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Application of the Process Safety Management Standard in Canada

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Introduction

In the early morning hours of December 03, 1984, over forty (40) tonnes of methyl isocyanate (MIC) leaked from the Union Carbide India plant in Bhopal, India. More than 3000 people immediately perished from the accidental release of highly toxic MIC gas, and an additional 15 000 deaths, along with numerous health-related claims, were attributed to this event.

On July 06, 1988, the Piper Alpha oil production platform, operating in the North Sea, suffered a series of explosions that led to an uncontrollable fire that engulfed the platform and claimed the lives of 167 crewmembers. A leak of natural gas condensate, which had built up beneath the platform was deemed to be the cause of the first explosion that eventually led to the demise and sinking of the platform. Like the Bhopal, India catastrophe, the sudden and unexpected release of a highly hazardous substance initiated a series of events that led to a significant loss of life and assets.

These are only two examples of the disasters that have plagued the evolution of industrial processing and manufacturing. While there have been significant advances in technology and control systems, the opportunity for these situations to be repeated continue to exist in the 21st century. It has been recognized that to prevent these critical loss occurrences a systematic approach towards hazard identification and risk analysis is also needed.

In 1992, the Occupational Safety and Health Administration (OSHA) formally recognized this vital component for managing high hazard chemical processes within the United States. A company that is involved in high hazard chemical processes or activities is mandated to implement a process safety management system. This system must include the systematic identification of hazards, risk level, and control strategies or corrective actions needed to prevent and/or minimize the consequences of a hazardous substance release. These requirements are defined by the Process Safety Management (PSM) of Highly Hazardous Chemicals, Explosives and Blasting Agents standard; OSHA 29 CFR 1910.119.

Process Safety Management

Process Hazard Management is also called Safety Systems Management or Process Safety Management. Regardless of the terminology, these are all systems that have been developed to

manage the risk to personnel, property, production, the environment and ultimately, the company reputation. The occurrence of major industrial accidents and subsequent implementation of forceful safety and environmental legislation in many countries has made the Process Safety Management (PSM) or Process Hazard Management program an industry standard. The Process Safety Management (PSM) standard (OHSA 29- Part 1910.119) is the regulatory framework for process industries in the USA and is quickly becoming the industry " best practices" standard for responsible companies worldwide. American Petroleum Institute (API) Recommended Practice 750-1990, is the recommended standard for Canadian process industries and includes similar considerations for a PSM program and PHA evaluation.

The main objective of process safety management, as defined by OSHA 29 - Part 1910.119, is to prevent the release of highly hazardous chemicals, such as toxic, reactive, flammable, and/or explosive substances, and subsequent exposure of people to the hazards associated with these substances. This is especially critical in densely populated areas or locations. Specific processes that should be evaluated through a formal PSM program include:

- Manufacturing, keeping, having, storage, sale, transportation, and use of explosives, blasting agents and pyrotechnics;
- A process that involves a chemical at or above the specified threshold quantity listed in Appendix A of the OSHA PSM regulation;
- A process that involves a flammable liquid or gas (as defined by 1910.1200(c)) at one location of one site in excess of 10 000 pounds (4535.9 kg) or more; [1]

Management commitment, process safety information and hazard identification are the core elements in a successful safety management program. To have an effective Process Safety Management Program, however, requires a systematic evaluation of the whole process. Using this approach, the process design, process technology, operational, maintenance and emergency activities and procedures, training programs, incident investigation and regular audits need to be considered. The methods that can help a company achieve this rigorous evaluation activity are often referred to as a Process Hazard Analysis (PHA) study. The PHA study can be used to identify hazards, risk level and control strategies for different levels, both macro and microanalysis, within the process. The results of these studies can then be incorporated into the PSM program, which provides ongoing management of hazards in a facility.

The Process Hazard Analysis (PHA)

Process Hazard Analysis is the foundation of any Process Safety Management Program. The Hazard and Operability (HAZOP) method was the first formal PHA developed and used by ICI in the UK over thirty years ago. Other methods soon followed as companies became increasingly aware that operating a safe facility meant operating a more profitable business. Using the PHA process, and associated methods, can help a company obtain the information necessary to make operating decisions that will manage the risk, and improve the safety, of their operations.

PHA focuses on identifying the potential causes, likelihood and consequences of process accidents by combining the experience, knowledge and intuitive imaginations of expert team members using a selected analytical methodology. Exhibit 1 depicts this structure.

