Making your retrospective HAZOP reviews smarter and more efficient whilst still ensuring that key holes in process safety barriers are identified

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Introduction

Companies operating high hazard plants in the Process Industry have a responsibility to identify potential process safety hazards, implement robust risk controls, and ensure that these barriers are maintained throughout the lifecycle of the facility. Design stage risk assessments, including Hazard and Operability (HAZOP) studies, only address the first step in this process, and need to be followed by periodic reviews of ongoing performance in order to demonstrate continuous improvement. These periodic reviews have the primary purpose of identifying weaknesses in barriers, and making recommendations for practical improvements to address these concerns.

Best practice requires reviews every 5 years, driven partly by global regulations for thorough reviews of Safety Reports/Cases, plus a recognition of the extent of change and new learning on a facility over this timescale. The traditional approach in some sectors is retrospective HAZOP studies which require a line-by-line or step-by-step assessment of the process using standard deviation guidewords. Although a more streamlined approach with reduced focus on 'Operability' issues can be applied, HAZOP studies are inevitably very time consuming and present a major resourcing challenge for an operations based team.

The well-established Process Hazard Review (PHR) method [*Ellis, 2005 & 2010*] provides an alternative approach to HAZOP, using a higher level system-by-system approach with hazardous event guidewords. PHR is more efficient and can typically be completed 4-5 times faster than a HAZOP on the same facility. Whilst PHR offers clear benefits in terms of resource requirements, some companies have continued to use HAZOP due to corporate requirements, the need to meet perceived Regulator demands, or the need for an in-depth study where there were serious deficiencies in the original process design.

This paper will describe an approach for retrospective hazard reviews on existing facilities that combines HAZOP and PHR in a flexible and efficient manner, optimising the time required for busy operations based teams. Different approaches to the use of HAZOP or PHR will be discussed based on practical experience in both the Oil/Gas and Chemicals sectors, with advice provided on how to select the most appropriate approach for a given situation.

The Need for Retrospective Hazard Reviews

Process plants undergo detailed hazard identification and risk assessment during the design stage, often using a combination of Hazard Identification (HAZID) studies on the preliminary design followed by HAZOP studies at the detailed design stage. These studies are supported by further risk assessment methods such as Layer of Protection Analysis (LOPA) and Quantified Risk Assessment (QRA) to ensure that risks have been reduced to as low as reasonably practicable (ALARP). The resultant risk assessments should be developed into a Basis of Safety for the process, with key prevention and mitigation barriers clearly identified, and the complete risk assessment captured in Process Hazard Analysis (PHA) documentation.

During the operational stage of a facility there is a need to periodically review and update the PHA documentation to ensure that key barriers are working effectively, to take account of new information that has been gained on the process, and to ensure continuous improvement in reducing risks to ALARP. These reviews need to take account of changes including.

- Creeping change caused by many smaller modifications
- Loss of experienced staff
- Ageing or obsolete equipment
- New understanding of hazards from inside or outside the company.

Companies operating on-shore in the EU need to comply with the Major Accident Hazard (MAH) Directive (COMAH Regulations in the UK), which requires all MAH's to be identified and a demonstration made that 'all measures necessary' have been taken to prevent and mitigate these hazards. There are similar requirements in place for off-shore facilities where a Safety Case is required to make the required demonstrations. Retrospective Hazard Reviews have been routinely carried out during the preparation of Safety Reports/Cases in order to identify all MAH's and the associated risk control barriers, and to meet the need for thorough reviews every 5 years.

