BowTie Pro

The modern, fast and easy to use risk analysis tool

Advanced Features

How to Quantify LOPA Probabilities in BowTie Pro™

BowTie Pro™
Westhill Business Centre
Arnhall Business Park
Westhill, Aberdeenshire,
AB32 6UF, UK

Tel: +44 (0) 1224 51 50 94

enquiries@BowTiePro.com
www.BowTiePro.com

Introduction

In this document Layer of protection analysis LOPA methodology is summarized in order to make it easier for BowTie Pro™ users to understand the idea behind it and easily utilise Bowtie pro LOPA function for their own scenarios.

Here, Comparing Calculated Risk to Scenario Risk Tolerance Criteria is only LOPA decision making tool is used as it is the criteria used in the software.

All the information found in this document came from the AICHE Center for Chemical Process Safety (CCPS) Layer of Protection Analysis guidelines.

Layer of Protection Analysis LOPA

What is LOPA?

LOPA is a simplified form of risk assessment. LOPA typically uses order of magnitude categories for initiating event frequency, consequence severity, and the likelihood of failure of independent protection layers (IPLs) to approximate the risk of a scenario.

LOPA is an analysis tool that typically builds on the information developed during a qualitative hazard evaluation, such as a process hazard analysis (PHA). LOPA is implemented using a set of rules.

Like many other hazard analysis methods, the primary purpose of LOPA is to determine if there are sufficient layers of protection against an accident scenario (can the risk be tolerated?).

As illustrated in the next figure, many types of protective layers are possible. A scenario may require one or many protection layers depending on the process complexity and potential severity of a consequence. Note that for a given scenario; only one layer must work successfully for the consequence to be prevented. However, since no layer is perfectly effective, sufficient protection layers must be provided to render the risk of the accident tolerable.

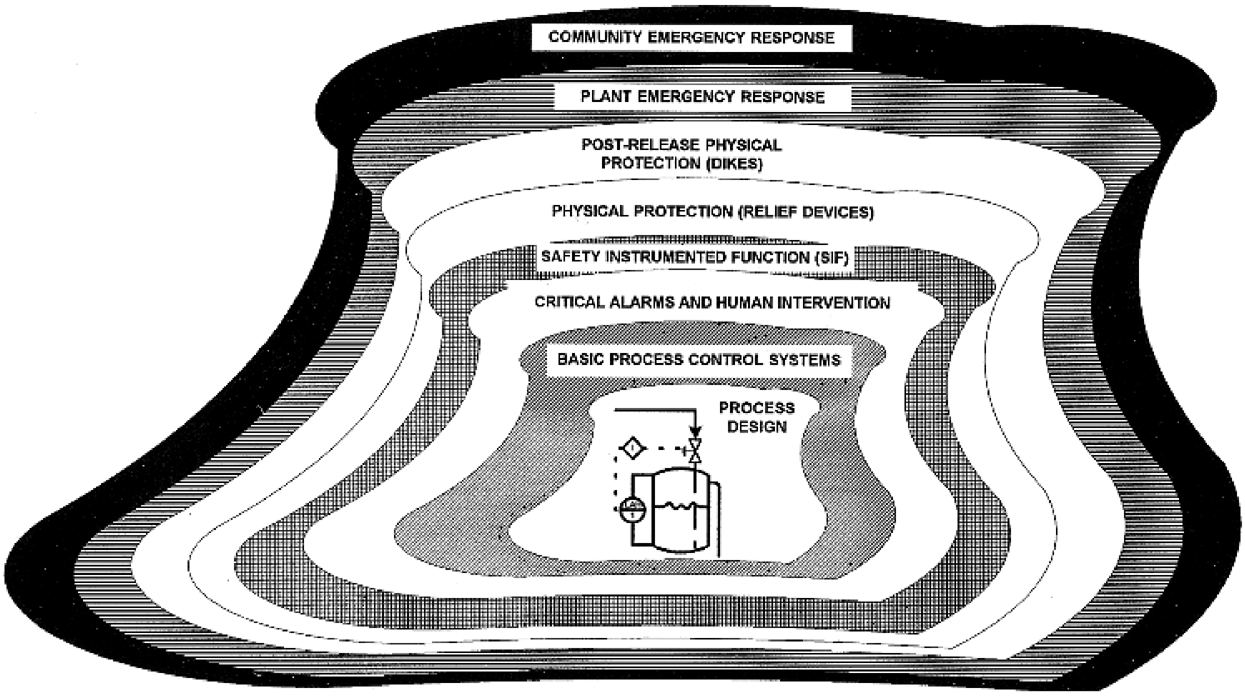

Figure 1 Layers of defense against a possible accident.

