



The modern, fast and easy to use risk analysis tool

Advanced Features

Using LOPA to Quantify a BowTie Analysis

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

Tel: +44 (0) 1224 51 50 94

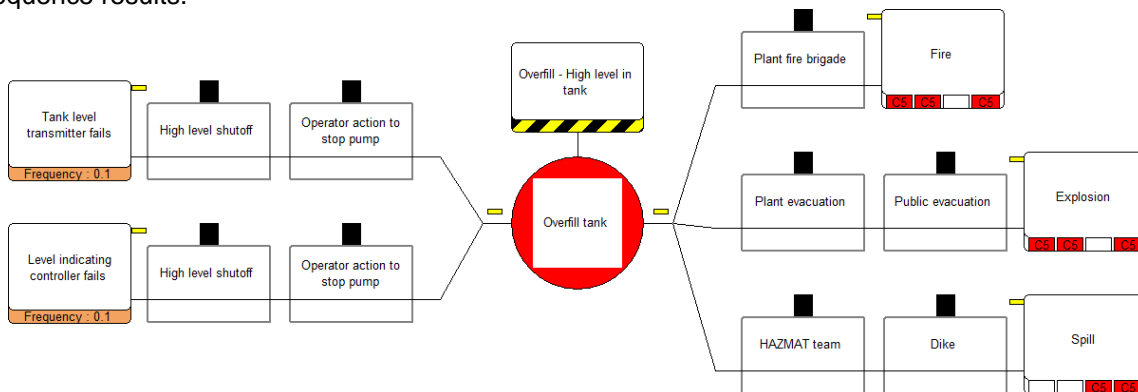
enquiries@BowTiePro.com
www.BowTiePro.com

Introduction

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 usually 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-quantitative 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 overflow 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 a 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.

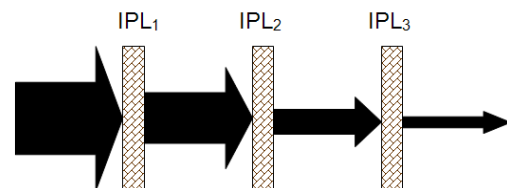
A Frequency needs to be assigned to each Threat. A Threat may need an Enabling Factor for the Threat to be released and this can also be entered in LOPA diagram, then each Control is evaluated for reducing the probability of the Threat causing the event to reach the Consequence.

For this to be evaluated each Control must be an Independent Protection Layer (IPL) which, as standard, is defined by two key characteristics:

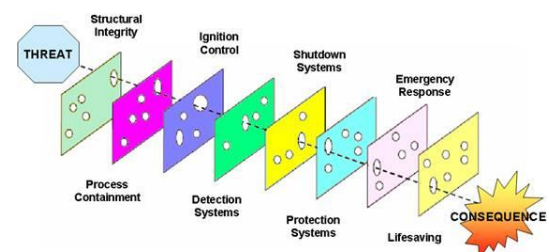
- ✓ the Control is effective in preventing the scenario from reaching the Consequence
- ✓ the Control is independent of the initiating event and the other Controls

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.



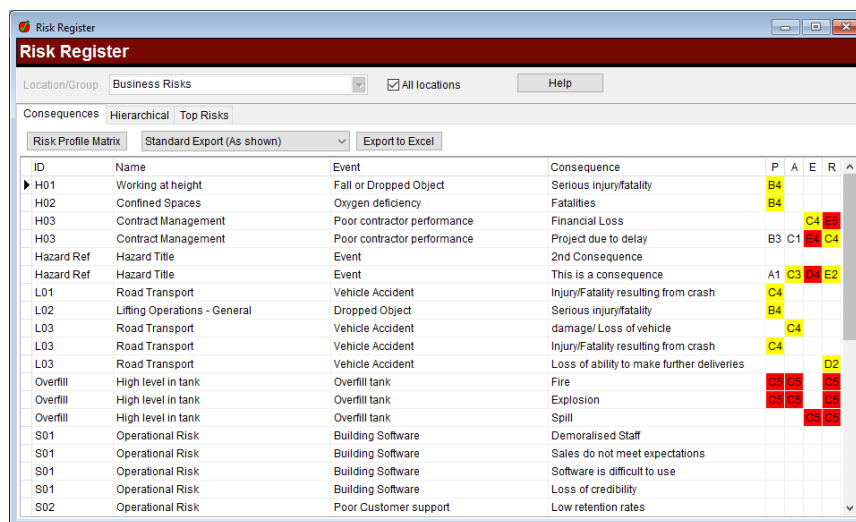
The Bowtie LOPA Process

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 is LOPA implemented?

