LAYERS OF PROTECTION ANALYSIS FOR HUMAN FACTORS (LOPA-HF)

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A version of this paper appeared in Process Safety Progress, Vol. 21, No. 2, pps. 119 - 129, June, 2002.

Abstract

Process hazard analysis (PHA) performed to meet the requirements of OSHA and EPA regulations must address human factors. Both the human failures that can cause accidents and the human factors that can influence them must be addressed. This is important because it is generally believed that 50 - 90% of process accidents can be attributed to human failures. Human failures are usually identified in a PHA by simple brainstorming. However, PHA teams have a tendency to focus on equipment failures. A better approach is needed. Common approaches for identifying the human factors that influence human failures involve the use of checklists during the PHA. Unfortunately, these approaches have proven problematic. There is a need for an improved method that is both efficient and effective in helping to control process risk.

This paper describes improved approaches for identifying human failures in PHA and human factors issues that impact on the hazard scenarios identified by PHA. The former is accomplished using an approach that conceptually identifies human failures in a manner analogous to generating deviations in a hazard and operability study. The latter is achieved by the application of the framework and methods of Layers of Protection Analysis (LOPA), a simplified risk assessment method. These approaches are described and illustrative examples are provided in the paper.

Introduction

OSHA's Process Safety Management (PSM) standard, 29 CFR 1910.119 and EPA's Risk Management Program (RMP) rule, 40 CFR Part 68 require that a Process Hazard Analysis (PHA) be performed for processes covered by the regulations and that, among other things, "the PHA shall address human factors". Although the regulations do not define or explain what this means or entails, it is generally accepted that PHA must:

- Account for human failure as a cause of hazard scenarios and,
- Consider factors that impact human performance.

It is entirely appropriate that PHA should address human factors since it is generally believed that 50 - 90 percent of all accidents are caused by human failures[1]. Examples of human factors issues that OSHA is concerned about, and that can contribute to hazard scenarios, include the accessibility, clarity and usability of controls and instrumentation, task overload and work schedules. Human factors engineering deals with the person-process and person-person interfaces and how they influence the performance of people. Human failure analysis deals with the errors and mistakes people may make in their interface with a process. These failures and their rates are influenced directly by the human factors engineering design of the process.

Human failures are usually identified in PHA, along with equipment failures and external events, by brainstorming causes of hazard scenarios. However, PHA teams have a tendency to focus on equipment failures at the expense of human failures and this simple brainstorming approach, although commonly used, leaves something to be desired. Consequently, owing to their usually dominant contribution to risk, it is desirable to identify potential human failures in a more systematic, yet straightforward, way consistent with the usual level of detail and effort of PHA.

With regard to addressing human factors in PHA, current practice achieves results that are probably even less satisfactory than those for the treatment of human failures. Typically, a checklist is used as a reminder and aid for the PHA team to consider human factors issues that may affect process risk. A simple example of such a checklist is shown in Table 1. Using a checklist, entries are made in the PHA worksheet that identify human factors issues and their impact on hazard scenarios. Unfortunately, such checklist approaches are cumbersome, and quickly become repetitive and tiresome. Therefore, they are susceptible to producing inadequate results. Moreover, many PHA team members are not comfortable with or informed about human factors concepts and have difficulty using the checklists. Furthermore, at best the checklists produce only a simplistic analysis of human factors, unless much more detailed checklists are used. The PHA study can become bogged down, or even transformed into a human factors study, probably better performed by human factors specialists.

These checklist approaches also address human factors for all hazard scenarios regardless of their contribution to overall process risk and without adequate consideration of the extent of human involvement in the scenario. A better focused approach would use PHA to screen for high risk scenarios with significant human contributions and then analyze the human factors issues that impact the scenarios to determine how risk can be made tolerable.

Consequently, there is a need for an improved approach for addressing human factors in PHA that is efficient and effective in helping to control process risk.

Human Contributions to Process Risk

Process risk is determined by the hazard scenarios that are possible for the process. Therefore, in order to consider how best to address the impact of human failures and human factors on process risk, it is necessary to examine how people are involved with individual hazard scenarios.

Figure 1 depicts the constituent elements of a hazard scenario. The initiating event can be an equipment failure, human failure or an external event. These are the "causes" of a PHA study such as the Hazard and Operability (HAZOP) method. Intermediate events can include operator actions as well as automated responses of the process control and safety systems. Enabling events or conditions can include human factors issues such as an error-inducing environment, for example, work overload, or human failures such as mis-calibrated instruments. The consequence is the effect of the scenario on people (on-site or off-site), property (on-site or off-site), the process (downtime, product quality, etc.), the environment, etc.

In order to address human factors and failures properly in PHA, their impact on each individual constituent of a hazard scenario must be determined, namely:

- the initiating event
- intermediate events
- enabling events or conditions
- the consequence

This paper describes a method for analyzing the human factors impacts on these constituents of hazard scenarios using an approach analogous to Layers of Protection Analysis[(2)] (LOPA). The new method, called LOPA for Human Factors (LOPA-HF), provides an improvement over current methods of addressing human factors in PHA.