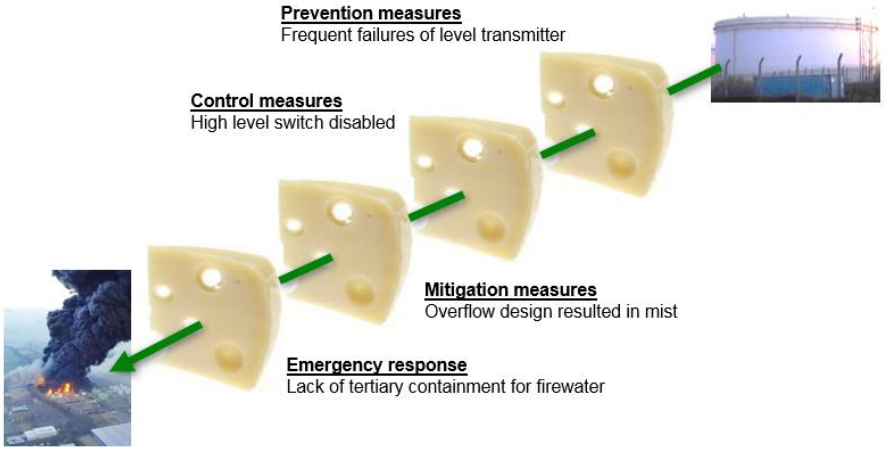
In the US, companies handling hazardous chemicals must comply with the Process Safety Management (PSM) Standard which includes a requirement for PHA's to be revalidated every 5 years for existing major hazard installations. A number of methods are proposed in the standard; What-if, What-if / Checklist, HAZOP, FMEA, Fault tree analysis, or an appropriate equivalent methodology, such as PHR.

Comparison of HAZOP and PHR Methods

The layers of protection or barriers built into a process design can deteriorate over time such that they no longer provide the required level of risk reduction. This is characterised by holes in the 'Swiss Cheese Model' which can reduce the

effectiveness of the hierarchy of prevention, control and mitigation measures and emergency response as shown on Figure 1. A key requirement for any Retrospective Hazard Review team is to identify potential hazardous events on the process and look for holes or weaknesses in the associated barriers. If done effectively this process can identify deficiencies in the current process design and operating standards, allowing remedial actions to be agreed and implemented in order that risk can be brought back under control before a serious incident occurs on the facility.

Figure 1: 'Swiss Cheese Model' applied to the UK Buncefield Accident



A number a common features of a Retrospective Hazard Review need to be considered, whether the approach selected is HAZOP study, PHR or some other equivalent method.

- Typically carried out every 5 years on existing facilities
- Team of experienced operations and technical staff
- Facilitated by a competent Process Safety specialist
- Considers real experience on the facility
- Assesses the robustness of barriers
- Identifies deviations from standards
- Generates a risk prioritised improvement plan

HAZOP studies were originally developed by UK based chemical company ICI in the mid 1960's for the detailed design stage of projects. The objective of HAZOP studies is to ensure that the process design as shown on the Piping and Instrument Diagrams (P&IDs) is fit for purpose and meets the applicable standards. The process is split into Nodes as individual lines on the P&ID (continuous processes) or steps in the operating sequence (batch processes), and a series of guidewords such a 'No Flow' or 'High Pressure' used to identify the causes of any significant deviations from the design intent. The team considers if these deviations can escalate into a serious event, and then assesses the risk and need for improved safeguards, such as; alarms/trips, pressure relief, procedural controls, secondary containment, etc.

HAZOP studies have been used extensively for retrospective studies on existing facilities, often as the company has specified the use of HAZOP studies for the design stage. On an existing facility HAZOP is often applied at a higher level than for design based studies, by selecting Nodes covering a larger section of the P&ID, and focusing on hazardous events with the potential for significant impacts on people, the environment or business, rather than operability or product quality issues.

The PHR methodology was originally developed by ICI in the early 1990's for the periodic review of existing facilities, to address the following difficulties experienced during trials using the established HAZOP study method on ICI global facilities.

- Excess time required involving busy operations staff
- Excess number of actions with many related to operational issues
- Failure to identify the bigger picture related to process safety events
- Difficulties applying HAZOP with out-of-date P&ID's.

ICI also recognised the need for retrospective reviews to takes a broader view of the facility than normal with HAZOP studies. This requirement was built into the early stages of the PHR process, with consideration of various issues including.