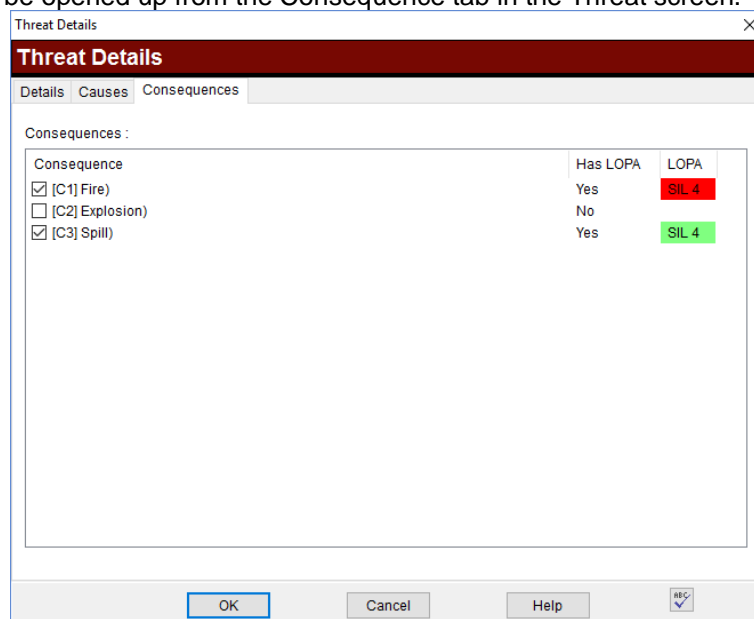
The Risks that require further analysis can be viewed in the Risk Register. The Risk Register allows entry and analysis of Hazards and Consequences on a screen similar to a Hazard Register. The screen is opened by going Analysis -> Risk Register on the menu bar.




ID	Name	Event	Consequence	P	A	E	R
H01	Working at height	Fall or Dropped Object	Serious injury/fatality	B4			
H02	Confined Spaces	Oxygen deficiency	Fatalities	B4			
H03	Contract Management	Poor contractor performance	Financial Loss		C4	E5	
H03	Contract Management	Poor contractor performance	Project due to delay	B3	C1	E4	C4
Hazard Ref	Hazard Title	Event	2nd Consequence				
Hazard Ref	Hazard Title	Event	This is a consequence	A1	C3	D4	E2
L01	Road Transport	Vehicle Accident	Injury/Fatality resulting from crash		C4		
L02	Lifting Operations - General	Dropped Object	Serious injury/fatality		B4		
L03	Road Transport	Vehicle Accident	damage/ Loss of vehicle			C4	
L03	Road Transport	Vehicle Accident	Injury/Fatality resulting from crash		C4		
L03	Road Transport	Vehicle Accident	Loss of ability to make further deliveries				D2
Overfill	High level in tank	Overfill tank	Fire	C2	C3	C3	
Overfill	High level in tank	Overfill tank	Explosion	C2	C3	C3	
Overfill	High level in tank	Overfill tank	Spill				C5
S01	Operational Risk	Building Software	Demoralised Staff				
S01	Operational Risk	Building Software	Sales do not meet expectations				
S01	Operational Risk	Building Software	Software is difficult to use				
S01	Operational Risk	Building Software	Loss of credibility				
S02	Operational Risk	Poor Customer support	Low retention rates				

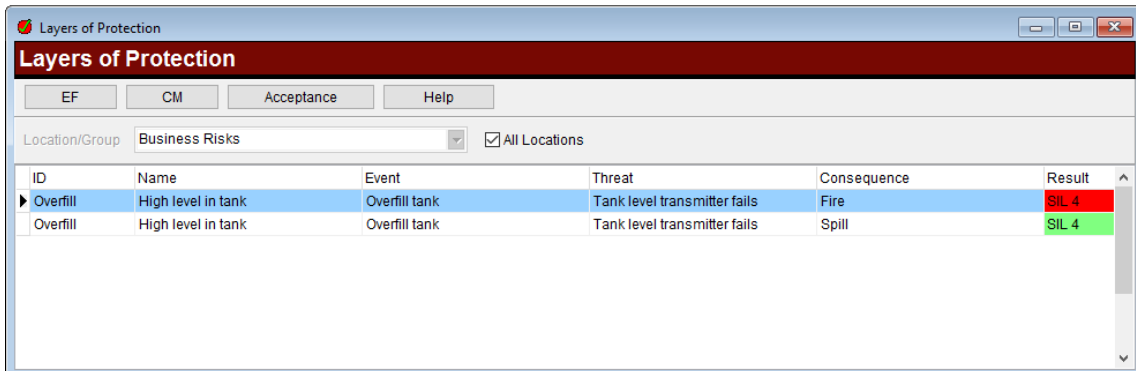
Once the risks that require further analysis have been identified a LOPA analysis can begin.

