Network Output Measures Health & Risk Reporting Methodology & Framework

A common methodology framework, adopted by all Gas Distribution Networks, for the assessment, forecasting and regulatory reporting of asset risk.

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Contents

Contents 3

Glossary 5

1. Introduction 8

1.1 Purpose 8
1.2 Background 8
1.3 Objectives 8

2 Methodology Overview 9

2.1 Principles 9
2.2 Asset Base 10
2.3 Grouping of Assets 11
2.4 Probability of Failure 13
2.5 Consequence of Failure 14
2.6 Financial Cost of Failure 14
2.7 Monetised Risk 14
2.8 Treatment of Asset Interdependence 15

3 Event Tree Development 17

3.1 Development Overview 17
3.2 Define Approach 18
3.3 Worked Example 21
3.4 Derive Probability of Failure 23
3.5 Derive Consequence of Failure 25
3.6 Final Risk Map 26
3.7 Data Reference Libraries 29

4 Event Tree Utilisation 32

4.1 Utilisation Overview 32
4.2 Data Assessment 32
4.3 Probability of Failure, Deterioration & Asset Health 34
4.4 Consequence of Failure & Derived Criticality 41
4.5 Calculate Risk Values 47
4.6 Intervention Options 49
4.7 Impact of Intervention 51

5 Regulatory Reporting 57

5.1 Overview 57
5.2 Asset Groups 57

5.3 Health & Risk Reporting 58

6 Governance **61**

6.1 SRWG Membership 61

6.2 SRWG Annual Work Programme 61

6.3 SRWG Annual Report 62

6.4 Modification Process 62

6.5 Publication of Methodology Statement 63

Appendix A – Distribution Mains **64**

A1. Distribution Mains Definition 64

A2. Distribution Mains Event Tree Development 64

A3. Distribution Mains Event Tree Utilisation 71

Appendix B – Services **82**

B1. Services Definition 82

B2. Services Event Tree Development 82

B3. Services Event Tree Utilisation 89

Appendix C – Governors **101**

C1. Governors Definition 101

C2. Governors Event Tree Development 101

C3. Governors Event Tree Utilisation 108

Appendix D – LTS Pipelines **128**

D1. LTS Pipelines Definitions 128

D2. LTS Event Tree Development 128

D3. LTS Event Tree Utilisation 140

Appendix E – Offtakes & PRSs **156**

E1. Offtake & PRS Definition 156

E2. Offtake & PRS Event Tree Development 163

E3. Offtake & PRS Event Tree Utilisation 189

Appendix F –Risers **204**

F1. Risers Definition 204

F2. Risers Event Tree Development 205

F3. Risers Event Tree Utilisation 212

Glossary

Asset Base - Core asset data records providing specification/configuration and location data.

Asset Cohort – a grouping of individual assets which can be assessed together meaningfully for intervention/investment planning purposes or regulatory reporting purposes. Within the NOMs methodology cohorts are defined specifically for planning and assessing investment interventions to quantify health and monetised risk benefits.

Asset Failure - Any operation or function which the asset fails to correctly perform which gives rise to consequences.

Asset Groups – A collection or class of assets, defined as the primary assets utilised in Event Tree Analysis.

Asset Health – A measure of an asset's current ability to perform its operation or function.

Asset Risk – The product of the Probability of Failure and the effective quantity of consequence. The expected number of consequence events.

Asset Risk Value - The product of the Probability of Failure and the consequence of failure. Expressed in monetary terms.

Asset Stratification – a grouping of asset attributes that statistically define the asset in terms of (for example) current of future performance/risk

Asset Sub-group – a sub-division of the above, predominantly where a specific asset attribute is considered material to be reporting separately (e.g. Iron Mains)

Attribute – A piece of information which determines the properties of the PoF or CoF calculations

Cost of Consequence – The per unit monetary cost of a consequence.

Consequence Quantity – The potential quantity of consequence "units" that could be generated from an asset failure (e.g. lives lost through a gas explosion in a property)

Consequence of Failure – Any unintended impact which results from an Asset Failure expressed in monetary terms. Calculated from the product of the quantity, probability of consequence, and the cost of consequence.

Criticality – A measure of an asset's safety, reliability and environmental impact resulting from an Asset Failure

Data Reference Library – A data template detailing the node name/reference, a description, unit of measure and potentially the value used including source or calculation.

Deterioration Rate – The rate at which the Probability of Failure changes over time.

Discount Rate – The rate at which future costs are expressed in their net present value terms.

Effective Quantity – The product of the quantity and the probability of consequence.

Event Tree – An approach to mapping Failure Modes and their affect in a structured manner. Event Tree Analysis (ETA) is a graphical technique for representing the mutually exclusive sequences of events following an initiating event (an asset failure) according to the various events that may mitigate/influence its consequences.

Expert Elicitation – The synthesis of opinions of authorities of a subject where there is uncertainty due to insufficient data or when such data is unattainable because of physical constraints or lack of resources. Expert Elicitation is essentially a scientific consensus methodology.

Failure Mode – Failures associated with a particular Asset Group, categorised by the nature of the failure.

Financial Risk– The direct financial costs to the business for without-Intervention work to the assets such as such as repair.

GDN – Gas Distribution Networks (Distribution network operators).

Industrial & Commercial (I&C) – supply to an industrial/commercial premises

Innovation – New technology or techniques used as an alternative to current intervention activities.

Intervention - Any activity which is carried out, beyond the scope of Maintenance that changes either the probability or consequence of asset failure, or extends the life of the asset.

LTS – Local Transmission System (pipeline network)

Monetised Risk – The total Asset Risk Value based on the required output metric.

NOMs Methodology – Network Output Measures Health & Risk Reporting Methodology and Framework

Non-repairable Assets – Assets failure result in the asset being replaced and returned to 'as good as new'.

PE – polyethylene mains pipe

PoF (Probability of Failure) – The probability an asset will fail at a given point in time, conditional that it has survived to that time. Units are expressed per year. This is also known as the hazard rate.

PoF (Failure Rate) – For an asset this is the rate of occurrence (frequency) of failures at a given point in time, typically measured as the number of failures over a year.

PRS – Pressure Reduction Station

Planned Maintenance - Any activity which is normally and routinely carried out to maintain an asset in good working order, or extend the life of the asset. This does not change the ongoing Probability of Failure.

Primary Asset – A defined list of assets as per Table 1.

Private or company risk – The cost of dealing with the failure such as the cost of lost gas, the requirements to undertaken network inspections, the cost of restoring supplies.

Probability of Consequence (PoC) – The probability or proportion of quantity (usually between 0 and 1) that ends up being affected.

Public risk – Indirect environmental and societal costs associated with health and safety, traffic disruption etc.

Reliability Block Diagram (RBD) – A simulation technique for estimating system availability taking the connectivity of multiple assets within a system into account.

Repairable Assets – Assets that when fail can be repaired and generally returned to 'as bad as old'. The Probability of Failure is identical immediately before and after failure

RIIO-GD1 – A price control sets out the outputs that the eight Gas Distribution Networks (GDNs) need to deliver for their consumers and the associated revenues they are allowed to collect for the eight-year period from 1 April 2013 until 31 March 2021.

Secondary Asset – An asset that supports or impacts a primary asset

1. Introduction

1.1 Purpose

The purpose of this document is to set out a common methodology which shall be used by all Gas Distribution Networks (GDNs) to assess the health, Criticality and associated Risk Value of network assets to meet special licence condition 4G (Methodology for Network Output Measures). This methodology is called the Network Output Measures Health & Risk Reporting Methodology & Framework, hereafter referred to as the NOMs Methodology.

The document sets out the overall process for assessing condition based risk and specifies the parameters, values and calculation methods to be used. The collective outputs of the assessment, used for regulatory reporting purposes, are known as the Network Output Measures. The methodology can be amended subject to the change process outlined in licence condition 4G Part F.

When approved by Ofgem, this methodology will require GDNs to re-align their current processes and practices to this new standard. GDNs will also need to re-baseline their Network Output Measures consistent with the methodology detailed within this document for the RIIO-GD1 period.

When adopted, GDNs will be required to report annually against the targets set using the methodology. These reporting requirements are set down in Section 9 to the RIIO-GD1 Regulatory Instructions and Guidance (RIGs).

1.2 Background

In the RIIO regulation regime, as first implemented in RIIO-GD1, Ofgem seeks to move to a more output based measurement of the drivers for network business plans. One such measure is in the development of a measurement of the health and risk associated with assets and subsequently the impact the proposals/investments in business plans make upon the health and risk of the assets over the regulatory period.

A risk assessment and reporting solution is proposed in order to ensure health management is appropriate to the needs of the Gas Distribution Network. This process identifies the potential impact arising from the unavailability or failure of a network's assets through the assessment of the consequence and risk associated with such failures. Risk values are represented in monetary terms as a "common currency" for comparison between different failure types and Asset Groups. This defined common currency for the statement of asset risk is subsequently referred to as Monetised Risk throughout this document.

The Asset Health and Risk Assessment process based is described in this methodology together with the assumptions needed to project the current assessment forward to future years.

The effect of example intervention plans and the associated risk impact is also described. This enables the comparison of current and future with- and without intervention scenarios using both a relative asset Health value and an absolute Monetised Risk value for each planned intervention.

1.3 Objectives

In developing this methodology the following objectives have been targeted:

- Comparative analysis:
  - Over time;
  - Between geographical areas; and
  - Between network assets;
- Evaluation of:

- Probability of Failure (PoF) of an asset failing to fulfil its intended purpose during any year (see glossary for definition of Probability of Failure) ;
- Rate of deterioration to forecast future Probability of Failure;
- Asset criticality (safety, environmental, reliability, financial); and
- Network risk, taking into account Probability of Failure, asset criticality and, if feasible, asset inter-dependence.

Achieving the objectives outlined above will ensure that the benefits of business plan interventions across different gas distribution asset classes can be articulated on a consistent basis and compared and traded off. This will ensure that customers continue to get best value from the investments GDNs plan to implement in their networks.

2 Methodology Overview

This section lays out the methodology principles and provides an overview on:

- Principles (of the NOMs methodology)
- Asset Base (how the baseline for each Asset Groups is defined)
- Grouping of Assets (how groupings are defined for reporting and planning)
- Probability of Failure (Defining the PoF for assets)
- Consequence of Failure (defining the CoF for assets)
- Financial Cost of Failure (defining the financial cost of failure for assets)

2.1 Principles

The key principles which have been adopted to facilitate the assessment of the health, criticality and risk of assets are:

- Asset Health can be equated to the probability that the asset fails to fulfil its intended purpose and thus gives rise to consequences for the network.
- The consequences (and therefore Criticality) can be assessed in monetary terms
- The risk is determined from the product of the number of failures and the consequence of those failures

BS EN ISO 31010 [1], Risk Assessment Techniques, describes methods of assessing risk, including quantitative methods, one of which is Event Tree Analysis (ETA). ETA is a graphical technique for representing the mutually exclusive sequences of events following an initiating event (an asset failure) according to the various events that may mitigate/influence its consequences. These techniques have been followed in the development of the standard Event Trees used by this methodology.

This technique has been adopted due to its ability to translate probabilities of different initiating events into possible outcomes. The key benefits of this technique, as stated in BS EN 31010 [1], are:

- that failure consequences are displayed in a diagrammatic way
- that it accounts for dependencies (problematic to models in other techniques)
- that it provides a quantitative output with relatively low uncertainty
- that the resource and capability requirements are manageable

The core principle is that Risk is the product of Probability of Failure (PoF) of an asset and the Consequence (PoC) that such failure could lead to and the cost (monetised value) associated with those Consequences.

The combination of these factors derives an annual Monetised Risk (Figure 1 – Broad Monetised Risk Process).

Asset Risk Value = PoF (Asset) x PoC x Cost of Consequence

Where the:

Cost of Consequence= Consequence Quantity (units) x Unit monetary value

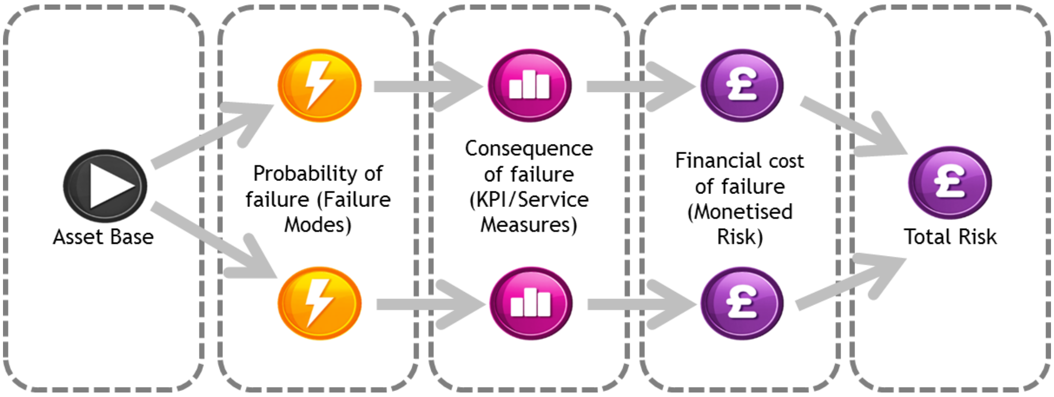


Figure 1 – Broad Monetised Risk Process

The Asset Risk Value calculation can be utilised to quantify the network risk reduction following Intervention by comparing it to a base-line value (without-Intervention). As a result of Intervention the PoF is reduced or maintained in line with the type of investment activity whilst PoC will generally remain unchanged, with the exception of system or network design alterations. This will in turn result in a reduction in the Asset Risk Value enabling the comparison of with/without Intervention scenarios in the form of Network Output Measures as defined in licence condition 4G part C.

Each Event Tree that is developed will follow a similar structure to provide consistency of approach.

For each class of primary assets an Event Tree has been produced which models each known Failure Mode that the Asset Group could experience. This determines which of the consequence measures would be impacted by a failure of that nature. The link is made through the Event Tree showing the outcomes that can occur and the probability of each outcome.

Each Asset Group's Event Tree is published in their respective sections within the appendices. All Event Trees are common across the GDNs and any changes to the Event Trees are subject to the joint governance process as per 6 Governance.

2.2 Asset Base

Event Tree Analysis will be built from asset data, taken from GDN-specific asset repositories. This will form the basis for the next steps in calculating the Health and Risk Value, therefore facilitating consistent outputs when comparing different Asset Groups and planning investments.

To facilitate consistent implementation and utilisation across all GDNs, asset data will be aligned to the required structure, including attributes and data formats, prior to populating the models.

The required asset attributes are determined during the development of the Event Trees and detailed within the Data Reference Library.

2.3 Grouping of Assets

How individual assets are combined and grouped for both investment planning and reporting applications is very important within the NOMs methodology.

The NOMs methodology breaks the complete network assets into groups for analysis, risk calculation and reporting. At the highest level they are split into a suite of Asset Groups. These high level groups are then split into sub-groups where the nature, importance and relevance of this lower level information is considered. These groups and sub-groups are common across all networks and have been agreed with Ofgem to form the basis of regulatory reporting of asset health, critically and risk. Further details of these groups are given in section 5 (Regulatory Reporting).

As outlined in section 2.1 (Principles), this methodology will develop methods by which the risk associated with an asset will be determined by identifying the PoF, CoF and associated cost for assets. In a number of cases these values will be determined for each asset. However for a large number of assets these values will be determined for a collection of assets which all have the same characteristics and hence the same attribute values of PoF, CoF and Cost of Failure. The collection of assets for this purpose is called an Asset Cohort.

Asset Groups

An Asset Group is a collection or class of assets, defined as the primary assets utilised in Event Tree Analysis (e.g. Distribution Mains)

Asset Sub-group

An Asset Sub-group is a sub-division of the above, predominantly where a specific asset attribute is considered material to be reporting separately (e.g. Iron Mains)

Asset Cohort

An Asset Cohort is a grouping of individual assets which can be assessed together meaningfully for intervention/investment planning and reporting purposes. Asset Cohorts must be defined appropriately and at a sufficient detail to be able to describe differences in Health and Risk, before and after investment

Asset Cohort groupings will be formed with regard to;

- the level of asset data which is available
- planning and assessing investment interventions
- Required level of detail for assessing and reporting Asset Health, both pre- and post-interventions

To facilitate the consistent reporting of Asset Health and Risk, a minimum set of Asset Cohorts must be agreed between GDNs for each Asset Group. These agreed Cohorts will represent the factors that most accurately reflect the Health of the asset. Example Cohort attributes which have been modelled to represent statistical differences in Health for Distribution Mains include:

- Material
- Pressure
- Diameter Band

- Age

These attributes will be used to define Cohorts which can be used for pre- and post-intervention Health and Risk assessments However, Cohorts can also be defined flexibly according to specific GDN requirements to support higher level asset reporting or for more detailed targeting of specific assets for investment. The methodology will ensure that any such variations do not materially impact the comparable risk assessment which is carried out.

It is likely that intervention plans cause assets to move from one Cohort to another during the period to reflect the way in which the intervention has impacted PoF, CoF or Cost.

It is also likely that during the period of operation of this methodology reasons emerge which requires assets to be moved from one Cohort to another or to split Cohorts. The methodology has a process in place to ensure a consistent risk assessment is tracked as a result of any such movements.

Asset Stratification

Asset Stratification is a grouping of asset attributes that statistically define the asset in terms of (for example) current or future performance/risk (e.g. Ductile Iron pipes installed in 1970's in Yorkshire). Asset stratification assessment and modelling is required to identify which asset attributes contribute significantly to Health assessments prior to intervention planning.

In order to determine the appropriate characteristics of PoF, CoF and Cost statistical analysis will be carried out using data available for different asset types. Such analysis is very likely to cut across Cohort groups. This will not change the definition of the Cohort group, but may feed attribute information for more than one Cohort Group.

Figure 2 - Asset Cohort/Stratification shows an example of stratification to gather information which is relevant to the material type of an iron pipe. The example shows the Cohort Groups which have been adopted. In this example Tier 1 mains have been selected as a Cohort together with Iron Mains between 9" and 12". However a specific intervention plan for 9" ductile Iron pipes has meant a specific Cohort for these assets.

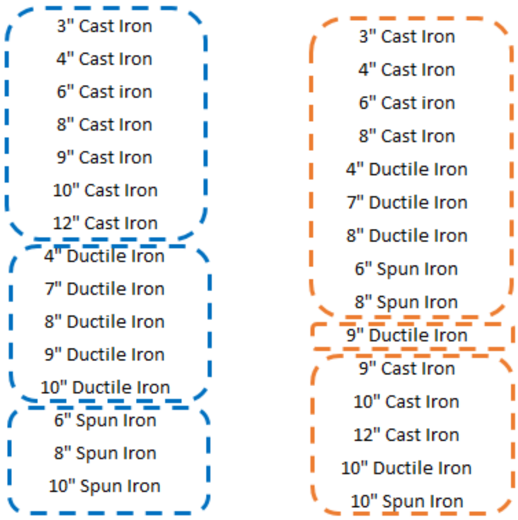


Figure 2 - Asset Cohort/Stratification

The relationships between Asset Groups, Sub-groups, Cohorts and Stratifications are summarised below.

Figure 3 - Grouping of Assets Summary

Cohort Definition

An example of a Mains Cohort previously used for RIIO GD1 planning is Tier 1, Ductile Iron mains (where Tier is a combination of diameter and assessed risk). This can be refined to include a geographic context if supported by the underlying data (e.g. Distribution Zone).

An example Mains Cohort to be used for Health reporting could be Cast Iron Mains, in MP networks, in Diameter Band B, which were installed in the1960's, defined as the explanatory factors making up the Cohort have been proven to show contribute to the observed (and statistically proven) differences in PoF within the Asset Group.

2.4 Probability of Failure

Asset failure is defined here to be "any operation or function which the asset fails to correctly perform which gives rise to consequences". The failures are categorised into Failure Modes.

The probability of asset failure can be calculated to estimate the expected number of consequence events in any given time period, and the deterioration of this curve over time.

A 'failure rate' will be used to calculate the Probability of Failure. The failure rate gives the rate of occurrence (frequency) of failures at a given point in time and may also include an age/time variable, known as asset deterioration, which estimates how this rate changes over time. The failure rate can be approximated by fitting various parametric models to observed data to predict failures now and in the future.

The NOMs methodology is designed to accommodate a wide range of different gas transmission and distribution asset types. In order to decide on the best modelling approach to be adopted it is important to agree upon the failure rate model to be adopted for each Failure Mode as part of the risk model development process. One such example is to categorise non-repairable and repairable failures:

- **Non-repairable failures** – failures result in the asset being replaced and returned to "as good as new". For example, Steel service failures result in a full asset replacement. Where data is not available the parameters of these models will be estimated using Expert Elicitation.
- **Repairable failures** – for assets, which are repaired and generally returned to "as bad as old". For example, over-pressurisations resulting from a regulator failure can generally be resolved through a maintenance process, rather than full asset replacement. The frequency of failures is estimated using counting process regression models. Where data is not available the parameters of these models will be estimated using Expert Elicitation.

Each Failure Mode is used as a specific component within an Asset Group's Event Tree. The Probability of Failure value for each Failure Mode is independent and is determined through analysis of Asset Failure data or Expert Elicitation where necessary.

The PoF value will be dynamic (whereas PoC will largely remain static) therefore the Asset Risk Values, in terms of current and future with/without-Investment scenarios, are highly sensitive to the PoF value within the Failure Mode function.

Further detail on how the PoF values and the deterioration rates are derived is explained within section 4.3.1.

2.5 Consequence of Failure

Consequence analysis determines the nature and type of impact which could occur assuming that a particular event (i.e. caused by Asset Failure) has occurred. When an asset fails, there will be an associated impact resulting from that failure (referred to as an event).

An event may have a range of impacts of different magnitudes, and affect a range of different network assets and different stakeholders. For example, there could be a loss of supply to customers, or an injury, resulting from a failure. Such impacts are referred to as Consequences of Failure. The types of consequence to be analysed and the stakeholders affected will be considered during the development of the Event Trees.

Each identified event (Consequence of Failure) is used as a specific component within an Asset Group's Event Tree. The Probability of Consequence (PoC) value for each Consequence of Failure event is independent and is determined through consequence analysis techniques such as:

- Statistical analysis of associated failure data
- HAZOP techniques (Risk assessment)
- Historic incident data
- GIS (Geographic Information System) analysis
- Network modelling analysis

2.6 Financial Cost of Failure

Each Consequence of Failure event may have an associated financial cost (Cost of Consequence), based upon the type and scale of impact, representing a monetary risk value. These values are categorised into the following 3 areas:

- Private Risk (Reliability)
- Public Risk (Health & Safety)
- Public Risk (Environmental)

The financial Cost of Consequence value for each Consequence of Failure event is independent and is determined through analysis of financial models or Expert Elicitation.

2.7 Monetised Risk

The overall asset Monetised Risk value is using the PoF, PoC, volumetric (quantity) data and monetary value for each Failure Mode in each Event Tree. These are then aggregated to form the overall Monetised Risk value for the Event Tree.

2.8 Treatment of Asset Interdependence

This section seeks to explain the approach taken to asset interdependence in monetising risk. The detail of the modelling can be found in the respective appendices for each asset group.

The asset groups modelled for monetised risk generally form part of integrated gas supply network and therefore asset interdependence needs to be considered. For the purposes of monetised risk modelling, we have reviewed asset interdependence in a number of categories:

1. Asset downstream of other assets who would fail to supply gas if the upstream asset failed to supply gas
2. Assets that influence supply loss volumes when another asset in the same supply network fail
3. Assets with the potential to have their integrity breached due to other assets failing to operate as expected
4. Assets on a single site that interact with other assets on that site.

Details of each are described in the sections below.

2.8.1 Assets downstream of other assets who would fail to supply gas if the upstream asset failed to supply gas

As gas flows through the network, each downstream asset requires the upstream assets in the same supply network to provide gas at sufficient volume and pressure for them to operate and maintain security of supply. In this case it is not necessary to understand every asset downstream of the failing asset, but it is important to understand the consumers downstream of the failing asset. The GDNs have determined the number and type of consumers downstream of every asset in the monetised risk portfolio. Therefore supply losses can be calculated if any asset in the network fails to supply gas at sufficient flow and pressure to its downstream assets.

2.8.2 Assets that influence supply loss volumes when another asset in the same supply network fail

In some cases when an asset fails to supply, other assets can support the network or can also fail to supply themselves due to the increased load caused by the original asset failing. The GDNs have dealt with this in the following ways

- LTS Pipelines – there is a factor in the model to reduce supply loss volumes when there are parallel Pipelines that would help continuity of supply in the event of one asset failing to supply
- Offtakes & PRIs – customer loss calculations take account of supply networks with 2 or more feeds into that network and the impact of the multiple feeds if one fails
- Governors – customer loss calculations take account of supply networks with 2 or more feeds into that network and the impact of the multiple feeds if one fails
- Mains – no impact modelled as supply loss from a main is modelled to be the customers fed from that main
- Services – no impact
- Risers – no impact

2.8.3 Assets with the potential to have their integrity breached due to other assets failing to operate as expected

There are some assets whose integrity could be directly impacted by the failure of another asset to operate normally. The GDNs have dealt with this in the following ways

- LTS Pipelines – the model has factors for the health of Cathodic Protection (CP) Systems and protective sleeves. These factors impact on the probability of corrosion failure of a pipe
- Offtakes & PRIs – the model simulates an over-pressurisation incident by considering the impact on integrity of the downstream pipe network if the Offtakes/PRIs failed to regulate pressure. The model also simulates a preheater failing and the potential for the downstream pipe network to fail due to freezing. In bothe scenarios the simulation considers the impact of gas escaping from the downstream pipe network
- Governors – the model simulates an over-pressurisation incident by considering the impact on integrity of the downstream pipe network if the Governor failed to regulate pressure. The simulation considers the impact of gas escaping from the downstream pipe network
- Mains – no impact
- Services – no impact
- Risers – no impact

2.8.4 Assets on a single site that interact with other assets on that site

Some sites have multiple assets and subsystems where failure of one asset can impact on performance of other assets on that site. The GDNs have considered this but have also made sure not to overcomplicate modelling where multiple assets on the same site have negligible impact on each other

- LTS Pipelines – no impact
- Offtakes & PRIs – There are many subsystems on some of these sites so to avoid over complicating the modelling we have split the model into 3 asset groups due to the negligible impact of their performance on each other – Odourisation & Metering, Filters & Regulators, Preheating
- Governors – no impact
- Mains – no impact
- Services – no impact
- Risers – no impact

3 Event Tree Development

3.1 Development Overview

This section explains the key principles of the NOMs methodology. The process for undertaking asset risk analysis and reporting consists of the following steps:

- Define approach. This includes:
  - Agree Asset Groups and Asset Sub-groups to be modelled
  - Agree appropriate level of detail to be analysed (between sub-group population level and individual assets)
- Determine Failure Modes;
- Determine Asset Configuration (i.e. how sub-components of each asset may contribute to the overall PoF or PoC for an individual asset; for example slam-shut valves within a Governor stream);
- Determine Consequence Measures and their relationship with both Failure Mode and asset configuration;

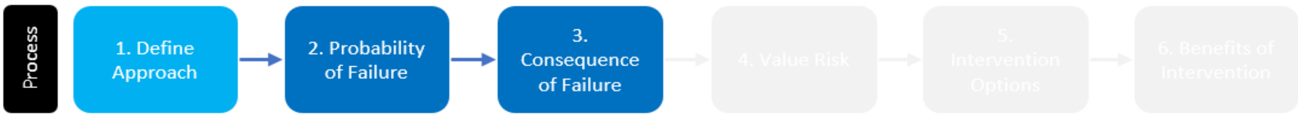
This is summarised in Figure 4 below:

Figure 4 - Event Tree Development Flow Chart

Each Event Tree follows a similar structure to provide consistency of approach.

For each Asset Group an Event Tree is produced which models each known Failure Mode that the Asset Group could experience. This determines which of the Consequence measures would be impacted by a failure of that nature. The link is made through the Event Tree showing the outcomes that can occur and the Probability of each outcome.

3.2 Define Approach



3.2.1 Determine Asset Groups

A common suite of Asset Groups to be used as a basis for risk assessment and reporting has been developed and agreed between all GDNs. These are defined based upon the key operational components within the gas supply system.

The Asset Groups are consolidated within the Event Tree analysis by assessing which assets:

- Provide a similar function/purpose;
- Have similar Failure Modes;
- Have a similar Probability of Consequences (PoC); and
- Have a material effect on the investment plans being proposed.

For example, District, Industrial/Commercial and Service Governors will be considered within the same analysis, but separated out for reporting purposes. There are 6 primary Asset Groups, for which Event Trees will be developed, as per Table 1 below. 8 Risk Maps will be developed for the primary asset types, with Offtakes and PRS having 3 separate risk maps for Odorant and Metering, Pre-heating and Filters and Pressure Control.

Primary Assets for Event Tree Analysis	Risk Map Level	Reporting Secondary Asset
A - Mains	Asset Level	Iron
		PE
		Steel
		Other
B - Services	Asset Level	Asset level
C- Governors	Asset Level	District
		I&C
		Service
D – LTS Pipelines	Asset Level	Piggable
		Non-Piggable
E – Offtakes & PRS	Odorant & Metering	Offtake Metering System
		Offtake Odorisation System
	Pre-heating	Offtake Preheating
		PRS Pre-Heating
	Filters and Pressure Control	Offtake Filters
		Slam Shut & Regulators
		PRS Filters
		PRS Slam Shut & Regulators
F - Risers	Asset Level	Asset Level

Table 1 - Primary Asset Groups

Secondary assets, such as electrical, instrumentation and civils (housing/fencing), are considered and included within primary Event Trees where there is a quantifiable effect on the risk value of the primary asset.

Asset-specific details related to Event Tree structure are included within the Appendices to this document where applicable.

Event Trees may be consolidated in future where there is a benefit to do so and the intervention planning and Heath/Risk reporting requirements are not compromised. Beyond July 2016 the SRWG will, in line with Licence Condition 4G, keep the NOMs Methodology under review as described in section 6. This could include development of monetised risk models for further asset groups if they are needed to demonstrate risk trading or if investment is being sought in future Price Controls.

3.2.2 Develop Risk Map

A key part of the design phase is to determine the optimum level of detail required for each Asset Group It is recognised that GDNs hold data at different levels of detail, but a consistent level of detail required for each Asset Group will be agreed by the SRWG. **In principle, analysis will be built up from asset-level data, where available, but the detail of reporting and analysis will be at an aggregated or population level**.

Options for the level of detail of analysis include:

- Asset group, or population level
- Asset sub-group or cohort (e.g. assets sharing a PoF and PoC, but with a different magnitude of consequence. An example of this is downstream service outage due to Governor failure)
- Individual assets (e.g. pipe level analysis, such as carried out in MRPS).

The risk maps were developed using the following generic process. This was undertaken through a series of facilitated workshops, supported by meetings with asset or financial experts

- Identify specific Asset Group or financial experts to build and validate model
- Collect failure data (including explanatory factors, where available)
- Collect internal cost data (repair, maintenance, refurbishment, replacement)
- Collect external cost data (e.g. cost of carbon, value of a life)
- Brainstorm potential Failure Modes for each Asset Group
- Brainstorm potential consequences arising from failure
- Develop risk map by linking asset to failure to consequence to cost (of failure and response to failure)
- Assign PoF (current and deterioration) to Failure Modes
- Quantify consequences (impact of failure on costs, service, safety, environment etc.)
- Value consequence (cost of failure and remediation, environmental cost etc.)
- Undertake monetised risk analysis for each Failure Mode; compare against company expected values and iterate as required

- Sum monetised risk for each Failure Mode to obtain baseline monetised risk profile for each Failure Mode over the life of the asset
- Identify interventions (options to reduce monetised risk)
- Revise risk map (if required) to enable modelling of identified interventions
- Apply interventions to baseline model to test impact on monetised risk
- Use the difference between baseline and with-intervention monetised risk profile to determine the benefit of each intervention
- Ready the model for reporting or investment targeting applications
- Generate Asset Health and Risk Reports

Data sources to populate the risk map are classified as follows:

- Company-specific data (including analysed data) from a known and reliable source.
- Pooled data (using best available source across all participating companies, with appropriate extrapolation to individual companies)
- Previous studies, industry-standard or default values. Data obtained from relevant industry studies or published data sets (e.g. cost of carbon; value of a life; data from RRP tables)
- No data source exists. Data is estimated or expert judgement used or derived through elicitation processes
- The data source chosen to populate each node on the Event Tree can be classified into Options A, B or C as detailed further in Section 4 below.

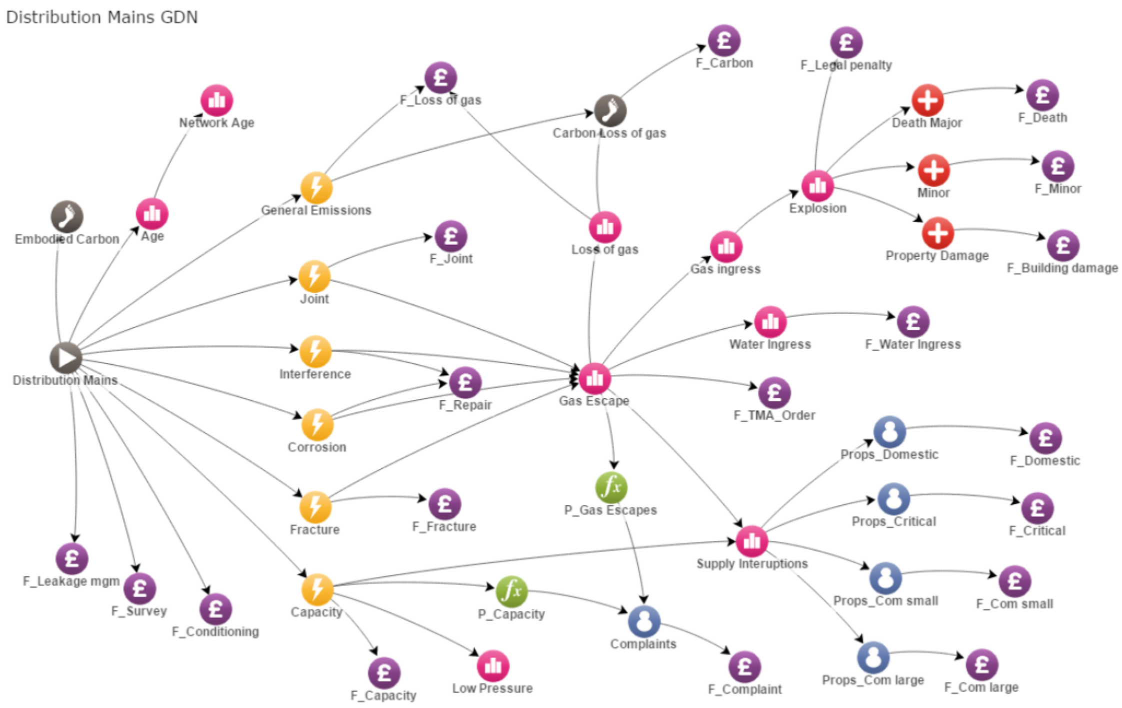


Figure 5 - Example Final Risk Tree

3.3 Worked Example

A detailed walk-through of the monetised risk modelling process for a single cohort (Tier 1 Ductile Iron Pipes in the North-East area of Northern Gas Networks (hereafter referred to as DI/NO/1) - is provided throughout the document. The process will be identical for the remaining cohorts within the Distribution Mains risk model.

Risk models for other Asset Groups will vary (as they have different Failure Modes and consequences) but the process to delivered overall monetised risk assessments for the cohort will be identical. As such detailed walk-throughs should be unnecessary as and when these models are delivered. Details of any material differences are documented in the Appendices.

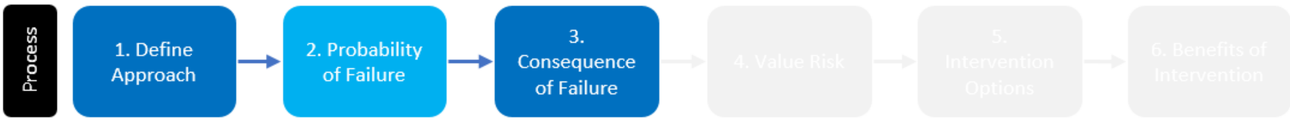
The base year length of the DI/NO/1 cohort is 1,096 kilometres. The total base year monetised risk value is £1,721,370. The overall levels of monetised risk for the DI/NO/1 cohort, broken down by individual monetised risk elements, are illustrated in Figure 6.

Clearly the largest monetised risk elements are associated with the values of carbon emissions (F_Carbon) and joint repairs (F_Joint). The following worked example will focus on the path taken through the risk model, from Failure Modes to economic analysis and risk trading.

Cohort Monetised Risk		
F_Capacity	£	715.18
F_Complaint	£	2,740.68
F_Com large	£	511.72
F_Com small	£	1,156.33
F_Critical	£	637.49
F_Domestic	£	71,426.24
F_TMA_Order	£	28,741.76
F_Water Ingress	£	11,970.94
F_Building damage	£	1,916.34
F_Minor	£	1,875.78
F_Death	£	73,003.40
F_Legal penalty	£	10,139.36
F_Carbon	£	664,058.90
F_Loss of gas	£	184,104.34
F_Repair	£	151,488.71
F_Fracture	£	88,650.53
F_Joint	£	285,099.85
F_Leakage mgm	£	13,794.28
F_Survey	£	109,608.90
F_Conditioning	£	19,729.60
Total Cohort Monetised Risk		
Cohort Risk Value	£	1,721,370.33

Figure 6 - Base year monetised risk values for the DI/NO/1 Cohort

3.4 Derive Probability of Failure



3.4.1 Identify Failure Modes for each Asset Group

The first step is to identify all the potential ways an asset could fail, known as Failure Modes. These modes will be grouped together where similar. Each Failure Mode will also be defined as either repairable or non-repairable and assigned a PoF model.

Failure Modes are defined as a specific deviation in the performance of the asset which will give rise to a Consequence (cost, service, safety or environment). Clearly, Failure Modes are highly asset specific. It is essential that all modes of failure that are likely to generate a significant consequence are identified up front. If appropriate failure data is not available and the failure and consequences are judged to be significant, then gaps can be filled through expert judgement, through structured elicitation exercises and/or data collection plans developed.

All PoF values and deterioration rates are applied against individual Failure Modes within the Event Tree analysis.

Asset Interventions are identified to address specific modes of asset failure as thus reduce further risk (although "negative" interventions can also be applied which increase future risk, such as undertaking less proactive maintenance). Understanding the available intervention options at this stage in Event Tree development provides a useful check that all significant failure modes have been considered.

Some example Failure Modes for different asset types are listed below:

Asset	Failure Mode	Failure Type
Gas Pre Heating	Low temperature failure	Repairable
Distribution Mains	Joint failure	Repairable
Domestic Service	Corrosion failure	Non-repairable
District Governor	Interference failure	Repairable

Table 2 - Example of identified Failure Modes & type

3.4.2 Identify asset configuration for each Asset Group

The Asset Configuration will be taken into account to include the effect of any system reliability and related redundancy that may exist. There are two main configurations, parallel and series.

Note: the PoF values in the equations below relate to the true Probability of Failure (i.e. the number of failure events per year divided by the size of the asset population. Units are percentages), **not** the failure/hazard rate (the number of failure events occurring on the asset population over the year. Units are Events per asset per year).

When an asset is operating **in parallel** an asset will consist of two (or more) components that need only one of them in functional state to operate. If one component fails then the asset will continue to operate unless all components fail at the same time. A simple parallel system can be approximated as the multiplication of all the component failure rates, thereby reducing the overall asset PoF.

POF (Asset in parallel) = POF (component 1) * POF(component 2)

When an asset is operating **in series** an asset will consist of two (or more) components that needs all of them in a functional state to operate. A simple asset in series can be approximated as the addition of all the component failure rates, thereby increasing the overall asset Probability of Failure.

POF (Asset in series) = POF (component 1) + POF (component 2)

These equations can be modified as required to represent obsolescence and common Failure Modes.

3.4.3 Worked Example – Failure Modes

The Failure Modes to be examined in the worked example for the DI/NO/1 cohort are listed below along with their associated initial (Year 0) probabilities of failure. The PoFs are discussed further in the next section.

The Failure Modes to be tracked through this worked example are Joint and General Emissions as these Failure Modes contribute most significantly to the overall monetised risk value for the cohort. The remaining Failure Mode monetised risk values are generally calculated in similar ways to either Joint or General Emissions.

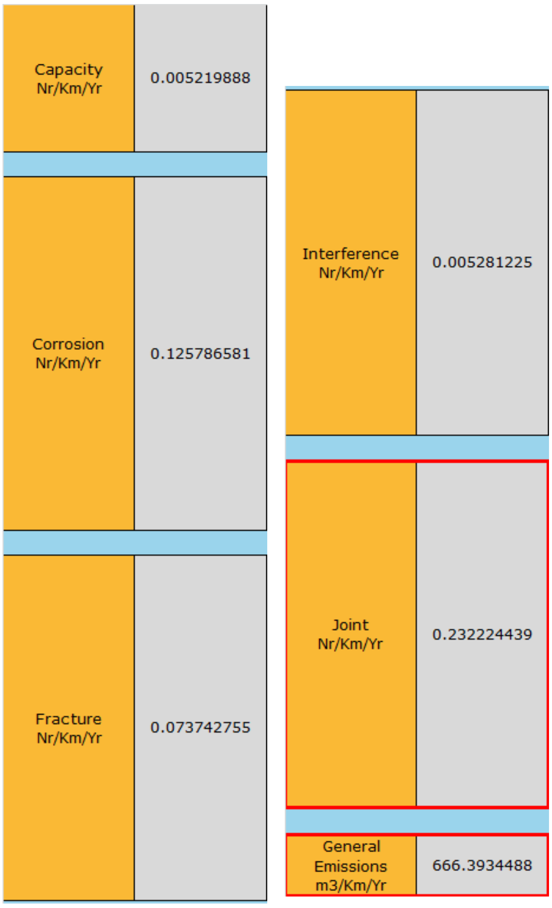
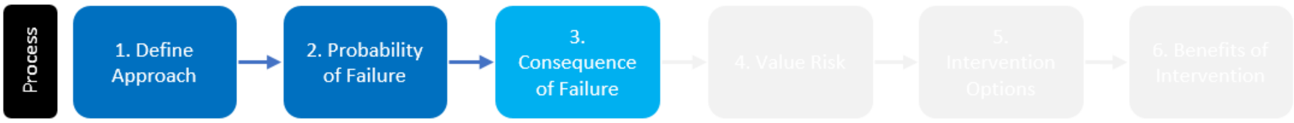


Figure 7 - Worked Example - DI/NO/1 Cohort Failure Modes and Year 0 PoF

3.5 Derive Consequence of Failure



One of the key concepts of the NOMs methodology is that for each failure there may be a Consequence of Failure which can be valued in monetary terms. Clearly, for an accurate assessment of Monetised Risk it is essential that all Consequences of Failure are captured and linked back to the asset failures that give rise to these consequences. The risk mapping process is designed to capture these links between asset failure and consequence, and there can be complex relationships between Failure Modes and consequences which may not otherwise be captured without a structured risk mapping process.

3.5.1 Define list of Consequence measures

A common suite of Consequence measures will be developed and agreed between all GDNs. These will be defined using the observed consequences that typically result from failure of gas distribution assets.

The Consequence measure can be defined in the following categories:

- **Financial risk** – Those that lead to a direct financial cost to the business for remedial work to the assets, such as repair
- **Private or company risk** – Those associated with the cost of dealing with the failure such as the cost of lost gas, the requirements to undertaken network inspections, the cost of restoring supplies; or
- **Public risk** – Those indirect environmental and societal costs associated with health and safety, traffic disruption etc.

Table 3 below provides examples of typical Consequence measures that could be considered as part of Event Tree development for each Asset Group (this list should not be considered exhaustive).

Primary Consequence Measure		Secondary Consequence measure		Metric
1	Public Risk (HSE, Environmental)	1	Death / Major Injury	No. of people impacted
		2	Minor Injury	No. of people impacted
		3	Burns	No. of people impacted
		4	Property damage	No. of properties impacted
		5	Traffic disruption	Duration of disruption (Hrs.)
		6	Pollution	No. of incidents
		7	Carbon emissions	Tonnes
2	Financial Risk	8	Repairs	No.
3	Private Risk (Customers, Monetised Risk)	9	Loss of gas	m^3
		10	Network integrity inspections	No. of properties/premises
		11	Restoration of supply	No. of properties/premises
		12	Third party damage	No. of events
		13	Crop damage	No. of events
		14	Prosecution	£
		15	Supply Losses - Domestic	No. of properties
		16	Supply Losses – Commercial - Small	No. of premises
		17	Supply Losses – Commercial - Large	No. of premises
		18	Supply Losses - Critical	No. of critical customers

Table 3 - Primary and secondary consequence measures

The link is made through the Event Tree showing the outcomes that can occur and the Probability of each outcome.

3.6 Final Risk Map

Once the Failure Modes and Consequence measures are identified and linked together, including types of Cost of Consequence, a final risk map is established that will enable the tracking of consequences and costs for each Failure Mode through each branch of the Event Tree. This enables the impact of intervention, which addresses the probability of an asset failing, to be tracked through the associated consequences and costs.

Each final Event Tree will be common across all of the GDNs and any proposed modifications, such as additional Failure Modes or the inclusion of additional secondary assets, will be subject to the governance process as per section 6.

Event Tree Development

Figure 8 below, illustrates the broad sections of an Event Tree, from the Asset Base data to the Monetised Risk data (in line with the diagram in section 2.1).

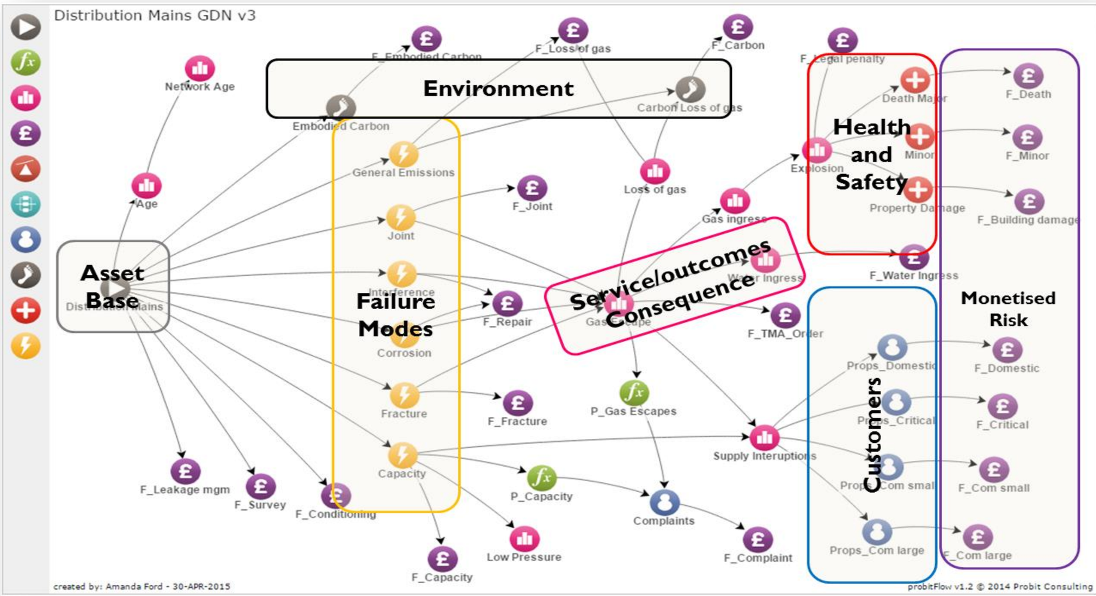


Figure 8 - Example Event Tree Sections

Table 4 below expands on those sections further, providing a description of each section, examples of the types of data used. Table 4 is colour coded for each node of the event tree. Subsequent risk maps within this methodology and the appendices reflect this colour coding to indicate which values are associated with each node.

	Description	Examples
Asset Base	Asset data and attributes from company asset repositories	List of individual distribution mains including diameter, material and location
Probability of Failure (per Failure Mode)	Applicable Failure Modes per asset class, each with calculated Probability of Failures per annum (value >=0)	Corrosion failure, capacity constraint, interference damage
Probability of Consequence	Applicable outcomes resulting from a failure, each with a calculated probability of consequence (value from 0 to 1)	Loss of gas, gas escape, supply interruption, explosion
Environmental Consequence	Environmental outcomes resulting from a failure, each with a calculated volume (value >=0)	Carbon Loss of Gas, Embodied Carbon
Health & Safety Consequence	Health & Safety outcomes resulting from a failure, each with a calculated quantity (value >=0)	No of Deaths, No of Injuries, No of Buildings Damaged
Customer Consequence	Customer outcomes resulting from a failure, each with a calculated quantity (value >=0)	No of domestic properties effected, No of critical properties effected (hospitals/schools)

Monetised Risk Value	Applicable costs associated with consequences, failure resolution and asset management (value in £)	Repair costs, restoration of supplies, cost of complaints

Table 4 - Event Tree Section Detail

3.7 Data Reference Libraries

3.7.1 Overview

Each of the nodes within an Event Tree represents a data point. Various elements will contain GDN-specific values (such as PoF values and Consequence outcomes) and others will contain common (global) values (see section 6.2 below).

Data Reference Libraries (DRLs) will be developed for each of the event-trees to ensure the data values or the methods for deriving the data values are consistently applied. The Data Reference Libraries will be in a table format and contain information such as the Event Tree node name/reference, a description, unit of measure, the value used including source or calculation (Global values only, where Global values are data items shared across different Asset Group Event Trees, or are common across all GDNs).

A broad sensitivity category is defined for global values where applicable, shown as Low (L), medium (M) or high (H) sensitivity. Changes in the value of a node with low sensitivity may have a minor impact on the overall Health or Risk value. Similarly changes in the value of a node with High sensitivity may have a major impact on the overall Health or Risk values.

Asset-specific DRLs, are included within the Appendices, contain detail on the data applied to each Event Tree node as per the assessment detailed in Section 4.1.

Any changes to the data values or the methods for deriving the data values will be subject to the governance process as per section 6. Node values defined as High sensitivity can be subject to the modification process at any time.

3.7.2 Global Values

Global Values are those values that are applied across all Asset Groups and Event Trees and can be either be GDN specific or common to all GDNs. Global values used within all risk models are listed below. All Global values will be subject to an annual review and identified changes to values and/or data sources agreed with the SRWG. If changes are identified and approved for inclusion, any potentially significant changes to individual GDN investment programmes will identified by re-running the relevant risk assessment models. Any material differences generated by changes to these Global values may trigger discussions with Ofgem prior to incorporation.

Sens.	Node ID / Variable	Description	Value	Notes / Source	GDN or Common value
H	**F_Loss_Of_ Gas**	Cost per m3 of loss of gas	£0.22	2p/kWh = £0.22/m3 (QUARTERLY ENERGY PRICES 2015 DECC)	Common
L	**F_Legal_ Penalty**	Legal penalty payment	£1M	SRWG estimate based on civil action costs.	Common
H	**F_Carbon**	Cost of carbon	Formula to model bi-linear increase over time. if(Dyear+2015<=2030,Dyear+2015-1953,7.3587*(2015+Dyear)-14860)	0.0020461 tonnes carbon per m3 Carbon price based on "Valuation of energy use and greenhouse gas (GHG) emission - Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government Sept 14"	Common

Sens.	Node ID / Variable	Description	Value	Notes / Source	GDN or Common value
				Box 3.4 Non-traded value of Carbon (£/tCo2e) Scaling factor for methane to be included within volume calculation (see Carbon Loss of Gas)	
L	**F_Com_large**	Cost of large commercial supply interruption	GDN specific or £200 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £100 compensation payment cost + £100 visit cost;	GDN Specific
L	**F_Com_small**	Cost of small commercial supply interruption	GDN specific or £200 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £100 compensation payment cost + £100 visit cost;	GDN Specific
L	**F_Complaint or F_Complaint SI**	Cost of complaint	GDN specific or £450 per complaint	Complaint cost based on data from company systems, or (where no data available) default cost based on £450 complaint cost;	GDN Specific
L	**F_Critical**	Cost of critical customer supply interruption	GDN specific or £200 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £100 compensation payment cost + £100 visit cost;	GDN Specific
M	**F_Domestic**	Cost of domestic customer supply interruption	GDN specific or £150 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £50 compensation payment cost + £100 visit cost;	GDN Specific
L	**F_Building_ damage**	Cost of building damage	GDN specific based on regional cost or default £189,000.00	Based on average regional rebuild cost for a property or (where no data available) default national cost of £189,000 (source: BCIS) http://calculator.bcis.co.uk/register/register.aspx the average price of a house	GDN Specific
L	**F_Minor**	Cost of minor injury	£ 185,000.00	Sum historically agreed based on legacy Business Plan submissions and discussions with Ofgem/HSE	Common
M	**F_Death**	Cost of death	£16,000,000.00	Sum historically agreed based on legacy Business Plan submissions and discussions with Ofgem/HSE	Common

Sens.	Node ID / Variable	Description	Value	Notes / Source	GDN or Common value
	Discount Rate	Financial discount rate	WACC. Real discount rate i.e. net of inflation if costs not inflated. Or discount rate to include inflation if costs are inflated.	Data taken from Company systems	GDN Specific
H	**Carbon_ Equivalent**	Scalar value for carbon methane uplift	Carbon equivalent = sum (GWP x %mass)	Conversion factor to account for Loss_of_Gas is methane, not carbon. Based on DECC values weighted for the composition of gas supplied into the network. GWP Value agreed with SRWG for non-ignited gas.	GDN Specific
H	**Carbon_Loss_Of _Gas**	m3 of carbon equivalent from loss of gas	1 m3 of carbon equivalent from Loss of Gas Carbon Loss of Gas = relative density x carbon equivalent.	Value calculated by each GDN based on actual gas composition in the network.	GDN Specific
	Inflation	Annual increase in financial costs	RPI. (Discount rate net of inflation if costs not inflated. Or discount rate to include inflation if costs are inflated.)	Data taken from Company systems	GDN Specific
	Base Price Year	Base Price Year	Current RRP year	Current RRP year	Common

Table 5 - Global Values

4 Event Tree Utilisation

4.1 Utilisation Overview

The process for undertaking asset risk assessment and reporting consists of the following steps:

- Determine the Probability of Failure for each Failure Mode;
- Determine probability that a failure will result in a specific Consequence;
    - quantify the magnitude of each Consequence arising from failure
- Quantify and value the risk (the Monetised Risk value);
- Identify Intervention options to mitigate the Monetised Risk ; and
- Evaluate the costs and benefits of intervention to mitigate the identified Monetised Risk.