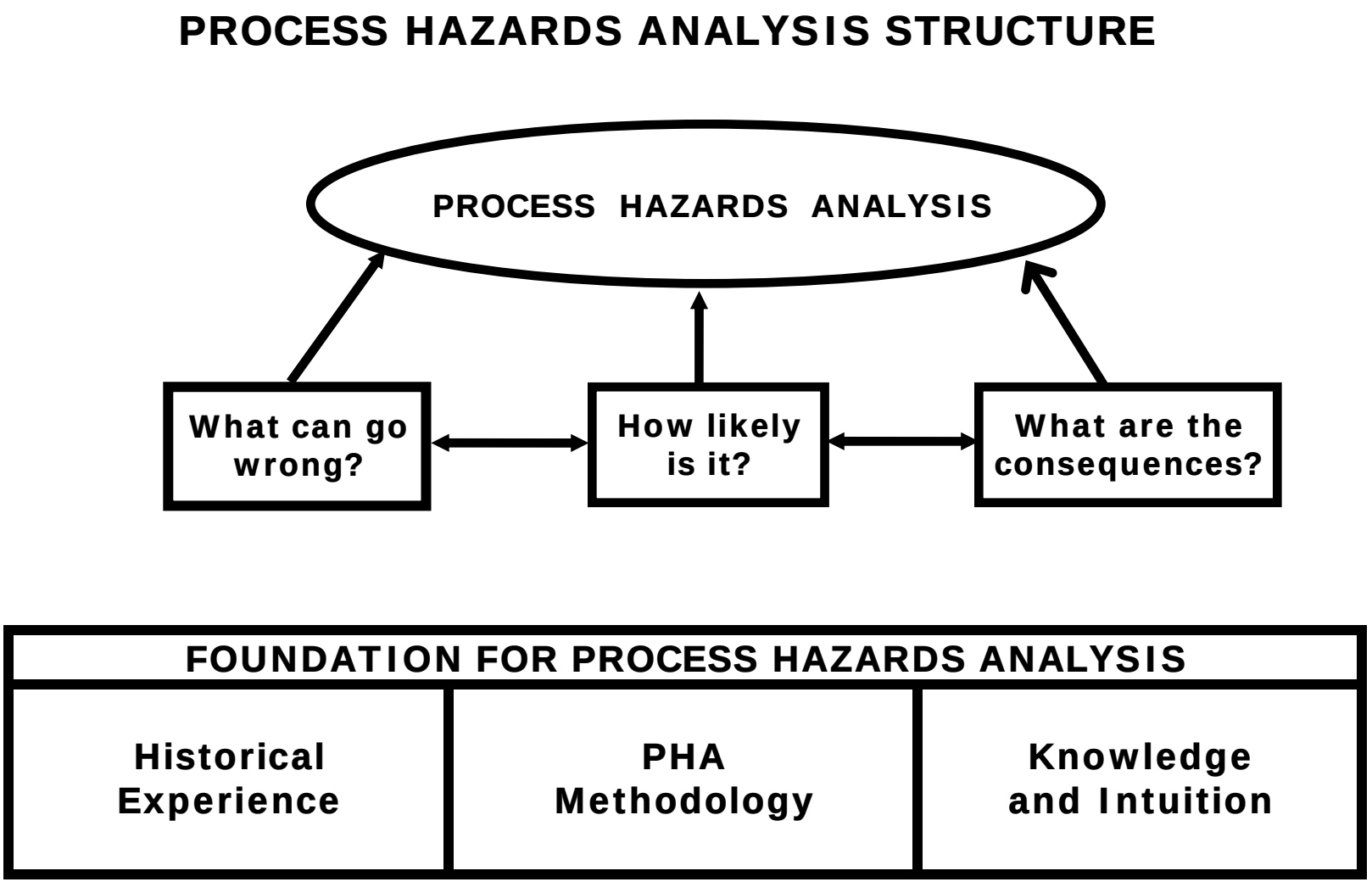

Exhibit 1. The Process Hazards Analysis Structure.[2]

There are a variety of hazard identification methodologies that provide flexibility in meeting the scope and objectives of a process evaluation. These may include a general system analysis (Preliminary Hazard Analysis, HAZID, What-IF/Checklist), a detailed process or sub-system evaluation (HAZOP, FMEA/FMECA, FTA), a consequence analysis (HAZAN) and/or a predictive assessment of safety-related system performance (SILS, LOPA). A PHA study should be conducted several times during a facility's design, construction and operating life cycle. The recent availability of sophisticated PHA or Risk assessment software has provided many companies, who previously lacked the resources or time needed to conduct a thorough PHA study, with the ability to complete an efficient and effective PHA study of their processes.

Quantitative and Qualitative Risk Analysis

Process Hazards Analysis is the predictive identification of hazards, their cause and consequence, and the ***qualitative*** estimation of likelihood and severity, followed by recommendations for improvement of the hazardous situation. **Risk Analysis** provides a statistically based quantitative assessment of the probability and consequence of identified hazards as compared to the quantified cost of prevention or mitigation.

When is PHA Performed (Qualitative)?

Hazards, and the problems that could prevent efficient operation, are identified first and may occur:

- When process, material, worksite and human interactions occur;
- During start-up, shut down, maintenance and normal operations;
- When a change occurs to any of the above.

Hazard identification should be performed:

- At conceptual stage to identify the potential for major hazards.
- At pre-construction design stage to minimize the cost of design changes.
- At pre-start-up to ensure a smooth, less expensive start-up.
- Before modifications to ensure safety compatibility with design intent.
- At decommissioning and demolition to provide hazards information for effective planning.