A LOPA analysis can be opened up from the Consequence tab in the Threat screen.



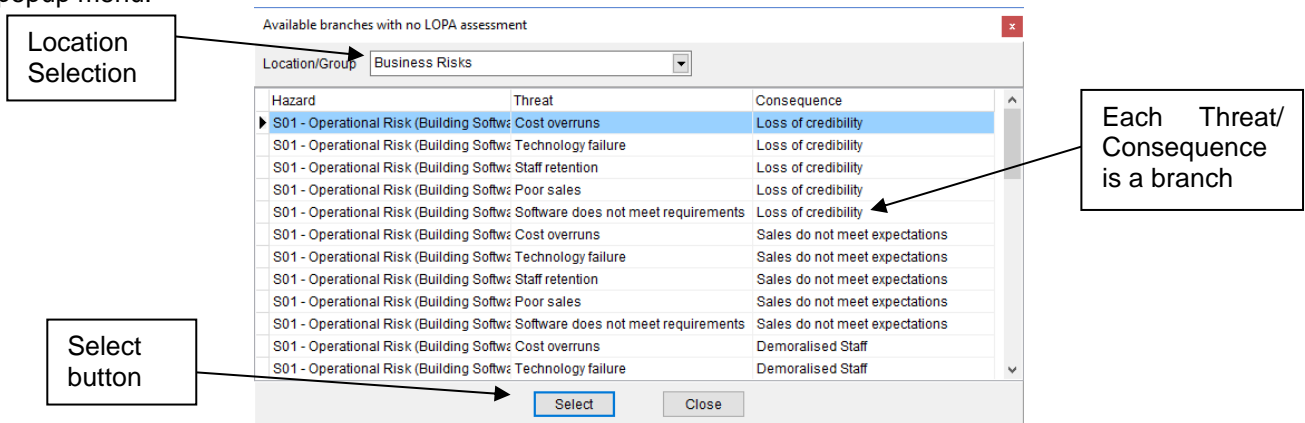
Consequence	Has LOPA	LOPA
<input checked="" type="checkbox"/> [C1] Fire)	Yes	SIL 4
<input type="checkbox"/> [C2] Explosion)	No	
<input checked="" type="checkbox"/> [C3] Spill)	Yes	SIL 4

All the LOPA branches can be viewed on the Layers of Protection Manager screen, from which all other analyses branches for the open file can be managed. This screen is accessed by going to the Analysis -> "Layers of Protection" option from the tool bar or by clicking the  button on the menu bar.



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.

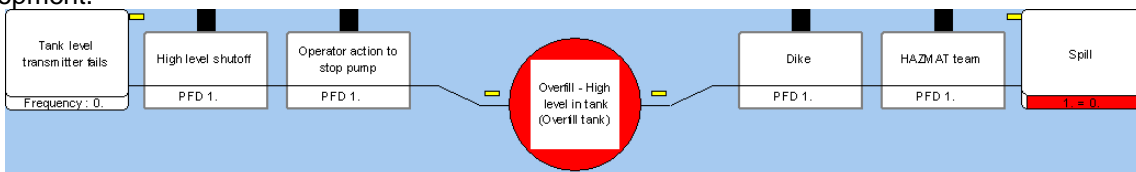
To start a new assessment right click on the bottom section and select "New LOPA Assessment" from the popup menu.