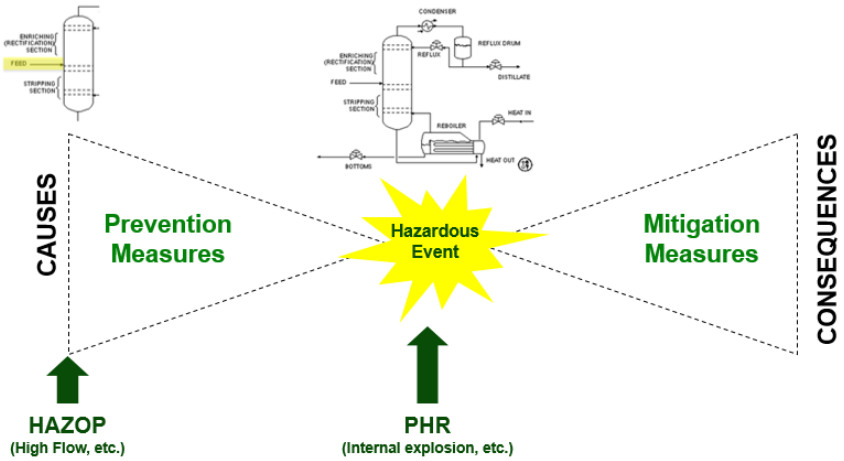
- Potential for knock-on effects from neighbouring facilities
- Incident history on this and similar facilities
- Observations of plant condition and operation standards from site tours
- Potential for impact on vulnerable locations on-site and off-site
- Reliability and dependability of key utility systems

PHR is typically 4-5 times quicker than HAZOP for a similar facility and therefore offers a significant saving in costs and resource requirements. The key difference with PHR is splitting the process into larger Nodes than for HAZOP, at the system level rather than line/step level, and using guidewords directly related to hazardous events, i.e. those located in the middle of a Bow Tie diagram, with guidewords linked to hazardous events causing a loss of containment or release of energy, such as 'Internal Explosion' or 'Puncture'.

The differences between the HAZOP and PHR approaches are shown on the Bow Tie diagram in Figure 2. The efficiency of the PHR method results from progressing more quickly through the process on a system-by-system basis, where a system could be a Distillation Unit as shown on the diagram. In addition, PHR only looks for detailed initiating causes on the left hand side of the Bow Tie diagram where a significant hazardous event has already been identified. By comparison, HAZOP is more structured and results in more complete records with all potential initiating causes identified by considering every line/step on the process and going through all potential deviations. However, HAZOP teams often go down blind alleys for deviations which do have the potential to escalate into a significant process safety incidents, with time wasted in making this assessment and a record of 'no serious consequences'.

There are occasions when HAZOP teams working at the detailed line/step level fail to recognise a hazardous event at the system level, which can be characterised by 'not seeing the woods for the trees'. This is often caused by the consequences not being realised on the Node under review or the need for several barriers to be ineffective or a 'double jeopardy' event to occur, which often results in the event being wrongly dismissed by the HAZOP team as 'not credible'.

Figure 2: Bow Tie diagram illustrating HAZOP and PHR methods



Factors Affecting Choice of HAZOP or PHR

The author routinely carries out PHA revalidations on existing facilities using both HAZOP and PHR methods, and has developed delivery tools that allow a common approach and recording method in all aspects other than splitting of the process into larger Nodes for PHR and use of different guidewords as described above.

The choice of HAZOP or PHR often depends on meeting Regulator requirements, client corporate preferences or previous practices on the site. Table 1 provides a number of factors that should be considered before embarking on a PHA Revalidation, providing an improved justification for the choice of HAZOP or PHR.

