major equipment items, for example the Flow Line from the Wellhead to an isolation valve at the inlet to the Production Separator. For each Node the design intent is described with key parameters and controls, and a set of guidewords applied to identify possible deviations such as ‘High Flow’. The structured nature of the study ensures that all guidewords are considered for each Node, and the Nodes cover to entire scope of the study.

HAZOP studies can be applied retrospectively to an existing facility in a similar manner to project related studies, although the focus should be on actual experience gained on the facility and on events with more significant consequences. This allows the time required to be reduced by paying less attention to operability issues or minor safety hazards. Further time savings are possible using a high level Hazard Identification (HAZID) or Process Hazard Review (PHR) technique, with Nodes at a system level and guidewords focussed on hazardous events involving loss of containment or release of energy. Such an approach was not possible for the study covered by this paper due to the need to comply with the company standards for HAZOP study.

### LOPA Study

The LOPA method was originally developed in the US as a means of estimating the likelihood of a hazardous event. This is achieved by first assessing the frequency of the initiating event and then the risk reduction contribution assignable to the various layers of protection. These include safeguards such as pressure relief systems or safety instrumented systems (SIS), and their risk reduction is given coarse order of magnitude values. Combining the initiating event frequency with probability values for the safeguards being ineffective, with other factors such as ignition probability, occupancy or vulnerability, allows the overall frequency for the harmful event to be determined.

LOPA studies have become the preferred method with most companies for Safety Integrity Level (SIL) Determination for SIS in compliance with international standard IEC61511. The ‘Risk Graph’ method within the standard is now considered too coarse for high hazard scenarios and difficult to calibrate against company risk criteria. The LOPA method has been developed to provide greater detail and increased level of quantification, with close checks on the independence between initiating causes and safeguards, plus the use of generic reliability data backed by field experience. In this context, LOPA is mostly being applied to hazardous events where a SIS provides a layer of protection, with the output providing a target Probability of Failure on Demand (PFD) for the SIS.

The company LOPA guidance used for this work extends beyond the use for SIL Determination as described above, although the overall methodology remains similar. The key difference is the requirement to carry out LOPA on all high hazard events, regardless of whether the safeguards include a SIS. There are exclusions to the types of events considered, where LOPA is judged inappropriate, such as equipment integrity issues that could directly result in loss of containment, where the safeguards rely on routine inspection and testing. By using LOPA in this manner, all the high hazard events are assessed to ensure that company risk criteria is met, and the contribution for the various SIS and non-SIS related safeguards can be assigned. The output from the study therefore provides a list of the key Independent Protective Layers (IPL) for the facility and the required performance standard in terms of PFD.

## Practical Experience

Implementing combined HAZOP and LOPA studies across several large scale facilities generated many challenges from both an organisation and technical viewpoint. The key learning points are described in this section with the experience gained and approaches taken to mitigate these issues. To assist understanding these are presented in chronological order for carrying out these studies, from the initial planning stage to carrying out first the HAZOP studies and then the LOPA studies.

### Planning Stage

Competence of Leaders

The Leader of HAZOP and LOPA studies has the overall responsibility to ensure that the studies comply with the requirements of the ToR documents and are thorough and searching. In addition there is a need for consistency of approach throughout the study, which may extend for up to a year in duration, in order to avoid the need for reworking. The company has a strict policy of using approved Leaders, where approval is granted by the Technical Authority based on a demonstration of experience and detailed interviews to ensure that the company standards have been fully understood.

Due to the lengthy nature of the studies is was generally difficult to ensure the same Leader throughout, even though this is preferable wherever possible. Effective handover between Leaders was a key aspect, and good practice involved a formal ‘end of cycle’ report prepared by the outgoing Leader with clear instructions on progress and the required next steps. It was also found that new company approved Leaders needed to be fully briefed on the specific requirements of the ToR document. Their early studies also needed close monitoring to ensure that these points were being implemented, and that personal preferences and styles for conducting and recording the studies were not being followed.