This is summarised in Figure 9 below:

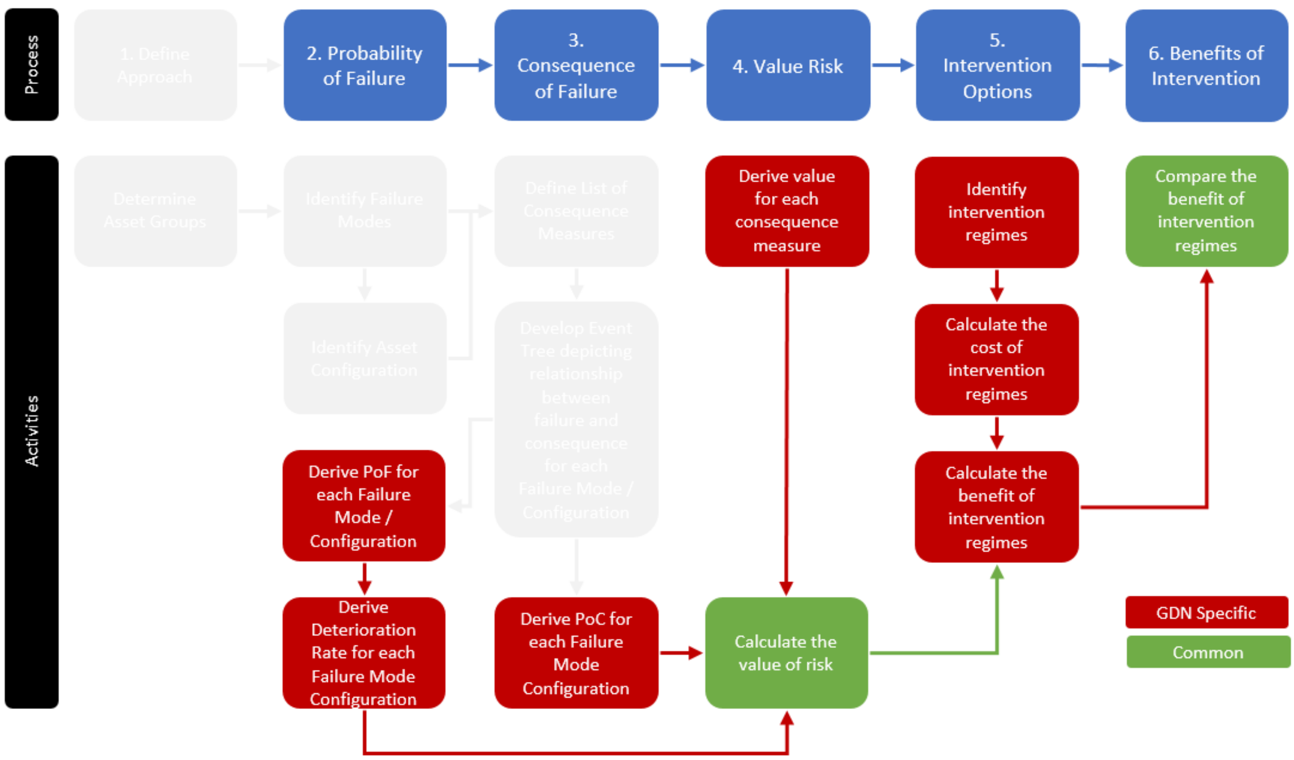


Figure 9 - Event Tree Utilisation Flow Chart

4.2 Data Assessment

Each derived asset category and associated Event Tree Analysis will be accompanied with details of Global Values applied (see section 3.7.2) and a Data Reference Library (see section 3.7). The Data Reference Library will detail the inputs required. Gap analysis of specific GDN data quality levels against these data reference libraries will ensure that GDNs work towards having the required asset, fault and financial data structure to enable consistent annual reporting of asset risk, health and criticality.

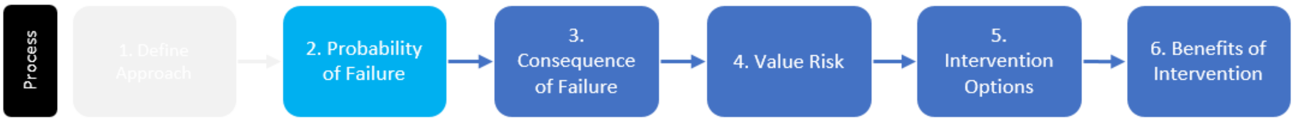
Event Tree analysis will be undertaken using asset level data where such data exists in company systems however, a number of sub-population and global values may be used to complete the Event Tree analysis. It is recognised that the GDNs will have data gaps and will not hold the same level of asset data, therefore to facilitate the population of the Event Trees and Monetised Risk and Health outputs, a flexible but consistent methodology (with options) will be utilised to derive the Probability of Failure, Deterioration, Probability of Consequence and associated impacts of Intervention.

Table 6 below depicts the options available for each element of an event-tree:

	Option A (GDN Specific Data)	Option B (Pooled/Shared)	Option C (Global/Assumed)
Asset Base	Complete asset data and attributes from asset repositories	N/A	Known asset numbers, gaps in asset data - Assumptions or default values applied
Probability of Failure (per Failure Mode)	Consistent and complete failure data enabling PoF and deterioration rate calculation	Robust failure data owned by one or more GDN, pooling or sharing of data agreed to enable PoF and deterioration rate calculation	Limited or no failure data available. Engineering expert knowledge/elicitation used to determine PoF based on age or condition and deterioration based on end-of-life assumption
Probability of Consequence (per outcome)	Consistent and complete consequence data enabling probability of consequence calculation	Industry accepted model or robust consequence data owned by one or more GDN, pooling or sharing of data agreed to enable consequence calculation	Limited or no consequence data available. Expert knowledge/elicitation or published studies/reports used to determine consequence outcomes
Environmental Consequence	N/A	N/A	Expert knowledge or published studies/reports used to calculate environmental consequences
Health & Safety Consequence	N/A	N/A	Expert knowledge or published studies/reports used to determine health & safety consequences (i.e. probability of death)
Customer Consequence	Consistent and complete customer/flow data enabling customer consequence calculation	N/A	N/A
Monetised Risk Value	Consistent and complete financial/cost data	N/A	Published studies/reports used to determine financial/cost values (i.e. societal and carbon costs)

Table 6 - Data Options

4.3 Probability of Failure, Deterioration & Asset Health



The first step is to define an initial likelihood of failure, or Probability of Failure (PoF) for each Failure Mode. This is typically expressed as a number of failures per year (this must be normalised to a consistent unit for linear assets such as Mains or Services e.g. failures per kilometre per year).

To model the change in this PoF over time a deterioration relationship must also be derived for each Failure Mode. The initial PoF defines the starting point on the asset deterioration curve. Using the modelled PoF deterioration curve it is possible to estimate the PoF for the asset at any point in the future. Using the same deterioration curve it is also possible to back-calculate the failure rate in a historical year to verify the predictive capability of the deterioration model.

4.3.1 Probability of Failure (PoF) Calculation

Probability of Failure models predict either the PoF (Probability of Failure) or the PoF (Failure Rate) at a given time, and can include constant, linear, exponential, power law, and Weibull hazard models, as shown in figure 10 below.

The models and related failure rates are built at asset level, population or sub-population level depending on the level of data. Sub-population models typically split the assets into groups based on key asset attributes, such as material, size, etc.

PoF (Probability of Failure) i.e. probability of failing in a given year = function (age, asset attributes, condition)

PoF (Failure Rate) i.e. number per year = function (age, asset attributes, condition)

The starting point on the failure rate curve (age=current) will be estimated by the appropriate method to determine the current number rate of failure, either for individual assets or some appropriate stratification grouping. This will be undertaken wherever possible using observed failure data from company records.

The deterioration rate of an asset measures how the failure rate changes over time, i.e. age increasing. This is used to forecast the number of future failures for each year over the planning horizon and at a given time period. To calculate deterioration, the rate of change in failures per unit increase in age is estimated.

Statistical fitting methods can be used to ensure that each model is robust and is statistically significant. Examples of appropriate modelling include for alternative Failure Mode types:

- Non-repairable Failure Modes – Survival/lifetime analysis modelling
- Repairable Failure Modes – Counting process regression modelling

For assets where there is condition data, the condition data will either be included as an attribute in the Failure Model or used to map the condition on to an effective age, which then determines the initial PoF (failure rate) as a starting point for the deterioration curve.

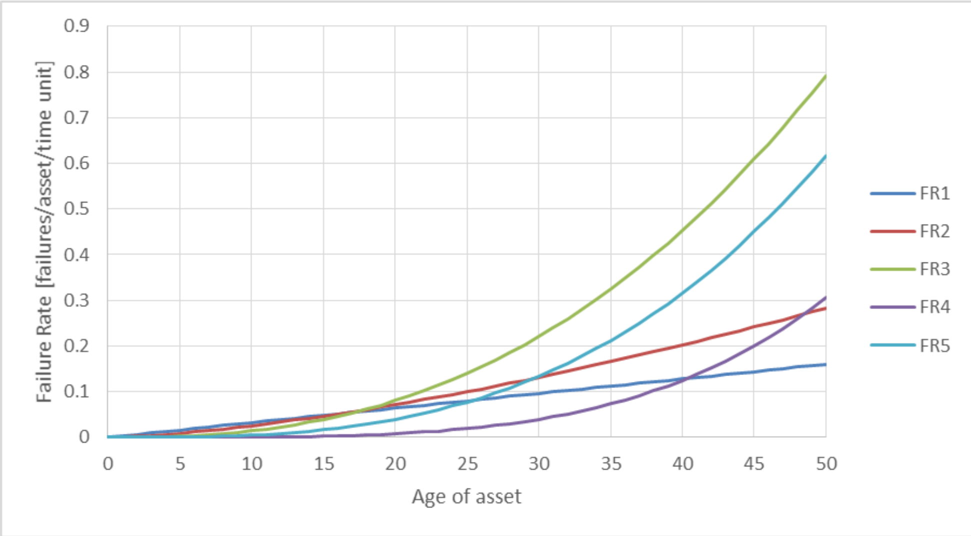


Figure 10 - Example PoF Curves

Gap analysis will be undertaken for each Failure Mode and related observed failure data in the determination of PoF values and deterioration rates for each asset's Failure Mode. The applicable method for determining Probability of Failure and Deterioration rates will be dependent on the level of data availability and quality derived from this analysis, as per the 3 options in Section 4.2.

For each of the Failure Modes, the GDNs will determine which option applies based on the consistency, completeness and quality of asset failure data.

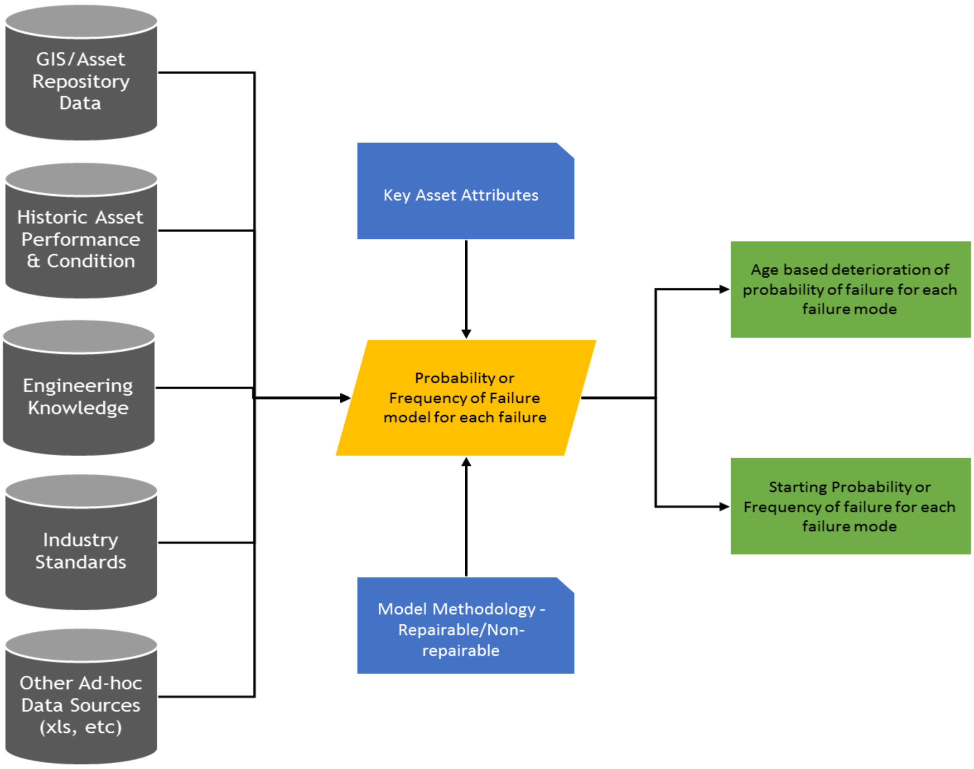


Figure 11 - Data Sources

Where a GDN has inconsistent, incomplete and/or poor quality data for a particular Failure Mode, the methodology allows for the utilisation of either an agreed standard PoF curve with derived starting-point (Option C) or pooled/shared PoF values and deterioration rates (Option B). Data Improvement plans will be established to move to 'Option A' data where applicable/possible and where the plans benefit the consistency and completeness of data for accurate and comparable reporting.

4.3.1.1 Option A (Data Driven)

Where a GDN has consistent and complete asset failure data available for a specific asset's Failure Mode, this data will be used to derive the PoF at a given point in time, measured as the number of failures over a year and the deterioration rate, measured as a percentage change in the number of failures year on year. These values will be used within the applicable Event Tree.

Additionally, where a GDN has condition data, this will be used to enhance and/or modify the Failure Models where appropriate.

4.3.1.2 Option B (Pooled/Industry Accepted Model)

Where a GDN has inconsistent, incomplete and/or poor quality data for a particular Failure Mode, there is an option to use, where agreed, the PoF values and deterioration rates derived from a nominated GDN's calculations or an industry accepted model.

4.3.1.3 Option C (Expert Elicitation)

Alternatively, where another GDNs values or industry accepted model cannot be used, engineering Expert Elicitation will be utilised to estimate the Failure Model.

An example of this is shown in Figure 12 below for a non-repairable Failure Mode, where experts are asked to identify failure percentages (e.g. 10, 50 and 90%) over the life of an asset for a particular asset or cohort. This is then used to fit a statistical distribution (cumulative distribution function – CDF) to the responses and re-parameterised to give the parameters of the underlying PoF model, for example the hazard function.

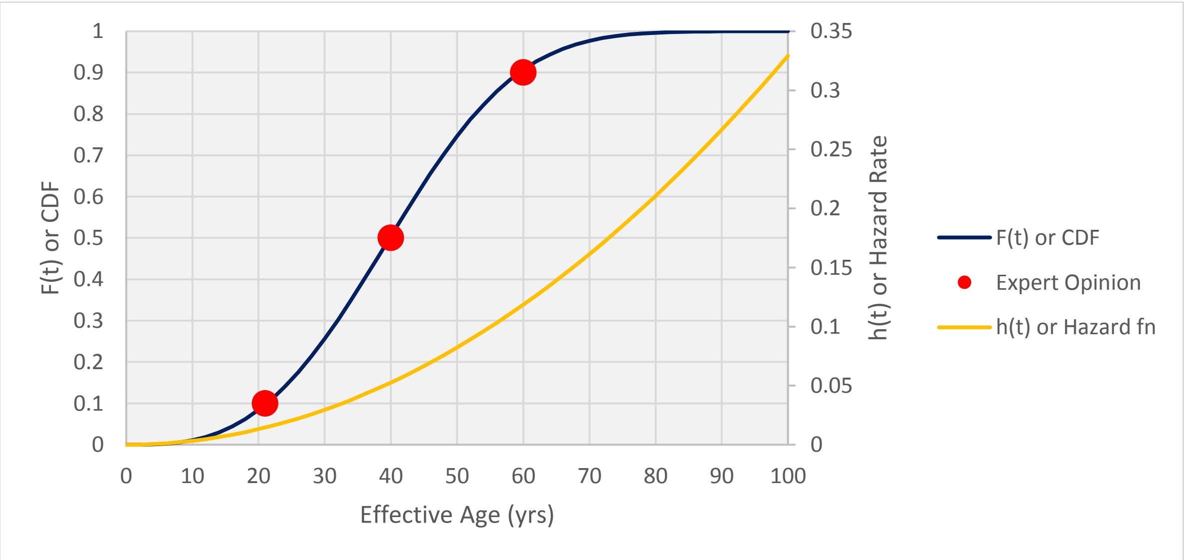


Figure 12 - Derived Failure Curve

Condition and/or age data can also be used to determine an effective age which provides a start point on the curve and a conditional Probability of Failure value for use in the Event Tree.

4.3.2 Worked Example – PoF and Deterioration

Continuing on from the Worked Example in section 3.4.3, where there is consistent and complete asset failure data available (Option A), this section describes how the Joint and General Emissions Failure Modes Probability of Failure values and Deterioration rates have been calculated.

4.3.2.1 Joint

From the table in section 3.4.3, it can be seen that the initial PoF of a Joint failure is 0.232 failures per kilometre per year for the DI/NO/1 cohort.

An initial PoF was assigned to each pipe element represented in the NGN GIS database using base pipe attributes taken from the GIS (Install Decade, Diameter, Material, Pressure, and Distribution Zone). This analysis predicts a total number of joint failures of 179 per year for the DI/NO/1 cohort alone. This value is normalised to a per kilometre value by dividing by the cohort length (1096 km) and then factored to ensure the predicted number of joint failures is equal to the actual number reported by NGN (a factor of 1.42 is applied in this example). Differences in predicted-vs-actual are due to missing location or material data in the company repair records.

Joint PoF (Year 0) = (Total Joint Failures / Cohort Length) x Scaling Factor

Joint PoF (Year 0) = 179 / 1096 x 1.42 = 0.232 failures per km per year

The method used to calculate the deterioration rate of the PoF for joint failures (and other Failure Modes) is discussed in Appendix A. The deterioration rate for joints on Ductile Iron mains (from the analysed failure data set) has been assessed to be 4.9% per year.

The deterioration rate for joint failure uses an exponential relationship to model the increase in the number of annual failures given a reactive maintenance only policy (i.e. no replacement). The following equation is used to predict the number of joint failures in Year n:

Joint Failures (Year n) = exp(n x Joint Deterioration Rate) x (Total Joint Failures (Year 0) / Cohort Length) x Scaling Factor

So for Year 10 the new level of joint failures calculated from the Year 0 value (of 0.232 failures/km/year) will be:

Joint Failures (Year 10) = exp(10 x 0.049) x (179 / 1096) x 1.42 = 0.379 failures / km / year

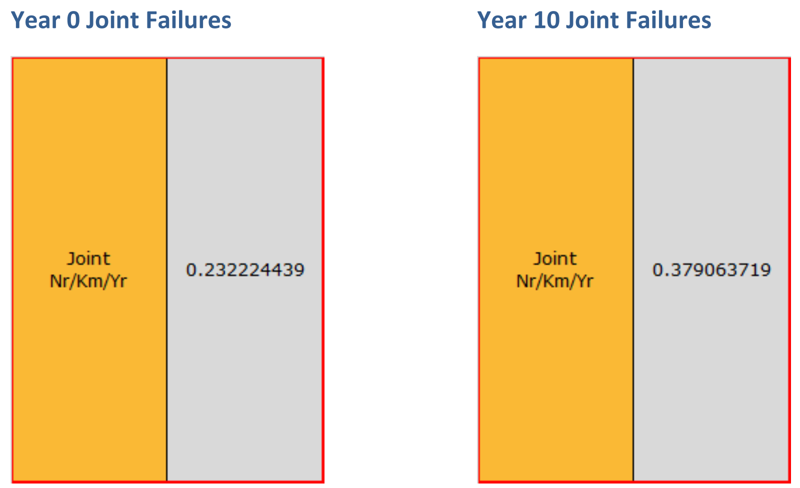


Figure 13 - Worked Example - Joint Failure Figures

The annual increase in the numbers of joint failures over the life of the asset is represented in Figure 14 below (all joint failures).

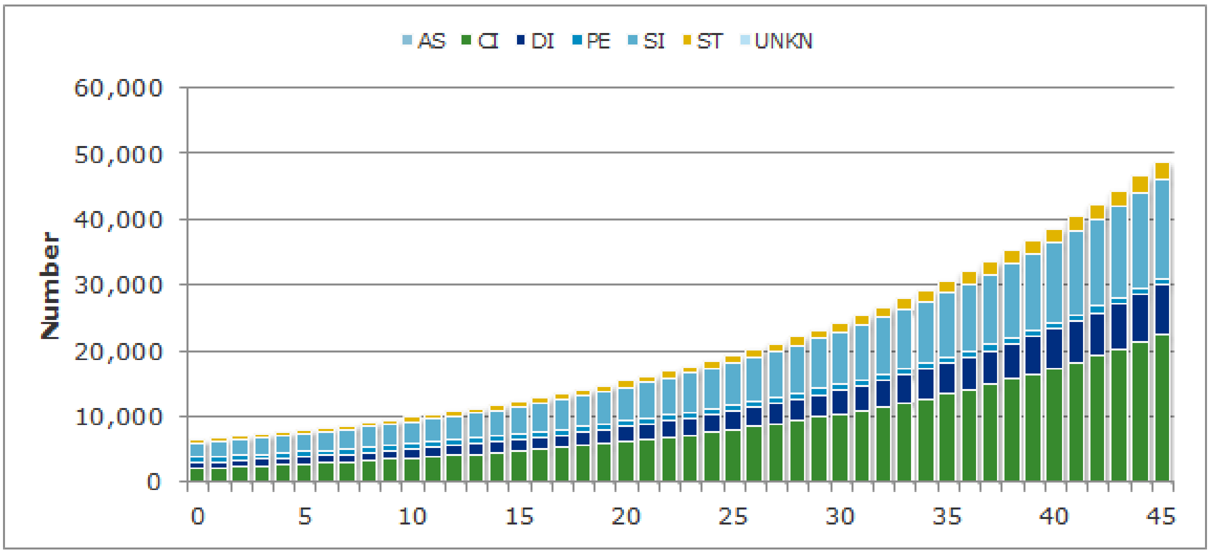


Figure 14 - Worked Example - Total numbers of joint failures per year given reactive only maintenance (all materials and all cohorts)

4.3.2.2 General Emissions

General Emissions relate to leakage or shrinkage from the pipe network. The values are calculated directly from industry shrinkage models as per the table below.

Diameters in GIS are converted to imperial values and values were applied at the individual pipe level using the lookup using the leakage rate lookup table below using the assigned material and diameter.

MATERIAL	<=3"	4"-5"	6"-7"	8"-11"	>=12"
PE	63.51	63.51	63.51	63.51	63.51
Steel	3416.34	3854.34	3854.34	3854.34	3854.34
Ductile	719.18	719.18	576.40	576.40	576.40
Pit Cast	2407.21	1639.85	2525.47	2203.98	7463.40
Spun Cast	1075.71	1075.71	1075.71	1075.71	1075.71

Table 7- Worked Example - Leakage rates in cubic metres/year/km at 30mb Standard System Pressure

Cohort values are then calculated by summing emissions values for all the pipes within the specified cohort. For the DI/NO/1 cohort the total annual emissions are calculated to be 730,427 cubic metres per year calculated by summing individual pipe lengths using the lookup table above. This is normalised to a per kilometre value by dividing by the cohort length (1096 km).

General Emissions (Year 0) = 730,427 / 1096 = 666.3 cubic metres / km / year

Deterioration of general emissions assumes a simple linear annual increase according to the equation below:

General Emissions (Year n) = General Emissions (Year 0) x (1 + (n /100))

So for Year 10 the new level of General Emissions calculated from the Year 0 value (of 666.3 m3/km/year) will be:

General Emissions (Year 10) = 666.3 x (1 +(10/100)) = 733.0 cubic metres / km / year

Year 0 General Emissions

General Emissions m3/Km/Yr	666.3934488

Year 10 General Emissions

General Emissions m3/Km/Yr	733.0327937

Figure 15 - Worked Example - General Emissions Figures

The chart below illustrates the assumed deterioration in general emissions (for all mains cohorts).

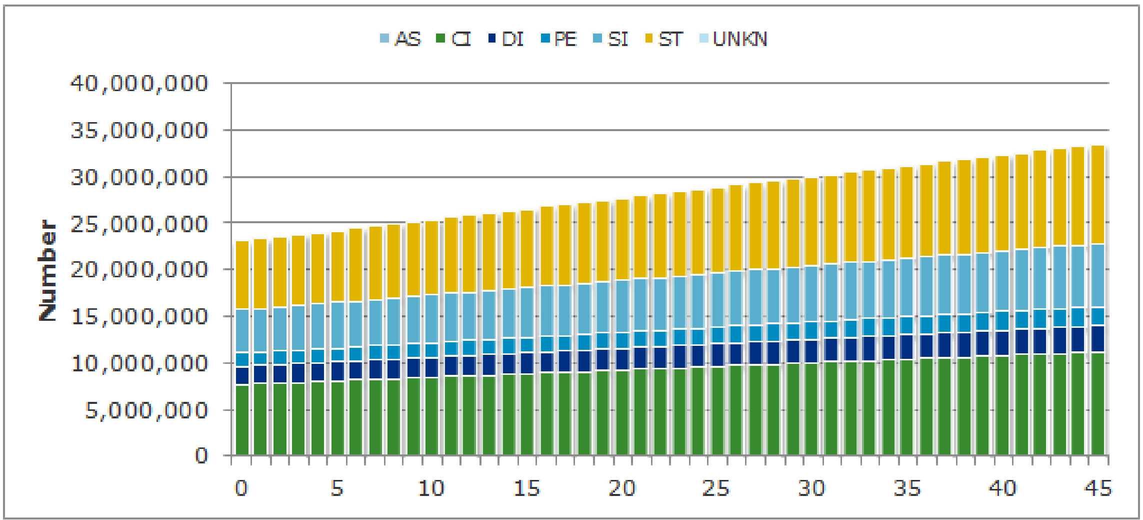


Figure 16 - Worked Example - Total general emissions given reactive only maintenance (all materials and all cohorts). Units are in cubic metres per year

4.3.3 Derived Asset Health

A view of the health of an asset population can be calculated from the sum of the individual Failure Modes where they have the same units and can be considered independent.

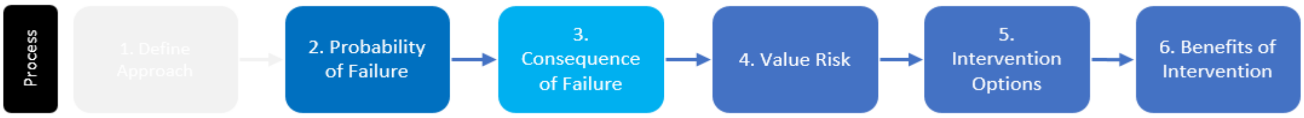
4.3.3.1 Example

Following on from the example above, the Asset Health is considered to be the sum of all the PoF modes (where expressed in common units, in this case the number of failures per kilometre per year).

Failure Mode	PoF
Corrosion Nr/Km/Yr	0.004
Fracture Nr/Km/Yr	0.002
Interference Nr/Km/Yr	0.011
Joint Nr/Km/Yr	0.031
Total	**0.048**

Table 8 - Example Asset Health Figure

4.4 Consequence of Failure & Derived Criticality



4.4.1 Probability of Consequence (PoC) Calculation

For each of the of consequence measures, including customer, environmental, health & safety, the quantity and probability of consequence value is required for each step in the Event Tree. The scale or quantity of risk articulates the size of any potential Consequence. The Consequence Value is then calculated taking the probability of that occurrence into account as determined by the Event Tree.

Gap analysis will be undertaken for consequence data that will be used in the determination of these values. The applicable method for determining each value will be dependent on the level of data availability and quality derived from this analysis, as per the options in section 4.2.

For each of the consequence measures, the GDNs will jointly determine which option applies based on the consistency, completeness and quality of data available. Methods may include:

- GIS analysis – e.g. number of properties connected to an asset
- Network Modelling – e.g. number of customers served by a governor
- Observed data – e.g. number of historical explosions
- Industry accepted values
- Expert opinion

Where a GDN has inconsistent, incomplete and/or poor quality data for a particular consequence measure, the methodology allows for the utilisation of either expert knowledge or published studies/reports (Option C) or pooled/shared PoC values (Option B), as described for determining Probability of Failure.

Option A

Consequence values derived from GDN specific data sources.

Option B

Consequence values derived from shared data sources where the valuation data is not available or is uncertain within individual GDNs. This may be because data capture systems do not currently exist in specific GDNs or the consequence event is so infrequent that there is a high degree of uncertainty in the consequence value.

Option C

Data taken from industry standard data sources, such as HSE or DECC reports. This will also include assumptions agreed with Ofgem or as agreed with independent experts.

4.4.2 Worked Example – Probability of Consequence

Joint

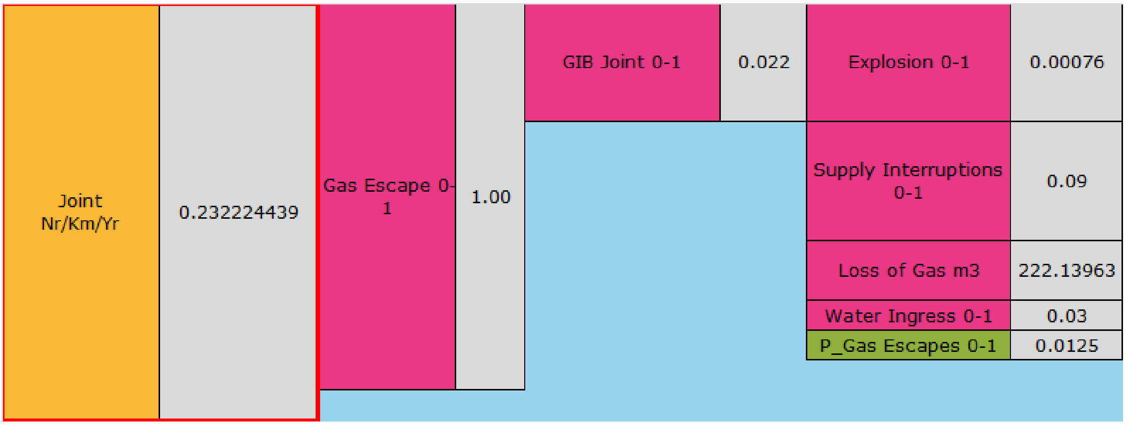


Figure 17 - Worked Example – Joint PoC Figures

The Consequences of Failure identified for a joint failure are shown in the pink boxes above accompanied by associated Probability of Consequence (PoC) values for the DI/NO/1 cohort. Further details of how these PoC values have been calculated are provided in Appendix A. For joints:

- All joint failures will lead to a Gas Escape (PoC for a Gas Escape equals 1)
- A proportion of Gas Escapes will lead to a Gas in Building (GIB) event (the PoC for a GIB arising from a joint failure equals 2.2% in this example)
- If a GIB results from a joint failure then then an explosion within the property may occur (PoC equals 0.076% in this example)
- A proportion of joint failures will lead to a supply interruption (PoC equals 9% in this case)
- All joint failures will lead to a loss of gas (PoC is 1, with an associated value of 222 cubic metres per failure, based on a weighted average of the pressure bands within the cohort)
- A proportion of joint failures will lead to a water ingress event (PoC equals 3% in this case)

General Emissions

General emissions are a special case where the Failure Mode of a gas emission leads to a consequence of increased carbon footprint arising from the level of emission.

4.4.3 Consequence of Failure (£) Calculation

Each potential Consequence measure, must be expressed as a **monetary value (£) per unit of risk**. This is then multiplied by the effective quantity of consequence to derive the monetised consequence.

The GDN's will decide which data option is applicable for each of the Cost of Consequence values. They will either be:

Option A – GDN specific values (consistent and complete financial/cost data). Examples include: repair costs; main-laying costs etc.

Option C – Global values (Expert opinion or published studies/reports). Examples include: environmental costs of carbon emissions; value of a loss of life (plus agreed inflation for wider costs associated with reputational damage) etc.

4.4.4 Worked Example – Consequence of Failure (£)

Joint

Explosion 0-1	0.00076	Property Damage 0-1	1.00	F_Building damage £/prop	£	189,000.00	£	0.72
		Minor 0-1	1.00	F_Minor £/person	£	185,000.00	£	0.70
		Death Major 0-1	0.45	F_Death £/person	£	16,000,000.00	£	27.41
				F_Legal penalty £/incident	£	1,000,000.00	£	3.81
Supply Interruptions 0-1	0.09	Props_Com Large Nr/Km	0.05865	F_Com large £/premises	£	200.00	£	0.25
		Props_Com Small Nr/Km	0.13252	F_Com small £/premises	£	200.00	£	0.55
		Props_Critical Nr/Km	0.07306	F_Critical £/premises	£	200.00	£	0.31
		Props_Domestic Nr/Km	10.91454	F_Domestic £/prop	£	150.00	£	34.22
Loss of Gas m3	222.13963	Carbon Loss of gas m3	0.01344972	F_Carbon £/tonne	£	59.00	£	40.94
				F_Loss of gas £/m3	£	0.22	£	11.35
Water Ingress 0-1	0.03			F_Water Ingress £	£	833.00	£	5.80
P_Gas Escapes 0-1	0.0125	Complaints 0-1	1.00	F-Complaint £/complaint	£	450.00	£	1.31
				F_TMA_Order £	£	60.00	£	13.93
				F_Joint £/repair	£	1,120.07	£	260.11

Figure 18- Worked Example – Joint CoF Figures

The identified consequences of joint failures and their associated Probability of Consequence (PoC) values are used to derive monetary values for each consequence of failure for the DI/NO/1 cohort. This uses the following calculation:

Consequence Value = Monetary value of a specific consequence event x PoC for the specific consequence

Examples for the Joint Failure Mode are provided below for the three most significant consequence values:

- Financial cost of repairing a joint failure (F_Joint)
- The carbon footprint value associated with the loss of gas arising from a joint failure (F_Carbon)
- The consequence value of a death arising from an explosion (F_Death)

All calculated consequence values are inflated annually, as discussed in the Probability of Failure section above. An example for F_Joint is shown in the chart below:

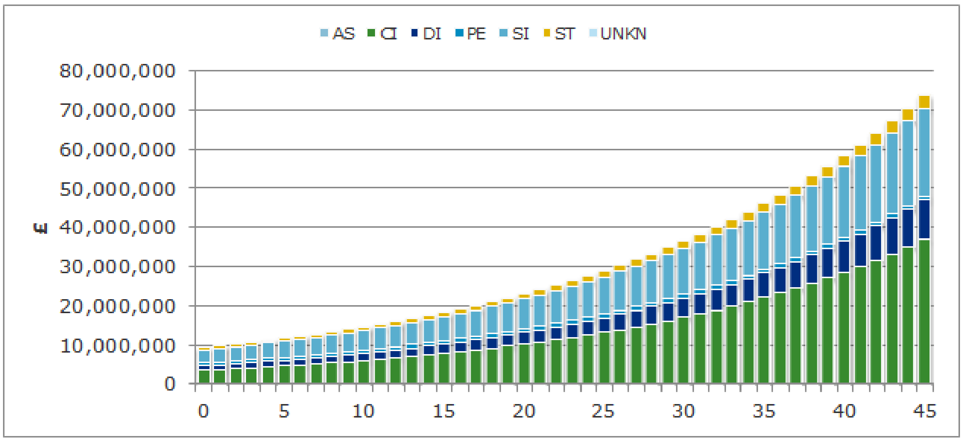


Figure 19 - Worked Example - Joint consequence values over life of asset given reactive only maintenance (all materials and cohorts)

F_Joint

The unit cost of repairing a joint has been estimated from company financial systems, using actual costs and the repaired mains diameter. For the DI/NO/1 cohort this diameter will be the length weighted diameter of all pipe sections within the cohort. This has produced the following equation (which is GDN specific):

Unit cost (£) = Cost Uplift x (3.96646*Diameter + 251.237)

The Cost Uplift is a GDN specific uplift to include back-office costs. This produces a unit cost of £1,120 per joint repair for the DI/NO/1 cohort.

The consequence value is calculated by multiplying the unit cost by the predicted number of failure per year:

F_Joint (Year 0) = £1,120.07 x 0.232 failures/km/year = £260.11 per km per year

F_Carbon

The external value of carbon emissions is based on "Valuation of energy use and greenhouse gas (GHG) emission - Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government – September 2014". The value we have used is the non-traded value of carbon expressed in units of £/tonneCo2e. This is further uplifted to take account of the higher greenhouse impact of natural gas compared to carbon dioxide. This uplift has been estimated to be 17.697 for the example below, but this will be GDN specific based on their distributed gas composition.

The consequence value of carbon for the DI/NO/1 cohort is derived from the following factors which are multiplied together:

- The Year 0 value of carbon is £59 per tonne of carbon dioxide. This is inflated in future years according to HM Treasury guidelines
- This is converted to a value in cubic metres (to align with the loss of gas estimate) and uplifted to account for the higher greenhouse impact of natural gas
    - 1 cubic tonnes of CO2 to tonnes of natural gas = 17.697
        - Conversion factor (tonnes CO2 to m3 natural gas) = 0.00076 x 17.697 = 0.0134
- The annual volume of the loss of gas due to joint failures is calculated by multiplying the predicted joint PoF by the loss of gas per joint failure (222.14 m3)

- The total annual loss of gas is multiplied by the value of carbon emissions associated with the calculated loss of gas

The calculation is shown below:

F_Carbon (Year 0)** = **0.232 failures/km/year x 222.14 m3 x 0.0134 x £59 per tonneCo2e = £40.94 per km per year

F_Death

The Death consequence value is calculated by estimating the following which are then multiplied together:

- The numbers of joint failure per year for the DI/NO/1 cohort
- The probability of a gas escape following failure (PoF equals 1)
- The probability of a GIB following a gas escape (PoF = 0.022)
- The probability of an explosion given a GIB (PoF = 0.00076)
- The probability of an explosion causing a death (PoF = 0.45)
- The value of a death, assumed to be the HSE published value uplifted by a factor to account for wider costs of a loss of life (value = £16 million).

The calculation for F_Death is as follows:

F_Death (Year 0) = 0.232 failures/km/year x 1 x 0.022 x 0.00076 x 0.45 x £16million = £27.41 per km per year

General Emissions

General Emissions m3/Km/Yr	666.3934488	Carbon Loss of gas (m^3)	0.01344972	F_Carbon £/tonne	£	59.00	£	528.81
				F_Loss of gas £/m3	£	0.22	£	146.61

Figure 20 - Worked Example – General Emissions CoF Figures

The identified consequences of General Emissions failures and associated probability of consequence (PoC) values are used to derive monetary values for each consequence of failure for the DI/NO/1 cohort. This uses the following calculation:

Consequence Value = Monetary value of a specific consequence event x PoC for the specific consequence

Examples of consequence value calculations for the following General Emissions Failure Mode are shown below:

- The carbon footprint value associated with the gas lost from general emissions (**F_Carbon**)
- The cost associated with the retail value of loss of product (**F_Loss of Gas**)

All calculated Consequence Values are increase according to the modelled deterioration in the PoF as discussed previously in Section 4.3. An example for the F_Carbon and F_Loss of Gas value is shown below:

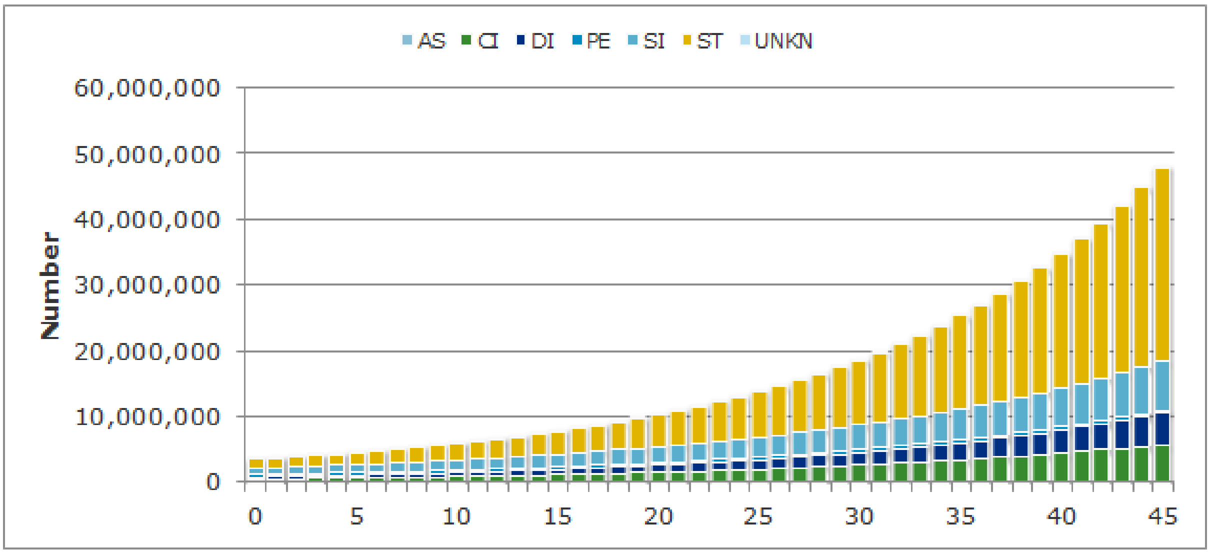


Figure 21 - . Worked Example - Loss of Gas consequence values over life of asset given reactive only maintenance (all materials and cohorts). Units are £/year

F_Carbon

This is calculated in a similar way to F_Carbon. The consequence for the DI/NO/1 cohort is calculated by multiplying the volume of gas lost per year through general emissions (666.3 m3/km/year) by the conversion factor (tonnes CO2 to m3 natural gas) by the value of carbon (£59 per tonne). The Year 0 calculation is shown below:

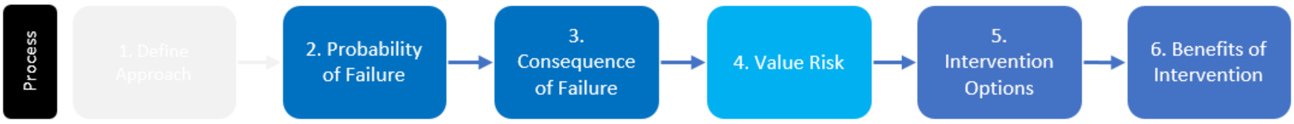
F_Carbon (Year 0) = 666.3 m3/km/year x 0.0134 x £59 per tonne = £528.81per km per year

F_Loss of Gas

The consequence value for loss of gas is calculated by multiplying the annual volume lost through emissions by the retail value of gas (assumed to be 22 pence per cubic metre). The Year 0 calculation is shown below:

F_Loss of Gas (Year 0) = 666.3 m3/km/year x £0.22 = £146.61 per km per year

4.5 Calculate Risk Values



In order to calculate the current (year 0) overall risk value for a Failure Mode, all weighted consequences values are added together, multiplied by the PoF for the Failure mode and then multiplied by the asset population of the Asset Group. The risk values for each Failure Mode are then added together to understand the total risk presented by the secondary and primary Asset Groups.

4.5.1 Worked Example – Monetised Risk Calculation

The sum of all consequence values derived for each Failure Mode provides the overall level of monetised risk for the cohort.

This increases in in future years according to the PoF deterioration modelling discussed previously. Examples for the DI/NO/1 Joint and General Emissions Failure Modes are shown below in Figure 22 and 23.

Joint

Year 0 Total Monetised Risk

F_Building damage £/prop	£	0.72
F_Minor £/person	£	0.70
F_Death £/person	£	27.41
F_Legal penalty £/incident	£	3.81
F_Com large £/premises	£	0.25
F_Com small £/premises	£	0.55
F_Critical £/premises	£	0.31
F_Domestic £/prop	£	34.22
F_Carbon £/tonne	£	40.94
F_Loss of gas £/m3	£	11.35
F_Water Ingress £	£	5.80
F-Complaint £/complaint	£	1.31
F_TMA_Order £	£	13.93
F_Joint £/repair	£	260.11
Joint	**£**	**401.40**

Year 10 Total Monetised Risk

F_Building damage £/prop	£	0.88
F_Minor £/person	£	0.86
F_Death £/person	£	33.48
F_Legal penalty £/incident	£	4.65
F_Com large £/premises	£	0.30
F_Com small £/premises	£	0.68
F_Critical £/premises	£	0.37
F_Domestic £/prop	£	41.79
F_Carbon £/tonne	£	58.47
F_Loss of gas £/m3	£	13.86
F_Water Ingress £	£	7.09
F-Complaint £/complaint	£	1.60
F_TMA_Order £	£	17.02
F_Joint £/repair	£	317.69
Joint	**£**	**498.75**

Figure 22 - Worked Example – Joint Risk Calculation

The annual monetised risk value for DI/NO/1 cohort joint failures is £401 per km per year in Year 0, rising to £499 per km per year in Year 10. This is largely driven by the joint failure deterioration rate given no replacement.

General Emissions

Year 0 Total Monetised Risk

F_Carbon £/tonne	£	528.81
F_Loss of gas £/m3	£	146.61
General Emissions	**£**	**675.41**

Year 10 Total Monetised Risk

F_Carbon £/tonne	£	680.28
F_Loss of gas £/m3	£	161.27
General Emissions	**£**	**841.54**

Figure 23- Worked Example – General Emissions Risk Calculation

The annual monetised risk value for DI/NO/1 cohort general emissions is £675 per km per year in Year 0, rising to £842 per km per year in Year 10. This significant increase is largely driven by HM Treasury forecast increases in the value of carbon.

Total Monetised Risk

The total annual monetised risk values for the DI/NO/1 cohort are calculated by summing all the calculated consequence values for all Failure Modes and multiplying by the cohort length (1096 km) – Figure 24 provides the total monetised risk values at year 0 and year 10.

Year 0 Total Monetised Risk

Cohort Monetised Risk		
F_Capacity	£	715.18
F_Complaint	£	2,740.68
F_Com large	£	511.72
F_Com small	£	1,156.33
F_Critical	£	637.49
F_Domestic	£	71,426.24
F_TMA_Order	£	28,741.76
F_Water Ingress	£	11,970.94
F_Building damage	£	1,916.34
F_Minor	£	1,875.78
F_Death	£	73,003.40
F_Legal penalty	£	10,139.36
F_Carbon	£	664,058.90
F_Loss of gas	£	184,104.34
F_Repair	£	151,488.71
F_Fracture	£	88,650.53
F_Joint	£	285,099.85
F_Leakage mgm	£	13,794.28
F_Survey	£	109,608.90
F_Conditioning	£	19,729.60
Total Cohort Monetised Risk		
Cohort Risk Value	£	1,721,370.33

Year 10 Total Monetised Risk

Cohort Monetised Risk		
F_Capacity	£	715.18
F_Complaint	£	3,330.05
F_Com large	£	622.32
F_Com small	£	1,406.27
F_Critical	£	775.28
F_Domestic	£	86,864.72
F_TMA_Order	£	35,028.36
F_Water Ingress	£	14,589.31
F_Building damage	£	2,338.74
F_Minor	£	2,289.24
F_Death	£	89,094.81
F_Legal penalty	£	12,374.28
F_Carbon	£	865,997.06
F_Loss of gas	£	205,294.24
F_Repair	£	183,677.27
F_Fracture	£	108,278.00
F_Joint	£	348,221.74
F_Leakage mgm	£	13,794.28
F_Survey	£	109,608.90
F_Conditioning	£	19,729.60
Total Cohort Monetised Risk		
Cohort Risk Value	£	2,104,029.65

Figure 24 - Worked Example – Total Monetised Risk Calculation

The total annual monetised risk value for the DI/NO/1 cohort is £1,721,370 per year in Year 0, rising to £2,104,029 per year in Year 10. The increase in total monetised risk over the life of the asset is shown in the chart below.

Please note that no interventions are modelled, therefore no value is assigned to the post-intervention risk profile).

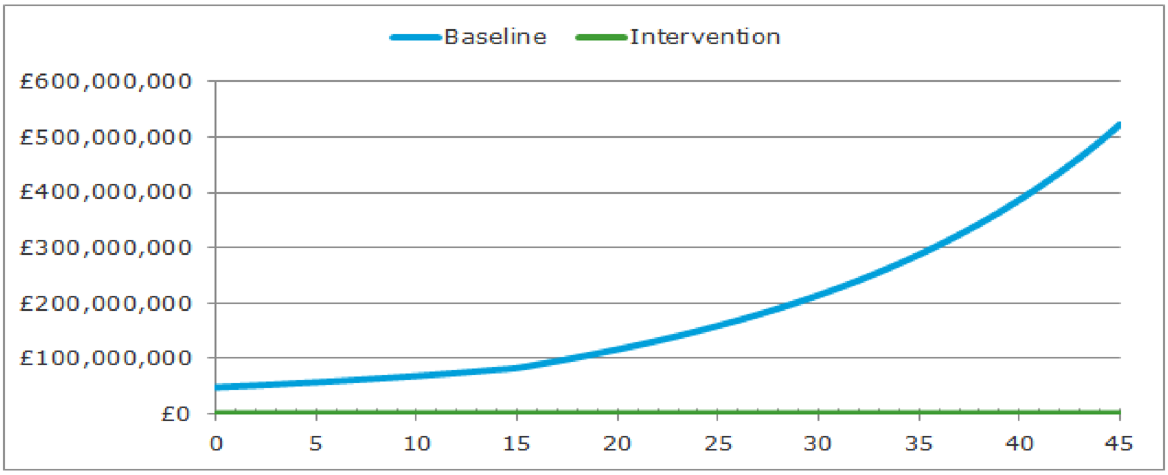
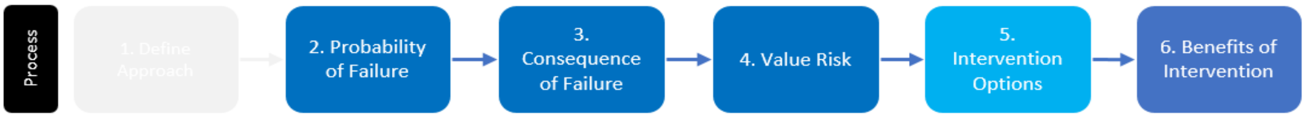


Figure 25- Worked Example - Total monetised risk values for the DI/NO/1 cohort with no intervention (reactive maintenance only)

4.6 Intervention Options



Interventions will be defined as either **reactive** or **proactive**. A reactive intervention is defined as an action undertaken on an asset that is unplanned, while a proactive intervention is planned in advance. Each will have a cost and benefit attributed to it.

4.6.1 Types of Intervention

The main types of interventions considered are:

- **Repair** – a reactive intervention that restores a failed asset back to:
    - an operable state for repairable assets
    - a new asset for non-repairable assets;
- **Planned maintenance and inspections** – routine activities carried out on a regular basis that may not change the underlying PoF
- **Replacement** – a proactive intervention that replaces an asset or a proportion of the asset population with new assets.
    - with like for like assets
    - with different assets, such as a different material, new model, etc.
- **Refurbishment** – a proactive intervention that extends the life of an asset.

A reactive only (i.e. repair) intervention regime will be considered the baseline strategy in which other regimes will be compared against. Combinations of the proactive interventions are also considered.

Worked Example - Types of Intervention

For the purposes of this worked example we will consider 2 simple (and exaggerated) interventions for the DI/NO/1 cohort and then compare them.

- 50 km of mains replacement for each of the first 8 years of the RIIO GD1 period
- 50 km of spray-lining for each of the first 8 years of the RIIO GD1 period

The methodology allows costs to be expressed in a number of ways. All values and results within the simplified examples provided are illustrative only and require more validation before results can be considered definitive.

4.6.2 Calculate intervention strategy costs

For each Asset Group a set of unit costs will be established for each potential intervention. The cost unit will be either per asset or per unit length, and split by asset attributes where appropriate (i.e. material, size, asset type).

A cost profile will be estimated by summing the costs of a given intervention strategy over the planning horizon. In the case of reactive repair, this will be the repair costs multiplied by the annual PoF. Routine maintenance costs will also be included in the cost analysis so that different intervention strategies can be compared with one other.

All costs will be expressed at a common price base date as per RIIO-GD1 requirements.