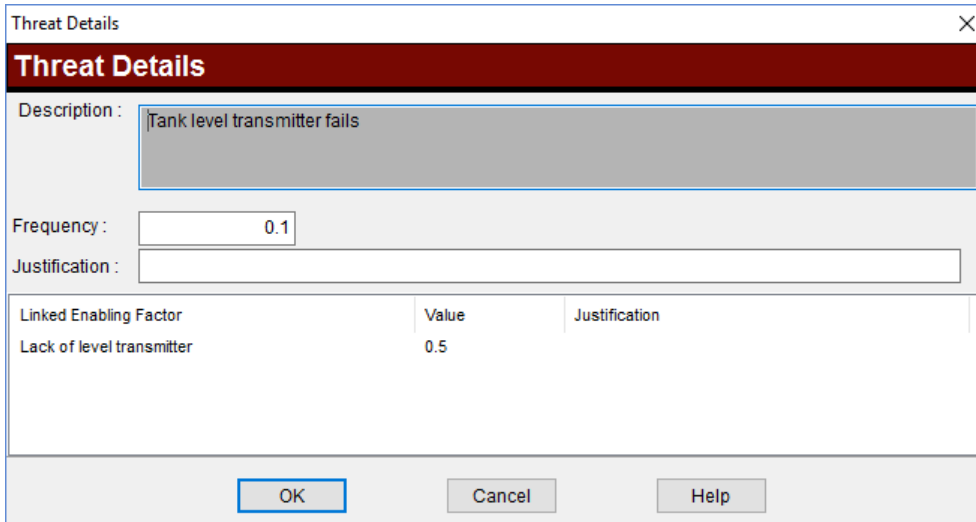
This will show all the branches that do not already have a LOPA assessment against them categorised by location.

Select the Threat -> Consequence branch that you wish to analyse and then press the "Select" button on the bottom of the screen

This will create a new LOPA analysis and open up a LOPA diagram from which you can start the development.



To start refining the branch, double click on the Threat. This will display a different Threat screen that is used when developing the bowties.



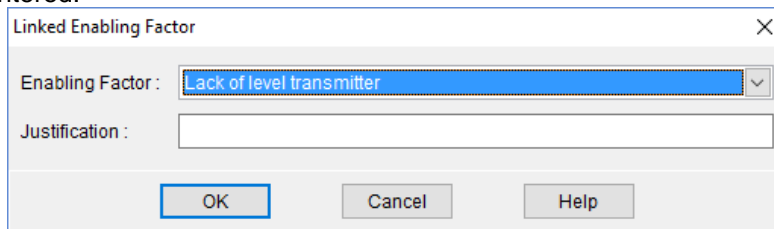
Linked Enabling Factor	Value	Justification
Lack of level transmitter	0.5	

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.

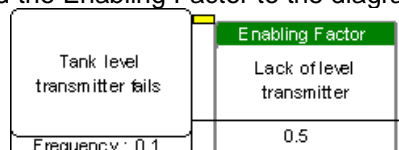
The list of used Enabling Factors is displayed in the middle of the Threat screen and additional factors can be added to the branch by selecting the grid and pressing “New” from the popup menu.

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

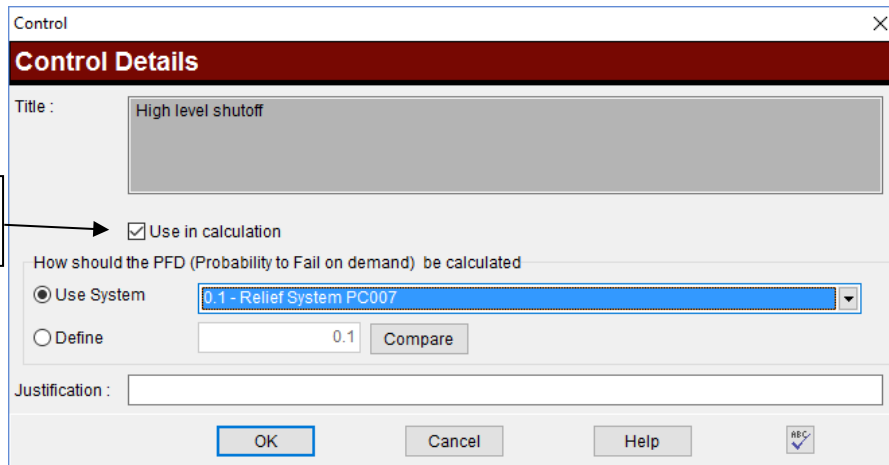


To remove an item simply highlight the item in the list on the Threat screen and then press “Remove” from the right click menu. This can also be done on the diagram using the right click menu when over the object.

