BowTie
Pro

The modern, fast and easy to use risk analysis tool

Cloud Edition
Advanced Features

Using LOPA to
Quantify a BowTie Analysis

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Introduction

Layers of Protection Analysis (LOPA) is one of many safety systems that are often used to analyse how to reduce the risk associated with a potentially hazardous process or plant. The result is determined by a calculation and this is compared to the acceptable level which is usual to expressed as a Safety Integrity Level (SIL). As such, selecting an appropriate SIL is a fundamental step in any safety specification. LOPA is arguably the method of choice and fits well into the bowtie methodology as the Threats, Controls and Consequences have already been identified.

Why LOPA?

LOPA is a systematic semi-quantitive methodology for examining defence-in-depth and assigning SIL targets. Its careful application can ensure that an organisation achieves a defined and consistent level of safety across all of its processes and plant. This is usually based on the outcomes of a bow-tie analysis. The following bowtie displays the result of an overfill of a tank in a refinery. The analysis has identified high consequence results.
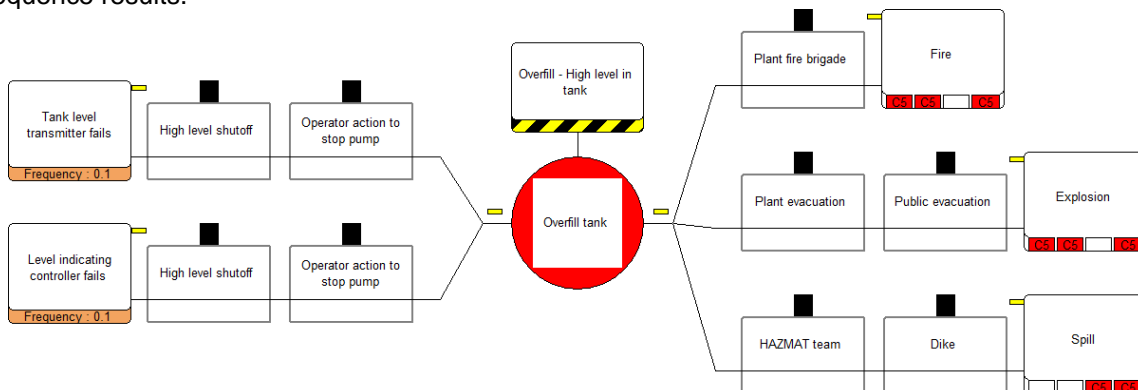
One or more Threats may lead to a Consequence. Each Threat-Consequence pair is called a branch. LOPA focuses on one branch at time. In the example above there are six possible branches i.e. Threat 1 to each of the three consequences and Threat 2 to each of the three consequences.

A Frequency needs to be assigned to each Threat. A Threat may need an Enabling Factor for the Threat to be released and this can also be entered in LOPA diagram, then each Control is evaluated for reducing the probability of the Threat causing the event to reach the Consequence.

For this to be evaluated each Control must be an Independent Protection Layer (IPL) which, as standard, is defined by two key characteristics:
✓   the Control is effective in preventing the scenario from reaching the Consequence
✓   the Control is independent of the initiating event and the other Controls
If the safeguard meets BOTH of these tests, it is an IPL.

The figure right illustrates the concept of LOPA, ie that each IPL acts as a barrier to reduce the frequency of the consequence. The thickness of the arrow represents the frequency of the Consequence if later IPLs are not successful.
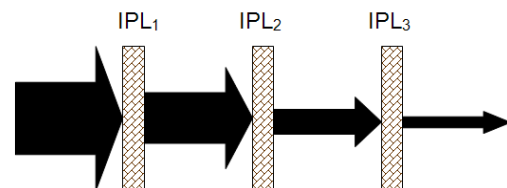
In many cases the barrier is a physical system such as a cut-off valve and these systems can have a Probability of Failure on Demand (PFD) defined from historical evidence. The equipment types can be added to an item of equipment in the set-up and each Control can have one item of equipment (labelled a system). By using this method the "Equipment Swiss cheese" model is developed, as shown left. Within BowTie Pro™ the Equipment Systems can be coloured.
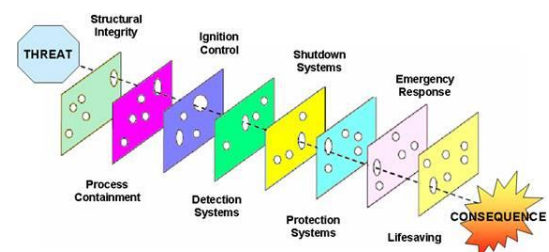
The Bowtie LOPA Process