Table 1: Factors affecting Choice of HAZOP or PHR

Factor	Comments
Company standards/ Regulator requirement	In some companies there is a corporate requirement for either HAZOP or a PHR approach written into corporate standards, in which case this method is mandatory. Regulators have directed companies towards HAZOP based on their preferences or perceived compliance with the US-PSM standard which explicitly mentions HAZOP.
Recent Process Safety Incidents / No or poor design stage HAZOP	The higher level approach for PHR works well if there are no serious deficiencies in the basic process design. The structured and thorough approach offered by HAZOP may be required if there have been serious process safety incidents, or where there are concerns about the basic process design due to lack of design stage HAZOP or evidence of poor quality in this HAZOP.
Complexity of process	PHR at system level works effectively for relatively simple processes such as storage systems and continuous processes. The more thorough approach to identifying initiating causes offered by HAZOP may be appropriate with more complex processes, such as batch reactors with multiple steps or at HP/LP interfaces on Oil & Gas facilities.
Availability of Operations based staff	Retrospective Hazard Reviews place a great demand on busy operations based staff, yet input from knowledgeable plant based staff is key to success whether using PHR or HAZOP. For some companies the use of the more time efficient PHR method is the only viable option given limited staff availability. There are examples where reviews using HAZOP have not been completed due to the excess time required.
Quality of design data including P&ID's	On many operating plants the accuracy of the P&ID's is poor, especially those beyond 10 years old where many modifications have been carried out. The nature of HAZOP using structured line-by-line approach based on the P&ID's can lead to problems on existing facilities where the P&ID's are out-of-date. PHR provides an increased flexibility with the higher system level approach, and allows progress on risk reduction without the need to wait for P&ID updates to be carried out.
Need for quick results	The increased time for HAZOP can result in delays between the start of the study and the results being finalised and improvement actions taken. Based on ABB experience, an Offshore platform may take a total of 6-9 months to complete, compared with 1-2 months for a PHR of the same facility. Some companies with concerns about current performance may be looking for quicker identification of improvement actions in order to reduce risks as offered by PHR.
Availability of skilled Facilitators	PHR is a more demanding technique for the Leader, requiring hazardous events at a system level to be identified using a 'helicopter view' of the process, with the experience of knowing when to dive deeper into specific issues. By comparison HAZOP provides a more structured approach for less experienced Leaders, and may be the preferred route if such internal resources are to be used.
Limit number of actions / Focus on major accidents	The additional time required for HAZOP often results in a proportionate increase in the number of actions or recommendations raised, which can present challenges for the company in effectively closing out with an adequate justification. Experience has shown that the PHR approach with greater focus on major accident hazards generally results in less recommendations focussed on high risk issues.

Table 2 provides metrics on reviews carried out using the HAZOP and PHR techniques respectively. This data is presented to illustrate the differences between the techniques but it should be noted that these were carried out for different companies on different plants by different teams, and are therefore not a direct comparison.

Table 2: Comparison of HAZOP or PHR outputs

	Case 1: HAZOP	Case 2: PHR
Facility Type	UK Gas Reception terminal	UK Gas Reception terminal
Number of Units	15	11
Days of study	105	10
Total recommendations	498	90
High priority items	14	45

For these reviews PHR was almost eight times faster than HAZOP per unit, partly explained by a wider focus on SHE issues for the HAZOP case, but supporting the more typical advantage of PHR being 4-5 times faster. Another clear difference is the greater number of recommendations for HAZOP, whilst PHR has less overall but more aimed at higher priority issues. Although this can partly be explained by different risk ranking approaches it also reflects the greater focus on significant hazardous events with PHR.

Flexible use of HAZOP and PHR

The decision on whether to use HAZOP or PHR for a retrospective review on a specific facility is normally applied to the complete facility, including all the process systems from raw material supply via processing to product storage and export, plus the related utility systems. The latest tools developed allow a more flexible approach where both HAZOP and PHR approaches can be used for a single facility, with Node sizes chosen appropriately and the choice of guidewords for each Node varied between those for HAZOP (deviation based) or PHR (hazardous event based).

When both HAZOP and PHR approaches are being used on a facility, a decision is made on a system by system basis and the following are typical factors that should be taken into account.

- Simple systems use PHR approach, e.g. raw material storage, simple continuous process units (e.g. distillation unit), utility systems
- Complex systems use HAZOP approach, e.g. batch reactor with multiple steps, complex continuous process units (e.g. at a, HP/LP interface)
- HAZOP approach used where significant incidents or near misses have occurred, or where there are concerns about the adequacy of the basic process design.

Improving the Efficiency of Retrospective Reviews

Companies have used a range of approaches to reduce the overall costs and time commitments for their staff when carrying out retrospective reviews, regardless of whether HAZOP or PHR is being used. The author has concerns whether some pared back reviews can meet the minimal standards required by the Regulators, and considers the following as essential elements to ensure the thoroughness and quality of a retrospective review.

- A multi-disciplined team to ensure that relevant knowledge on the plant under review is considered, including a core team with an Operations representative and person with knowledge of the process design intent.
- Competent and knowledgeable Facilitator with expertise in Process Safety and responsibility for ensuring the quality and depth of the review.
- Full team present at the same location rather than using teleconference or videoconference facilities, to retain a focus on the design information under review.
- Recommendations are a key output and time should be spent to ensure that these are self-explanatory and meet the requirement for “3 W’s”, i.e. clearly state ‘what-where-why’.