To identify ways to eliminate or reduce the frequency and consequences of process accidents it is also essential to understand what can occur, how it can occur and what consequences may be expected. A critical sequence of events (critical path), along with inappropriate human responses to those events, can create the opportunity for an accident or loss to occur. Each event in the sequence presents the opportunity to avert the accident sequence or to mitigate the severity of the outcome. A direct relationship usually exists between the magnitude of hazard potential and the severity of an accident. Experience, human intuition and knowledge combined with appropriate hazard identification and evaluation technique is the basis for assessing the significance of hazard potential.

When is Risk Analysis Performed (Quantitative)?

Risk Analysis is used selectively AFTER hazards have been identified to weigh the resources required to improve or resolved the situation as compared to the probability and consequences of an accident. They are performed if the potential exists for a catastrophic accident, or if there is no easy and obvious solution for avoiding or removing an identified hazard. Refer to Table 1 for comparison.

PROCESS HAZARDS ANALYSIS	RISK ANALYSIS
IDENTIFIES HAZARDS, estimates likelihood and severity, suggests improvements.	**ASSESSES HAZARDS**
USE ON EVERY PROJECT	**SELECTIVE** - use when other methods prove inadequate or excessively costly.
QUALITATIVE - based on experience, knowledge and creative thinking.	**QUANTITATIVE** - requires extensive data and special expertise.
Most often done by **MULTIDISCIPLINARY TEAM**	Done by **ONE OR TWO SPECIALLY TRAINED PEOPLE**
Several methodologies available • **What-if** • **What-if/Checklist** • **HAZOP** • **FMEA** • **Preliminary Hazards Analysis**	Also called: • **Hazan** • **Risk Assessment** • **Probabilistic Risk Assessment (PRA)** • **Quantitative Risk Assessment (QRA**)

Table 1. Process Hazard and Risk Analysis Compared.[3]

To conduct a thorough Risk Analysis, special expertise may be required along with extensive and current data, which is subject to uncertainties and is often incomplete. This has led to the use of **qualitative** PHA methods for most hazard potential assessments.

Elements of Facility Risk

A process that is regulated by the OSHA PSM standard (1910.119) must be evaluated to determine the hazards, and risk, that may occur if there is a hazardous chemical release. This requirement is also part of American Petroleum Institute (API) Recommended Practice 750- 1990, the recommended standard for Canadian process industries. To meet these requirements, a systematic approach that considers the process components listed below should be used. These components are:

- Process Design;
- Process Technology;
- Operational and Maintenance activities and procedures;
- Non routine activities and procedures;
- Emergency Preparedness plans and procedures;
- Training Programs;
- And other elements that may impact the process.

Within these process components are the basic sources of Facility or Process Risk that can contribute to the occurrence of a hazardous chemical release. The main hazard/risk sources are Process, Human, Site/Location and the Environment. [4]

Process Hazards

Process hazards are a combination of hazardous materials and the process conditions under which they are handled.

HAZARDOUS MATERIALS	+	PROCESS CONDITIONS
Flammable materials		High temperatures
Combustible materials		Extremely low temperatures
Unstable materials		High pressures
Reactive materials		Vacuum
Corrosive materials		Pressure cycling
Asphyxiates		Temperature cycling
Shock-sensitive materials		Vibration/liquid hammering
Highly reactive materials		Rotating equipment
Toxic materials		Ionizing radiation
Inert gases		High voltage/current
Combustible dusts		Erosion/Corrosion
		Material transfer/exchange

Table 2. The creation of Process Hazards.[4]

Human Factors or Errors

Human error is viewed as the incompatibility of task demands and human factors, such as emotional, mental and physical capabilities. Human factors can interact with other facility hazards, and these have led to human errors that have been the major cause of many of the catastrophic accidents in the chemical process industry. There are 2 basic types of errors that occur:

1. **ACTIVE HUMAN ERROR** has an immediate and direct effect on the cause of a hazardous situation or is the direct initiator of a chain of events, which leads to an accident.

2. **LATENT HUMAN ERROR** is different in that the consequences of the error may only become dynamic after a period of time when the condition caused by the original error combines with other errors or system failures to bring about unsafe conditions.

Latent human error is of the greatest concern for Process Hazards Analysis teams. Most latent human errors occur at the engineering design or at management policy level. It is at the engineering design level that PHA study teams must be most vigilant. For instance, inappropriate design for valve placement or inadequate space allowed for worker movement in attending to routine inspections and maintenance will increase the probability of human errors, and subsequently, loss occurrences.

Human error can have an immediate and significant impact on profitability through losses and lower quality product. The potential for these errors is either exacerbated or mitigated by the corporate culture and its management systems. Human errors can be reduced if the workplace and the tasks within it are designed with consideration for the needs and capabilities of those who will interact with this worksite or facility.

