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Risk-Based Approach - Hazard Identification

Guidance for Identifying Loss of Containment Scenarios

An ioMosaic White Paper

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Abstract

All phases during the development of a risk-based quantitative assessment are important. However, hazard identification is a key step; a discipline that "establishes the game rules" and can be considered as the foundation for risk management; i.e., if a hazardous scenario is ignored, it will not be evaluated, directly affecting risk estimation results for realistic decision-making. The present paper provides guidance and criteria for maximizing the identification of both generic and specific Loss of Containment scenarios (LOCs) with potential contribution to the risk level of a given facility. The software tool PHAGlobal®, a component of ioMosaic's Process Safety Office™ suite, helps on maximizing the identification of hazardous scenarios while minimizing efforts, time, and subjectivity.

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Introduction

Managing industrial risks requires the systematic application of management policies, procedures, and practices to analyzing, assessing, and controlling risks in order to protect employees, the general public, the environment, and company assets. Several management activities should be addressed for risk analysis, the process of gathering data and synthesizing information in order to develop an understanding of the risk of a particular facility. Chemical process facilities have many possible applications for risk analysis, but actual interests are focused on knowing how to allocate resources to minimize the chance of a catastrophic accident by assessing the risk of episodic events. With the understanding gained from such risk analyses, it is possible to evaluate and select among different risk management options. **Figure 01** illustrates a simplified risk management program flowchart, and Hazard Identification is the first step in the process.

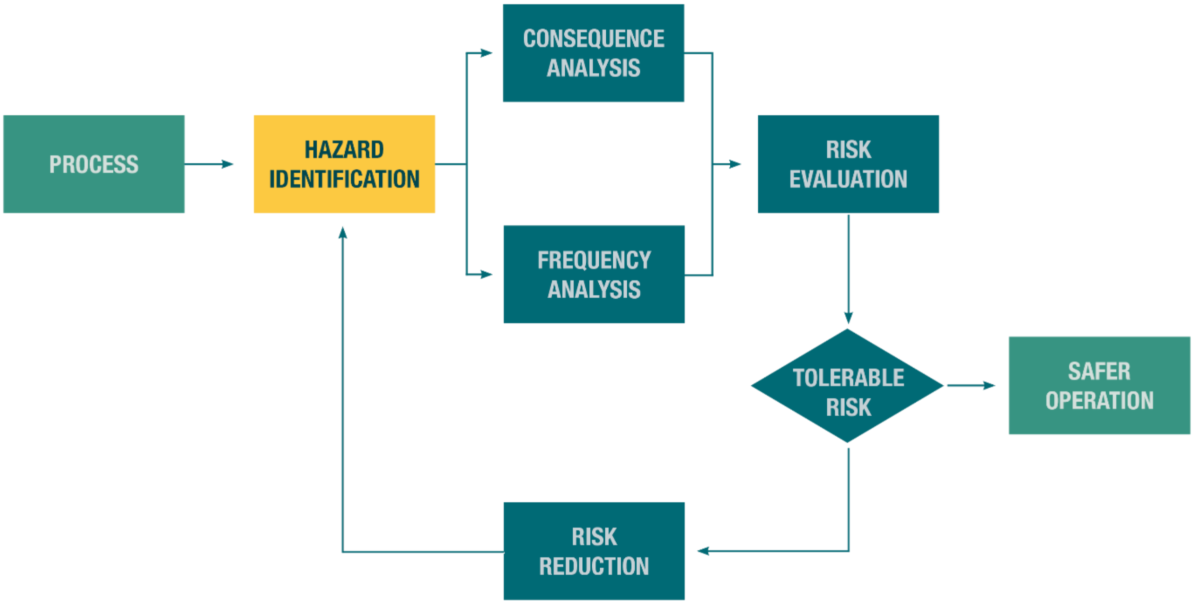

Figure 01: Risk Management Program Simplified Flowchart

The Hazard Identification step is intended to answer the question: ***"What can go wrong?"***. It is considered the foundation of process safety and loss prevention; i.e., it is not possible to evaluate and manage the risk of a hazardous scenario which has not been identified.

Hazard Identification as the Foundation of Process Safety

Hazard identification focuses on identifying what can go wrong and lead to hazardous scenarios (the sources of risk). Industrial plant hazards include failures of equipment, human error, and the use of equipment outside its design specification whereas in the formation of high-level policy they may be the potential causes of impact on society or environmental problems. In any case, the aim of the activity is to maximize the identification of hazards. There are many Process Hazard Analysis (PHA) techniques for hazard identification, and all of them depend on human observation, judgment, and creativity **[1]**. As a result, there is potential for bias **[2]**. Consequently, the hazard identification step must involve plant personnel. For an existing process, plant personnel should know the status of process equipment and the current operating and maintenance practices. Excluding plant personnel from the hazard identification step increases the chance of over-looking important potential hazards **[3]**.

