Using Risk Assessment to Support Investment Decision-Making

An ioMosaic White Paper

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This paper concerns the management of onshore transmission oil and gas pipelines and the choices that operators must make for investment decision-making, particularly concerning the environmental consequences of incidents where there is a loss of containment (LOC) event from the pipeline (i.e. a leak or rupture). Compared to road and rail, pipelines are widely regarded as the safest mode of transport of hazardous fluids over long distances between facilities, although failures, when they do occur, can be serious. Safety-related regulations are generally considered to be more comprehensive and prescriptive than their environmental counterpart and are included in the full range of compliance and risk-based approaches. The highly location-specific nature of environmental impacts makes it harder to have the same assurances from environmental compliance and does little to protect the operator against the incurred costs of clean-up after LOC events have occurred. Advances in environmental quantitative risk assessment can provide location-specific estimates of the financial costs of remediation, and so the challenge for the operator is in deciding risk equivalence to balance expenditure on pipeline inspection and maintenance that may mitigate environmental risks, versus expenditure for other purposes such as safety improvements. This paper shows one possible approach for comparing risks based on equivalent values to aid decision-making.

Keywords: risk assessment, environment, risk, environmental risk, decision-making, onshore pipelines, quantitative risk analysis, risk matrices

Introduction

This paper concerns the management of onshore transmission oil and gas pipelines and the choices that operators must make for investment decision-making, particularly concerning the environmental consequences of incidents where there is a loss of containment (LOC) event from the pipeline (i.e. a leak or rupture). Understanding the tolerability of environmental impact is a difficult concept within the assessment process; there is no simple equivalence with safety risk tolerability where the principle of gross disproportionality may be used in decision-making to screen safety expenditure. Pipeline operators must develop alternative approaches to balance expenditure on pipeline inspection and maintenance that may mitigate environmental risks, versus expenditure for other purposes such as safety improvements. This paper explores how pipeline operation is regulated, the types of failures that operators must safeguard against and some possible approaches to aid decision-making.

The significant environmental liabilities associated with the decommissioning and abandonment of pipelines are not considered here. However, it is important to note that the management of pipelines beyond their useful economic life has important challenges and its own separate set of regulations.

Onshore pipelines have functionally similar roles to road and rail transportation – i.e. the bulk movement of natural gas, petroleum liquids and less frequently other chemicals over long distances. Compared to road and rail, pipelines are widely regarded as the safest mode of transport of hazardous fluids over long distances between facilities. However, pipeline management is complicated by the typical absence of secondary containment, with bunding, surface water traps and other measures usually only constructed at key points along the pipeline – such as valve chambers and pump stations. If LOC events occur the pipeline product may therefore contaminate the immediate pipeline vicinity. Depending on specific factors such as topography and location of isolating valves, the volume of product released into the environment can be significant.

The safety consequences of pipeline failure can be serious. For example, the San Bruno, California pipeline explosion of 2010, caused by the rupture of a large-diameter gas pipeline within a neighbourhood resulted in the deaths of eight residents (see Figure 1). However, less catastrophic events may still lead to significant environmental impact including soil contamination and the pollution of water courses. For example, the Kalamazoo River oil spill (Parfomak, 2016:11), has to-date cost the operator Enbridge Energy approximately USD 1 billion to remediate (Belvederisi, C., Thompson, M., and Komers, P., 2018:15). Whilst pipeline failures are fortunately rare it is the potential consequences of these events that is recognised in the various regulatory approaches adopted internationally.

Figure 1: Figure 1. Damage caused to residential area by the explosion at San Bruno (Published under Creative Commons Attribution. Credit: Brocken Inaglory, ttps://commons.wikimedia.org/wiki/File:Devastation_in_San_Bruno.jpg)

Regulating the environmental impacts of pipeline operation

Pipeline failure is widely addressed within international good practice, national standards and various databases of primary incident causes, with the collective aim of ensuring that a pipeline has been correctly designed, commissioned and operated. A wide range of regulatory approaches exist, including compliance-based standards and risk-based approaches.