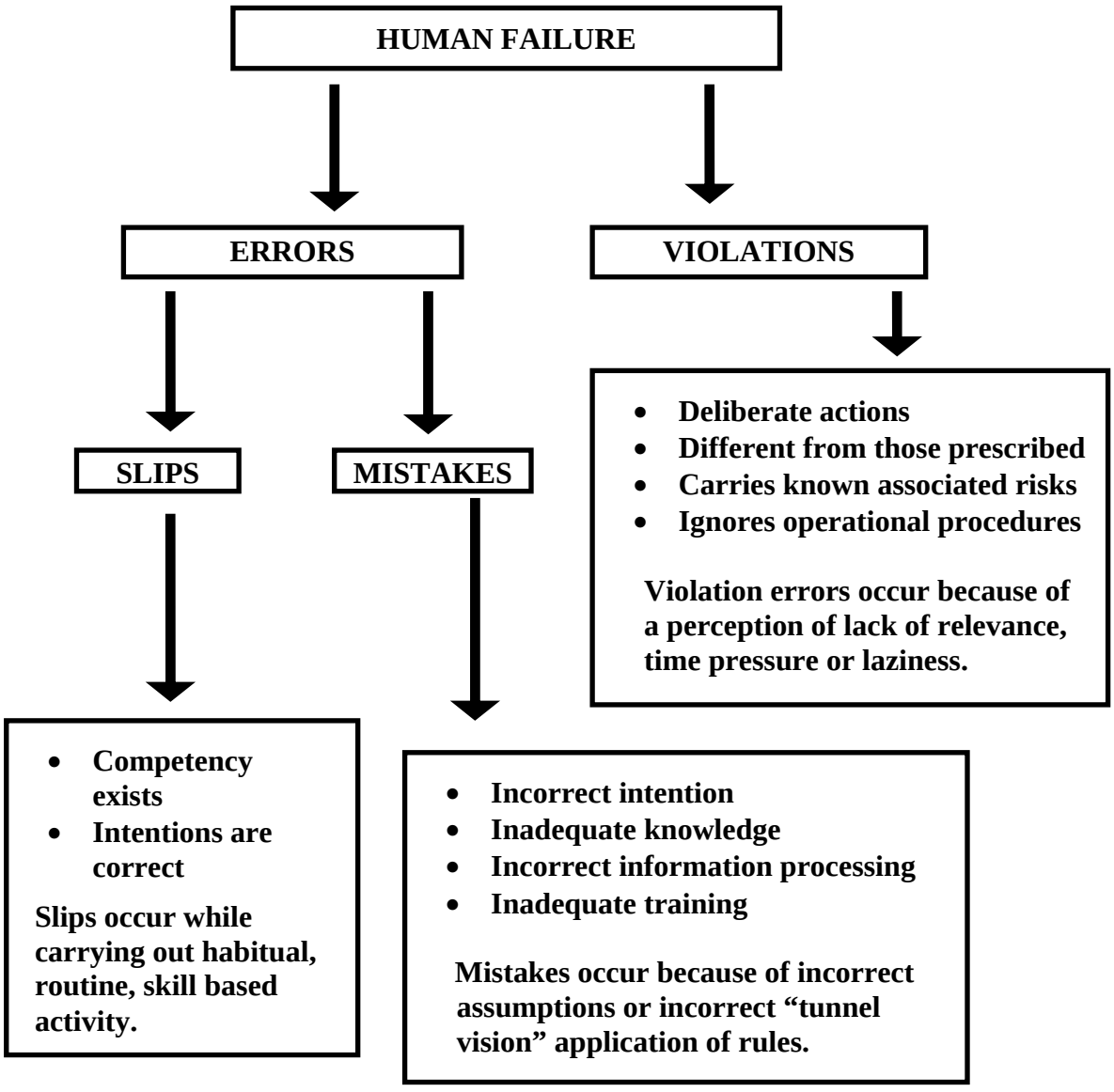

Exhibit 2. The Path and Scope of Human Error. [4]

Site or Location Hazards

Site or Location hazards include the physical site of the facility, and the location and layout of equipment and buildings. "Siting" issues are considered in relation to the people who occupy the site for any length of time and the geographic and environmental implications. In a PHA study, site hazards are also interested in the location of hazardous material processing and storage.

Site/Location issues can be incorporated into a general PHA, or for a large complex facility, "Siting" can be the subject of its own specialised PHA. Site, layout and location issues or hazards should be reviewed and addressed in every PHA study; examples of these considerations are listed below. Site Selection Considerations **are generally considered at the conceptual stage of the facility lifecycle and may include:**

- adjacent facilities
- nearby communities
- transport availability
- availability of utilities (i.e. power and water)
- topography and average weather conditions
- environmental sensitivity

Layout Considerations should be considered during the design stage of the facility lifecycle, but may be modified during and after construction. To determine the layout of a facility, review:

- Industry and insurance guidelines and statutory regulations;
- Process materials being handled or stored (inherent properties);
- Extremity of physical process conditions;
- Location and spacing of process plant buildings and equipment to provide access for routine operation and emergency services;
- Location and spacing of process plant buildings and equipment to ensure safe distances from process and storage of hazardous chemicals;
- Buffer zones between hazardous material storage and extreme processes to reduce potential for domino effects;
- Building design and construction standards to withstand the intrusion of fire, explosion and toxic effects;
- Occupancy level of areas in proximity to process units and material storage.

Environmental Issues

Both on and off-site contamination of the following components of the environment should be considered.

