Layer of Protection Analysis – An effective tool in PHA

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Abstract

Layer of Protection Analysis (LOPA), a semi quantitative Process Hazard Analysis (PHA) is found to be the effective tool in hazard evaluation and risk assessment. It is found to be the potential semi quantitative tool for statutory compliance purposes in UK and effective Process Safety Management tool satisfying OSHA requirements in USA. It is a simple tool and identifies the safeguards to be considered for risk assessment and risk reduction. Details of the technique with examples are given in this article.

Introduction

Process Hazard Analysis utilizes various tools viz Check lists, Hazard and Operability study, Failure Mode and Effect Analysis, Fault Tree Analysis, Event Tree Analysis to identify the Hazards involved in the chemical operations. While some of them like such as HAZOP and What-if are qualitative, others such as Fault Trees and Event Trees are quantitative. Layer of Protection Analysis (LOPA) is the newest methodology for hazard evaluation and risk assessment. The LOPA methodology lies between the qualitative end of the scale and the quantitative end. It provides a method for evaluating the risk of hazard scenarios and comparing it with risk tolerance criteria to decide if existing safeguards are adequate and if additional safeguards are needed. Some people view LOPA as an extension of Process Hazard Analysis because it is applied on the data developed by PHA like HAZOP. This article attempts to introduce this technique which is widely used by all process industries in all developed countries.

Origin and Concept of LOPA

The LOPA method was originally developed in the context of defining Safety Integrity Levels (SILs) for electronic/electronic/programmable electronic safety related systems. Use of LOPA is consistent with the requirements of standards such as ANSI/ISA-84.01-1996 (Application of Safety Instrumented Systems for the Process Industries) and IEC 61508 (Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems). Subsequently LOPA has found more widespread use as a risk assessment technique.

It is a simplified risk assessment method. LOPA is applied when a scenario is too complex or the consequence is too severe for the HAZOP team to make a sound judgment based solely upon the qualitative information. On the other hand, it can screen scenarios as a precedent to a QRA. LOPA helps organizations to make consistent decisions on the adequacy of the existing or proposed layer of protection against an accident scenario.

This method utilizes the hazardous events, event severity, initiating causes and initiating likelihood data developed during HAZOP. It evaluates risks by orders of magnitude of the selected accident scenarios and builds on the information developed in qualitative hazard evaluation e.g. PHA.

LOPA helps the user to determine the risks associated with the various hazardous events by utilizing their severity and the likelihood of the events being initiated. The risk reduction measures employed by the industry concerned such as process design are estimated and credit is given for such measures while estimating the severity and likelihood. The industry can set their corporate risk standard or follow the risk acceptability levels specified by the local governments. If the risk levels are not with in the acceptable limits additional risk reduction measures by means of Basic Process Control System (BPCS), alarms, human intervention, Safety Instrumented Function etc. can be employed.

LOPA Process

LOPA is based on the assessment of single event- consequence scenarios. A scenario consists of an initiating event and a consequence. Though multiple initiating events can lead to same consequence, all these initiating events must be used to develop scenarios for subsequent assessment. A typical LOPA scenario chain is indicated as figure 1 for understanding:

