Operational Risk Using BowTie Methodology

Richard Emery, MMI Engineering Ltd, The Brew House, Wilderspool Park, Greenall's Avenue, Warrington, WA4 6HL.

Management of risk on COMAH sites relies on diverse methods and technologies to reduce risk. As facilities mature, these safeguards may become less effective or degraded meaning risks may increase. A challenge of modern industry is to assess the effect of degraded safeguards on operations for both personnel and financial protection.

Assessing the level of degradation of one safeguard in isolation is a relatively simple task. Considering the effect of a degraded safeguard for an entire operation becomes more complex however, and becomes more so when considering multiple safeguards at varying levels of degradation. There is currently no industry standard on performing this type of analysis.

Despite no standard methodology however, the requirement to assess the effect of degraded safeguards on an operation is legal requirement, as specified in the Management of Health and safety at Work Regulations [MHSWR, 1999]. This states in Regulation 5 that:

'Every employer shall make and give effect to such arrangements as are appropriate, having regard to the nature of his activities and the size of his undertaking, for the effective planning, organisation, control, monitoring and review of the preventive and protective measures'.

BowTie methodology provides a useful framework within which to present a risk 'picture' and to satisfy Management of Health and safety at Work Regulations. It shows the relationship between the hazards, potential adverse consequences and the factors that could cause harm.

The following paper describes how quantified BowTie methodology can be applied to an onshore gas plant using Meercat's RiskView software. The following key features are presented

- Production of Bow and linkage to Quantitative Risk Assessment (QRA)
- Overall risk picture
- Inspections and audits of safeguards to evaluate effectiveness
- Maintenance and inspection prioritization

Introduction

Management of risk on COMAH sites relies on diverse methods and technologies to reduce risk. As facilities mature, these safeguards may become less effective or degraded meaning risks may increase. A challenge of modern industry is to assess the effect of degraded safeguards on operations for both personnel and financial protection.

Assessing the level of degradation of one safeguard in isolation is a relatively simple task. Considering the effect of a degraded safeguard for an entire operation becomes more complex however, and becomes more so when considering multiple safeguards at varying levels of degradation. There is currently no industry standard on performing this type of analysis.

Despite no standard methodology however, the requirement to assess the effect of degraded safeguards on an operation is a legal requirement, as specified in the Management of Health and safety at Work Regulations [MHSWR, 1999]. This states in Regulation 5 that:

> *'Every employer shall make and give effect to such arrangements as are appropriate, having regard to the nature of his activities and the size of his undertaking, for the effective planning, organisation, **control, monitoring and review of the preventive and protective measures**'.*

BowTie methodology provides a useful framework within which to present a risk 'picture' and to satisfy Management of Health and safety at Work Regulations. It shows the relationship between the hazards, potential adverse consequences and the factors that could cause harm. Further, it shows how the engineered and management controls reduce the risks associated with the hazards to tolerable levels.

The use of fully auditable and quantitative Bow Ties, as per Meercat's RiskView software provides a powerful tool to actually quantify these relationships. In particular, it allows for the development of an understanding of the relative importance of the risk controls. Further, RiskView enables the linkage of inspection and audit results to the effectiveness of barriers. It can also be configured such that the effects of overdue audits or maintenance on the risk profile would be instantaneously updated thereby gradually degrading the controls' effectiveness over time.

In short, RiskView provides a tool that affords all levels of management to have an appropriately detailed visibility of the current risk profile of their assets. This report details the methodology of producing a quantitative bow tie in Meercat's RiskView software for a gas storage plant and demonstrates key tools available to users including;

- Importing existing HAZID studies into RiskView.
- Auditing and reviewing protective barriers / controls

- Analysing the effect of degraded protective barriers /controls on the effectiveness of the whole system
- Establishing maintenance priorities of barriers

Limitations of QRA

Site risks are typically assessed by Quantified Risk Assessments, which might only be updated as part of the COMAH thorough review every 5 years. QRA-calculated risks do not vary on a day to day basis, and only represent year average values.

The frequency of loss of containment in a QRA is obtained by performing a 'Parts Count'. This involves counting all piping items (e.g. flanges, valves, instruments) and process equipment (e.g. pumps, vessels) and multiplying by a leak frequency factor for each item (this data is obtained from available databases). In this way, leak frequencies can be calculated on a fire area or isolable section basis.

This method has a shortcoming in that it assumes that the cause of the leak is the piping item, and no consideration is taken for the external factors that may influence why the item leaks in the first place. To take this to an extreme, a process plant operated by highly skilled, motivated, and resourced personnel would apparently have the same loss of containment frequency as the same plant operated by an irresponsible operator who completely overlooks process safety and/or integrity management.

Following a leak, mitigation protection layers help to limit the severity of the consequences and prevent further escalation from the initial loss of containment. The reliability of mitigation protection layers such as fire and gas detection, emergency shutdown and blowdown, are typically considered constant in QRAs. The fact that leak rates and performance standards for barriers / controls are assumed constant means that the QRA-calculated risks do not change with time which does not reflect reality. Essentially, QRA is useful for demonstrating that risks are within tolerable limits but is relatively inflexible for supporting day to day operational risk-based decision making.

The above points are illustrated in Figure 1 below. All the day to day barriers that prevent a leak are summed up in a single parts count, and all mitigating barriers take fixed values. The frequency of each outcome, and hence risk, is therefore a fixed value.