Endeavors to perform the hazard identification depend on the size of the problem and the specific techniques used. For example, while in some well-understood and simple systems, the use of brainstorming, what-if analysis, or checklist may be adequate; more laborious, time-consuming, and more-structured methods (e.g., HAZard & OPerability study - HAZOP, Failure Modes and Effects Analysis - FMEA) should be conducted for complex systems. Likewise, there is greater confidence in the exhaustiveness of HAZOP and FMEA techniques due to their rigorous approach, helping to ensure thoroughness while analyzing a process based on guiding the freedom and creative thinking of the experts involved. However, no technique can guarantee that all hazards or potential accidents have been identified.

Finally, qualitative risk ranking is used for prioritizing the planning for the control of the hazards that have been identified. Risk ranking is accomplished by qualitatively estimating severities/consequences and likelihoods and combining them into risk estimates using a risk matrix, grid, or table. Even so, while it is advisable to establish corporate or site-wide risk ranking schemes with the aim of enforcing consistency to all PHA studies, there are no accepted industry standards for risk ranking schemes. In the end, what is essential for risk ranking is the presence of consistency on assigning values throughout the entire study, a fact that will be supported by expertise.

Process Hazard Analysis (PHA) Overview

PHAs are mandatory for process facilities that manage hazardous materials. PHA is a technique focused on analyzing equipment, instrumentation, utilities, human factors, and external events that might impact a given process; i.e., identification of potential system interactions and failures that could result in an accident. PHAs are the foundation of all risk and safety analysis and should ensure complete risk evaluations and adequate protection devices. While hazard identification may be the most important stage for risk management, it depends on subjectivity issues (e.g., human observation, good judgment and intuition, creativity, expertise, knowledge) which can introduce some degree of bias.

Identifying hazards is fundamental for ensuring the safe design and operation of a system in process plants and other facilities. Several techniques are available to identify hazardous situations, all of which require rigorous, thorough, and systematic application by a multi-disciplinary team of experts; i.e., team-based approach. Success depends upon first identifying and subsequently analyzing possible scenarios that can cause accidents of different degrees of severity. Without a structured identification system, hazards can be overlooked thus entailing incomplete risk-evaluations and potential loss of information. There is a plethora of references that listed PHAs. However, none of these are comprehensive, and most of them provide a brief listing of methodologies. In this sense, the most-valued publications reviewing PHAs include a report by the U.K Health and Safety Laboratory **[4]**, and two books **[5]**, **[6]** that discuss the purposes, execution methodologies, advantages, and limitations of the most often used PHA techniques.

PHAs are fundamental for the assessment of incident consequences, risks involved, and selection of the most appropriate preventive and protective systems **[5]**. Additionally, a PHA technique can also highlight gaps in the management systems of a process safety program; thus, it can be used to investigate the probable causes of an incident that has occurred as part of a facility's management of change program (MOC) and identify critical safety equipment for special maintenance, testing, or inspection as part of a facility's mechanical integrity program **[7]**.

The first systematic technique of hazard identification to be used within process industries was the HAZOP, formally published by Lawley in 1974 **[8]**. This hazard identification technique is still used extensively today. Since then, a number of other techniques have been developed, some to address specific problems, others to provide more rapid assessments. A total of 40 techniques have been reviewed **[4]**. Thus, the broad range of techniques available can make it difficult for a manager or a safety specialist to decide which is the most appropriate and effective technique to use in a particular situation, and knowledge from process safety experts is an added-value for addressing this issue.

PHA techniques could be classified into two methods: flexible and rigorous. As far as flexible methods are concerned, there is a lack of formal guidance in order to apply it in a wide range of circumstances. For this reason, guidance for applying these techniques concentrates on providing a description of the technique rather than setting any standards related to the quality of its application. Rigorous methods, being more structured techniques, are defined by their necessity for analyzing more complex facilities.

Checklist

A checklist can be applied during the whole process life-time, from the initial design to the decommissioning. It is easy-to-use, versatile, cost-effective, and able to identify common and customarily-recognized hazards. It provides the simplest of hazard analyses, a technique which uses a list of prepared questions (normally “yes” or “no” answers) about the design and operation of a facility, and is used to identify common hazards. The methodology works well when the process is very stable and no changes are made, but it is not as effective when the process has undergone extensive change. The checklist may miss the most recent changes and consequently the changes would not be evaluated. Therefore, its use is adequate for well-understood systems. Without extensive past experience, careful observation, and documented fault and hazard logs, a checklist would not be soundly based **[9]**. Moreover, its adequacy also depends on the circumstances used to be the same as those in which it was created; if they differ, the checklist could be out-of-date and dangerously misleading. Checklists, even when appropriate, need to be reviewed periodically.