Worked Example - Types of Intervention

Example 1 - Mains replacement intervention

Costs of mains replacement interventions have been estimated using NGN actual rates. Unit costs of mains replacement are outlined below and the following assumptions have been made:

- DI mains are replaced with polyethylene (PE)
- Service transfers (reconnection of existing services) are included. Initially it is have assumed that only PE services are transferred
- Service relays are excluded (to be modelled as service replacement intervention)

Unit cost of mains replacement (£/km) = Unit cost of mains laying (per km) + (Unit costs of PE service laying x Number of connected PE services (per km)

In consultation with NGN, the unit cost of main-laying is calculated to be the maximum value of either £85.26 per metre or (15.971 + 0.8206 x Cohort Diameter). The weighted average cohort diameter for DI/NO/1 is 124.9mm.

Unit cost of mains laying = 15.971 + 0.8206 x 124.9 = £118.46 per metre or £118,463 per km (1)

As the unit cost is greater than £85.26 it is retained for the remainder of the analysis.

The number of PE services to be transferred in the DI/NO/1 cohort is 43 services per km. The unit cost of PE service transfer is £223.75.

Cost of service transfers = 43 x £223.75 = £9,621

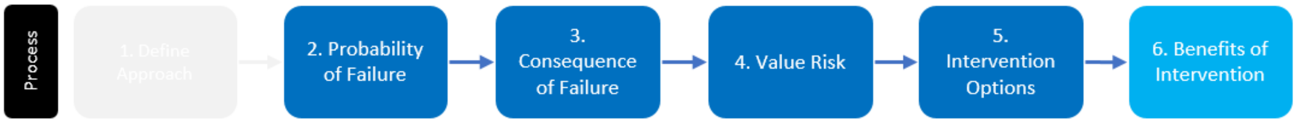
Unit cost of mains replacement = £128,084 per km

Example 2 - Spray-lining intervention

This is example of a potential innovative intervention and costs are not yet fully understood. A value of £22 per metre (£22,000 per km) has been assumed for this example.

Unit cost of mains spray-lining = £22,000 per km

4.7 Impact of Intervention



The benefit (value) of each intervention will be established to calculate the net effect of applying an intervention across the planning horizon. An example is given in the plot below where the asset is:

- **Either** completely replaced with a new and different asset and the PoF is reset to zero (red),
- **Or** the asset is refurbished and the age is only partially reset, on the same failure curve but shifted towards the left.

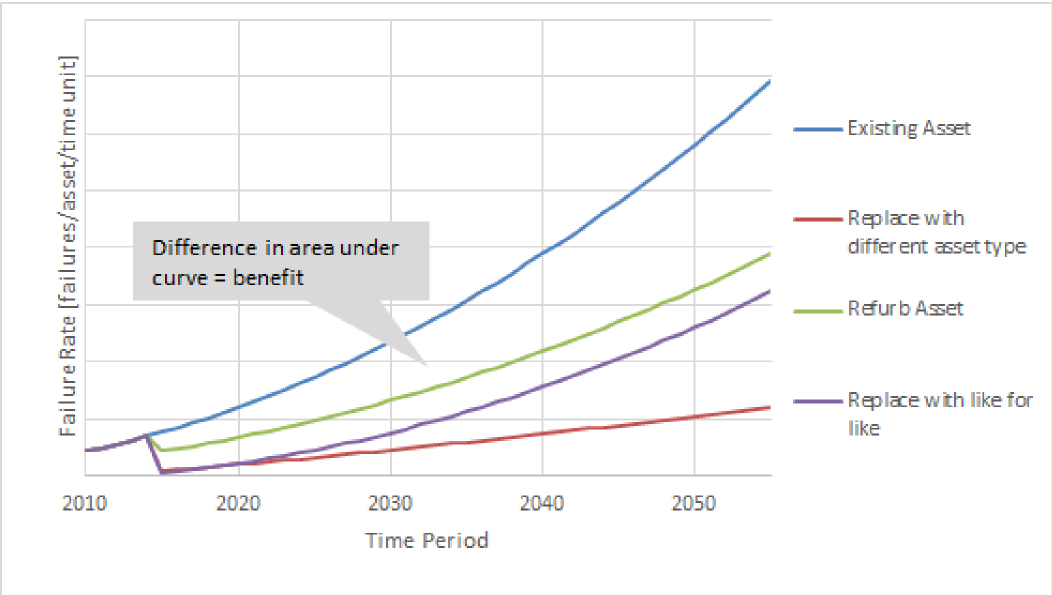


Figure 26 - Example Intervention Curves

Worked Example - Impact of Intervention

Appendix A discusses how the intervention benefits for mains replacement were assessed. The benefits of mains spray-lining on PoF etc. are just estimates and should not be considered definitive at this stage.

The methodology allows the intervention benefits to be modelled as:

- A change in the Probability of Failure (and deterioration rate)
- A change in the probability of consequence
- A change in the consequence value (e.g. unit costs of repair and maintenance)

Example 1 - Mains replacement intervention

For mains replacement intervention benefits are modelled as:

- A reduction in the initial Probability of Failure for the new pipe (PE) – which is assumed to be 0.0234 failures/km/year for joint failures. Other Failure Modes have specific initial PoF values

- A reduction in the deterioration rate to that of a new PE pipe – assumed to be the joint deterioration for PE (0.5% per annum).

For our example mains replacement scenario - 50 km of replacement in each of the first 8 years of the RIIO GD1 period - this has the following impact on the overall joint monetised risk value in Year 4 and Year 8 when compared to the base year.

Scenario	Year 0	Year 4	Year 8
Without intervention **Monetised risk**	£1.72M	£2.07M	£2.36M
With intervention **Monetised risk**	£1.72M	£1.82M	£1.86M
Monetised risk reduction benefit	-	*£0.25M*	*£0.50M*

Table 9- Worked Example - Monetised risk for DI/NO/1 cohort without and with 50km of mains replacement per annum. Note "with intervention" risk value includes both remaining DI/NO/1 and new PE/NO/1 cohorts

Example 2 – Spray lining intervention

Spray-lining has been identified as a potential option to extend the life of the mains asset as an alternative to full replacement. A semi-structural lining is added to the internal wall of the pipe improving integrity and reducing leakage. The benefits of spray lining are currently unknown so some simple assumptions have been made for this analysis.

For spray-lining, benefits are modelled as:

- A reduction in Joint failures by 20%
- A reduction in Fracture failures by 20%

These post-intervention benefits are replied to only to the DI/NO/1 pipes targeted for spray-lining creating a new modified DI/NO/1 cohort. Our example spray-lining scenario has the following impact on the overall joint monetised risk value in Year 4 and Year 8 when compared to the base year.

Scenario	Year 0	Year 4	Year 8
Without intervention **Monetised risk**	£1.72M	£2.07M	£2.36M
With intervention **Monetised risk**	£1.72M	£1.95M	£2.17M
Monetised risk reduction benefit	-	*£0.12M*	*£0.19*

Table 10- Worked Example - Monetised risk for DI/NO/1 cohort without and with 50km of spray-lining per annum. Note "with intervention" risk value includes both remaining DI/NO/1 and new lined DI/NO/1 cohorts

Comparison of Monetised Risk Reduction Benefits

By comparing the monetised risk reduction benefits (not costs at this stage) of mains replacement versus spray-lining it can be seen that by undertaking similar lengths of activity (50km per annum), mains replacement delivers a £0.25M per year reduction in monetised risk by Year 4, compared to only £0.12M for spray-lining. By Year 8 the risk reduction delivered by replacement rises to £0.5M per year, compared to £0.19M for lining.

4.7.1 Future without-intervention Risk Values

The deterioration rate is applied year on year so that the risk value can be calculated at any point in the future, taking the progressive deterioration of the Asset Group into account. The deterioration rate can vary according to each Failure Mode.

Future 'without-intervention' risks can be calculated for the end point of the RIIO GD1 period.

Worked Example – Without Intervention Risk Values

For the DI/NO/1 cohort monetised risk values are calculated for each year assuming only reactive maintenance is carried out (generally repairs or base levels of maintenance activity, such as surveying or pressure management). This produces a "without intervention" profile of monetised risk as shown in Figure 27 below (only Years 0 to 8 are listed).

		0	1	2	3	4	5	6	7	8
Cohort Number	Cohort Name	Risk Value	Risk Value	Risk Value	Risk Value	Risk Value	Risk Value	Risk Value	Risk Value	Risk Value
11	DI / NO / 1	£1,721,370.33	£1,787,904.89	£1,857,666.42	£1,930,848.81	£2,007,658.81	£2,088,316.91	£2,173,058.33	£2,262,134.02	£2,355,811.70

Figure 27 - Worked Example - Monetised risk for DI/NO/1 cohort without intervention (Years 1 to 8)

However, the analysis does not only consider the DI/NO/1 cohort in isolation, it calculates the monetised risk value of the entire mains Asset Group both before and after intervention. These interventions can be analysed on either single or multiple cohorts in combination (e.g. all Tier 1 mains replacement interventions, regardless of material, can be modelled together if required). Without intervention risk values for all mains assets are shown in Table 11 below.

Year	BaseLine
0	£ 48,027,765.37
1	£ 49,711,779.15
2	£ 51,466,630.73
3	£ 53,296,250.54
4	£ 55,204,824.22
5	£ 57,196,810.33
6	£ 59,276,959.10
7	£ 61,450,332.95
8	£ 63,722,328.31

Table 11- Worked Example - Monetised risk for all mains without intervention (Years 0-8)

4.7.2 Future with-intervention risk values

The intervention regime is defined based upon the changes it makes to the Event Tree. These in turn are used to calculate the post intervention risk value and the difference between the pre and post intervention risk is therefore the risk benefit value delivered by undertaking the intervention regime.

As before, the deterioration rate is applied year on year so that the risk value can be calculated at any point in the future taking the progressive deterioration of the Asset Group into account. The deterioration rate can vary according to each Failure Mode. The end point of the RIIO GD1 period is calculated to determine the extent to which risk and the value associated with it is changing over time.

To compare costs and benefits of intervention regimes, similar analyses can be undertaken for a variety of intervention regimes against each Asset Group. These are then compared between Asset Groups to identify the best intervention approach for each Asset Group.

This methodology can also be used to identify opportunities for risk trading where investment can be re-targeted to deliver better returns on investment.

Worked Example – With-Intervention Risk Values

With-intervention monetised risk analysis is now considered using the mains replacement and spray-lining interventions discussed previously.

Example 1 - Mains replacement

The risk reduction benefits of replacing 50km of DI/NO/1 mains per year and replacing with PE were assessed using the approach described.

The with- and without intervention benefits for the whole mains Asset Group are shown below. It is worth stating that the change in risk value shown below is delivered only by the modelled intervention(s) – in this case 50km of mains replacement between Years 1 and 8. All other assets are deteriorating according to the specified reactive-only maintenance rules.

Year	BaseLine	Intervention	Change in Risk Value due to intervention
0	£ 48,027,765.37	£ 48,027,765.37	£ -
1	£ 49,711,779.15	£ 49,673,369.32	£ 38,409.83
2	£ 51,466,630.73	£ 51,384,255.93	£ 82,374.80
3	£ 53,296,250.54	£ 53,163,900.11	£ 132,350.43
4	£ 55,204,824.22	£ 55,015,994.39	£ 188,829.83
5	£ 57,196,810.33	£ 56,944,463.59	£ 252,346.74
6	£ 59,276,959.10	£ 58,953,480.08	£ 323,479.02
7	£ 61,450,332.95	£ 61,047,480.64	£ 402,852.31
8	£ 63,722,328.31	£ 63,231,184.38	£ 491,143.93

Table 12- Worked Example - Monetised risk for the whole mains Asset Group without and with 50km of DI/NO/1 mains replacement per annum

To demonstrate how the monetised risk calculation method responds to modelling different volumes of intervention, the annual replacement is reduced to 10km of DI/NO/1 per year and the analysis repeated.

Year	BaseLine	Intervention	Change in Risk Value due to intervention
0	£ 48,027,765.37	£ 48,027,765.37	£ -
1	£ 49,711,779.15	£ 49,704,097.18	£ 7,681.97
2	£ 51,466,630.73	£ 51,450,155.77	£ 16,474.96
3	£ 53,296,250.54	£ 53,269,780.45	£ 26,470.09
4	£ 55,204,824.22	£ 55,167,058.25	£ 37,765.97
5	£ 57,196,810.33	£ 57,146,340.97	£ 50,469.36
6	£ 59,276,959.10	£ 59,212,263.29	£ 64,695.81
7	£ 61,450,332.95	£ 61,369,762.47	£ 80,570.48
8	£ 63,722,328.31	£ 63,624,099.51	£ 98,228.80

Table 13- Worked Example - Monetised risk for the whole mains Asset Group without and with 10km of DI/NO/1 mains replacement per annum

Example 2 - Spray-lining

The same analysis as described for replacement was carried out for the 50km per annum of spray-lining intervention.

The with- and without monetised risk value benefits are shown in Table 14 (again for the whole mains Asset Group).

Year	BaseLine	Intervention	Change in Risk Value due to intervention
0	£ 48,027,765.37	£ 48,027,765.37	£ -
1	£ 49,711,779.15	£ 49,703,396.43	£ 8,382.72
2	£ 51,466,630.73	£ 51,446,256.47	£ 20,374.26
3	£ 53,296,250.54	£ 53,259,940.44	£ 36,310.10
4	£ 55,204,824.22	£ 55,148,268.80	£ 56,555.42
5	£ 57,196,810.33	£ 57,115,302.78	£ 81,507.55
6	£ 59,276,959.10	£ 59,165,360.20	£ 111,598.90
7	£ 61,450,332.95	£ 61,303,032.94	£ 147,300.01
8	£ 63,722,328.31	£ 63,533,205.58	£ 189,122.73

Table 14- Worked Example - Monetised risk for the whole mains Asset Group without and with 50km of DI/NO/1 spray-ling per annum

4.7.3 Assessing Risk

In order to assess and compare Health and Risk reductions achieved by different interventions and on different asset groups, the analysis outlined in the previous sections can be repeated according to individual company policies and strategies:

- For a number of different interventions within asset groups. For example, replacement or lining options on different mains cohorts at various annual intervention rates and phasing between years
- Across different asset groups to compare risk value reduction between interventions on different asset groups
- To understand a true optimised programme of investment (e.g. to assess the optimum risk reduction at lowest whole life cost) a large number of alternative interventions need to be tested or optimisation techniques/tools adopted. Optimisation techniques are

beyond the scope of this Health and Risk assessment methodology and are not discussed further in this document.

Worked Example – Monetised Risk Comparison between Interventions

The analysis undertaken above for the three simple mains replacement and spray-lining interventions discussed previously is summarised in Table 15 as at the end of RIIO-GD1 (Year 8):

Proposed Investment	Baseline (£M)	Post Investment (£M)	Delta (±£M)
Mains replacement			
50km pa	63.72	63.23	-0.49
10km pa	63.72	63.62	-0.10
Spray-lining			
50km pa	63.72	63.53	-0.19

Table 15- Worked Example – Risk Comparison

This data derived for each planned Intervention interventions can be further used to undertake cost-benefit (CBA) analysis and in the planning of future asset management and investment strategies.

5 Regulatory Reporting

5.1 Overview

Regulatory reporting is currently provided within RRP table 7.3 of the annual Regulatory Reporting Pack (RRP). It is proposed that this is updated and modified to incorporate the monetised risk approach detailed in this document. The updated report will contain the following key principles:

- Be able to communicate to a general audience the overall state of each Asset Group in a consistent and comparable manner across a number of key performance measures
- Incorporate asset health expressed as the number of failures per annum

Risk is a combination of several components and therefore providing asset health by itself may not reflect the true underlying state of the network. For example, an asset may have a high failure rate but very low Consequence of Failure, thereby moderate overall risk, compared to a similar asset with a moderate failure rate but extreme Consequence of Failure, thereby high risk. It is therefore important to capture both these occurrences and the overall spread of the underlying health and risk.

5.2 Asset Groups

There are Event Trees for 8 primary Asset Groups. These primary Asset Groups will be split into 18 sub-groups for regulatory reporting, as per the table below:

Primary Assets for Event-Tree Analysis	Maximum Assets Reported
1. LTS Pipelines	1. OLI1 LTS Pipelines
	2. OLI4 LTS Pipelines
2. Distribution Mains	3. Iron Mains
	4. PE Mains
	5. Steel Mains
	6. Other Mains
3. Services	7. Services
4. Risers	8. Risers
5. Offtake/PRS Filters & Pressure Control	9. Offtake Filters
	10. PRS Filters
	11. Offtake Slamshut/Regulators
	12. PRS Slamshut/Regulators
6. Offtake/PRS Pre Heating	13. Offtake Pre-heating
	14. PRS Pre-heating
7. Offtake Odorant & Metering	15. Odorisation & Metering
8. District, I&C and Service Governors	16. District Governors
	17. I&C Governors
	18. Service Governors

Table 16- Asset Groups & Sub-Groups for Reporting

5.3 Health & Risk Reporting

GDNs will report on six key performance measures for each of the 18 asset groups and sub-groups. This provides an overall view of the health, criticality (customer, environmental and health & safety) and risk and a breakdown of the key components. The six performance measures are provided in the table below. Data will be provided as absolute and normalised by the appropriate unit.

ID	Key Performance Measure	Description	Units
1	Length/Number of assets	The total length or number of assets in each Asset Grouping	km nr
2	Asset Health	The failure frequency. A measure of the overall health of the network for each Asset Group.	Failures/km/yr Failures/nr/yr
3	Reliability Risk	Monetised value of customer risk normalised by length or numbers of assets.	£/km/yr Failures/nr/yr
4	Health & Safety Risk	Monetised value of all health and safety risks normalised by length or numbers of assets.	£/km/yr Failures/nr/yr
5	Environmental Risk	Monetised value of all reactive carbon risks normalised by length or numbers of assets.	£/km/yr Failures/nr/yr
6	Monetised Risk	Monetised Total Risk normalised by length or numbers of assets.	£/km/yr Failures/nr/yr

Table 17- Reporting Performance Measures

Each of the Asset Groups and Asset Sub-groups consist of a number of underlying assets that have been modelled at a cohort level to derive the probability/frequency of failure and also the consequence. Histograms of asset health and overall risk will be provided to show the spread of these underlying cohorts and assets.

The underlying continuous values of asset health (i.e. the failure rate) are banded into 10 bands. Each health index (HI) band is defined for each individual asset group separately and is consistent across GDNs to allow for easy visual comparison. For asset health, the data should be generated to reflect the key factors that influence the underlying Failure Rate and the asset attributes used to determine the asset Failure Modes. Similarly the values of Monetised Risk are banded into 10 bands, again defined for each individual asset group separately and consistent across GDNs.

Tables 18 and 19 illustrate example regulatory reporting templates provided by Ofgem for use in the July 2016 NOMs submission and 2017 regulatory reporting submission. The design of precise regulatory requirements will be informed by the NOMs Cross Sector Working Group and Ofgem, who will establish the Reward and Penalty implementation framework.

Regulatory Reporting Pack									
7.3 Asset Health and Risk Data - Current Position									
	Primary Asset	**Secondary Asset**	**Units**	**Km/Nr**	**Asset Health (Failures/Unit)**	**Reliability Risk (£m)**	**Health & Safety Risk (£m)**	**Environmental Risk (£m)**	**Monetised Risk (£m)**
1	LTS Pipelines	LTS Pipelines - Piggable	km						
		LTS Pipelines – Non Piggable	km						
2	Distribution mains inc all services above 2"	Distribution Mains (Iron)	km						
		Distribution Mains (PE)	km						
		Distribution Mains (Steel)	km						
		Distribution Mains (other)	km						
3	Services	Asset Level	Number of						
4	MOB Risers	Asset Level	Number of						
5	NTS Offtakes	Slam Shut & Regulators System	Systems						
		Filter System	Systems						
		Pre-heating System	Systems						
		Odorisation System	Systems						
		Metering System	Systems						
6	PRSs	Slam Shut & Regulators System	Systems						
		Filter System	Systems						
		Pre-heating System	Systems						
7	Governors	District Governors	Number of						
		I&C Governors	Number of						
		Service Governors	Number of						

Table 18- Reporting Health & Risk – Example 1

					Health (Km or Nr)										Risk (Km or Nr)									
	Primary Asset	**Secondary Asset**	**Units**	**Km/Nr**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	LTS Pipelines	LTS Pipelines - Piggable	km																					
		LTS Pipelines – Non Piggable	km																					
2	Distribution mains inc all services above 2"	Distribution Mains (Iron)	km																					
		Distribution Mains (PE)	km																					
		Distribution Mains (Steel)	km																					
		Distribution Mains (other)	km																					
3	Services	Asset Level	Number of																					
4	MOB Risers	Asset Level	Number of																					
5	NTS Offtakes	Slam Shut & Regulators System	Systems																					
		Filter System	Systems																					
		Pre-heating System	Systems																					
		Odorisation System	Systems																					
		Metering System	Systems																					
6	PRSs	Slam Shut & Regulators System	Systems																					
		Filter System	Systems																					
		Pre-heating System	Systems																					
7	Governors	District Governors	Number of																					
		I&C Governors	Number of																					
		Service Governors	Number of																					

Table 19- Reporting Health & Risk – Example 2

6 Governance

The publication and maintenance of NOMs Methodology (as set out in this document) will be managed and governed by the Gas Safety & Reliability Working Group (SRWG) to ensure compliance with the Gas Transporters Licence objectives:

- The comparative analysis of performance over time between geographic areas of, and Network Assets within, the pipeline system to which this license relates; and
- The communication of relevant information regarding the pipeline system to which this license relates between the Licensee, the Authority and, as appropriate, other interested parties in a transparent manner

6.1 SRWG Membership

The Gas SWRG Membership will include;

- Representatives from each of the four Gas Distribution Networks;
  - Cadent Gas Ltd
  - Scotia Gas Networks
  - Wales & West Utilities
  - Northern Gas Networks
- A nominated chairperson appointed jointly by the GDNs (changed annually)
- Secretarial Support
- Ofgem – with a standing invite to the Group

The Gas SRWG will convene on a quarterly basis as a minimum. The agenda for each of the meetings will be agreed by the members of group. Attendance of additional parties at the Gas SRWG will be as a result of specific invite by the Group.

Gas SRWG meeting agendas, minutes, reports and correspondence will be published.

6.2 SRWG Annual Work Programme

The Gas Distribution Networks (GDNs) will collectively monitor the performance and effectiveness of the NOMs Methodology and associated information gathering plan via the Gas SRWG. The Gas SRWG will be responsible for the following:

- Monitoring the performance and effectiveness of the NOMs Methodology and associated information gathering plan;
- Assessing impacts on the Risk baselines previously agreed with Ofgem and contained within any License Obligation
- Develop and assess changes to the Broad NOMs Methodology Statement;
- Assessing the impact of changes to external inputs to the Methodology and proposing updates to Risk & Health values as appropriate;
- Assessing the impact of delivery of the actions set out in the Information Gathering Plan and proposing updates to Risk & Health values as appropriate; and
- Evaluating and assessing feedback from stakeholders on the NOMs Methodology and Outputs.

6.3 SRWG Annual Report

The SRWG will publish, on behalf of the GDNs, an Annual Report setting out the results of its work during the previous year. The Annual Review will consider a wide range of factors relating to the methodology and each separate class of assets within the methodology.

Each report will be a joint annual report across all GDNs. This allows stakeholders to view the management of asset risk at an industry, GDN and Asset Class level. This process will also make it easier for all interested parties to provide their comments to a single source on common issues that are applicable to all GDNs.

The Annual Report will include;

- Update on the assessment of the Core Methodology
- Update on the assessment of key inputs to methodology
- Summary of Proposed Changes to Methodology and/or Key Inputs
- Future SRWG Work Programmed

The review process will take into account those factors where it is appropriate to make consistent across all GDNs and where it is appropriate for GDN specific factors to be employed within the methodology (e.g. deterioration factors, data gathering plans).

6.4 Modification Process

The SRWG can at any time propose a modification to the NOMs methodology that it believes would better meet the NOMs Objectives and wider Licence Obligations.

The GDNs will jointly publish a consultation via the SRWG on any proposed changes as required by the Gas Transporters Licence. The consultation will include any supporting information, data and analysis used to support the proposed modification including any independent assessment of the proposed modification as required.

Following consultation, any proposed modification to the Methodology Statement will be set out in a separate report and include;

- A detailed explanation of the proposed modification and how it will better meet the relevant obligations
- Any impact on the Risk baselines previously agreed with Ofgem and contained within any License Obligation
- Any representations from third parties on the modification
- A copy of the independent expert's report on the modification detailing;
    - Opinion on the extent to which it better meets the objectives
    - Opinion on validity of any change to the core methodology outlined in the Statement
    - Validation of the deployment of the methodology and the impact on any Risk baselines
- A timetable for deployment of modification into the core methodology.

Each Modification Report will be presented to Ofgem and the Authority for approval/direction. The Methodology Statement will be updated following approval from the Authority.

6.5 Publication of Methodology Statement

The GDNs will make publically available the most recent NOMs Methodology Statement and all associated appendices along with the results and supporting information of each Annual Review of the NOMs Methodology.

Appendix A – Distribution Mains

A1. Distribution Mains Definition

A main, that is to be recorded as such in the asset record, is a below ground pipe, laid as an extension of, or change to, the system that supplies, or has the capability to supply, more than 2 primary meter installations operating below 7 bar gauge.

A2. Distribution Mains Event Tree Development

A2.1. Distribution Mains Failure Modes

As per the process in section 3.4, the following Failure Modes have been identified for Distribution Mains. Failure modes were identified through a number of workshops with asset experts and through careful analysis of available data held by companies to assess and quantify the rate of failures and future asset deterioration.

- Capacity failure – where the pipe network is under-sized to meet demand
- Corrosion failure
- Fracture failure
- Interference failure – for example 3rd party damage
- Joint failure
- General emissions – background leakage or shrinkage from the pipe network

Values are typically expressed in number of failures per kilometre of pipe.

A2.2. Distribution Mains Consequence Measures

As per the process in section 3.5, the following consequence measures have been identified for Distribution Mains.

- Gas escape
- Gas in buildings
- Supply interruption
- Loss of gas
- Water ingress
- Explosion

A2.3. Distribution Mains Risk Map

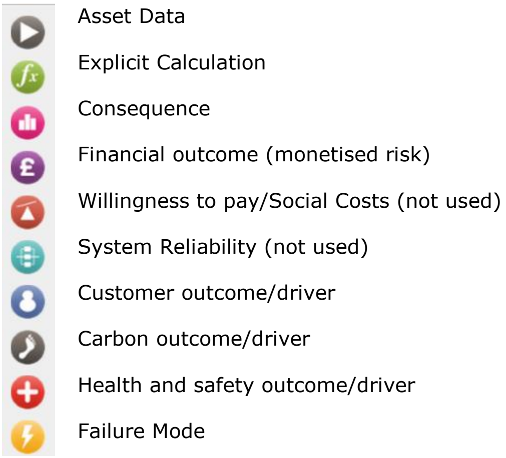


Figure A- 1 - Risk Map Key

Figure A-1 outlines the risk map key for Distribution Mains. The risk map is colour coded for each node of the event tree to indicate which values are associated with each node. The colours are reflected in both the risk map and risk map template in Figures A2 and A3.

As per the process described within Section 3.5 of the main methodology, the risk map for Distribution Mains is shown below:

Distribution Mains GDN v5

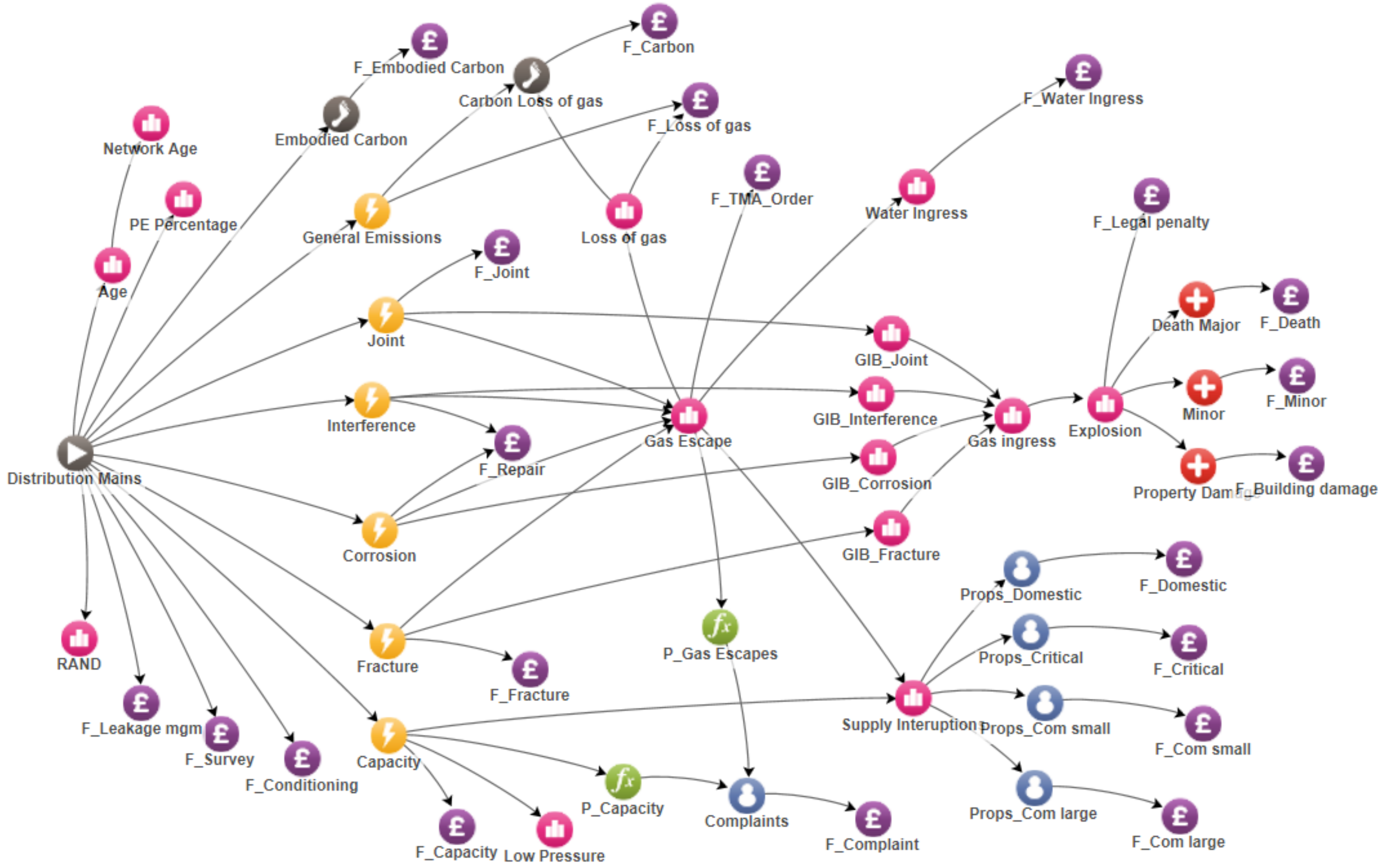


Figure A- 2 - Distribution Mains Risk Map

A2.4. Distribution Mains Risk Template

The following table demonstrates how the total risk value is derived for any given Mains cohort. An individual, populated risk map is developed for every cohort to be modelled to deliver a baseline monetised risk value prior to intervention modelling.

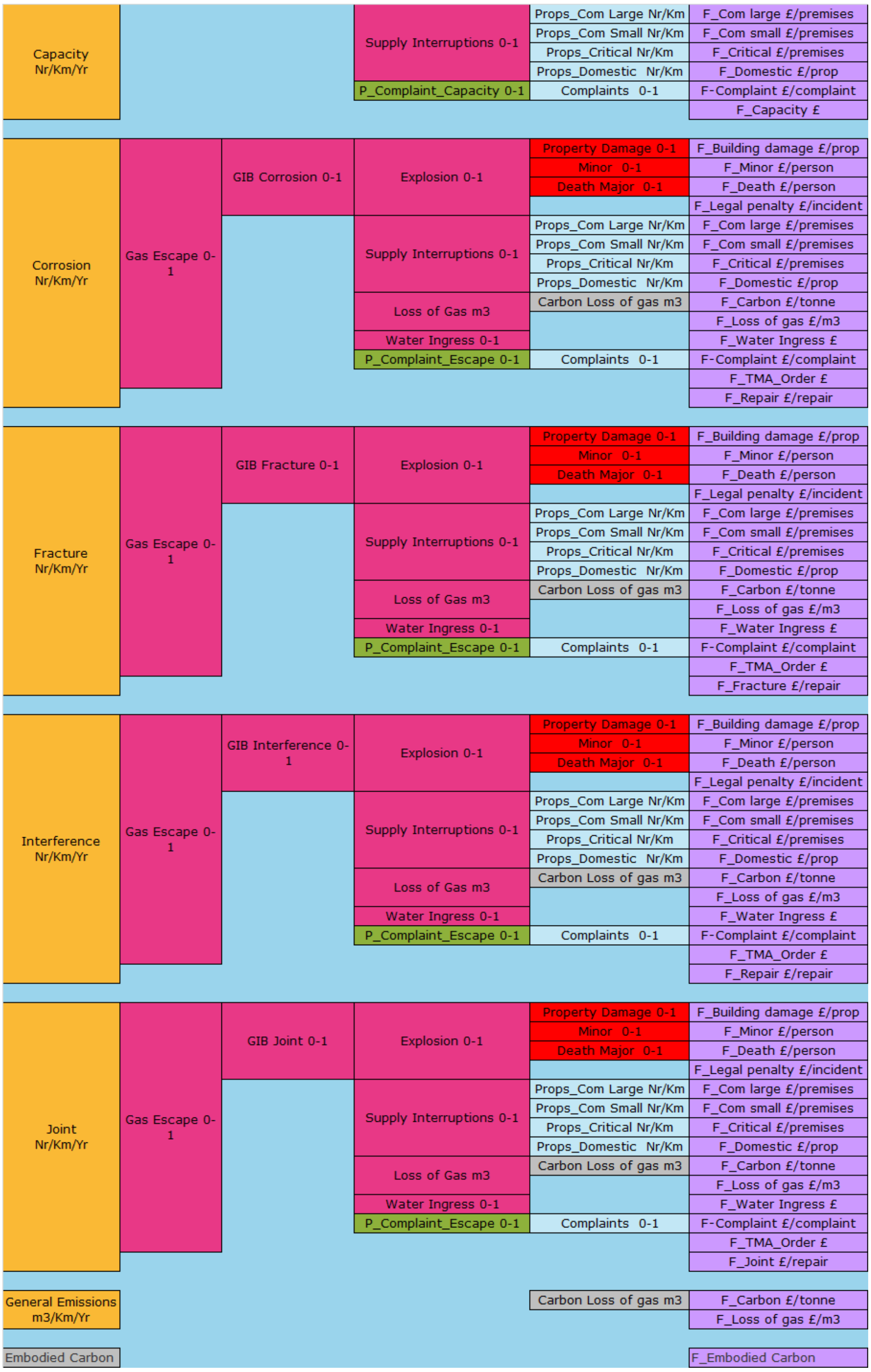


Figure A- 3 - Distribution Mains Risk Map Template

A2.5. Distribution Mains Data Reference Library

In line with Section 3.7 of the main report, the following table provides a brief description of the risk nodes modelled in the Event Tree, the source of the data and/or a high level description as to how the values were derived and a flag to indicate whether the data will be provided individually by each GDN or through common/shared analysis:

Node ID / Variable	Description	Data Source	Source
Capacity	Probability of capacity issues	Data taken from company systems.	GDN Specific
Carbon_Loss_Of_Gas	m^3 of carbon equivalent (CO2e) arising from loss of gas	Carbon Loss of Gas = relative density x carbon equivalent. Value calculated by each GDN based on actual gas composition in the network	GDN Specific
Complaints	Number of customer complaints	Data taken from company systems.	GDN Specific
Corrosion	Frequency of corrosion failures	Adjustment or development of statistical models developed for each Failure Mode by segmenting historical failure data (for example; by Diameter, Material, Pressure Class, Age and Distribution Zone). These are used to assign a pipe-specific initial failure frequency, which is used as the starting point for deterioration analysis. Deterioration of this initial failure rate can be estimated for each Failure Mode and Material using the statistical relationship between estimated pipe failure rates and installed Age.	GDN Specific
Death_Major	Number of deaths or major injuries given an explosion	Value based on research values (Newcastle University)	Common
Explosion	Probability of explosion given gas ingress	Data taken from company systems.	GDN Specific
F_Capacity	Cost of responding to capacity issues (note: this is not the cost of resolving capacity issues)	Data taken from company systems.	GDN Specific
F_Complaints	Cost of handling customer complaints	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific
F_Conditioning	Cost of conditioning of iron pipes	Data taken from company systems.	GDN Specific
F_Fracture	Average cost of repairing a fracture	Data taken from company systems. A statistical model can be used to relate unit cost to pipe diameter.	GDN Specific
F_Joint	Average cost of repairing a joint	Data taken from company systems. A statistical model	GDN Specific

Node ID / Variable	Description	Data Source	Source
		can be used to relate unit cost to pipe diameter.	
F_Leakage_mgm	Cost of leakage management per unit length	~~Data taken from company systems.~~ Nil costs reported for services. Cost of leakage management (e.g. profiling) captured under Governors model	~~GDN Specific~~ Common
F_Legal_Penalty	Cost of legal enforcement and penalty payments following ignition/explosion	Default/assumed value agreed with SRWG based on historical incidents.	Common
F_Repair	Average cost of a general repair due to corrosion / Interference	Data taken from company systems. A statistical model can be used to relate unit cost to pipe diameter.	GDN Specific
F_Survey	Cost of MRPS survey of iron pipes, assume survey every 5 years	Data taken from company systems.	GDN Specific
F_TMA_Order	Cost of compliance with local authority traffic management order	Data taken from company systems.	GDN Specific
F_Water_Ingress	Cost of water ingress	Data taken from company systems.	GDN Specific
Fracture	Frequency of fracture failures	As per Corrosion, but for fracture failure mode	GDN Specific
Gas Escape	Gas Escapes due to corrosion, fracture, interference or joint failure	Value of 1 used as a multiplier to enable the grouping/summation of the probability of corrosion, fracture, interference and joint failures	Common
General Emissions	Leakage	Consistent with NLRMM leakage models	Common
GIB_Fracture	Probability of gas ingress given failure – Fracture	Data taken from company systems.	GDN Specific
GIB_Interference	Probability of gas ingress given failure – Interference	Data taken from company systems.	GDN Specific
GIB_Joint	Probability of gas ingress given failure – Joint Failure	Data taken from company systems.	GDN Specific
Interference	Frequency of interference failures	As per Corrosion, but for interference node	GDN Specific
Joint	Frequency of joint failures	As per Corrosion, but for joint node	GDN Specific
Loss_of_Gas	M3 of gas lost from a failure or failure mode	Taken from standard gas industry leakage models. Linear extrapolation utilised for Intermediate pressure for	Common

Node ID / Variable	Description	Data Source	Source
		which no data currently exists	
Minor	Number of minor injuries given an explosion in a property	Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common
P_Complaint_Capacity	Probability of customer complaints given a network capacity issue	Data taken from company systems.	GDN Specific
P_Complaint_Escape	Probability of complaints given a failure has occurred	Data taken from company systems.	GDN Specific
Property_Damage	Number Level of property damage given explosion	Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common
Props_Com_Large	Number of large commercial properties affected by supply interruption (C3 and C4 type properties, i.e. Hotels, Pubs/clubs, restaurants)	Data taken from company systems based on either network analysis or assumptions based on proportion of property types.	GDN Specific
Props_Com_Small	Number of small commercial properties affected by supply interruption (C1 type properties, i.e. shops and offices)	Data taken from company systems based on either network analysis or assumptions based on proportion of property types.	GDN Specific
Props_Critical	Number of critical properties at risk of supply interruption (C2 and I2 type properties, i.e. schools, hospitals, firm industrial)	Data taken from company systems or assumed based on network/geographic analysis and proportion of property types.	GDN Specific
Props_Domestic	Number of domestic properties at risk of supply interruption (D1 type properties)	Data taken from company systems or assumed based on network/geographic analysis and proportion of property types.	GDN Specific
Supply Interruptions	Probability of supply interruptions given a failure has occurred	Data taken from company systems.	GDN Specific
Water_Ingress	Probability of water ingress given a failure has occurred	Data taken from company systems.	GDN Specific

Table A- 1 - Distribution Mains Data Reference Library

A3. Distribution Mains Event Tree Utilisation

A3.1. Distribution Mains Base Data

For a number of years a common risk process has been used within the UK gas industry driven from the need to manage the risks from iron mains. This methodology builds upon this long standing pipe based data set to feed into the new risk assessment process. The data used includes (but is not limited to):

- Pipe length
- Diameter
- Material
- Distribution Zone
- Pressure Tier
- Installation date

All of these data sets can be used to create Asset Cohorts to be used for investment and reporting purposes. The Distribution Mains risk models have been developed from pipe asset level data, held in company GIS systems. It should be noted that the Mains and Services risk models are very similar. It has been decided to retain them as separate models for risk assessment purposes, but they could be combined in the future to simplify reporting.

An example of data input format is shown below:

ASSET_ID	ASSET_LENGTH	BASEMENT_PROP	CONSTRUCTION_METHOD_BIN	DIAMETER	DIAM_BIN	TIER	JOINT_TYPE_BIN	ASSET_MATERIAL_BIN	POSTCODE	PRESSURE_CLASS_BIN
14919819	106.3121257	UNKN	ID	90	BAND_B	0	BF	PE	NE15AQ	LOW_PRESSURE
10148200	220.235089	UNKN	OC	63	BAND_A	0	S	PE	NE616LQ	LOW_PRESSURE
16481919	8.473002124	UNKN	ID	90	BAND_B	0	EL	PE	NE35NB	LOW_PRESSURE
15021415	665.6687463	UNKN	ID	125	BAND_B	0	S	PE	DN147NA	LOW_PRESSURE
10080694	12.27650411	UNKN	OC	63	BAND_A	0	K	PE	DH11QJ	LOW_PRESSURE
10045946	30.04423822	UNKN	UNKN	63	BAND_A	0	S	PE	HU74TU	LOW_PRESSURE
10253631	40.90789591	UNKN	OC	90	BAND_B	0	EL	PE	OL147HH	LOW_PRESSURE
16640712	154.5313538	UNKN	OC	63	BAND_A	0	EL	PE	DN148GA	MEDIUM_PRESSURE
10421092	55.18633209	UNKN	OC	125	BAND_B	0	K	PE	NE242HB	LOW_PRESSURE
16342912	21.57842112	UNKN	OC	63	BAND_A	0	EL	PE	YO179GA	LOW_PRESSURE
10023043	29.17854198	UNKN	OC	125	BAND_B	0	SF	PE	TS67DT	LOW_PRESSURE
10276757	59.67956718	UNKN	OC	63	BAND_A	0	S	PE	SR29DR	LOW_PRESSURE
14997453	6.156805178	UNKN	ID	63	BAND_A	0	T	PE	TS89BA	LOW_PRESSURE
10441055	31.01504523	UNKN	OC	90	BAND_B	0	S	PE	BD14AN	LOW_PRESSURE
10233426	18.62553348	UNKN	OC	63	BAND_A	0	EL	PE	HD88BX	LOW_PRESSURE
10465873	15.48663405	UNKN	OC	180	BAND_C	0	S	PE	TS159EQ	MEDIUM_PRESSURE
10000230	7.076589927	UNKN	OC	125	BAND_B	0	S	PE	NE31YG	LOW_PRESSURE
10092519	60.33027636	UNKN	OC	180	BAND_C	0	S	PE	NE372QX	LOW_PRESSURE
10466276	709.7568994	UNKN	GM	180	BAND_C	0	S	PE	DL13RT	MEDIUM_PRESSURE
14973183	113.429012	UNKN	ID	250	BAND_E	0	T	PE	SR52ET	MEDIUM_PRESSURE
10066663	15.03537952	UNKN	UNKN	250	BAND_E	0	T	PE	HU139NS	MEDIUM_PRESSURE
14999388	179.6814472	UNKN	ID	90	BAND_B	0	S	PE	NE63NR	LOW_PRESSURE
10349440	59.90689232	UNKN	OC	315	BAND_F	0	S	PE	HX48LR	MEDIUM_PRESSURE
10177605	15.11582986	UNKN	OC	180	BAND_C	0	S	PE	SR33XL	LOW_PRESSURE

Table A- 2 - Example of the base data format for the Mains risk models showing individual pipe level information.

Please note all columns used in the base data are not shown.

A3.2. Distribution Mains Probability of Failure Assessment

There are many ways that asset failure rates can be statistically derived. An example that has been applied for NGN distribution mains modelling is described below, but this methodology could be GDN specific given suitable data holdings.

For Distribution Mains analysis has been carried out to determine the underlying relationship between mains attributes and the observed PoF. This failure data recorded not only the failed asset but the Failure Mode. The process involves the identification of statistically significant "explanatory factors" that influence the underlying rate of failure and the derivation of a mathematical relationship between the PoF and the explanatory factors for each Failure Mode. In statistical terms this is described as a counting process regression model.

Because the Mains failure data has been referenced to individual (failed) pipes, this enables the data to be split by key explanatory factors to derive the initial PoF for each Failure Mode. The explanatory factors include:

- Asset age/installation date bin/decade
- Diameter
- Material
- Pressure class
- Distribution Zone

Although other mains characteristics are available, engineering experience suggests that these are the most likely explanatory factors that influence variations in the initial rate of failure (and deterioration). If other significant factors that influence failures are identified (e.g. weather/temperature), and can be related to the base asset data, the statistical model can be adapted to accommodate them.

An example for mains joint failures is shown in the graph below. The PoF (Failure Rate) is on the y-axis and the key attributes on the x-axis. This shows the variation in PoF based on the modelled explanatory factors. *Install bin (decade)*, which is effectively the pipe age, shows the most variation and PoF increases with age.

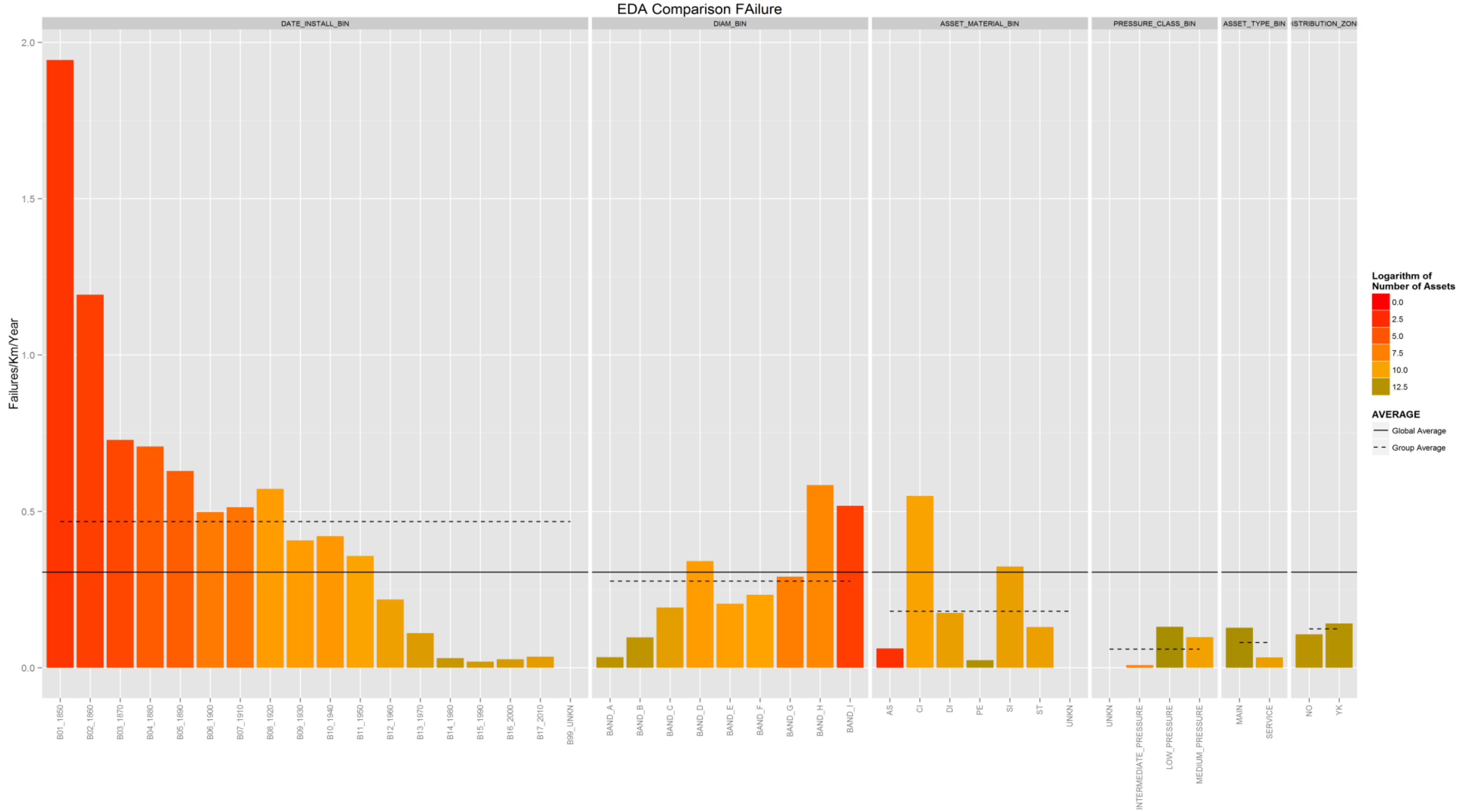


Figure A- 4 Initial Joint failure rates for Mains by asset cohort. This illustrates the explanatory factors explored in deriving the predictive function.

The height of the bars indicates the contribution of each explanatory factor to the overall predicted Joint failure rate.

Using the statistical analysis above a functional relationship was developed between the PoF and asset characteristics as follows.

PoF = Function (Install Decade, Diameter, Material, Pressure, Distribution Zone)

From this analysis we can calculate a starting PoF for any pipe, or cohort of pipes, in the network by using the relevant coefficients for each pipe and the functional relationship above. The units are number of failures per year per pipe length (Km). The derived coefficients will be GDN specific (Option A) except for when insufficient data exists to derive useful predictive functions. If this is the case then pooled data may be used (Option B).

Functional relationships (using the same explanatory factors) are then developed for each of the Failure Modes:

- Joint failure
- Interference (no age relationship modelled)
- Corrosion
- Fracture

The derived PoF relationship coefficients will vary between GDNs and should be revisited on a regular basis as new failure data is collected. Asset age is used later as a continuous variable (not an Install Decade as above) to inform the PoF deterioration analysis (See section A2.3).

These initial PoF values are used as the starting point (Year zero) on the "curve" for deterioration analysis. Interventions to install new assets typically reset these initial failure rates to a near-zero value.

The PoF values for mains are derived directly from historic failure rates. Validation can be carried out in three ways:

- Analysis of a different (longer) time series of data to test model sensitivity to the volume/time period of failure data assessed
- Appending a further period of data to test the sensitivity of the model to the addition of new data
- Inter-comparison of failure rates between GDNs to understand reasons for any material differences between failure rates for similar asset characteristics and Failure Modes

A3.3. Distribution Mains Deterioration Assessment

There are many ways that asset deterioration can be statistically derived. An example that has been applied for NGN distribution mains modelling is described below, but this methodology could be GDN specific given suitable data holdings.

Two alternative scenarios were initially explored for testing the sensitivity of the applied deterioration rates on risk value.

Initially, a global 2% exponential deterioration rate was tested, taken from the 2-4% range suggested in the Ofgem/HSE sponsored CEPA report.

This was followed up by a high level analysis of actual failure data (by Failure Mode) collected over a 7 year period (2007-2014). Example deterioration models for the Corrosion and Joint Failure Modes are shown below.