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



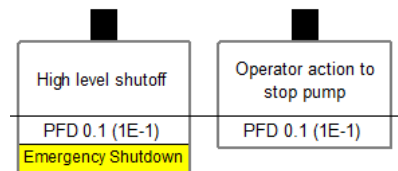
Each of the controls can now be assessed in turn. Double clicking on an item will open up the LOPA Control screen.



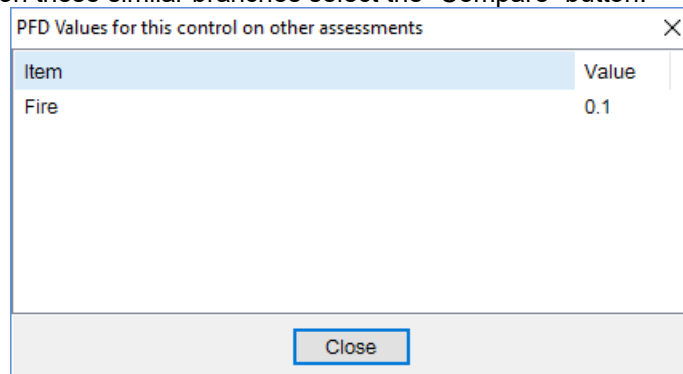
Use in Calculation

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



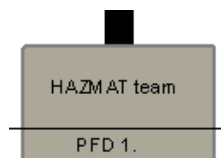
To view the other PFDs on these similar branches select the “Compare” button.



Item	Value
Fire	0.1

A justification can be added to explain why this PFD was entered.

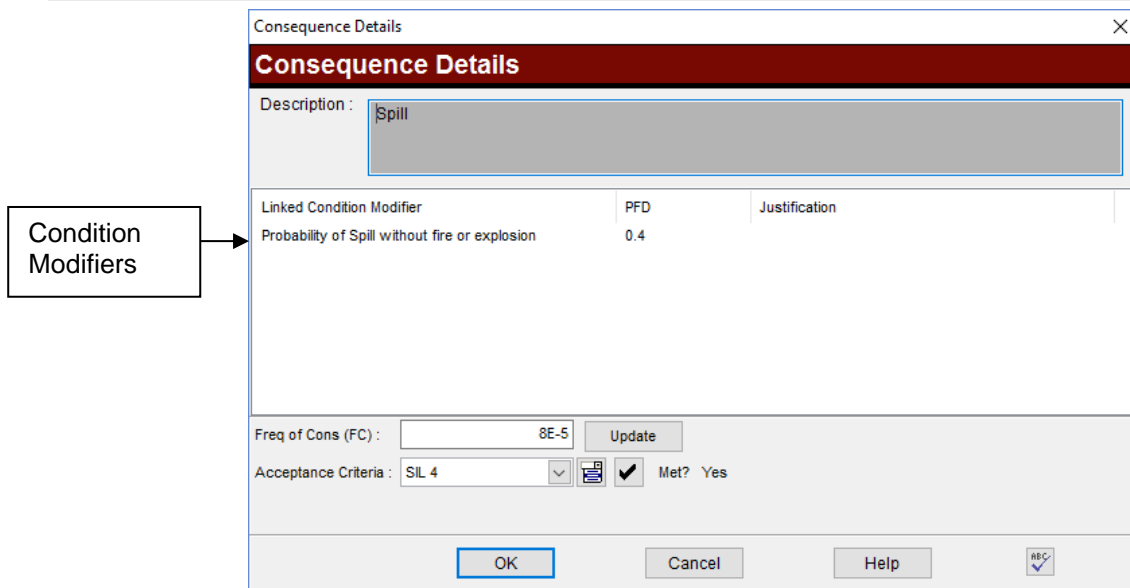
If the control is not appropriate in this particular branch then un-tick the “Use in calculation” checkbox on the controls screen highlighted above. This will remove the value when making the calculation of the overall frequency and will also draw the control as a dark box if “LOPA show all Controls” 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.