The LOPA approach is to
- ✓ Develop the bowties
- ✓ Identify the high risk consequences for analysis
- ✓ Determine the branch by selecting the Threat and the Consequence already entered into the bowties
- ✓ Calculate the Frequency of the Consequence by:
  - ▪ Identifying the Threat Frequency for the branch (mandatory)
  - ▪ Identifying all the Enabling Factor for the branch (optional)
  - ▪ Quantifying the probability of failure of each control along the branch
  - ▪ Identifying all the Conditional Modifiers for the branch (optional)
- ✓ Identify an Acceptance Criteria
- ✓ Determine if the Consequence is acceptably managed ALARP

How to enable Bowtie LOPA module

The LOPA module is included in BowTie Pro Cloud Edition but needs to be enabled. This is performed in the "Overall Settings" within the Admin section by selecting "**Use LOPA Module**"

How is LOPA implemented?

LOPA is often only used on high risk Consequences. Consequences that have been assigned as high risk can be viewed in the Risk Register. The screen is opened by going Analysis -> Risk Register on the menu bar.
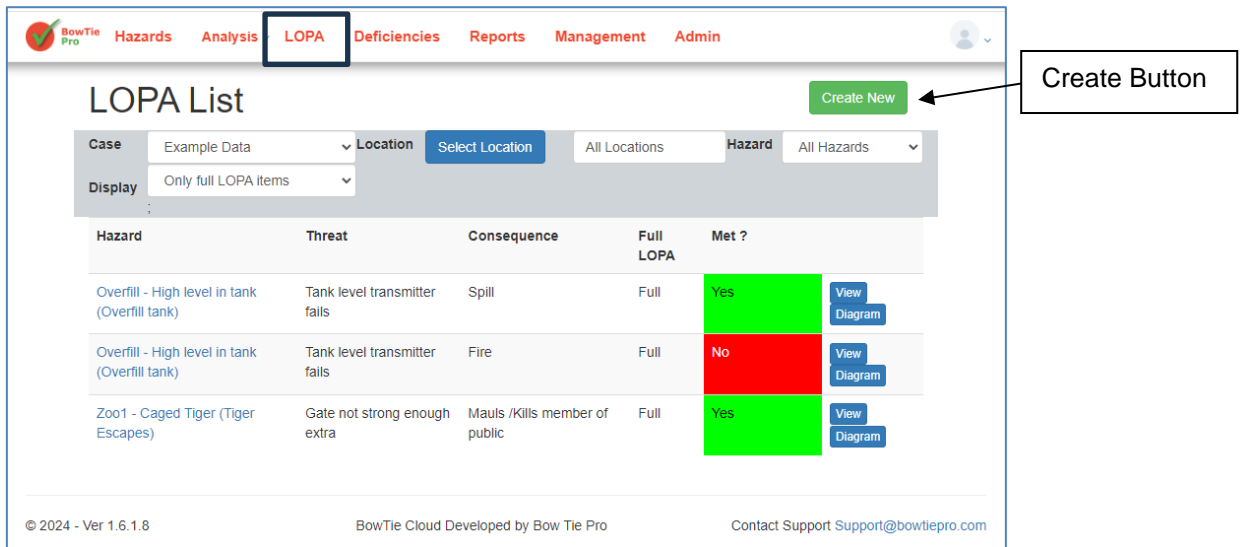
Risk Register

Hazard	Consequence	P	A	E	R
Overfill High level in tank (Overfill tank)	Fire	C5	C5		C5
Overfill High level in tank (Overfill tank)	Explosion	C5	C5		C5
Overfill High level in tank (Overfill tank)	Spill			C5	C5

Case: Example Data   Location: Select Location   Tank Filling   Display: Standard Register   Export to Excel

Once the risks that require further analysis have been identified a LOPA analysis can begin.