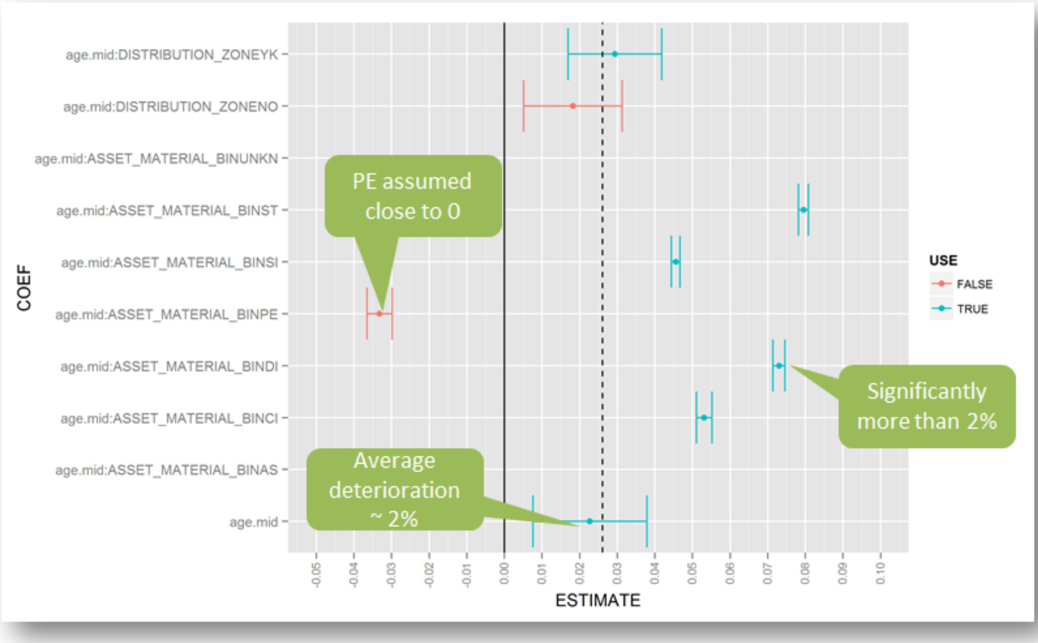


Figure A- 5 - Corrosion failure rates by Material and Zone

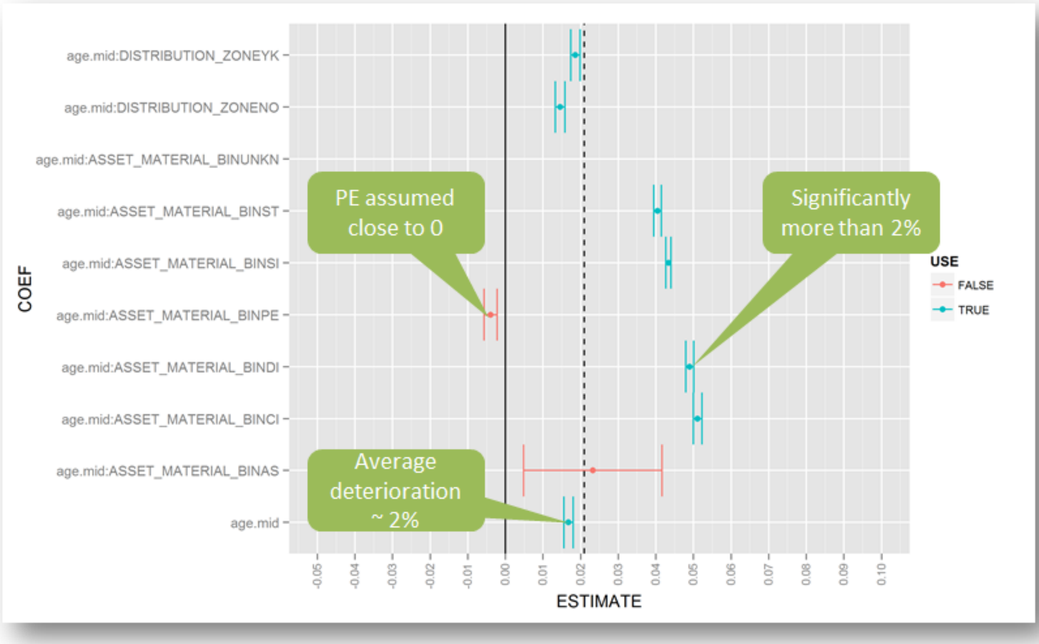


Figure A- 6 - Joint failure deterioration rates by Material and Zone

These figures illustrate that there is evidence to suggest than actual joint and corrosion deterioration rates on iron pipes are significantly greater than the initially assumed 2% values.

The figure below illustrates the impact of these differing assumptions with the model on the number of gas escapes (and hence the risk value associated with mitigating these escapes).

These higher values have been applied in the Mains risk model rather than the assumed 2% values and a sensitivity analysis undertaken against the "2%" model.

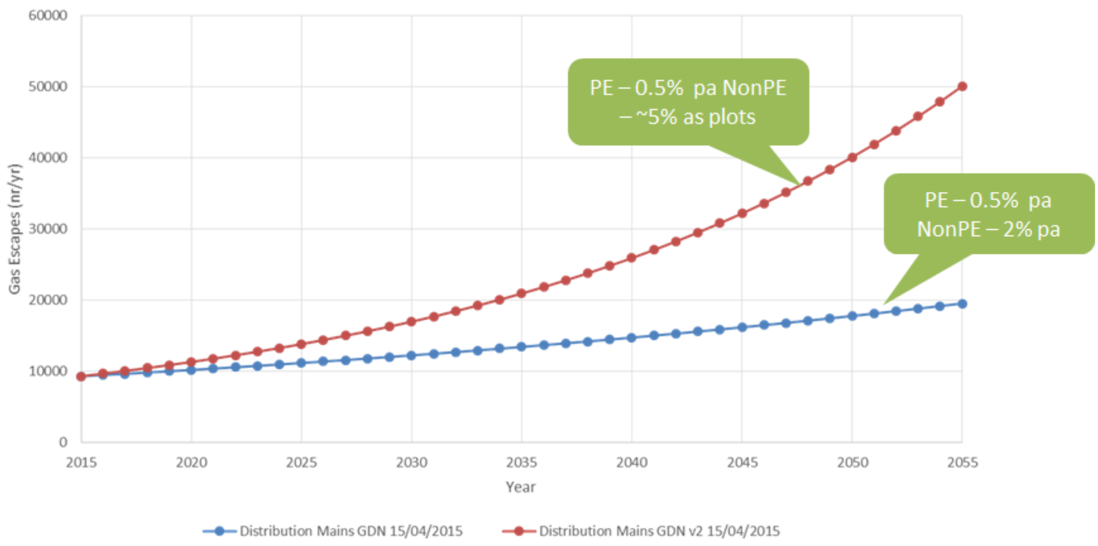


Figure A- 7 - Comparison of 2% and derived deterioration rates on predicted gas escapes

By undertaking further statistical analysis it may be possible to distinguish and quantify the explanatory factors for these varying failure and deterioration rates, such as:

- Pipe age
- Material/pressure
- Service connection density
- Geographic area
- etc.

An improved understanding of the relationships that affect the PoF will allow the magnitude of deterioration to be further quantified and an updated functional relationship (linear or exponential) applied. Further work will be required to explore the underlying explanatory factors for varying failure rates and extend the analysis to the other Failure Modes.

New PE pipes have been assumed to have a low initial failure and deterioration rate, based on the low levels of failure observed in the network. This maximises the benefit of any replacement interventions. Further research is required to understand the true failure rate of modern PE materials.

Regular validation will be carried out to test the predictive ability of the deterioration model, for example by using the derived deterioration rate to back-calculate historic failure rates. Sensitivity as to the impact of the shape and magnitude of the deterioration assumptions on monetised risk calculations will be carried out.

A3.4. Distribution Mains Consequence of Failure Assessment

There are many consequences of failure identified for the Distribution Mains Asset Group. These can be viewed in the risk maps and Data Reference Library in Section A2.5. For simplicity each Consequence of Failure for mains has been categorised as Internal Costs, Environmental, Health & Safety or Customer consequences. Examples of Distribution Mains consequence modelling are also illustrated. The data source and derivation for all Costs of Failure are explained in the Data Reference Library.

A3.4.1. Internal Consequence Costs

This includes the internal costs of responding to or remediation of failures. These are generally derived from internal company financial systems. Examples include Joint, Corrosion or Fracture repair costs. Legal costs associated with HSE or Customer consequences are also included as internal costs, as are the costs of managing work in the highway (TMA orders).

A3.4.2. Environment Consequence Costs

Environmental consequences include the monetary value of product lost due to failures or leakage plus the shadow cost of carbon associated with failure or emissions. In particular, the shadow cost of carbon increases annually (and hence the consequence value increases) in line with government carbon valuation guidelines.

A3.4.3. Health & Safety Consequence Costs

Health & Safety consequences are primarily associated with the damage caused by ignition following asset failure and subsequent entry into customer properties. The largest HSE consequence is associated with loss of life, but minor injury and property damage are also considered.

A3.4.4. Customer Consequence Costs

Customer consequences include compensation payments generated through loss of service caused by asset failure. These are categorised into Domestic, Commercial and Critical customers to account for the differences in the monetary value of these compensation payments.

A3.4.5. Corrosion Consequences of Failure

For a mains corrosion failure the assessed initial consequence is a loss of gas (PoC=1), which may lead to a gas in building (GIB) event (PoC=0.029). A GIB event may lead to an explosion (PoC=0.00076) which may lead to property damage (PoC=1), a minor injury (PoC=1) or a death (PoC=0.45). Each consequence is then assigned a monetary value (using the cost of consequence calculated as per Figure A8.). The sum of all consequences is the monetised risk for the Corrosion Failure Mode.

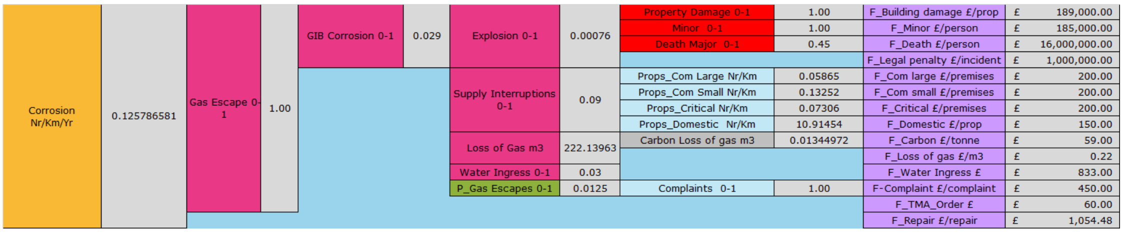


Figure A- 8 - Modelled consequences and values for Mains Corrosion failure.

Further consequences arising from a corrosion failure are calculated in a similar way e.g.

- Supply interruptions
- Loss of gas
- Water ingress
- Customer complaints

A3.4.6. General Emissions Consequences of Failure

For an emissions failure a simplified approach is adopted. The volume per kilometre per year is simply multiplied by the carbon value of the gas lost through emissions. This is then added to the retail value of the lost gas to give the monetised risk value for the General Emissions Failure Mode.

Figure A- 9 - Modelled consequences and values for Mains General Emissions failure

A3.5. Distribution Mains Intervention Definitions

Intervention activities can be flexibly defined within the monetised risk trading methodology by modelling the change in risk enabled by the intervention activity.

Some interventions, such as replacing CI mains with PE, will reduce both the Probability of Failure and deterioration of the overall asset base, thus changing the monetised risk value over the life of the asset. This is called a **With Investment** activity below.

Other types of intervention may just represent the base costs of maintaining the asset at an acceptable level of performance (i.e. to counteract deterioration or where the consequences of failure are unacceptably high). This is called a **Without Investment** activity.

Definitions of activities undertaken as part of normal maintenance (i.e. 'without intervention') and interventions for Distribution Mains are listed below.

'Without intervention' activities:

- Gas conditioning
- Surveys
- Repairs following leakage/ingress

'With intervention' activities:

Number	Description	Definition
Intervention 1	Replacement	Replacement of Non PE main with PE main (includes service PE transfers)
Intervention 2	Decommissioning	Decommissioning/abandonment of existing main
Intervention 3	CIPP Lining	Cured in place lining refurbishment of main
Intervention 4	Planned internal repairs (e.g. CISBOT)	Internal repair/refurbishment of mains e.g. joint repairs.

Table A- 3 - Potential With- and Without Investment interventions for Mains

A3.5.1. Mains Replacement Intervention Benefits

The major benefits of replacing metallic pipes with polyethylene (PE) have been assessed to be:

- A reduction in the rate of Joint, Fracture and Corrosion failure
- A reduction in the rate of deterioration of Joint, Fracture and Corrosion failure

The rate of failure of new pipes was assessed by analysing the NGN repair database for failures occurring on PE pipes that are less than 10 years old which allowed a Failure Mode specific value for the rate of failure following replacement to be assessed.

The deterioration rate of the new PE following replacement will be very low, but non-zero. The deterioration rate for PE pipe (derived as above) was used to model the post-intervention PoF deterioration. Example values used to model post-intervention PoF and deterioration (by Failure Mode) are shown below:

Failure mode	PoF (new PE main) (Nr/km/year)	PoF deterioration (new PE main) (per annum)
Joint	0.0234	0.5%
Corrosion	0.00431	0.5%
Fracture	0.000879	0.5%

Table A- 4 - Applied PoF and PoF deterioration for new PE mains

A3.5.2. Example Mains Replacement Interventions

A detailed example of a Mains Replacement intervention is included throughout the main body of the report. The process provides flexibility for all types of intervention to be modelled, including proactive maintenance activities such as modelling. This is achieved by defining Intervention Rules which are applied to the asset/cohort post-intervention. These usually reduce (but can add) to the overall monetised risk value for the Asset Group or sub-group.

			Year0	Year1	Year2	Year3	Year4	Year5	Year6	Year7	Year8
Cohort Number	Cohort Name	Intervention Plan	Initial Length (Km)	Proposed Intervention (Km)	Proposed Intervention (Km)	Proposed Intervention (Km)	Proposed Intervention (Km)	Proposed Intervention (Km)	Proposed Intervention (Km)	Proposed Intervention (Km)	Proposed Intervention (Km)
1	AS / NO / 0		1.79								
2	AS / YK / 0		0.01								
3	CI / NO / 1	Intervention 1	735.87	20	20	20	20	20	20	20	20
4	CI / NO / 2A		2.30								
5	CI / NO / 2B		366.13								
6	CI / NO / 3		74.17								
7	CI / YK / 1		895.96								

Figure A- 10 - Example intervention plan for 20km pa mains replacement (CI with PE)

BaseLine		
Node	Rule	Test Value
Capacity Nr/Km/Yr	0.0004/76.63*1000	0.00522
Corrosion Nr/Km/Yr	Scalar_Corrosion*Corrosion*exp(DYear*Material_Corrosion)	0.12579
Fracture Nr/Km/Yr	Scalar_Fracture*Fracture*exp(DYear*Material_Fracture)	0.07374
General Emissions m3/Km/Yr	Leakage_Rate*(1+(Dyear/100))	666.39345
Interference Nr/Km/Yr	Scalar_Intereference*Interference	0.00528
Joint Nr/Km/Yr	Scalar_Joints*Failure*exp(DYear*Material_Joint)	0.23222

Intervention 1		
Node	Rule	Test Value
Capacity Nr/Km/Yr	0.0004/76.63*1000	0.00522
Corrosion Nr/Km/Yr	Corrosion_New_Pipe*1000*exp(Dyear*Corrosion_PE)	0.00431
Fracture Nr/Km/Yr	Fracture_New_Pipe *1000*exp(Dyear*Fracture_PE)	0.00088
General Emissions m3/Km/Yr	Leakage_Rate*exp(Dyear/100)	666.39345
Interference Nr/Km/Yr	Interference	0.00467
Joint Nr/Km/Yr	Joint_New_Pipe *1000*exp(Dyear*Joint_PE)	0.02340

Figure A- 11 - Example pre and post intervention rules for the above mains replacement intervention (CI with PE)

Using the example above the pre-intervention CI Fracture rate can be seen to be 0.074 failures/km/year prior to replacement with PE and 0.001 failures/km/year post replacement.

Appendix B – Services

B1. Services Definition

A Service, that is to be recorded as such in the asset record, is a pipe from a main up to and including the outlet of the 1st Emergency Control Valve (ECV) to an individual meter installation. This definition may occasionally include a dual service, supplying up to 2 primary meter installations in one or two buildings, with no other potential connections. The elements of a service include: the connection fittings to the main; service valves; bends; above ground sleeves; service entries; service termination fittings; elbows and the ECV / Customer control valve.

A pipe laid as a service to a large industrial premise might be suitable for re-designation as a main if subsequent connections are required and the pipe has been tested to the appropriate mains standard. This would result in movement of assets from one asset component category to the other.

For the purposes of the NOMs methodology Services have been split into two types as follows based on simple size/diameter rules:

- **Domestic**. Service pipes which are less than 63mm in diameter. There are no company records held of these individual services or their locations and characteristics have needed to be estimated (see B3. below).
- **Non-domestic**. Service pipes which are greater than 63mm in diameter. These tend to be feeding larger industrial/commercial premises. These larger services are recorded as individual pipes in company GIS systems (and have individual risk scores in MRPS). As such Non-domestic services are included as individual assets within the Service risk model.

"Domestic" is a naming convention used only to distinguish where services location/characteristics are estimated rather than held on company GIS systems. There will be some industrial/commercial properties with smaller diameter services which will be classified under "Domestic".

B2. Services Event Tree Development

B2.1. Services Failure Modes

The following Failure Modes have been identified for Services. These are the same as for Distribution Mains. Failure modes were identified through a number of workshops with asset experts and through careful analysis of available data held by companies to assess and quantify the rate of failures and future asset deterioration.

- Capacity failure – where the pipe network is under-sized to meet demand
- Corrosion failure
- Fracture failure
- Interference failure – for example 3rd party damage
- Joint failure
- General emissions – background leakage or shrinkage from the pipe network

Values are typically expressed in 'per Service' units. The Failure Modes are highlighted in yellow on the risk map below.

B2.2. Services Consequence Measures

As per the process in Section 3.4, the following consequence measures have been identified for Services.

- Gas escape
- Gas in buildings
- Supply interruption
- Loss of gas
- Water ingress
- Explosion

B2.3. Services Risk Map

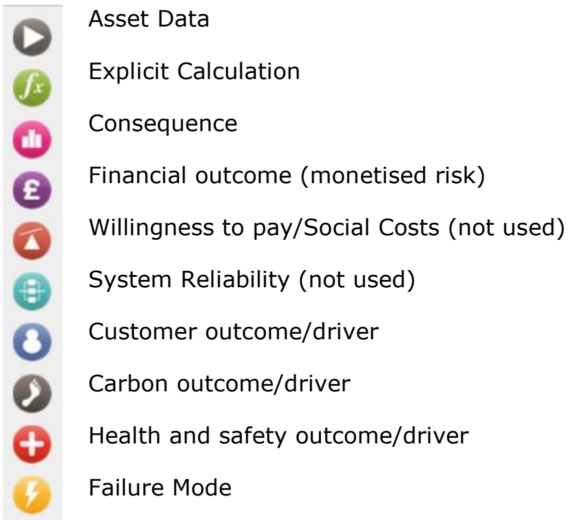


Figure B- 1 - Risk Map Key

Figure B-1 outlines the risk map key for Services. The risk map is colour coded for each node of the event tree to indicate which values are associated with each node. The colours are reflected in both the risk map and risk map template in Figures B2 and B3.

As per the process described within Section 3.5 of the main methodology, the risk map for Services is shown below:

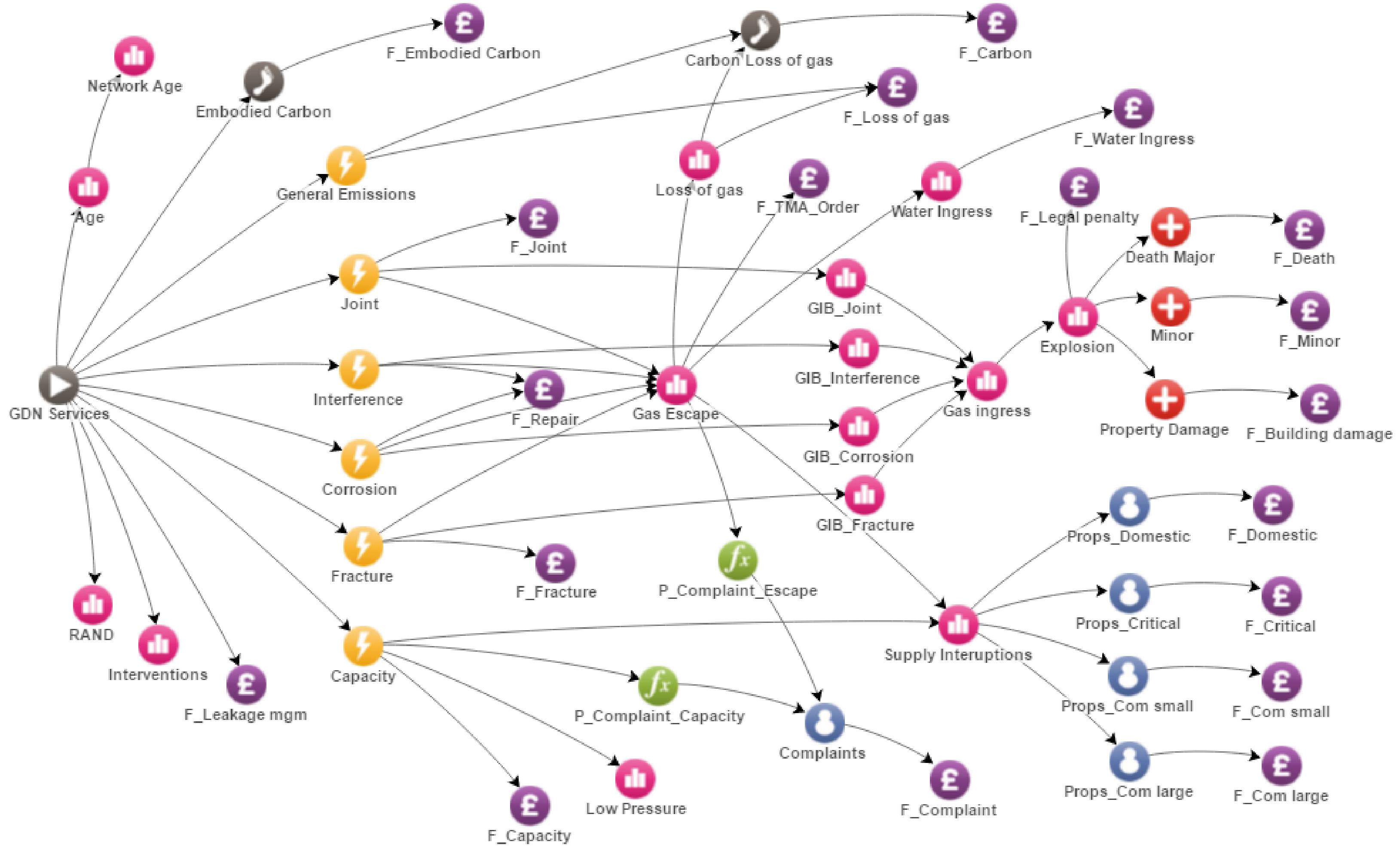


Figure B- 2 - Services Risk Map

B2.4. Services Risk Template

The following table demonstrates how the total risk value is derived for any given Services cohort. Effectively an individual, populated risk map is developed for every cohort to be modelled to deliver a baseline monetised risk value prior to intervention modelling.

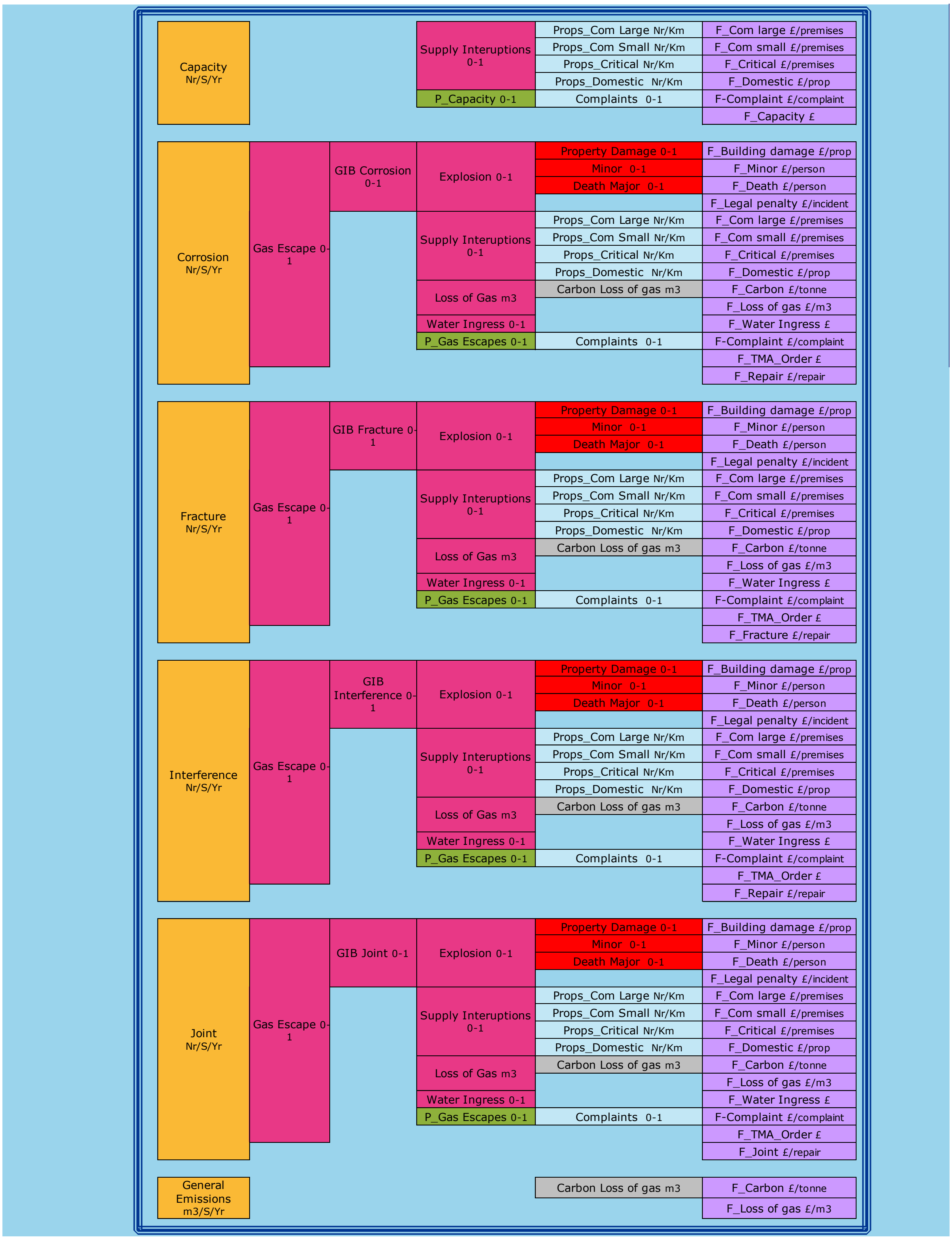


Figure B- 3 - Services Risk Map Template

B2.5. Services Data Reference Library

In line with Section 3.7 of the main report, the following table provides a brief description of the risk nodes modelled in the Event Tree, the source of the data and/or a high level description as to how the values were derived and a flag to indicate whether the data will be provided individually by each GDN or through common/shared analysis:

Node ID / Variable	Description	Data Source	Source
Capacity	Probability of capacity issues	Data taken from company systems.	GDN Specific
Complaints	Number of customer complaints	Data taken from company systems.	GDN Specific
Corrosion	Frequency of corrosion failures	A similar approach was taken to derive initial Service failure rates as per Mains. This used Material (non-PE or PE) and Network ID to provide an estimate of the geographic distribution of initial Service failure rates.	GDN Specific
Death_Major	Number of deaths or major injuries given an explosion in a property	Value based on research values (Newcastle University)	Common
Explosion	Probability of explosion given gas ingress	Data taken from company systems.	GDN Specific
F_Capacity	Cost of responding to capacity issues (not this is not the cost of resolving capacity issues)	Data taken from company systems.	GDN Specific
F_Complaints	Cost of handling customer complains	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific
F_Fracture	Average cost of repairing a fracture	Data taken from company systems. A statistical model can be used to relate unit cost to pipe diameter.	GDN Specific
F_Joint	Average cost of repairing a joint	Data taken from company systems. A statistical model can be used to relate unit cost to pipe diameter.	GDN Specific
F_Leakage_mgm	Cost of leakage management per unit length	~~Data taken from company systems. Applied only to Services that are represented as individual assets in GIS (>=63mm)~~ Nil costs reported for services. Cost of leakage management (e.g. profiling) captured under Governors model	~~GDN Specific~~ Common
F_Repair	Average cost of a general repair due to corrosion or interruption	Data taken from company systems. A statistical model can be used to relate unit cost to pipe diameter.	GDN Specific
F_TMA_Order	Local authority management order	Data taken from company systems.	GDN Specific
F_Water_Ingress	Cost of water ingress	Data taken from company systems.	GDN Specific
Fracture	Frequency of fracture failures	As per Corrosion, but for fracture failure modes	GDN Specific
GIB_Corrosion	Probability of gas ingress given failure - Corrosion	Data taken from company systems where available (i.e. no. of gas ingress events due to corrosion / no. of corrosion	GDN Specific

Node ID / Variable	Description	Data Source	Source
		failures) or a default/assumed value agreed with SRWG	
GIB_Fracture	Probability of gas ingress given failure – Fracture	Data taken from company systems where available (i.e. no. of gas ingress events due to fracture / no. of fracture failures) or a default/assumed value agreed with SRWG	GDN Specific
GIB_Interference	Probability of gas ingress given failure – Interference	Data taken from company systems where available (i.e. no. of gas ingress events due to interference / no. of interference failures) or a default/assumed value agreed with SRWG	GDN Specific
GIB_Joint	Probability of gas ingress given failure – Joint Failure	Data taken from company systems where available (i.e. no. of gas ingress events due to joint / no. of joint failures) or a default/assumed value agreed with SRWG	GDN Specific
Interference	Frequency of interference failures	As per Corrosion, but for interference failure mode	GDN Specific
Joint	Frequency of joint failures	As per Corrosion, but for interference failure mode	GDN Specific
Loss_Of_Gas	Loss of gas arising from a failure	Taken from standard gas industry leakage models. Linear extrapolation utilised for Intermediate Pressure	Common
Minor	Number of minor injuries given an explosion	Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common
Non_PE_Det	Deterioration rate of Non_PE pipes	Limited data was available to estimate the deterioration of services over time. Default/assumed value agreed with SRWG	Common
P_Complaint_Capacity	Probability of customer complaints given a network capacity issue	Data taken from company systems	GDN Specific
P_Complaint_Escape	Probability of complaints given a failure has occurred	Data taken from company systems	GDN Specific
PE_Det	Deterioration rate of PE pipes	Limited data was available to estimate the deterioration of services over time. Default/assumed value agreed with SRWG	Common
Property_Damage	Number of property damage given explosion	Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common
Props_Com_Large	Number of commercial large properties at risk of supply interruption	Data taken from company systems or assumed based on network/geographic analysis and proportion of property types.	GDN Specific
Props_Com_Small	Number of commercial small properties at risk of supply interruption	Data taken from company systems or assumed based on network/geographic analysis and proportion of property types.	GDN Specific

Node ID / Variable	Description	Data Source	Source
Props_Critical	Number of critical properties at risk of supply interruption	Data taken from company systems or assumed based on network/geographic analysis and proportion of property types.	GDN Specific
Props_Domestic	Number of domestic properties at risk of supply interruption	Data taken from company systems or assumed based on network/geographic analysis and proportion of property types.	GDN Specific
Supply Interruptions	Probability of supply interruptions given a failure has occurred	~~Data taken from company systems.~~ Common value of 100% to be used since all failures wil result in a supply interruption in order to restore or replace the supply.	~~GDN Specific~~ Common
Water_Ingress	Probability of water ingress given a failure has occurred	Data taken from company systems.	GDN Specific

Table B- 1 - Services Data Reference Library

B3. Services Event Tree Utilisation

B3.1. Services Base Data

The definition of Services cohorts within the NOMs methodology has been driven by the lack of asset-level data for Domestic (less than 63mm diameter) services. To address this gap a hybrid approach was adopted. Firstly, the property density per mains pipe section was calculated based on the total number of domestic meters in each postcode area and the total length of gas main in each postcode. This was then used to allocate a number of services to a length of mains pipe in proportion to this calculated property density. This approach could be improved using GIS property layers (if available) and spatial allocation to pipes, however other methodologies can be used.

Each individual record within the Services base model comprises a section of pipe extracted from the GIS, which are classified as Mains or Services. Where the service diameter is greater than 63mm, and recorded as such in GIS, the service record is classed as Non-domestic.

Where no service record exists in GIS a section of mains pipe can be used with a number of services allocated as per the method described above. These are classed as Domestic services. The attributes for Non-domestic services are taken from GIS.

Where the diameter and material (etc.) for Domestic services are unknown they can be estimated using assumed non-PE/PE service proportions. For the example data set, the proportion of PE and non-PE mains was calculated at a Network level using GIS. This proportion of mains materials was then applied to the service proportions in that Network area. For example, if a Network area contained 100% PE mains then we would assume there were 100% PE services, and vice versa.

There are many alternative approaches to estimate the PE/non-PE service numbers and proportions; the flexibility of the methodology allows for this split to be undertaken at an individual (mains) pipe level if the data exists to do so.

Hence for Non-domestic services there is a 1-to-1 relationship between the mains pipe length and the service. For Domestic services there is a 1-to-many relationship between a mains pipe length and the service. Where no meters are present in the postcode data we assume there are no services attached and the mains pipe section does not appear in the base data. The diagram below illustrates how service asset base data is modelled within the NOMs methodology.

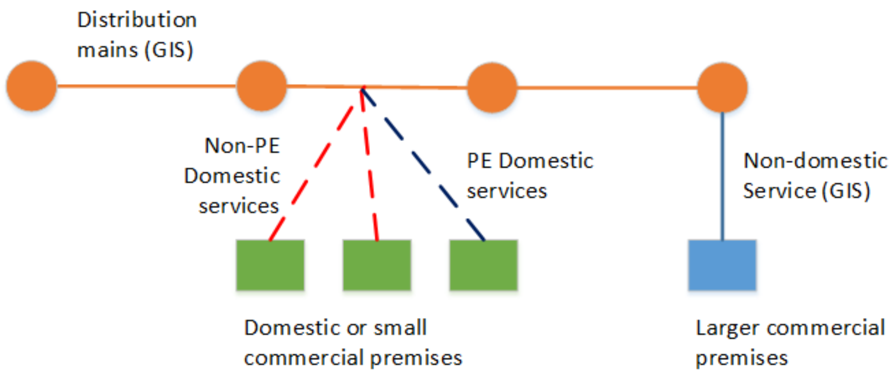


Figure B- 4 - representation of Services with respect to Mains in the base data

This can be further illustrated using the base data model format used for the Services risk model:

ASSET_ID	CUSTOMER_TYPE	ASSET_TYPE_BIN	DIAMETER	DIAM_BIN	ASSET_MATERIAL_BIN	TOTAL_SERVICE_LENGTH_M	NO_OF_METERS_ON_ASSET	ASSET_LENGTH	PRESSURE_CLASS_BIN	POSTCODE	NETWORK_ID	NUMBER_OF_SERVICES	PROP_CONNECT_DOMESTIC
16167978	NON DOMESTIC	SERVICE	63	BAND_A	PE	47.56627772	1	47.56627772	LOW_PRESSURE	HU12PS	20L0012	1	0
14503118	NON DOMESTIC	SERVICE	50.8	BAND_A	ST	199.4159709	1	199.4159709	LOW_PRESSURE	WF20QQ	20L0019	1	0
17369792	NON DOMESTIC	SERVICE	63	BAND_A	PE	4.26481517	1	4.26481517	LOW_PRESSURE	LS15SP	22L0106	1	0
14425626	NON DOMESTIC	SERVICE	63	BAND_A	PE	26.68010729	1	26.68010729	LOW_PRESSURE	WF157LQ	22L0110	1	0
17187905	NON DOMESTIC	SERVICE	63	BAND_A	PE	2.999908832	1	2.999908832	LOW_PRESSURE	HU128NW	20L0013	1	0
16879428	NON DOMESTIC	SERVICE	63	BAND_A	PE	34.76818563	1	34.76818563	LOW_PRESSURE	CA117EG	66L1031	1	0
13997950	NON DOMESTIC	SERVICE	63	BAND_A	PE	3.000013484	1	3.000013484	LOW_PRESSURE	HU87HB	20L0011	1	0
14505492	NON DOMESTIC	SERVICE	90	BAND_B	PE	64.98642372	1	64.98642372	LOW_PRESSURE	NE62XJ	66L7007	1	0
16441406	NON DOMESTIC	SERVICE	125	BAND_B	PE	49.15743872	1	49.15743872	MEDIUM_PRESSURE	DN148GA	20M0519	1	0
14443947	NON DOMESTIC	SERVICE	50.8	BAND_A	ST	27.34421728	1	27.34421728	LOW_PRESSURE	HD75SP	22L0102	1	0
16488245	NON DOMESTIC	SERVICE	25	BAND_A	PE	2.746793039	1	2.746793039	MEDIUM_PRESSURE	DL107JF	68M2005	1	0
16655158	NON DOMESTIC	SERVICE	63	BAND_A	PE	16.26486798	1	16.26486798	LOW_PRESSURE	DL166RH	68L1008	1	0
15381207	NON DOMESTIC	SERVICE	63	BAND_A	PE	50.77909898	1	50.77909898	LOW_PRESSURE	HG58LJ	20L0010	1	0
16167025	NON DOMESTIC	SERVICE	63	BAND_A	PE	25.82301541	1	25.82301541	LOW_PRESSURE	HX38JE	22L0112	1	0

Table B- 2 - Example of data format for the Non-domestic services model showing asset level information.

One Service per connection is assumed. Material and diameter is taken from GIS

ASSET_	CUSTOMER_TY	ASSET_TYPE_B	DIAMET	DIAM_B	ASSET_MATERIAL_B	TOTAL_SERVICE_LENGTH_	NO_OF_METERS_ON_ASSI	ASSET_LENG	PRESSURE_CLASS_B	POSTCO	NETWORK_	PROP_CONNECT_DOMEST	SERVICE_MATERIAL_B
10462195	DOMESTIC	SERVICE	63	BAND_A	PE	129.5860516	11	66.02359513	LOW_PRESSURE	LS103RL	22L0106	7.62270892	PE
10125213	DOMESTIC	SERVICE	63	BAND_A	PE	8.439716312	3	60.3961851	LOW_PRESSURE	TS95FB	68L1084	0.496453901	NONPE
10125213	DOMESTIC	SERVICE	63	BAND_A	PE	42.56028369	3	60.3961851	LOW_PRESSURE	TS95FB	68L1084	2.503546099	PE
17216557	DOMESTIC	SERVICE	63	BAND_A	PE	30.90929437	7	33.62798142	LOW_PRESSURE	LS278SL	22L0109	1.818193786	NONPE
17216557	DOMESTIC	SERVICE	63	BAND_A	PE	88.09070563	7	33.62798142	LOW_PRESSURE	LS278SL	22L0109	5.181806214	PE
10052941	DOMESTIC	SERVICE	63	BAND_A	PE	34.00668567	6	48.65459386	LOW_PRESSURE	NE332AF	66L7009	2.000393275	NONPE
10052941	DOMESTIC	SERVICE	63	BAND_A	PE	67.99331433	6	48.65459386	LOW_PRESSURE	NE332AF	66L7009	3.999606725	PE
10311116	DOMESTIC	SERVICE	63	BAND_A	PE	3.810344828	2	34.41050574	LOW_PRESSURE	HG44HA	68L1087	0.224137931	NONPE
10311116	DOMESTIC	SERVICE	63	BAND_A	PE	30.18965517	2	34.41050574	LOW_PRESSURE	HG44HA	68L1087	1.775862069	PE
10161640	DOMESTIC	SERVICE	63	BAND_A	CI	13.01757299	3	38.9226734	LOW_PRESSURE	NE53NL	66L7007	0.765739588	NONPE
10161640	DOMESTIC	SERVICE	63	BAND_A	CI	37.98242701	3	38.9226734	LOW_PRESSURE	NE53NL	66L7007	2.234260412	PE
10065656	DOMESTIC	SERVICE	63	BAND_A	PE	3.752956636	1	141.0832767	LOW_PRESSURE	DN149NS	20L0008	0.220762155	NONPE
10065656	DOMESTIC	SERVICE	63	BAND_A	PE	13.24704336	1	141.0832767	LOW_PRESSURE	DN149NS	20L0008	0.779237845	PE
10446019	DOMESTIC	SERVICE	63	BAND_A	PE	57.41394835	11	65.12385611	LOW_PRESSURE	LS178XA	22L0106	3.37729108	NONPE
10446019	DOMESTIC	SERVICE	63	BAND_A	PE	129.5860516	11	65.12385611	LOW_PRESSURE	LS178XA	22L0106	7.62270892	PE

Table B- 3 - Example of data format for Domestic services model.

This shows how each Domestic service asset is split into two lines; one representing the connected PE services and the other representing the connected non-PE assets. These PE/non-PE splits are currently based on global proportions but can be changed at a mains (pipe) level if this information is known.

The material is split on each mains pipe length between metallic and PE initially using a global ratio of PE on non-PE. If pipe specific PE/non-PE counts are available this can easily be incorporated into the base data for improved granularity of analysis.

Service relays are counted as a service replacement intervention (metallic replaced with PE) whilst service transfers are included (within the Mains risk model) as an additional cost of main-laying (as a non-PE to PE replacement is not carried out). At a future point in time it may be sensible to combine the Mains and Services model to simplify the transfer/relay modelling process.

It should be noted that for NOMs reporting purposes the Domestic services base data set has been split into two separate lines in the base: one line for Domestic PE services, the other for Domestic Non-PE services. This has no bearing on the approach or analysis presented in the remainder of Appendix B.

B3.2. Services Probability of Failure Assessment

There are many ways that asset failure rates can be statistically derived. An example that has been applied for NGN services modelling is described below, but this methodology could be GDN specific given suitable data holdings.

A similar approach to Mains is used to assess Service PoF values. However, Service assets are not individually recorded in company systems so a slightly different approach to assess localised failure rates must be adopted.

The PoF analysis for services is effectively based on failure "hotspots":

- Service failures have an coordinate taken from job management systems which are used to aggregate failures to postcode level by Failure Mode
- The number of Services per postcode is estimated from the number of gas meters in each postcode area (DECC data)
- These calculated Service numbers are proportioned to each main and split by PE and non-PE as described previously

This approach is used to derive a functional relationship for Services of the form:

PoF = Function (Service Material, Network ID)

Network ID is a grouping of the distribution network used for operational planning services. It was used for the statistical analysis as it was large enough to contain enough historic failures but small enough to provide granularity in the distribution of PE and non-PE service failure rates throughout the network, potentially allowing for targeting of future service investment based on geographic location.

This functional relationship is much simpler than Mains but can be used in the same way to assign a PoF to each Service asset (or group of Services) based on assumed Service Material and geographic location. Please note (from Section 3.1) that <63mm diameter Services are not individually represented in the base data, but are allocated to Mains pipe sections (which may hold a mixture of PE and non-PE Services). The PoF for the grouped Services on a <63mm diameter pipe section will be weighted average of the PE and non-PE PoF values for that Network ID. Where Services are less than 63mm in diameter they will have their own individual pipe sections and will have a PoF value directly related to their Material and Network ID.

In terms of the PoF calculation:

- **Domestic**: PoF value per (mains) pipe section is the weighted average of the PoF values for the non-PE and PE services allocated to that pipe section, which are based on the Network ID in which the (mains) pipe is located

- **Non-domestic**: PoF is allocated based on the service material and Network ID of the service

B3.3. Services Deterioration Assessment

There are many ways that asset deterioration can be statistically derived. An example that has been applied for NGN services modelling is described below, but this methodology could be GDN specific given suitable data holdings.

As described above limited data was available to estimate the deterioration of services over time and so an Option B approach was adopted. Initial failure rates were taken from historic NGN failure data based on analysis at a Network ID level. This provides a sub-population variation in initial failure rates. Deterioration rates in failures have been assumed based on the Mains model analysis or by using default values agreed by the SRWG working group:

- 5% deterioration per annum was assumed for all non-PE material types, for all Failure Modes except Interference
- 0.5% deterioration per annum was assumed for PE
- 0% deterioration per annum was assumed for Interference
- 1% per annum was assumed for General Emissions

B3.4. Services Consequence of Failure Assessment

There are many consequences of failure identified for the Services Asset Group. These can be viewed in the risk maps and Data Reference Library in Section B2.5. For simplicity each Consequence of Failure for services has been categorised as Internal Costs, Environmental, Health & Safety or Customer consequences. Examples of Services consequence modelling are also illustrated. The data source and derivation for all Costs of Failure are explained in the Data Reference Library.

B3.4.1. Internal Consequence Costs

This includes the internal costs of responding to or remediation of failures. These are generally derived from internal company financial systems. Examples include Joint, Corrosion or Fracture repair costs. Legal costs associated with HSE or Customer consequences are also included as internal costs, as are the costs of managing work in the highway (TMA orders).

B3.4.2. Environment Consequence Costs

Environmental consequences include the monetary value of product lost due to failures or leakage plus the shadow cost of carbon associated with failure or emissions. In particular, the shadow cost of carbon increases annually (and hence the consequence value increases) in line with government carbon valuation guidelines.

B3.4.3. Health & Safety Consequence Costs

Health & Safety consequences are primarily associated with the damage caused by ignition following asset failure and subsequent entry into customer properties. The largest HSE consequence is associated with loss of life, but minor injury and property damage are also considered.

B3.4.4. Customer Consequence Costs

Customer consequences include compensation payments generated through loss of service caused by asset failure. These are categorised into Domestic, Commercial and Critical customers to account for the differences in the monetary value of these compensation payments.

B3.4.5 Corrosion Consequences of Failure

For a services corrosion failure the assessed initial consequence is a loss of gas (PoC=1), which may lead to a gas in building (GIB) event (PoC=0.029). A GIB event may lead to an explosion (PoC=0.00076) which may lead to property damage (PoC=1), a minor injury (PoC=1) or a death (PoC=0.45). Each consequence is then assigned a monetary value (using the cost of consequence calculated as per Figure B5.). The sum of all consequences is the monetised risk for the Corrosion Failure Mode.

Corrosion Nr/S/Yr	0.002426179	Gas Escape 0-1	1.00	GIB Corrosion 0-1	0.029	Explosion 0-1	0.00	Property Damage 0-1	1.00	F_Building damage £/prop	£	189,000.00	£	0.01
								Minor 0-1	1.00	F_Minor £/person	£	185,000.00	£	0.01
								Death Major 0-1	0.45	F_Death £/person	£	16,000,000.00	£	0.39
										F_Legal penalty £/incident	£	1,000,000.00	£	0.05
						Supply Interruption 0-1	0.09	Props_Com Large Nr/Km	0.00	F_Com large £/premises	£	200.00	£	-
								Props_Com Small Nr/Km	0.00	F_Com small £/premises	£	200.00	£	-
								Props_Critical Nr/Km	0.00	F_Critical £/premises	£	200.00	£	-
								Props_Domestic Nr/Km	19.67	F_Domestic £/prop	£	150.00	£	0.64
						Loss of Gas m3	34	Carbon Loss of gas m3	0.01344972	F_Carbon £/tonne	£	59.00	£	0.07
										F_Loss of gas £/m3	£	0.22	£	0.02
						Water Ingress 0-1	0.03			F_Water Ingress £	£	156.00	£	0.01
						P_Gas Escapes 0-1	0.0125	Complaints 0-1	1.4	F-Complaint £/complaint	£	450.00	£	0.02
										F_TMA_Order £	£	60.00	£	0.15
										F_Repair £/repair	£	2,255.06	£	5.47

Figure B- 5 - Modelled consequences and values for Services Corrosion failure

Further consequences arising from a corrosion failure are calculated in a similar way e.g.

- Supply interruptions
- Loss of gas
- Water ingress
- Customer complaints

B3.4.6 General Emissions Consequences of Failure

For an emissions failure a simplified approach is adopted. The volume (m3) per year is simply multiplied by the carbon value of the gas lost through emissions. This is then added to the retail value of the lost gas to give the monetised risk value for the General Emissions Failure Mode.

General Emissions m3/S/Yr	2.917754557	Carbon Loss of gas m3	0.01344972	F_Carbon £/tonne	£	59.00	£	2.32
				F_Loss of gas £/m3	£	0.22	£	0.64

Figure B- 6 - Modelled consequences and values for Services General Emissions failure

B3.5. Service Intervention Definitions

Intervention activities can be flexibly defined within the NOMs methodology by modelling the change in risk enabled by the intervention activity.

Some interventions, such as replacing non-PE services with PE, will reduce both the Probability of Failure and deterioration of the overall asset base, thus changing the monetised risk value over the life of the asset. This is called a **With Investment** activity below.

Other types of intervention may just represent the base costs of maintaining the asset at an acceptable level of performance (i.e. to counteract deterioration or where the consequences of failure are unacceptably high). This is called a **Without Investment** activity below.

Definitions of activities undertaken as part of normal maintenance (i.e. 'without intervention') and interventions for Services are listed below.

'Without intervention' activities:

- ECV replacement
- Service valve replacement

'With intervention' activities:

Number	Description	Definition
Intervention 1	Service relays	Replace non PE service with PE service
Intervention 2	Bulk service replacements	Bulk replacement of services with PE
Intervention 3	Alteration	Customer driven service/meter move Associated with extensions and property development.
Intervention 4	Decommission	Decommission/abandonment of services

Table B- 4 - Potential With- and Without Investment interventions for Services

B3.5.1 Services Intervention Benefits

The major benefits of replacing metallic services with polyethylene (PE) have been assessed to be:

- A reduction in the rate of Joint, Fracture and Corrosion failure
- A reduction in the rate of deterioration of Joint, Fracture and Corrosion failure

Given no specific information, the rate of failure of new PE service pipes was assumed to be equal to the rate of failure of new PE mains (based on historic NGN failure records) – converted to Nr/service/yr rate.

The deterioration rate of the new PE following replacement will be very low, but non-zero. This was assumed to be the same as for PE mains (0.5% per annum). Example values used to model post-intervention PoF and deterioration (by Failure Mode) are presented below:

Failure mode	PoF (new PE service)* (Nr/Service/year)	PoF deterioration (new PE service) (per annum)
Joint	0.0003978	0.5%
Corrosion	0.00007327	0.5%
Fracture	0.000014943	0.5%

Table B- 5 - PoF and PoF deterioration for new PE Services

*Assumes an average service pipe length of 17 metres

B3.5.2 Example Services Interventions

To plan a service intervention both the Domestic/Non-domestic attribute and the pipe material of the service (PE or Non-PE) must be stated. For Domestic services materials are stated simply as PE or Non-PE as actual non-PE materials are not currently known. The PE/non-PE split is currently based on global proportions but can be made (mains) pipe specific simply by changing the number of connected PE/non-PE services in the base data.

The calculations follow exactly the same workings as the detailed worked example provided in the main body of the report (for Mains) and are not reproduced here. Two examples of service pipe replacements for Domestic and Non-domestic services supplied from DI mains are included below.

Example 1 – 1000 replacements per annum of non-PE Domestic services

			Year0	Year1	Year2	Year3	Year4	Year5	Year6	Year7	Year8
Cohort Name	Intervention Plan	Intervention Description	Initial Number of Services	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention
CI / NON DOMESTIC			315								
DI / NON DOMESTIC			444								
NONPE / DOMESTIC			2267465	1000	1000	1000	1000	1000	1000	1000	1000
PE / DOMESTIC			2306729								
PE / NON DOMESTIC			31633								
SI / NON DOMESTIC			323								
ST / NON DOMESTIC			4944								
UNKN / NON DOMESTIC			3								

Figure B- 7- Intervention definition in monetised risk trading tool. Intervention is to replace a Non-PE service with PE.

The pre- and post-intervention rules that have been developed to model replacement of non-PE Domestic services with PE Domestic services are shown in the table below.

BaseLine		
Node	**Rule**	**Test Value**
Capacity Nr/S/Yr	0.0004/76.6*Cohort_Length*1000	0.00009
Corrosion Nr/S/Yr	Scalar_Corrosion*Scalar_Unmatched*((Corrosion_Non_PE*exp(Dyear*Non_PE_Det))+(Corrosion_PE*exp(Dyear*PE_Det)))	0.00176
Fracture Nr/S/Yr	Scalar_Fracture*Scalar_Unmatched*((Fracture_Non_PE*exp(Dyear*Non_PE_Det))+(Fracture_PE*exp(Dyear*PE_Det)))	0.00001
General Emissions m3/S/Yr	Leakage_Rate*(1+(Dyear/100))	3.09459
Interference Nr/S/Yr	Scalar_Interference*Scalar_Unmatched*((Interference_Non_PE)+(Interference_PE))	0.00074
Joint Nr/S/Yr	Scalar_Joints*Scalar_Unmatched*((Failure_Non_PE)*exp(Dyear*Non_PE_Det))+((Failure_PE)*exp(Dyear*PE_Det))	0.00381

Intervention 1		
Node	**Rule**	**Test Value**
Capacity Nr/S/Yr	0	0.00000
Corrosion Nr/S/Yr	Scalar_Corrosion*Scalar_Unmatched*(((Corrosion_New_Pipe*Cohort_Length*1000)*exp(Dyear*PE_Det)))	0.00009
Fracture Nr/S/Yr	Scalar_Fracture*Scalar_Unmatched*(((Fracture_New_Pipe*Cohort_Length*1000)*exp(Dyear*PE_Det)))	0.00002
General Emissions m3/S/Yr	0	0.00000
Interference Nr/S/Yr	Scalar_Interference*Scalar_Unmatched*((Interference_Non_PE)+(Interference_PE))	0.00074
Joint Nr/S/Yr	Scalar_Joints*Scalar_Unmatched*(((Joint_New_Pipe*Cohort_Length*1000)*exp(Dyear*PE_Det)))	0.00046
Cost Per Service	Cost_Uplift*if(Customer_Type="DOMESTIC",439.34,731.8)	659.010

Table B- 6 - Example pre and post intervention rules for the above services replacement intervention (non-PE Services with PE)

This illustrates that the replacement of an individual Domestic, non-PE service with PE reduces (for example) corrosion failure from a rate of 0.00176 failures/service/year to 0.00009 failures/service/year for a cost of £659 per Service in the year of intervention.

Appling these rules and modelling the costs and benefits over a 45 year period delivers the following risk reduction profile. A cumulative monetised risk reduction of £705,017 has been delivered over 8 years. By 45 years this cumulative risk reduction benefit has risen to £8.67 million for an initial £4.69 million (discounted) investment.