The following paper describes how data can be taken from a QRA and mapped onto an operational risk BowTie, where frequencies and consequence severities may change, and more importantly each barrier has the potential to increase or decrease its effectiveness over time allowing a real time insight into current risk exposure.

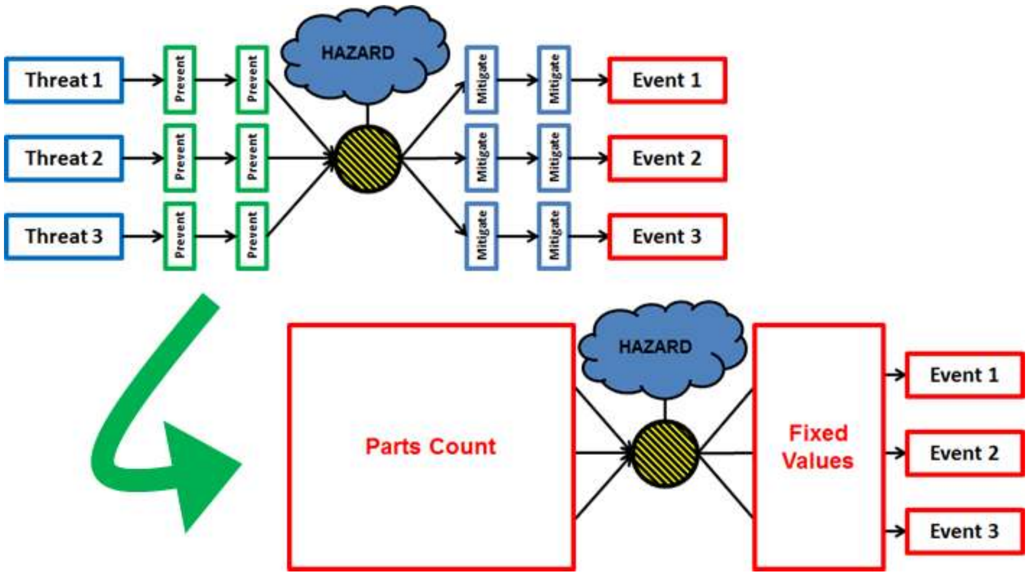


Figure 1: Limitation of QRA approach to Operational Risk Assessment

Scope

A HAZID conducted on an onshore gas plant identified a number of major accident scenarios. Of these, the following major accident scenarios all had the same top event namely 'Loss of Containment' and were analysed using the BowTie methodology;

- Jet flame following pipeline or pipework failure within the plant;
- Vapour cloud explosion, release of gas in congested area;
- Flash fire, resulting from delayed ignition of a large release.

During the HAZID, the following causes were identified and are considered in this paper;

- C01 - Start up after maintenance;
- C02 - Pipelines;
- C03 - Wrong / defective equipment e.g. incorrect specification or installation;
- C04 - Modifications / Design e.g.SIS;
- C05 - Corrosion / erosion of pipework, vessels, pipelines;
- C06 - Maloperation in manual mode;
- C07 - Physical damage due to major maintenance / vehicle impact;
- C08 - Out of design temperature range of pipework;
- C09 - Surge e.g. caused by produced water in pipelines, NGCs;
- C10 - Maintenance: Pigging - opening of containment;
- C11 – Maintenance: other opening of containment;
- C12 - Dropped object;
- C13 - Commissioning / inadequate purge;
- C14 - Valve / flange leaks;
- C15 - Vessels, e.g. gas dehydration units;
- C16 - Gas exchanger tube rupture;
- C17 - Sabotage / arson;
- C18 - Human error.

For each of the above causes, preventative and mitigative barriers were identified and listed.

Methodology

Basic BowTie Structure

The following basic bowtie structure was developed in RiskView and graphically show (from left to right) all causes, preventative barriers, the top event (loss of containment), mitigative barriers, and final consequences. The model considers intermediate events including fire and explosion, and also considers a range of consequence categories namely;

- Loss of Personnel;
- Loss of Asset;
- Loss of Company Reputation;
- Damage to Environment.