What-If…

What-If… can be applied during the whole process life-time because it is a very flexible tool used in a wide range of circumstances. However, it is one of the least structured hazard identification methods available today. Therefore, its success is highly dependent upon the experience of the hazard identification team. The technique involves personnel brainstorming a series of questions that begin “What if…”. All questions represent a potential failure or misoperation of the facility. The response of the process and/or operators is evaluated to determine if a potential hazard can occur. If so, the adequacy of any existing safeguards is weighed against the likelihood and severity of the potential scenario to determine whether modifications to the system should be recommended.

Furthermore, the success of a “What-If” analysis is highly dependent upon the thoroughness of the "What If" questions posed, a task which at the same time is dynamic: as one question is asked other questions will be generated to the team. These questions should be documented as they occur for later consideration.

The process being analyzed is first broken down into smaller parts (i.e., sub-systems), and for each part, the system drawings and operating procedures are studied and "What If" questions are developed. Hereafter, each sub-system is systematically reviewed, recommendations are identified as appropriate, and assignments are made to be followed up.

Event Tree Analysis

Event Tree Analysis (ETA) is an inductive methodology which uses a graphical representation for describing (i.e., qualitative and quantitative) all possible consequences (e.g., vapor cloud explosion, pool fire) that could occur once an initiating event is being analyzed (e.g., release of a hazardous material). The technique is able to identify the scenario sequence from the cause to the final impacts according to enabling events (e.g., layers of protection) or conditions. Normally, it is conducted after brainstorming hazard identification techniques (e.g., HAZOP), which have identified Loss of Containment scenarios (LOCs) that require further analysis.

Fault Tree Analysis

Fault Tree Analysis (FTA) is a deductive methodology which uses a graphical representation of the combination of faults leading to a predefined undesired event called “Top Event”. The methodology uses Boolean logic gates (i.e., AND, OR) to describe (i.e., qualitatively and quantitatively) how equipment failures and human errors are combined to cause a main system failure. While ETA identifies outcomes from an initiating event (inductive), FTA proceeds in the opposite direction, identifying most of the basic events that could lead to a predetermined outcome (deductive). It allows the analyst to identify preventive and/or protective measures on significant basic causes that could reduce the likelihood of an accident. As in ETAs, it is conducted after brainstorming hazard identification techniques, which may entail further analysis of specific scenarios. Thus, while FTA is useful for identifying the whole set of initiating events that can lead to an undesired outcome (e.g., runaway reaction), it also can provide tools for quantitative data of Top Event frequencies of occurrence.

Failure Modes and Effects Analysis

The Failure Modes and Effects Analysis (FMEA) examines the failure effects of each component of a system. It is a formal technique that identifies and evaluates the significance of the failure, and establishes preliminary recommendations to reduce the likelihood or severity of the failure occurring. As the need for a team is not often emphasized, the method is often carried out by one person. However, an individual lacks the multiple viewpoints required in hazard identification, is subject to the inside view and an “overconfidence bias”, and is unlikely to carry out a thorough investigation. FMEA is also likely to miss hazards that result from the interactions of components rather than from the failure of the components themselves, and hazards are frequent in modern systems, particularly those in which control is provided by software.

Table 01 illustrates the key advantages and disadvantages of the PHA techniques discussed above, which is valuable information for selecting the appropriate technique according to a particular situation.

Table 01: PHA Techniques – Advantages and Disadvantages

PHA	Advantages	Disadvantages
Checklist	Customizable according to individual applications / companies' requirements Straightforward, well-structured, easily understood and consistent technique Useful for standard, repeated, and well-understood operations and processes Less expensive to be applied rather than other time-consuming techniques	Requires considerable expertise and experience from hazard identification team If key questions are missing, hazard may be over-looked Limited usefulness for new systems with lack of previous experience It is as good as knowledge of the compilers at the time
What-If	It can be used at any part of the project lifetime It is simple and relatively quick to be completed It allows the use of imagination and brainstorming in a team-based approach Useful in the early stages to identify major issues for further analysis	Dependent on the leader skills, discussions, imagination and intuition The team may waste time on trivial events or miss important areas if the defined structured questions are not well-thought Qualitative and less detailed results than other techniques Key questions to be taken into account only depend on the leader
FMEA	Able to identify mechanical and electrical equipment failures, and reliability Not difficult to be applied, and the results are easily understood The analysis can highlight both local and general system failures A semi-quantitative ranking of the hazards can be produced	Not effective for identifying combination of failures Concentrates on equipment and does not address operational errors
ETA	Logical graphical description of potential outcomes from initiating events (inductive technique) Structured and methodological technique, yet relatively simple Qualitative and quantitative results can be obtained	Limited to the identification of specific hazards (loss of containment scenarios) Probabilities used in the quantification must be robust and clearly peerless
FTA	Deductive technique able to identify combination of failures, equipment and human errors Logical graphical description of the root causes of a hazard Applicable for estimating plant and equipment availability	It is time-consuming and requires a high degree of experience Each fault tree should refer to a specific problem Results should be conditioned by consequence analysis and risk criteria when addressing major accidents