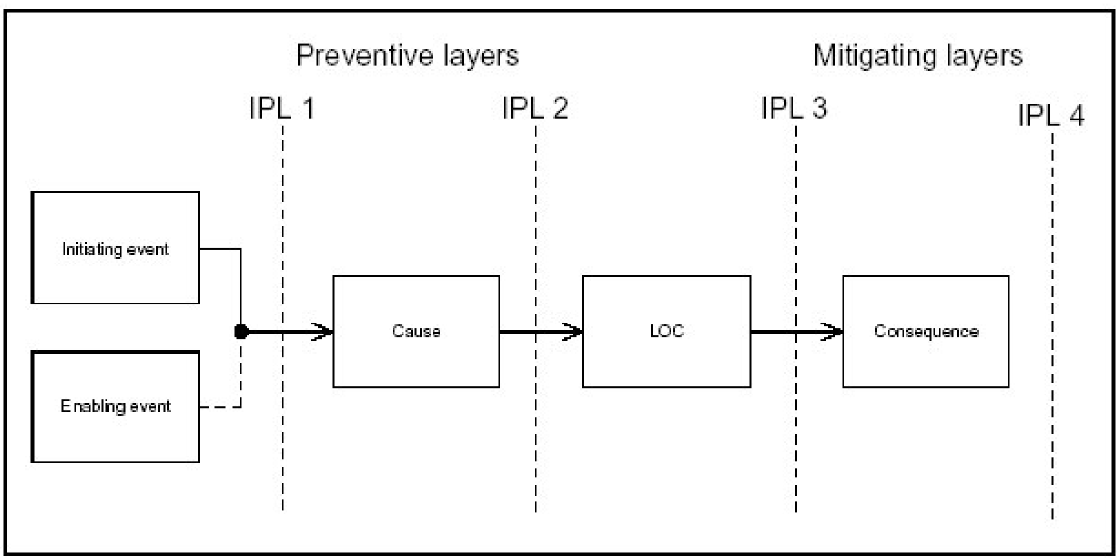


Fig 1: LOPA scenario

Let us discuss the various terminology used in the above chain with the help of an example for easy understanding:

Event – Initiating and Enabling

An event is an occurrence to an accident scenario. The initiating event is the event that starts the chain of events leading to the undesired consequence. An enabling event or enabling condition is an event or condition that is required for the initiating event to unleash a scenario. Enabling events are neither failures nor protection layers. They are expressed as probabilities. For example fire due to release of LPG gas from a cylinder can be considered as an event. In this case LPG leak from the cylinder can be the initiating event. Presence of Ignition source in the area can be the enabling condition. Initiating events could be external events like earthquake, wind storm, flood etc, failures of equipment like rupture or leak of vessel, pipeline etc. or human failures.

Cause

Condition or state resulting from the events that allowed the Loss Of Containment to occur. The faulty valve is the cause of LPG leak.

Loss of Containment (LOC)

Loss of containment is defined as the top event in a scenario, that one aims to prevent from occurring. Ignition of LPG vapor- air cloud is the loss of containment.

Consequence

The consequence or effect is defined as the undesired outcome of an accident scenario. Consequences are expressed in terms of material damage, environmental pollution, injuries, fatalities etc. In our example both the material damage and injury due to LPG fire are the consequences.

Independent Protective Layers (IPL)

After having discussed all the important terminology in the chain, it is important to understand the vertical lines shown at every stage of LOPA scenario. Independent Protective Layers are devices, systems, or actions that are capable of preventing a scenario from proceeding to an undesired consequence and all these layers are independent from one another so that any one failure of the layer will not affect the functioning of the other layers. The layers can be either preventive in nature by avoiding an occurrence of the scenario or mitigating by minimizing the effects of consequences. Examples for preventive independent protective layers are inherently safe design features, physical protection such as relief devices, Safety Instrumented Systems etc. Post release physical protection like fire protection systems, plant and community emergency response etc can be considered as mitigating protective layers. Provision of valve cap on the cylinder can be one of the Independent Protective Layer.

There are different opinions on which should be considered as IPL. Some literature suggest that the training, certification, normal testing and inspection, existence of standard operating procedures, routine maintenance, communications, signs, human factors etc. OSHA's Process Safety Management Standard and EPA's Risk Management Programme require that PHA should address human factors also.

Methodology

The analytical LOPA method consists of a number of steps viz establishing a consequence criteria, identification of accident scenarios and their frequency of occurrence, identification of IPLs, estimation of risk and review of existing risk control measures based on the acceptance criteria. (Refer figure 1)