Estimation of Time Required

For a large HAZOP/LOPA study a reasonably accurate estimate is required of the time required for the full team to complete the work. This is needed so the costs of the studies can be agreed and for logistical reasons to ensure that the team are available throughout the duration of the study. Simple measures based on the number of P&ID’s can be misleading due to the relative complexity of the P&IDs and handling multiple trains of equipment with largely similar designs.

Good practice developed during this work was to carry out initial ‘Noding’ of the studies as part of the planning stage, based on the full set of P&ID’s that covered the study scope. This is best carried out by the nominated study Leader, who can assign a complexity factor for each Node depending on the process and take account of Nodes studies ‘by difference’ from other similar Nodes. The Utility systems in particular require careful consideration, taking into account that the systems may be relatively low hazard, for example cooling water systems, or highly complex on the P&ID’s, for example a Gas Turbine driven Generator set.

Experience on these studies using a detailed HAZOP approach gave an overall rate of progress of 1-2 Nodes per day. The actual rate of progress can then be tracked against the plan to provide an ongoing view for the team and early indication if the overall timescales are likely to be exceeded. The time required for the LOPA studies is dependent on the number of major accident hazard (MAH) scenarios generated by the HAZOP study. For this work, where LOPA was being used for most MAH scenarios, even those where no SIS was involved, the LOPA study time was typically 33-50% of the time required for the HAZOP study of the same process.

Gathering Process Data

For studies on existing facilities rather than new process designs, there is a significant challenge obtaining the required process data to allow the study to progress effectively. Often up-to-date data on key systems is not readily available and this can result in the team going down ‘blind alleys’. For example, if the dead head pressure for a pump or compressor with the downstream line isolated is not available, the team should conservatively assume that overpressure and line failure is a credible outcome. In reality the dead head pressure is often found to be within the design limits of the piping system, and if the pump or compressor curve is available the scenario can be immediately ruled out.

Key data for HAZOP and LOPA studies includes the following;

- Material Safety Data Sheets for all hazardous substances, including raw materials, intermediates and products
- Plot plan showing the location of major equipment items, safety systems and occupied buildings
- Process description and description of process chemistry where applicable
- Equipment specifications, including design pressure and temperature and materials of construction
- Piping class specifications, with design pressure/temperature and materials of construction

- Setpoint data for control functions, alarms and safety instrumented systems
- Cause and effect matrices for safety instrumented systems
- Pressure relief system data sheets with setpoints and sizing basis
- Area classification drawing showing zoned areas
- Pump and compressor operating curves showing dead head pressures
- Operating, Maintenance and Emergency procedures
- Preventative maintenance records, with intervals, results, current condition.
- Previous process safety reports, e.g. Safety Reports/Cases, with consequence assessment data

An Independent Process Engineer (IPE) was assigned to the teams, with the responsibility of ensuring that access to process data was considered during the Planning stage and made readily available during the team meetings. This type of information is typically held electronically on shared IT systems and can be accessed readily in the meeting room if Wi-Fi access is provided. The IPE role is also helpful for the Leader during the studies, ensuring that P&ID's marked up with study Nodes are made available to the full team as the study progresses.

Availability of Study team

A knowledgeable and experienced team is an essential element for a successful study, and can be difficult to maintain throughout a lengthy study period. Apart from the Leader, IPE and Scribe, the core members of the team should include the Process Engineer for the facility under review and an experienced Operator. Is it helpful to have a statement in the study ToR that team meetings will be postponed if any core team members are absent. This reinforces the key input from Operations staff to share their experience of how the facility is actually performing and any current shortcomings with equipment and systems.

Experience showed that securing the presence of a suitably knowledgeable Operator was the major challenge for the study teams, causing a number days of study to be lost despite efforts by the company coordinator. In practice it is highly unlikely that the same Operator will be available throughout a lengthy study due to factors such as shift rotations. New Operators to the team need to be inducted quickly, and a short presentation is useful to ensure the new team member receives the key messages. A benefit from having different Operators attending team meetings is getting alternative viewpoints on the current issues, avoiding the study conclusions being too much the view of an individual.