The easiest way to create or see the existing LOPA analysis branches is on the "LOPA Links" tab on the Hazard Overview screen.

Hazard Overview

Location	Zoo
Hazard	Zoo1 - Caged Tiger
Top Event	Tiger Escapes

Diagram Edit Delete Copy Email User History

Tree View Details Sign Off Deficiencies LOPA Links Reports

LOPA Links

Create New

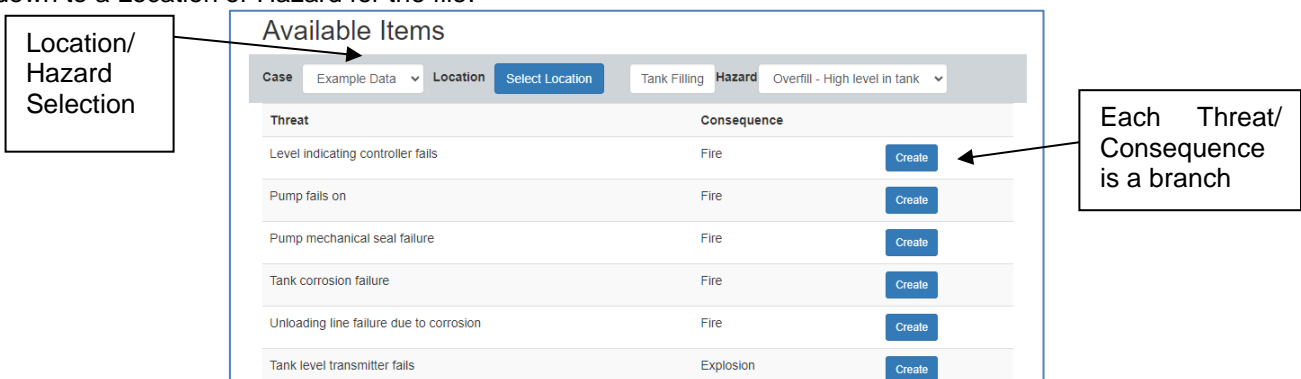| Threat	Consequence	Full LOPA	Met ?		
Gate not strong enough extra	Mauls /Kills member of public	Full	Yes	View	Diagram

All the LOPA branches can be viewed on the LOPA List screen which can be reached by pressing the LOPA button at the top of the site.
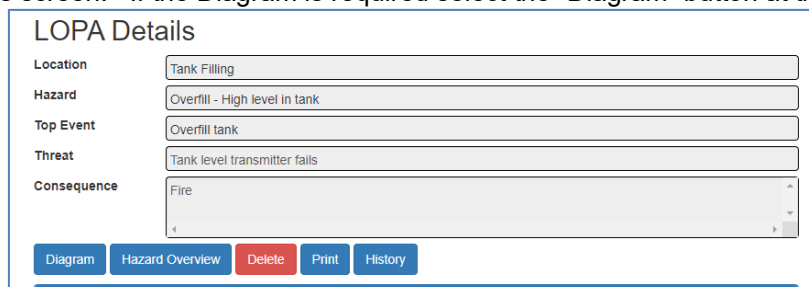

This screen will list all existing LOPA analysis. The line displays the Threat / Consequence branch and the Acceptance Criteria and if it passes this acceptance is passed is displayed on the right. More details on this is discussed later in this document.

To start a new assessment click "Create New" button from either screen. This will show the available threats to consequences that do not already have a LOPA assessment against it. This list can be filtered down to a Location or Hazard for the file.

Press the "Create" button next to the appropriate branch. This will create the LOPA Assessment and open up the LOPA Details screen. If the Diagram is required select the "Diagram" button at the top of the screen.

To start refining the branch, edit the Threat. This will display a different Threat screen to the one used when developing the bowties.

The description is read-only and the Frequency is now a mandatory value. This is the same as the value entered on the bowtie Threat screen and is defined as the Frequency of the Threat occurring per year, in this example 10^{-1} (0.1).   Ideally a justification for this Frequency should also be provided.