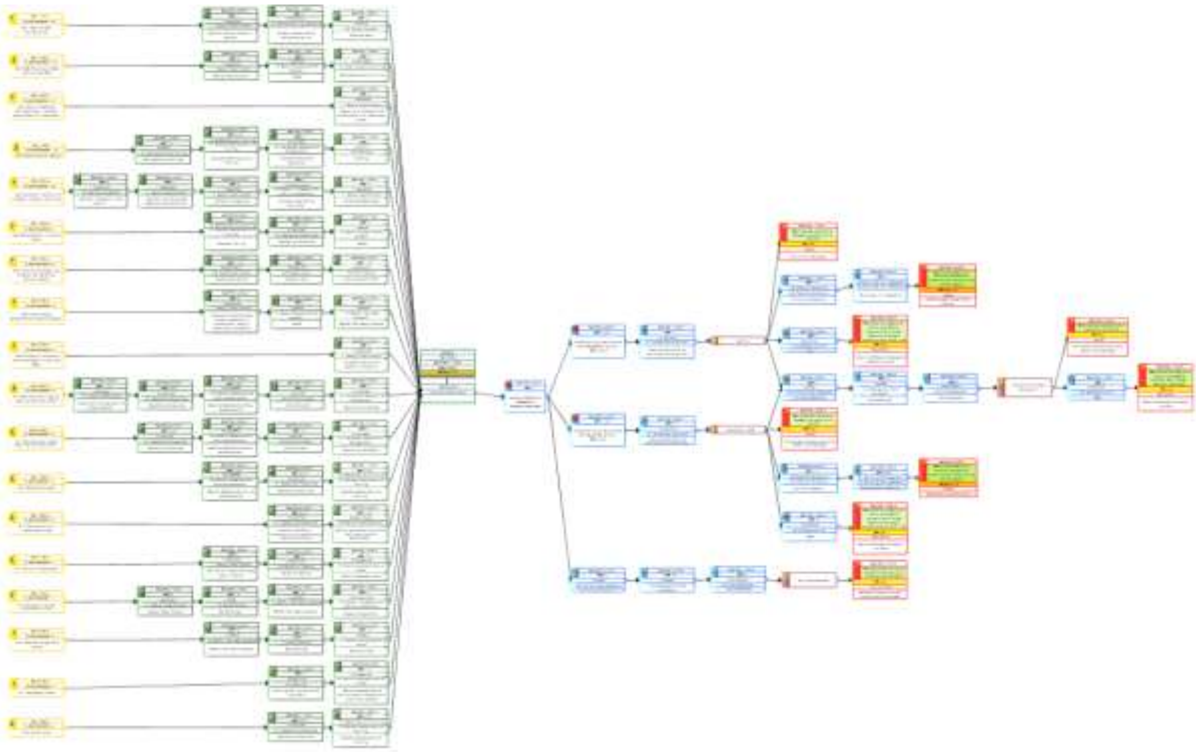


Figure 2: Overview of RiskView Bowtie Model Used

Target Leak Frequency

The 'top event', or centre of the BowTie, is defined as 'Loss of containment' and has an associated frequency. This frequency was taken from the Quantitative Risk Assessment section of the plant COMAH report as 1.16×10^{-2} leaks per year, or one leak every 86 years

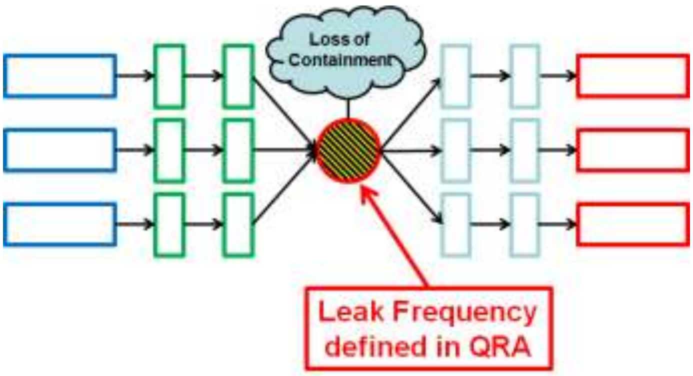


Figure 3: Target leak Frequency and Position in Bow Tie

Actual Leak Frequency

The leak frequency calculated for the QRA is based on average historical data [in this case HSE's Hydrocarbon Release Database - HCR]. These leaks arise as some of the safeguards against loss of containment are degraded. A plant operating with all safeguards in 100% working condition would have a reduced (not zero) frequency of leaks, as all barriers would still have some inherent probability of failure on demand.

In the current study it is assumed that with the plant running with all barriers in full working order, the leak frequency is 20% lower than industry average. Operators will tend to be optimistic when stating how a particular barrier is performing, therefore a larger reduction in frequency is not considered reasonable. The base case leak frequency, i.e. that to which the bowties is tuned, is therefore $1.16 \times 10^{-2} \times (1 - 20\%) = 9.6 \times 10^{-3}$ year^{-1}, or a little less than once every 100 years.

This number may be a little low when compared to actual site specific historical data. Modification of this base leak frequency can easily be adjusted as required in the model.

Threat Contribution

18 causes were identified in the HAZID study. Rather than assign a uniform probability of occurrence to each cause, the following method is used to determine each cause's specific probability of occurrence. **This is a subjective assessment** and could be performed in different ways, however the method presented is considered reasonable and can be justified based on HSE data. It is recommended that such an exercise be conducted in a workshop type meeting, with personnel with a wide range of experience including bowtie, safety, operations and design.

Based on information obtained from the HSE HCR database [HSE HCR], and QRA leak frequency data, the percentage contribution to risk from the threats identified in the HAZID have been calculated as described below. Alongside each percentage is a description of the rationale used to establish each percentage.

The absolute frequency attributed to each threat can be calculated by multiplying these percentage contributions by the total leak frequency calculated for the plant (and reported in the QRA).

It should be noted that the allocation of these percentages is based on opinion and might generally be performed as a workshop with experienced plant operators.

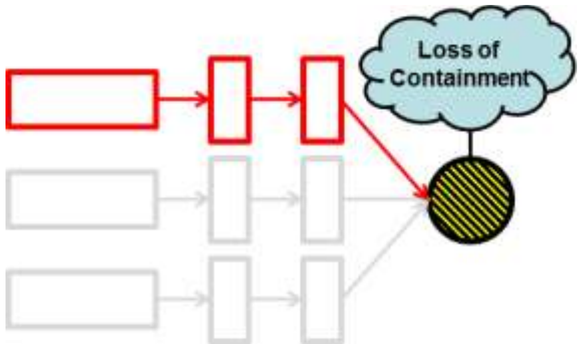


Figure 4: Individual Threat Pathway

C01 - Start up after maintenance – 19.2%

The proportion of leaks due to 'Start up after maintenance' was considered equal to that of leaks recorded in the HSE HCR database occurring after '*Reinstatement of equipment after maintenance'* and '*Initial start-up of equipment after commissioning'*

C02 –Pipelines – 14.9%

Releases from the pipelines may occur underground, or at the reception / export area of the plant. From data provided in the QRA section of the COMAH report, 14.9% of leaks come from the Gas Reception \ Export area. Pipeline releases (S11) are not considered in this current study.