Whilst the core team supported by an appropriate Control Engineer and Mechanical Engineer is suitable for a majority of the study, additional competent resources are required for certain aspects, with examples as below. Having a credible plan with timescales helps to ensure that these people can be made available at the right time to cover the Nodes where their input is required.

- Safety Engineer, at early stages of study to ensure that severity ratings of events are consistent with existing modelling work, for example as contained in the Safety Report/Case.
- Machines Engineer, for large machines such as Gas Turbines and Compressors, with knowledge of the support systems such as Lube Oil, and capable of judging potential consequences in fault conditions.
- Pipelines Engineer, for specialist systems such as Subsea pipelines, able to comments on the routing, current condition and likely failures modes.
- Vendor Technical Representative, for package units where the Operations team have less involvement in the operation and/or maintenance of the equipment, for example an Effluent Treatment Unit.

## HAZOP Stage

Choice of Software

The key outputs from the HAZOP and LOPA studies are the written records and it is essential that these are produced in a consistent and clear manner. Some form a tabular record is required and traditionally use is made of standard office software such as MS-Word or MS-Excel. Whilst this approach is acceptable for small studies, the records can become difficult to manage for large studies due to quantity of information being generated. For the studies in this paper the bespoke HAZOP recording package 'PHA-Pro' was utilised as the company preferred system. This has a number of benefits that can aid the ease and thoroughness of recording, but care must be taken during the planning stage to set up the records to meet the specific requirements of the ToR and company standards.

Features of PHA-Pro software found useful for this study include;

- Node set-up allows simple monitoring of progress and prompts full recoding of details including design specifications and design intent
- Table of recommendations generated with links to HAZOP records, allows simple repeating of same recommendation to multiple events
- System for generating 'Parking Lot' issues for resolution outside of HAZOP meeting, with record of responses.

- List of team members and attendance record, with total numbers of meeting hours attended
- Selection of severity and likelihood levels automatically generates risk level based on company risk matrix
- Automatic generation of HAZOP statistics, such as number of scenarios at each risk level
- Listing of study document including P&IDs and reference documents that can be linked for example into the Node details sheet
- The HAZOP scenarios can be taken forward to LOPA within the same software, allowing the HAZOP and LOPA studies to be completed in the same file.

Role of Scribe

For large HAZOP studies recorded on a software system and projected on-screen during the team meetings, a Scribe is an essential part of the team. This allows the Leader to focus on facilitating the meetings and avoids being distracted from ongoing discussions whilst making the required detailed records. It is important that the Scribe accurately reflects the issues under discussion and takes account of the directions from the Leader to avoid the need for re-working of the records after the meeting. In addition it was found that the Scribe can have a negative impact on the pace and momentum of the team if not carefully selected and inducted.

A key requirement is a technically competent person, typically a graduate Process Engineer, who is familiar with the technical terminology under discussion. Ideally they should have the study language as their first language to ensure that any nuances from the discussions are picked up and acted on. They also need to be competent in the use of the software tool and able to navigate the system without delays, and efficiently carry out functions such as duplicating scenarios and Nodes. Good practice for this study involved testing of potential Scribes to ensure that their basic language and computer skills would withstand the scrutiny of the team, and allowing them to shadow other Scribes for a short period prior to being directly involved in a study.

Quality of Study Records

With a number of HAZOP teams working in parallel at any time and a turnover in Leaders between cycles, maintaining the quality of the records and ensuring compliance with the requirements of the ToR and company standards was an ongoing challenge. Issues were of a technical nature but if not resolved could lead to inconsistencies between records and non-compliances with the company requirements needing extra time to resolve later in the study.