Safety-related regulations are generally considered to be more comprehensive and prescriptive than their environmental counterpart and are included in the full range of compliance and risk-based approaches. Where environmental regulations do exist, they may build on existing safety-based regulations. For example, in the United States the concept of high consequence areas (HCA) is used for both safety and environmental hazards. For gas pipelines the potential for environmental damage is more limited than for liquid lines and may therefore be excluded from assessment of HCA (DOT, 2019). For liquid lines the consequences of LOC events may be more wide-ranging and the definition of 'high consequence' may be expanded to include environmental harm (USFR, 2016).

European risk-based approaches to pipeline management are intended to guide the design and operation of onshore pipelines to ensure identification of foreseeable hazards, safe operation and control and maintenance of pipeline integrity (HSE, 2019; BSI, 2019). Risk tolerability is determined with reference to societal risk acceptance criteria. If the predicted cumulative frequency of different levels of casualties from LOC-related events (e.g. an explosion) falls below a criterion line then the risks are deemed to be broadly acceptable. Although more nuanced than equivalent prescriptive regulations, the application of such risk-based approaches can be complex and are not always universally accepted (HSE, 2009:18).

In the UK, environmental risk tolerability criteria have recently been introduced for upper and lower-tier facilities subject to the Control of Major Accident Hazard (COMAH) regulations (CDOIF, 2013), which require operators to provide risk assessments as part of their safety reports for the control of major accidents to the environment (MATTE). Pipelines may become subject to these regulations if they form part of the overall COMAH facility.

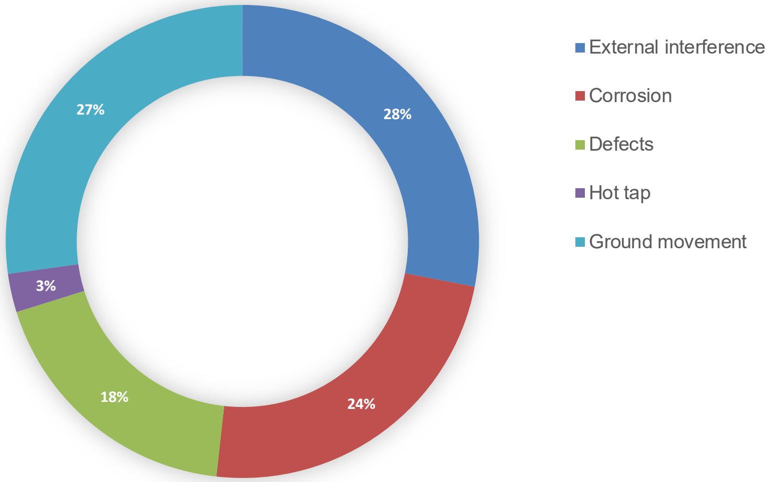
Irrespective of approach, pipeline regulation is adopted to achieve a particular aim – in the case of safety regulation to reduce the level of potential harm to individuals. Safety regulation often builds on the historical knowledge of why harmful events occurred and how they can be mitigated. Examples include the relationship between line pipe wall thickness and the failure frequency due to external interference designed to eliminate risk through design (BSI, 2013:24) or the recommendations following investigation of an incident designed to control risk (Parfomak, P., 2016:11). Compliance with safety regulation provides the operator with assurance that they are already prioritising the right elements of pipeline management.

The highly location-specific nature of environmental impacts makes it harder to have the same assurances from environmental compliance and does little to protect the operator against the incurred costs of clean-up after LOC events have occurred. The costs of environmental remediation can be significant irrespective of assessment of environmental sensitivity. Remediation costs quoted in the literature vary depending on whether soil excavation and disposal is required and whether the spill has caused additional contamination to groundwater (Bonvicini, S., Antonoioni, G., Morra, P., and Cozzani, V., 2015:43). Pipeline operators must therefore make their own decisions on pipeline inspection and maintenance regimes that best protect them from incurring environmental remediation costs after potential LOC events.