New Services	Investment	Disscounted Investment
1000	£659,010.00	£ 659,010.00
1000	£659,010.00	£ 636,724.64
1000	£659,010.00	£ 615,192.89
1000	£659,010.00	£ 594,389.26
1000	£659,010.00	£ 574,289.14
1000	£659,010.00	£ 554,868.74
1000	£659,010.00	£ 536,105.06
1000	£659,010.00	£ 517,975.90

Initial Investment £4.69m

Year	BaseLine	Intervention	Change in Risk Value due to intervention	Discounted change in Risk Value due to intervention	Cumulative change in Risk Value due to intervention
0	£ 49,141,757.58	£ 49,141,757.58	£ -	£ -	£ -
1	£ 50,984,365.49	£ 50,965,056.80	£ 19,308.69	£ 18,655.74	£ 18,655.74
2	£ 52,917,224.09	£ 52,876,847.68	£ 40,376.41	£ 37,691.81	£ 56,347.55
3	£ 54,944,923.62	£ 54,881,594.23	£ 63,329.39	£ 57,119.48	£ 113,467.03
4	£ 57,072,290.45	£ 56,983,988.19	£ 88,302.26	£ 76,950.32	£ 190,417.35
5	£ 59,304,399.10	£ 59,188,960.39	£ 115,438.71	£ 97,196.30	£ 287,613.65
6	£ 61,646,585.20	£ 61,501,693.19	£ 144,892.01	£ 117,869.74	£ 405,483.39
7	£ 64,104,458.73	£ 63,927,633.00	£ 176,825.73	£ 138,983.43	£ 544,466.81
8	£ 66,683,918.34	£ 66,472,504.13	£ 211,414.21	£ 160,550.39	£ 705,017.21
45	£ 364,878,079.95	£ 363,567,531.29	£ 1,310,548.66	£ 278,700.28	£ 8,671,573.28

Table B- 7 - Discounted costs and benefits of 1000 service per annum Domestic service replacement programme

Example 2 – 50 replacements per annum of Ductile Iron (non-PE) Non-domestic services

Cohort Name	Intervention Plan	Intervention Description	Year0 Initial Number of Services	Year1 Proposed Intervention	Year2 Proposed Intervention	Year3 Proposed Intervention	Year4 Proposed Intervention	Year5 Proposed Intervention	Year6 Proposed Intervention	Year7 Proposed Intervention	Year8 Proposed Intervention
CI / NON DOMESTIC			315								
DI / NON DOMESTIC			444	50	50	50	50	50	50	50	50
NONPE / DOMESTIC			2267465								
PE / DOMESTIC			2306729								
PE / NON DOMESTIC			31633								
SI / NON DOMESTIC			323								
ST / NON DOMESTIC			4944								
UNKN / NON DOMESTIC			3								

Table B- 8 - Intervention definition in monetised risk trading tool. Intervention is to replace a DI service with PE.

The pre- and post-intervention rules that have been developed to model replacement of non-PE Non-domestic services with PE Non-domestic services are shown below.

BaseLine		
Node	**Rule**	**Test Value**
Capacity Nr/S/Yr	0.0004/76.6*Cohort_Length*1000	0.00018
Corrosion Nr/S/Yr	Scalar_Corrosion*Scalar_Unmatched*((Corrosion_Non_PE*exp(Dyear*Non_PE_Det))+(Corrosion_PE*exp(Dyear*PE_Det)))	0.00430
Fracture Nr/S/Yr	Scalar_Fracture*Scalar_Unmatched*((Fracture_Non_PE*exp(Dyear*Non_PE_Det))+(Fracture_PE*exp(Dyear*PE_Det)))	0.00064
General Emissions m3/S/Yr	Leakage_Rate*(1+(Dyear/100))	22.81234
Interference Nr/S/Yr	Scalar_Interference*Scalar_Unmatched*((Interference_Non_PE)+(Interference_PE))	0.00030
Joint Nr/S/Yr	Scalar_Joints*Scalar_Unmatched*((Failure_Non_PE)*exp(Dyear*Non_PE_Det))+((Failure_PE)*exp(Dyear*PE_Det))	0.00429

Intervention 1		
Node	**Rule**	**Test Value**
Capacity Nr/S/Yr	0	0.00000
Corrosion Nr/S/Yr	Scalar_Corrosion*Scalar_Unmatched*(((Corrosion_New_Pipe*Cohort_Length*1000)*exp(Dyear*PE_Det)))	0.00017
Fracture Nr/S/Yr	Scalar_Fracture*Scalar_Unmatched*(((Fracture_New_Pipe*Cohort_Length*1000)*exp(Dyear*PE_Det)))	0.00004
General Emissions m3/S/Yr	0	0.00000
Interference Nr/S/Yr	Scalar_Interference*Scalar_Unmatched*((Interference_Non_PE)+(Interference_PE))	0.00030
Joint Nr/S/Yr	Scalar_Joints*Scalar_Unmatched*(((Joint_New_Pipe*Cohort_Length*1000)*exp(Dyear*PE_Det)))	0.00092
Cost Per Service	Cost_Uplift*if(Customer_Type="DOMESTIC",439.34,731.8)	1097.700

Table B- 9 - Example pre and post intervention rules for the Non-domestic replacement intervention (DI with PE).

This illustrates that the replacement of an individual Non-domestic, non-PE service with PE reduces (for example) corrosion failure from a rate of 0.004 failures/service/year to 0.0002 failures/service/year for a cost of £1,098 per Service in the year of intervention.

Appling these rules and modelling the costs and benefits over a 45 year period delivers the following risk reduction profile. A cumulative monetised risk reduction of £51,189 has been delivered over 8 years. By 45 years this cumulative risk reduction benefit has risen to £594,893 for an initial £390,481 (discounted) investment.

New Services	Investment	Discounted Investment
50	£54,885.00	£ 54,885.00
50	£54,885.00	£ 53,028.99
50	£54,885.00	£ 51,235.73
50	£54,885.00	£ 49,503.13
50	£54,885.00	£ 47,829.11
50	£54,885.00	£ 46,211.70
50	£54,885.00	£ 44,648.98
50	£54,885.00	£ 43,139.11

Initial Investment £390,481

Year	BaseLine	Intervention	Change in Risk Value due to intervention	Discounted change in Risk Value due to intervention	Cumulative change in Risk Value due to intervention
0	£ 49,141,757.58	£ 49,141,757.58	£ -	£ -	£ -
1	£ 50,984,365.49	£ 50,982,876.85	£ 1,488.64	£ 1,438.30	£ 1,438.30
2	£ 52,917,224.09	£ 52,914,149.98	£ 3,074.11	£ 2,869.71	£ 4,308.01
3	£ 54,944,923.62	£ 54,940,162.68	£ 4,760.94	£ 4,294.10	£ 8,602.11
4	£ 57,072,290.45	£ 57,065,736.53	£ 6,553.92	£ 5,711.36	£ 14,313.47
5	£ 59,304,399.10	£ 59,295,941.06	£ 8,458.04	£ 7,121.44	£ 21,434.91
6	£ 61,646,585.20	£ 61,636,106.52	£ 10,478.68	£ 8,524.41	£ 29,959.33
7	£ 64,104,458.73	£ 64,091,837.29	£ 12,621.44	£ 9,920.34	£ 39,879.67
8	£ 66,683,918.34	£ 66,669,026.03	£ 14,892.31	£ 11,309.39	£ 51,189.06
45	£ 364,878,079.95	£ 364,793,402.41	£ 84,677.54	£ 18,007.46	£ 594,893.47

Table B- 10 - Discounted costs and benefits of 50 service per annum Non-domestic service replacement programme

Appendix C – Governors

C1. Governors Definition

A Governor is a Pressure Reduction Unit which has an inlet pressure less than 7 Bar.

C1.1. District Governors

A pressure regulating installation operating with inlet pressures below 7bar and supplying an intermediate, medium or low-pressure system.

C1.2. I&C Governors

A pressure regulating installation operating with an inlet pressure below 7bar and supplying large individual non-domestic customers

C1.3. Service Governors

A pressure regulating installation with inlet pressures above 75mbar and up to 7bar supplying domestic or smaller commercial and industrial customers

C1.4. Civils

Civils assets, which include: inner/outer fencing; security systems; roadways; drainage; bunds/berms; ductwork; and buildings, are not treated as separate assets in the event tree. Kiosks and Fencing are treated as attributes of the Governor which impact on the Corrosion and Interference Failure risk nodes. Other asset maintenance costs are considered to be included in General Maintenance risk node. Costs to ensure site compliance with safety or legislative requirements are included in the Compliance risk node.

C1.5. Electrical & Telecommunication

A telemetry system (profiling / closed loop control), including electrical, instrumentation systems and data logging, which controls and/or monitors a Governor installation. These costs are captured within the Control System risk nodes.

C2. Governors Event Tree Development

C2.1. Governors Failure Modes

Failure Modes have been identified for Governors consistently with the process outlined in section 3.4 of the main methodology. The same failure modes are used for all Governor Types, however, the probability of failure (failure rates) will be different. Failure modes were identified through a number of workshops with asset experts and through careful analysis of available data held by companies to assess and quantify the rate of failures and future asset deterioration. The failure modes for Governors include:

- **Capacity failure** – where the Governor is under-sized to meet downstream demand
- **Failure closed** – where a regulator fault has been assessed to result in a fail in the closed mode
- **Failure open** - where a regulator fault has been assessed to result in a fail in the open mode
- **Interference failure** – for example 3rd party damage

- **Corrosion failure** – corrosion of the internal pipework. Corrosion of components assessed to result in a Failure Open or Failure Closed are considered within these risk nodes
- **Governor emissions** – background leakage or shrinkage from the Governor
- **Control System failure** – failure of the telemetry or associated electrical/instrumentation systems and profilers

C2.2. Governors Consequence Measures

Consequence measures have been identified for Governors consistently with process identified in section 3.5 of the main methodology and include the following:

- **Governor gas escape -** – that could result in increased PRE's, a carbon loss of gas and/or an explosion
- **Loss of control** – this results in a sub-optimum pressure leaving the station, but is not severe enough to result in a supply interruption
- **Loss of gas** – arising from the Governor station itself or the downstream network (e.g. as a result of poor control)
- **Over-pressurisation -** this could result in supply interruptions and/or explosions
- **Supply interruption** (SI) – to customers in the network downstream of the Governor station
- **Explosion** – either at the Governor itself or in the downstream network

Consequences values are dependent on the consequences being assessed. Some of these consequences are clearly inter-related, as detailed in the risk map.

C2.3. Governors Risk Map

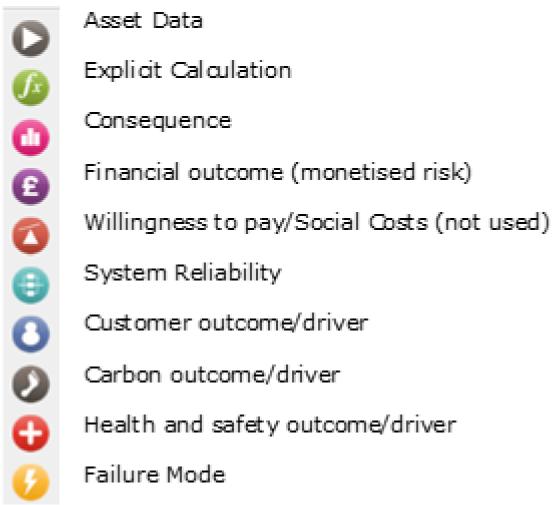


Figure C- 8 - Risk Map Key

Figure C-1 outlines the risk map key for Governors. The risk map is colour coded for each node of the event tree to indicate which values are associated with each node. The colours are reflected in both the risk map and risk map template in Figures C2 and C3.

As per the process described within Section 3.6 of the main methodology, the risk map for Governors is shown below:

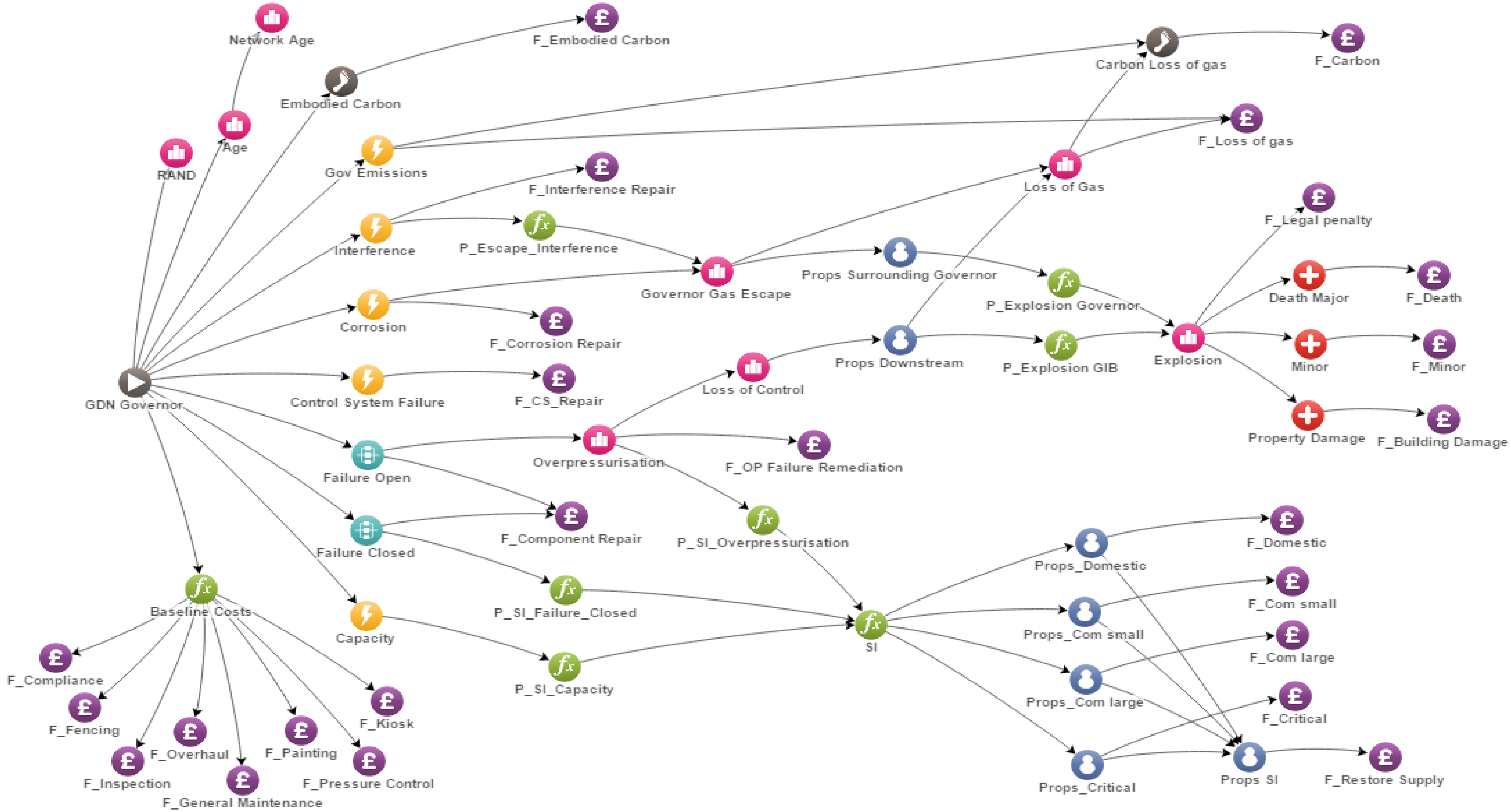


Figure C- 9 -Governors Risk Map

C2.4. Governors Risk Template

The following table demonstrates how the total risk value is derived for any given Governor cohort. An individual, populated risk map is developed for every cohort to be modelled to deliver a baseline monetised risk value prior to intervention modelling.

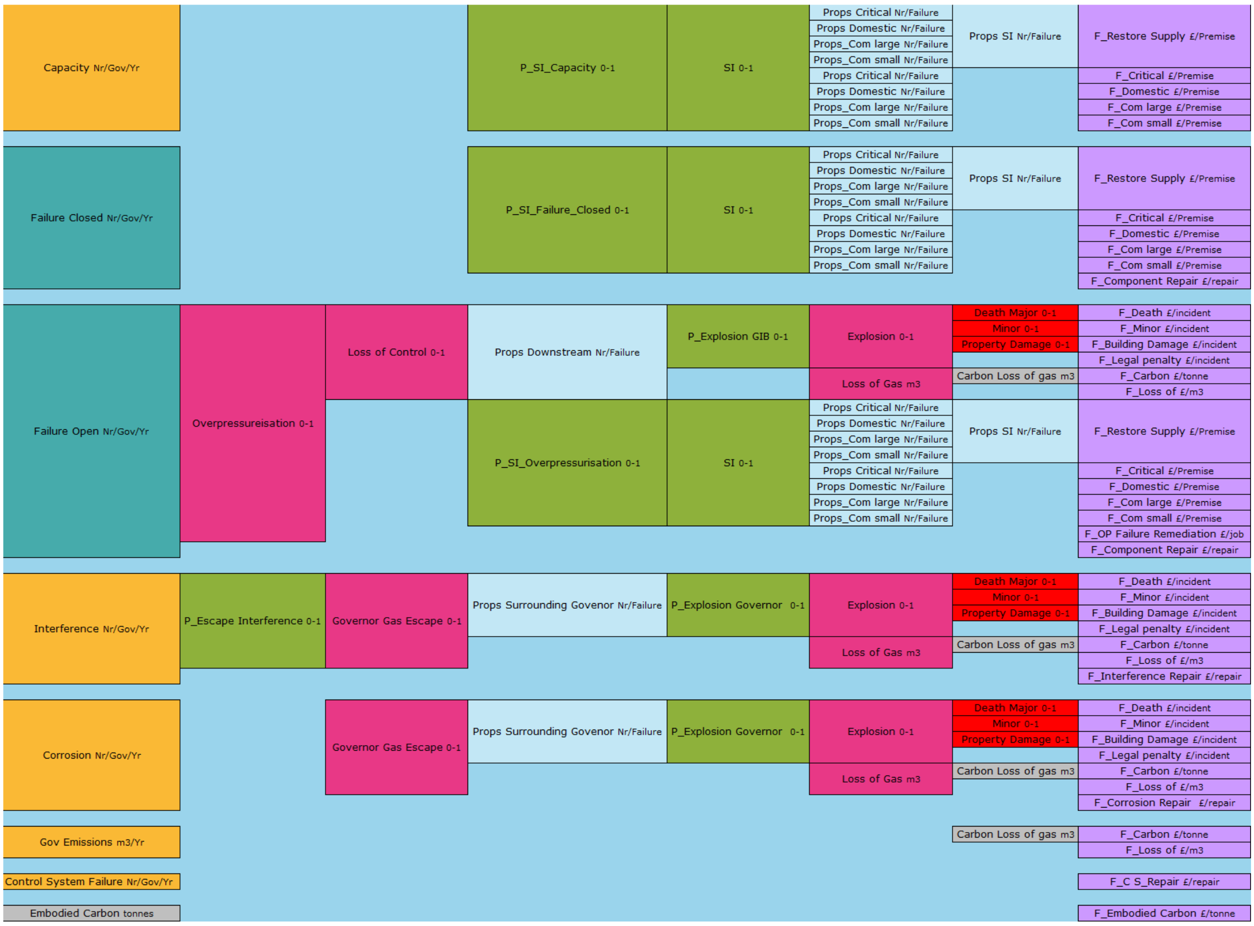


Figure B- 10 - Governors Risk Map Template

C2.5. Governors Data Reference Library

In line with section 3.7 of the main report, the following table provides a brief description of the risk nodes modelled in the Event Tree, the source of the data and/or a high level description as to how the values were derived and a flag to indicate whether the data will be provided individually by each GDN or through common/shared analysis:

Node ID / Variable	Description	Data Source	Source
Age	Age of asset	Calculated using asset specific age. Currently estimated using regulator model definition where actual age is not available.	GDN Specific
Capacity	Flag to define whether a Governor station has a known capacity issue. **P_SI_Capacity** is the probability of a supply interruption given a capacity exceedance event.	Binary value used at asset level where known capacity issues using off-line sizing/capacity analysis. Capacity issues flagged in data with a 'Y'	GDN Specific
Carbon Loss of gas	m^3 of carbon equivalent (CO_2e) arising from loss of gas or general emissions	Carbon Loss of Gas = relative density x carbon equivalent. Value calculated by each GDN based on actual gas composition in the network	GDN Specific
Control System Failure	Frequency of failure of the control system (controller or communications) leading to sub-optimum pressures leaving the Governor station	Data taken from company systems where available or a default value applied (agreed with SRWG)	GDN Specific
Corrosion	Frequency of corrosion failures associated with pipework at the Governor station. All other corrosion failures are considered as part of other failure modes (e.g. Fail Open/Closed)	From company RCM fault records and/or job management systems. The probability of a corrosion failure is factored by the presence and condition of housing (kiosk). The starting point on the deterioration curve is estimated using the Effective Age of the asset, which can be determined through condition surveys.	GDN Specific
Death Major	Probability of death following an explosion. This includes explosions at, or downstream of, the Governor station.	Value based on research values (Newcastle University)	Common
Explosion	Number of explosions following gas ingress into a building and/or loss of gas at a Governor site.	Calculated from loss of gas frequency and assumed ignition probabilities (DNVGL Value agreed with SRWG).	Common
F_CS_Repair	Unit cost of repair/maintenance to a control system. Increase in costs incurred where obsolete.	Data taken from company systems.	GDN Specific
F_Compliance	Financial cost of achieving compliance with HSE and other legislative requirements (e.g. DSEAR; PSSR Inspections, working at height)	Data taken from company systems.	GDN Specific
F_Component Repair	Unit cost of reactive maintenance (repair or replacement) of Governor components in response to identified Failure Open or Failure Close faults. Increase in costs incurred where obsolete.	Data taken from company systems.	GDN Specific

F_Corrosion Repair	Unit cost of reactively resolving identified corrosion issues at Governor sites (e.g. painting)	Data taken from company systems.	GDN Specific
F_Fencing	Financial costs of fencing maintenance where associated with Governor stations.	Data taken from company systems.	GDN Specific
F_General Maintenance	Financial cost of general maintenance activities associated with Governor station where not included in other financial risk nodes (e.g. site husbandry; general repairs)	Data taken from company systems.	GDN Specific
F_Inspection	Financial costs of time-based Reliability Centred Maintenance (RCM) activities associated with District Governor stations. Includes maintenance activities carried out as part of RCM inspections.	Data taken from company systems.	GDN Specific
F_Interference Repair	Financial costs of remedial actions associated with failures arising due to interference (contractor or 3rd party). Increase in costs incurred where obsolete.	Data taken from company systems.	GDN Specific
F_Kiosk	Financial cost of kiosk maintenance where associated with Governor station.	Data taken from company systems.	GDN Specific
F_OP Failure Remediation	Financial cost of resolving over-pressurisation failures, including inspections and network repairs	Data taken from company systems.	GDN Specific
F_Overhaul	Financial cost of reactive Regulator overhauls	Data taken from company systems.	GDN Specific
F_Painting	Financial costs associated with proactive painting of Governor stations.	Data taken from company systems.	GDN Specific
F_Pressure Control	Financial cost associated with maintaining pressure control systems, including batteries. controllers and data loggers.	Data taken from company systems.	GDN Specific
F_Restore Supply	Financial cost of restoring supply to downstream properties following a supply interruption	Data taken from company systems.	GDN Specific
Failure Closed	Probability of a fault which may give rise to a station Failure Closed event. **P_SI_Failure_Closed** is the probability of a supply interruption given a Failure Closed event. (factored by obsolescence)	Calculated using actual fault data arising from RCM survey. RCM has assigned a consequence arising from an identified fault for each component within the Governor station. Fail Closed consequences for each component asset were combined to derive the overall probability of a Failure Closed event for the Governor station. Redundancy in the form of multiple streams and/or Monitor/Active configurations was considered as part of this combination process. See Section 3.2.1. for more details. The probability of failure is factored by the location, distance to coast and flood risk. The starting point on the deterioration curve is estimated using the Effective Age of the asset, which can be determined through condition surveys.	GDN Specific

		The probability of a supply interruption given a Failure Closed event is based on SRWG estimates and calibrated to the expected numbers of annual failures.	
Failure Open	Probability of a fault which may give rise to a station Failure Open event.	Calculated using actual fault data arising from RCM survey. RCM has assigned a consequence arising from an identified fault for each component within the Governor station. Fail Open consequences for each component asset were combined to derive the overall probability of a Failure Open event for the Governor station. Redundancy in the form of multiple streams and/or Monitor/Active configurations was considered as part of this combination process. See Appendix C for more details. The probability of failure is factored by the location, distance to coast and flood risk. The starting point on the deterioration curve is estimated using the Effective Age of the asset, which can be determined through condition surveys.	GDN Specific
Gov Emissions	General emissions associated with the Governor station	Consistent with NLRMM leakage models	Common
Governor Gas Escape	The sum of modelled annual gas escapes arising from corrosion and interference failures.	Calculated from the modelled number of corrosion and interference failures.	GDN Specific
Interference	The sum of annual interference failures, arising from 3rd parties or contractors. **P_Escape_Interference** is the probability of a gas escape given an interference event.	Estimated based on historic company records. The probability of an interference failure is factored by the presence and condition of housing (kiosk) and/or fencing (including security rating/measures).	GDN Specific
Loss of Gas	The assumed volumetric loss of gas arising from a Governor gas escape.	A value of 166 m3 per failure was agreed with the SRWG based on Mains loss of gas estimates (assuming the majority of loss of gas will be from the Governor pipework).	Common
Loss of Control	A factor representing the benefit of a pressure control system on the downstream loss of gas and explosion risk.	A Loss of Control value of 0.5 represents 50% reduction in loss of gas if there is a control system present. If no control system the full loss of gas value applies (Loss of Control = 1).	Common
Minor	Probability of minor injury following an explosion. This includes explosions	Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common

	at, or downstream of, the Governor station.		
Network Age	Average age of Governor population	Calculation using individual Governor (Regulator) age values	GDN Specific
Overpressurisation	Frequency of an over-pressurisation event given a Failure Open. **P_SI_Overpressurisation** is the probability of a supply interruption given an Overpressurisation event (factored by obsolescence)	Default/assumed values agreed with SRWG.	Common
Property Damage	Properties damaged given an explosion arising from a gas in building event and/or an explosion at the governor location	Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common
Props Downstream	Number of gas-in-building events downstream of a Governor station, due to increase in gas escapes from over pressurisation, based on number of properties downstream. **P_Explosion_GIB** s the probability of an explosion arising from a gas in building event.	For property numbers, data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy. The probability values of an explosion given a gas in building will be consistent with the Mains & Services models.	GDN Specific
Props SI	Number of properties requiring supply restoration support following a supply interruption. **SI** is the sum of all modelled supply interruption events.	Value of 1 used as a multiplier to enable the grouping/summation of props_domestic, props_com small, props_com large and props_critical	GDN Specific
Props Surrounding Governor	Number of properties surrounding a Governor station which are at risk of damage by explosion of the station itself following a loss of gas. **P_Explosion_Governor** is the probability of an explosion in a property surrounding the Governor given a corrosion or interference event.	Defined as Properties within 50 metres of the governor station. Derived from GIS analysis or other company records where available. Includes the Governor itself. The probability of explosion given a loss of gas at a Governor is based on SRWG estimates.	GDN Specific
Props_Com large	Number of large commercial properties affected by supply interruption (C3 and C4 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Com small	Number of small commercial properties affected by supply interruption (C1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Critical	Number of critical properties affected by supply interruption (C2 and I2 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Domestic	Number of critical properties affected by supply interruption (D1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific

C3. Governors Event Tree Utilisation

C3.1. Governors Base Data

The Governors base data will be created from company asset databases, financial systems, Reliability Centred Maintenance (RCM) reports and other data sources. Where available, condition assessment, of Governor assets and ancillaries (such as kiosks and fencing) can be used to improve the starting failure rate assessments.

The analysis assumes that the Governor station itself, not the component assets (such as slam-shuts, regulators and auxiliary control) form the unit of risk assessment and intervention planning. Where possible, the individual probabilities of failure of components assets are combined to calculate the overall station probability of failure using the site configuration details. This is explained in more detail in Section C3.2.

A further important input is an understanding of the downstream consequences of failure, for example which properties experience a supply interruption following an over-pressurisation event. This information can be derived from network modelling or approximated using GIS analysis.

An example of data input format is shown in Table C1 below:

ICS_GOVERNOR_ID	SERVICE_TYPE	RCM_REVIEW_NO	CITY	MAKE	GOVERNOR	CONFIGURATION	OBSOLETE_YR	AGE	HOUSING
DB5646F0E7334D9A95B27386BDD1AB00	COMMERCIAL_CRITICAL	M126	KENDAL	DONKIN	270	2ASWd	2025	35	K
11986C5F497C48F79CD90F8035205C66	COMMERCIAL_CRITICAL	M875	AINTREE	IGA	1800	2MASa	2025	35	K
0DD20DEAB91740DAAADBB02C98471FF7	COMMERCIAL_LARGE	M383	BARROW IN FURNESS	DONKIN	280	2ASa	2025	35	K
0763549D5926447F913F1DA8ABFC37B2	COMMERCIAL_LARGE	M865	HARROW	AXIAL FLOW	AXIAL FLOW	2ASa	2035	25	O
D88953BDEB354B3186285F13C8389AAC	COMMERCIAL_LARGE	M641	WARRINGTON	IGA	1843	2ASd	2025	35	U
A3B46B5B5E9A455787160F0CE8802964	COMMERCIAL_LARGE	M352	LIVERPOOL	IGA	3000	2ASWa	2025	35	K
80D074A244D44E309C2908448290FA66	COMMERCIAL_LARGE	M850	RICKMANSWORTH	DONKIN	280	2ASWa	2025	35	K
C726FC0E6882484284EDA14A34143C87	COMMERCIAL_LARGE	M126	DROITWICH	DONKIN	270	2ASWd	2025	35	K
891E036746E145648D93D5FEB6004D7F	DOMESTIC	M463	WARRINGTON	ERS	ERS	1ASWd	2045	15	P
7B0AA0A5A4B247DDA534D67DDA26DB70	DOMESTIC	M1173	GT. DODDINGTON	AXIAL FLOW	AXIAL FLOW	2ASa	2035	25	K
13BF005509AB4BCE9DFD5A8076E62454	DOMESTIC	M492	NORTHAMPTON	DONKIN	280	2ASa	2025	35	K
59116F1696F14232900450D750171E53	DOMESTIC	M1430	TAMWORTH	ORPHEUS 4	ORPHEUS 4	2ASa	2055	5	MODULE
A68B618C88B14E42A1E5F1771B008FF6	DOMESTIC	M1555	WEMBLEY	ORPHEUS 10	ORPHEUS 10	2ASa	2055	5	MODULE
03D043681EB84D9084AC7A5C1A320BEC	DOMESTIC	M417	STOCKPORT	IGA	3000	2ASd	2025	35	K

ICS_GOVERNOR_ID	PROPERTY_DENSITY	PROPS_GOV	GOV_DENSITY	STREAM	FO_M_WORKING	FO_A_WORKING	FO_S_WORKING	FO_W_WORKING	FO_A2_WORKING	FO_M_STANDBY
DB5646F0E7334D9A95B27386BDD1AB00	0.000361605	1	1	2	1	0.001257795	0.000261786	0.000102082	0	1
11986C5F497C48F79CD90F8035205C66	0.000773644	1	1	2	0.001988884	0.001257795	0.000261786	0	0.000262554	0.002319814
0DD20DEAB91740DAAADBB02C98471FF7	0.000364679	1	1	2	1	0.001257795	0.000261786	0	0.000262554	1
0763549D5926447F913F1DA8ABFC37B2	0.001997239	1	1	2	1	0.001257795	0.000261786	0	0.000262554	1
D88953BDEB354B3186285F13C8389AAC	0.000422886	1	1	2	1	0.001257795	0.000261786	0	0	1
A3B46B5B5E9A455787160F0CE8802964	0.000875896	1	1	2	1	0.001257795	0.000261786	0.000102082	0.000262554	1
80D074A244D44E309C2908448290FA66	0.000557438	1	1	2	1	0.001257795	0.000261786	0.000102082	0.000262554	1
C726FC0E6882484284EDA14A34143C87	0.000100276	1	1	2	1	0.001257795	0.000261786	0.000102082	0	1
891E036746E145648D93D5FEB6004D7F	0.000522969	1350	1	1	1	0.001257795	0.000261786	0.000102082	0	1
7B0AA0A5A4B247DDA534D67DDA26DB70	9.81197E-05	639	1	2	1	0.001257795	0.000261786	0	0.000262554	1
13BF005509AB4BCE9DFD5A8076E62454	0.00091258	1088	1	2	1	0.001257795	0.000261786	0	0.000262554	1
59116F1696F14232900450D750171E53	0.000292585	1087	1	2	1	0.001257795	0.000261786	0	0.000262554	1
A68B618C88B14E42A1E5F1771B008FF6	0.0018408	805	1	2	1	0.001257795	0.000261786	0	0.000262554	1
03D043681EB84D9084AC7A5C1A320BEC	0.001352053	5003	1	2	1	0.001257795	0.000261786	0	0	1

Table C1 - Example of the base data format for the Governor Risk models showing Governor level information

C3.2. Governors Probability of Failure Assessment

As maintainable assets (as opposed to Mains and Services which are generally classified as non-maintainable) with a high consequence of failure, significant investment is made to prevent Governor assets from failing. Therefore it would be expected that for the failure modes with highest consequences of failure the observed failure rates will be very low.

Two methods have been used to derive failure rates for the identified failure nodes (as per section 4.3. of the main document):

- **Failure Open & Failure Closed** – have been derived from assessments of RCM fault data, site location and Condition assessments where available (Option A)
- **Other Failure Modes** – have been derived from company failure records supplemented by expert judgement and calibrated to expected levels of failure (Option A or B)

These methods are described separately below:

C3.2.1. Failure Open and Failure Closed

An identical approach was taken for both Failure Open and Failure Closed risk nodes. A simplified diagram showing a typical two stream pressure reduction facility is shown below for the purposes of showing how individual component PoF estimates have been combined in order to derive an overall estimate of PoF for the Governor station:

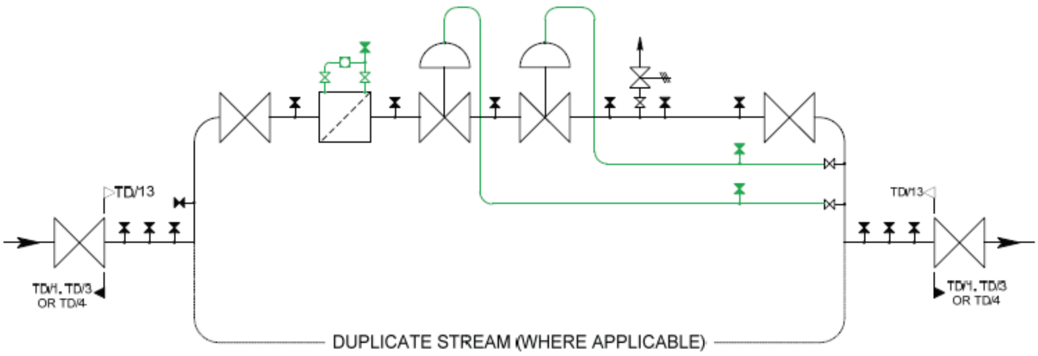


Figure C4 - Typical Monitor and Active Regulator arrangement (from IGEM TD/13)

Each Governor in the base data, whether District, Industrial/Commercial (I&C) or Service has an assigned configuration. For example in the Cadent Gas Ltd Governor database:

2MASWa = Twin (**2**) stream with **M**onitor regulator and **A**ctive regulator and **S**lam-shut valve and **W**afer check/NRV and **a**uxiliary* control

1ASd = Single (**1**) stream with **A**ctive regulator and **S**lam-shut valve and **d**irect-acting control

All other permutations of configuration can be identified using the combination of components described in the examples above. All assets subject to RCM inspections are assumed to have a filter fitted.

From RCM data collected over a number of years we can calculate the annual failure rate for each component. The RCM data collected includes (but is not limited to):

- The Active regulator on the Working stream

- The Monitor regulator on the Standby stream
- The Slam-shut valve on the Working stream

RCM fault data has been assessed to identify if the fault would have resulted in a Failure Open or Failure Closed event. This assessment is used to populate the PoF calculations.

It is noted that Failure Open/Closed is not an actual mode of failure (actually a consequence of failure) but this assumption provides a method to group several failure modes with multiple root causes, but shared failure consequences, together. For our analysis, as long as the failure consequence and cost of consequence is the same, this approach is valid. An example of this is the Corrosion failure mode. Where a site corrosion issue results in a Fail Open/Closed event it is classified as a Failure Open/Closed failure, otherwise it is treated as a separate Corrosion failure mode with different consequences (e.g. a loss of gas rather than a potential supply interruption).

Although RCM fault data may be available for individual regulator and slam-shut models this data may be sparse and can be combined. Where there is additional data available to support that specific models and/or stations have higher failure rates this can be incorporated directly into the base data.

To combine individual probability of failures we adopt a logical approach by which:

- If assets are in **series** (i.e. in a Governor stream), then the PoF values are **summed** (i.e. only one of the in-series assets needs to fail for the whole stream to fail)
- If assets are in **parallel** (i.e. in Governor streams) when the PoF values are **multiplied** (i.e. both streams need to fail in combination for the whole station to fail)

Where a station has more than two streams the third/fourth etc. streams are considered as additional Standby streams.

As a general rule for an *n*-stream Governor the following calculation is applied.

$$\textbf{POF (Station Failed Open/Closed) = POF (Working Failed Open/Closed) x [POF (Standby Failed Open/Closed)]}^{n}$$

These calculated failure rates for Failure Open and Failure Closed are applied to all Governor stations. Initially, failure rate vary only between stations only by configuration (as fault reports for individual regulator/slamshut models are combined due to low sample sizes). In general, single stream stations are more likely to fail than twin (or greater) stream stations which have greater in-built resilience. These initial configuration-based failure rates are then further adjusted using:

- Governor housing – e.g. kiosk, open air or below ground etc.
- Governor location – coastal or non-coastal
- Assessed Condition (or Effective Age) – from surveys

These factors are discussed further in section C3.2.2.

Where no RCM surveys are carried out (e.g. >2 bar governors and Service Governors) the site configuration and resulting Failure Open/Closed rates calculated from RCM data are inferred to assign an initial failure rate. These are then adjusted according to housing, location etc. where data exists.

Previous analysis has shown that not all faults will be identified through RCM inspections, therefore a reasonable approach is to apply a Fault Detection Factor, which is GDN specific

(40% as a default which is applied to factor the observed number of faults to the expected number of faults. It is assumed that all faults identified as having the potential to cause a Fail Open/Closed event will eventually result in actual Fail Open/Closed failures. The Fault Detection Rate will be reviewed by each GDN in line with RCM policies.

Fault Detection Rate = 1 / (0.4) = 2.5

C3.2.2. Other Failure Modes

The failure rate assessment methods for other failure modes in the Governors model are described briefly below. For each failure model, the actual number of faults/failures was extracted from company job management systems for a number of years (3.5 years in the case of the pilot data set) and divided by the total number of assets the specific fault could have occurred at over that period. This gave an annualised failure rate for each failure mode, which provided a starting point for deterioration analysis (where relevant):

Capacity

Capacity is modelled in the base data as a flag indicating that the Governor station (as a whole) has been identified as being under capacity. The investment required to address the capacity issue can then be modelled as a with-investment intervention. Identification of capacity issues at Governor stations is outside the scope of this methodology.

Corrosion

Corrosion failures on Governors specifically refer to the pipework systems, rather than corrosion of individual components (component corrosion is covered within RCM Fail Open/Close assessments). The corrosion failure rates can be derived from historic failure records. The average of the whole population of corrosion failures can then be factored for individual Governors using location and condition assessments of the rig (as per Failure Open/Closed) and additionally the condition of the kiosk/housing (again as per Failure Open/Closed).

Governor Emissions

Rates of emissions from Governors are derived from standard Governor shrinkage models (470 m^3/year for a District Governor; 8 m^3/year for an I&C or Service Governor). These are taken from NLRMM shrinkage assessments.

Interference

Interference frequencies at Governors leading to downstream consequences (ranging from a remediation cost to an actual escape of gas) are derived from historic company records. The average of the whole population of interference failures can then be factored (using a weighted average) for individual Governors using the condition of the fencing/security and those with known security issues.

Control System

Failure of any pressure control system (which could be due to electrical, instrumentation or communication issues) will result in sub-optimum control of pressures leaving the site. The rate of loss of control incidents can be inferred from historic company records. The proportional impact of the loss of the control system is modelled in the Loss of Control failure mode (below).

Loss of Control

As above, the failure of the pressure control system will result in sub-optimum control of pressures leaving the site. The model has been set up such that the maximum consequence value arising from a control system failure occurs when there is no control systems present (i.e. no fine-tuning of pressure leaving the site in response to downstream demand). If a control system is available, then the annual rate of instances resulting in a sub-optimal control of pressures is calculated as a proportion of control system unavailability. Therefore, the modelled Loss of Control value is always less than or equal to one, implying that having a control system available on site is always more beneficial that when no control system is present. For example:

- If no control system is present the Loss of Control value is 1 failure/year (i.e. has no control = always "failed")
- If a control system is present and "fails" at the assessed rate per year (see Control System failure mode) the value will be between zero and one (depending on the number of control systems present in the Governor cohort and the failure rate)

C3.2.3. Factors Applied to Initial Failure Rates

As briefly discussed above, initially derived failure rates are for the whole population of assets, with adjustments made to these assessed failure based on station configuration (or resilience) or at a site level (in the base data).

To recap, the Initial Failure Rate is calculated as follows:

Initial Failure Rate = Fault Detection Rate x Probability of a Failure event

Using the report 'Pressure Control and Storage Assets: Asset Health Model' (*Model Report 1569, SEAMS Ltd, November 2014*) and Part 2 of the previous methodology (*Manual for Assessing Health and Criticality of Gas Distribution Assets*) it is possible to factor these assessed failure rates based on Governor location, flood and condition risk (effective age). The Report 1569 factors are derived from elicitation exercises involving asset experts to estimate the remaining lives of various assets under specified conditions. The derived factors are each discussed below:

Location Risk (Location Factor)

Report 1569 explored how the Governor housing and its geographical location could potentially impact the remaining life of the asset. The factors explored were:

- Coastal or non-coastal
- Installed above- or below-ground
- If below-ground, then:
    - Installed in a pit (chamber)
    - Other below ground (e.g. cellar / basement)

These were combined in various ways and used to elicit the expected life time remaining per asset cohort. The questions were posed in terms of "50%/75%/90% of the assets of this type will have gone (failed) by the time they reach Age x". The derived values were then fitted to a Weibull curve. The Weibull shape and scales values (taken from Report 1569) and the derived PoF multiplication factors are shown in Table C2 below:

Category	Type	Weibull Shape (λ)	Weibull Scale (k)	Location Factor
Coastal	Coastal	2.960909	33.95314	1.667
Below ground (pit)	Housing	2.960909	22.63543	2.5
Above ground (non-coastal)	Housing	2.960909	56.58856	1

Table C2 - Weibull coefficients and derived initial probability of failure scaling factors for Governor location and housing

The Governor housing and locations were taken from the Governor asset database and the relevant PoF factors were applied to the cohort and configuration-derived failure rates, as calculated in C3.2.1.

The distance from the coast at which the coastal factor applies was not documented in Report 1569. This can be applied flexibly in the analysis using a 'Distance to Coast' attribute in the base data. A value of 3km has been applied initially.

Note, where a Governor is Coastal and Below ground (pit) a factor of (2.5 x 1.667 = 4.168) applies to the derived failure rate.

Condition Risk (Effective Age)

The assessed failure rate for each Governor is initially an average value for the whole population, adjusted by individual site configurations. For example, sites with more resilience, multiple streams or Monitor/Active regulators, will have lower probability of failure due to this resilience. There was insufficient RCM fault data to break down the analysis further by regulator/slam-shut manufacturers/models etc. To allow this average failure rate to be adjusted, based on assessed condition, a concept of Effective Age was introduced. Effective Age is the modified age of the asset according to its assessed condition (including the housing/kiosk) which can be greater or less than its actual age (based on date installed).

This concept is illustrated in Figure C5 below:

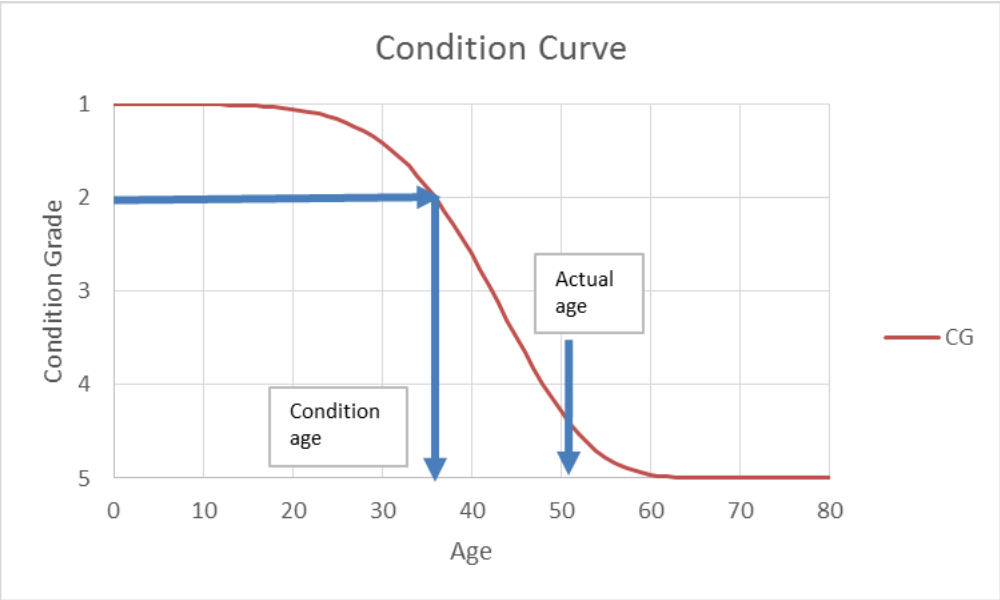


Figure C5 – Derivation of Effective Age from assessed Condition Grades

The assessed condition is determined via GDN-specific visual condition surveys, where available, aligned to common condition grades 1 to 5 as follows:

Condition Grade	Description	Factor (c)
1	As new, no corrosion	0.005
2	Superficial corrosion to asset	0.1
3	Minor corrosion to asset	0.25
4	Moderate corrosion to asset (intervention considered).	0.4
5	Severe corrosion to asset (intervention required)	0.75

Table C3 – c Factors applied in Effective Age assessment

The age of an individual governor or the mean age of a governor cohort is calculated and an initial default Condition Grade 2 is applied. To determine the Effective Age, the actual condition grade is used to adjust the Age to an Effective Age using the equation below.

$$Effective\ Age = Mean\ Age \times ((k \times (-\ln(1-c))^{1/\lambda})/((k \times (-\ln(0.9))^{1/\lambda})$$

NB**:** Where there are multiple components/sub-assets, the worst-case condition applies.

Housing Risk (Housing Factor)

The assessed condition of the building/housing is used as an adjustment factor, where applicable. The derived PoF multiplication factors are shown in the table below:

Condition Grade	Description	Housing Factor
1	As new	0.5
2	minor cosmetic damage to housing	0.8
3	some damage to housing (assessment/monitoring required)	1
4	considerable damage to housing (intervention considered).	1.5
5	severe damage to housing (intervention required)	2

Table C4 – Factors applied to PoF based on assessed Housing Condition Grade

Fencing/Security Risk (FS Factor)

The assessed condition of the fencing and security is used as an adjustment factor, where applicable. The derived PoF multiplication factors are shown in the table below:

Condition Grade	Description	FS Factor
1	As new, no issues	0.5
2	minor cosmetic damage to fencing, no security issues	0.8
3	Low security concerns/issues, some damage to fencing (assessment/monitoring required).	1
4	Medium security concerns/issues, considerable damage to fencing (intervention considered).	1.5
5	High security concerns/issues, severe damage to fencing (intervention required).	2

Table C5 – Factors applied to PoF based on assessed Fencing/Security Condition Grade

NB**:** Where there are multiple components/sub-assets, the worst-case condition applies.

Flood Risk (Flood Factor)

In a 2009 Environment Agency report titled "Flooding in England – a national assessment of flood risk", the EA identified that some "28% of gas infrastructure assets were identified as being at significant risk of flooding".

As part of the EA's approach to managing flood risk they provide mapping datasets for classifications/risk levels in relation to flooding as follows:

- Zone 3 (significant) – Land assessed, ignoring the presence of flood defences, as having a 1% or greater annual probability of fluvial flooding or a 0.5% or greater annual probability of tidal flooding.
- Zone 2 (moderate) – Land assessed, ignoring the presence of flood defences, as having between a 1% and 0.1% annual probability of fluvial flooding or between a 0.5% and 0.1% annual probability of tidal flooding.
- Zone 1 (low risk) – Less than 0.1% probability.

For the purposes of the methodology, the following flood risk factors apply:

Zone	Flood Factor
1	1.0
2	1.5
3	2

Table C6 – Factors applied to PoF based on assessed Flood risk factor according to Zone

Please note, if sufficient flood protection or defences are in place, ensuring the asset is fully protected from flooding, then a Zone 1 factor applies.

Final Adjustment Calculation

The calculation applied to the Initial Failure Rate, to include condition, flood and location adjustments, is as follows:

Fail Open/Closed (Nr/Gov/year) = Initial Failure Rate x (exp[(Effective Age – Mean Age) x Deterioration Rate]) x Housing Factor x FS Factor x Location Factor x Flood Factor

C3.3. Governors Deterioration Assessment

The impact of deterioration is applied to the following failure mode risk nodes in the Governors model:

Fail Open and Fail Closed

The fault rate analysis above was carried out using 3.5 year sample of RCM survey data from the pilot company. This was an insufficient time series of data to observe and measure and actual deterioration in the rates of fault occurring that would result in Fail Open or Fail Closed events (as also observed in Report 1569).

The Weibull curves presented in Section 5.2 of Report 1569 were used to derive a deterioration rate of 5% per annum. These Weibull curves were derived using elicitation workshops with asset experts as described above. It is possible that the deterioration rates assessed through this elicitation process may be sensitive to the actual questions posed to these experts. Revisiting this exercise in the future may prove valuable to provide further confidence in this deterioration assessment.

Corrosion

Corrosion deterioration was assumed to be 2% per annum through discussion with asset experts and using insight gained from the Mains corrosion deterioration analysis in Appendix A. The starting failure rate is adjusted using condition surveys as for Fail Open/Closed. Corrosion refers to the internal pipework within the Governor station, not the corrosion of component assets.

Emissions

No deterioration rate applies to General Emissions in the Governor model. This should be revisited as part of industry shrinkage assumptions.

Control System and Loss of Gas

Deterioration of the control system (telemetry and associated electrical and instrumentation assets) was assumed to be 10% per annum in line with current assessed replacement rates. This deterioration rate applies both to the costs of Control System maintenance (and the consequences arising from lack of maintenance) and to the Loss of Control risk node, which models the benefits of having a control system on the loss of gas due to sub-optimal downstream network pressures.

C3.4. Governors Consequence of Failure Assessment

There are several consequences of failure identified for the Governors Asset Group. These can be viewed in the risk maps and Data Reference Library in Section C2.5. For simplicity each Consequence of Failure for mains has been categorised as Internal Costs, Environmental, Health & Safety or Customer consequences. Examples of Governors consequence modelling are also illustrated. The data source and derivation for all Costs of Failure are explained in the Data Reference Library.

As maintainable assets it is important to consider the consequences of **obsolescence** within the Governors model (mains and services are replaced when deemed non-serviceable). As the probability of failure does not automatically increase when an asset becomes obsolete, we have adopted asset management best practice, as applied in other industries, which suggests that the **consequences of failure** (not the probability of failure) increase when an asset becomes obsolete. For example, that when an asset becomes obsolete the cost and/or time and/or impacts of failure are correspondingly greater when this asset is serviceable (e.g. spare parts are not readily available) which may impact on response time/cost and the potential length of any service outage. The magnitude of these obsolescence factors is estimated using expected values of failure consequence, derived through workshops with asset experts. As companies spend significant sums of proactive maintenance to avoid potentially catastrophic failures, the impact of obsolescence is a significant factor driving investment as would be expected.

C3.4.1. Internal Consequence Costs

Internal consequences refer both to the proactive costs of preventing failure (or maintaining the asset to an acceptable level or risk) and the reactive costs of responding to failure. Proactive consequences modelled include the costs of:

- **Painting** – to prevent corrosion of internal pipework
- **Housing** - to reduce corrosion and reduce the risk of interference damage
- **Fencing** – to reduce risk of interference damage (site security)
- **Inspections** – Reliability Centred Maintenance (RCM) activity to proactively identify and potentially undertake minor maintenance to remedy faults identified
- **Compliance** – costs of compliance with HSE and other legislative requirements (e.g. DSEAR; working at height; PSSR)
- **General Maintenance** – pre-emptive maintenance activity conducted outside of the RCM programme
- **Pressure Control** – maintenance of telemetry, electrical and instrumentation systems to optimise station pressure control

Reactive consequences modelled include the costs of responding to control system, corrosion, component and interference failures. The costs of repairing the downstream network and restoring supplies following a supply outage are also included.