Enabling Factors are events or conditions that make it possible for the Threat to occur.   It is possible to add many Enabling Factors but these are not mandatory.   The Enabling Factor is selected from the list of predefined items and each of these items has a value defined.
The list of used Enabling Factors is displayed in the middle of the Threat screen and additional factors can be added to the branch by selecting the grid and pressing "New" from the popup menu.

This will then display the Linked Enabling Factor screen from which a value can be selected, and a justification can be entered.
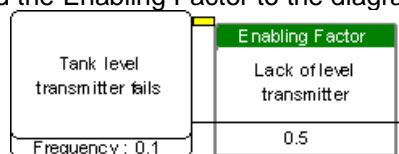

To remove an item simply highlight the item in the list on the Threat screen and then press "Remove" from the right click menu.   This can also be done on the diagram using the right click menu when over the object.

This will change the diagram and add the Enabling Factor to the diagram

Each of the controls can now be assessed in turn in the LOPA Control screen.

The control can have a Probability of Failure on Demand (PFD). The PFD is independent of the other controls on similar branches eg the same control but leading to a fire rather than a Spill may have a different value

The PFD setting can come from either the value defined on the Equipment or a value manually entered.   If the item does come from the equipment then the equipment will be listed on the PFD and the Equipment Category colour will be used as the background. If manually entered then it will just display the PDF as shown on the control on the right
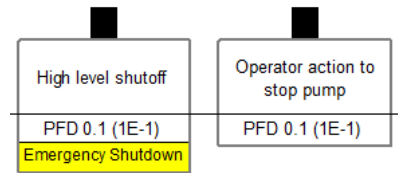
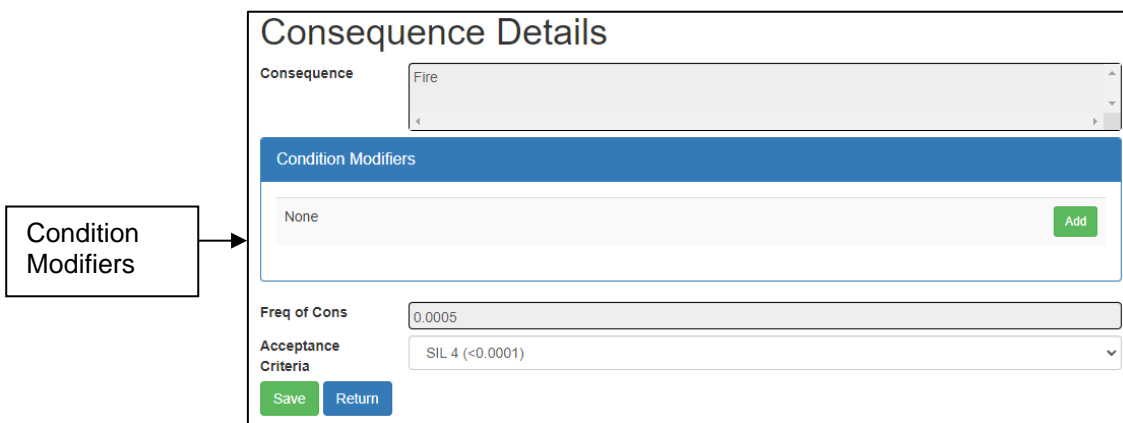A justification can be added to explain why this PFD was entered.

If the control is not appropriate in this particular branch then un-tick the "Use in calculation" checkbox on the controls screen highlighted above. This will remove the value when making the calculation of the overall frequency and will also draw the control as a dark box if "LOPA show all Controls" options is ticked on the Diagram menu bar or not show the control at all if this option is not checked.
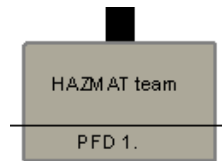
The title on the control screen is read-only and can only be changed on the main bowtie.
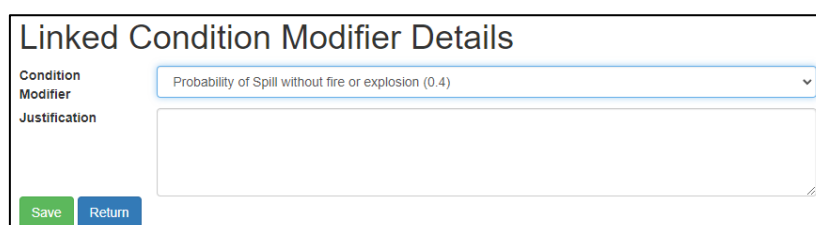
The Consequence displays the result of all the frequency calculation eg

Threat Frequency
x
Enabling Factor
**x**
PFD of each control
=
Result

From this screen or the diagram it is possible to add many Condition Modifiers. A condition modifier is used to determine the probability of a specific event, eg in this example if there is a release of oil what is the probability of it just spilling rather than causing a fire. The list of used Condition Modifiers is displayed in the middle of the screen and additional Condition Modifiers can be added to the branch.