C03 - Wrong / defective equipment e.g. incorrect specification or installation – 13.2%

The proportion of events due to 'Wrong / defective equipment' was considered to be represented by leaks recorded in the HSE HCR database due to *'Incorrectly fitted '* and *'QC failure, usually linked with manufacturing failure'*

C04 - Modifications / Design e.g.SIS – 11.6%

50% of 'Design causes' represent 11.6% of leaks recorded in the HCR database, and is considered to represent leaks due to 'Modifications / Design e.g.SIS'

C05 - Corrosion / erosion of Pipework, vessels, pipelines – 10.6%

The HCR database lists leaks due to 'Internal Corrosion', 'External Corrosion' and 'Erosion' to represent 13.3% of all leaks. The offshore environment is harsher than a typical onshore environment, and fluids are not as highly processed, thus the proportion of leaks onshore due to corrosion / erosion should be lower. The figure of 13% is reduced by 20% to take account of the differing environments equipment is exposed. Wet gas is processed at the plant thus a larger reduction is not considered reasonable.

C06 - Maloperation in manual mode – 6.3%

The HCR database records leaks due to '*Improper Operation'*. 50% of these leaks were considered representative of leaks due to maloperation in manual mode.

C07 - Physical Damage due to Major Maintenance / Vehicle Impact – 1.5%

During major maintenance, there will be a significant number of relatively new personnel on site. The safe movement of plant and personnel around the site will be managed via site procedures. This may include ensuring roadways and temporary roadways are kept free from obstruction, ensuring that such roadways are used, and ensuring that site speed limits are adhered to.

The proportion of hydrocarbon leaks that occur due to physical damage due to major Maintenance / vehicle impact is considered to be equal to 10% of leaks recorded in the HSE HCR database caused by *'Non-compliance with a procedure'* and *'Deficient procedure'*, equal to 1.5%.

C08 - Out of design temperature range of pipework – 2.5%

High temperatures may be witnessed due to safety instrumented system failure (SIS. It is considered that for such a condition to arise without providing sufficient time for operator response, the plant will have been operating too close to design conditions. The proportion of leaks arising due to 'Out of design temperature range of pipework' was thus considered to be represented by 20% of leaks recorded as '*Improper operation*' in the HSE HCR database.

C09 - Surge e.g. caused by produced water in pipelines, NGCs – 2.5%

Operating close to a surge line may be an operational necessity, however safe operating procedures should be in place to prevent the compressors actually going into surge. Failure to follow these procedures may lead to surge and resultant equipment failure. This event is therefore considered a procedural failure, and is considered to be represented by 10% of leak s recorded for *'Non-compliance with a procedure'* and *'Deficient procedure'* in the HSE HCR database.

C10 - Maintenance: Pigging - Opening of containment – 2.3%

The HSE HCR database lists leaks due to 'Opened up whilst containing hydrocarbons'. 50% of these leaks are considered to occur as a result of opening containment while pigging.

C11 - Maintenance Other Opening of containment – 2.3%

As above, 50% of leaks due to 'Opened up whilst containing hydrocarbons' are considered to occur as a result of opening containment during maintenance.

C12 - Dropped Object – 1.2%

Dropped objects are specifically mentioned in HSE data and cause approximately 1% of all leaks. There are fewer crane operations and less scaffolding in an onshore facility when compared to an offshore facility, however the proportion is still considered to be of the correct magnitude

C13 - Commissioning / Inadequate Purge – 0.4%

No specific mention is made to purging activities in any of the categories listed in the HSE database. The closest operational mode that may cover this was *'Carrying out the commissioning of newly installed equipment'*. The fraction of leaks that have occurred during this operating mode is 0.4%.

C14 - Valve / flange leaks - 3.7%, C15 – Vessels – 1.1%

The QRA section of the COMAH report states the leak frequency for valves, flanges and vessels. The leak frequency for each item may be due to one of the reasons stated above (C01-C13), or a different reason entirely. Causes C01-C13 account for approximately 90% of total leak frequency. Leaks due to other reasons are considered to be covered in this threat.

Item	Leak Frequency (year^{-1})	Proportion	Adjusted Proportion
C14 - Valves / Flanges	4.13E-03	35.7%	3.7%
C15 – Vessels	1.27E-03	11.0%	1.1%

C16 - Gas exchanger tube rupture - 0.2%

From QRA data, the total process equipment release frequency from the 'gas heating' area represents 0.2% of overall leaks. As a gas exchanger tube rupture represents a very specific case, when considering all other possible mechanisms that may cause a leak, thus 0.2% is considered to be conservative but of the correct magnitude for this threat

C17 - Sabotage / Arson – 0.1%

There is no mention of Sabotage / Arson as a cause of leaks in the HSE database. This may be due in part to the remote location of oil platforms, and the fact that the majority (you would hope all) of persons working offshore are fully aware of the risks a leak may present.