Pipeline failures

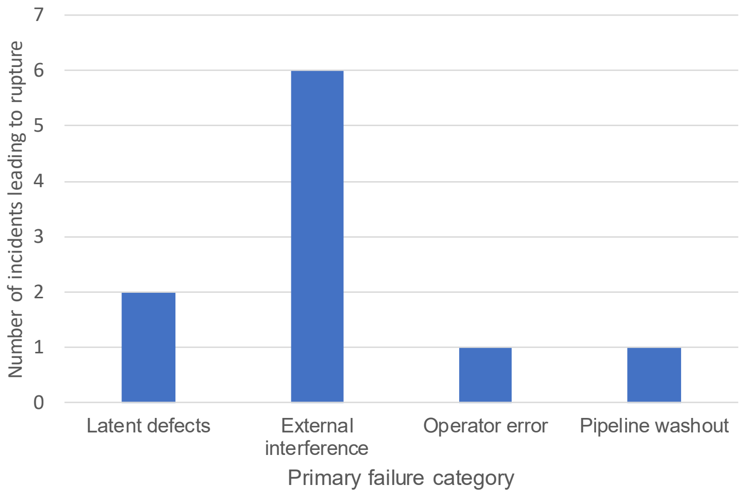
Pipeline failures are variously classified in the literature and incident database published by organisations that include EGIG in Europe, the PHSMA in the US and UKOPA in the UK (PHMSA, 2019, EGIG, 2018; Dai, L., Wang, D., Wang, T., Feng, Q. and Yang, X., 2017). Present-day primary causes of pipeline failure given in Figure 2 below are taken from EGIG data but typical of other data sources reviewed by the authors.

Figure 2 – Contribution of primary failure frequencies per cause to total failure frequency, 2012-2016 (adapted from EGIG 2018:21)



External interference, ground movement and corrosion are the three dominant primary causes of failure within contemporary EGIG data, with other international analyses indicating a similar picture (Dai, L. et al, 2017:2). This is reflected in the author's own experiences of pipeline inspection in southern Africa (Mozambique and South Africa) between 2004 and 2016 (illustrated in Figure 3 below); the great majority of significant pipeline failures were caused by external interference. The two significant failures caused by defects were both attributed to seam weld failures of pre-1970s ERW line pipe.

Figure 3. Causes of significant primary pipeline failure in South Africa 2004 to 2016 (author's own survey)



Historical trends have seen a reduction in total failure frequencies. The reduction in failures due to external interference is particularly marked (EGIG, 2018:21, Dai, L. et al, 2017:4) with improved awareness of the factors influencing failure frequency and the publication of guidance on these risk factors (BSI, 2013:21). Table 1 below shows how the relative contributions of primary causes has changed since 1970 (EGIG 2018:21), with other international analyses again showing a similar picture (Dai, L. et al, 2017:2).

Table 1: Primary failure frequencies per cause (adapted from EGIG 2018:21)

Primary cause	1970-2016 per 1000 km.yr	Contribution / %	2012-2016 per 1000 km.yr	Contribution / %
External interference	0.144	50	0.032	28
Corrosion	0.052	18	0.027	24
Construction defects	0.051	18	0.021	18
Hot tap error	0.014	5	0.003	3
Ground movement	0.026	9	0.031	27

An important observation made by EGIG (2018:23) concerns failure type by primary cause. External interference and ground movement are noted by EGIG to lead predominantly to ruptures and holes, contrasting with corrosion that tends to lead to pinholes and pipeline cracks (EGIG, 2018:23). The primary cause of failure is therefore important in determining failure consequences in that it will dictate the rate of product release to the environment (Belvederisi, C., et al, 2018:17).

The challenge for operators wishing to mitigate the potential environmental impacts of pipeline failure is in predicting where these failures are likely to occur. As Dai, L. et al note (2017:7), failures due to external interference tend to occur in economically active areas – but not exclusively; several of the failures illustrated in Figure 3 were in remote rural locations where pipelines had been damaged by agricultural equipment. Uncertainty over where failures may occur requires the operator to develop better site-specific understanding of the potential consequences of pipeline failure as part of their decision-making process.