LOPA provides a consistent basis for judging whether there are sufficient IPLs to control the risk of an accident for a given scenario. If the estimated risk of a scenario is not acceptable, additional IPLs may be added. Alternatives encompassing inherently safer design can be evaluated as well. LOPA does **not** suggest which IPLs to add or which design to choose, but it assists in judging between alternatives for risk mitigation. LOPA is **not** a fully quantitative risk assessment approach, but is rather a simplified method for assessing the value of protection layers for a well-defined accident scenario.

What LOPA does

LOPA provides a risk analyst with a method to reproducibly evaluate the risk of selected accident scenarios. A scenario is typically identified during a qualitative hazard evaluation (HE), such as a PHA, management of change evaluation, or design review. LOPA is applied after an unacceptable consequence, and a credible cause for it, is selected. It then provides an order of magnitude approximation of the risk of a scenario.

LOPA is limited to evaluating a single cause–consequence pair as a scenario.

Once a cause–consequence pair is selected for analysis, the analyst can use LOPA to determine which engineering and administrative controls (often called safeguards) meet the definition of IPLs, and then estimate the as-is risk of the scenario. The results can then be extended to make risk judgments and to help the analyst decide how much additional risk reduction may be required to reach a tolerable risk level.

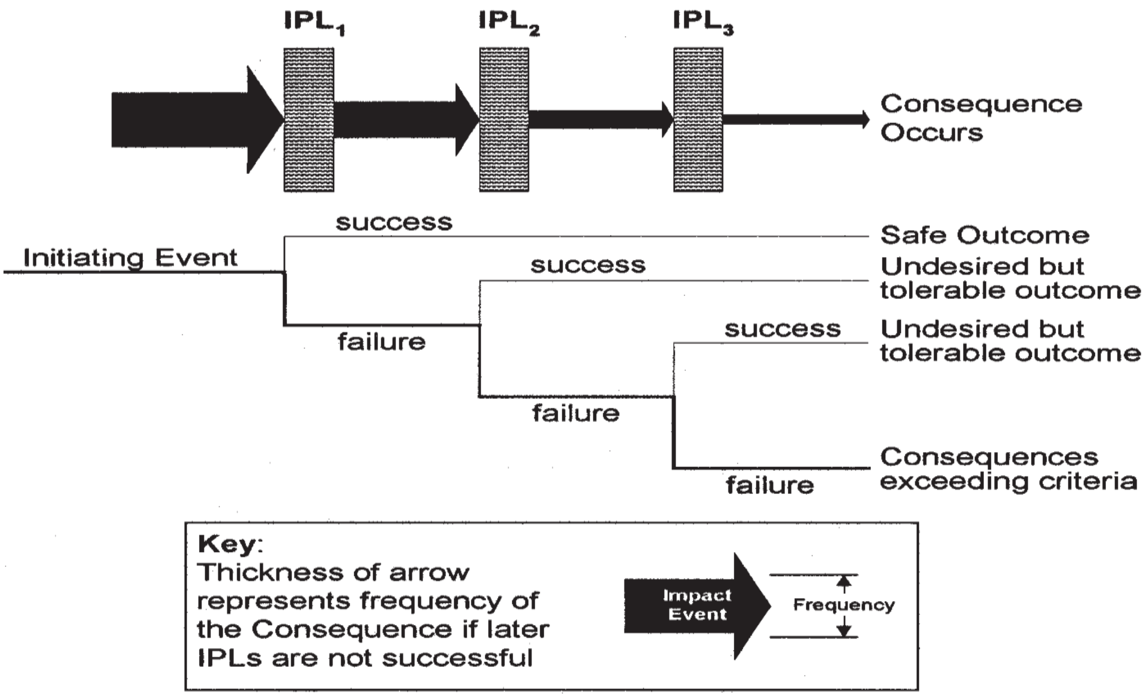

Figure 2 - Comparison between LOPA and Bowies / Event Trees

When to use LOPA

LOPA is typically applied after a qualitative hazard evaluation (e.g., Process Hazard Analysis) using the scenarios identified by the qualitative hazard review team. However, “typically” means just that - LOPA can also be used to analyse scenarios that originate from any source, including design option analysis and incident investigations. LOPA can also be applied when a hazard evaluation team (or other entity)

- ✓ believes a scenario is too complex for the team to make a reasonable risk judgment using purely qualitative judgment, or
- ✓ The consequences are too severe to rely solely on qualitative risk judgment.