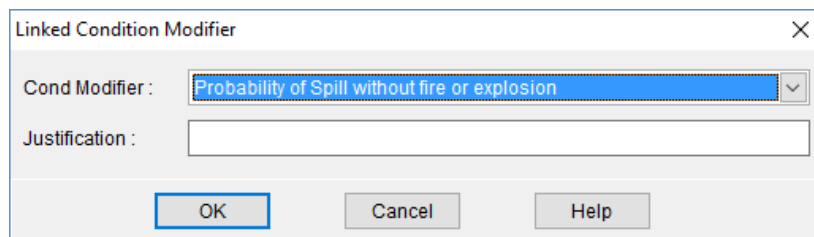
The Consequence displays the result of all the frequency calculation eg

$$\begin{aligned}
 &\text{Threat Frequency} \\
 &\quad \times \\
 &\quad \text{Enabling Factor} \\
 &\quad \times \\
 &\text{PFD of each control} \\
 &= \\
 &\text{Result}
 \end{aligned}$$



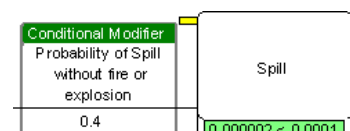
From this screen it is possible to add many Condition Modifiers. A condition modifier is used to determine the probability of a specific event, eg in this example if there is a release of oil what is the probability of it just spilling rather than causing a fire. The list of used Condition Modifiers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

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 highlight the item in the Condition Modifier list above and then press “Remove” from the right click popup menu.

The condition modifiers will be displayed on the diagram

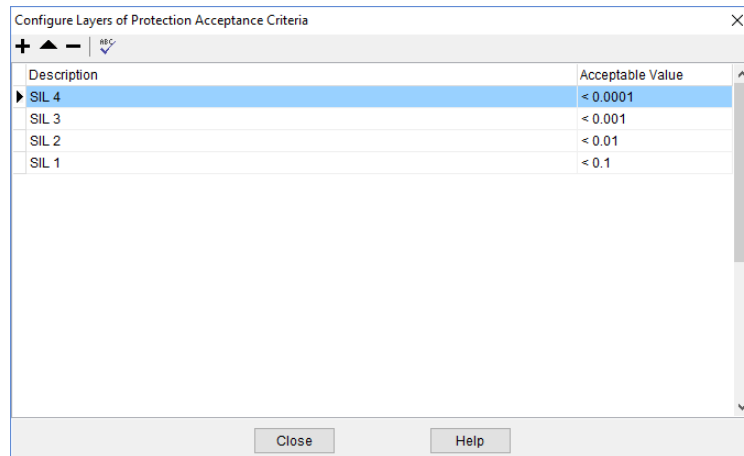


The bottom of the consequence screen displays the result of the Frequency of the Consequence calculation and allows the acceptance criteria to be defined.

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 by pressing the button.

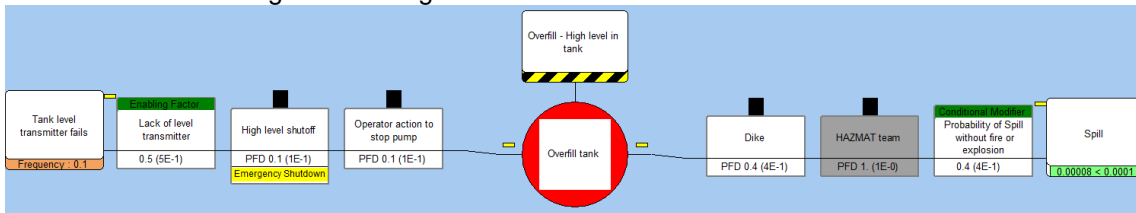
A possible way of defining the acceptance is to use the Safety Integrity Level (SIL) for safety functions operating in low demand of operation adapted from IEC 61511 (2003) as shown in the Table below.