Quantitative assessment of pipeline environmental impact

QRA techniques have been successfully used for pipeline risk assessment for several decades but have tended to be limited to calculation of risk for exposed human populations. This is now changing with the publication of proposed approaches for quantitative assessment of environmental hazards (Bonvicini, S. et al, 2015; CDOIF, 2013). However, the techniques remain arguably more complex than comparable approaches for assessing safety risk, given the location-specific nature of many environmental impacts.

An environmental QRA must screen LOC events to determine whether quantifiable environmental impacts are likely to occur for a given scenario, illustrated in Figure 4 below.

Figure 4. Simplified event tree for a pipeline LOC

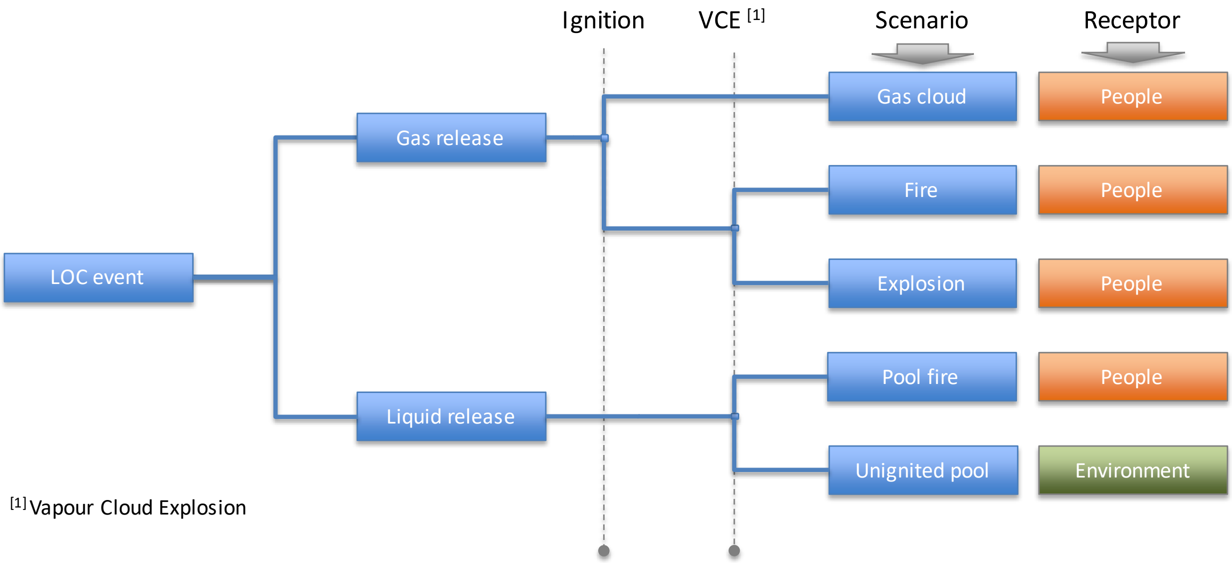
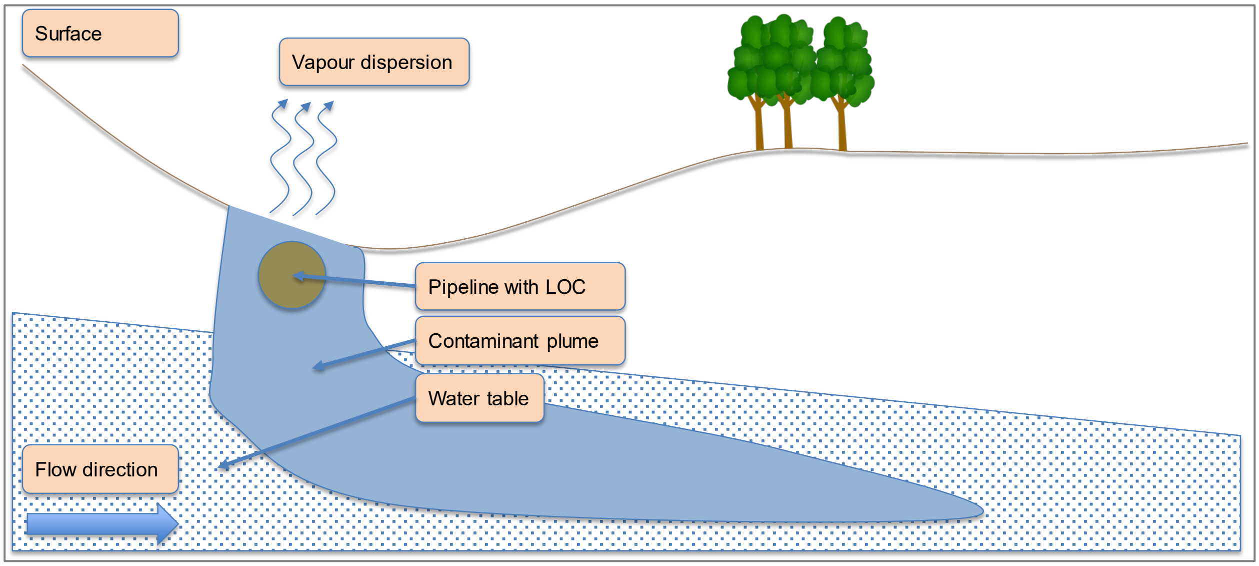