How LOPA works

Like other methods, LOPA can be divided into steps. The LOPA steps are outlined in the next figure and summarized below.

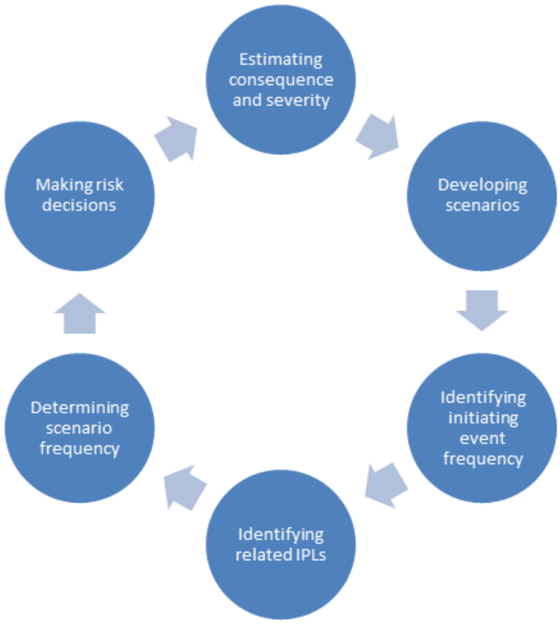

Figure 3 LOPA steps

Step 1: Identify the consequence to screen the scenarios.

Since LOPA typically evaluates scenarios that have been developed in a prior study, a first step by the LOPA analyst(s) is to screen these scenarios, and the most common screening method is based on consequence and an estimate of the Consequence magnitude. Some companies stop at the magnitude of a release (of material or energy), which implies, but does not explicitly state, the impact to people, the environment, and the production system. Other companies will model the release and more explicitly estimate the risk to people, the environment, and production by accounting for the likelihood of harm resulting from a specific scenario, for instance by also accounting for the probability of operators being in harm's way during a release scenario.

With the bow-tie methodology being an ideal way of ranking the consequence it is a natural that BowTie Pro™ has a LOPA analysis built into the system.

Release Characteristic	Size of Release (beyond a dike)					
	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 boiling point	Category 3	Category 4	Category 5	Category 5	Category 5	Category 5
Extremely toxic below boiling point or highly toxic above boiling	Category 2	Category 3	Category 4	Category 5	Category 5	Category 5
Highly toxic below boiling point or flammable above boiling point	Category 2	Category 2	Category 3	Category 4	Category 5	Category 5
Flammable below boiling point	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

Consequence Characteristic	Magnitude of Loss					
	Spared or non-essential equipment	Plant outage <1 month	Plant outage 1–3 months	Plant outage >3 months	Vessel rupture 3,000 to 10,000 gal 100–300 psi	Vessel rupture >10,000 gal >300 psi
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

Figure 4 Quantitative categorization

Low Consequence	
Personnel	Minor or no injury; no lost time
Community	No injury, hazard, or annoyance to public
Environment	Recordable event with no agency notification or permit violation
Facility	Minimal equipment damage at an estimated cost of less than $100,000 and with no loss of production
Medium Consequence	
Personnel	Single injury, not severe; possible lost time
Community	Odour or noise complaint from the public
Environment	Release that results in agency notification or permit violation
Facility	Some equipment damage at an estimated cost greater than $100,000 and with minimal loss of production
High Consequence	
Personnel	One or more severe injuries
Community	One or more minor injuries
Environment	Significant release with serious offsite impact
Facility	Major damage to process area(s) at an estimated cost greater than $1,000,000 or some loss of production
Very High Consequence	
Personnel	Fatality or permanently disabling injury
Community	One or more severe injuries
Environment	Significant release with serious offsite impact and more likely than not to cause immediate or long-term health effects
Facility	Major or total destruction of process area(s) at an estimated cost greater than $10,000,000 or a significant loss of production

Figure 5 Qualitative categorization

Step 2: Select an accident scenario

LOPA is applied to one scenario at a time.