HAZard & OPerability (HAZOP) Study

A HAZOP study is a highly-disciplined procedure meant to identify how a process may deviate from its design intent. It is defined as the application of a formal, systematic, critical examination of the process and the engineering intentions of new or existing facilities to assess the potential for malfunctioning of individual pieces of equipment and the consequential effects on the facility as a whole. Its success lies in the strength of the methodology in following a system's Piping and Instrumentation Diagrams (P&IDs) and Process Flow Diagrams (PFDs), breaking the design into manageable sections with definite boundaries called nodes, and ensuring the analysis of each piece of equipment in the process. If a small multi-disciplinary team undertakes the analysis, the HAZOP members should have sufficient experience and knowledge to answer most questions on the spot. The members are selected carefully, and are given the authority to recommend any needed changes in the process design.

Executing the method is based on using guidewords (e.g., no, more, less) combined with process parameters (e.g., temperature, flow, pressure) that aim to reveal deviations (e.g., less flow, more temperature) of the process intention or normal operation. This procedure is applied in a particular node as a part of the system characterized for a nominal intention of the operative parameters. Having determined the deviations, the expert team explores their feasible causes and their potential consequences. For every pair of cause-consequence, safeguards must be identified that could prevent, detect, control, or mitigate the hazardous situation. Finally, if the safeguards are insufficient to solve the problem, offering recommendations must be considered.

Table 02 lists the Specific HAZOP Strengths and Weaknesses.

Detailed information on the HAZOP methodology can be found in reference **[1]**.

Table 02: HAZOP Study Strengths and Weaknesses

HAZOP Study Strengths
The method is used to identify hazards and operating problems
Highly structured and formal approach
A wide range of hazards can be assessed (e.g., chemical, mechanical, control
New, novel, and existing processes can be analyzed
The team gains a deep understanding of how the process is likely to operate
Much better operating procedures can be written after the study
Systematically applies guide words and parameters to all process equipment
It examines the consequences of the failure, fact that aids the production of recommendations for risk reduction
HAZOP Study Weaknesses
High resource requirements, both in manpower and data
Time-consuming and expensive, especially in continuous chemical processes which involve a large number of equipment
To fully perform the study the process has to be designed to such a level that P&IDs are available
Additional guide words are required for unusual hazards
The study requires leader judgment and team expertise to identify all possible causes and consequences of the deviations
The results are subject to the analyst’s bias, experience, knowledge, and creativity
HAZOP documentation is not always written in a style to ensure easy reading by external members

Identification of Loss of Containment Scenarios

ioMosaic has developed specific criteria for ensuring a structured and systematic identification of Loss of Containment scenarios (LOCs), which are the basis for performing risk-based assessments such as a Quantitative Risk Assessment (QRA). LOCs are focused on fixed installations (i.e., process equipment and pipelines) and transport units (i.e., trucks, ships, and trains). Additionally, the hazard identification stage not only has to address LOCs of hazardous materials (i.e., toxic, flammable, reactive), but also has to take into account potential dust explosions in units intended to handle/process combustible dusts in a case-by-case basis. Process equipment and operations, interconnecting piping (both above and underground), and pipe racks have to be included in the scope of the LOCs identification.

As the foundation of a risk-based approach intended to quantitatively analyze the risk level of a given facility, the identification of LOCs can be considered the foundation of the entire assessment. With the aim to ensure completeness and thorough identification, it is necessary to split the LOCs into two categories:

- Generic: based on catastrophic failures and different leak sizes of process equipment. While the defined leak sizes, catastrophic failures, and process equipment to be considered can vary according to the criteria to be followed, all generic LOCs to be identified are simply a function of the equipment process type. Thus, generic LOCs can be identified via an inductive systematic approach ensuring that all pieces of equipment will be evaluated.

- Specific: based on process deviations caused by equipment and instrumentation failures, human errors, or external events that can lead major accidents. The identification of specific LOCs should be based on hazardous scenarios identified during the execution of PHAs.

The minimum required sources of information for the identification of generic and specific LOCs are listed in **Table 03**. Additional information would be required depending on the process nature and main purpose of the analysis.