While LOPA-HF can utilize any human factors model as the basis for identifying human factors issues, a people-process model[(1)] that is broader than the classical human-machine model is suggested. The people-process model includes issues that can be missed using the human-machine model, for example, consideration of the impact of communications between people and organizational structure on human performance.

Since PHA identifies many hazard scenarios, it is reasonable to use PHA to screen for high risk scenarios that merit a human factors analysis. A simple risk ranking of hazard scenarios, as is often done as part of PHA, can be used as the basis for deciding which scenarios merit human factors analysis. However, in using PHA for screening it is important that all high risk scenarios with human factors contributions be captured by the screening process. This means that it is particularly important to identify scenarios with initiating events that are human failures and which are therefore susceptible to influence by human factors. A suggested improved method for identifying such scenarios is described below.

Layers of Protection Analysis

The principal objective of PHA is the identification of hazard scenarios. This is accomplished by brainstorming initiating events, or causes, of hazard scenarios and identifying the consequences that may result. Safeguards that can prevent, detect, or mitigate the scenarios are also usually identified. The PHA team or follow-up analysts identify the possible need for additional safeguards based on their view of the adequacy of existing safeguards in achieving an acceptable, or tolerable, level of risk. However, it has been found in practice that this subjective approach using engineering judgement can lead to disagreements and possibly inappropriate measures to reduce risk(2). It was recognized that a more rational and objective approach was needed, at least when considering risk remediation measures for high risk scenarios. This led to the development of Layers of Protection Analysis (LOPA)(2).

LOPA is a simplified risk assessment method. It provides an objective, rational and reproducible method of evaluating scenario risk and comparing it with risk tolerance criteria to decide if existing safeguards are adequate, and if additional safeguards are needed. LOPA can be viewed as an extension of Process Hazards Analysis (PHA). Typically, it is applied after a PHA has been performed. LOPA builds on the information developed in the PHA.

LOPA is used to analyze individual hazard scenarios defined by cause-consequence pairs. It considers safeguards that are Independent Protection Layers (IPLs), defined as those whose failure is independent of any other failures involved in the scenario. Such safeguards include Safety Instrumented Systems (SIS), also called interlocks and emergency shutdown systems. SIS are addressed by the standard ANSI/ISA S84.01-1996, Application of Safety Instrumented Systems for the Process Industries, 1996 (called S84 herein) which can include the use of LOPA(3).

S84 specifically excludes the analysis of the capability of humans to act on human-machine interface information. It is considered to be part of PHA. S84 also excludes systems where operator action is the sole means required to return the process to a safe state, e.g., alarm systems, fire and gas monitoring systems, etc. However, there is no inherent reason these issues cannot be considered by LOPA.

To approximate the risk of a scenario, LOPA typically uses order of magnitude categories for the initiating event frequency, the likelihood of failure of IPLs and the consequence severity. Scenario frequency is determined by combining the initiating event frequency, IPL failure probabilities, and probabilities of enabling events / conditions. Scenario risk is determined by combining scenario frequency and consequence severity and is compared to risk tolerance criteria to determine if additional risk reduction is required to reach a tolerable level.

LOPA follows a set procedure in which high risk scenarios are first identified for consideration using PHA. Each of these scenarios is then analyzed. A key part of this analysis involves determining the Safety Integrity Level (SIL) provided by the IPLs involved in the scenario. The SIL is usually defined as a Probability of Failure on Demand (PFD). This is the probability the IPL fails to perform its required safety function on demand. For example, ANSI/ISA S84.01 defines three SIL levels in terms of the PFD:

SIL LEVEL	PFD
1	0.1 to 0.01
2	0.01 to 0.001
3	0.001 to 0.0001

This approach of using categories simplifies the analysis and enables guidelines to be developed to assist in the selection of safeguards needed to achieve particular levels of tolerable risk. As part of LOPA, guidelines have also been developed to determine PFDs for specific safeguards.

Safeguards can involve three functions: sensing, decision making and action. These can occur automatically, involve only people, or be a combination of both. Human performance is usually considered less reliable than engineering controls and, although LOPA can consider human safeguards, usually the emphasis is on engineered protective systems.

This paper proposes an approach for evaluating human factors that employs the standard LOPA framework but focuses on human performance issues rather than automated safety systems.

LOPA-HF

Typically, LOPA involves the consideration of high risk scenarios, usually identified by PHA. For each scenario, the initiating event, IPLs and enabling events/conditions are identified. The scenario risk is estimated and compared with risk tolerance criteria to determine if further IPLs are needed.

LOPA-HF uses this framework to identify the human factors issues that contribute to these high risk scenarios. It does so for each constituent element of the scenario as described below.