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	$<10^{-1}$



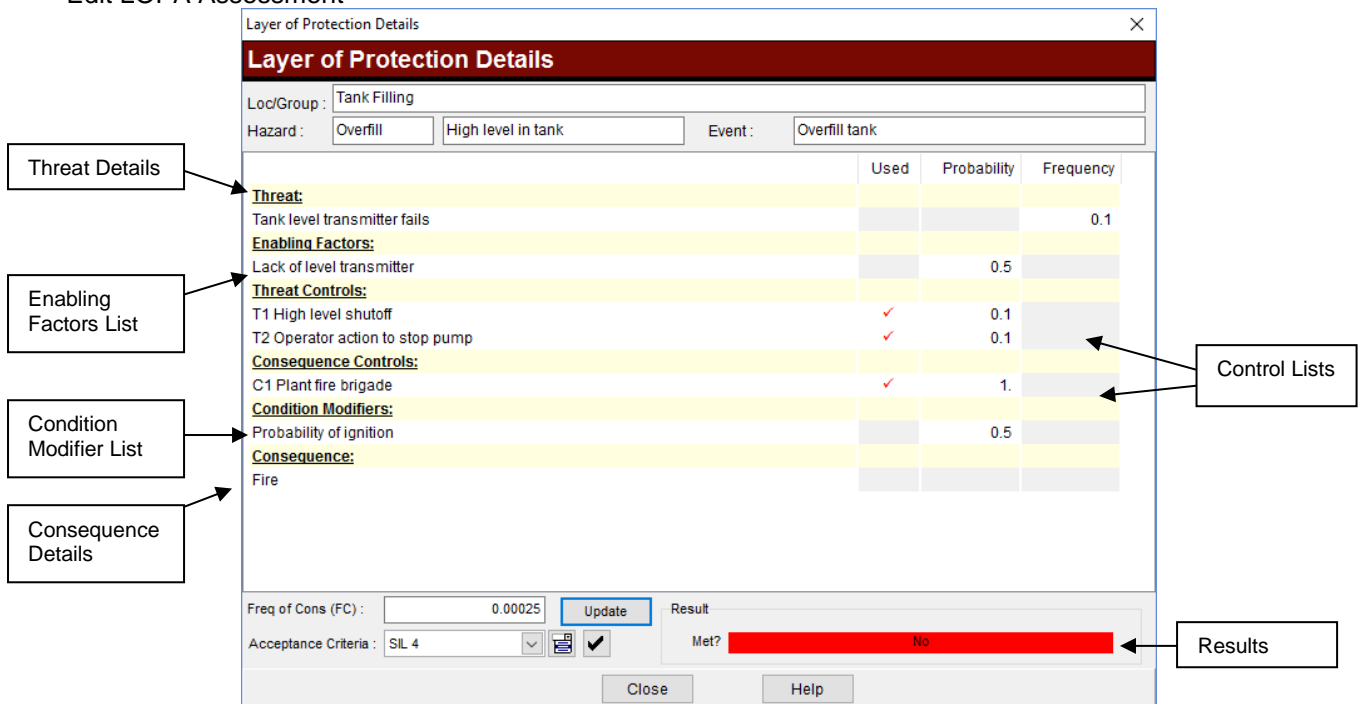
Whatever the acceptance criteria used BowTie Pro™ will display if the criteria is Met by displaying a red or green bar at the bottom of the screen and the Consequence box on the diagram.

The result will look something like the diagram below.



The data can also be entered using a non-visual LOPA screen but the method and calculation remain the same.

To open this screen right click an item on a the grid on the Layers of Protection Manager screen and select "Edit LOPA Assessment"



	Used	Probability	Frequency
Threat:			
Tank level transmitter fails			0.1
Enabling Factors:			
Lack of level transmitter		0.5	
Threat Controls:			
T1 High level shutoff	✓	0.1	
T2 Operator action to stop pump	✓	0.1	
Consequence Controls:			
C1 Plant fire brigade	✓	1.	
Condition Modifiers:			
Probability of ignition		0.5	
Consequence:			
Fire			

Freq of Cons (FC) : 0.00025 Result: Met? No

Acceptance Criteria : SIL 4

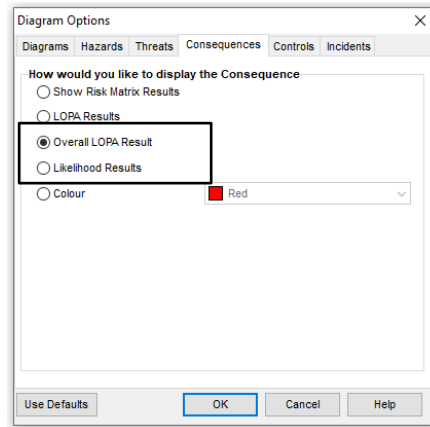
The screen allow the entry of the information as detailed in the LOPA overview with the results being displayed at the bottom.