Table 03: Sources of Information for Identifying LOCs

Input Data	Comments
Facility Plot Plan	Identification of the location of process equipment that may entail LOCs. Additionally, identification of congested areas, ignition sources, facility workforce, buildings and key critical equipment, and public areas at the vicinity of the facility.
Process Flow Diagrams	Summary of the major process equipment involved in the facility under analysis. Process Flow Diagrams (PFDs) are useful for defining the “Principal Sections” which are intended to segregate the facility under analysis into smaller and more manageable sections to be analyzed.
Piping & Instrumentation Diagrams	Detailed information of all process equipment conforming the facility under analysis. Piping & Instrumentation Diagrams (P&IDs) are useful for identifying process equipment, dimensions, liquid inventories, and available instrumentation which help on the identification of LOCs and the subsequent consequence modeling
Heat & Mass Balances	Detailed information of all process streams providing process conditions and mixture compositions. Heat & Material Balance (H&MB) is useful for ensuring that a hazardous LOC has to be considered if sources of hazardous materials or energy are evidenced from streams information
Material Safety Data Sheets	Material Safety Data Sheets (MSDSs) provide key information on basic physical and thermodynamic properties of chemicals; furthermore, these also provide valuable information on hazard classification; e.g., toxicity, flammability, reactivity.
Previous PHAs and Process Procedures	Information collected in previous PHAs (e.g., HAZOP) is valuable for identifying specific LOCs to be considered for a quantitative risk-based analysis. Scenarios such as overfilling a storage tank during the loading operation, or a runaway reaction due to a human error are examples of specific LOCs to be considered.

LOCs Identification Procedure

Selection of Principal Sections

It is impracticable to manage all the information contained in P&IDs because doing so would over-look potential hazardous scenarios. Conversely, by breaking the process into very small sections, the identification procedure would become extremely time-consuming, and the general picture of the process would be more difficult to comprehend. Thus, the process has to be broken into manageable sections by optimizing the time allotted for their review and ensuring identification of most of the potential hazardous scenarios.

Complex chemical processes involve a wide range of equipment, instrumentation, utilities, and further devices all interconnected via complex schemes thereby assuring fulfillment of the main design intent. However, this intent is susceptible to disruption by grouping specific equipment that share a same sub-aim or intention (e.g., equipment for distilling a mixture of products, equipment for pre-heating a certain feed before starting to operate a specific unit operation). Therefore, it is recommended to distinguish the sub-aim intentions from the main process-design intent. The selection of principal sections attempts to identify a group of lines and equipment suitable to review together because they share the same design intent. Considering a well-grouped set of process items as a principal section, the hazard identification procedure will be faster and more reliable without losing the desired level of detail. The principal sections are addressed as encompassing a wide variety and large number of equipment that are involved in achieving a sub-aim, contributing to the overall design intention of the process. Therefore, these principal sections will be marked on PFDs, diagrams that graphically provide the following details:

- How the principal sections are connected. It is important to be aware of which equipment share the principal section’s boundaries (e.g., control valves, pumps).
- Which major equipment is involved, ensuring all pieces of equipment to be analyzed within the defined principal section.

Figure 02 shows an example of selected principal sections for a given process unit.