Initiating Events

Initiating events that are human failures can arise from various human factors. LOPA-HF analysts use simple Issues Lists to identify the dominant human factors contributors to the failure rate, existing protective measures and any recommendations for additional protective measures. This information is recorded in a LOPA-HF worksheet (see Figure 2). For example, in the case of the initiating event: “Operator inadvertently opens wrong valve” the LOPA-HF analysts consider the items on an Issues List, such as:

HUMAN FACTORS ISSUES LIST
Incorrect Action By Operator
Work overload/underload
Insufficient training
Inadequate skills
Inadequate resources
Inadequate procedures
Inadequate labeling
Equipment not easily operable
Displays/controls not visible/heard
Displays/controls confusing
Displays/controls not accessible/usable
Inadequate communications
Environmental issues (temperature, humidity, light, noise, distractions)
Error (wrong action, no specific reason)
Mistake (wrong action, misunderstood)
Other?

These Issues Lists are provided for various types of human failures that may be initiating events and are typically standardized so that LOPA-HF analysts become accustomed to working with them, although they can also be customized for particular types of processes and/or specific companies’ cultures. LOPA-HF analysts may flag more than one applicable issue.

The result of this step may be:

Initiating Event: Operator inadvertently opens wrong valve.	
Human Factors:	Inadequate procedure. No/inadequate labeling.
Protective Measures:	
Recommendations:	

The LOPA-HF analysts next consider protective measures that may be in place for the initiating event. They consider the items on an Issues List, such as:

PROTECTIVE MEASURES ISSUES LIST
Incorrect Action by Operator
Training
Procedures
Equipment labeled
Check
Other?

The result of this step may be:

Initiating Event: Operator inadvertently opens wrong valve.	
Human Factors:	Inadequate procedure. No/inadequate labeling.
Protective Measures:	Training
Recommendations:	

The LOPA-HF analysts next consider whether additional protective measures should be in place. This decision can be made using the standard LOPA technique of comparing estimated scenario risk with risk tolerance criteria. If risk reduction is needed, consideration can be given to reducing the frequency of the human failure initiating event by providing additional protective measures, The LOPA-HF analysts use the Protective Measures Issues List as a guide. The result of this step may be:

Initiating Event: Operator inadvertently opens wrong valve.	
Human Factors:	Inadequate procedure. No/inadequate labeling.
Protective Measures:	Training
Recommendations:	Consider placing a caution in operating procedure P-009-2001 to confirm correct valve selection. Consider labeling valve MV-32.

Initiating events resulting from equipment failures and external events may also have human factors contributors. For example, a pump may fail off due to inadequate maintenance or an object may be dropped from a crane and rupture a line due to inadequate training of the crane operator. Human factors issues for these types of initiating events are handled in a similar way to human failures.

Independent Protection Layers

IPLs may be automated systems that operate without human involvement, manual systems triggered by alarms, or a combination of both. Failure rates of both types of systems can be influenced by human factors. The analysis is similar to that for initiating events. Consider the IPL: “Operator activates reactor quench on high-high temperature alarm”. The LOPA-HF analysts consider the items on the “Incorrect Action By Operator” Issues List that could cause the failure of the IPL, the protective measures that may be in place already and those that may be needed if the IPL SIL does not meet risk tolerance criteria. The results of these steps may be:

Independent Protection Layer: Operator activates reactor quench on high-high temperature alarm.	
Human Factors:	Inaudible alarm. Poorly accessible quench valve.
Protective Measures:	None.
Recommendations:	Relocate alarm to operator work station. Install fixed ladder to access quench valve.

The LOPA-HF worksheet is completed for each IPL in the scenario.

For the case of an automated IPL, consider a quench valve activated by a high temperature trip. The LOPA analysis for this IPL may produce the results:

Independent Protection Layer: Quench valve activated by a high temperature trip.	
Human Factors:	Inadequate maintenance on trip sensor. Inadequate testing of quench valve.
Protective Measures:	Preventive maintenance program.
Recommendations:	Review testing and inspection program for components of quench trip system to ensure adequacy.

Enabling Events/Conditions

Enabling events/conditions do not directly cause the hazard scenario. They make possible another event in the scenario. They must be present or active for the scenario to proceed, for example, a process being in a particular mode, phase or step. Consider an operator who drops a gas cylinder. This may be the initiating event of a hazard scenario. If the cylinder is uncapped there will be a release. This is the enabling condition for that scenario. Enabling events/conditions frequently can be influenced by human factors, for example, disabled alarms. Incorrect maintenance may leave the process in an unsafe state that may not be detected until an initiating event occurs.

LOPA-HF addresses enabling events/conditions in a similar way to initiating events and IPLs. However, there is an additional first step of identifying applicable enabling events/conditions since they may not have been identified or considered in the PHA. This is done by reviewing an Issues List of enabling events/conditions, for example:

ENABLING EVENTS/CONDITIONS ISSUES LIST
Installation of incorrect seals, gaskets, etc.
Process left in incorrect state after turnaround, maintenance, sampling, or other operation
Disabled alarms
Overrides
LOTO not effected
Startup/shutdown/operating/emergency mode, etc.
Other?