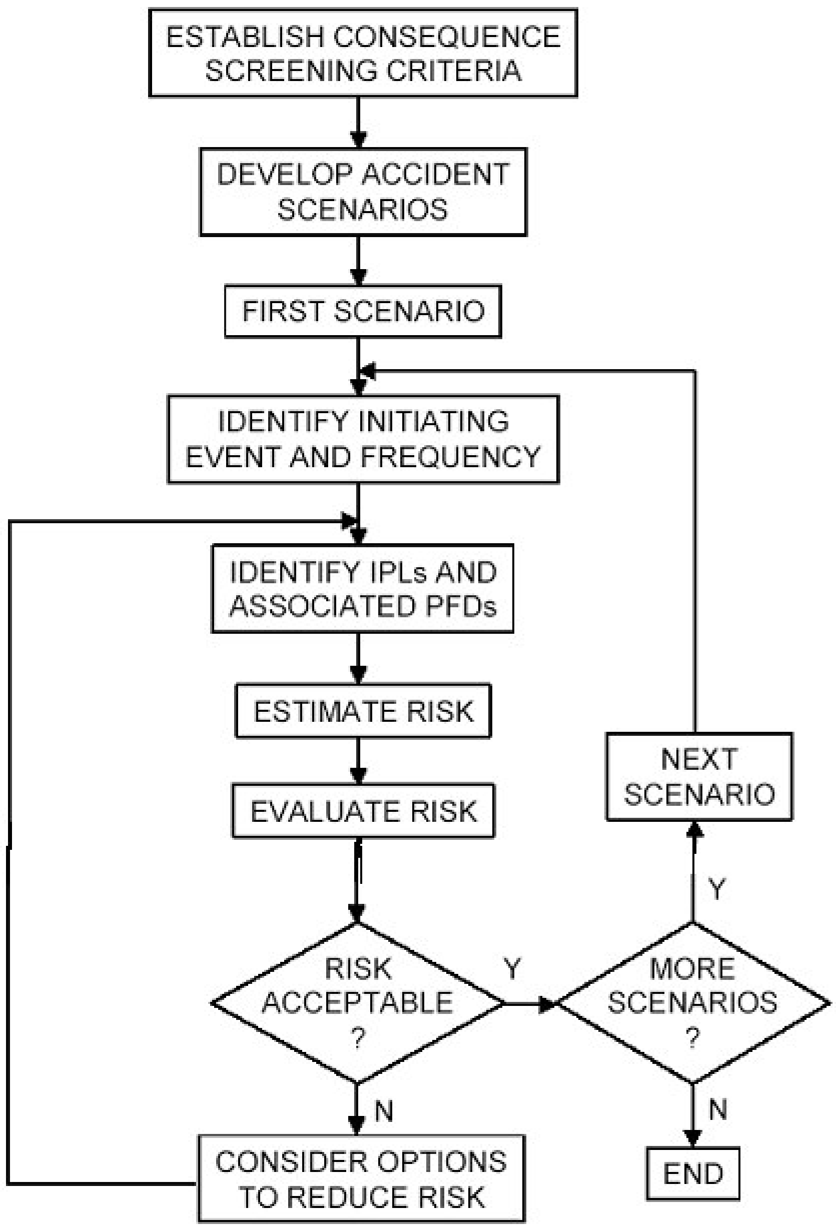


Fig 1: Steps involved in LOPA process

Criteria for evaluation

The crucial step of LOPA is evaluation process for which criteria need to be selected. Three criteria are considered for LOPA study :

- Consequence class characteristics,
- Likelihood estimation and
- Tolerance limits fixed by local legislations.

Consequence class

Consequence class characteristics are classified in different ways from three levels to five levels as chosen by the study team members. The basis for classification depends on local regulations and corporate safety and environment philosophy. Consequences are measured in terms of damage to people, property and environment. The extent of damage can be predicted by means of experimental values or simulated values available for the chemicals. The advantage of LOPA technique lies in the fact that it can be used even if no software simulation is available for quantification of consequences. To reduce the subjectivity, the guidelines for estimation of consequences have been developed by some experts based on the quantity of chemicals involved in the scenario. The guidelines suggested by Colin S. 'Chip' Howat Ph.D. are widely accepted for estimation purposes. (Refer table 1)

Release Characteristic \ Consequence Size	1- to 10-pound Release	10- to 100-pound Release	100- to 1,000-pound Release	1,000- to 10,000-pound Release	10,000- to 100,000-pound Release	>100,000-pound Release
Extremely toxic, above B.P.*	Category 3	Category 4	Category 5	Category 5	Category 5	Category 5
Extremely toxic, below B.P. or Highly toxic, above B.P.	Category 2	Category 3	Category 4	Category 5	Category 5	Category 5
Highly toxic, below B.P. or Flammable, above B.P.	Category 2	Category 2	Category 3	Category 4	Category 5	Category 5
Flammable, below B.P.	Category 1	Category 2	Category 2	Category 3	Category 4	Category 5
Combustible liquid	Category 1	Category 1	Category 1	Category 2	Category 2	Category 3