This will then display the Linked Condition Modifier screen and allow a justification for selecting this value to be entered.

To remove an item simply click the "Delete" button on the right hand side of the item in the Condition Modifier list.
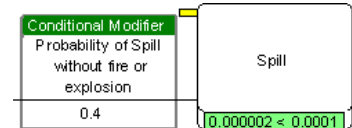
The condition modifiers will be displayed on the diagram

The bottom of the consequence screen displays the result of the Frequency of the Consequence calculation and allows the acceptance criteria to be defined.

The acceptance criteria can be defined in many ways. If it is determined that an acceptable target frequency of fire is less than 10^{-6} per annum then this can be entered in the acceptable list and selected on the Consequence screen. The acceptance criteria can be amended in the Admin -> "Acceptance Criteria" under the "Layers of Protection" section.

A possible way of defining the acceptance is to use the Safety Integrity Level (SIL) for safety functions operating in low demand of operation adapted from IEC 61511 (2003) as shown in the Table below.

Safety integrity level (SIL)	Average probability of failure to perform its design function on demand
SIL 4	$<10^{-4}$
SIL 3	$<10^{-3}$
SIL 2	$<10^{-2}$
SIL 1	$<10^{-1}$

Whatever the acceptance criteria used BowTie Pro™ will display if the criteria is Met by displaying a red or green bar at the bottom of the screen and the Consequence box on the diagram.

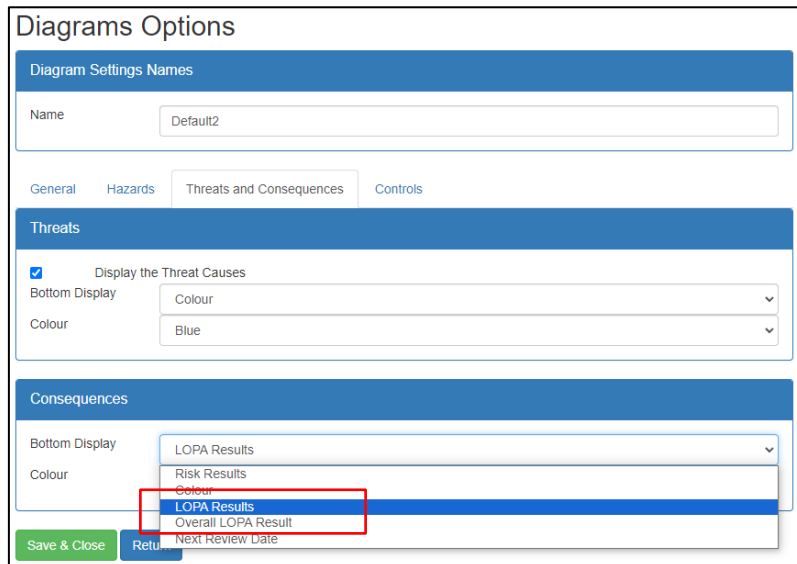The result will look something like the diagram below.
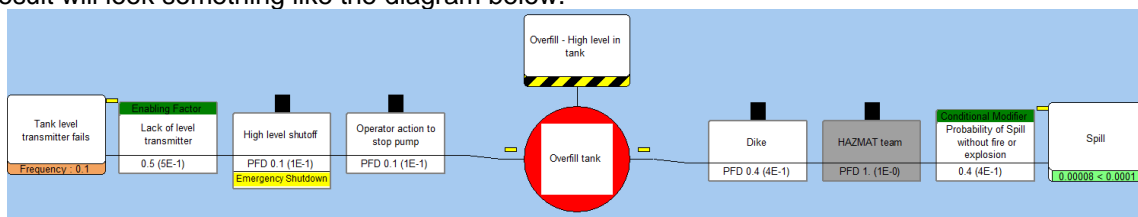
The data can be entered either on the diagram or using a non-visual LOPA details screen but the method and calculation remain the same.
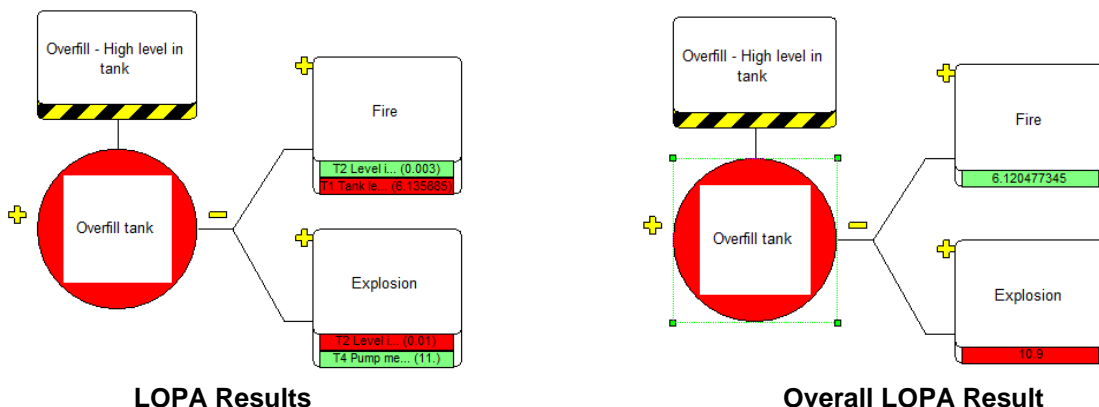
Overall LOPA Consequence Acceptable