Consider the enabling condition: “High-high temperature alarm disabled”. The LOPA-HF analysts consider the items on a “Disabled Items” Human Factors Issues List to identify those that could result in the enabling condition, identify protective measures that may be already in place by reviewing a “Protective Measures” Issues List and recommend those that may be needed if the IPL SILs do not meet risk tolerance criteria. The results of these steps may be:

Enabling Events/Conditions: High-high temperature alarm disabled.	
Human Factors:	Too many false alarms. Operators rely on automated quench.
Protective Measures:	None.
Recommendations:	Re-engineer manual system to reduce false alarms. Address importance of manual quench in operator initial and refresher training.

The LOPA-HF worksheet is completed for the enabling events/conditions in the scenario.

<u>Consequence</u>

Human factors issues that directly impact the scenario consequence include the probability of a person being present in the area of the hazard and the probability they will be injured as a result of their exposure. The former issue can also be considered as an enabling event. Both issues can be included in a standard LOPA study by incorporating their probabilities into the evaluation of scenario risk. However, there may be improvements in the process design or operation that can reduce these probabilities. These are addressed by LOPA-HF. Consider a scenario involving a release of chlorine into a process control room. The consequence is possible exposure of control room operators to chlorine. LOPA-HF identifies human factors issues and protective measures for this consequence by using Issues Lists for the appropriate type of consequence. The results of these steps may be:

Consequence: Possible exposure of control room operators to chlorine.	
Human Factors:	Control room not posted as possible chlorine exposure area. Insufficient PPE in control room at shift changeover.
Protective Measures:	PPE (SCBA's) available in control room.
Recommendations:	Provide three additional SCBA's in the control room. Post signs warning of potential chlorine exposure at entrances to control room.

The LOPA-HF worksheet is completed for the consequence of the scenario.

Evaluating The Impact of Risk Reduction Measures on Scenario Likelihood

Once the human factors issues that adversely affect the performance of the constituent elements of the hazard scenario have been identified, the contributions of corrective actions to reducing the scenario likelihood can be assessed. Their effects will combine together through reductions in the likelihoods of the initiating event, intermediate events, enabling events/conditions and consequences. Their impact on each of these likelihoods can be estimated individually in a similar way to assessing SIL improvements in SIS from design improvements using standard LOPA.

Human failure probabilities (HFP) can be used to represent the probability of failures by people such as operators when faced with the need to act. They address both inaction and incorrect action (errors of omission and commission). They are analogous to PFDs (probability of failure on demand) used for independent protection layers (IPLs) in standard LOPA.

Alternatively, an approach can be used in which credits are assigned for each type of human factors improvement according to its effectiveness. The approach involves assigning credits to human factors recommendations so that, for example, improvement in the accessibility of a control is worth 3 credits and improved training is worth 2 credits. When aggregated, each 10 credits of improvements contributes an order of magnitude reduction in the scenario likelihood. The aggregation is made for human factors improvements regardless of the event or condition in the hazard scenario that they impact and regardless of whether the event is a human failure (represented by a HFP) or another type of failure (represented by a PFD) thus simplifying the analysis considerably. The use of credits also facilitates deciding between alternative improvements since their relative contributions to risk reduction are made obvious. A target risk level can be met by accumulating sufficient credits and the analysts can decide which of various possible combinations are preferred.

Standard tables of credits can be established using performance data from the human factors literature so that the assessments become routine. The use of credits is intended to provide order of magnitude risk estimates yet produce conservative results. This is the philosophy of standard LOPA which is intended to provide a more rational, reproducible and objective basis for risk-based decisions than PHA while avoiding the need to perform quantitative risk analysis. The use of a credit-based approach is also consistent with the use of IPL credits in standard LOPA where one approach uses tolerable risk criteria embedded into tables that specify the number of IPL credits for scenarios of specific consequence levels and frequency.

The use of credits can be demonstrated with the previous example. The recommendations for human factors improvements identified by LOPA-HF are shown in the table below.

SCENARIO ELEMENT	EVENT	RECOMMENDATIONS	CREDITS
Initiating event	Operator inadvertently opens wrong valve	Consider labeling valve MV-32 and placing a caution in operating procedure P-009-2001 to confirm correct valve selection.	2 + 1 = 3
IPL1	Operator activates reactor quench on high-high temperature alarm	Relocate alarm to operator work station.	4
		Install fixed ladder to access quench valve.	3
IPL2	Quench valve activated by a high temperature trip.	Review testing and inspection program for components of quench trip system to ensure adequacy.	5
Enabling condition	High-high temperature alarm disabled	Re-engineer manual system to reduce false alarms.	5
		Address importance of manual quench in operator initial and refresher training.	2
Consequence	Possible exposure of control room operators to chlorine	Provide three additional SCBA's in the control room.	3
		Post signs warning of potential chlorine exposure at entrances to control room.	2

If we assume that standard LOPA identified the need for a reduction in the scenario likelihood by 1×10^{-1} then, if we want to accomplish this through human factors improvements, we must find 10 human factors credits. Credits have been assigned to each recommended improvement in the table. Various choices are possible to reach 10 credits. For example, the company may wish to improve the testing and inspection program for the high temperature trip system (5 credits) and re-engineer the manual system to reduce false alarms (5 credits). This option focuses on just two recommendations in separate parts of the process which may simplify implementation while enhancing safety through diversification. Alternatively, other recommendations may be judged easier to accomplish and be implemented instead. Also, there is no reason why recommendations totaling more than 10 credits cannot be implemented.