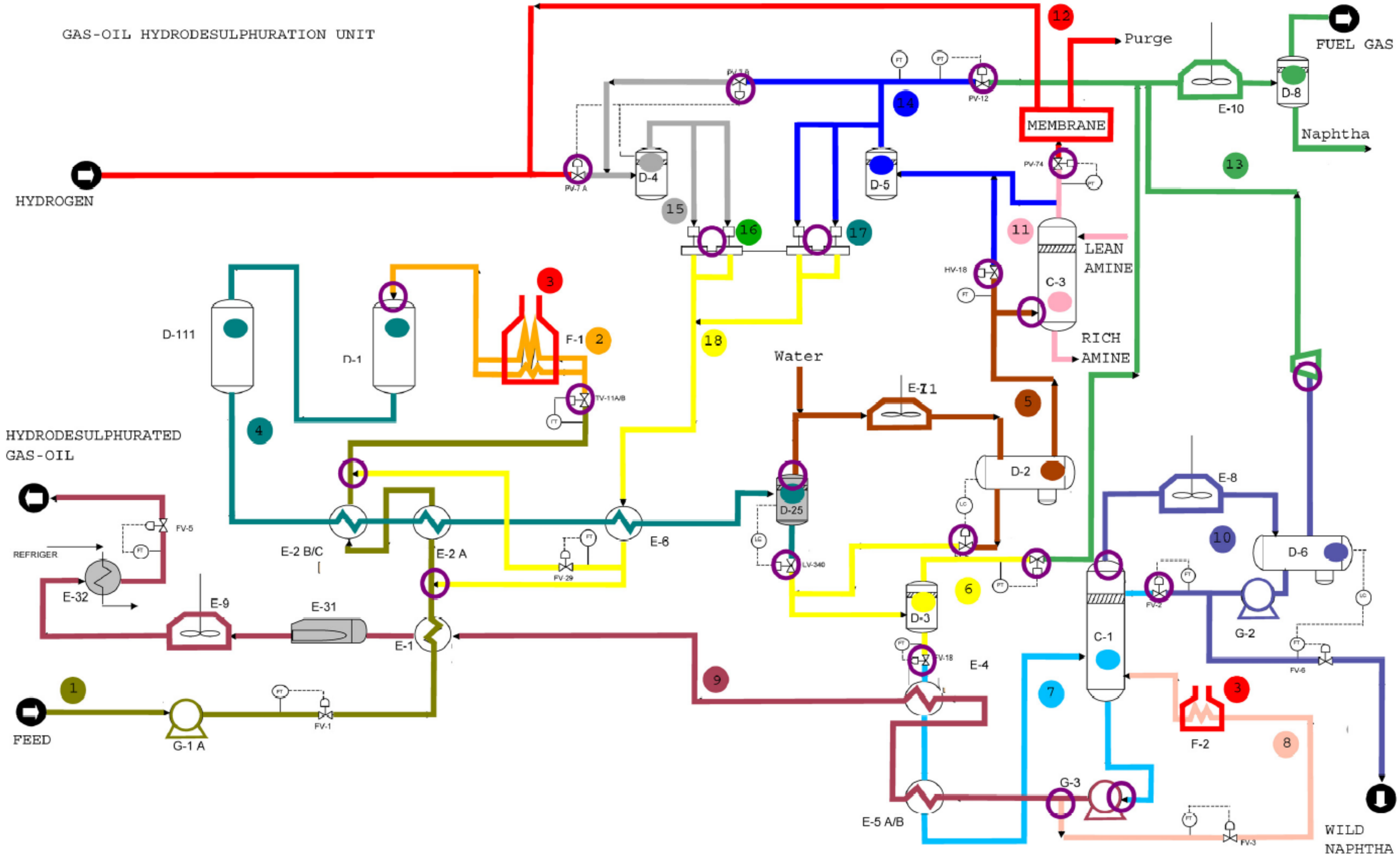

Figure 02: Example of Principal Sections Selection

Identification of LOCs entails to review P&IDs. The last step for acquiring definite principal sections is to transfer the process equipment included in a principal section highlighted in PFDs to P&IDs. Therefore, after selecting the preliminary principal section and detecting its boundary items, the involved equipment should be identified in the corresponding P&IDs. Thereafter, the identification of each piece of equipment and associated generic LOCs are identified per principal section selected. The same procedure will be repeated iteratively per all principal sections considered. Note that additional equipment and control loops will be involved during the transfer procedure from PFDs to P&IDs. It is important to include all this additional equipment and instrumentation when reviewing the P&IDs for LOCs identification.

Definition of Generic LOCs

Generic LOCs are a function of the type of process equipment identified during the P&IDs review after selection of principal sections. Different worldwide recognized standards and guidelines are available for the definition of generic LOCs. While each standard or guideline proposes specific criteria to be considered, it is possible to confirm that most of them account for three or four LOCs. The approach is to consider the following LOCs per type of process equipment: a catastrophic failure of the equipment and different leak sizes in equipment; e.g., major, medium, and small. **Table 04** lists some of the well-known references that address LOCs identification and the associated frequency of occurrence. **Table 05** provides an example of LOCs considered for references **[15]**, **[16]**, and **[17]** for a given pressure vessel.

Table 04: Information to be Gathered When Identifying LOCs

Reference
Guidelines for Quantitative Risk Assessment “CPR-18E; Purple Book” **[15]**
Risk Based Inspection Technology “API RP 581” **[16]**
Failure Rate and Event Data for use with Risk Assessment “UK HSE” **[17]**
Risk Assessment Data Directory; Storage incident frequencies “OGP” **[18]**
Offshore and Onshore Reliability Data (OREDA) **[19]**