Onshore terminals are a lot more accessible to attack from outside, and workers may not be as aware of the hazards presented by hydrocarbons, therefore a small frequency of leaks is considered reasonable at 0.1%.

The contribution to leak frequency can be modified due to the current UK terrorist threat level. At the time of writing this report, the UK terrorist threat level was 'substantial'. At higher threat levels, the contribution could be modified.

C18 – Human Error – 5.2%

Each of the causes above can in some way be attributed to Human Error. This cause was considered to be a catchall for any reasons missed above, with the percentage calculated to make up 100%

Barrier Risk Reduction Factor (RRF)

Every protective barrier is afforded a 'risk reduction factor'. The unmitigated risk, i.e. the risk without the protective barrier, divided by the risk reduction factor, gives the mitigated risk. Mathematically, this can be expressed;

$$\frac{\boldsymbol{Unmitigated\ Risk}}{\boldsymbol{Mitigated\ Risk}} = \boldsymbol{Risk\ Reduction\ Factor} \qquad \textbf{(i)}$$

In normal operation, at a normal site, the overall mitigated risk is the same as the residual risk i.e. the risk reported in the QRA and which the COMAH safety report justifies as being tolerable.

For a given barrier, the Risk Reduction Factor is obtained by considering how the risk would increase if that barrier was not present. This is also considered to be 'opinion' engineering which would best be performed in a workshop with plant operators and HSE representatives present in order that the plant personnel demonstrate ownership of the risk model. Given that this is a pilot study, it was decided to ascribe the risk reduction factors in isolation (i.e. without conducting a workshop), as the aim was to produce an exemplar model.

The above thought process can be carried out for a single safeguard, or a combination of safe guards. For example, safeguards against leaks due to 'Dropped Objects' includes 'Method Statements', 'Operating Procedures' and 'Operator Awareness and Training'. Considering a scenario in which none of these safeguards were in place it was estimated that leaks due to dropped objects would increase by a factor of 3. The overall risk reduction factor afforded by these three barriers is therefore estimated to be 3.

The overall risk reduction for a *set* of safeguards on the same branch of the model is the product of the risk reduction factors afforded by each safeguard. For the above example, assuming that 'Method Statements' gives a risk reduction factor of 2, the total risk reduction afforded by 'Operating Procedures' together with 'Operator Awareness and Training' is 1.5 (3 / 2). Assuming that the two barriers afford equal risk reduction, each of the latter two barrier's risk reduction factor would be 1.22 ($\sqrt{\mathbf{1.5}}$)

$$\boldsymbol{RRF}\mathbf{1} \times \boldsymbol{RRF}\mathbf{2} \times \boldsymbol{RRF}\mathbf{3} = \boldsymbol{Total\ Risk\ Reduction\ Factor}$$

Consequence Frequency, and Mitigative Barriers

The frequency of unignited release, jet fire, explosion / flashfire, and the resulting fatalities were extracted from the QRA. The risk reduction factors of the mitigative barriers between 'loss of containment', and the various consequences was estimated based on typical ignition probabilities [UKOOA 2006], and similar thought processes to those described in Section 3.4.

Barrier Audit

Each barrier's risk reduction factor may be reduced to reflect a degradation of the barrier's effectiveness. This may be done via a number of different methods. In this case the effectiveness (or lack thereof) of a given barrier is ascribed according to the results of an 'Audit' performed on that barrier.

Two types of audits are possible in RiskView namely:

- Operational Assessment – used for procedural compliance barriers;
- Performance Standard Review – used for all other types of barriers.

Each of these audit types is described in more detail below.

How Audits Affect the Risk Reduction Factor

The output from the audit is a score, or percentage to quantify the degree of barrier degradation. In the case of a 100% satisfactory audit, a barrier will achieve its ascribed maximum RRF, but in the event of the audit returning less than 100% satisfactory results the barrier's effectiveness is degraded. Essentially, an audit will return a score up to a max value (where max score indicates totally effective). A score less than the maximum score indicates by how much the effectiveness is reduced as a result of the audit as follows:

$$\boldsymbol{Risk\ Reduction\ Factor} = (\boldsymbol{RRF_0} - \mathbf{1}) \times \frac{\boldsymbol{Score}}{\boldsymbol{Max\ Score}} + \mathbf{1} \qquad \textbf{(ii)}$$

where $\boldsymbol{RRF_0}$ is the maximum risk reduction factor the barrier can take (as assigned during the bowtie quantification exercise).

The above formula ensures the RRF cannot fall below a value of 1. A barrier with a RRF of 1 offers no protection, and is essentially the same as the barrier not being present. A RRF of less than 1 could indicate that risk frequencies are being amplified, e.g. the bow tie could in theory predict that jet fires occur more frequently than process leaks. For this reason, RRFs are specified and modified by audit results such that they can never be less than one.

Audits should take place at appropriate, regular intervals to ensure that '*control, monitoring and review of the preventive and protective measures'* are being undertaken [MHSWR, 1999]. Audit / inspection frequency will generally be assigned in order to ensure that a given safety critical item or task fulfils its required performance standard. To support this requirement, review dates may be assigned to barriers in RiskView defining the next audit due date. If an audit is overdue, the RRF of the barrier may be degraded with time and thus an apparent increase in risk is observed if audits are not carried out.

Barrier effectiveness may also be degraded automatically by the software if audit due dates have elapsed to represent the gradual deterioration of barrier effectiveness over time.