- Ground water contamination and/ or contaminated surface water run-off
- Soil contamination
- Plant life destruction
- Food chain effects
- Air quality and ozone depletion

Environmental impacts to the "living" environment must also be considered.

"LIVING" ENVIRONMENT	POTENTIAL IMPACTS
Human impacts: Chronic and acute exposure to toxic materials through contaminated drinking water, agricultural products and air	• Allergies • Eye irritation • Lung damage • Genetic mutations • Poisoning
Wildlife impacts:	• Migratory routes • Critical habitats for endangered species • Genetic mutations
Domestic Animal Impacts:	• Contamination of feed and water • Genetic mutations • Poisoning • Impact on agriculture and food supply
Micro/Macro biological Impacts:	• Ecosystems • Food chain • Surface and ground water • Air quality • Eradication of species

Table 3. A partial list of potential "Living Environment" impacts due to chemical contamination. [4]

To assist the PHA team in determining the "Elements/ Sources of Facility or Process Risk" in a timely manner, a standard deviation list may be used to focus the team on common deficiencies or deviations that can occur in a process. A sample deviation list that has been used in HAZOP, and other PHA studies, is provided in Table 4 below.

#	***DEVIATION***	***MEANING***
1.	Low / No Flow	Reduction / partial or total loss of flow. Ex. Valve closed.
2.	High Flow	Excessive Flow. Ex. Control valve malfunction.

#	*DEVIATION*	*MEANING*
3.	Reverse / Misdirected Flow	Process stream not following primary path.
4.	Leak / Rupture	Leak - minor leak Ex. - Flange leak. Ex. Rupture - exchanger tube ruptures.
5.	Loss of Containment	Serious facility leak. Ex. Storage tank leaks - are adequate dykes and berms in place?
6.	Hydraulic Surge	Pressure wave. Ex. - Water Hammer. Consider high flow.
7.	High Pressure	Above design pressure or MAWP.
8.	Low Pressure	Below operating pressure. Ex. Pump failure.
9.	Vacuum	Condensing of gases, loss of liquid level. Ex. Maintenance - steaming of vessels.
10.	HP / LP Interface Pressure	Introduction of high pressure into a low pressure system. Ex. DP across control valve when flow on one side is 600 psig and flow on other side is 900 psig.
11.	High Temperature	Higher than design temperature. Ex. Temperature control valve failure.

Table 4. A partial list of the 35 Deviations used during PHA studies.[5]

The PHA study should be performed by a team of specialists in the field or processes being assessed and led by a person knowledgeable in the PHA technique being used. A typical team consists of an experienced PHA Facilitator and team representatives who have expertise in Process Engineering, Electrical, Instrumentation, Maintenance, Operations, Safety/Loss Prevention and Inspections/Materials.

PHA Methodologies

There are a variety of methods that can be used to conduct a Process Hazard Analysis. The most common of these methodologies include:

1.) Hazard and Operability Study;
2.) What-If, Checklist or What-If / Checklist;
3.) Failure Mode and Effects Analysis (FMEA);
4.) Fault Tree Analysis; or
5.) An appropriate equivalent methodology.

Hazard and Operability Study (HAZOP)

The HAZOP technique provides a means of systematically reviewing the design and operability of a system to identify potential hazards and/or operability problems. The technique involves structured brainstorming, using guidewords describing the appropriate parameters of various pieces of equipment and lines, to find deviations from design intent and normal process conditions. The objectives of a HAZOP study are:

- To review the process, layout, design, materials, conditions and operating philosophy of the management/ engineering group with the intent of ensuring it would be safe to operate and have minimal downtime, low operating costs and minimal impact on the environment.
- To develop recommendations to minimize the likelihood and severity of the consequences of significant hazards.
- To consider factors that would promote maintainability and minimize turnarounds where feasible, as well as identify changes to the process that could improve quality, operability and/or efficiency.

The study begins by defining the ***Node(s)*** which are locations on a process diagram (usually a P&ID) at which process parameters are investigated for deviations from identified design intents. Nodes are usually pipe sections or vessels/equipment. Each node is reviewed against a defined set of parameters and deviations. A ***Parameter*** describes what is happening in the process, physically, chemically, or in other engineering/operational terms. Parameters are usually classified as specific or general. Specific parameters are those that describe physical aspects of the process. General parameters are those that describe aspects of design intent remaining after the specific parameters have been addressed. Common parameters that are used in a HAZOP study include:

1.) SPECIFIC: Flow, Temperature, Pressure, Composition, Phase, Level
2.) GENERAL: Siting, Testing, Maintenance, Contamination, Sampling, Corrosion/Erosion, Safety, Sources of Ignition, Accessibility/Visibility, Concerns and Comments

A guideword or phrase is also used to qualify or quantify the intention and associated parameters in order to discover deviations. There are eight standard guidewords:

Guideword	**Meaning**
No	Negation of the design intent
More	Quantitative increase
Less	Quantitative decrease
As Well As	Qualitative increase
Part of	Qualitative decrease
Reverse	Logical opposite of the intent
Other than	Complete substitution
General	Inclusive

Table 5. A list of parameter guidewords and phrases used in HAZOP studies.[6]

The above list of guidewords is not intended to restrict users from adding others as required. A guideword sometimes is modified in order to clarify the meaning of a deviation when a certain parameter is used. For example, "higher" and "lower" are used instead of "more" and "less" when temperatures or pressures are being considered.