Table 05: Example of LOCs for a Process Vessel

Reference	Type of Release	Meaning
CPR-18E **[15]**	Instantaneous release of the complete inventory	Catastrophic Failure
	Continuous release of the complete inventory in 10 minutes at a constant release rate	Major Leak
	Continuous release from a hole with an effective diameter of 10 mm	Minor Leak
API RP 581 **[16]**	Catastrophic failure of the equipment	Catastrophic Failure
	Release from a hole with an effective diameter of 4 inches (101.6 mm)	Major Leak
	Release from a hole with an effective diameter of 1 inch (25.4 mm)	Medium Leak
	Release from a hole with an effective diameter of 0.25 inches (6.35 mm)	Minor Leak
UK HSE **[17]**	Catastrophic failure of the equipment	Catastrophic Failure
	Release from a hole with an effective diameter of 50 mm	Major Leak
	Release from a hole with an effective diameter of 25 mm	Medium Leak
	Release from a hole with an effective diameter of 13 mm	Medium-Minor Leak
	Release from a hole with an effective diameter of 6 mm	Minor Leak

*****Note that PHAGlobal® **[11]** contains knowledge and criteria from references cited in **Table 06**, including the associated frequencies of occurrence of LOCs. The frequency analysis step is fully addressed in reference **[13]**.

Definition of Specific LOCs

Identification of specific LOCs requires expertise and judgement for ensuring a credible and reliable characterization of hazardous scenarios to be addressed. Valuable information on LOCs to be taken into account for a risk-based quantitative analysis can be found in previous PHA studies conducted in the facility under analysis. Therefore, it is important to have access to these mentioned PHA studies, and review the contents for the inclusion of specific LOCs. Furthermore, if considered necessary due to missing available information, a team-based approach identification analysis should be proposed for ensuring the identification of potential specific LOCs. The evaluation of specific LOCs usually is detailed, and it requires experience; i.e., each potential scenario is analyzed individually and evaluated in a case-by-case basis. Examples of specific LOCs are the following: overfilling a vessel, runaway reaction, overpressure contingency due to a failure of a control valve or a manual blocked outlet. Additionally, another typology of specific LOCs that contribute to the risk level of a facility under analysis are dust explosions, and for this reason those have also to be addressed for a complete risk-based quantitative assessment.

Further information related to specific LOCs can be found in reference **[14]**.

Addressing Dust Explosions

Any solid material that can burn in air will do so with a violence and speed that increases with increasing degree of subdivision of the material. The smaller the particle size, the greater the combustion rate because the total contact surface area between the combustible dust and air increases. Potential dust explosions are considered if all the following conditions are present at the same time: (1) combustible dust with small particles of sizes on the order of 0.1 mm or less, (2) particles were suspended in a sufficiently large volume of air to give each particle enough space for its unrestricted burning, and (3) presence of an ignition source.

Collection of Most Relevant Information

When reviewing and identifying the process equipment via P&IDs involved in a selected principal section able to entail a hazardous scenario; i.e., a release of a hazardous material, it is a good practice to collect the most relevant information required for the related consequence modeling. Therefore, the identification of LOCs associated to the type of equipment is performed, and also the following key information listed in **Table 06** should be collected mainly from P&IDs, Plot Plan, and Heat and Material Balance (H&MB).

ioMosaic has developed a PHA software tool called PHAGlobal® **[11]**, an element of ioMosaic's Process Safety Office™ suite which helps conduct PHA studies in an efficient and reliable way.

PHAGlobal® **[11]** includes templates for performing HAZOP studies, What-if, and other PHA techniques, and also includes a dedicated template intended to speed-up the identification of LOCs to be accounted for in a detailed risk-based analysis. The template incorporates all potential parameters and an extensive database of process equipment types with associated LOCs from several applicable worldwide recognized references. Furthermore, PHAGlobal® **[11]** includes two key added-value characteristics:

- Advanced reporting capabilities for compliance with regulatory requirements;
- Automatic transfer of LOCs from PHAGlobal® **[11]** to SuperChems™ **[12]**, software tool which is used for the next risk-based approach step; i.e., consequence modeling.

Table 06: Information to be Gathered When Identifying LOCs

Process Equipment	**Comments**
Type	Type of process equipment; e.g., heat exchanger, reactor, column
ID	Equipment tag number
Orientation	Equipment orientation; i.e., vertical or horizontal
Length	Equipment length
Diameter	Equipment diameter
Volume	Equipment volume
Liquid Level	Normal or high liquid level depending on study criteria
Pipeline	**Comments**
Stream Number	Stream number based on PFD or H&MB
Diameter	Piping diameter
Length	Piping length
Pump/Compressor	**Comments**
Type	Type of pump or compressor; e.g., reciprocal, centrifugal
ID	Pump or compressor tag number
Capacity	Pump or compressor capacity
Mixture	**Comments**
Mixture Composition	Mixture composition based on heat and material balance
Hazardous Mixture Nature	Mixture Hazardous Classification: Flammable and/or Toxic
Chemical Reactivity	Parameter based on *****Baker-Strehlow method
Release	**Comments**
Release Coordinates	Location of the release in the plot plan
Release Angle	Angle respect to horizontal
Release Elevation	Equipment elevation above ground level
Release Geometry	Parameter based on *****Baker-Strehlow method
Degree of Confinement	Parameter based on *****Baker-Strehlow method
Detection System Type	Type of detection system; e.g., automatic, manual
Isolation System Type	Type of isolation system; e.g., automatic, manual

***Baker-Strehlow Method (BSM)**: criteria intended to address Vapor Cloud Explosions by correlating flame speed with chemical reactivity, degree of confinement, and release geometry. BSM is out of the scope of this paper, and further information can be found in reference **[13]**.