The analysis of human factors for hazard scenarios using LOPA methods can be performed as an adjunct to a standard LOPA study or independently. The LOPA-HF method is depicted in the flowchart in Figure 3.

Suggested Approach For Identifying Human Failures in PHA

In order to ensure that key human failure scenarios are considered by LOPA-HF, it is vital that the PHA used to screen scenarios for LOPA-HF addresses human failures as initiating events since they will make significant contributions to the overall process risk.

For a number of years Primatech has advocated use of a structured brainstorming approach to identify possible human failures in PHA. In this approach human failures are identified by conceptually combining elements of three simple lists to prompt the PHA team throughout the PHA to consider all the people who are involved with the process, the various functions they may perform and the different types of errors or mistakes they may make. The process is analogous to combining guide words with parameters to generate deviations in a HAZOP study, except three items are combined. The following formula is used:

Person + Facility Aspect + Failure Type = Specific Human Failure

For example, “Operator" + "Procedure" + "Action is not performed" identifies the failure “Operator does not follow the procedure”.

Examples of these three lists are provided in Tables 2 - 4. The items in the three lists are *not* combined in a formal, exhaustive way. The lists are simply reviewed to identify conceptually any combinations that may have been missed by the team brainstorming. This helps ensure that initiating events arising from human failures have been addressed appropriately in PHA.

Example of the Application of LOPA-HF

One of the examples used throughout the CCPS concept book on LOPA involves a hexane storage tank[(2)]. A similar example is used here so that the LOPA-HF approach described in this paper can be compared readily with a standard LOPA study.

Consider the hexane storage tank shown in Figure 4. Hexane is unloaded from a tank truck into a storage tank using a pump. The storage tank is surrounded by a dike. The storage tank is equipped with a level indicator and a high level alarm that annunciates in the control room. Two operators are typically involved in the unloading operation. A field operator initiates the transfer with the truck driver and a control room operator monitors and operates various process functions from a computer interface. The truck driver is required to supervise the transfer.

In a LOPA study on this process, one scenario selected for analysis involved overfilling the hexane storage tank with the spill not contained by the dike. The PHA identified the initiating event as tank overflow as a result of the arrival of a tank truck with insufficient room in the storage tank due to a failure of the inventory control system. IPLs are the dike and operator response to the alarm. The consequence of the scenario is a hexane release outside the dike that can result in fire and/or injury to personnel.

LOPA-HF can be applied to identify human factors that impact this scenario to assist in developing recommendations that will help achieve the tolerable level of risk. A completed LOPA-HF worksheet is shown in Figure 5.

This worksheet shows the initiating event as “Delivery of hexane when there is insufficient room in the storage tank due to a failure in the inventory control system”. The human factors identified as contributing to this event were a mistake in ordering and a mistake in gaging the tank contents. Existing protective measures were the level indicator and the high level alarm. A recommendation was made to consider installing a high level trip for the feed pump and an inlet shutdown valve to help prevent overfilling accidents.

Of the two IPLs, there were no human factors issues identified for the dike. In the case of the operator response to alarms, an inadequately designed computer control interface was identified as a pertinent human factor. The level indicator was identified as weak protection and the recommendation to install an automated trip was made again.

The enabling condition of “high temperature alarm overridden” was identified for the scenario. A human factor impacting this condition was the alarm left inoperable after process adjustments. There were no existing protective measures. Therefore, a recommendation was made to revise the process optimization procedure to confirm operation of the alarm after completion of adjustments.

The consequence of the scenario was “hexane release outside the dike that could result in fire and/or injury”. Human factors impacts identified for the consequence were the lack of awareness of this hazard by process personnel and the lack of a smoking prohibition outside the area of the tank farm where the spill could reach. No existing protective measures were identified. Recommendations were made to address this hazard in the initial and refresher training for all affected personnel and to restrict smoking to designated locations.

Recommendations relating to human factors resulting from the LOPA-HF study can be used to assist in reaching a tolerable risk level.

Advantages of LOPA-HF

The use of LOPA-HF offers a number of advantages over the conventional checklist approach for addressing human factors issues in PHA. These include:

- Considers a wide range of human factors issues but in an organized and manageable way using simple Issues Lists.
- Focuses on high risk scenarios and the specific human factors issues that contribute to the risk
- Provides a structured analysis.
- Builds on PHA.
- Complements standard LOPA.
- Can be performed using qualitative methods but can be refined using quantitative analysis where high risk levels may warrant.
- Easily used by people experienced with PHA or LOPA .