C3.4.2. Environment Consequence Costs

Environmental consequences include the monetary value of product lost due to failures or leakage plus the shadow cost of carbon associated with failure or emissions. In particular, the shadow cost of carbon increases annually (and hence the consequence value increases) in line with government carbon valuation guidelines. Environmental consequences modelled include:

- **Carbon** – the external cost of carbon associated with general emissions and loss of gas following failures. The environmental costs of burnt and unburnt gas are treated separately
- **Loss of Gas** – the product value of the loss of gas due to failure and general emissions. These volumetric values are taken from standard industry models

C3.4.3. Health & Safety Consequence Costs

Health & Safety consequences are primarily associated with the damage caused by ignition following asset failure and subsequent entry into customer properties. The largest HSE consequence is associated with loss of life, but minor injury and property damage are also considered. The HSE consequences are similar to the Mains and Services models, but include potential injury and loss of life at the Governor station itself.

C3.4.4. Customer Consequence Costs

Customer consequences include compensation payments generated through loss of service caused by asset failure. These are categorised into Domestic, Commercial and Critical customers to account for the differences in the monetary value of these compensation payments.

The major (non-HSE) consequence of Governor failure is a supply interruption, which can be due to over- or under-pressurisation events. Over-pressurisation would typically arise from a total shut-down of the Governor station. Capacity, Fail Open and Fail Closed failure modes could potentially result in supply interruptions. The number of properties downstream of the Governor can be estimated using throughputs, GIS or (ideally) network modelling analysis. Large-scale supply interruptions are rare events and the consequence costs are estimated based on real experience and judgement.

C3.5. Governors Intervention Definitions

Intervention activities can be flexibly defined within the monetised risk trading methodology by modelling the change in risk enabled by the intervention activity.

Some interventions, such as replacing a regulator, will reduce both the Probability of Failure and deterioration of the overall asset base, thus changing the monetised risk value over the life of the asset. This is called a **With Intervention** activity below.

Other types of intervention may just represent the base costs of maintaining the asset at an acceptable level of performance, for example fencing maintenance or patch painting to arrest corrosion. This is called a **Without Intervention** action below.

Definitions of activities undertaken as part of normal maintenance (i.e. 'without intervention') and interventions for governors are listed below.

'Without intervention' activities:

- Kiosk maintenance

- Housing maintenance
- Civil / Security maintenance
- Patch paint
- VSO2 inspection
- PSSR Inspection
- Routine inspection
- Site husbandry

'With intervention' activities:

Number	Description	Definition
Intervention 1	Governor Replacement	Replacement of complete unit within kiosk including control system. Resets asset age to 0, failure rate then represents an initial failure rate on deterioration curve.
Intervention 2	Fencing	Includes installation or replacement of a fence and reduces the interference
Intervention 3	Kiosk replacement	Replacing the entire kiosk/housing of the governor
Intervention 4	Governor Refurbishment	Improving the governor condition by painting, reducing corrosion and overall deterioration
Intervention 5	Regulator Replacement	Refer to Intervention 1 (minus kiosk replacement)
Intervention 6	ERS Replacement	Replacement of underground module with an above ground governor
Intervention 7	Service Governor Replacement	Replacement of complete unit within kiosk
Intervention 8	Governor Removal	Used for Re-Base lining only
Intervention 9	KIOSK - Negative Intervention	Used for Re-Base lining only

Table C7 – Potential With- and Without Intervention investment options for Governors

C3.5.1. Governors Intervention Benefits

The risk modelling tools developed provide the ability to flexibly model any intervention by adjusting the values of the calculated risk nodes to match the expected performance of the asset following intervention. For example, painting of internal pipework will reduce the probability of a corrosion failure and potentially the deterioration of the rate of corrosion. This allows the new risk value to be calculated post-intervention and compared with the pre-intervention (do nothing) monetised risk.

Compared to Mains and Services, there are many alternative interventions possible at Governor stations. Because of the degree of resilience built into the assets and the high level of proactive maintenance activity and programmes of investment, failure rates are generally low.

The developed models allow "negative" interventions to be modelled to test the benefits of existing (and ongoing) proactive maintenance work. For example the benefit of Fencing and Housing maintenance programmes can be tested by removing these costs from the programme (and thereby reducing the baseline level of monetised risk). By assessing the increased failure rate (or consequences) arising from this lack of proactive maintenance the cost-effectiveness of these interventions can be quantified.

C3.5.2. Example Governors Interventions

Two example Governors interventions are provided for illustration of the process using a subset of GDN data.

- Governor replacement – a With Investment intervention
- Governor Housing and Fencing maintenance – a Without Investment intervention. This will be modelled as a "negative" intervention (as described above) to assess the benefits of the current proactive maintenance spend

The baseline level of monetised risk for each financial risk node is shown below:

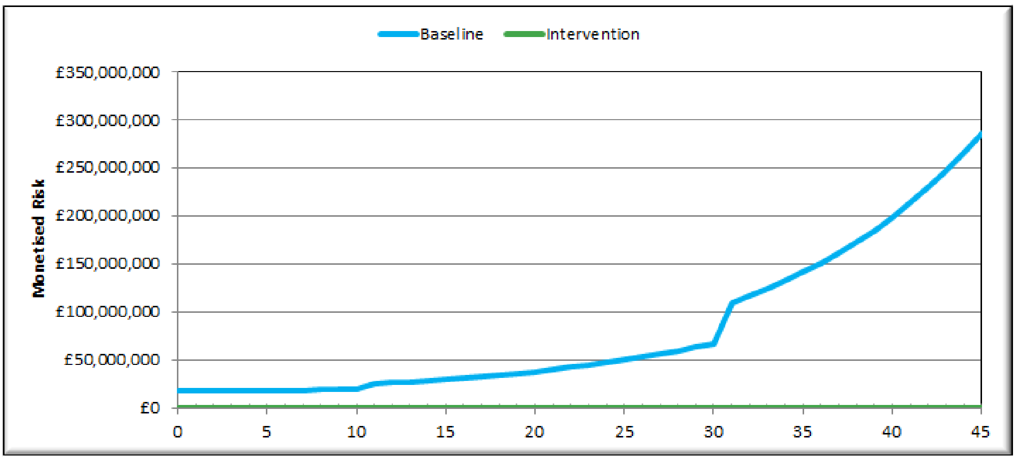


Figure C6 – Example baseline monetised risk for Governors over 45 years

Figure C6 shows how the baseline risk for all Governors changes over 45 years. Deterioration is generally low (due to inbuilt resilience and underlying proactive maintenance) until populations of specific regulator models become obsolete, thus significantly changing the level of monetised risk (e.g. at 30 years when the ERS and Tartarini regulator models become obsolete).

Regulator Replacement

For the purposes of the example Governor cohorts have been created using:

- Installation Type (e.g. regulator at District; I&C; Service Governor)
- Age of regulator

It is important to use Age within cohort definitions to enable the impact of obsolescence to be modelled accurately.

Cohort	Asset Count
<2BAR INDUSTRIAL & COMMERCIAL / 5	4
<2BAR INDUSTRIAL & COMMERCIAL / 15	5
<2BAR INDUSTRIAL & COMMERCIAL / 25	5
<2BAR INDUSTRIAL & COMMERCIAL / 35	943
<2BAR INDUSTRIAL & COMMERCIAL / 40	4033
<2BAR INDUSTRIAL & COMMERCIAL / 46	66
<2BAR PRS / 5	122
<2BAR PRS / 15	626
<2BAR PRS / 25	40
<2BAR PRS / 35	5330
<2BAR PRS / 40	1653
<2BAR PRS / 46	497
2-7BAR INDUSTRIAL & COMMECIAL / 15	2
2-7BAR INDUSTRIAL & COMMECIAL / 25	16
2-7BAR INDUSTRIAL & COMMECIAL / 35	18
2-7BAR INDUSTRIAL & COMMECIAL / 40	51
2-7BAR INDUSTRIAL & COMMECIAL / 46	3
2-7BAR PRS / 5	7
2-7BAR PRS / 15	38
2-7BAR PRS / 25	228
2-7BAR PRS / 35	242
2-7BAR PRS / 40	415
2-7BAR PRS / 46	64
IP SERVICE GOVERNOR / 40	945
MP SERVICE GOVERNOR / 35	10
MP SERVICE GOVERNOR / 40	36987

Table C8 - Selected cohorts for intervention planning

For this example we will model the impact of replacing all regulator assets with an age of 46 years over an 8 year period.

Cohort Name	Intervention Plan	Intervention Description	Asset Count (Nr)	Proposed Intervention (Nr)	Proposed Intervention (Nr)	Proposed Intervention (Nr)	Proposed Intervention (Nr)	Proposed Intervention (Nr)	Proposed Intervention (Nr)	Proposed Intervention (Nr)	Proposed Intervention (Nr)
<2BAR INDUSTRIAL & COMMERCIAL / 5			4								
<2BAR INDUSTRIAL & COMMERCIAL / 15			5								
<2BAR INDUSTRIAL & COMMERCIAL / 25			5								
<2BAR INDUSTRIAL & COMMERCIAL / 35			943								
<2BAR INDUSTRIAL & COMMERCIAL / 40			4033								
<2BAR INDUSTRIAL & COMMERCIAL / 46			66	10	8	8	8	8	8	8	8
<2BAR PRS / 5			122								
<2BAR PRS / 15			626								
<2BAR PRS / 25			40								
<2BAR PRS / 35			5330								
<2BAR PRS / 40			1653								
<2BAR PRS / 46			497	97	50	50	50	50	50	50	50
2-7BAR INDUSTRIAL & COMMECIAL / 15			2								
2-7BAR INDUSTRIAL & COMMECIAL / 25			16								
2-7BAR INDUSTRIAL & COMMECIAL / 35			18								
2-7BAR INDUSTRIAL & COMMECIAL / 40			51								
2-7BAR INDUSTRIAL & COMMECIAL / 46			3	3							
2-7BAR PRS / 5			7								
2-7BAR PRS / 15			38								
2-7BAR PRS / 25			228								
2-7BAR PRS / 35			242								
2-7BAR PRS / 40			415								
2-7BAR PRS / 46			64	8	8	8	8	8	8	8	8
IP SERVICE GOVERNOR / 40			945								
MP SERVICE GOVERNOR / 35			10								
MP SERVICE GOVERNOR / 40			36987								

Table C9 - Intervention plan to replace all 46 year old assets

The pre- and post-intervention rules that have been developed to model replacement of 46 year old regulators are shown in the figure below taken from the MRS Governors model.

BaseLine		
Node	**Rule**	**Test Value**
Failure Closed Nr/Gov/Yr	fault_detection_rate*FAIL_CLOSED*exp((AGE_EFFECTIVE-age_mean+DYear)*gov_system_deterioration)*HOUSING*COAST	3.99362E-05
Failure Open Nr/Gov/Yr	fault_detection_rate*FAIL_OPEN*exp((AGE_EFFECTIVE-age_mean+DYear)*gov_system_deterioration)*HOUSING*COAST	3.42587E-05

Intervention 5		
Regulator		
Failure Closed Nr/Gov/Yr	fault_detection_rate*FAIL_CLOSED*0.8*exp((DYear)*gov_system_deterioration)*HOUSING*COAST	2.25141E-05
Failure Open Nr/Gov/Yr	fault_detection_rate*FAIL_OPEN*0.8*exp((DYear)*gov_system_deterioration)*HOUSING*COAST	1.93133E-05

Table C10 - Pre- and post-intervention rules for Regulator replacement

In simple terms, the benefit of replacing the regulator asset (only in this intervention) is to reduce the initial probability of failure to the value of an asset with an Effective Age of zero (i.e. a new asset). The failure rate of the pre-intervention asset is based on its configuration, Effective Age (based on condition survey), its location (coastal or non-coastal) and housing type. The deterioration rate of regulators pre- and post-replacement is assumed to be the same at present, but as the initial failure rate of the new asset is very low the impact of this deterioration assumption is minor.

Applying these rules and modelling the costs and benefits over a 45 year period delivers the following risk reduction profile. A cumulative monetised risk reduction of £1.1million has been delivered over 8 years. By 45 years this cumulative risk reduction benefit has risen to £24.5 million for an initial £4.1 million (discounted) investment. This investment is highly cost beneficial due to the benefits of replacing obsolete assets.

	New Governors (Nr)	Investment	Discounted Investment
1	118.00	£934,695.87	£ 934,695.87
2	66.00	£519,780.44	£ 502,203.32
3	66.00	£519,780.44	£ 485,220.60
4	66.00	£519,780.44	£ 468,812.18
5	66.00	£519,780.44	£ 452,958.62
6	66.00	£519,780.44	£ 437,641.18
7	66.00	£519,780.44	£ 422,841.72
8	66.00	£519,780.44	£ 408,542.73

Year	BaseLine	Intervention	Change in Risk Value due to intervention	3.50%	Discounted change in Risk Value due to intervention	Cumulative discounted change in Risk Value due to intervention
0	£ 17,284,307.68	£ 17,284,307.68	£ -	1	£ -	£ -
1	£ 17,456,054.71	£ 17,421,060.71	£ 34,994.01	0.966183575	£ 33,810.63	£ 33,810.63
2	£ 17,634,488.73	£ 17,574,087.85	£ 60,400.88	0.9335107	£ 56,384.87	£ 90,195.50
3	£ 17,820,089.84	£ 17,729,022.29	£ 91,067.55	0.901942706	£ 82,137.71	£ 172,333.22
4	£ 18,013,383.66	£ 17,885,732.37	£ 127,651.29	0.871442228	£ 111,240.72	£ 283,573.94
5	£ 18,214,946.02	£ 18,044,051.59	£ 170,894.43	0.841973167	£ 143,888.52	£ 427,462.47
6	£ 18,425,408.13	£ 18,203,772.80	£ 221,635.33	0.813500644	£ 180,300.48	£ 607,762.95
7	£ 18,645,462.29	£ 18,364,641.25	£ 280,821.04	0.785990961	£ 220,722.80	£ 828,485.75
8	£ 18,875,868.23	£ 18,526,346.93	£ 349,521.29	0.759411556	£ 265,430.51	£ 1,093,916.26

Table C11 - Discounted costs and benefits per annum of replacing all 46 year old Governors

Housing and Fencing Replacement

A similar modelling approach was adopted to model the benefits of the ongoing investment in Governor painting and kiosk replacement. For the purposes of this example some simple assumptions are made:

- No painting or kiosk maintenance is undertaken
- A tenfold increase in the rate of corrosion deterioration (initial corrosion levels in Year 0 are unchanged)
- As a result of no maintenance the rate of interference increases by 10%

When these "negative" interventions are modelled the pre- and post-intervention monetised risk profiles can be compared.

The modelled intervention plan is shown below. For all maintenance interventions all cohorts will be changed (i.e. subject to reduced maintenance), in this case from Year 1.

			Year0	Year1
Cohort Name	Intervention Plan	Intervention Description	Asset Count (Nr)	Proposed Intervention (Nr)
<2BAR INDUSTRIAL & COMMERCIAL / 5	Intervention 10	KIOSK - Negative Inte	4	4
<2BAR INDUSTRIAL & COMMERCIAL / 15	Intervention 10	KIOSK - Negative Inte	5	5
<2BAR INDUSTRIAL & COMMERCIAL / 25	Intervention 10	KIOSK - Negative Inte	5	5
<2BAR INDUSTRIAL & COMMERCIAL / 35	Intervention 10	KIOSK - Negative Inte	943	943
<2BAR INDUSTRIAL & COMMERCIAL / 40	Intervention 10	KIOSK - Negative Inte	4033	4033
<2BAR INDUSTRIAL & COMMERCIAL / 46	Intervention 10	KIOSK - Negative Inte	66	66
<2BAR PRS / 5	Intervention 10	KIOSK - Negative Inte	122	122
<2BAR PRS / 15	Intervention 10	KIOSK - Negative Inte	626	626
<2BAR PRS / 25	Intervention 10	KIOSK - Negative Inte	40	40
<2BAR PRS / 35	Intervention 10	KIOSK - Negative Inte	5330	5330
<2BAR PRS / 40	Intervention 10	KIOSK - Negative Inte	1653	1653
<2BAR PRS / 46	Intervention 10	KIOSK - Negative Inte	497	497
2-7BAR INDUSTRIAL & COMMECIAL / 15	Intervention 10	KIOSK - Negative Inte	2	2
2-7BAR INDUSTRIAL & COMMECIAL / 25	Intervention 10	KIOSK - Negative Inte	16	16
2-7BAR INDUSTRIAL & COMMECIAL / 35	Intervention 10	KIOSK - Negative Inte	18	18
2-7BAR INDUSTRIAL & COMMECIAL / 40	Intervention 10	KIOSK - Negative Inte	51	51
2-7BAR INDUSTRIAL & COMMECIAL / 46	Intervention 10	KIOSK - Negative Inte	3	3
2-7BAR PRS / 5	Intervention 10	KIOSK - Negative Inte	7	7
2-7BAR PRS / 15	Intervention 10	KIOSK - Negative Inte	38	38
2-7BAR PRS / 25	Intervention 10	KIOSK - Negative Inte	228	228
2-7BAR PRS / 35	Intervention 10	KIOSK - Negative Inte	242	242
2-7BAR PRS / 40	Intervention 10	KIOSK - Negative Inte	415	415
2-7BAR PRS / 46	Intervention 10	KIOSK - Negative Inte	64	64
IP SERVICE GOVERNOR / 40	Intervention 10	KIOSK - Negative Inte	945	945
MP SERVICE GOVERNOR / 35	Intervention 10	KIOSK - Negative Inte	10	10
MP SERVICE GOVERNOR / 40	Intervention 10	KIOSK - Negative Inte	36987	36987

Table C11 - Intervention plan modelling impact of stopping painting and kiosk maintenance interventions

Appendix D – LTS Pipelines

D1. LTS Pipelines Definitions

D1.1. OLI1 Pipelines

Transmission pipelines operating at pressures above 7 bar but not exceeding 100 bar. Includes all pipelines that can be inspected using internal inspection vehicles (OLI1) or other internal inspection technique and includes pig trap installations.

D1.2. OLI4 Pipelines

Transmission pipelines that cannot be inspected internally due to changes in diameter, tight radius bends or other limiting features. Operate at pressures above 7 bar but not exceeding 100 bar. Inspection method is OLI4.

D1.3. Crossings

Sections of pipeline constructed to cross features such as rivers, railway lines etc. Category includes any pipe bridges, support structures, anti-vandal guards etc. Crossings can be Above Ground (Exposed) or Below Ground. Crossing sections are modelled as an attribute of the LTS Pipeline within the LTS Pipeline model.

D1.4. Sleeves

Type 1 & 2 sleeves (Nitrogen/Construction) used for protection/proximity purposes, high traffic density or for construction (i.e. road crossings). Edition 5 of IGEM standard TD/1 now requires that protection / proximity issues are addressed by heavy wall pipe rather than sleeves'. Sleeves are modelled as a secondary asset, which is assigned to the parent pipeline within the LTS Pipeline Risk Model. It should be noted that the model assesses the risk of the sleeved section of pipeline as a whole within the model.

D1.5. Block Valves

In-line isolation valves & actuators including bypass & bridle & associated pressure points. Also includes civils infrastructure such as fences, pits etc. Block Valves are modelled as a secondary asset, which is assigned to the parent pipeline within the LTS Pipeline Risk Model.

D1.6. Cathodic Protection

Cathodic Protection (CP) is the system and / or subsystems that are used to protect all steel pipelines from external corrosion. CP is typically provided either by impressed current systems, including transformer rectifiers, groundbeds and test posts, or via the attachment of sacrificial anodes' CP is treated as an attribute within the failure nodes of the LTS pipeline model.

D2. LTS Event Tree Development

D2.1. LTS Pipelines Failure Modes

Failure Modes have been identified for LTS Pipelines consistently with the process outlined in Section 3.4 of the main methodology. Failure modes were identified through a number of workshops with asset experts and through careful analysis of available data held by companies to assess and quantify the rate of failures and future asset deterioration. The failure modes for LTS Pipelines include:

- **Faults** – a defect that has the potential to lead to a wall loss failure.-
- **Corrosion** – either internal or external corrosion of the pipe.
- **Mechanical failures** - including material and weld defects created when the pipe was manufactured or constructed.
- **General failures** – general and other causes, e.g. due to over-pressurisation, fatigue or operation outside design limit.
- **Interference** – external interference caused by third parties.
- **Ground movement** - either natural e.g. landslide, or man-made e.g. excavation or mining.
- **Capacity** – capacity issues identified on pipelines.

Failure Modes are highlighted in on the risk map in D2.3.

D2.2. LTS Pipelines Consequence Measures

Consequence measures have been identified for LTS Pipelines consistently with process identified in section 3.5 of the main methodology.

A *leak* is defined as a gas escape from a stable hole whose size is less than the diameter of the LTS pipeline (TD2 Edn2). The model has the ability to model leaks of different sizes.

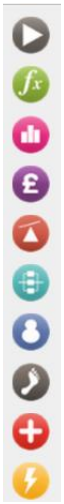
A *rupture* is a gas escape through an unstable defect which extends during failure to result in a full break or failure of an equivalent size to the pipeline (TD2 Edn2).

The number of leaks/ruptures per year is calculated based on the frequency of corrosion, mechanical failures, general failures, interference events, ground movement failures combined with the probability that each of the failure modes will lead to a leak/rupture respectively. These failures can then in turn result in a number of consequences such as:

- Loss of gas
- Ignitions
- Non-ignition impacts
- Health and safety incidents
- Supply interruptions
- Reactive repair costs
- Prosecution costs

Consequence values (both probability of occurrence and financial effect) are dependent on the consequences events being assessed. Some of these consequences are clearly inter-related, as detailed in the risk map.

D2.3. LTS Pipelines Risk Map



Asset Data
Explicit Calculation
Consequence
Financial outcome (monetised risk)
Willingness to pay/Social Costs (not used)
System Reliability (not used)
Customer outcome/driver
Carbon outcome/driver
Health and safety outcome/driver
Failure Mode

Figure D- 11 - Risk Map Key

As per the process described within Section 3.6 of the main methodology, the risk map for LTS Pipelines is shown below:

Figure D-1 outlines the risk map key for LTS. The risk map is colour coded for each node of the event tree to indicate which values are associated with each node. The colours are reflected in both the risk map and risk map template in Figures D2 and D3.

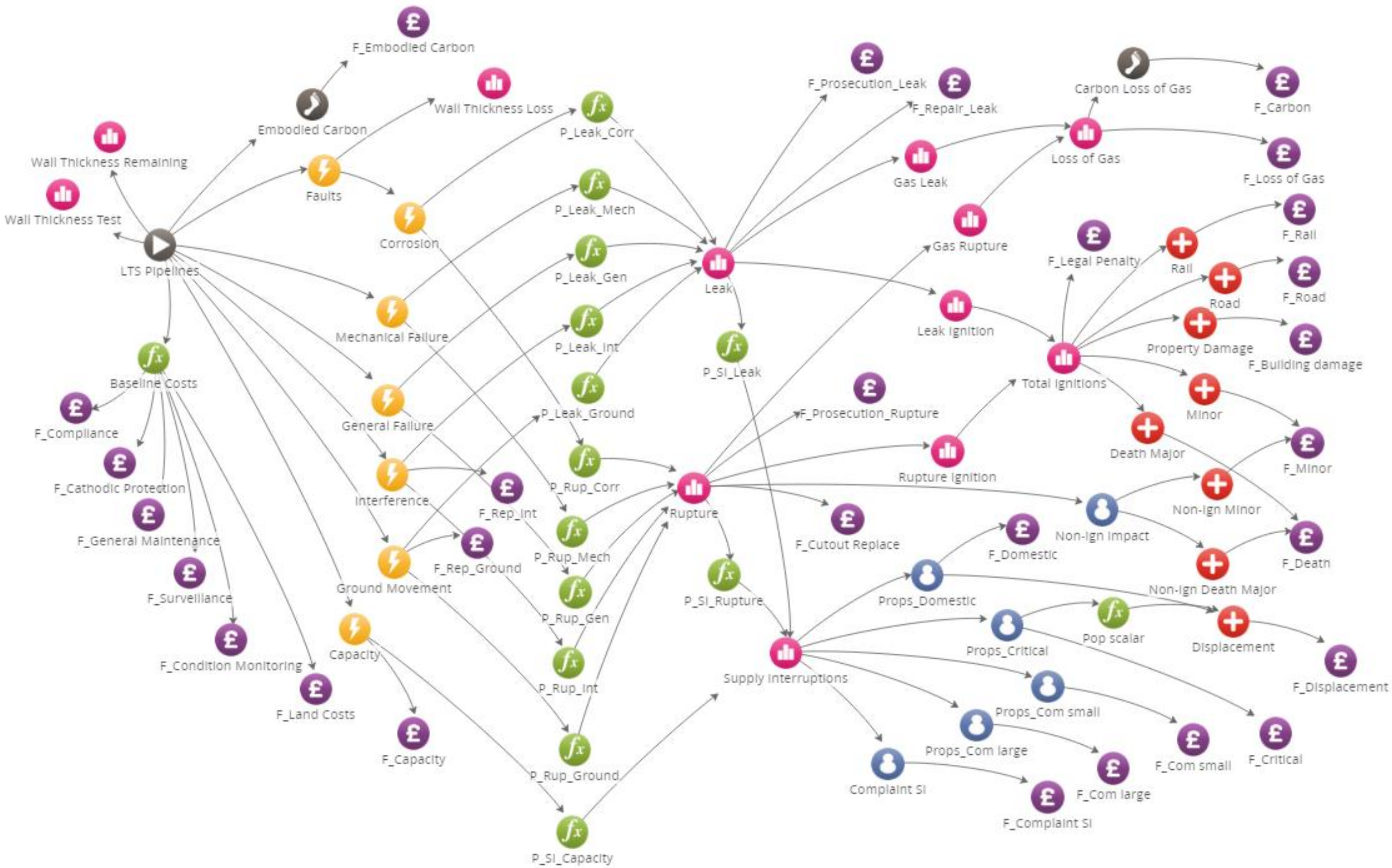


Figure D- 12 -LTS Risk Map

D2.4. LTS Pipelines Risk Template

The following table demonstrates how the total risk value is derived for any given LTS Pipeline cohort. An individual, populated risk map is developed for every asset to be modelled to deliver a baseline monetised risk value prior to intervention modelling.

Faults (Nr)	0.001290323	Corrosion Nr/Asset/Yr	2.6135E-11	P_Leak_Corr 0-1	0.23	Leak	1	P_SI_Leak 0-1	0.15	Supply Interruptions 0-1	1	Props_Critical Nr/Asset	40	Pop Scalar 0-1	869.5652	Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 0.00
												Props_Domestic Nr/Asset	2000			Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 0.00
												Complaint_SSI Nr/Asset	684					F_Complaint SI	£ 450.00	£ 0.00
												Props_Com large Nr/Asset	40					F_Com large	£ 200.00	£ 0.00
												Props_Com small Nr/Asset	200					F_Com Small	£ 200.00	£ 0.00
												Props_Critical Nr/Asset	40					F_Critical	£ 200.00	£ 0.00
												Props_Domestic Nr/Asset	2000					F_Domestic	£ 200.00	£ 0.00
												Leak Ignition 0-1	0.05555206	Total Ignitions 0-1	1	Rail m	0	F_Rail	£ -	£ -
																Road m	0	F_Road	£ -	£ -
																Death Major Persons	4.925972076	F_Death	£ 16,000,000.00	£ 0.00
																Minor Persons	0.084456603	F_Minor	£ 185,000.00	£ 0.00
																Property Damage Props	2.288608039	F_Building Damage	£ 189,000.00	£ 0.00
																		F_Legal penalty	£ 20,000,000.00	£ 0.00
												Gas Leak m3	32793.12	Loss of Gas 0-1	1	Carbon Loss of Gas m3	0.014	F_Carbon	£ 60.00	£ 0.00
																		F_Loss of gas	£ 0.22	£ 0.00
																		F_Repair_Leak	£ 65,000.00	£ 0.00
																		F_Prosecution_Leak	£ 20,000.00	£ 0.00
				P_Rup_Corr 0-1	0.00047	Rupture 0-1	1	P_SI_Rupture 0-1	1	Supply Interruptions 0-1	1	Props_Critical Nr/Asset	40	Pop Scalar 0-1	869.5652	Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 0.00
												Props_Domestic Nr/Asset	2000			Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 0.00
												Complaint_SSI Nr/Asset	684					F_Complaint SI	£ 450.00	£ 0.00
												Props_Com large Nr/Asset	40					F_Com large	£ 200.00	£ 0.00
												Props_Com small Nr/Asset	200					F_Com Small	£ 200.00	£ 0.00
												Props_Critical Nr/Asset	40					F_Critical	£ 200.00	£ 0.00
												Props_Domestic Nr/Asset	2000					F_Domestic	£ 200.00	£ 0.00
												Gas Rupture m3	964663.8718	Loss of Gas 0-1	1	Carbon Loss of Gas m3	0.014	F_Carbon	£ 60.00	£ 0.00
																		F_Loss of gas	£ 0.22	£ 0.00
												Rupture Ignition 0-1	0.15235763	Total Ignitions 0-1	1	Rail m	0	F_Rail	£ -	£ -
																Road m	0	F_Road	£ -	£ -
																Death Major Persons	4.925972076	F_Death	£ 16,000,000.00	£ 0.00
																Minor Persons	0.084456603	F_Minor	£ 185,000.00	£ 0.00
																Property Damage Props	2.288608039	F_Building Damage	£ 189,000.00	£ 0.00
																		F_Legal penalty	£ 20,000,000.00	£ 0.00
												Non-Ign Impact 0-1	0.00001			Non-Ign Minor Persons	0.000484152	F_Minor	£ 185,000.00	£ 0.00
																Non-Ign Death Major Persons	4.84152E-05	F_Death	£ 16,000,000.00	£ 0.00
																		F_Prosecution_Rupture	£ 500,000.00	£ 0.00
																		F_Cutout Replace	£ 1,500,000.00	£ 0.00
		Mechanical Failure Nr/Asset/Yr	0.000220132	P_Rup_Mech 0-1	0.00034	Rupture 0-1	1	P_SI_Rupture 0-1	1	Supply Interruptions 0-1	1	Props_Critical Nr/Asset	40	Pop Scalar 0-1	869.5652	Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 0.60
												Props_Domestic Nr/Asset	2000			Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 0.03
												Complaint_SSI Nr/Asset	684					F_Complaint SI	£ 450.00	£ 0.02
												Props_Com large Nr/Asset	40					F_Com large	£ 200.00	£ 0.00
												Props_Com small Nr/Asset	200					F_Com Small	£ 200.00	£ 0.00
												Props_Critical Nr/Asset	40					F_Critical	£ 200.00	£ 0.00
												Props_Domestic Nr/Asset	2000					F_Domestic	£ 200.00	£ 0.03
												Gas Rupture m3	964663.8718	Loss of Gas 0-1	1	Carbon Loss of Gas m3	0.014	F_Carbon	£ 60.00	£ 0.06
																		F_Loss of gas	£ 0.22	£ 0.02
												Rupture Ignition 0-1	0.15235763	Total Ignitions 0-1	1	Rail m	0	F_Rail	£ -	£ -
																Road m	0	F_Road	£ -	£ -
																Death Major Persons	4.925972076	F_Death	£ 16,000,000.00	£ 0.90
																Minor Persons	0.084456603	F_Minor	£ 185,000.00	£ 0.00
																Property Damage Props	2.288608039	F_Building Damage	£ 189,000.00	£ 0.00
																		F_Legal penalty	£ 20,000,000.00	£ 0.23
												Non-Ign Impact 0-1	0.00001			Non-Ign Minor Persons	0.000484152	F_Minor	£ 185,000.00	£ 0.00
																Non-Ign Death Major Persons	4.84152E-05	F_Death	£ 16,000,000.00	£ 0.00
																		F_Prosecution_Rupture	£ 500,000.00	£ 0.04
																		F_Cutout Replace	£ 1,500,000.00	£ 0.11
				P_Leak_Mech 0-1	0.21	Leak 0-1	1	P_SI_Leak 0-1	0.15	Supply Interruptions 0-1	1	Props_Critical Nr/Asset	40	Pop Scalar 0-1	869.5652	Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 55.47
												Props_Domestic Nr/Asset	2000			Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 3.19
												Complaint_SSI Nr/Asset	684					F_Complaint SI	£ 450.00	£ 2.13
												Props_Com large Nr/Asset	40					F_Com large	£ 200.00	£ 0.06
												Props_Com small Nr/Asset	200					F_Com Small	£ 200.00	£ 0.28
												Props_Critical Nr/Asset	40					F_Critical	£ 200.00	£ 0.06
												Props_Domestic Nr/Asset	2000					F_Domestic	£ 200.00	£ 2.77
												Leak Ignition 0-1	0.05555206	Total Ignitions 0-1	1	Rail m	0	F_Rail	£ -	£ -
																Road m	0	F_Road	£ -	£ -
																Death Major Persons	4.925972076	F_Death	£ 16,000,000.00	£ 202.40
																Minor Persons	0.084456603	F_Minor	£ 185,000.00	£ 0.04
																Property Damage Props	2.288608039	F_Building Damage	£ 189,000.00	£ 1.11
																		F_Legal penalty	£ 20,000,000.00	£ 51.36
												Gas Leak m3	32793.12	Loss of Gas 0-1	1	Carbon Loss of Gas m3	0.014	F_Carbon	£ 60.00	£ 1.27
																		F_Loss of gas	£ 0.22	£ 0.33
																		F_Repair_Leak	£ 65,000.00	£ 3.00
																		F_Prosecution_Leak	£ 20,000.00	£ 0.92
		General Failure Nr/Asset/Yr	0.00037973	P_Rup_Gen 0-1	0.04014	Rupture 0-1	1	P_SI_Rupture 0-1	1	Supply Interruptions 0-1	1	Props_Critical Nr/Asset	40	Pop Scalar 0-1	869.5652	Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 121.94
												Props_Domestic Nr/Asset	2000			Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 7.01
												Complaint_SSI Nr/Asset	684					F_Complaint SI	£ 450.00	£ 4.69
												Props_Com large Nr/Asset	40					F_Com large	£ 200.00	£ 0.12
												Props_Com small Nr/Asset	200					F_Com Small	£ 200.00	£ 0.61
												Props_Critical Nr/Asset	40					F_Critical	£ 200.00	£ 0.12
												Props_Domestic Nr/Asset	2000					F_Domestic	£ 200.00	£ 6.10
												Gas Rupture m3	964663.8718	Loss of Gas 0-1	1	Carbon Loss of Gas m3	0.014	F_Carbon	£ 60.00	£ 12.35
																		F_Loss of gas	£ 0.22	£ 3.23
												Rupture Ignition 0-1	0.15235763	Total Ignitions 0-1	1	Rail m	0	F_Rail	£ -	£ -
																Road m	0	F_Road	£ -	£ -
																Death Major Persons	4.925972076	F_Death	£ 16,000,000.00	£ 183.03
																Minor Persons	0.084456603	F_Minor	£ 185,000.00	£ 0.04
																Property Damage Props	2.288608039	F_Building Damage	£ 189,000.00	£ 1.00
																		F_Legal penalty	£ 20,000,000.00	£ 46.45
												Non-Ign Impact 0-1	0.00001			Non-Ign Minor Persons	0.000484152	F_Minor	£ 185,000.00	£ 0.00
																Non-Ign Death Major Persons	4.84152E-05	F_Death	£ 16,000,000.00	£ 0.00
																		F_Prosecution_Rupture	£ 500,000.00	£ 7.62
																		F_Cutout Replace	£ 1,500,000.00	£ 22.86
				P_Leak_Gen 0-1	0.65	Leak 0-1	1	P_SI_Leak 0-1	0.15	Supply Interruptions 0-1	1	Props_Critical Nr/Asset	40	Pop Scalar 0-1	869.5652	Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 296.19
												Props_Domestic Nr/Asset	2000			Displacement people/prop	0.23	F_Displacement	£ 1,000.00	£ 17.03
												Complaint_SSI Nr/Asset	684					F_Complaint SI	£ 450.00	£ 11.40
												Props_Com large Nr/Asset	40					F_Com large	£ 200.00	£ 0.30
												Props_Com small Nr/Asset	200					F_Com Small	£ 200.00	£ 1.48
												Props_Critical Nr/Asset	40					F_Critical	£ 200.00	£ 0.30
												Props_Domestic Nr/Asset	2000					F_Domestic	£ 200.00	£ 14.81
												Leak Ignition 0-1	0.05555206	Total Ignitions 0-1	1	Rail m	0	F_Rail	£ -	£ -
																Road m	0	F_Road	£ -	£ -
																Death Major Persons	4.925972076	F_Death	£ 16,000,000.00	£ 1,080.69
																Minor Persons	0.084456603	F_Minor	£ 185,000.00	£ 0.21
																Property Damage Props	2.288608039	F_Building Damage	£ 189,000.00	£ 5.93
																		F_Legal penalty	£ 20,000,000.00	£ 274.23
												Gas Leak m3	32793.12	Loss of Gas 0-1	1	Carbon Loss of Gas m3	0.014	F_Carbon	£ 60.00	£ 6.80
																		F_Loss of gas	£ 0.22	£ 1.78
																		F_Repair_Leak	£ 65,000.00	£ 16.04
																		F_Prosecution_Leak	£ 20,000.00	£ 4.94

Continued overleaf….

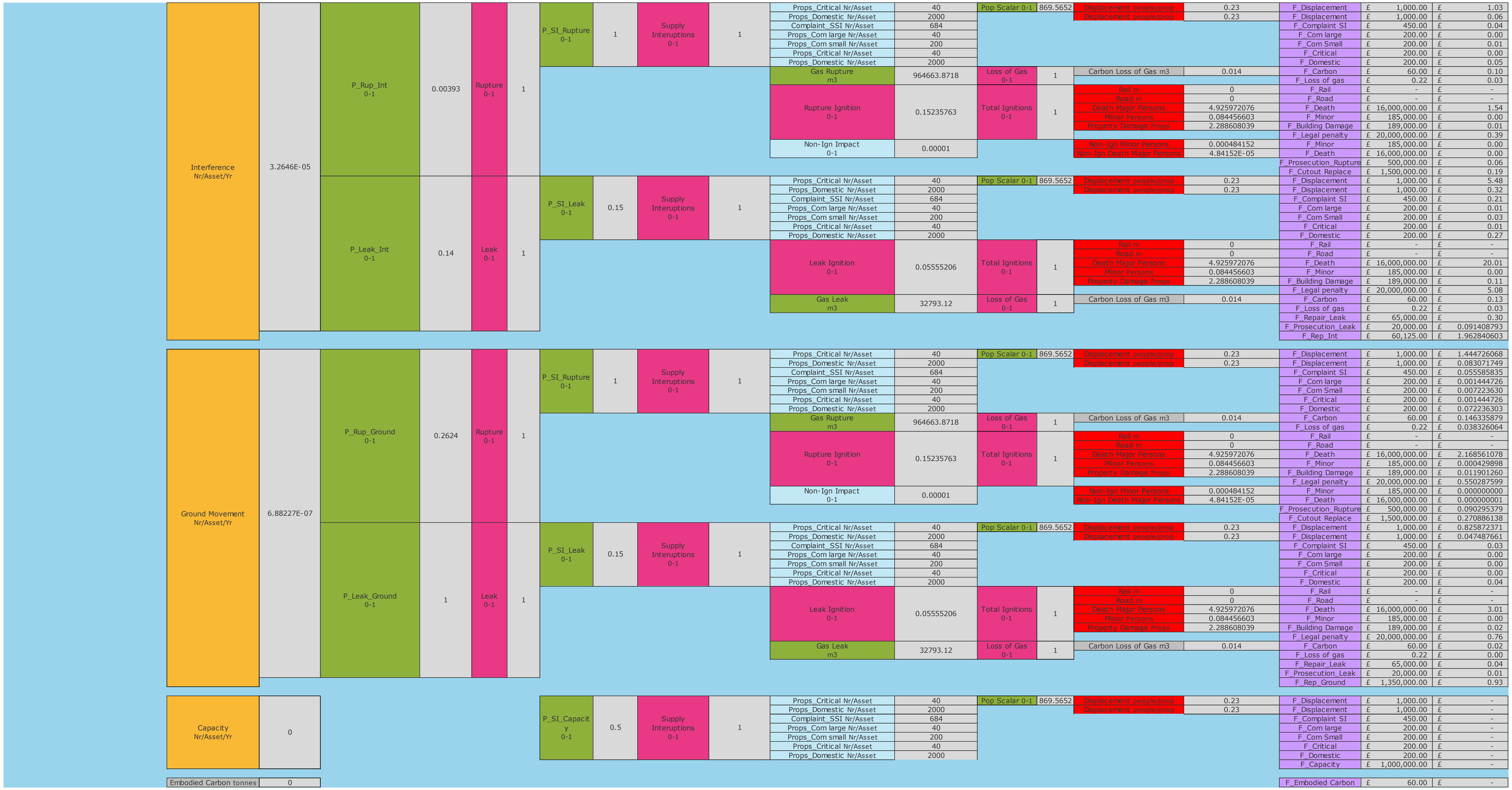


Figure D- 13 - LTS Risk Map Template

D2.5. LTS Pipelines Data Reference Library

As per Section 3.7 of the main report, the following table gives a description of data required for nodes on the LTS Pipelines Risk Map (Event Tree).

Node ID / Variable	Description	Data Source	GDN or Common Value
Age	Age of individual pipeline, sleeve or valve	Calculation using individual asset age where known or assumed values used (as Year Install).	GDN Specific
Capacity	Flag to define whether a LTS pipeline has a known capacity issue. **P_SI_Capacity** is the probability of a supply interruption given a capacity exceedance event.	Binary value used at asset level where known capacity issues using off-line sizing/capacity analysis. Capacity issues flagged in data with a 'Y'	GDN Specific
Carbon Loss of gas	m^3 of carbon equivalent (CO2e)arising from loss of gas or general emissions	Value calculated by each GDN based on actual gas composition in the network. Relative Density x Carbon Equivalent	GDN Specific
Complaint SI	Complaint arising from supply interruption.	Percentage of people who complain multiplied by the customers supplied. Assumes 30% of customers (residential, small commercial, large commercial and critical) and all direct fed customers complain	Common
Corrosion	Frequency of corrosion failures associated with LTS pipework or valves.	Existing PIE report (**PIE/14/TN113),** using Weibull probability distribution curve based on wall thickness deterioration and corrosion resistance (high, average, low). Other calculation factors include type of coating, history of town gas usage, defects and sleeve condition.	GDN Specific
Death and Major	Number of deaths following an explosion (caused by ignition of a pipeline leak/rupture).	Number of deaths of people in surrounding houses and immediate vicinity The Burning Building Distance is closest to the pipeline and the represents. It is assumed there would be a 50% chance of a loss of life and 50% chance of major injury in the area defined by the Burning Building Distance (Inner Zone). The Escape Zone (Middle Zone) is further away and represents the difference between the Inner and the Middle Zone areas. It is assumed there would be a 5% chance of a loss of life or a major injury in the Middle Zone. As a default value we use 1 property per hectare for Rural and 10 properties per hectare for Suburban areas – based	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		on TD1 and advice from DNV GL. . GDNs can perform own analysis and change these values if required.	
Displacement	Number of persons displaced (relocated) due to Supply Interruption	As per the latest OFGEM Domestic Suppliers Social Obligations report (2014) the number of customers on the Priority Services Register is at 2.3 million (10%). The PSR eligibility covers the disabled, chronically sick, pensionable age and those households with children under the age of 5. https://www.ofgem.gov.uk/sites/default/files/docs/2015/09/annual_report_2014_final_0.pdf Therefore assumed 10%, i.e. all customers on PSR are displaced.	Common
Faults	Frequency of wall thickness defects	Uses defects per km pre and post 1972. Defect frequency for pipes with install dates <=1972 based on lognormal distribution	GDN Specific
F_Capacity	Fines for non-compliance. Failure to address known capacity issue	Default/assumed value agreed with SRWG	GDN Specific
F_Cathodic Protection	Annual Cost of maintaining compliant Cathodic Protection schemes	Data taken from company systems.	GDN Specific
F_Compliance	Annual Cost of ensuring compliance with relevant regulations, i.e. aerial surveys, river surveys, access prevention measures	Data taken from company systems.	GDN Specific
F_Condition Monitoring	Annual Cost of undertaking condition monitoring.	Data taken from company systems.	GDN Specific
F_Cutout Replace	Average cost of repairing (cut-out and replace) a LTS pipeline following a rupture	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific
F_Displacement	Cost of displacement per person includes transportation, accommodation, meals, welfare arrangements, etc.	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific
F_General Maintenance	Annual Cost of undertaking maintenance activities not captured within other Financial nodes	Data taken from company systems.	GDN Specific
F_Land Costs	Annual Cost of easement and access rights.	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
F_Legal penalty	Cost of legal enforcement and penalty payments following ignition/explosion	Default/assumed value agreed with SRWG based on historical incidents.	Common
F_Prosecution_Leak	Cost of legal enforcement and penalty payments following gas leak	Default/assumed value agreed with SRWG	Common
F_Prosecution_Rupture	Cost of legal enforcement and penalty payments following pipe rupture	Default/assumed value agreed with SRWG	Common
F_Rail	Cost of damage to network rail infrastructure	Default/assumed value agreed with SRWG for regional railways. Scalar applied to Principle railways and Local railways.	Common
F_Rep_Ground	Costs associated with ground movement that has not led to a rupture or leak.	Data taken from company systems where available, or a default/assumed value agreed with SRWG. This value is multiplied by (1-probability of ground movement leading to a rupture-probability of ground movement leading to leak) to ensure there is no double counting with F_Cutout_Replace and F_Repair_Leak	GDN Specific
F_Rep_Int	Cost of fixing a interference incident that has not led to a rupture or leak	Data taken from company systems where available, or a default/assumed value agreed with SRWG... This value is multiplied by (1-probability of interference leading to a rupture-probability of interference leading to leak) to ensure there is no double counting with F_Cutout_Replace and F_Repair_Leak	GDN Specific
F_Repair_Leak	Average cost of repairing a LTS pipeline leak due to a failure	Data taken from company systems where available, or a default/assumed value agreed with SRWG.	GDN Specific
F_Road	Cost of road damage, reinstatement, and disruption based on road classification	Default/assumed values agreed with SRWG based on Local authority notification, TFL authority, plant permit, road signage, public notification/liaison, reinstatement and road type.	Common
F_Surveillance	Annual Surveillance Costs - reactive cost from aerial/vantage surveys (SRP visits)	Data taken from company systems where available, or a default/assumed value agreed with SRWG.	GDN Specific
General Failure	General and other causes - "due to over-pressurisation, fatigue or operation outside design limits" IGEM TD2 p24	Data taken from company systems where available, or a default value as per IGEM TD2 pg50	GDN Specific
Ground Movement	Either natural, for example landslide or man-made, for example excavation or mining" IGEM TD2 p24	Data taken from company systems where available, or a default calculation used as per TD2. Pipeline failure frequency is obtained from the	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		landslide incident rate IGEM TD2 pg48 Table 8. This is scaled up based on the landslide potential to obtain the values detailed in Table 8. This includes watercourses and flood potential. Survival value for poor quality and high quality girth welds used as per IGEM TD2 pg49 fig15	
Interference	Failures due to 3rd party interference	Data taken from company systems where available, or a default calculation used as per TD2. Generic failure frequency for pipelines in rural areas is given in Fig 13 IGEM TD2 pg44 Failure frequency in a suburban area is 4 times that in a rural area IGEM TD2 p25 Reduction in external interference probability of failure based on wall thickness and design factors IGEM TD2 pg27 Reduction rate based on depth of cover, surveillance frequency and protection (concrete slabbing)/marker posts IGEM TD2 pg28, 29, 30, 39Valves interference failures default/assumed value agreed with SRWG.	GDN Specific
Leak	Stable gas escape - gas escape from stable hole with size less than diameter of pipe (IGEM TD2 A4.1 page 43)	Value of 1 used as a multiplier to enable the grouping/summation of the probability of corrosion, mechanical, general, interference and ground movement failures	Common
Leak Ignition	The probability of ignition following a leak	Assumes small hole of 40mm diameter IGEM TD2 pg43 (upper end of classification) but with uncertainty, upper bound on ignition probability of 0.44	Common
Loss of gas	Sums loss of gas from leaks and ruptures	Value of 1 used as a multiplier to enable the grouping/summation of the probability of Gas Leak and Gas Rupture	Common
Mechanical Failure	Mechanical failure including material and weld defects created when the pipe was manufactured or constructed (IGEM TD2 p24)	Data taken from company systems where available, or a default calculation used as per TD2. IGEM TD2 pg47 table 7 provides frequencies related to wall thickness. For pipelines commissioned after 1980, the material and construction failure frequency rate can be assumed to reduce by a factor of 5 (IGEM TD2 pg48)	GDN Specific
Minor	Number of minor injury of people in surrounding	See Death and Major. We assume that 5% of population in the Middle Zone suffer a minor injury	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	houses and immediate vicinity	(the other 5% is killed or suffers a major injury).	
Non-Ign Death Major	Number of death / major injury from non-ignition	See Death and Major. Assumes 1% of the people living in the Inner Zone would be in the immediate vicinity and there is a 0.1% likelihood of them being killed or suffer a major injury.	GDN Specific
Non-Ign Impact	Probability of impact from non-ignition events - e.g. blast damage - pressure wave. Release of pressure energy from the initial fractured section; pressure generated from combustion during the initial phase if the release is ignited immediately; missiles generated from overlying soil or from pipe fragments (IGEM TD2 pg12)	Probability of a blast impact assumed to be negligible compared to fire effects p12 TD2, therefore a small value has been used)	GDN Specific
Non-Ign Minor	Number of minor injuries from non-ignition	Assumes 1% of the people living in the Inner Zone would be in the immediate vicinity and there is a 1% likelihood of them suffering a minor injury. As a default, use 2.5 people per hectare for Rural and 25 people per hectare for Suburban – based on TD1 and advice from GL (Phil Baldwin). GDNs can perform own analysis.	GDN Specific
Property Damage	Number of property damage due to ignition/explosion impact	Assumes 100% of properties in inner zone and 10% in middle zone are destroyed Multiply by property density (depends on rural /suburban).	GDN Specific
Props_Com large	Number of large commercial properties affected by supply interruption (C3 and C4 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Com small	Number of small commercial properties affected by supply interruption (C1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Critical	Number of critical properties affected by supply interruption (C2 and I2 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Domestic	Number of critical properties affected by	Data taken from company systems based on either network analysis or	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	supply interruption (D1 type properties)	assumptions based on demands, flow & redundancy	
Rail	damage to network rail infrastructure caused by a pipeline ignition/explosion	length of rail as a proxy to probability of rail damage used	GDN Specific
Road	road damage, reinstatement, and disruption caused by a pipeline ignition/explosion	length of road as a proxy to probability of rail damage used	GDN Specific
Rupture	Unstable gas escape - gas escape from unstable hole with size equal or greater than diameter of pipe (IGEM TD2 A4.1 page 43). A rupture release is a full bore , double-ended break or equivalent from which gas is released into a crater from both sections of pipe (IGEM TD2 4.4.1 pg11)	Value of 1 used as a multiplier to enable the grouping/summation of the probability of mechanical, general, interference and ground movement failures	Common
Rupture Ignition	The probability of ignition following a rupture	Probability of ignition as per IGEM TD2 Ed2 Section 4.6.	Common
Supply Interruptions	Supply interruptions due to leak, rupture or capacity issues	Value of 1 used as a multiplier to enable the grouping/summation of the probability of leak, rupture or capacity failures leading to a supply interruption	Common
Total Ignitions	Total ignitions (leak and rupture ignitions)	Value of 1 used as a multiplier to enable the grouping/summation of the probability of leak and rupture ignitions	Common
Pop Scalar	A scalar factor to consider the population estimates in hospitals (critical property)	A value is used as the population equivalent per hospital (NHS website) divided by 2.3 to turn it in to property equivalent	Common
Gas Leak	A model for the loss of gas volume caused by a gas leak	A value calculated using a combination of pipeline pressure and diameter to estimate the volume of gas lost over a given duration. This value was calculated using DNV GL's PIPESAFE model for a sample data set and a 40mm hole and a linear model fitted. The hole size and leak duration can be adjusted in the model to recalculate the gas leak value.	GDN Specific
Gas Rupture	A model for the loss of gas volume caused by a rupture	A value calculated using a combination of pipeline pressure and diameter, to estimate the volume of gas lost over initial "eruptive" and subsequent steady-state rupture durations. These values were calculated using DNV GL's PIPESAFE model for a sample data set and a quadratic model fitted. The times	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		of the eruptive and steady-state flow durations can be changed in the model.	
P_SI_Leak	Probability of supply interruption given leak	Assumes no supply interruptions if there is an alternate source. Data taken from company systems where available, or a default/assumed value agreed with SRWG if no alternate source (agreed with SRWG).	GDN Specific
P_SI_Rupture	Probability of supply interruption given rupture	Data taken from company systems where available or a default/assumed value of supply interruptions agreed with SRWG.	GDN Specific

D3. LTS Event Tree Utilisation

D3.1. LTS Pipelines Base Data

The LTS Pipelines base data will be created from company asset databases, financial systems and other data sources. This includes pipeline characteristics e.g. installation year, wall thickness, depth, pressure, protection and properties supplied.