Whilst meeting the basic requirements listed above, there are a number of ways that the overall efficiency of the review process can be improved, based on practical experience gained on many large studies. Table 3 provides options to be considered when planning a retrospective review that could have a significant effect on the overall timescales and thoroughness of the review.

Table 3: Decisions affecting Efficiency of Reviews

Option	Comments
Scope of Review	The overall scope of the review should include all process and utility systems with the potential to result in significant consequences as a result of events involving loss of containment of hazardous substances or release of stored energy. Some parts of a facility can be excluded from the scope of the review as not having the potential for a significant process safety hazard due to the small inventory of hazardous substances, e.g. a packing line at a Paints manufacturing facility.
Utility Systems	The loss of utilities such as cooling water and the potential for a major accident hazard to be initiated, such as a reaction hazard on a batch reactor, should be considered as part of the process system review. When assessing the need to review the complete utility system, the scale of hazards is generally lower than for process systems. Some systems such as process water can be excluded from the study on the basis of low hazard potential. Other systems can be considered as a large Node covering all or a large part of the system, to reduce the time required. Care should be taken when developing the study scope to identify any high hazard parts of utility systems that require a full review, e.g. chlorine injection into a Cooling Water system.

Option	Comments
Parallel Systems	On many plants there are parallel systems such as storage tanks with the same design basis or parallel process trains with largely similar designs. It is efficient in these cases to study a single system fully and then check the similar parallel systems 'by difference'. Time should be spent when developing the scope to understand how many systems on the plant will require a full review and how many will be reviewed 'by difference'.
Size of Team	The size of the review team should be limited to those making key contributions, whilst retaining the core inputs from Operations and Design. In practice the team size for a retrospective review should not exceed 5-6 plus the Leader/Scribe and any specialists on a part-time basis, in order to avoid increased levels of discussions.
Review Scribe	The need for a Scribe rather than relying on the Facilitator to keep records is judged a key requirement for reviews lasting more than a few days. The choice of Scribe has a key effect on the speed and efficiency of the study and should assess the following skills and competencies, 1) Technical background, ideally a Process Engineer, 2) Fully familiar with recording software, 3) First language same as review language, 4) Capable of recording study with minimal guidance from Leader.
Noding Out in Advance	During the preparation stage it is beneficial to carry out preliminary noding out of the review using the P&ID's, identifying all cut points between Nodes. This allows a complete list of Nodes to be prepared for the scope of the study, with indication of the relative complexity of the Nodes or whether the Node can be studied 'by difference'. This data can be used to determine the time required and to monitor progress against the plan throughout the review. Providing a means of monitoring progress during a lengthy study has been found a key aspect for on-time completion.
Equipment Data	Key equipment data is required to ensure risk assessments to the required level of accuracy. If not prepared in advance this can lead to delays in obtaining the data during the meeting, or re-working of conclusions at a later date. This data should be collected in advance of the review and either made available to the team in document form or marked out on the master P&ID's. Typical data required for the review includes equipment design pressure/temperature, pump/compressor dead head pressure, relief system/trip system set-points, cause-and-effect diagrams, etc.
Severity Levels	If risk ranking is to be done during the review it is beneficial to calibrate the risk matrix consequence word models against potential hazardous events on the facility, covering all aspects of impact on people, environment, business and reputation. For example, this would set the size of loss of specific substances to give an environmental impact off-site at various severity levels. Such information is often available from existing documents such as the site Safety Report, or can be developed during discussions with the site SHE Manager to take account of site specific factors. This approach can avoid excessive discussions when assigning severity levels to specific hazardous events and ensure that a consistent approach is maintained.
Recording Software	The speed of the review can be significantly affected by the choice of recording software, and potentially slowed down when using bespoke company developed worksheets. These may require an excessive amount of typing or include additional columns, for example risk ranking to be done for both the unmitigated and mitigated risk, and in some cases the risk level post action completion.
Flexible use of Guidewords	Some companies require a record for every guideword on every Node in order to demonstrate that a 'thorough' approach has been taken. In practice this can result in extra time being required to prompt for a team response for each guideword, and to make records such as 'no further hazards identified'. This can be avoided by the Leader being responsible for prompting a response for relevant guidewords only on the Node, and records only made where a relevant initiating cause has been identified. It should be noted that the more flexible approach requires an experienced Leader that can quickly assess the key issues for a Node, whereas an inexperienced Leader may need to follow the more structured and slower approach.