*B.P. = atmospheric boiling point

Consequence Characteristic \ Consequence Category	Spared or Nonessential Equipment	Plant Outage <1 Month	Plant Outage 1 to 3 Months	Plant Outage >3 Months	Vessel Rupture 3,000 to 10,000 gal 100 to 300 psig	Vessel Rupture >10,000 gal >300 psig
Mechanical damage to large main product plant	Category 2	Category 3	Category 4	Category 4	Category 4	Category 5
Mechanical damage to small by-product plant	Category 2	Category 2	Category 3	Category 4	Category 4	Category 5

Consequence Characteristic \ Consequence Cost (U.S. dollars)	\$0 – \$10,000	\$10,000 – \$100,000	\$100,000 – \$1,000,000	\$1,000,000 – \$10,000,000	> \$10,000,000
Overall cost of event	Category 1	Category 2	Category 3	Category 4	Category 5

Table 1: Guidelines on consequence estimation

It may be noted that categories can be defined in terms of financial loss as shown in table 1. However the values stated in the table may vary based on the size and financial risk tolerance limits chosen by the organization. The category referred in the table 1 is defined in terms of effects on plant personnel, community and environment as shown in table 2.

Consequence class	Plant personnel	Community	Environment
1/2	No lost time	No hazard	No notification
3.	Single injury	Odour / noise	Permit violation
4.	> 1 injury	One or more injuries	Serious offsite impact
5.	Fatality	One or more severe injuries	Serious offsite impact

Table 2: Definition of categories of consequence

Likelihood Estimation

The frequency of initiating event is based on the past industry data, company experience or incident histories. If no data available, estimation can be made based on the subjective assessment of expert team. Some of the data used by the industry for various events have been published in the literature. Table 3 gives the frequency details for few initiating events.

Initiating Event	Frequency Range from Literature (/yr)	Example of a Value Chosen by a Company for Use in LOPA (/yr)
Pressure Vessel Rupture	10^{-5} to 10^{-7}	$1x10^{-6}$
Piping Rupture - 100 m - Full Breach	10^{-5} to 10^{-6}	$1x10^{-5}$
Piping Leak (10% section) - 100 m	10^{-3} to 10^{-4}	$1x10^{-3}$
Atmospheric Tank Failure	10^{-3} to 10^{-5}	$1x10^{-3}$
Gasket/Packing Blowout	10^{-2} to 10^{-6}	$1x10^{-2}$
Turbine/Diesel Engine Overspeed with Casing Breach	10^{-3} to 10^{-4}	$1x10^{-4}$
Third-party Intervention (external impact by backhoe, vehicle, etc.)	10^{-2} to 10^{-4}	$1x10^{-2}$
Crane Load Drop	10^{-3} to 10^{-4}/Lift	$1x10^{-4}$(/Lift)
Lightning Strike	10^{-3} to 10^{-4}	$1x10^{-3}$
Safety Valve Opens Spuriously	10^{-2} to 10^{-4}	$1x10^{-2}$
Cooling Water Failure	1 to 10^{-2}	$1x10^{-1}$
Pump Seal Failure	10^{-1} to 10^{-2}	$1x10^{-1}$
Unloading/Loading Hose Failure	1 to 10^{-2}	$1x10^{-1}$
BPCS Instrument Loop Failure	1 to 10^{-2}	$1x10^{-1}$
Regulator Failure	1 to 10^{-1}	$1x10^{-1}$
Small External Fire (aggregate causes)	10^{-1} to 10^{-2}	$1x10^{-1}$
Large External Fire (aggregate causes)	10^{-2} to 10^{-3}	$1x10^{-2}$
Operator Failure (to execute a complete, routine procedure; well-trained operator, unstressed, not fatigued)	10^{-1} to 10^{-3}/Opportunity	$1x10^{-2}$/Opportunity

Table 3: Sample frequency table for few initiating events

The logarithmic frequency of failure can be explained analytically as stated in table 4 for simple understanding.