Sub-type assets

The LTS pipelines are split into subtypes (pipe, sleeve and block valves) and there is a record in the base data for each of these. 'Pipe' refers to an un-sleeved section of pipeline; 'Sleeve' refers to a sleeved section of pipeline, i.e. the pipe and sleeve and 'Valve' refers to block valve installations on a section of pipeline.

Risk analysis is performed by splitting the pipeline up into sections and sub-type assets that have different underlying risk characteristics and hence different paths through the risk models. Each sub-type asset is linked to the parent LTS pipeline in the base data.

Attributes

Above Ground (AG/Exposed) or Below Ground (BG) Crossings and Cathodic Protection installations are captured as attributes within the base data. Attributes act as a risk modifier to the LTS pipeline section that they are located on.

A further important input is an understanding of the downstream consequences of failure, for example which properties experience a supply interruption following an over-pressurisation event. This information can be derived from network modelling or approximated using GIS analysis.

An example of data input format is shown is Table D-1 below:

ICS_ASSET_ID	CLIENT_UID	ASSET_TYPE	MATERIAL	DIAMETER	CONSTRUCTION_METHOD	YEAR_INSTALL	INTERNAL_PROTECTION	WELD_QUALITY	OWNERSHIP	ASSET_LENGTH
C4499DBF123C44BF9F6320728EEE0083	MSC0022	LTS	STEEL	325	Seamless	1960	Red Lead	Flood	SGN	180
C50FBA0A84944DBDBC5E93718A03AB35	MSC0017	LTS	STEEL	325	Seamless	1962	Red Lead	Flood	SGN	478
79436D93C65D4E90BFC15067A899F742	MSC0011	LTS	STEEL	274	Seamless	1976	Epoxy Resin	FLOOD/TAPE	SGN	124
F5D1CCECC8AB4895A3976A98B3D854A4	MSC0008	LTS	STEEL	102	Longditudinal ERW	1961	Red Lead	Flood	SGN	524
235F984CE31A439391D1A760A18A8ECB	MSC0001	LTS	STEEL	325	Seamless	1960	Red Lead	Flood	SGN	404
D7D292CBF5C24C96A64DA4E2B9FC3168	DSC0110	LTS	STEEL	102	Seamless	1982	Red Lead	Tape Wrap	SGN	74
C881D63C50CA4437963EC732863FA73D	MSC0048	LTS	STEEL	168	Seamless	1968	Red Lead	Flood	SGN	360
C69DC341F27A4F3D8DDBB065A60CB529	MSC0047	LTS	STEEL	102	Seamless	1960	Red Lead	Flood	SGN	80
FEFAD6CDED404031BD7F2BD38867E3F9	MSC0042	LTS	STEEL	457	Seamless	1968	Red Lead	Flood	SGN	184
B8AB1483AD0B489993BEB6B27B0D45C4	MSC0039	LTS	STEEL	274	Seamless	1965	Red Lead	Flood	SGN	436
86734F58F16E4DCFB377523115EE0256	MSC0036	LTS	STEEL	218	Seamless	1965	Red Lead	Flood	SGN	380
29A7E6E796724A4798310349DC8B49D4	MSC0035	LTS	STEEL	325	Seamless	1963	Red Lead	Flood	SGN	1543
4FEC47A62A344F55A3A382DF129EE788	MSC0033	LTS	STEEL	325	Seamless	1967	Red Lead	Flood	SGN	47
32560F07BD154717A9DDE0E605B84703	MS0032	LTS	STEEL	508	Longditudinal SAW	1964	Red Lead	Flood	SGN	18
4CFEC4E6FFA44327B8AB8CB73464B6FB	MSE0015	LTS	STEEL	457	Seamless	1969	Other	FLOOD/TAPE	SGN	295
D10E49B504124A919B5DAB30D0380FF6	MS0036	LTS	STEEL	508	Seamless	1964	Red Lead	Flood	SGN	195
B314BE30B17C4D3AB95302D033366563	MSE0084	LTS	STEEL	457	Seamless	1970	Red Lead	FLOOD/TAPE	SGN	73

ICS_ASSET_ID	SUBURBAN_LENGTH	URBAN_LENGTH	ASSET_SUBTYPE	PIGGING	MATERIAL_GRADE	LOSS_CONSEQ	PIPELINE_COATING	HISTORY_OF_CORR	CORR_RESISTANCE
C4499DBF123C44BF9F6320728EEE0083	0	0	SLEEVE	N	B	UNKN	Bitumen (Not Insulated)	UNKN	UNKN
C50FBA0A84944DBDBC5E93718A03AB35	2640	0	SLEEVE	N	B	UNKN	Bitumen (Not Insulated)	UNKN	UNKN
79436D93C65D4E90BFC15067A899F742	0	0	SLEEVE	N	X46	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
F5D1CCECC8AB4895A3976A98B3D854A4	0	0	SLEEVE	N	B	UNKN	Bitumen (Not Insulated)	UNKN	UNKN
235F984CE31A439391D1A760A18A8ECB	0	0	SLEEVE	N	B	UNKN	Bitumen (Not Insulated)	UNKN	UNKN
D7D292CBF5C24C96A64DA4E2B9FC3168	0	0	SLEEVE	N	B	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
C881D63C50CA4437963EC732863FA73D	1860	0	SLEEVE	N	X52	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
C69DC341F27A4F3D8DDBB065A60CB529	0	0	SLEEVE	N	B	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
FEFAD6CDED404031BD7F2BD38867E3F9	0	0	SLEEVE	N	X52	UNKN	Bitumen (Not Insulated)	UNKN	UNKN
B8AB1483AD0B489993BEB6B27B0D45C4	4830	0	SLEEVE	N	B	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
86734F58F16E4DCFB377523115EE0256	0	0	SLEEVE	N	B	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
29A7E6E796724A4798310349DC8B49D4	1640	0	SLEEVE	N	B	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
4FEC47A62A344F55A3A382DF129EE788	0	0	SLEEVE	N	B	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
32560F07BD154717A9DDE0E605B84703	1130	0	SLEEVE	N	X42	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
4CFEC4E6FFA44327B8AB8CB73464B6FB	0	0	SLEEVE	Y	X52	High	Coal Tar (Not Insulated)	No/Unknown	HIGH
D10E49B504124A919B5DAB30D0380FF6	18510	0	SLEEVE	N	X42	UNKN	Coal Tar (Not Insulated)	UNKN	UNKN
B314BE30B17C4D3AB95302D033366563	0	0	SLEEVE	Y	X52	High	Coal Tar (Not Insulated)	No/Unknown	HIGH

Table D1 - Example of the base data format for the LTS Pipeline risk models showing sub-types and attributes as discussed above

D3.2. LTS Pipelines Probability of Failure & Deterioration Assessment

As maintainable assets with a high consequence of failure, significant investment is made to prevent LTS Pipelines from failing. Therefore it would be expected that for the failure modes with highest consequences of failure the observed failure rates will be very low. All theoretical failure modes have been benchmarked against and scaled to actual observed failures in the UKOPA records.

The main documents that the failure models have been based on are:

- UKOPA Pipeline Product Loss Incidents and Faults Report (1962-2013), December 2014, McConnell & Haswell, Ref UKOPA/14/0031.
- Assessing the risks from high pressure Natural Gas pipelines, IGEM/TD/2 Edition 2 with amendments July 2015 Communication 1779.
- Technical Note PIE/14/TN113:-Development of a model for classifying the health index of non-piggable pipelines.
- Technical Note PIE/14/TN125:- Models for classifying the health indices of block valves, sleeves and above ground crossings.
- Revision of the Intervals Methodology for Scheduling of In-line Inspection Frequency - Feasibility study (Cadent Gas Ltd)
- EGIG Gas Pipeline Incidents – 9th Report of the European Gas Pipeline Incident Data Group (period 1970-2013)

D3.2.1. Pipe Faults

A fault is a defect that has the potential to lead to a wall loss failure. The fault risk node calculates the number of faults along a pipe proportional to the number of defects. This equation ensures that every pipe has a non-zero risk and increases over time.

- For piggable pipes we use the actual number of defects wherever available and where zero the equation used to generate a future expected number of faults by replacing age with the simulation time period
- For non-piggable pipes we use an estimated number of defects per length split by pre- and post-1972 based on piggable pipes. This is then scaled by diameter. Faults increase as diameter increases due the increase in surface area of the pipe.
- Fault growth rate is then based on age
- Diameter, coating and depth scalars are used on a pie by pipe basis. Where depth is less than 1.1 metres the pipeline has an increased defect frequency (see Figure D4). To calculate this defect frequency multiplier the following equation is applied:

Defect Frequency Multiplier = 5+exp(DEPTH_M*-0.8)

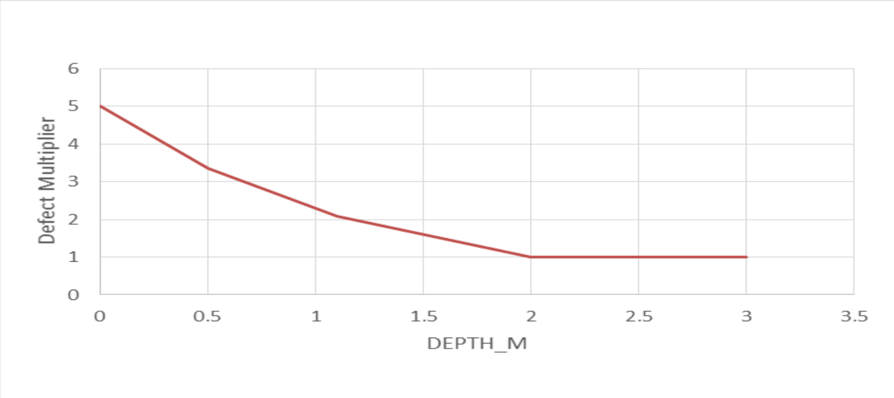


Figure D4 – Use of defect frequency multiplier to account for impact of pipeline depth

A global scalar is then used based on UKOPA data at company level

D3.2.2. Block Valve Defects

A Weibull model was fitted to the model outlined in the PIE report (PIE/14/TN125). This gives a survival curve fitted to a fixed end of life of 60 years and the related Hazard function to give the annual probability of failure (i.e. the red line).

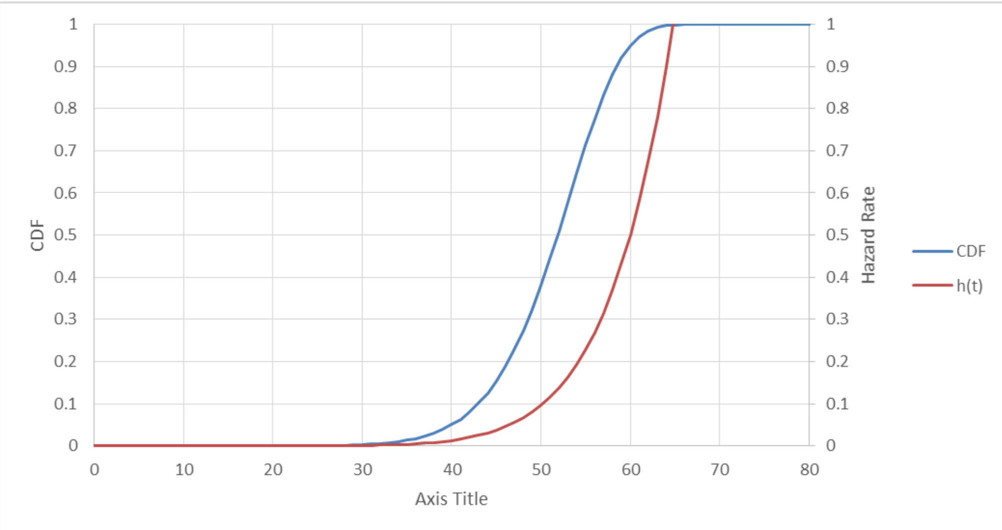


Figure D5 – Weibull model for block valve defects

The Weibull curve's shape and scale values are as per the Coefficients table in section D2.5.1.

The condition of the valve is used as a factor to adjust the probability of failure via an Effective Age calculation (As per D3.2.4)

The assessed condition is determined via GDN-specific visual condition surveys where available, aligned to common condition grades 1 to 5 as follows:

Condition Grade	Description
1	As new, no corrosion
2	Superficial corrosion
3	Minor corrosion, assessment/monitoring required
4	Moderate corrosion, intervention considered

5	Severe corrosion, intervention required

Table D2 – Condition Grade assessment

D3.2.3. Sleeve Defects

For Sleeve Defects the same model is used as per D3.2.2, but includes multiplying factors for each of the attributes as follows:

Attribute	Type	Factor
Pipeline Coating	Coal Tar	1.0
	Bitumen	1.2
	Polyethylene	1.1
	Epoxy	0.5
	Bare	1.5
Sleeve Material	Steel	1.2
	Concrete	1.0
	Other	1.5
Sleeve End Seal	Rigid	1.0
	Flexible	1.1
	Shuttering	1.3
	Other	1.3
Sleeve Fill Material	Concrete	0.8
	Thixotropic	1.0
	Air	2.0
	Nitrogen	1.2
	Other	1.0

Table D3 – Multiplying factors applied for Sleeve defects

D3.2.4. Effective Age

Age should be substituted for an 'effective age'. Effective age is a combination of condition and actual age.

- The Condition Grade of 1-5 is mapped against an age profile
- The inverse of this function is used to give an age at a given Condition Grade (see Figure D6)
- The Effective Age is a weighted combination the actual age and the condition-assessed age.

$$\mathbf{AGE\_EFFECTIVE = w * Condition\_Age + (w-1) * Actual\_Age}$$

Where w is a percentage weighting factor.

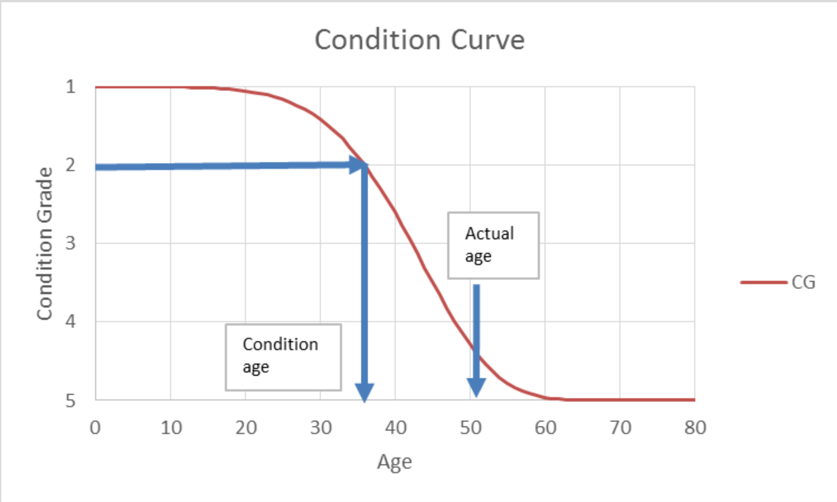


Figure D6 – Derivation of Effective Age from assessed Condition Grade

D3.2.5. Pipe Corrosion

The calculation for pipe corrosion is based on wall thickness deterioration..

- Wall deterioration coefficients are based on high, moderate or low corrosion resistance condition as reported in Intervals and PIE.
- For piggable pipes we use ACTUAL_WALL_THICKNESS as starting value where available
- For non-piggable pipes we use age (or Effective Age) and CP condition to calculate a predicted wall loss
- Feed the % wall thickness remaining into Weibull CDF model to predict probability of pipeline failure (as per PIE report, page 7).
- Scale by factors to account for town gas, coating, and sleeves (see Table D4).

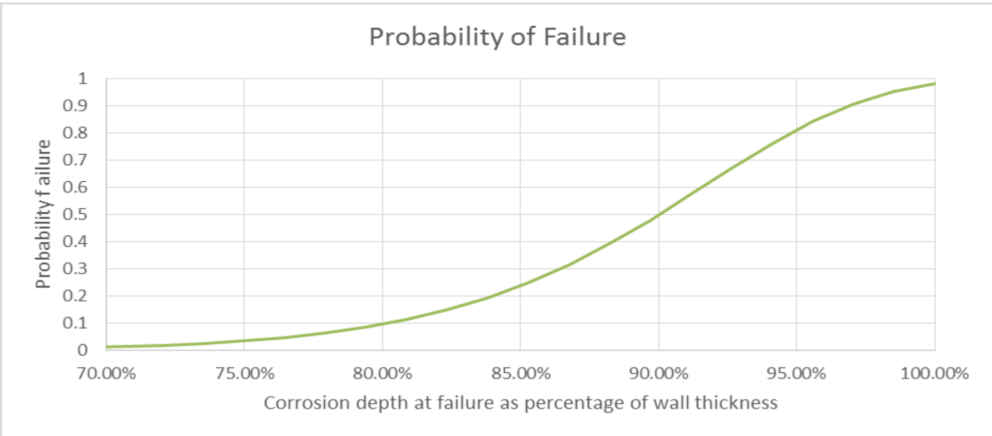


Figure D7 – Relationship between corrosion depth and PoF

For any Age (or Effective Age) of asset the PoF can then be calculated as per Figure D8.

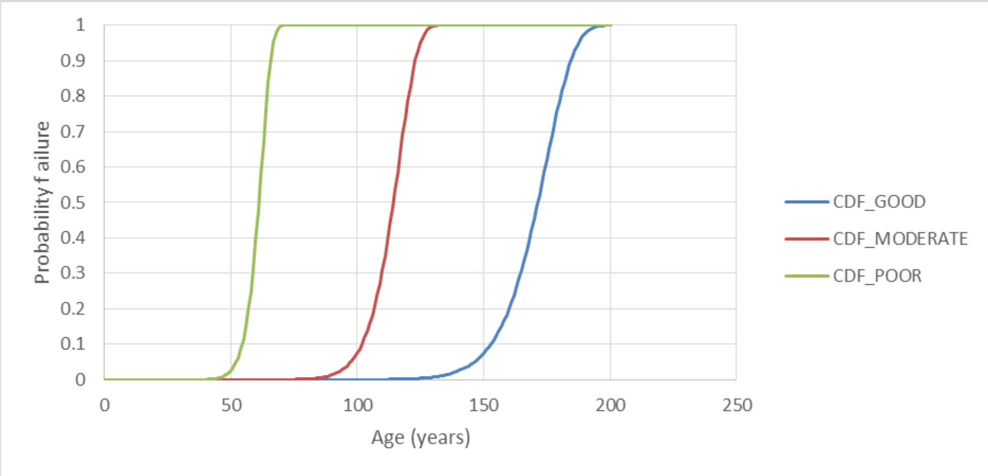


Figure D8 – Relationship between Effective Age and PoF

The Weibull shape and scale values are derived as per the coefficients table in D2.5.1 and scaling factors are applied as per Table D4:

Attribute	Type	Factor
Pipeline Coating	Coal Tar	1.0
	Bitumen	1.2
	Polyethylene	1.1
	Epoxy	0.5
	Bare	1.5
Town Gas	Yes	1.2
	No	1.0
Sleeve Condition	1	0.1
	2	0.1
	3	0.2
	4	0.6
	5	1
	None/Unknown	0.2

Table D4 – Factors applied to PoF to account for varying pipeline characteristics

Corrosion Deterioration

Analysis of UKOPA data has been undertaken to determine corrosion growth. This is shown in Figure D9 below and is compared to corrosion rates from Intervals and PIE.

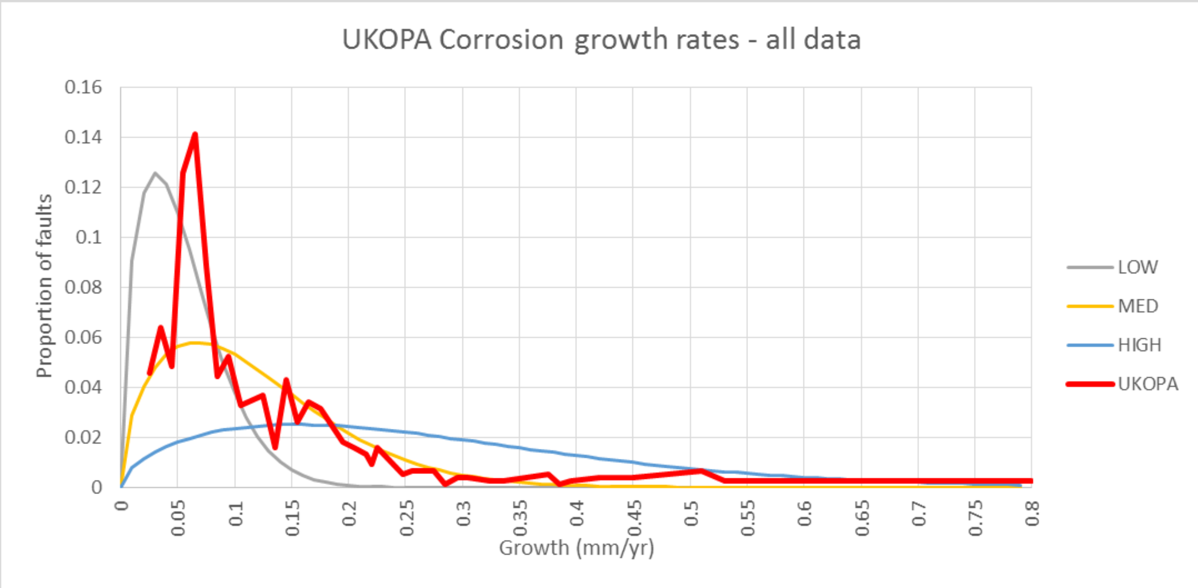


Figure D-9 Analysis of UKOPA data has been undertaken to determine corrosion growth

These are the Weibull distributions:

- High resistivity/low corrosion rate – Weibull(1.55,0.06), EV = 0.05 mm/yr
- Med resistivity/med corrosion rate – Weibull(1.55,0.13), EV = 0.12 mm/yr
- Low resistivity/high corrosion rate – Weibull(1.55,0.30), EV = 0.27 mm/yr

These values are considered in line with UKOPA data and therefore we would not recommend they are changed. However, uncertainty analysis can be undertaken by applying the Weibull distributions rather than using the expected values

When determining the level of corrosion resistance, it is important to recognise that a pipeline can be subject to different corrosion rates through the life on the pipeline.

In the early life of a pipeline when the coating and CP systems are generally in good condition, the pipeline would have a high resistance to corrosion. However, as the coating deteriorates and the CP system becomes less effective, the corrosion resistance reduces and the pipeline is subjected to higher rates of corrosion. If the high corrosion rate is applied to a thin wall pipeline over 40 years old, then it is not surprising that the pipeline will fail. It is important therefore to apply different corrosion rates to a pipeline as it ages to better reflect the condition of the pipeline.

CP System deterioration

The CP system deterioration affects the corrosion protection of the pipe and hence the corrosion deterioration. There are two types of CP Systems, Impressed Current and Sacrificial Anode, and while there are differences between the two, we believe for simplicity it is appropriate to consider them as the same.

The lifetime of a CP System is defined to be approximately 25 years (with onset of failure after 20 years), the corrosion protection is related to the deterioration of the CP system over its lifetime.

If a CP system has been replaced or refurbished, then the corrosion rate would reduce. Therefore, where a CP system has been recently surveyed, the actual condition of the CP system should be used to determine corrosion rate; however, this corrosion rate would only apply to the recent life of the pipeline.

The corrosion rate of a pipeline should therefore be modelled as follows;

0 - 20 years of pipeline life low corrosion rate unless actual survey results show a higher corrosion rate; this higher corrosion rate would apply for the whole of the last survey period.

OLI4 pipeline – 5 years (standard period between inspections)

OLI1 pipeline - 10 years (standard period between inspections)

20-30 years of pipeline life medium corrosion rate unless actual survey results show a lower or higher corrosion rate, this higher/lower corrosion rate would apply for the whole of the last survey period as above.

30+ years of pipeline life high corrosion rate unless actual survey results show a lower corrosion rate, this lower corrosion rate would apply for the whole of the last survey period as above.

Examples of how this would apply are given below;

Example 1 – OLI4 Pipeline constructed in 1970 (47-year-old), last CP survey carried out in 2014 showed the pipeline was well protected (i.e. low corrosion rate), would have the following corrosion rate profile:

0 to 20 yrs - Low Corrosion Rate

20 to 30 yrs - Medium Corrosion Rate

30 to 39 yrs - High Corrosion Rate

39 to 47 yrs - Low Corrosion Rate (2014 survey applies to last 5 years)

Example 2 – OLI1 Pipeline constructed in 1987 (30-year-old) with the last CIPP survey carried out in 2016 showed pipeline was not protected (i.e. high corrosion rate) would have the following corrosion rate profile:

0 to 19 yrs - Low Corrosion Rate

19 to 30 yrs - High Corrosion Rate (2016 survey applies to last 10 years)

D3.2.6 Pipe Mechanical Failures

Within IGEM TD2 Edition 2 page 24 (Assessing the Risks from High Pressure Natural Gas Pipelines) pipe mechanical failures are defined as "Mechanical failure including material or weld defects created when the pipe was manufactured or constructed".

IGEM TD2 page 47 Table 7 provides frequencies related to wall thickness. This can be turned into a power law function and then the predicted wall thickness from the corrosion model can be used as show in Figure D-10.

Wall Thickness (mm)	Pin	Small Hole	Large Hole	Rupture	Total
≤ 5	0.418	0.019	negligible	negligible	0.437
> 5 ≤ 10	0.040	0.016	negligible	negligible	0.056
> 10 ≤ 15	0.017	0.000	negligible	negligible	0.017
> 15	negligible	0.017	negligible	negligible	0.017

Table D5 – Frequency of mechanical failure (per 1000km) as a function of wall thickness

For pipelines commissioned after 1980, the material and construction failure frequency rate can be assumed to reduce by a factor of 5 (IGEM TD2 page 48).

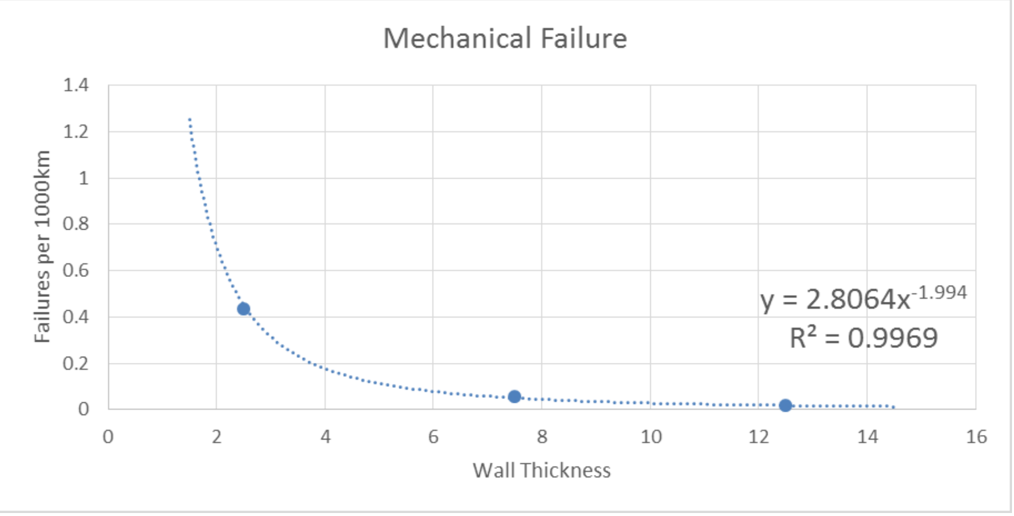


Figure D10 – Frequency of mechanical failure as a function of wall thickness as applied in model

D3.2.7. General Failures

For the purposes of the methodology, General failures and other causes are defined as failures "due to overpressure, fatigue or operation outside design limits" as per TD2 Ed2 page 24. No Deterioration rate has been assumed.

It is assumed that every failure causes a leak. This is assumed to be at a rate of 0.023 leaks per 1000 km per year, as per IGEM TD2 page 50.

D3.2.8. Interference

As per TD2 Section 8.2, the primary residual risk of failure for existing pipelines is due to external interference. Factors that influence the Interference failure rate include protection and depth and marker posts and surveillance along with wall thickness and design factor.

The Generic failure frequency for pipelines in "R" areas (rural) is given in Fig 13 IGEM TD2 page 44. Failure frequency in an "S" area (suburban) is 4 times that in an "R" area (rural) as per TD2 page 25.

The reduction in external interference probability of failure based on wall thickness and design factors (three design factors: 0.3, 0.5 and 0.72 as per IGEM TD2 page 27). Also the reduction rate is based on depth of cover, surveillance frequency and protection (concrete slabbing/marker posts) (as per TD2 pages 28, 29, 30 and 39).

For the purposes of the methodology it is assumed that the interference failure rate for valves is 1 in 10,000 per annum.

D3.2.9. Ground Movement

Ground Movement is defined as either natural (for example a landslide) or man-made (for example excavation or mining) as per IGEM TD2 p24.

Pipeline failure frequency is obtained from the landslide incident rate IGEM TD2 page 48 Table 8. It is assumed that there is a global frequency of ground movement events of 0.02 per 1000km per year as per IGEM TD2 page 48.

When global frequency is used, it is scaled up based on the landslide potential to obtain the values detailed in TD2 page 48 Table 8 (0.5, 0.05, 0.005). This includes watercourses and flood potential.

Survival value is also used as a multiplier for poor quality and high quality girth welds as per IGEM TD2 page 49 Figure 15.

Civils condition (graded 1 to 5) is also utilised to adjust the probability of failure.

- Where condition >3 then multiply by ***0.15 x exp(-0.18 x Wall Thickness)***
- Where condition <=3 then multiply by ***0.15 x exp(-0.30 x Wall Thickness)***

D3.3. LTS Pipelines Consequence of Failure Assessment

The following consequences of failure have been defined for LTS Pipelines and their ancillary assets.

Leak

A leak is defined as a gas escape from a stable hole whose size is less than the diameter of pipe. The number of leaks per year is calculated based on the frequency of corrosion, mechanical failures, general failures, interference events, and failures relating to ground movements along with the probability that each of the failure modes will lead to a leak. These were benchmarked against Product Loss - EGIG 9th Report Table 4 (1970-2013 period)

Rupture

A rupture is defined as a gas escape through an unstable defect which extends during failure to result in a full break or failure of an equivalent size to the pipeline. The number of ruptures per year is calculated based on the frequency of corrosion, mechanical failures, general failures, interference events, and failures relating to ground movements along with the probability that each of the failure modes will lead to a rupture. These were benchmarked against Product Loss - EGIG 9th Report Table 4 (1970-2013 period)

Ignitions

Leaks and ruptures have the potential to ignite. The probability of a leak igniting is based on the size of hole and operating pressure of the pipeline. The probability of a rupture igniting is based on the diameter and operating pressure of the pipeline. This considers, i) fireballs which occur in the event of an immediate ignition and ii) crater fires which occur in the event of a delayed ignition of the gas released into the crater formed by the release, or following the immediate ignition fireball.

Non-Ignition Impacts

A rupture can lead to a non-ignition impact e.g. blast damage/pressure wave. This may be i) a release of pressure energy from the initial fractured section, or ii) missiles generated pipe fragments or overlying soil. The consequence of a non-ignition impact have been assumed to be negligible compared to fire effects.

D3.3.1. Internal Consequence Costs

Internal consequences refer both to the proactive costs of preventing failure (or maintaining the asset to an acceptable level or risk) and the reactive costs of responding to failure. Proactive consequences include the costs of:

- Surveillance - cost from aerial/vantage surveys (**F_Surveillance**)
- Condition monitoring - OLI4,OLI1, valve, sleeve (**F_Condition Monitoring**)
- Land Costs – easement and access rights (**F_Land Costs**)
- General Maintenance – general maintenance on pipes, sleeves and valves etc. (**F_General Maintenance**)
- Compliance - aerial surveys, river surveys, access prevention measures, anti-vandal guards (**F_Compliance**)
- Cathodic Protection - inspections and new ground beds (**F_Cathodic Protection**)

Reactive consequences of failure include:

- Leak repair costs (**F_Repair Leak**)
- Cutout/replacement costs associated with repairing a rupture (**F_Cutout Replace**)
- Repair costs resulting from ground movement that has not led to a leak or rupture (**F_Rep_Ground**)
- Repair costs associated with an interference event that has not led to a leak or rupture (**F_Rep_Int**)
- Repair costs associated with fixing significant defects that have not lead to failures (**F_Defects**)

The costs of repairing the downstream network and restoring supplies following a supply outage are also included.

D3.3.2. Environment Consequence Costs

Environmental consequences include the monetary value of product lost due to failures or leakage plus the shadow cost of carbon associated with failure or emissions. In particular, the shadow cost of carbon increases annually (and hence the consequence value increases) in line with government carbon valuation guidelines. Environmental consequences modelled include:

- **Carbon** – the external cost of carbon associated with general emissions and loss of gas following failures. The environmental costs of burnt and unburnt gas are treated separately (**F_Carbon**)
- **Loss of Gas** – the product value of the loss of gas due to failure and general emissions. These volumetric values are taken from standard industry models (**F_Loss_of_Gas)**

A release of gas occurs because of a leak or rupture. The amount of gas released is dependent on the size of hole, diameter of pipe and the operating pressure.

There is carbon associated with the loss of gas. This is based on density multiplied by a carbon equivalent uplift which takes into account the composition of natural gas.

D3.3.3. Health & Safety Consequence Costs

Health and safety incidents can result from ignitions and non-ignition impacts. These can differ in severity, and the following severities have been included:

- Death or major injury from ignitions
- Minor injury from ignitions
- Property damage from ignitions
- Damage to railways from ignitions
- Damage to roads from ignitions
- Death or major injury from non-ignition impacts
- Minor injury from non-ignition impacts

The probability of death/major injury and minor injury following an ignition is based on the concept of properties within zones around the pipelines.

The 'Inner Zone' is closest to the pipeline and represents the area between the pipeline and the Building Burning Distance. It is assumed that 100% of people within the zone are killed, or receive major injuries. It is also assumed that all properties are damaged.

The 'Middle Zone' is the area between the Building Burning Distance and the Escape Distance. It is assumed that 5% of people within the zone are killed, or receive major injuries and 5% receive minor injuries. It is also assumed that 25% of properties in the 'Middle Zone' are damaged.

The 'Outer Zone' is outside of the previous two described zones and it is assumed that all people in these zones escape without injury and property damage is minimal

The length of road and rail in relation to the length of the asset is used as a proxy to the probability of road and rail damage.

The probability of death/major injury from a non-ignition event is based on the assumption that 1% of the people living in the inner zone would be in the immediate vicinity (e.g. dog walking) and there is a 0.1% likelihood of them being killed. The probability of a minor injury from a non-ignition event is based on the same assumption that 1% of the people living in the inner zone would be in the immediate vicinity, but that there is a 1% likelihood of them receiving minor injury.

Modelled health & safety consequence events include:

- **F_Death** (Death or major injury from ignitions, Death or major injury from non-ignition impacts)
- **F_Minor** (Minor injury from ignitions, Minor injury from non-ignition impacts)
- **F_Building** (Property damage from ignitions)
- **F_Rail** (Damage to railways from ignitions)
- **F_Road** (Damage to roads from ignitions)

D3.3.4. Customer Consequence Costs

Customer consequences include compensation payments generated through supply interruptions caused by asset failure.

Supply interruptions can result from leaks and ruptures. An interruption from a leak only occurs if there is no alternate source. If there is an alternate source a supply interruption from a leak will only occur 15% of the time. An interruption from a rupture is assumed to always occur if there is no alternate source and only occur 75% of the time if there is an alternate source.

Supply interruptions are categorised into the type of properties impacted; domestic, small commercial, large commercial and critical and the numbers in each category are calculated. A proportion of the domestic and critical customers will be displaced due to lack of supply. This has been estimated to be 10%, which is derived from the percentage of the population on the Priority Services Register.

Complaints arise as a result of a supply interruption. It has been assumed that 30% of domestic, small commercial, large commercial and critical premises would complain along with all directly fed premises.

Modelled customer compensation consequence events include:

- **F_Domestic** (D1 type properties compensation payments and cost of restoring supply)
- **F_Displacement** (D1 and C2 type properties cost of alternative accommodation & travel)
- **F_Critical** (C2 and I2 type properties compensation payments and cost of restoring supply)
- **F_Com Large** (C3 and C4 type properties compensation payments and cost of restoring supply)
- **F_Com Small** (C1 type properties compensation payments and cost of restoring supply)
- **F_Complaint SI** (Number of complaints arising from a supply interruption).

D3.4. LTS Pipelines Intervention Definitions

Intervention activities can be flexibly defined within the monetised risk trading methodology by modelling the change in risk enabled by the intervention activity.

Some interventions, such as sleeve remedials, will reduce both the Probability of Failure and deterioration of the overall asset base, thus changing the monetised risk value over the life of the asset. This is called a **With Investment** activity below.

Other types of intervention may just represent the base costs of maintaining the asset at an acceptable level of performance, for example undertaking surveys to assess corrosion. This is called a **Without Investment** activity below.

Definitions of activities undertaken as part of normal maintenance (i.e. 'without intervention') and interventions for LTS are listed below.

'Without intervention' activities:

- Aerial (Helicopter) Surveys

- Aerial Marker Post replacement
- TD1 Surveys
- TD1 infringement Surveys
- Vantage Point Surveys
- Landowner Liaison
- Above Ground Crossings Surveys
- River Bank/Bed Survey (when in proximity / crossing with a pipeline)
- OLI1/4 Surveys

'With intervention' activities:

Number	Description	Definition
Intervention 1	Diversions	Abandon old pipe and new pipe in new route.
Intervention 2	Pipe Refurbishment	Pipe remedial, eg recoating, sleeving
Intervention 3	CP Major Refurb	New transformer install and/or new anode ground bed.
Intervention 4	Above Ground Crossings Remedial (Structural, Painting, Anti-vandal Guards)	Remediate exposed crossings (above ground sections only) - support and coatings.

Table D6 – With Investment interventions for LTS Pipelines

D3.4.1. LTS Pipelines Intervention Benefits

The risk modelling tools developed for the monetised risk analysis provide the ability to flexibly model any intervention by adjusting the values of the calculated risk nodes to match the expected performance of the asset following intervention. For example, replacing a sleeve on an LTS Pipeline will:

- Reduce the number of defects by 1
- Set the corrosion rate to low
- Reduce the probability of interference and ground movement to 'low' (through improved design to mitigate the risk)

Because LTS Pipelines (and ancillaries, such as sleeves and valves) have highly individual characteristics, such as pressure, diameter and properties at risk, grouping into cohorts is not generally desirable and the analysis should be performed at asset level. However, it may be necessary on occasions to include descriptors (such as Flood Risk) in the cohort definition to allow specific interventions to be planned.

D3.4.2. Example LTS Pipelines Interventions

Two example LTS Pipelines interventions are provided for illustration of the process.

- LTS Pipeline Refurbishment
- CP System Refurbishment

These are both With Investment interventions.

The baseline level of monetised risk (or the sum of all financial risk nodes) for LTS Pipelines and ancillaries are shown below for the sample data set:

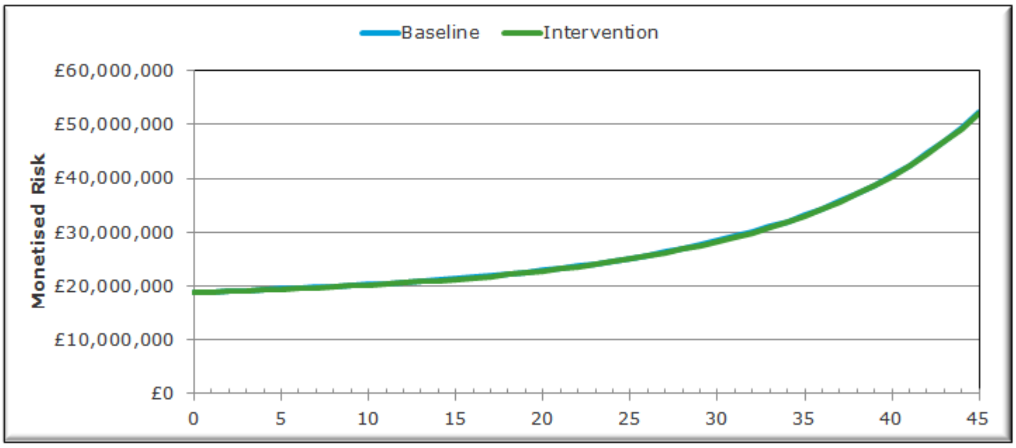


Figure D11 - Baseline monetised risk for LTS Pipelines over 45 years

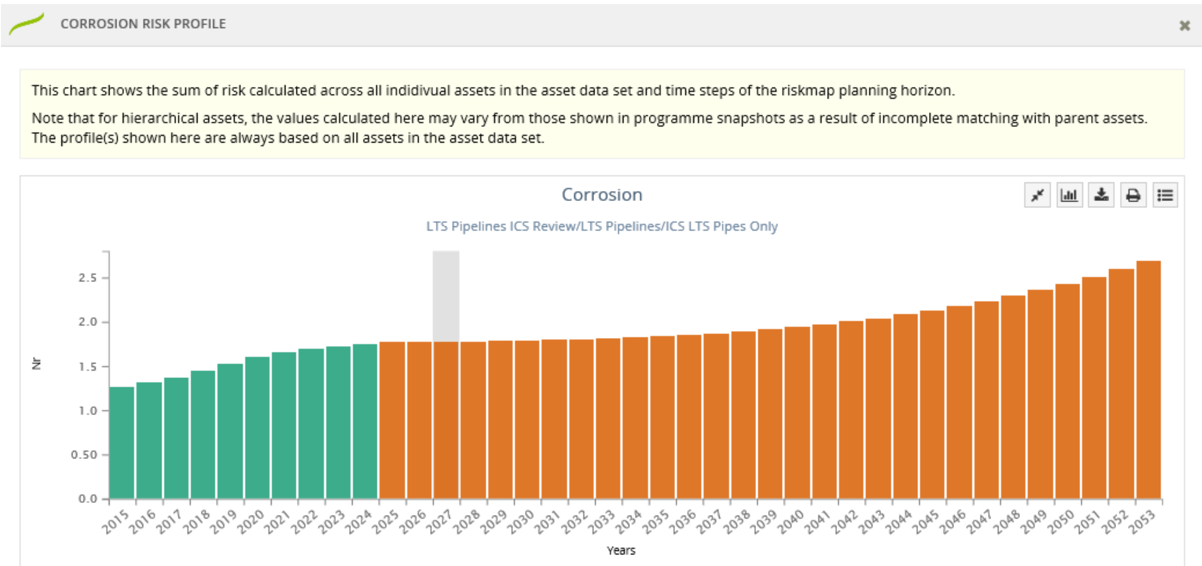
Figure D11 shows how the baseline risk for all LTS Pipelines changes over 45 years. Monetised risk (for the example dataset) increases from a current value of around £million per year to a value of around £52million in 45 years' time, without investment.

Example 1 – Pipe Refurbishment

The refurbishment is digging the pipe up and fixing that section, either by recoating the pipe or placing a sleeve over the leak. The assumption is that it reduces the risk of a fault on that section by 1. This allows for proportional risk on the rest of the pipe.

Example 2 – CP System Refurbishment

A CP system refurbishment is a large scale upgrade to a CP system, ie a new Transformer/rectifier and/or a new anode ground bed. This will reduces the corrosion deterioration rate in the model to low. It does not change the condition of the pipe, just the future deterioration.



Appendix E – Offtakes & PRSs

E1. Offtake & PRS Definition

Offtakes are installations which provide the exit point from the National Transmission System (NTS) into the Distribution System. They typically comprise the following components: Filters, Metering, Pre-heating, Slam Shuts, Pressure Reduction and Odorant plant. These are illustrated in Figure E1 below. PRS are installations within the Distribution system which progressively reduce pressure through the distribution system. Many elements are common between Offtakes & PRS.

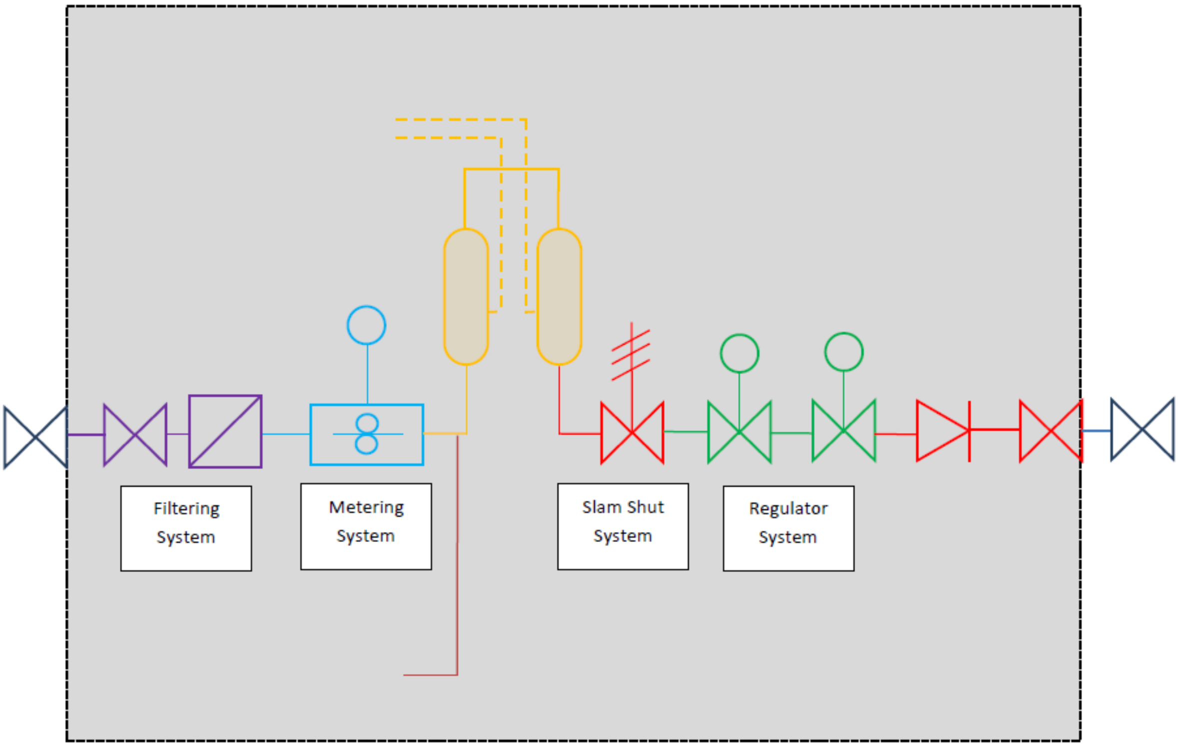


Figure E1 – Schematic of typical PRS/Offtake station (excluding odorant)

E1.1. Civils

Civils assets, which include: inner/outer fencing; security systems; roadways; drainage; bunds/berms; ductwork; and buildings, are not treated as separate assets in the event tree. Kiosks and Fencing are treated as attributes of the individual systems, which impact on the Corrosion and Interference Failure risk nodes. Other asset maintenance costs are considered to be included in General Maintenance risk node. Costs to ensure site compliance with safety or legislative requirements are included in the Compliance risk node.

E1.2. Electrical, Instrumentation & Telemetry

These assets are not treated as separate assets, but are considered through the analysis of the overall impact of failure associated with the PRS/Offtake station. These assets include (but are not limited to):

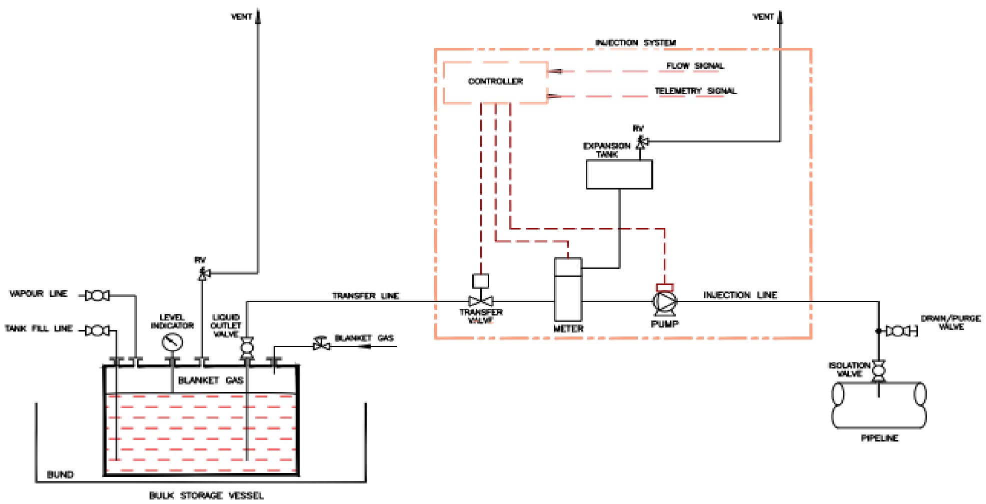
- Electrical supplies, distribution boards and earthing systems
- Offtake telemetry systems including back-up ISDN communications to provide constant communication back to Gas Control Centres. These will generally report flow rates, both energy and volume, and pressure from the Meter, whilst Odorant telemetry will report volume injected. Alarms such as LGT pump failure on the odorant system and Meter condition based alarms can be sent via telemetry.
- PRS telemetry systems, where installed, will generally monitor inlet pressure, outlet pressure, outlet temperature (where pre-heating is installed) and the differential pressure across each or all filters.

E1.3. Associated Pipework

The pipework connecting assets is included within the overall system. Such pipework is liable to failure through corrosion or interference. Pipework is especially vulnerable at the transition between above and below ground sections, where it passes through gland plates or walls, where it is located under lagging or in below ground ducts or where it is exposed to the elements.

E1.4. Odorisation

This is a facility to introduce odorant to the gas flow prior to its entry into the distribution network. Odour is injected via a pumping system into the LTS system at a National Offtake to give gas its distinctive smell. The odorant is stored in a tank surrounded by a concrete bund able to hold 110% of the capacity of the tank volume as per IGEM-SR-16 Edition 2.



Note: Illustrative purposes only. The diagram does not purport to show all necessary components.

Figure E2 – Schematic of Odorisation facility

E1.5. Metering

A Metering system compromising of one or more requisite meters is installed on a National Offtake upstream of the Pressure Reduction System. Metering systems are used to ensure accurate reporting of flows.

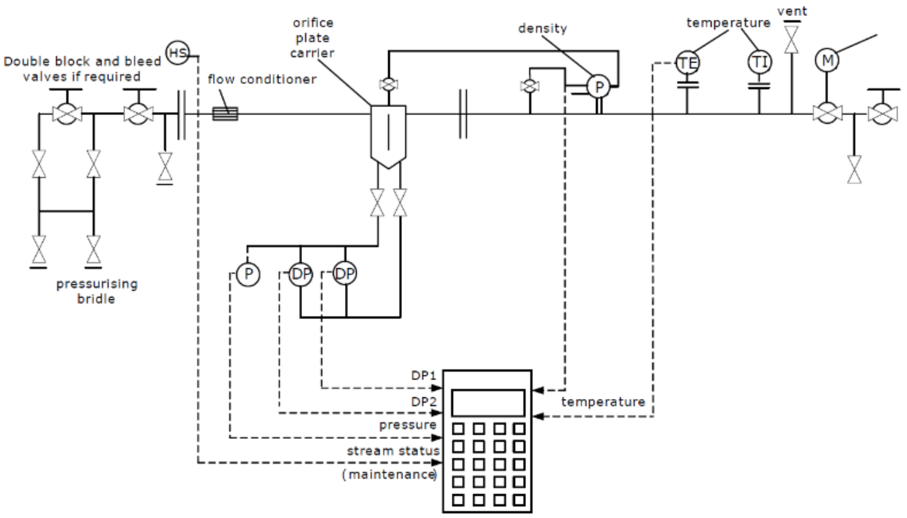


Figure E3 – Schematic of Metering facility

There are generally 3 types of Meters on National Offtake Installations:

Orifice Meter – An Orifice Meter determines flow by means of a measurement of the differential pressure (DP). DP is induced by the flow of gas through a thin plate with a sharp square-edged opening which is circular and concentric with the pipeline. The flow rate is related to DP, gas temperature, pressure, density, viscosity, isentropic exponent and the geometry of the orifice plate and the associated pipework.

Turbine Meter – The operation of a turbine meter is based on the measurement of the velocity of gas. The flowing gas is accelerated and conditioned by the meter's straightening section. The integrated straightening vanes prepare the gas flow profile by removing undesirable swirl, turbulence and asymmetry before the gas reaches the rotating turbine wheel. The turbine wheel is mounted on the main shaft with special high-precision, low-friction ball bearings. The turbine wheel has helical blades that have a known angle relative to the gas flow. The conditioned and accelerated gas drives the turbine wheel with an angular velocity that is proportional to the gas velocity. The rotation of the turbine wheel and the main shaft transfers this drive to a mechanical counter in the meter index head. The rotating turbine wheel can also generate pulses directly by proximity sensors that create a pulse for each passing turbine blade. By accumulating the pulses, the total passed volume and gas flow rate can be calculated.

Ultrasonic Meters (USM) – Ultrasonic Meters are based on the measurement of the propagation time of acoustic waves in a flowing medium. This 'time of flight' technique consists of a number of ultrasonic transmitters and receivers positioned across a chord in a circular pipe. The 'time of flight' of ultrasonic pulses is measured both with and against the flow. Since the ultrasonic pulses travel faster with the flow then against the flow, the transit time is shorter when they travel with the flow compared with that measured against the flow. (Source: IGE/GM/4 Edition 2).