Naming Identified LOCs

The LOCs identification procedure has to ensure a structured naming convention. If a risk-based quantitative assessment is intended to be conducted, for example, for an entire process facility, the total number of LOCs to be identified can be huge. Accordingly, it is very important to ensure coherence when naming these LOCs, and a well-though naming convention is key for statistical analysis, and identification of LOCs risk contribution in subsequent phases of the risk-based quantitative assessment development. ioMosaic uses code naming capable of explaining by itself the meaning of all LOCs characteristics. **Table 07** lists the meaning of the LOC code naming, and **Table 08** lists several examples.

Table 07: LOC Code Naming Definition

LOC Code Naming
FACILITY.UNIT_NUMBER.LOC_NUMBER. LOC_TYPE.EQUIPMENT_ID.HOLE_SIZE

Parameter	Description
FACILITY	Facility under analysis
UNIT_NUMBER	Process unit under analysis
LOC_NUMBER	Sequential number that counts the number of LOCs defined in a given process unit; e.g., 1 means that this is the first LOC considered in the process unit under analysis, 2 means that this is the second LOC considered, etc.
LOC_TYPE	type of LOC; i.e., Generic (G) or Specific (S)
EQUIPMENT_ID	process equipment tag number; e.g., P-11-105A/B; E-11-101A-C. Note that for pipelines the naming convention is defined as follows: S.XXX, where S stands for SEGMENT, and XXX stands for the stream number based on the Heat and Material Balance or Process Flow Diagram.
HOLE_SIZE	size of the hole defined for characterizing the leak; i.e., XXX MM (X millimeters), and CF (Catastrophic Failure based on equipment outside diameter)

Table 08: Examples of LOCs Code Naming

Example	Description
ABC.U11.2.G.E-11-101A-B.CF	Generic Loss Of Containment Scenario identified in process unit 11 of the ABC facility which considers a catastrophic failure in the heat exchanger system E-11-101A-C. The number 2 confirms that this scenario is the 2nd LOC considered in unit 11.
ABC.U11.44.G.P-11-105A/B.100MM	Generic Loss Of Containment Scenario identified in process unit 11 of the ABC facility which considers a release from a 100 mm hole in the pump system P-11-105A/B. The number 44 confirms that this scenario is the 44th LOC considered in unit 11.
ABC.U11.45.G.S.20A.450MM	Generic Loss Of Containment identified in process unit 11 of the ABC facility which considers a release from a 450 mm hole in a pipeline segment (stream number 20A). The number 45 confirms that scenario is the 45th LOC considered in unit 11.

Conclusions

PHA techniques are tools to guide responsible parties to identify what can go wrong; i.e., finding causes or operating problems for deciding what actions to take to prevent them. Their ultimate aim is to avoid injuries or death of workers and/or the public, environmental impacts, and economic losses. The hazard identification stage is reinforced based on using PHA techniques in a team-based approach; i.e., multi-disciplinary knowledge will ensure a more thorough analysis, which can be defined based on the following sentence: “two minds are better than one”. This approach is especially important when identifying specific loss of containment scenarios during the development of a risk-based quantitative assessment.

All phases during the development of a risk-based quantitative assessment are important. However, the authors consider that hazard identification is a key step; a discipline that “establishes the game rules” and can be considered as the foundation for risk management; i.e., if a hazardous scenario is ignored, it will not be evaluated, directly affecting risk estimation results for realistic decision-making. The present paper provides guidance and criteria for maximizing the identification of both generic and specific Loss of Containment scenarios (LOCs) with potential contribution to the risk level of a given facility.

Based on the contents illustrated in this manuscript, a HAZard & OPerability (HAZOP) study is considered one of the most structured and worldwide recognized PHA techniques. Trevor A. Kletz, one of the founders of process safety and loss prevention wrote:

> “*Learning from experience is a lantern on the stern, illuminating the hazards the ship has passed through. It is essential to do so as we may come the same way again. However, we should also have a lantern on the bow, so that we can see the hazards that lie ahead…*
>
> *…HAZOP is a lantern on the bow*”

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