Once the LOPA analysis has been completed on several branches the overall LOPA analysis can be set for a consequence. This is completed on the bowtie diagram.
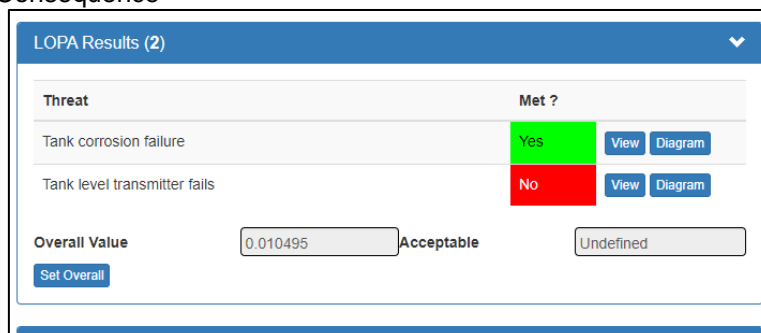
There are different ways to display the LOPA results on the bowtie diagram. These are set on the Consequence tab in the "Diagram Options" screen

The two settings are

LOPA Results   **Overall LOPA Result**

The LOPA Results show the result of the branch-by-branch analysis as described above. The Overall LOPA result is determined on a screen which is accessed by selecting on a Consequence in the Hazard Details tree and then pressing the "Set Overall" in the "LOPA Results" section. This is only available when there are multiple results for a Consequence

The screen lists all the LOPA Branch results and the "Frequency of the Consequence" as described above. An overall value is shown which is calculated by using the following formula

*Overall Value = (LOPA Result Threat 1) + (LOPA Result Threat 2) + (LOPA Result Threat 3) – ((LOPA Result Threat 1) * (LOPA Result Threat 2) * (LOPA Result Threat 3))*

The determination of whether this meets an acceptable level is qualitative. If the value is set to met then the value will be displayed with a green background and if it is not met then the background will be red.

Overall Consequence Value

Consequence: Fire

Threat	Full LOPA	Freq of Cons	Met ?	
Tank corrosion failure	Full	0.01	Yes	View
Tank level transmitter fails	Full	0.0005	No	View

Overall Value: 0.010495   Acceptable: Yes

Save Return

Overall Acceptable calculated value Details

Overall Acceptable Level