The scenario can come from other analyses (such as qualitative analyses), but the scenario describes a single cause–consequence pair.

Step 3: Identify the initiating event of the scenario and determine the initiating event frequency (events per year).

The initiating event must lead to the consequence (given failure of all of the safeguards). The frequency must account for background aspects of the scenario, such as the frequency of the mode of operation for which the scenario is valid. Most companies provide guidance on estimating the frequency to achieve consistency in LOPA results

Initiating Event	Frequency Range from Literature (per year)	Example of a Value Chosen by a Company for Use in LOPA (per year)
Pressure vessel residual failure	10^{-5} to 10^{-7}	1×10^{-6}
Piping residual failure—100 m—Full Breach	10^{-5} to 10^{-6}	1×10^{-5}
Piping leak (10% section)—100 m	10^{-3} to 10^{-4}	1×10^{-3}
Atmospheric tank failure	10^{-3} to 10^{-5}	1×10^{-3}
Gasket/packing blowout	10^{-2} to 10^{-6}	1×10^{-2}
Turbine/diesel engine over speed with casing breach	10^{-3} to 10^{-4}	1×10^{-4}
Third party intervention (external impact by backhoe, vehicle, etc.)	10^{-2} to 10^{-4}	1×10^{-2}
Crane load drop	10^{-3} to 10^{-4} per lift	1×10^{-4} per lift
Lightning strike	10^{-3} to 10^{-4}	1×10^{-3}
Safety valve opens spuriously	10^{-2} to 10^{-4}	1×10^{-2}
Cooling water failure	1 to 10^{-2}	1×10^{-1}
Pump seal failure	10^{-1} to 10^{-2}	1×10^{-1}
Unloading/loading hose failure	1 to 10^{-2}	1×10^{-1}
BPCS instrument loop failure *Note:* IEC 61511 limit is more than 1×10^{-5}/hr or 8.76×10^{-2}/yr (IEC, 2001)	1 to 10^{-2}	1×10^{-1}
Regulator failure	1 to 10^{-1}	1×10^{-1}
Small external fire (aggregate causes)	10^{-1} to 10^{-2}	1×10^{-1}
Large external fire (aggregate causes)	10^{-2} to 10^{-3}	1×10^{-2}
LOTO (lock-out tag-out) procedure* failure *overall failure of a multiple-element process	10^{-3} to 10^{-4} per opportunity	1×10^{-3} per opportunity
Operator failure (to execute routine procedure, assuming well trained, unstressed, not fatigued)	10^{-1} to 10^{-3} per opportunity	1×10^{-2} per opportunity

Figure 6 - Typical frequencies as per CCPS

Step 4: Identify the IPLs and estimate the probability of failure on demand of each IPL.

Recall that LOPA is short for “layer of protection analysis.” Some accident scenarios will require only one IPL, while other accident scenarios may require many IPLs, or IPLs of very low probability of failure on demand, to achieve a tolerable risk for the scenario. Recognizing the existing safeguards that meet the requirements of IPLs for a given scenario is the heart of LOPA. Most companies provide a predetermined set of IPL values for use by the analyst, so the analyst can pick the values that best fits the scenario being analysed.

IPL	**Comments** *Assuming an adequate design basis and adequate inspection and maintenance procedures*	**PFD from Literature and Industry**	**PFD Used here** (For screening)
Dike	Will reduce the frequency of large consequences (widespread spill) of a tank overfill/rupture/spill/ etc.	$1 \times 10^{-2} – 1 \times 10^{-3}$	1×10^{-2}
Underground Drainage System	Will reduce the frequency of large consequences (widespread spill) of a tank overfill/rupture/spill/ etc.	$1 \times 10^{-2} – 1 \times 10^{-3}$	1×10^{-2}
Open Vent (no valve)	Will prevent over pressure	$1 \times 10^{-2} – 1 \times 10^{-3}$	1×10^{-2}
Fireproofing	Will reduce rate of heat input and provide additional time for depressurizing/firefighting/etc.	$1 \times 10^{-2} – 1 \times 10^{-3}$	1×10^{-2}
Blast-wall/ Bunker	Will reduce the frequency of large consequences of an explosion by confining blast and protecting equipment/buildings/etc.	$1 \times 10^{-2} – 1 \times 10^{-3}$	1×10^{-3}
"Inherently Safe" Design	If properly implemented can significantly reduce the frequency of consequences associated with a scenario. Note: the LOPA rules for some companies allow inherently safe design features to eliminate certain scenarios (e.g., vessel design pressure exceeds all possible high pressure challenges).	$1 \times 10^{-1} – 1 \times 10^{-6}$	1×10^{-2}
Flame/Detonation Arrestors	If properly designed, installed and maintained these should eliminate the potential for flash- back through a piping system or into a vessel or tank.	$1 \times 10^{-1} – 1 \times 10^{-3}$	1×10^{-2}