Figure 4 shows possible event outcomes following a LOC, i.e. release, ignition, fire or explosion. This has been simplified for illustrative purposes – in practice, the identified scenarios are unlikely to exclusively impact people or environment. Not all scenarios will impact on the environment, as recognised by some regulators (e.g. DOT, 2019). The QRA must determine the probability of specific events occurring and decide on the scenarios where environmental damage is likely.

A key concern of pipeline LOC events is any potential liquid spill on land and its penetration into the soil towards the water table (the “unignited pool” scenario in Figure 4). The volume of pollutant liquid that penetrates the soil can increase the level of environmental impact (with a corresponding reduction in any vapour cloud dispersion hazards as the rate of release of vapour is slowed by its soil uptake), illustrated in Figure 5 below.

Figure 5. Percolation of chemicals into the soil and water table



The penetration of chemicals into the soil is a complex phenomenon dependent on soil type, geology, local conditions (e.g. moisture levels) and the physical properties of the pollutant.

To properly assess environmental risk the QRA must determine both the likelihood of a given scenario arising and the impact on the receiving environment, considering those location-specific factors affecting impact. With appropriate reference points for spill clean-up and remediation it is possible to estimate the financial costs of remediation (Bonvicini, S. et al, 2015:44). The value of a QRA is in allowing repeated application of the same model to each change in site-specific criteria along the pipeline corridor.

Application to decision-making

The previous sections of this paper have given different perspectives on pipeline regulation, the primary causes of failure that the operator must manage and current approaches in quantifying environmental impacts that may result from LOC events.

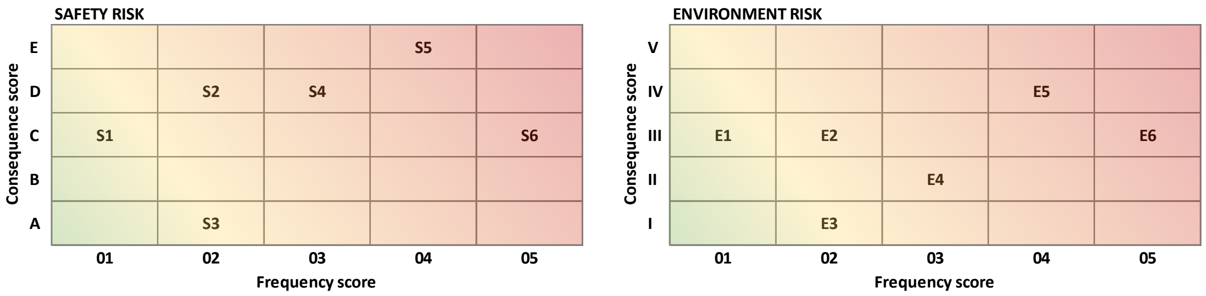
What does a pipeline operator do with this information? Setting aside assuring regulatory compliance, an operator may have a risk-based inspection (RBI) programme, for example based on the methodologies proposed by American Petroleum Institute (API, 2016) to prioritise expenditure on the inspection and maintenance of its pipeline assets. A typical RBI system relates equipment damage / degradation to the risk of failure of that equipment (a product of the failure frequency and the consequences of that failure). Failure consequences can be expressed as the potential loss of life (PLL) or, in the case of environmental damage, extent and persistence of environmental damage, time required for effective remediation and related remediation costs.