Operational Assessment

An operational assessment of a barrier's effectiveness is performed (in this model) on barriers involving procedural control, where quantification of performance is potentially difficult to quantify. The assessment asks a series of questions (based on ISO 31000) and offers a number of responses in the form of a drop down list. Additional comment boxes are provided by each question to allow the user to elaborate on the reasons for their chosen response. The questions asked are as follows.

- Is the Barrier design appropriate considering potential consequences
- Is there an accountable owner?
- Are the Barrier's, objective, process and limits documented?
- Is there a management process to track and measure performance?
- Are the Barrier and its objective understood by Barrier Owner and Operators?
- Is the Barrier being operating as designed?
- Has the Barrier failed since the last assessment?
- Are Barrier Owners / Operators competent?
- Is there an independent assurance process?

If the answer to all the questions is positive, the barrier scores 100% of its maximum score. If, for example, there is no independent assurance process for some reason, the barrier may only score 90% of its maximum. Essentially, the further from full compliance demonstrated by a barrier, the more its performance is degraded. In addition to the questions being user-defined, the amount by which the barrier effectiveness is degraded for different responses is also fully customisable.

Performance Standard Review

Performance standards are used for engineered protection layers with a physical performance that can be assessed. Each performance standard is comprised of a number of performance standard elements which can be used to define discrete components or sub systems that make up the overall system that is defined by the barrier. Each performance standard element has an individual maximum score, allowing for the relative importance of performance standard elements to be appropriately weighted. This is made clearer below.

To make this clearer, in this example, 'Speed Limits' is a safeguard against vehicle impact. The effectiveness of a speed limit to reduce vehicle collisions is considered to be quantifiable by a set of elements namely, site signage, induction training, and site speed adherence checks. Of these three elements, 'Site speed adherence checks' were allocated as being the most important and were therefore given a maximum score (or weighting) of 5, compared to the others with a maximum score/weighting of 1.

Each element can be evaluated with different performance levels. The designated performance levels are fully quantifiable but are presently taken as default settings: 'Excellent', 'Strong', 'Adequate', 'Needs to Improve' or 'Not Present'. Each category returns a specific score (again which may be defined by the user). The scores returned are described below:

Element	Weighting	Assessment	Score
Site Signage	1	Excellent . 100% – All signs in correct position and in good condition	1 x 100% = 1
Induction training	1	Adequate, 60% – Speed limit highlighted in induction	1 x 60% = 0.6
Site speed adherence checks	5	Strong, 80% – Yearly average incidents of speeding less than 12 per year.	5 x 80% = 4
Total	7	Total	5.6
Assessment Score			5.6 / 7 = **80%**

Table 1: Example Audit calculation on Performance Elements within a Performance Standard

Model Outputs

Current Operating Risk

The Operating Risk is the primary output that was taken from the RiskView Model in order to provide a measure of current risk versus residual risk. This value is the sum of the risks from all of the different consequence branches. The actual risk number produced in itself is fairly arbitrary and should not be thought of as having 'true' risk units, however the number can be considered as a 'key performance indicator'. Moreover, the number would under most assumption sets be proportional to risk, so relative changes in this number can be used to infer relative changes from the baseline QRA value (and hence convert to actual risk numbers). The operating risk number will fluctuate with time, but when compared to historical data, trends will be seen.

An example of how this may look over time is presented below in Figure 5

The operating risk will fluctuate above the site specific minimum risk due to small variations in barrier performance. Where a common cause degrades multiple barriers, or key individual barriers, spikes and trends in risk may be witnessed.

In the example below, one cause of this may be that a number of key personnel leave the company at a similar time without immediate replacements being found. This may result in a jump in risk if (say) these personnel had key knowledge and training to control the Permit to Work system, or Management of Change system.

Trends in risk may be seen if for example the inspection and maintenance budget is reduced. The effect of this would not be immediate, as the time at which items are due inspection will be staggered. Eventually, the operating risk will stabilise at a higher value as plant items' average condition will be more degraded.

There is no industry guidance on what level of operating risk is acceptable, thus setting operating risk limits is the responsibility of the company. As the company familiarises itself with the degree of variation it sees in operating risk and the key causes of this, 'Alarm', 'Action' and 'Intolerable' limits may be set.

Where risks are below the 'Alarm' level, the site should receive no special attention from corporate management aside from periodic reviews that barrier audits are being performed in accordance with procedures.

If risks rise above the 'Alarm' level, site management would be expected to attempt to reduce risks within its current restraints. This may involve analysing the causes of risks and re-distributing resources accordingly. At this level of operating risk corporate management will be made aware but is only expected to take a cursory check on causes and whether any additional assistance is needed

If risks rise above the 'Action' level corporate management would be expected in to intervene in the plant running immediately. Detailed analysis of the causes of higher risk will be undertaken and extra resources may be provided. Campaigns to improve boundary performance will be introduced.

If risks rise above the 'Intolerable' limit, serious consideration must be given to performing a plant shutdown. Further plant operation will be at the discretion and responsibility of the CEO and could only be allowed to operate once additional mitigations were in place to bring the risk down to tolerable levels. A shut down will allow time for the safe improvement in barrier performance through, for example, maintenance work, providing training to personnel, and revisiting of procedures and design.

There is a 'Residual Risk' at which the company is always exposed. As no protective barrier can be considered to be 100% reliable or effective, there always exists the potential for some base level of risk. The Residual risk level therefore represents that risk with all barriers considered to be in fully maintained condition.