Deviations, which are a departure from the design intention, are discovered by systematically applying the guidewords to each parameter at each node. Refer to Table 4 for an example of a standardized deviation list. It is usual to have more than one deviation from the application of a single guideword. For example, "more flow" could mean "faster flow" or "more quantity is flowed."

The identification of the "cause" or reason why a deviation may occur is one of the primary goals of a PHA or HAZOP study. Not all possible deviations are meaningful, and it is the responsibility of the HAZOP team to draw on its collective experience to identify meaningful deviations with credible causes. These causes may be equipment failures, human errors, external factors (e.g., loss of power) or any combination of the above. Subsequently, the consequences or result of a deviation, should it occur, must also be identified and reviewed. The most significant hazards are likely to arise from an uncontrolled loss of containment incident involving the release of flammable and toxic material onto the ground and/or the release of flammable and toxic gas into the area. This may result in a fire and subsequent explosion, environmental contamination or hazardous consequences to personnel.

To complete the study, safeguards, such as engineering and administrative controls that can prevent or mitigate potential consequences are identified and a risk assessment / ranking process is applied to determine if these control strategies are deemed adequate. Consequences that are assessed with a risk level that exceeds that which is accepted by the team, even with safeguards in place, require additional recommendations or corrective actions to be applied. This is either an action suggested by the HAZOP team members to prevent or improve the consequence of a deviation, or the identification of a need to obtain further information before the particular deviation can be properly assessed. This information should be documented along with the name of the person or department responsible.[6]

What-If and/or Checklist Method

Along with OSHA, the American Institute of Chemical Engineers has identified the What-if method as a recognized hazard evaluation technique. A What-if analysis provides a means of:

- identifying potential hazards in a facility or piece of equipment
- evaluating the significance of the hazards and the adequacy of existing safeguards
- listing preliminary recommendations to reduce or eliminate the likelihood or the severity of the hazards

The quality of the analysis and evaluation matches the experience and knowledge of the team. The What-if procedure involves sessions in which team members work through the various Systems and Subsystems and pose a series of questions that begin with "What if," such as, "What if the raw material was introduced in the wrong concentration?" or, "What if the operator forgot to manually close the valve?" Each question represents the potential for failure of equipment or an error in operating procedure to occur in the facility.

The study team addresses each question in turn, analyzing the effects of equipment failures, human errors or external events on the operation of the system. Potential hazards are identified and their likely consequences evaluated as described in the HAZOP study technique.[7]

The Failure Modes and Effects Analysis

This method was first used in the 1940's by the US military, and further developed by a group of reliability engineers in the aerospace and automotive industries to predict the reliability of complex products. To do this accurately, it was necessary to establish **how** and **how often** the components of a product could fail. With time, FMEA evolved into a method that also evaluated the effects of failures on a system. The FMEA method is most effective when applied to the analysis of single units or single failures.

A FMEA analysis can provide the following functions:

1. Systematic review of component failure modes to ensure that any failure produces minimal damage to the product;
2. Determine the effects that these failures will have on other items in the product, and their associated functions;
3. Determine the parts whose failure would have the most critical effect on product operations, the greatest damage, and the failure modes (factors) that may generate these effects;
4. Calculate the probabilities of failures in the assemblies, sub-assemblies, and products from the individual failure probabilities of their components and the arrangements in which they have been designed;
5. Determine how probabilities of failure of components, assemblies, and the product can be reduced by using high reliability components, redundancies in design or both;
6. Eliminate or minimize the adverse effects that assembly failures could generate and indicate safeguards to be incorporated if products cannot be made fail-safe or brought within acceptable failure limits.

Some of the limitations of this method include:

- It is a time-consuming and inefficient process for safety purposes;
- Human error and hazardous conditions are not taken into account;
- Limited consideration of environmental conditions and the stress effects these have on components (usage factor generally incorporated).[7]

Fault Tree Analysis (FTA)

Bell Laboratories developed this PHA method at the request of the U.S. Air force. FTA focuses on the possibility of one undesired event occurring and maps the complex relationships that can cause the event by including ***all*** of the contributory factors that are **known**. FTA is most effective in discovering sub-level problems, recognizing and controlling single-point failures, demonstrating

relationships between fault modes and mapping the likely sequences of failure. While the method was developed to determine quantitative probabilities, it is generally used for the qualitative aspects (visual representation of the factors and how they interact).