The challenge faced by the operator is in deciding risk equivalence, in this case environmental risk compared to other risks such as safety. The first step taken by some operators is to convert all risk consequences to equivalent values. This may be monetary (as used in the following figures). For example, environmental harm can be related to remediation cost. Safety consequences can be converted to a monetary value using an economic measure such as the Value to Prevent a Fatality (VPF – a metric comparing costs and benefits of proposed safety improvements as an aid to effective decision-making). Other measures of safety consequence can also be used – for example the cost of employee downtime during lost time injuries. Asset consequences can be related to costs of operational interruption.

The equivalent values, when multiplied by their frequency of occurrence (typically events per year), will give an equivalent risk score. This approach allows direct comparison of environment, safety and asset risks, with respect to the different risk ranking, risk tolerability and cost benefit criteria that might apply to each risk category.

For example, environment and safety risks may be initially scored separately, illustrated in Figure 6 below. Each risk matrix shows six risk scores, with consequences scored by risk type (denoted by letters A to E for safety risk and numerals I to V for environmental risk).

Figure 6. Risk matrices showing initial risk scores for sample safety and environment risks.



SAFETY RISK

Consequence score	01	02	03	04	05
E				S5	
D		S2	S4		
C	S1				S6
B					
A		S3			

Frequency score

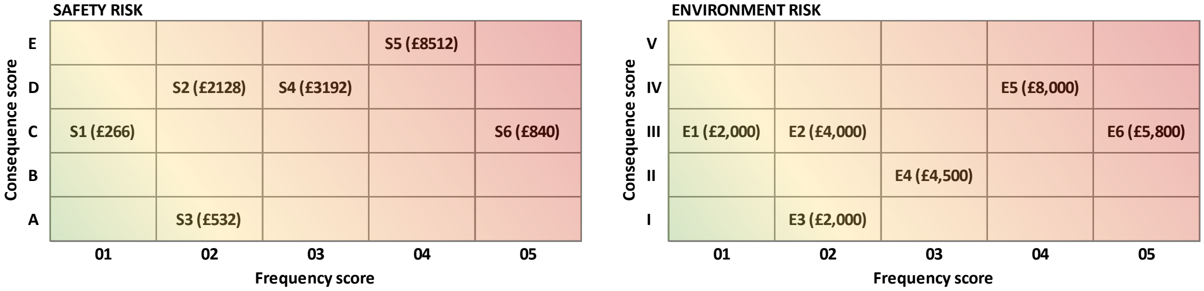
ENVIRONMENT RISK

Consequence score	01	02	03	04	05
V					
IV				E5	
III	E1	E2			E6
II			E4		
I		E3			

Frequency score

Conversion of risk consequences to equivalent values allows the latter to be added to each risk matrix, illustrated in Figure 7 below with specimen equivalent values provided for each risk (i.e. a notional equivalent consequence value multiplied by the frequency score representing the number of events per year). Note that the equivalent values are not used to rank risks at this point.

Figure 7. Risk matrices showing equivalent values added for sample safety and environment risks.