Standard LOPA has been found to facilitate the determination of more precise cause-consequence pairs and improve scenario identification(2). It can uncover scenarios that were not identified by PHA, even for fully mature processes that have previously undergone numerous PHAs. Other scenarios or issues may be revealed. It is anticipated that LOPA-HF will do the same for human factors scenarios.

LOPA has been applied in various situations including:

- Design hazard reviews
- PHAs for new processes
- PHA revalidations
- Management of Change (MOC)
- Incident investigations

LOPA-HF offers the same flexibility.

Conclusions

A better way of addressing human factors in PHA is badly needed owing to their importance and likely dominant role in contributing to process risk. LOPA-HF is an improvement over conventional approaches. LOPA-HF focuses consideration of human factors issues on particular aspects of a specific hazard scenario thus limiting, albeit appropriately, the scope of issues the analysts must consider. This provides an easier and more efficient treatment of human factors issues than broad-based brainstorming during a regular PHA. Furthermore, human factors expertise is encoded in the structured LOPA-HF approach and the short Issues Lists used to identify human factors problems for the constituents of the hazard scenario. Therefore, typical PHA teams usually are able to perform a LOPA-HF study without significant involvement by human factors specialists, although it may be advantageous in some situations. LOPA-HF analysts should receive training on understanding human factors issues but this is easily provided in a short course. With this training they can readily relate to the Issues Lists and identify those items that apply using their own process experience.

LOPA-HF takes advantage of the development over the past few years of the LOPA framework and methods which have been proven effective in evaluating process safeguards[(2)].

Literature Cited

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2) Layer of Protection Analysis, Simplified Process Risk Assessment, AIChE/CCPS, 2001.

2) Safety Shutdown Systems: Design, Analysis and Justification, Paul Gruhn and Harry Cheddie, ISA, 1998.

Table 1. Simple Example of Human Factors Checklist

Operator/process and operator/equipment interface
Clarity, simplicity, accessibility and usability of controls and indications
Automatic instrumentation versus manual procedures
Number and frequency of tasks operators must perform
Impacts of extended or unusual work schedules, including shift rotations
Design of tasks
Operator feedback
Communications systems
Clarity of signs and codes
Environment

Table 2. List of People Involved in a Process

Operators
Engineers
Designers
Maintenance
Testing
Inspection
Responders
Sampling
Supervision
Management
Contractors
Materials Handlers
Fork Lift Operators
Truck Drivers

Table 3. Aspects of a Process

Process
Instrumentation
Controls
Alarms
Interlocks
Shutdowns
Safeguards
Safety equipment
Instructions (verbal)
Procedures (written)
Equipment
Communications
Emergency response
Environment

Table 4. Types of Human Failures

Action is not performed
Action is performed incorrectly
Action is performed in wrong place
Action is performed in wrong sequence
Action is performed at wrong time
Non-required action is performed

Figure 1. Constituent Elements of a Hazard Scenario

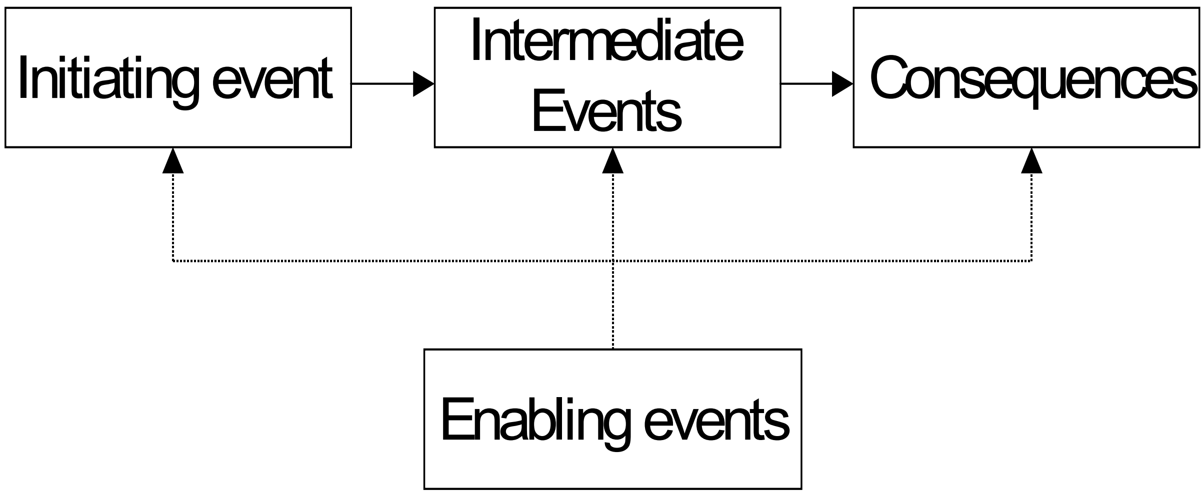

Figure 2. Simple LOPA-HF Worksheet

LOPA - HUMAN FACTORS WORKSHEET	
Scenario Description:	
Initiating event:	
Human Factors:	
Protective Measures:	
Recommendations:	
IPL 1:	
Human Factors:	
Protective Measures:	
Recommendations:	
IPL 2:	
Human Factors:	
Protective Measures:	
Recommendations:	
IPL 3:	
Human Factors:	
Protective Measures:	
Recommendations:	
Enabling event/condition:	
Human Factors:	
Protective Measures:	
Recommendations:	
Consequence:	
Human Factors:	
Protective Measures:	
Recommendations:	