Likelihood	**Log frequency (/ yr)**
Well probable, frequent	0-1
Occasional	1-2
Remote	2-3
Improbable	3-4
Nearly impossible	4-5

Table 4: Relation between likelihood and log frequency

Total risk level can be estimated in terms of severity and probability and can be presented as shown below:

Location: Equipment:

Sl. No.	Initiating event (IE)	Probability Per year f_{IE}	Enabling Event (EE)	Probability Per year f_{EE}	Protective Independent Protective Layers (IPL) Probable Failure on demand (PFD)					Mitigating IPL PFD	Consequence	
											Class	Frequency
		F_1		F_2	P_1	P 2	P 3	P 4	P 5	P6		F1XF2XP1x P2xP3xP4X P5X P6

After identifying the class and frequency, the results of each envisaged scenario should be compared with the tolerance limits selected by the organizations based on the local regulations or voluntary corporate standards. As statutes in India do not specify acceptable risk limits in statutes explicitly the standards adopted by HSE, UK or Netherlands Government can be followed as reference guidelines.

The risk is estimated and expressed in two different forms: individual risk and societal risk. The individual risk is defined as the chance that a person staying at a fixed location permanently is killed as a result of an accident in the hazard zone (units / year). The societal risk follows a chance that in a single accident in the hazard source a certain number of victims is exceeded. For individual risk, the limit is 10^{-6} per year and for societal risks are set at $f = 10^{-3} / N^2$ as a guideline where N is the number of casualties present in the damage contours. The table no.5 gives a reference tolerance risk criteria adopted by a company handling Ammonium Nitrate based on the statute in Netherlands.

Frequency of consequence (/yr)	Consequence Category				
	Category 1	Category 2	Category 3	Category 4	Category 5
$10^{0} – 10^{-1}$			Not acceptable		
$10^{-1} – 10^{-2}$					
$10^{-2} – 10^{-3}$			Intermediate range		
$10^{-3} – 10^{-4}$					
$10^{-4} – 10^{-5}$					
$10^{-5} – 10^{-6}$		Acceptable			
$10^{-6} – 10^{-7}$					

Table 5: Risk tolerance criteria

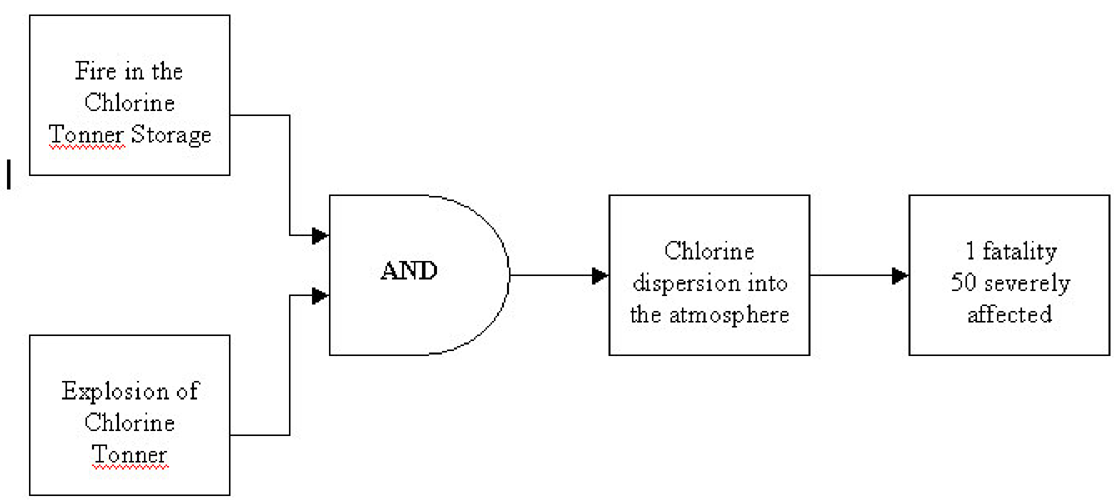
Box item 1 explains how LOPA can be used for a scenario of chlorine leak due to fire in the nearby vicinity.

Box item: 1

Example by using LOPA

Scenario: A simple single event consequence scenario of fire in chlorine tonner storage

Details: A fire occurs in a chlorine tonner storage area (initiating event). The fire causes an explosion of the chlorine tonner (enabling condition). The subsequent release of chlorine liquid/ gas may result in chlorine gas dispersion. The dispersion causes one fatality and injuries to 50 people in the vicinity.