Examples of technical issues related to the recording of HAZOP studies included;

- Failures of protective systems, e.g. relief system blocking, being recorded as an initiating cause. Such failures do not cause a hazardous event, and any reliability issues with protective systems should be recorded against the scenario, e.g. high pressure caused by fire engulfment, where the protective system is listed as a safeguard.
- Generating recommendations for issues that were not risk ranked and therefore not given a priority. The ToR required such issues to be recorded as 'Observations' with a lower priority. The recommendations also needs to be clear and standalone, complying with the '3 W's' approach, namely 'what' needs to be done, 'where' it applies, and 'why' the recommendation is required.
- Following the 'cause on Node, consequence anywhere' HAZOP approach can lead to inconsistencies in where scenarios are recorded. For example, overfilling of the Production Separator could result in liquid into the Flare system, which could be either recorded as a scenario on the Separator Node or the Flare System Node, which is likely to be studied somewhat later in the HAZOP programme. A pragmatic approach to this situation was to link the cause to a scenario on the later Node, making a clear record at the time it was identified, allowing a more thorough assessment on the later Node when other causes of the scenario have been identified and the safeguards on the Flare System Node can be best taken into account.

Good practice developed for these large scale studies involved the nomination of a 'Technical Steward' from the pool of HAZOP Leaders. This person was involved in leading studies but also given time to be a focal point for technical queries from other leaders and was required to take a pro-active role to routinely review records from other leaders, particularly where they were new to this work.

## LOPA Stage

Selection of Events for LOPA

The requirement was for LOPA to be carried following completion of the HAZOP studies, on all MAH events regardless of whether the safeguards included a SIS. In reality there needed to be a screening exercise following the HAZOP study to decide which events needed to be taken forward to the LOPA study, to exclude events where LOPA was not appropriate.

The following list shows types of events where LOPA may not be appropriate;

- Low severity events, based on setting an appropriate severity level below which events would not be considered for LOPA, for each of the impact categories of People, Environment, Assets/Business and Reputation. For Safety impact LOPA was required for events with potential for major injuries, i.e. irreversible harm, and worse.
- Domino events involving an initiating cause on another system, for example fire engulfment of equipment.

- Events protected by control of work activities, for example re-fitting blanks/caps to drain connections.
- Integrity management issues where events are prevented by routine inspection and testing.
- Design errors, where action is required to re-instate equipment to the correct design.
- Events initiated by external factors, such as natural phenomena or external activities.

Linking HAZOP causes to LOPA Scenarios

LOPA is a hazardous event or scenario driven exercise, where specific events such as overpressure of a process vessel are assessed taking account of all the initiating causes. The HAZOP process with Nodes at line level meant that LOPA scenarios often have initiating causes from several Nodes. With alternative recording tools this may have created a challenge to ensure that all causes had been picked up, but PHA-Pro allows HAZOP events to be linked to relevant LOPA scenario such that they are automatically listed within the LOPA assessment. This feature of PHA-Pro was very helpful to ensure that all the HAZOP initiating causes had been addressed.

Good practice developed during the work was to prepare a sketch for each LOPA scenario with the main equipment and protective systems clearly marked. Each HAZOP cause was then identified on the sketch with the reference number to provide a clear overview of all elements that needed consideration during the LOPA. Whilst this approach may be less beneficial for simple cases, it was found that for a majority of cases the improved visualisation from the sketch provided improved clarity and improved the overall quality and speed of the assessment.

Taking credit for HAZOP safeguards

The LOPA process requires identification of the relevant Independent Protective Layers (IPL) for which risk reduction credit can be taken, and then assigning a PFD value based on either generic values from the company guidance or alternatively based on operating experience. As a starting point the HAZOP safeguards were copied into the LOPA assessments and each of these tested against the requirements for an IPL, namely;

- Does the safeguard prevent the event escalating to the LOPA scenario under review. There were examples where safeguards listed in the HAZOP prevented some consequences being realised but not the hazardous event being assessed in the LOPA.
- Is the safeguard fully independent of the initiating cause and all the other IPL's. This was often not the case for example due to common instruments or reliance on response by the Operator who had initiated the event.
- Can a reliability figure be assigned to the IPL, generally this required the IPL to be a registered risk reduction feature that undergoes routine auditing, inspection and/or testing to ensure that the functionality is maintained. For example, if reverse flow is to be prevented by a non-return valve, in order to take risk reduction credit this must be registered as a safety-related device and included on a PM schedule.