Figure 3. LOPA-HF Flowchart

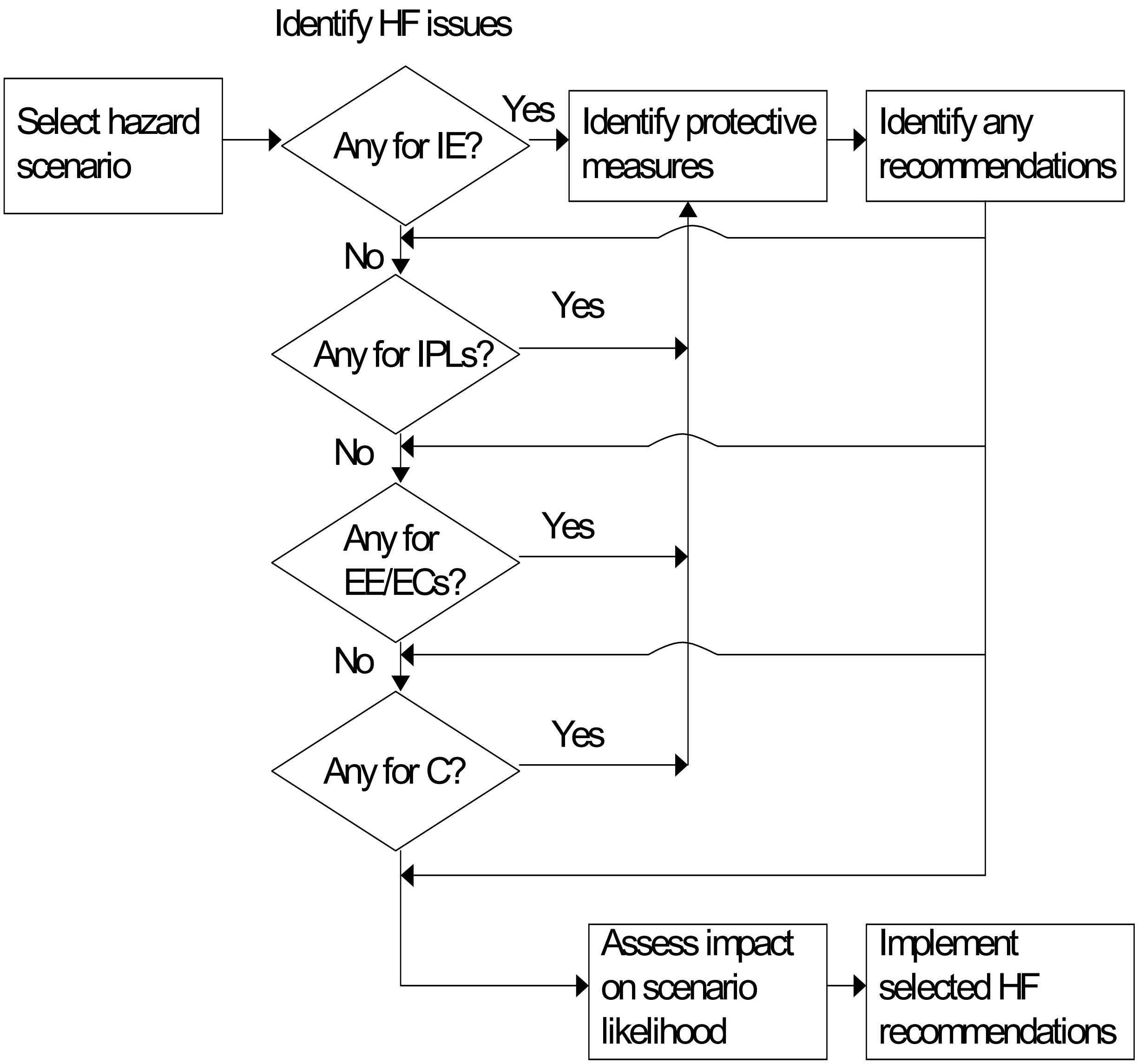
Identify HF issues
Select hazard scenario
Any for IE?
Yes
Identify protective measures
Identify any recommendations
No
Any for IPLs?
Yes
No
Any for EE/ECs?
Yes
No
Any for C?
Yes
Assess impact on scenario likelihood
Implement selected HF recommendations