The Fault Tree Analysis is initiated by the selecting a Top Event, which is the undesired event or consequence whose possibility, or probability of occurrence, is to be determined. The method then identifies and "builds a tree" of contributory events that could cause the top event; these are drawn below this event. As the "branches" of the tree are developed downward, "gates" are inserted to separate two or more contributory events. The two principal gates that are used with FTA are the "OR" and "AND" gates. The OR gate is used to indicate that the presence of **any** of the contributory events will cause the event above it to take place. The AND gate is used to indicate that **all** of the contributory events connected to that gate must be present in order to cause the event above it. As the tree develops, downward progression through the branches indicates causes and upward movement indicates the effects. To make this cause-and-effect relationship more informative, the expression of each event must have a subject, verb, and descriptor. I.e. Microwave: The rotating component fails without power, or "when the bearings overheat". Correct selection of the expression is imperative so that sequence logic and probability of failure rates are correctly assigned.

The FTA method evaluates each contributory event to determine the circumstances under which it will occur and the factors that will cause it. Each of these events are also examined to determine whether the event could be a result of a *primary fault*, a *secondary effect, input or command*, or a layered combination of each of these factors. A primary fault is one in which the component itself malfunctions, a secondary effect is one caused by the malfunction of another component, device or outside condition. An input or command event is one caused by an erroneous signal, error or similar input. This process continues until all available information has been used and the bottom level of each branch has identified a failure, error or other initiating event. A bottom event that cannot be investigated further, or an event that no one wants to investigate further should be referred and considered for further study, if deemed necessary, by reliability (FMEA/FMECA) or human factor engineers (human error).

Based upon the above information and evaluation, **Cut Sets**, which is the minimum sequence that can cause the top event, are identified. The probability of the top events occurring will be the sum of all the cut-sets if all the cut-sets are statistically independent. If there is duplication between two cut-sets, this replication must be accounted for during a quantitative analysis. This analysis requires the use of Boolean logic and equations that are generally managed by a computer software program.

Fault tree analysis is commonly used to

- Identify critical paths (which sequence of events is most likely to cause the top event);
- Identify corrective actions that can be taken;
- Identify critical parts that require dedicated maintenance or troubleshooting activities;
- Perform reliability calculations to determine the successful accomplishment of a function or the fact that the product will not operate;
- Assist in Accident Investigation "root-cause analysis";
- Evaluate management actions that contributed to an accident;
- Estimate risks beyond single-fault conditions.

Some of the limitations of the FTA method are:

- The creation of effective fault trees can only be made after the product has been designed;
- The use of quantitative fault trees to determine the probability of occurrence of a top event is usually costly and greater value can be derived from using the qualitative tree.
- Preparation of the tree requires intensive knowledge of the design, construction and operation of the product so "all" significant factors will be included.
- Fault-tree analysis symbols can be confusing to personnel with no training in FTA.
- FTA is a logic diagram that is generally limited to cause-and-effect relationships, and an estimation of probabilities if sufficient data is available.

Selecting the "Right" Method

The wide range of PHA methodologies that are available provide the PHA team with flexibility in meeting the objectives of a study. As there is not always "one best" methodology for a specific process or operation, the following criteria can help to provide a basis for making initial decisions on which technique, or blend of techniques to select. Some of the factors that should be considered when selecting a PHA methodology include:

- Purpose of study
- Type of results desired
- Type of information available
- The size and complexity of the facility
- The relative risks associated with the chemicals, the process and/or the facility location
- PHA team experience level
- Development stage of facility
- Past incidents (operating history)
- Resource availability and management/leader preference

This is also visually represented in the methodology selection flow chart in Exhibit 3.

As with any good business decision, the immediate cost of a PSM and PHA program commitment to both new projects and existing facilities has to be weighed against the long-term savings gained through improved safety and operability. The following factors can contribute to the cost of a PHA study.

- Methodology chosen will influence the study duration and comprehensiveness of results.
- Updating of data resources, (i.e. P&IDs).
- Dedicating personnel for specific and adequate time periods.
- Time will be required for problem solution meetings.
- Quantification of some identified hazards may be required.
- Commitment must be made to follow through on study results.
- Recommendation management system must be planned with clear accountability assigned for implementation and to monitor completion.