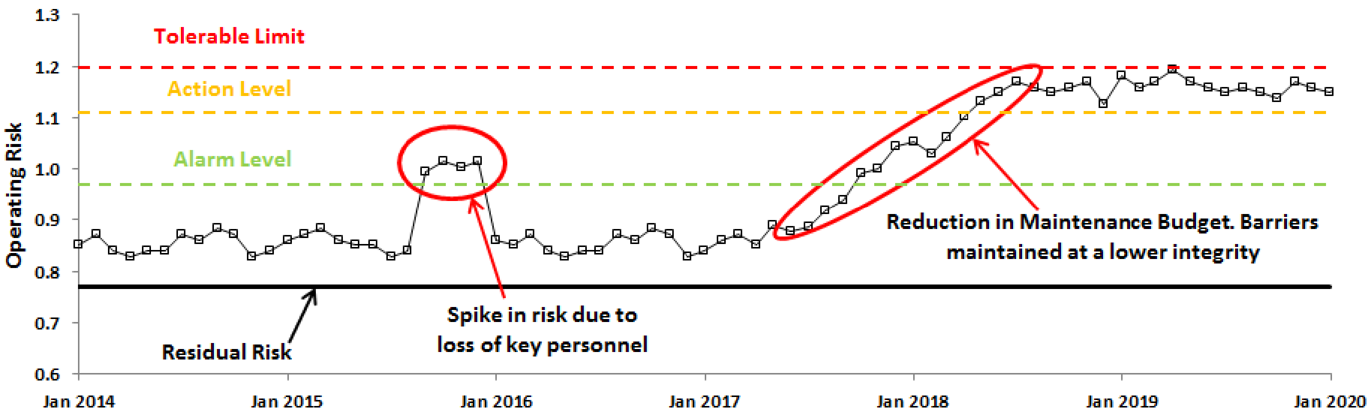


Figure 5: Example Operating Risk

Current Operating Risk Calculation

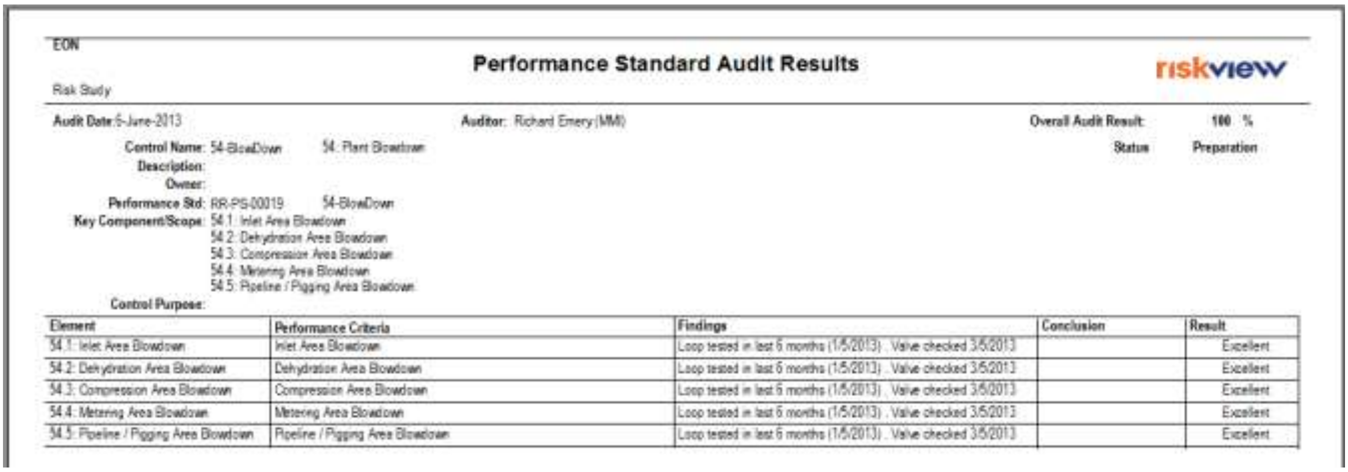
Operating risk is calculated by summing the frequency of occurrence by frequency of event for all consequences in the bowtie. For the model base case (all barriers in 100% condition) this can be summarised as follows. This represents the 'Minimum Risk' level shown in Figure 5.

Consequence	Severity	Frequency (year^{-1})	Risk / year)
Asset Damage due to Jet Fire	100	1.70×10^{-4}	1.70×10^{-2}
Loss of Life due to Jet Fire	10000	3.65×10^{-5}	3.65×10^{-1}
Reputation Damage due to Jet Fire	100	8.50×10^{-5}	8.50×10^{-3}
Asset Damage due to Explosion	100	3.96×10^{-4}	3.96×10^{-2}
Loss of Life due to Explosion	10000	2.99×10^{-5}	2.99×10^{-1}
Reputation Damage due to Explosion	100	1.98×10^{-4}	1.98×10^{-2}
Asset Damage due to Process Escalation	1000	6.29×10^{-6}	6.29×10^{-3}
Reputation Damage due to Process Escalation	1000	3.14×10^{-6}	3.14×10^{-3}
Environmental Damage due to Release	100	1.07×10^{-4}	1.07×10^{-2}
Operating Risk			**7.70×10^{-1}**

Table 2: Operating Risk Calculation

Audits of Control barriers

A report of the current status of all safeguard audits can be easily generated in RiskView. This details the results of the previous audit, and details when the next audit is required. An example audit sheet is shown below in Figure 6.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Risk Study