Figure 4. Hexane Storage Tank Example

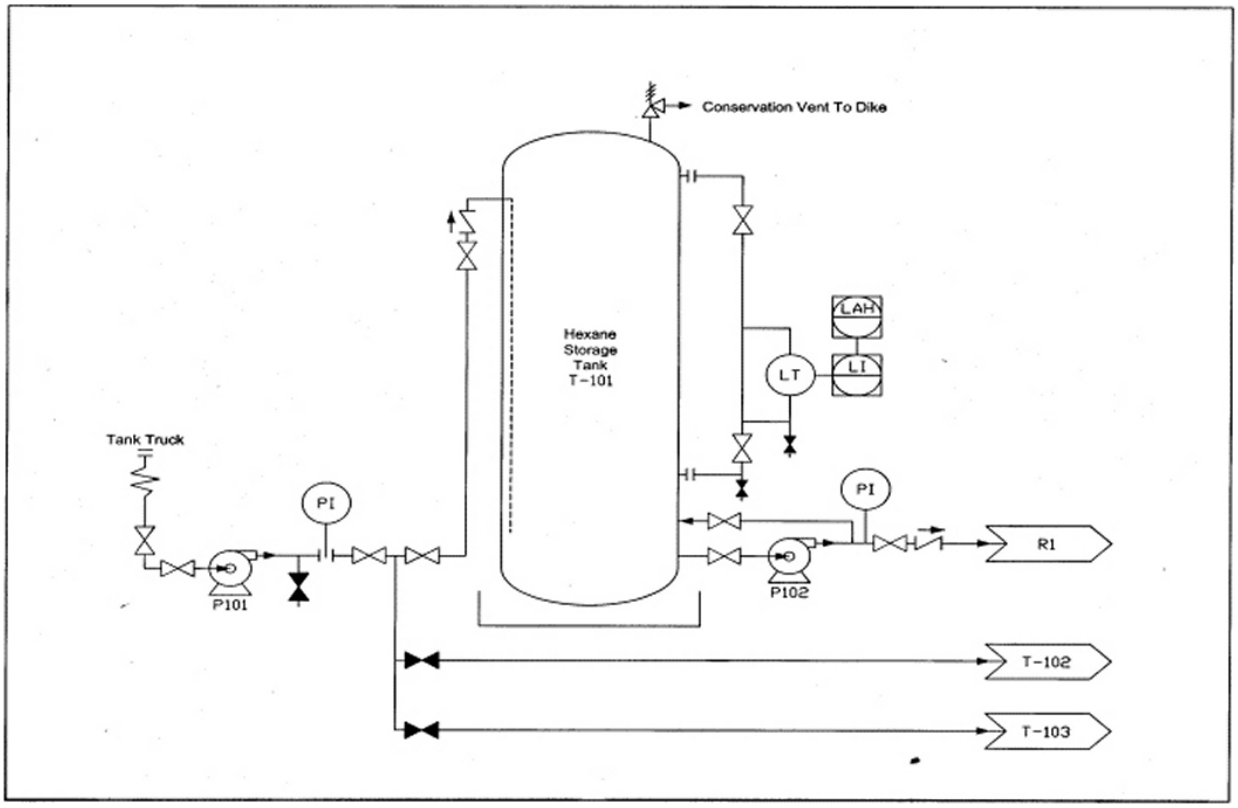

Figure 5. Example of Completed LOPA-HF Worksheet

LOPA - HF WORKSHEET	
Scenario Description: Overfilling the hexane storage tank with the spill not contained by the dike.	
Initiating event: Delivery of hexane when there is insufficient room in the storage tank due to a failure in the inventory control system.	
Human Factors:	Mistake in ordering. Mistake in gaging the tank contents.
Protective Measures:	Level indicator. High level alarm.
Recommendations:	Consider installing a high level trip for the feed pump and an inlet shutdown valve to help prevent overfilling accidents.
IPL1: Dike	
Human Factors:	None
Protective Measures:	
Recommendations:	
IPL2: Operator response to alarms	
Human Factors:	Inadequately designed computer control interface.
Protective Measures:	Level indicator (weak)
Recommendations:	Consider installing a high level trip for the feed pump and an inlet shutdown valve to help prevent overfilling accidents.
IPL 3:	
Human Factors:	
Protective Measures:	
Recommendations:	
Enabling event/condition: High temperature alarm overridden	
Human Factors:	Alarm left inoperable after process adjustments.
Protective Measures:	None.

Recommendations:	Revise the process optimization procedure to confirm operation of the alarm after completion of adjustments.
Consequence: Hexane release outside the dike that could result in fire and/or injury.	
Human Factors:	Lack of awareness of this hazard by the process personnel. Lack of a smoking prohibition outside the area of the tank farm where the spill could reach.
Protective Measures:	None.
Recommendations:	Address this hazard in the initial and refresher training for all affected personnel. Restrict smoking to designated locations.