A general observation from this process was how many of the HAZOP safeguards did not pass the test to become an IPL, particularly alarms on the DCS due to lack of independence from the controls or not being managed as a 'Safety Related Alarm'. This could lead to a false sense of security following the HAZOP that there are many safeguards and therefore the risk must be low. The LOPA process focusses the team on the key risk reduction systems that must be relied upon to prevent serious process safety incidents. LOPA is therefore an effective tool to determine the Barriers or Safety Critical Elements that need careful design and monitoring of performance throughout the facility lifetime, and could be captured on a 'Bow Tie' diagram to aid understanding of hazards by non-technical staff.

Reliability values for IPL's

The LOPA method requires PFD values to be assigned for all IPL's, including items such as; safety instrumented functions (SIF), pressure relief systems, safety related alarms, BPCS response, bunds/dykes, non-return valves, etc. The selection of suitable values was simplified by reference to generic values in the company guidance, which also helped to achieve greater consistency across the study. However, these generic values need to be tested against facility experience in order to determine if the observed performance is different to the generic figures. For example, a pressure relief system with a generic PFD of 0.01 that is assumed to be failed in 1% of high pressure demand cases, could be failed more frequently due to being installed on a dirty or blocking service.

A learning point from this study was the need to carry out deeper assessment of the design basis for IPLs, rather than simply using the generic failure rate data. The company had a key requirement that sizing calculations were available for pressure relief systems, and PFD calculations were available for SIF's taking account of the loop architecture and proof testing periods. Where the design basis could not be proven a PFD of 1.0 was used, which greatly increased the residual risk calculated in the LOPA. Although this approach could over-state the risk in situations where in reality the IPL's are suitably designed, it gives a strong driver to find or repeat the calculations to provide assurance that this is the case.

An example of where the design basis could be critical for determining the correct PFD value is where multiple pressure relief devices are on-line simultaneously. The question arises about how many of the on-line relief devices are required to provide protection against the hazardous event, and this is often not apparent without going back to the original sizing calculations. If any of the multiple relief devices are sized for the event, then the PFD would improve from the single device value of 0.01 to a multiple device value of 0.001. However, if say 3 relief devices all need to operate successfully to provide protection, the PFD value would rise to 0.03, a factor of 30 times higher.

## Results of Study

Several onshore and offshore facilities were included in the HAZOP and LOPA study programme during this retrospective process safety assessment. A general observation from the studies was the lack of consistency between the studies in terms of time taken and number of findings, even for facilities such as offshore platforms with largely similar processes. These can partly be explained by differences between the teams in terms of their experience, but also reflects significant differences in the process design at a detailed level and the performance of the equipment systems. This finding reinforces the requirement to study the facilities in isolation in order to identify the key improvements, avoiding a 'cut and paste' approach between facilities that could result in issues being overlooked.

In this section data will be provided on a single offshore platform to indicate the scale of the exercise, although this is not necessarily representative for the other facilities. The Hydrocarbon systems on this platform included approximately 20 wellheads and flow lines to HP and LP Separation, with oil route via exports pumps and sub-sea line to shore, and gas route via Flash Gas Compressor and sub-sea line to shore. In addition the Hydrocarbon systems included; Flare System, Glycol Regeneration, Closed Drains, Sand collection and gas/oil line pig launchers. The Utility systems for this platform included; Fuel Gas, Injection Water, Fire Water, Instrument Air, Diesel, Sewage Treatment, Open Drains, Chemicals, Power Generation and Potable Water.

Performance data for the HAZOP study of the Hydrocarbon and Utility Systems is presented in Table 1, with data for the LOPA study of the same facility in Table 2.

**Table 1: Performance Data for HAZOP study of Offshore Platform**

| Measure | Data |
|---|---|
| Number of P&ID's | Company 136, Vendor 23, Total 159 |
| Number of Nodes | Hydrocarbon 28, Utility 55, Total 83 |
| Duration of Study, weeks | Hydrocarbon 12, Utility 8, Total 20 |
| Meeting time, days (6 hours) | Hydrocarbon 45, Utility 27, Total 72 |
| Team members in total | Hydrocarbon 22, Utility 11 |
| Recommendations | Hydrocarbon 55, Utility 11, Total 66<br>49% Design Checks<br>31% Hardware Changes<br>12% Operating Procedure Updates<br>7% Risk Assessment<br>1% Further Information Needed |
| Observations | Hydrocarbon 55, Utility 66, Total 121<br>36% Drawing Updates<br>25% Operating Procedure Updates<br>25% Hardware Changes<br>12% Design Checks<br>2% Safety Related Device Register Updates |