SAFETY RISK

Consequence score	01	02	03	04	05
E				S5 (£8512)	
D		S2 (£2128)	S4 (£3192)		
C	S1 (£266)				S6 (£840)
B					
A		S3 (£532)			

Frequency score

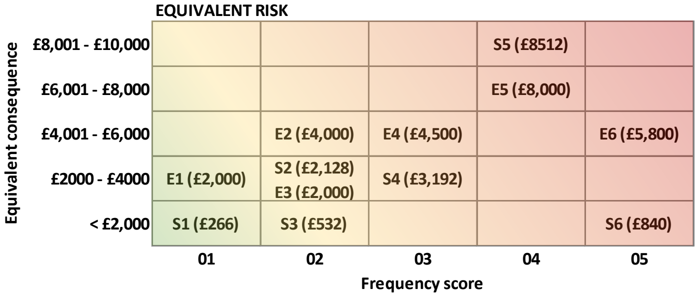
ENVIRONMENT RISK

Consequence score	01	02	03	04	05
V					
IV				E5 (£8,000)	
III	E1 (£2,000)	E2 (£4,000)			E6 (£5,800)
II			E4 (£4,500)		
I		E3 (£2,000)			

Frequency score

The equivalent values can be combined onto a single risk matrix, using the equivalent consequence value in place of the original consequence score, illustrated in Figure 8 below.

Figure 8. Combined risk matrix.



EQUIVALENT RISK

Equivalent consequence	01	02	03	04	05
£8,001 - £10,000				S5 (£8512)	
£6,001 - £8,000				E5 (£8,000)	
£4,001 - £6,000		E2 (£4,000)	E4 (£4,500)		E6 (£5,800)
£2000 - £4000	E1 (£2,000)	S2 (£2,128) E3 (£2,000)	S4 (£3,192)		
< £2,000	S1 (£266)	S3 (£532)			S6 (£840)

Frequency score

The combined risk matrix shows a re-ordering of the risks based on equivalent value. For example, safety risks S1 and S6 were originally scored as having moderate consequence. When scored based on equivalent value these risks are shown to be less important than environmental risks E1 and E6.

Comparison of equivalent values highlights differences between the estimated cost to the business of different risk types and suggests a priority for addressing those risks with highest business cost first. On discussion with operators these techniques have been observed to re-balance the ‘safety first’ priority of risk management that tends to discount other types of risk even if the safety-related hazards identified are not thought credible. In the example this would mean paying closer attention to risks E1 and E6 when deciding on priorities for risk management.

Some businesses choose to further weight equivalent values before making a direct comparison. Weighting typically means a multiplication of equivalent value by a constant weighting factor, i.e. an equivalent value of 100 with a weighting factor of 10 becomes 1,000. The same weighting factor is used for all risks of the same type. Different weighting factors are selected depending on risk type.

Risk weighting is not a new concept, with extensive research in the field of Life Cycle Impact Assessment (LCIA) on the use of weighting that also highlight concerns over its subjectivity (Pizzol, M., Laurent, A., Sala, S., B., Verones, F. and Koffler, C., 2017:3). This is recognised by organisations who choose to weight risks for direct comparison, with care taken over the weighting factors applied to different risk types. However, weighting remains a recognised approach in risk decision-making where different types of risk are prioritised for mitigation.

Conclusion

Pipelines, despite good safety records compared to other methods of transporting hazardous products, can fail with serious consequences. The cost of environmental remediation can be significant irrespective of regulatory compliance achieved by the operator because of the location-specific nature of environmental impacts. Decision-making is further complicated by operational hazards attributed to third party interference, a significant primary cause of pipeline failure, especially for LOC events involving ruptures and holes leading to rapid product release to the environment. Approaches to quantify the level of environmental harm have been developed that can calculate the potential cost of a LOC event. However, a pipeline operator must still decide the balance of expenditure on pipeline inspection and maintenance that may mitigate environmental risks, versus expenditure for other purposes such as safety improvements. This paper has suggested one possible technique of defining risk equivalence as a potential solution for decision-making.

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