The LOPA sections are detailed in bold text and the items will be displayed in the appropriate section below the heading their section. An item can be edited added, deleted or hidden by right clicking on it. An item can also be opened by double clicking on the text

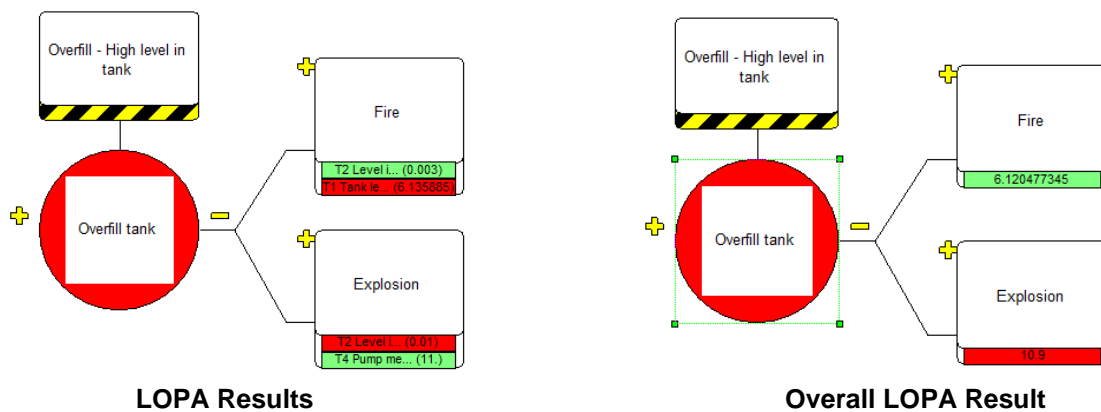
Overall LOPA Consequence Acceptable

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

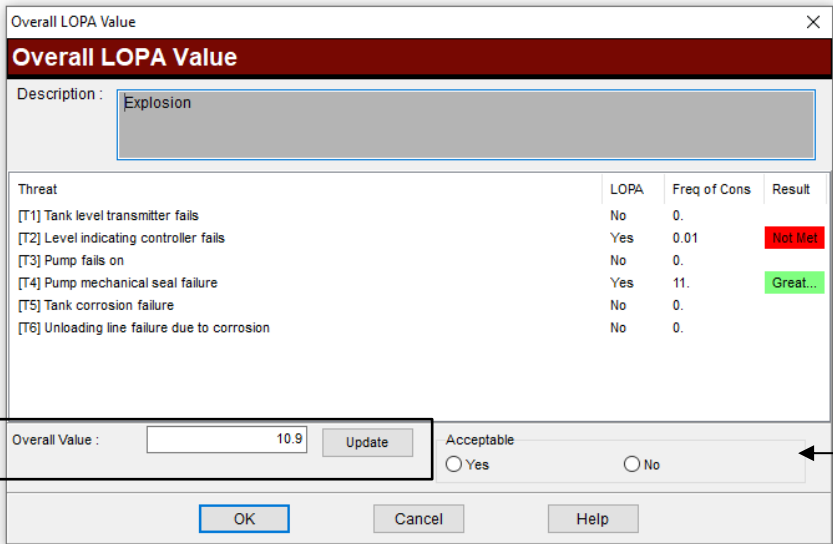


The LOPA Results show the result of the branch-by-branch analysis as described above. The Overall LOPA result is determined on a screen which is accessed by right clicking on the Consequence and selecting “Overall LOPA Consequence”.

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

$$\text{Overall Value} = (\text{LOPA Result Threat 1}) + (\text{LOPA Result Threat 2}) + (\text{LOPA Result Threat 3}) - ((\text{LOPA Result Threat 1}) * (\text{LOPA Result Threat 2}) * (\text{LOPA Result Threat 3}))$$

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.



The screenshot shows a software dialog box titled "Overall LOPA Value". It contains a description field with the text "Explosion". Below this is a table of threats with their corresponding LOPA values, frequencies of consequences, and results. At the bottom, there is a field for the overall value (10.9) and a radio button for the acceptable level (set to "No").

Threat	LOPA	Freq of Cons	Result
[T1] Tank level transmitter fails	No	0.	
[T2] Level indicating controller fails	Yes	0.01	Not Met
[T3] Pump fails on	No	0.	
[T4] Pump mechanical seal failure	Yes	11.	Great...
[T5] Tank corrosion failure	No	0.	
[T6] Unloading line failure due to corrosion	No	0.	

Annotations:

- A box on the left labeled "Overall Acceptable calculated value Details" points to the "Overall Value" field.
- A box on the right labeled "Overall Acceptable Level" points to the "Acceptable" radio button options.