Figure 7 - Examples of passive IPLs

IPL	**Comments** *Assuming an adequate design basis and inspection/maintenance procedures*	**PFD from Literature and Industry**	**PFD Used in This document** (For screening)
Relief valve	Prevents system exceeding specified overpressure. Effectiveness of this device is sensitive to service and experience.	$1 \times 10^{-1} – 1 \times 10^{-5}$	1×10^{-2}
Rupture disc	Prevents system exceeding specified overpressure. Effectiveness can be very sensitive to service and experience	$1 \times 10^{-1} – 1 \times 10^{-5}$	1×10^{-2}
Basic Process Control System	Can be credited as an IPL if not associated with the initiating event being considered (See IEC 61508 (IEC, 1998) and IEC 61511 (IEC, 2001) for additional discussion.)	$1 \times 10^{-1} – 1 \times 10^{-2}$ ($>1 \times 10^{-1}$ allowed by IEC)	1×10^{-1}
Safety Instrumented Functions (Interlocks)	See IEC 61508 (IEC, 1998) and IEC 61511 (IEC, 2001) for life cycle requirements and additional discussion		
SIL 1	Typically consists of: Single sensor (redundant for fault tolerance) Single logic processor (redundant for fault tolerance) Single final element (redundant for fault tolerance)	$\geq 1 \times 10^{-2}$–$<1 \times 10^{-1}$	This document does not specify a specific SIL level. Continuing examples calculate a required PFD for a SIF
SIL 2	Typically consists of: "Multiple" sensors (for fault tolerance) "Multiple" channel logic processor (for fault tolerance) "Multiple" final elements (for fault tolerance)	$\geq 1 \times 10^{-3}$–$<1 \times 10^{-2}$	
SIL 3	Typically consists of: Multiple sensors Multiple channel logic processor Multiple final elements	$\geq 1 \times 10^{-4}$–$<1 \times 10^{-3}$	

Figure 8 Examples of active IPLs

Note: Multiple includes 1 out of 2 (1oo2) and 2 out of 3 (2oo3) voting schemes

"Multiple" indicates that multiple components may or may not be required depending upon the architecture of the system, the components selected and the degree of fault tolerance required to achieve the required overall PFD and to minimize unnecessary trips caused by failure of individual components (see IEC 61511 (IEC, 2001) for guidance and requirements).

Step 5: Estimate the risk of the scenario by mathematically combining the consequence, initiating event, and IPL data.

We need now to calculate the actual frequency of the potential consequence we included in our scenario using the following equation:

$$= f_i \times \text{PFD}_{i1} \times \text{PFD}_{i2} \times \ldots\ldots \times \text{PFD}_{ij}$$

We have already known from the previous figures the category of our potential consequence.

Then, we need to compare the calculated frequency with the target value from the next figure to know whether we need to add a new IPL or take any further actions.

Frequency of Consequence (per year)*	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6
10^{-0}	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)	Immediate action (notify corporate management)	Immediate action (notify corporate management)	Immediate action (notify corporate management)
10^{-1}	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)	Immediate action (notify corporate management)	Immediate action (notify corporate management)
10^{-2}	No further action	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)	Action at next opportunity (notify corporate management)	Immediate action (notify corporate management)
10^{-3}	No further action	No further action	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)	Action at next opportunity (notify corporate management)
10^{-4}	No further action	No further action	No further action	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)
10^{-5}	No further action	No further action	No further action	No further action	Optional (evaluate alternatives)	Optional (evaluate alternatives)
10^{-6}	No further action	No further action	No further action	No further action	No further action	Optional (evaluate alternatives)
10^{-7}	No further action	No further action	No further action	No further action	No further action	No further action

*For example, 10-2 is equivalent to 1/100 years.

Figure 9 - Risk matrix with individual action zone