The data in Table 1 shows an overall rate of progress of approximately 1.2 Nodes per day, although for this study the rate was much slower on the Hydrocarbon systems at 0.6 Nodes per day. It should be noted that this timing is based on full HAZOP studies and recording, and the studies could be completed more quickly either by a coarse form of HAZOP focussing on just major accidents, or an alternative technique such as HAZID or PHR.

The number of Observations is approximately double the number of Recommendations, showing the value to separating out these lower priority issues. The Observations are dominated by Drawing Updates (36%) whereas the Recommendations are dominated by design checks (49%), reflecting that concerns relating to risk ranked events need further assessment on the scale of hazard and possible improvement options.

**Table 2: Performance Data for LOPA study of Offshore Platform**

| Measure | Data |
|---|---|
| Number of Scenarios sent from HAZOP | Hydrocarbon 73, Utility 22, Total 95 |
| Number of Scenarios assessed by LOPA | Hydrocarbon 26, Utility 8, Total 34 |
| Meeting time, 6 hour days | Hydrocarbon 19, Utility 2, Total 21 |

| | |
|---|---|
| Team members in total | Hydrocarbon 20, Utility 5 |
| Recommendations | Hydrocarbon 22, Utility 5, Total 27 |
| Independent Protective Layers | Hydrocarbon 36, Utility 21, Total 57<br>58% SIF's, 40% Pressure Relief, 2% Mechanical Interlock |

The data in Table 2 shows that LOPA scenarios were generated at an overall rate of around 1 per HAZOP Node, although much higher at around 2.5 per HAZOP Node on the Hydrocarbon systems. In both cases the number of LOPA Scenarios actually assessed was around 35% of the total brought forward from HAZOP. There were a number of reasons for events to be excluded from assessment at LOPA, such as being covered by another scenario or the events being ruled out by the LOPA team following a more detailed assessment. In addition for this study, an assessment was not required for Safety related events at the 'Major Injury' level, i.e. non-fatal, where a valid IPL to prevent the event could be assigned.

## Conclusions

This paper has described the key findings from a series of combined HAZOP and LOPA studies for an Offshore platform. The organisation and technical challenges with work of this scale can become significant when compared with smaller project related studies, and require effective planning before the studies and effective communication throughout.

Retrospective studies of this nature are more challenging than project related studies, in terms of obtaining accurate 'up-to-date' process design data and securing the involvement of knowledgeable Operations based staff over a lengthy study period. These aspects require careful attention if the studies are to be effective in identifying the key areas of concern requiring further attention.

This work has demonstrated benefits from carrying out combined HAZOP and LOPA studies, in order to achieve efficiency savings and greater consistency between the various risk assessment stages. This was helped by using software that integrates HAZOP and LOPA studies into a single assessment, but further work is required to make the transition between the studies more effective, avoiding the need for reworking by the LOPA team.

A focus on limiting the number of Recommendations from the studies was effective by only raising for risk ranked events where the resulting action would bring about significant risk reduction. The studies also brought benefits from raising awareness of process safety hazards for all those involved, and an opportunity to review and update key documents such as P&ID's, operating procedures, etc. The detailed study records also provide a document that can be referenced for improved process safety understanding during day-to-day activities, and updated at intervals to maintain an 'evergreen' risk assessment for the facility.

Companies with greater flexibility for carrying out Retrospective Hazard Reviews might be concerned about the significant time and hence costs to complete a full HAZOP on this scale. Consideration should be given to a higher level method such as HAZID or PHR, which might typically take 20-25% of the time required for a full HAZOP. The clearer focus on hazardous events that such techniques provide, allow a more efficient process for risk assessment whilst still allowing detailed causes of events and weaknesses with the current safeguards to be identified.