Option	Comments
Extent of Consequences	For a thorough approach the consequences of a deviation should be developed from the immediate effects, such as high level in a vessel, to the ultimate effects, such as tank overfill and ignition resulting in a pool fire and major injury burns to a person in the vicinity. Providing this level of detail can be time consuming but helps the team to focus efforts on areas of greatest concern and assists with subsequent work such as LOPA studies. A less detailed approach would focus on the immediate effects where it is judged that the ultimate hazards are likely to be significant, and ensuring that the prevention measures meet relevant good practice with less concern about the associated mitigation measures.
Recording of Design Intent	The initial stage of discussions on each Node should ensure that the design intent of the process is fully understood such that potential deviations from this design intent can be explored. Good practice requires this design intent to be written on the worksheet for future reference, and is written either during the meeting or immediately afterwards. This is seen as best practice but requires additional review time that could be omitted to speed up the process.
Equipment reference numbers	Thorough recording of reviews requires all equipment to be clearly identified using tag numbers or equivalent (e.g. P&ID grid reference), as this allows easier identification when the record is used at a later date, e.g. when closing out actions or during subsequent LOPA studies. As a time saving during team meetings equipment reference numbers can be omitted from the records, allowing scenarios to be 'cut-and-paste' without a requirement to check the P&ID's and amend the reference numbers.

Linkage with LOPA Studies

As a follow up to PHA Revalidation activity many companies are carrying out Layer of Protection Analysis (LOPA) studies, either to provide target Safety Integrity Levels (SIL) for their Safety Instrumented Systems, or to verify the required reliability for all independent protective layers. Ideally LOPA studies should be carried out following a retrospective review of the facility and using the review report as a key source of information on the hazardous events and existing protective systems. The author has experience of carrying out LOPA studies following both HAZOP studies and PHR reviews, and in both cases there can be issues requiring a degree of rework for the LOPA team.

HAZOP should in theory identify all initiating causes, but these are identified at line/step level and during the LOPA it can be difficult to link these to a specific hazardous event at system level. The LOPA team often needs to check back through the HAZOP records over several Nodes to gain a full understanding of the overall scenario.

PHR works at system level and looks to identify specific hazardous events, and where these are significant works backwards to identify initiating causes. In practice this helps the subsequent LOPA process by providing clear hazardous events with better thought out consequences, but there can be some further work for the LOPA team to ensure that all initiating causes have been identified.

Conclusions

When planning retrospective process safety reviews a key decision is required on the use of either a HAZOP or PHR approach, and this can have a major impact on the time required, with PHR being typically 4-5 times quicker than HAZOP. The author has a wide experience of using both methods and this paper has captured some of the factors that may influence the decision on the use of HAZOP or PHR. Key factors are that PHR requires a more experienced Leader to ensure that hazardous events are identified effectively, and HAZOP is likely to be the best option where there are concerns about the basic design of the process or quality of previous PHA documents.

In recent years the author has streamlined delivery tools to allow a flexible approach when carrying out baseline reviews or subsequent revalidation reviews. This allows both PHR (system level) and HAZOP (line/step level) approaches to be used on a single facility, with a decision on PHR or HAZOP at the system level based on factors such as; level of complexity, quality of current PHA documents, history of near misses/incidents, etc. This flexible approach allows the efficiency of the overall process to be optimised, with PHR used to make faster progress where possible, and more detailed HAZOP used where required to provide greater thoroughness.

Whether using HAZOP or PHR for a retrospective review, or a combination of both techniques, the overall efficiency of the review can be improved by attention to detail at the planning stage. This paper has presented a number of practical steps that can be taken to improve the efficiency of the review based on extensive experience, offering the potential for significant time savings on what can be very lengthy reviews involving key resources for several weeks or months.

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