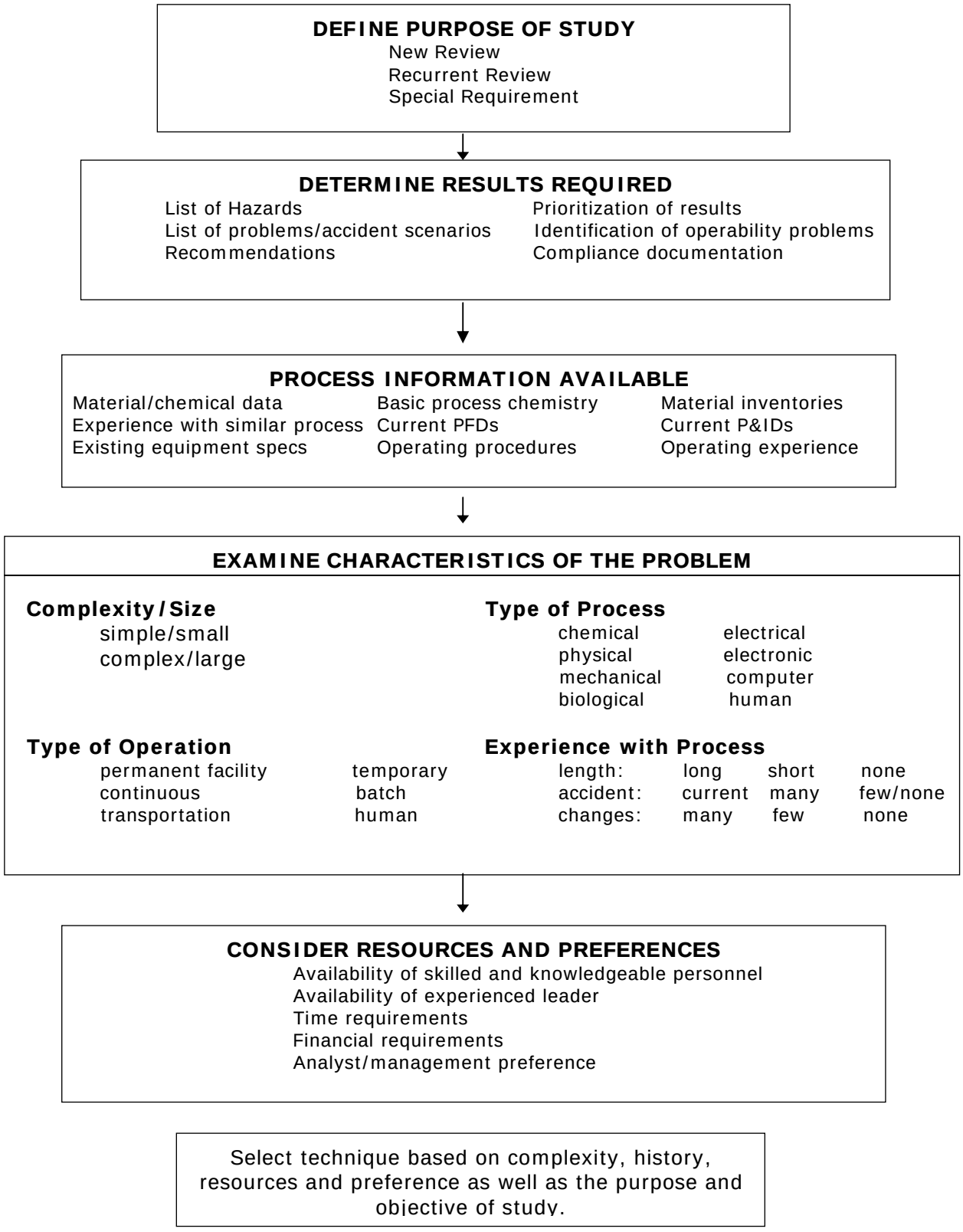

Exhibit 3. The Methodology Selection Flowchart for Process Hazard Analysis techniques. [8]

There are also numerous benefits of a PHA study or program at the design/engineering stage and for existing operational facilities. These are identified in the table below. Ultimately, the choice to adopt a PSM program, and supporting PHA studies, should be based on regulatory, industry and organizational requirements and capabilities.

Benefits at Design/Engineering stage	Benefits for existing operational facilities
• Shortens project schedules. • Minimises cost. • Provides high degree of safety and operability assurance. • Maximizes opportunities for improving/increasing production. • Minimizes environmental implications of process. • Ensures compliance with safety codes and regulations.	• Identifies and documents hazards. • Identifies and documents existing safety measures. • Reveals opportunities to improve safety measures that will reduce lost time incidents. • Assists in prioritising risk reduction projects. • Reveals opportunities for capacity increases.

Table 6. Cost benefits of a PHA study or program.[9]

Corrective Action Management and Closure

The decision to implement a PSM program and conduct a PHA study is only as effective as the action taken to implement the recommendations made during the study. "Due diligence" can only be shown if every effort has been made to implement and verify that the actions needed to make the process safe have been taken. The follow-up activity of the PHA study should be the responsibility of the project's facility management. This group is responsible to inform team members of corrective actions that have been resolved, and of any decisions that will affect the recommendations made by the team, including alternative solutions selected by management. To verify that the outcomes of the study have been addressed it is generally good practice to schedule one final PHA session to finalize project/process changes and to close the report.

To establish a closure loop for a PHA study, the following steps should be incorporated into the PHA methodology.

- Responsibility must be assigned and a schedule developed for recommendation resolution.
- A system for managing changes, that allows flexibility and leaves a "paper trail" for future reference and/or audit, should be used. This system must be filed on site for the life of the process.
- The resolution of each recommendation must be accurately documented, including dates for implementation of action and verification of the resolution.
- The owner/operator of the facility may, with clearly documented justification, opt not to adopt the recommendations made by the team. Acceptance, rejection, substitution, or modification of **any** recommendations should be documented and included with the project file and original report.
- Rejection of a recommendation should be communicated to the study team.

While the scope, purpose, focus and methodology chosen to assess a process or facility that uses highly hazardous chemicals may vary, the core steps that are required to meet the regulatory and industry requirements are the same. The consistent and standardized use of these steps to implement a Process Safety Management program, and applicable PHA studies, will provide a sound foundation for organizations to demonstrate their "due diligence" and to improve the effectiveness of their operations.

Footnotes

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