Performance Standard Audit Results

riskview

Audit Date: 6-June-2013 **Auditor:** Richard Emery (MMI) **Overall Audit Result:** 100 %

Control Name: 54-BlowDown 54: Plant Blowdown **Status** Preparation

Description:

Owner:

Performance Std: RR-PS-00019 54-BlowDown

Key Component/Scope: 54.1: Inlet Area Blowdown
54.2: Dehydration Area Blowdown
54.3: Compression Area Blowdown
54.4: Metering Area Blowdown
54.5: Pipeline / Pigging Area Blowdown

Control Purpose:

Element	Performance Criteria	Findings	Conclusion	Result
54.1: Inlet Area Blowdown	Inlet Area Blowdown	Loop tested in last 6 months (1/5/2013) . Valve checked 3/5/2013		Excellent
54.2: Dehydration Area Blowdown	Dehydration Area Blowdown	Loop tested in last 6 months (1/5/2013) . Valve checked 3/5/2013		Excellent
54.3: Compression Area Blowdown	Compression Area Blowdown	Loop tested in last 6 months (1/5/2013) . Valve checked 3/5/2013		Excellent
54.4: Metering Area Blowdown	Metering Area Blowdown	Loop tested in last 6 months (1/5/2013) . Valve checked 3/5/2013		Excellent
54.5: Pipeline / Pigging Area Blowdown	Pipeline / Pigging Area Blowdown	Loop tested in last 6 months (1/5/2013) . Valve checked 3/5/2013		Excellent

Figure 6: Example Audit Sheet

Cost Benefit Rating

Cost benefit rating (not a standard industry term), is a method used for prioritising maintenance on barriers. The method involves calculating the benefit (in terms of reduced operating risk) and dividing by the cost of implementation. This satisfies the Management of Health and Safety At Work regulations to *establish priorities* for remedial repair by providing a robust and documented decision process.

The calculation can be summarised as follows

Operational risk with Barrier at current RRF	A
Operational risk with Barrier at current RRF +10% (limited to its maximum / base case RRF)	B
Risk Benefit Rating - RBR	**[A-B] / 10%**
Cost of improving safeguard by 10%	**C**
Cost Benefit Ratio - CBR	**RBR / C x 1,000,000**

Table 3: Cost Benefit Ratio Derivation

Each barrier in the risk model has a calculated cost benefit rating (CBR). Those with highest CBR offer the most effective risk reduction for the least cost.

As an example, a degraded RiskView model where all barriers are only operating at 90% effectiveness is considered. Increasing the effectiveness of each safeguard by 10% gives the following example data presented in Table 4. Costs of improving safeguards are very much estimates and included to illustrate the calculation of Cost Benefit Ratio.

For this scenario, controlling ignition sources (safeguard 51) gives the highest risk benefit rating. Focussing on improving this safeguard (e.g. minimising hot work with plant online) as a priority would therefore be recommended. In a similar manner, focussing on security should not be given a high priority in terms of risk management.

Safeguard	Risk Benefit Rating	Cost (for 10% increase in performance)	Cost Benefit Rating
01: Operating Procedure	0.112	£10,000	11.2
02: Manual Gas Sampling	0.002	£1,000	2.4
03: Security	**0.001**	**£100,000**	**0.01**
04: Speed Limit	0.022	£1,000	22.4
05: Plant Layout	0.012	£100,000	0.1
07: Routing Op. walks / Visits	0.014	£1,000	13.8
08: Centralised Control	0.012	£100,000	0.1
09: Method Stat. & Risk Assess.	0.039	£10,000	3.9
10: Awareness and Training	0.156	£50,000	3.1
11: Design Spec	0.508	£10,000	50.8
12: BPCS	0.223	£100,000	2.2
13: Pipeline Alarms and Trips	0.140	£10,000	14.0
14: Relief valves	0.016	£10,000	1.6
15: HIPPS / SIL Rated Systems	0.043	£10,000	4.3
16: Inspections	0.073	£50,000	1.5
17: Bursting Discs	0.003	£10,000	0.3
18: Cathodic Protection	0.087	£50,000	1.7
19: Pigging Area Layout	0.012	£100,000	0.1
20: Permit to Work	0.255	£50,000	5.1
21: Contractor Selection & Engagement	0.100	£50,000	2.0
22: Management of Change	0.128	£50,000	2.6
23: Auditing	0.071	£50,000	1.4
24: Hydraulic Testing	0.027	£50,000	0.5
25: Commissioning Procedure	0.150	£50,000	3.0
51: Probability of Ignition	**1.067**	**£10,000**	**106.7**
52: Gas Detection System	0.021	£50,000	0.4
53: ESD System	0.028	£50,000	0.6
54: Blowdown	0.021	£50,000	0.4
55: Emergency Plan	0.023	£10,000	2.3
56: Personnel Exposure	0.334	£10,000	33.4
57: Building Overpressure Protection	0.405	£100,000	4.1

58: Building Fire Protection	0.369	£100,000	3.7

Table 4: Example Cost Benefit Ratio Assessment

References

[MHSWR, 1999] Management of Health and Safety at Work Regulations, 1999

[HSE HCR] HSE's Hydrocarbon Release Database; *https://www.hse.gov.uk/hcr3/index.asp*,

[UKOOA, 2006] Ignition Probability Review, Model Development and Lookup correlations, HSE / UKOOA, January 2006