The initiating event frequency (fire) is estimated as once every 100 years (0.01). The explosion of chlorine tonner is the enabling condition. The nearby presence and explosion of chlorine tonner is estimated as one out of ten times (0.1). Hence overall frequency for the scenario to occur is one in 1000 years. The consequence category from the scenario follows consequence class of 4. As per the risk tolerance table the scenario is unacceptable.

Effect of Independent Protective Layers

The frequency of the scenario can be changed by fire detection or a sprinkler system. Assuming that the detection system has the probability of failure of demand of one out of ten times the frequency of the scenario may get reduced from 10^{-3} to 10^{-4} per year. The strict guideline that all those in the hazardous area should use self contained breathing apparatus and Isolated location for chlorine shed can reduce the consequence. This makes the risk to come out of the unacceptable level. Further risk reduction measures or IPLs such as provision of chlorine detection cum alarm system, neutralization or scrubbing facility to take care of escaping chlorine gas etc can be employed.

Benefits of using LOPA

LOPA has numerous advantages compared to other qualitative risk assessment tools and combines the advantage of qualitative and quantitative tools. Some of the advantages are summarized below:

- Is a simple risk assessment tool and requires less time and resources than for a QRA but is more rigorous than HAZOP. It can be used a screening tool for QRA.
- Improves scenario identification by pairing of the cause and consequence from PHA studies
- Identifies operations, practices, systems and processes that do not have adequate safeguards and Helps in deciding the layers of protection required for a process operations and thereby focuses on the most critical safety systems. It helps to determine the need for Safety Instrumented Systems (SIS) and Safety Integrity Levels (SIL) for SIS. It provides basis for specification of IPLs as per ANSI/ISA S84.01, IEC 61508 and IEC 61511.
- Can be used as a Cost Benefit Analysis tool while selecting process safety instrumentation
- Is useful for making risk based decisions during stages like design, management of change, preparation of Safety Operating Procedures for operators, incident investigation, emergency response planning, bypassing a safety system etc
- Provides due credit to all protective layers and helps in estimating the specific risk level of the unit/ equipment.

- Removes subjectivity while providing clarity and consistency to risk assessment and helps to compare risks based on a common ground if it is used throughout a plant.
- Can be used as a tool in place of Quantitative Risk Analysis for substances for which standard damage distances or effects are not known. In such cases it helps decide if the risk is As Low As Reasonably Possible (ALARP) for compliance to regulatory requirements or standards.
- It also supports compliance with process safety regulations - including OSHA PSM 1910.119, Seveso II regulations, ANSI/ISA S84.01, IEC 61508 and IEC 61511

Limitations of LOPA

While using this technique, its limitations should also be kept in mind for deriving better results:

- Risk tolerance criteria must be established for LOPA exercise before the process starts. For countries where such criteria has not been specified by statutes it will be difficult to decide which standards are to be adopted.
- LOPA offers flexibility to the user in the areas of selecting IPLs and PFDs associated with the IPLs though the general industry data is available for the purpose. This brings in subjectivity in the assessment process and depends on the expertise of the user.
- It does not decide what specific IPLs should be used and decision depends on the experience and expertise of the user.

Conclusion

Process industries prefer techniques which can assess the risk levels and can identify the suitable safeguards for minimizing the risk levels to satisfy the statutory requirements. Semi Quantitative methods are favoured by industries for their less mathematical modeling. Among the semi quantitative methods, following methods can also be used though they are less known:

- The Technical Risk Audit Method (TRAM)
- AVRIM2, an audit and inspection tool developed for the Dutch Labour Inspectorate
- Protection Layer Analysis and Optimization (PLANOP)
- The Short-Cut Risk Assessment Method (SCRAM)
- Safety Barrier Diagrams

Though all of the above methods use layer of protection / line of defence concept, LOPA was found to be potentially the most useful for statutory purposes (Control of Major Accident Hazard Regulations (COMAH), 1999, UK) at the end of recent research. It is hoped that LOPA will get more prominence among the Indian Chemical Industries in the days to come and statutory recognition for such studies.

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