E1.6. Pre-Heating

This is a facility to pre-heat gas prior to pressure reduction to mitigate the effect of low outlet temperatures, due to the Joule-Thomson effect (a temperature drop as a result of pressure reduction). The installation of gas pre-heating is required to avoid a loss in control or possible failure of downstream pressure regulating equipment. As per IGEM TD/13 the outlet temperature needs to maintain a minimum temperature of 0°C.

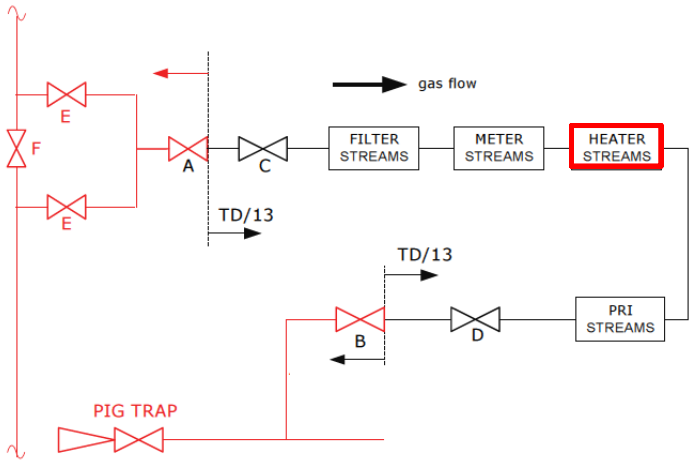


Figure E4 – Schematic of Pre-heating facility

Typical pre-heating methods include:

- Waterbath heater
- Package boiler systems with heat exchangers
- Electrical immersion

The sizing of these heating systems have been determined by calculating the amount of heat required to maintain the desired installation outlet temperature, accounting for the maximum pressure drop across the system, the flow through the system and any other heat losses associated with the system.

Although these are providing fundamentally the same function, there are significantly different types of complexity in both the mechanical make up and control systems

Waterbath Heaters - A waterbath heater provides the required thermal heat through a thermal solution of water with antifreeze and corrosion inhibitor properties. Gas burners are fired into a large fire tube which heats up this thermal medium to transfer heat to the gas coils that generally multipass and can vary greatly in size depending on the system design. Exhaust gases are released through a flue stack that must be sized and maintained along with the air intake to ensure efficiency of the system.

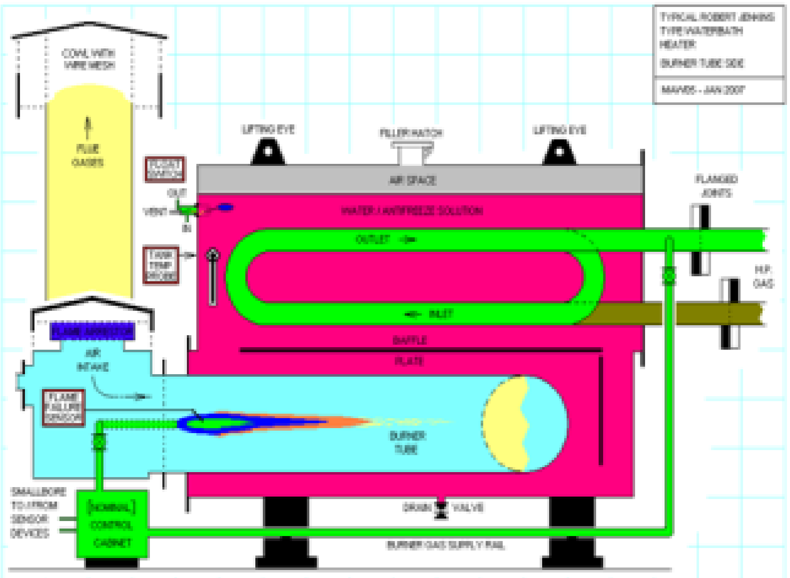


Figure E5 – Water Bath Heater

Modular Boiler Systems - Modular boiler systems offer an increased efficiency compared to waterbath heaters. They provide heat to the gas flow through external heat exchanger systems that are also subject to cyclical revalidation inspections. These include external and internal inspection of the heat exchanger tube bundle and pressure testing to identify and repair any defects. Although these systems are more efficient they can prove to be less reliable than waterbath heating systems due to the increased complexity of the technology (both boiler equipment and the PLC control system).

Electrical Heater Systems - An electrical pre-heating system provides gas heating through immersion heaters. These are reliable systems due to their low complexity of the heating delivery and control system. They are generally used on installations with low gas heating requirements as there are limitations on the heat transfer these units can provide due to the substantial power requirements which cannot be provided by standard mains power systems.

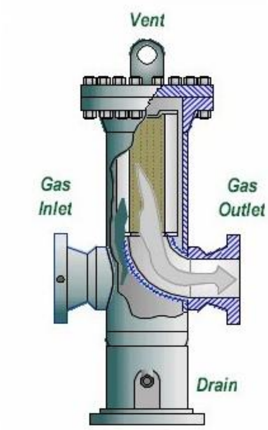
Figure E5 – Electrical Heating System

To ensure consistency in determining the population of pre-heating systems across the GDNs, the following definition will be used (this approach is consistent with the other asset systems on >7bar installations):

- Any pre-heating systems feeding into one pressure reduction system on site will be deemed as one pre-heating system with the number of heaters deemed as streams to ensure redundancy is considered
- Any installation that has one heating system followed by a pressure reduction system, then followed by another pressure reduction system that is not pre-heated again can be classed as one pre-heating system, with the number of relevant streams. This system will be assigned to the highest pressure level from an installation type.

E1.7. Filters

Filter systems comprising two or more gas filters are normally installed within an Offtake or PRS typically upstream of the pressure control system in order to filter out dust or debris in the gas flow. Such filtration serves to ensure a supply of clean gas to the downstream system and also protect the regulators or control valves from damage.



IGEM recommendations, IGEM/TD/13 Edition 2 states that "if there is any possibility that dust or liquid could be present in the upstream gas system, consideration shall be given to incorporating a filtration system".

Filters may be arranged in parallel with common inlet and/or outlet pipework or within individual pressure reduction streams. Valves located on the inlet and outlet of each filter allows isolation and removal of filter elements for cleaning or replacement.

Filters are normally categorised as pressure vessels and are therefore encompassed within the Pressure Systems Safety Regulations 2000 including relevant examinations.

E1.8 Pressure Control

The pressure control system within an Offtake or PRS is designed to provide a flow of gas at constant pressure into a downstream system and will typically comprise:

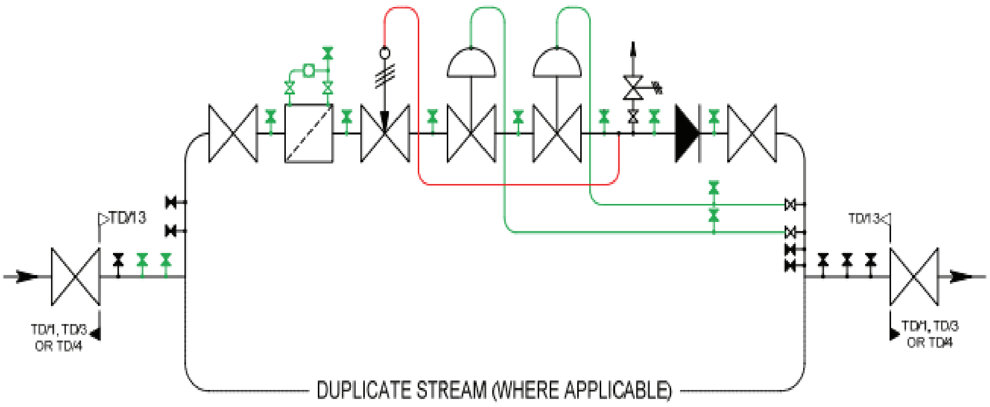


Fig E6: Typical slamshut, valve, monitor and active regulator arrangement

- Two or more parallel streams of regulators or control valves controlling the pressure to the downstream system. At least one stream would normally be denoted as a standby stream as a precaution against failure of another, thereby ensuring redundancy.

- Within each stream, there are typically two regulators or control valves operating either in monitor / active configuration or in first / second stage configuration with a monitor override within the first stage. Such configurations ensure pressure control is maintained in the event of any single component failure.
- The regulators or control valves will typically include a pilot or other auxiliary control system, which is considered to form part of the regulator or control valve.
- Each stream will also include a safety device; typically a slam shut valve or other actuated valve, upstream of the regulators or control valves to protect the downstream system from over-pressurisation.
- Each stream will also include valves upstream and downstream of the main components to allow isolation of the stream for maintenance.
- The pressure control system also includes stream selection systems and relief valves.

Many, but not all, offtakes are designed to control the flowrate of gas from the upstream systems, normally the National Transmission System, into Local Transmission Systems at a constant rate as agreed on an hourly basis between the Transmission operator and the Distribution Operator. These are termed 'volumetric controlled offtakes'.

For the purposes of this methodology, a volumetric control system is included within the 'Filter and Pressure Control' system.

E2. Offtake & PRS Event Tree Development

E2.1. Offtake & PRS Failure Modes

Failure Modes have been identified for Offtakes & PRSs consistent with the process outlined in Section 3.4 of the main methodology. Failure modes were identified through a number of workshops with asset experts and through careful analysis of available data held by companies to assess and quantify the rate of failures and future asset deterioration. The monetised risk analysis for Offtakes & PRS assets is split across 3 separate Event Trees, namely:

- Odorant & Metering
- Pre-Heating
- Filtration & Pressure Control

The logic for this split is that these 3 Event Trees are significantly different, in terms of identified failure modes and consequences of failure, whereas (for example) Odorant and Meters share similar failure modes and consequences. This is discussed later within this section. However, there is the possibility for these Event Trees to be combined at a later date if asset inter-dependencies can be identified and quantified.

E2.1.1Odorant & Metering

Odorant and metering systems comprise a number of components, to which a defined set of failure modes apply. To simplify matters, a more concise list of outcomes have been modelled. This avoids the need to accurately identify the root cause of the observed failure which can often be difficult to diagnose, or is not properly recorded. The failure nodes for Offtake and PRS Odorant & Metering comprise of the following:

Over-Meter Reading – where meter readings are higher than the actual flow, resulting in incorrect readings whilst also effecting the measurement of odorant being injected into the gas system. These failures can be caused by:

- Operator error
- Equipment fault

No/Under-Meter Reading – where meter readings are lower than actual or volumes aren't being read, resulting in incorrect readings whilst also affecting the measurement of odorant being injected into the gas system. These failures can be caused by:

- Operator error
- Equipment error
- Total failure
- Capacity issues

High Odorant – Where high levels of odorant are injected into the gas supply. This could result in an increase of public reported escapes. These failures can be caused by:

- A meter error
- Operator error (caused by instructing both pumps to inject)

Low Odorant – Where levels of odorant are too low to meet the flows of gas going through a site. This could lead to a non-detection of a gas escape. These failures can be caused by

- A meter error
- LGT pump failure
- Operator error
- Capacity issues

Release of Gas – relating to the failure of a pressure containing component on site leading to an unconstrained release of gas within and possibly of site. Such components failures include;

- Defects within the LGT injection system
- Corrosion or other defects in site pipework allowed to go to failure
- Interference damage leading to component failure

Relief valve operation and other controlled releases of gas are not included as such releases are constrained through appropriately designed vents with appropriate zoning of hazardous areas.

Release of Odorant – resulting from a failure of containment leading to a release of odorant into the atmosphere. This could lead to an increase in public reported escapes in the vicinity of the installation. This failure could be a result of;

- Severe corrosion of the odorant tank
- Severe breakdown of concrete bund
- Interference by 3rd party
- Release of odorant during delivery

General Failure - relating to other failures not leading to either a safety, environmental or gas supply related consequence. Such failures may include failure of the instrumentation/ telemetry system or a telemetered alarm (such as LGT Pump A alarm).

Note, for all failure modes above capacity issues are defined as when the system has insufficient capacity to meet forecast 1:20 peak day downstream demand.

E2.1.2Pre-Heating

A number of the failure modes are applicable to preheating systems such as but not limited to burner ignition, control, gas supply systems additional to mechanical failures. However, due to the variance of heater designs and the complexity and inter-related nature of these failure types it is regarded appropriate to model the failure modes in a more simplistic way by modelling the failure effects (or consequences). This avoids the need to accurately identify the root cause of the observed failure which can often be difficult to diagnose, or is not properly recorded.

As the vast majority of preheating systems are telemetered it is more accurate to model failure rates with regards to operation outside the allowable outlet temperature range. The failure nodes for Offtake and PRS Preheating comprise of the following:

Release of Gas – relating to the failure of a pressure containing component on site leading to an unconstrained release of gas within and possibly off the site. Such component failures include:

- Defects within waterbath heater, heat exchanger shells, gas supply pipework, gas tubes and other components allowed to propagate to failure
- Corrosion or other defects in preheating related pipework, flanges, fittings and preheating pressure vessel bodies
- Interference damage leading to component rupture.

High Outlet Temperature – relating to the failure of the preheating system to provide the correct heat input for that associated site gas flow rate resulting in high outlet temperatures. This event could result in the following types of failures:

- Degradation of perishable components such as seal and diaphragms resulting in a reduction or complete loss of control of downstream pressure regulation equipment

Low Outlet Temp – relates to the failure of the preheating system to provide the correct heat input for that associated site gas flow rate resulting in low outlet temperatures. This event could result in the following types of outcomes:

- Loss of ability of the downstream pipe material to retain satisfactory physical characteristics at any reduced temperature of operation
- Detrimental effects on pilot control systems
- Possibility of hydrate or liquid formation which could influence the operation of PRS and downstream equipment
- Ground heave on adjacent plant, buildings, roads and other services
- Potential damage caused to arable and cereal crops
- Mains failure due to low temperature embrittlement
- Loss of gas conditioning efficiency due to reduced MEG saturation
- Degradation of pipeline coatings
- Low temperature effects on agricultural irrigation systems

General Failure – relates to other failures not leading to release of gas, low/high outlet temperature or capacity failures. Applicable failures for preheating systems may include spurious heater water level alarms, burner and exhaust/flue adjustments and PLC control system resets etc.

Capacity – where the system has insufficient capacity to meet a forecast 1:20 peak day downstream demand

E2.1.3 Filters & Pressure Control

A number of failure modes are applicable to Filters & Pressure Control; therefore it is regarded appropriate to model the failure modes in a more simplistic way by modelling the failure effects (or consequences). This avoids the need to accurately identify the root cause of the observed failure which can often be difficult to diagnose, or is not properly recorded.

It should be noted that this is a different approach than that taken for Governors, which are similar/identical assets situated on lower pressure systems, where generally the true failure modes were modelled.

The failure nodes for Filters and Pressure Control comprise the following:

Release of Gas – relating to the failure of a pressure containing component on site leading to an unconstrained release of gas within and possibly off the site. Such component failures include:

- Defects within filter bodies or other components, which are allowed to propagate to failure
- Corrosion or other defects in site pipework allowed to lead to failure
- Interference damage leading to component rupture

Relief valve operation and other controlled releases of gas are not included as such releases are constrained through appropriately designed vents with appropriate zoning of hazardous areas.

High Outlet Pressure – relates to the failure of the Pressure Control system to control the pressure at least to within the Safe Operating Limit of the downstream system. This would typically require the concurrent failure of both regulators and the slamshut (failure to operate) within one Pressure Control stream. Such concurrent failures are rare, but the probability of failure may be inferred through available data associated with individual component faults.

Low Outlet Pressure – relates to the failure of the Filter and Pressure Control system to supply gas at adequate pressure leading to partial or total loss of downstream supplies. Such a failure mode may be the result of:

- Blockage of all filters due to upstream contamination
- The failure of all regulators in all streams leading to slam shut operations
- The spurious operation of all slam shut valves
- Another failure on-site necessitating isolation of the site to safeguard life and property

General Failure – relating to other failures not leading to either a safety, environmental or gas supply related consequence. Such failures may include failure of the instrumentation or telemetry system.

Capacity – where the system has insufficient capacity to meet a forecast 1:20 peak day downstream demand.

E2.2. Offtake & PRS Consequence Measures

Consequence measures have been identified for Offtakes & PRSs consistently with the process identified in Section 3.5 of the main methodology.

Consequence values are dependent on the consequences being assessed. Consequences are highlighted in pink on the risk map. Some of these consequences are clearly inter-related, as detailed in the risk map.

Due to lack of observed data consequence values were largely elicited through a workshop with over 20 asset experts representing each of the gas networks. For the response to each question posed a statistical distribution was fitted to the data to give an estimate of the average value for the consequence and a most likely uncertainty distribution associated with the average estimate. These are used in the relevant risk nodes.

For each asset sub type a Time to Detect and Repair (TTR) was elicited and a lognormal distribution fitted. This distribution is then compared to the time to service failure (TTSF). If the TTSF is less than the TTR then there is a high probability of a consequence occurring. Additionally, the likelihood of the failure event being detected by telemetry is also included. The probability of consequence is therefore:

PoC = (1-LnormCDF(TTSF, TTR_shape, TTR_scale)) * prob of telemetry not working + (1-LnormCDF(TTSF, TTR_shape, TTR_scale)) * prob of telemetry working

This is illustrated in Figure E7 below:

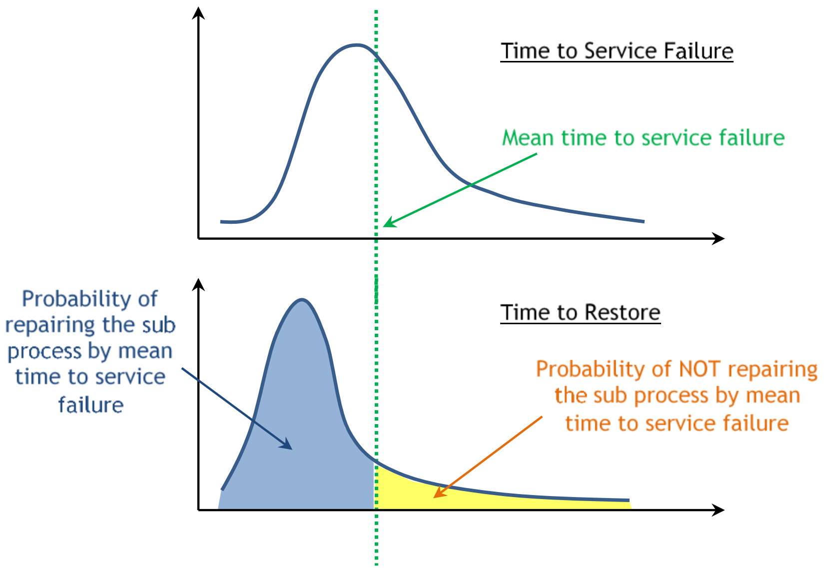


Figure E7 – Statistical modelling of TTSR and TTR

E2.2.1 Odorant & Metering

The following consequence measures were identified for Odorant and Metering assets:

- **PRE Odour Release** – an Increase in Publicly Reported Escapes in the vicinity of the Offtake due to Odour Release
- **Release of Gas** – a loss of gas arising from the Odorant/Metering asset itself
- **DS Undetected Escapes** – undetected gas escapes downstream
- **PRE High Odour** – an increase in Public Reported Escapes downstream of the network due to Odour Release
- **Explosion** – an explosion, either at the Odorant/Metering asset itself or in the downstream network

E2.2.2 Pre-Heating

The following consequence measures were identified for Pre-heating assets:

- **DS Gas Escapes** – an Increase in gas escapes in the downstream network due to low outlet temperatures
- **Loss of Gas** – a loss of gas arising from the Pre-heating asset itself or the downstream network
- **Explosion** – an explosion, either at the Pre-Heating asset itself or in the downstream network
- **Ground Heave** – Events resulting in damage to structures, roads and other assets due to low outlet temperatures
- **PRS Site Failure** – a site failure resulting in loss of supply to downstream domestic, commercial or industrial consumers

E2.2.3 Filters & Pressure Control

The following consequence measures were identified for Filter and Pressure Control assets:

- **DS Gas Escapes** – an Increase in gas escapes in the downstream network due to low outlet temperatures
- **Loss of Gas** – a loss of gas arising from the Filters & Pressure Control asset itself or the downstream network
- **Explosion** – an explosion, either at the Filters & Pressure Control asset itself or in the downstream network
- **PRS Site Failure** – a site failure resulting in loss of supply to downstream domestic, commercial or industrial consumers

E2.3. Offtake & PRS Risk Map

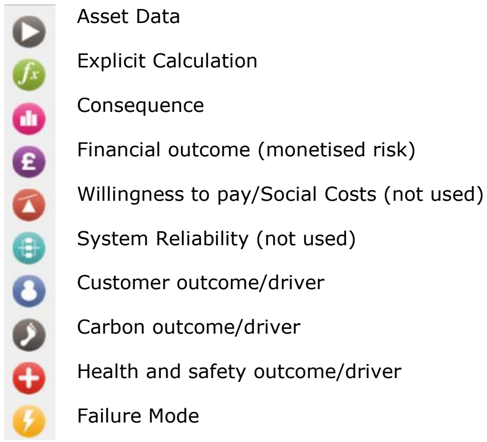


Figure E- 8 - Risk Map Key

As per the process described within section 3.6, the risk maps for Odorant & Metering, Pre-Heating and Filters & Pressure Control are shown below.

Figure E-8 outlines the risk map key for Offtakes and PRS. The risk map is colour coded for each node of the event tree to indicate which values are associated with each node. The colours are reflected in both the risk maps and risk map template in Figures E-9 to E-14.

E2.3.1 Odorant & Metering Risk Map

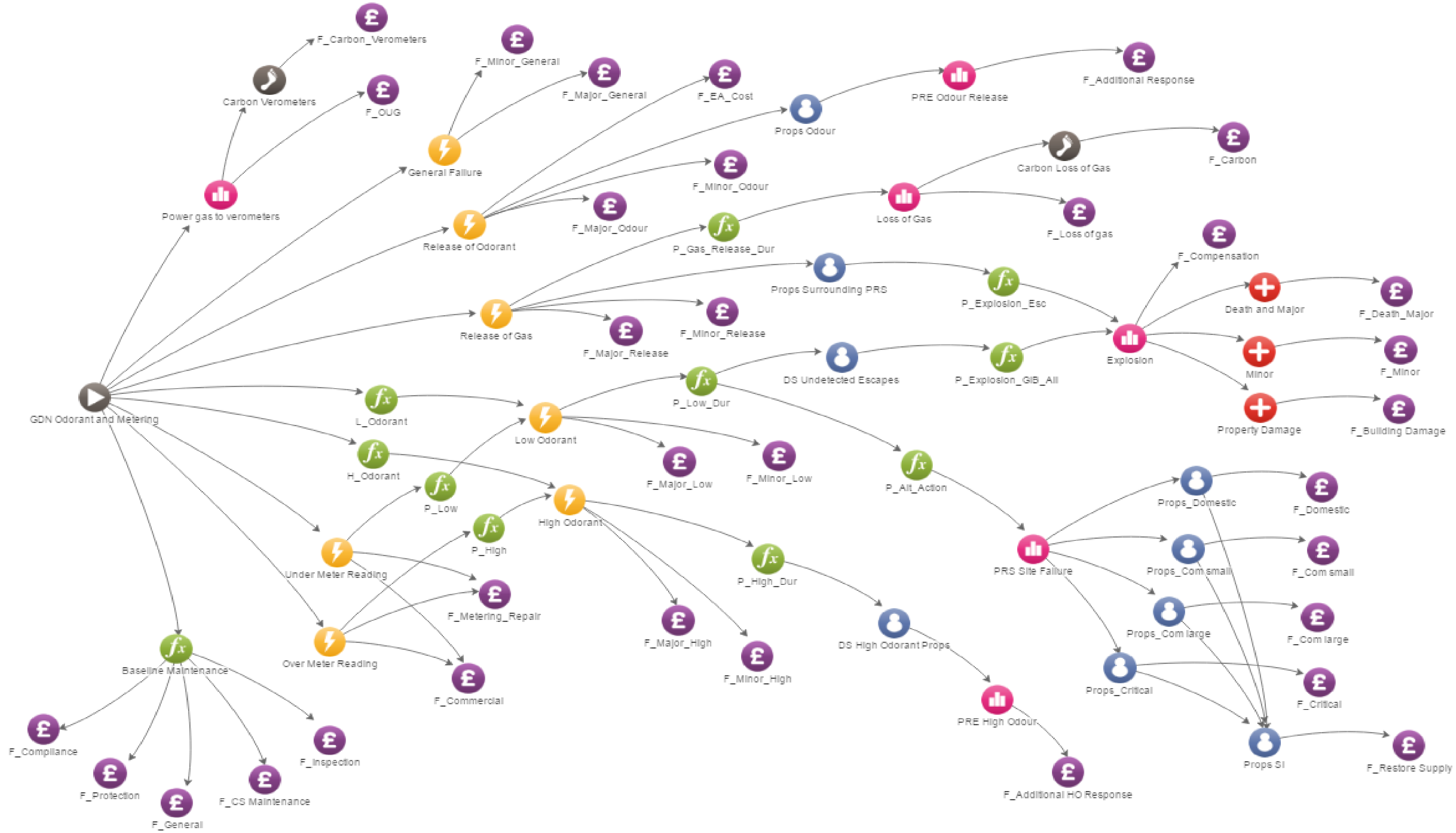


Figure E- 9 Odorant Risk Map

E2.3.2 Pre-heating Risk Map

PRS - Pre Heating v4

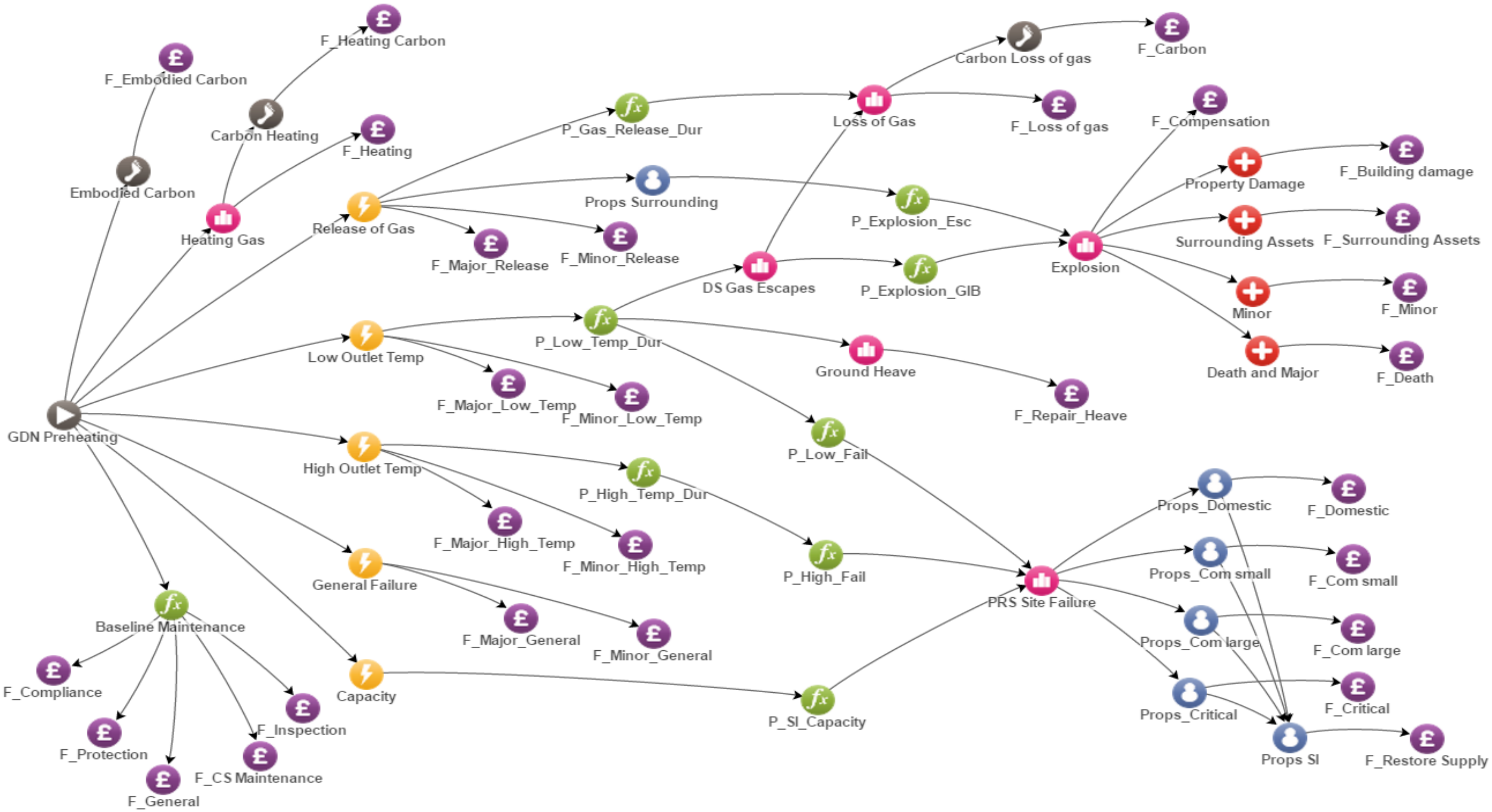


Figure E- 10 Pre-Heating Risk Map

E2.3.3 Filters & Pressure Control Risk Map

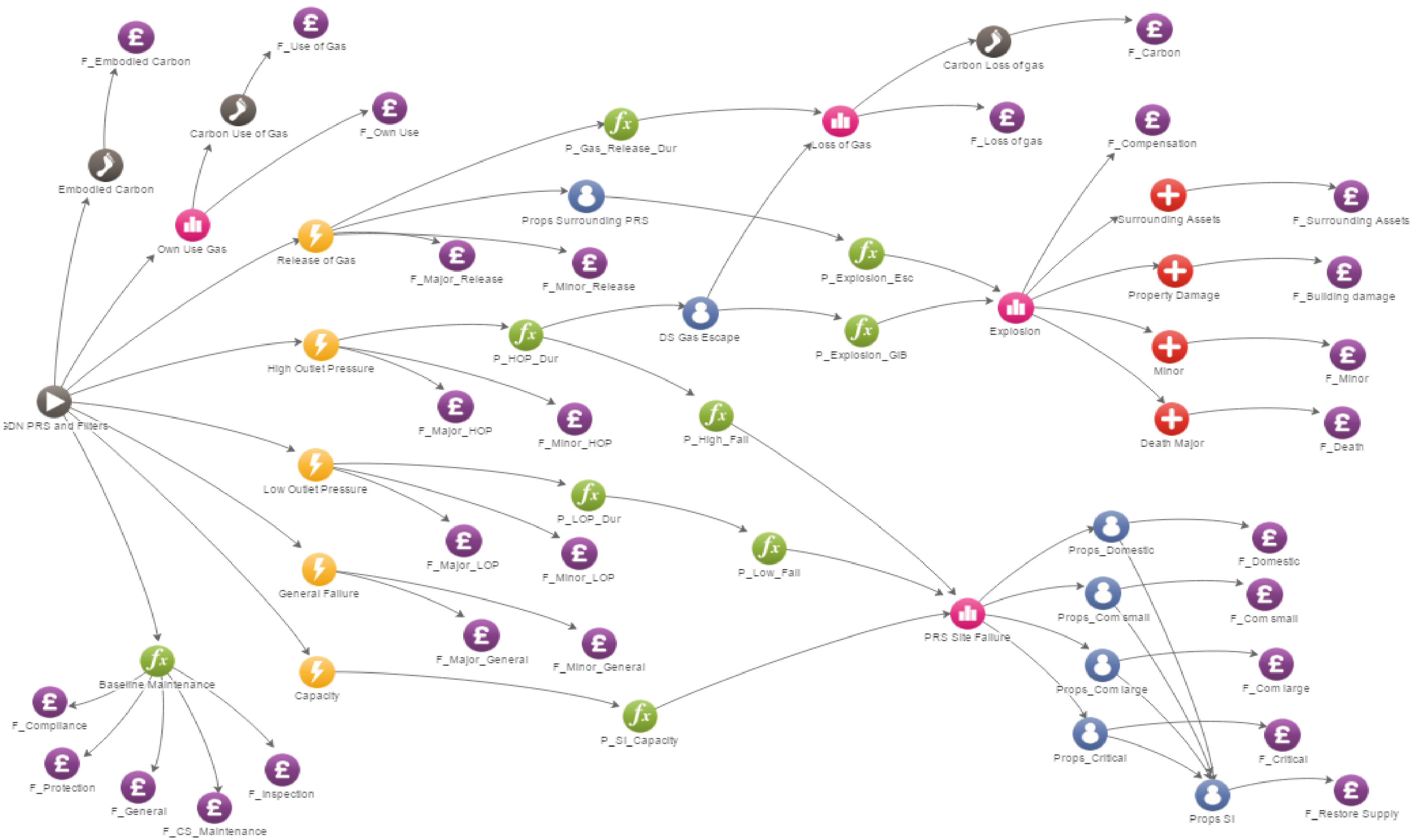


Figure E- 11 Filter and Pressure Control Risk Map

E2.4. Offtake & PRS Risk Template

The following tables demonstrate how the total risk value is derived for any given Offtake & PRS cohort. An individual, populated risk map is developed for every cohort to be modelled to deliver a baseline monetised risk value prior to intervention modelling.

E2.4.1 Odorant & Metering Risk Template

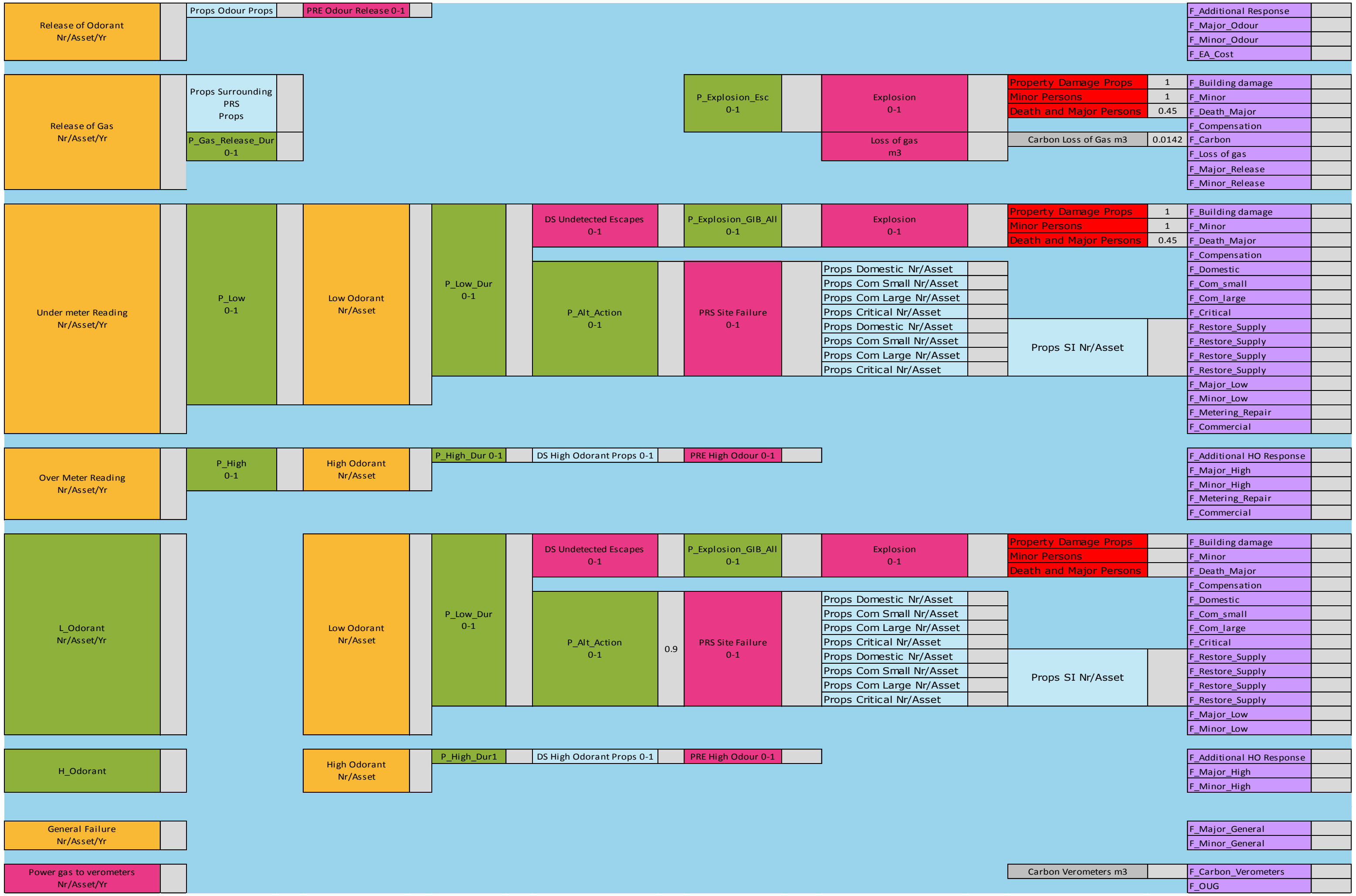


Figure E- 12 Odorant & Metering Risk Template

E2.4.2 Pre-heating Risk Template

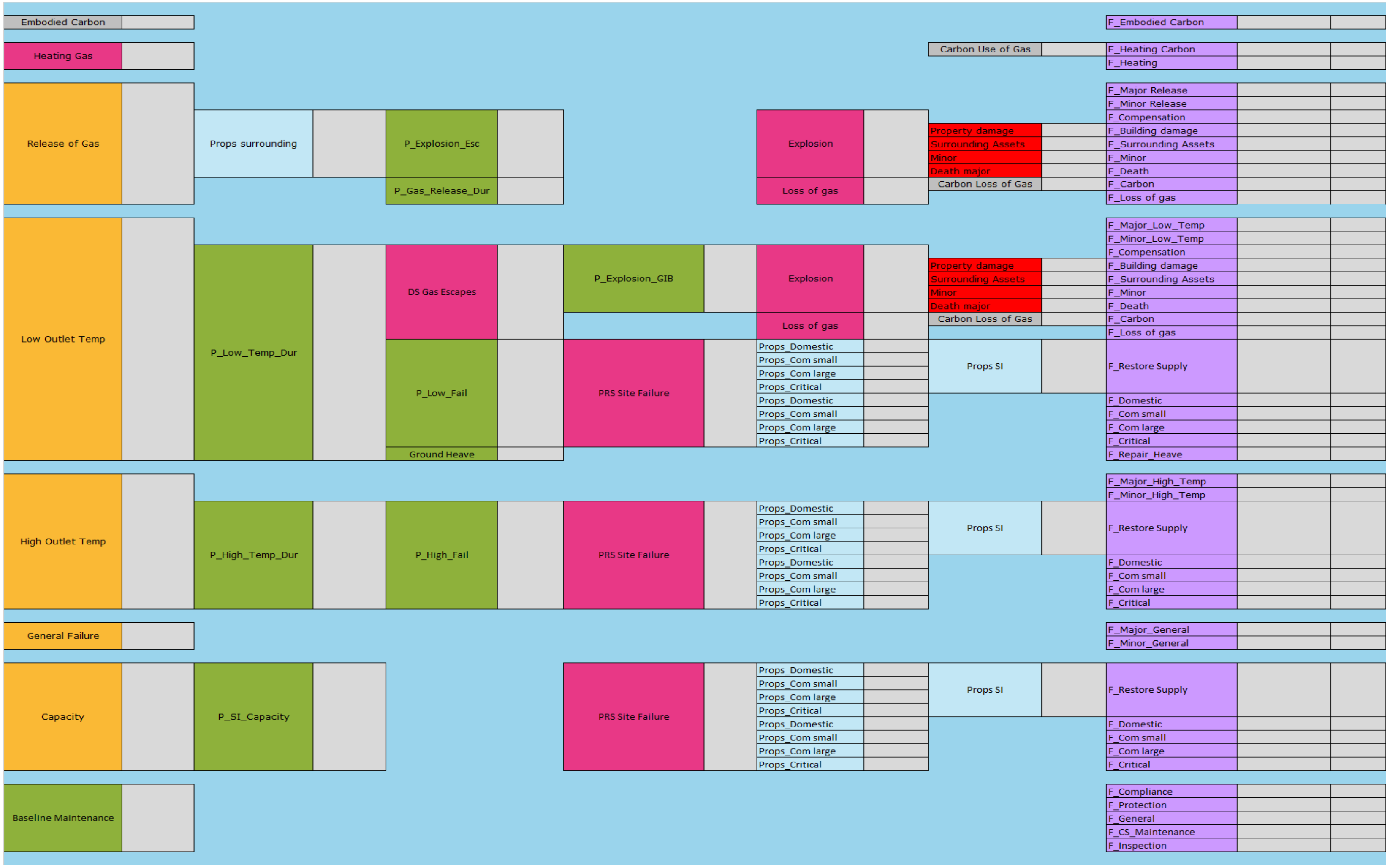


Figure E- 13 - Pre-heating Risk Template

E2.4.3 Filters & Pressure Control Risk Template

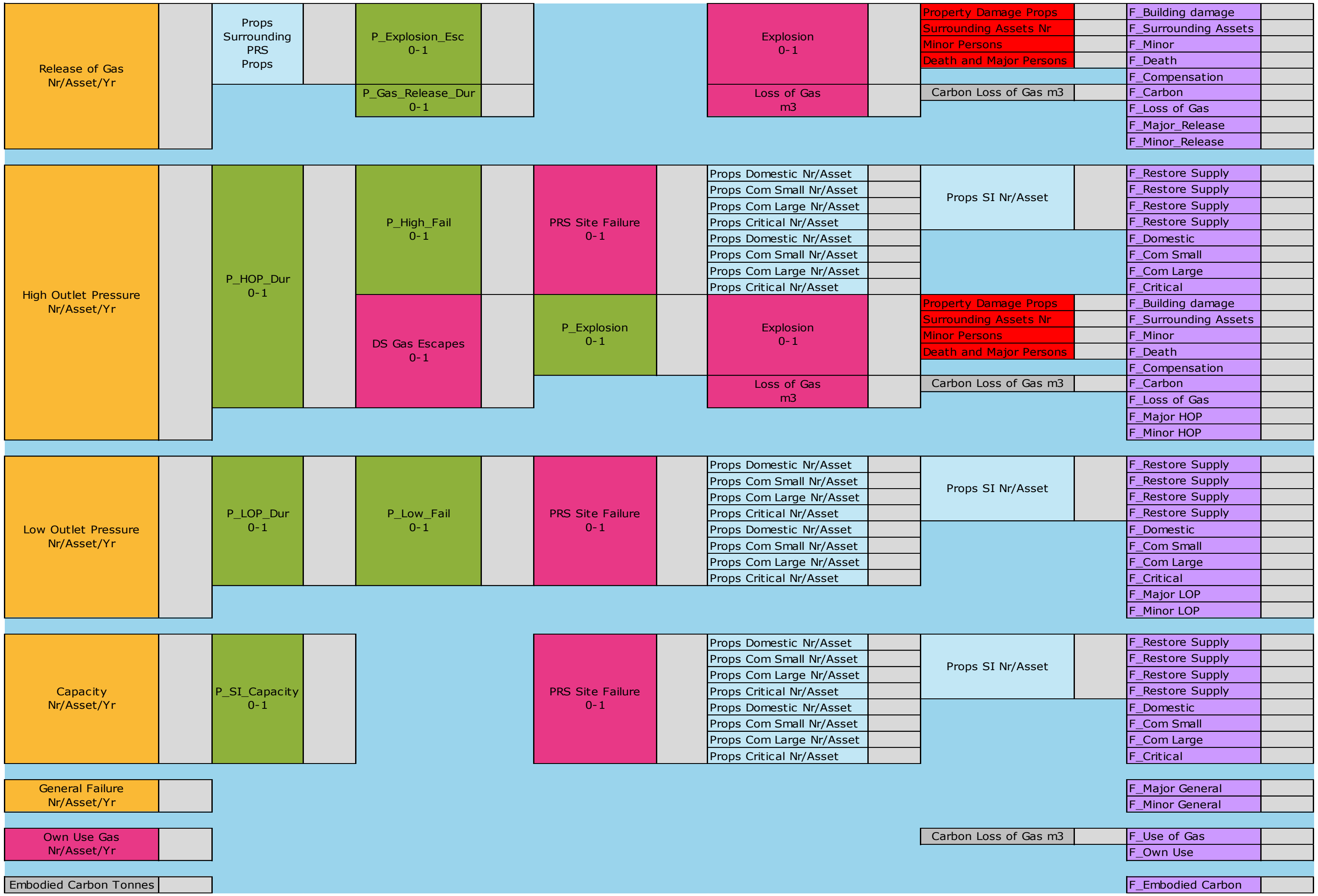


Figure E- 14 - Filters & Pressure Control Risk Template

E2.5. Offtake & PRS Data Reference Libraries

In line with Section 3.7 of the main report, the following table provides a brief description of the risk nodes modelled in the Event Tree, the source of the data and/or a high level description as to how the values were derived and a flag to indicate whether the data will be provided individually by each GDN or through common/shared analysis.

E2.5.1 Odorant & Metering Data Reference Library

Node ID / Variable	Description	Data Source	GDN or Common Value
Baseline Maintenance	This is the cost for annual maintenance activities that do not affect the health of the asset and the maintenance regime that is implicit in the initial failure rate	Data taken from company systems.	GDN Specific
Carbon Loss of gas	m3 of carbon equivalent from loss of gas	Carbon Loss of Gas = relative density x carbon equivalent. Value calculated by each GDN based on actual gas composition in the network	GDN Specific
Carbon Verometers	Carbon associated of unburnt gas associated with operation of verometers	As above	GDN Specific
Death & Major	The probability of a death or major injury caused by an explosion on the Metering and/or Odorant system	Based on research from Newcastle University	Common
DS High Odorant Props	Downstream properties supplied	Data taken from company systems.	GDN Specific
DS Undetected Escapes	Number of undetected gas escapes resulting from a low odorant event.	Taken from company systems/elicitation	GDN Specific
Explosion	Probability of an explosion from a release of gas or a low odorant event.	Grouping/summation of the probability of leak and rupture ignitions	Common
F_Additional HO Response	Additional cost to repair leaks identified by high odorant levels	Data taken from company systems.	GDN Specific
F_Additional Response	Additional site visit to respond to PREs identified by reports of release of odorant	Data taken from company systems.	GDN Specific
F_Carbon Verometers	Value of carbon associated of unburnt gas associated with operation of verometers	Same as F_Carbon (See Global Values section 3.7.2)	GDN Specific
F_Commercial	Financial penalty associated with inability to measure value of gas taken from the NTS by the shippers	Data taken from company systems.	GDN Specific
F_Compensation	Compensation value from an explosion caused by a release of gas of low odorant event	Data taken from company systems.	GDN Specific
F_Compliance	Annual Compliance Costs	Data taken from company systems.	GDN Specific
F_CS_Maintenance	Annual control system maintenance	Data taken from company systems.	GDN Specific
F_EA_Cost	EA Costs - environmental management (disposal) and fines	Data taken from company systems.	GDN Specific
F_General	General maintenance costs	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
F_Inspection	xx Inspection costs, including any maintenance carried out during surveys	Data taken from company systems.	GDN Specific
F_Major	Repairs greater than 12 hrs - everything not in minor (replacement, can't fix) requiring a component replacement	Data taken from company systems.	GDN Specific
F_Major_High	Repairs greater than 12 hrs - everything not in minor (replacement, can't fix) requiring a component replacement	Data taken from company systems.	GDN Specific
F_Major_Low	Repairs greater than 12 hrs - everything not in minor (replacement, can't fix) requiring a component replacement	Data taken from company systems.	GDN Specific
F_Major_Odour	Repairs greater than 12 hrs - everything not in minor (replacement, can't fix) requiring a component replacement	Data taken from company systems.	GDN Specific
F_Major_Release	Repairs greater than 12 hrs - everything not in minor (replacement, can't fix) requiring a component replacement	Data taken from company systems.	GDN Specific
F_Metering_Repair	Cost of resolving meter performance issues (assumed to be equivalent for high, low or no readings)	Data taken from company systems.	GDN Specific
F_Minor	Repair within 12 hours - Reset, adjusted, none, no action required, repaired cleaned lubricated (action field in data) (average cost of 2 people for 2 hours)	Data taken from company systems.	GDN Specific
F_Minor_High	Repair within 12 hours - Reset, adjusted, none, no action required, repaired cleaned lubricated (action field in data) (average cost of 2 people for 2 hours)	Data taken from company systems.	GDN Specific
F_Minor_Low	Repair within 12 hours - Reset, adjusted, none, no action required, repaired cleaned lubricated (action field in data) (average cost of 2 people for 2 hours)	Data taken from company systems.	GDN Specific
F_Minor_Odour	Repair within 12 hours - Reset, adjusted, none, no action required, repaired cleaned lubricated (action field in data) (average cost of 2 people for 2 hours)	Data taken from company systems.	GDN Specific
F_Minor_Release	Repair within 12 hours - Reset, adjusted, none, no action required, repaired cleaned lubricated (action field in data) (average cost of 2 people for 2 hours)	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
F_OUG	Cost of own use gas	Same as F_Loss_Of_Gas - 2p/kWh = £0.22/m3 (QUARTERLY ENERGY PRICES 2015 DECC)	GDN Specific
F_Protection	Costs of fence and kiosk maintenance. Include costs of pipework painting to mitigate corrosion	Data taken from company systems.	GDN Specific
F_Restore Supply	Costs of restoring supply following supply interruption (per property)	Data taken from company systems.	GDN Specific
General Failure	Relates to other failures not leading to either a safety, environmental or gas supply related consequence. Such failures may include failure of the instrumentation/ telemetry system or a telemetered alarm (such as LGT Pump A alarm).	Data taken from company systems.	GDN Specific
High Odorant	Where high levels of odorant are injected into the gas supply.	Data taken from company systems.	GDN Specific
Loss of Gas	The assumed volumetric loss of gas arising from a gas escape.	Same as LTS Model - A value calculated using pressure to estimate the volume of gas lost over a given duration. This value was calculated using DNV GL's PIPESAFE model for a sample data set and a 40mm hole and a linear model fitted. The hole size and leak duration can be adjusted in the model to recalculate the gas leak value.	GDN Specific
Low Odorant	Where levels of odorant are too low to meet the flows of gas going through a site.	Data taken from company systems.	GDN Specific
No or Under Meter Reading	Where meter readings are lower than actual or volumes aren't being read, resulting in incorrect readings whilst also affecting the measurement of odorant being injected into the gas system.	Data taken from company systems.	GDN Specific
Odorisation Control	Sum of all odorisation control failure	Taken from fault data/elicitation	GDN Specific
Over Meter Reading	Where meter readings are higher than the actual flow, resulting in incorrect readings whilst also effecting the measurement of odorant being injected into the gas system.	Data taken from company systems.	GDN Specific
P_Alt_Action	Probability of alternative action being taken to cease the supply of gas to consumers in the event of a full odourisation equipment failure	Probability of 90% assumed for all networks	Common
P_Explosion_Esc	Probability of explosion given gas release (on site)	Taken from fault data/elicitation	GDN Specific
P_Explosion_GIB_All	Probability of explosion given a GIB resulting from a low odorant event	Taken from fault data/elicitation	GDN Specific
P_Gas_Release_Dur	Probability of a loss of gas from a release of gas. Duration weighted based on E&I equipment on site	Taken from fault data/elicitation	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
P_High Dur	Probability of high odour resulting in PRE. Duration weighted based on E&I equipment on site	Taken from fault data/elicitation	GDN Specific
P_Low Dur	Probability of low odour resulting in PRE. Duration weighted based on E&I equipment on site	Taken from fault data/elicitation	GDN Specific
Power gas to verometers	Volume of gas venting associated with verometer (measurement device - pump)	Loss of gas - calculated at 5% x throughput x shrinkage rate	GDN Specific
PRE High Odour	Probability of a PRE resulting from a high odour release	Taken from fault data/elicitation	GDN Specific
PRE Odour Release	Probability of Public Reported Escape per property	Taken from fault data/elicitation	GDN Specific
Property Damage	Damage to properties in the vicinity of the PRS Installation from an explosion on the Metering and/or Odorant system	Assumes 100% of properties in inner zone and 25% in middle zone are destroyed	GDN Specific
Props_Com large	Number of large commercial properties at risk of supply interruption (C3 and C4 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Com small	Number of small commercial properties at risk of supply interruption (C1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Critical	Number of critical commercial properties at risk of supply interruption (C2 and I2 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Domestic	Number of domestic properties at risk of supply interruption (D1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props Odour	Properties impacted by odorant escape (relative to site and estimated pattern of dispersal)	Taken from fault data/elicitation	GDN Specific
Props Surrounding PRS	Number of at risk properties, probability of telemetry not picking up fault, and the time to service failure	Taken from fault data/elicitation	GDN Specific
Release of Gas	Relates to the failure of a pressure containing component on site leading to an unconstrained release of gas within and possibly of site.	Data taken from company systems.	GDN Specific
Release of Odorant	Result of a failure of containment leading to a release of odorant into the atmosphere.	Data taken from company systems.	GDN Specific

E2.5.2Pre-heating Data Reference Library

Node ID / Variable	Description	Data Source	GDN or Common Value
Baseline Maintenance	This is the cost for annual maintenance activities that do not affect the health of the asset and the maintenance regime that is implicit in the initial failure rate	Data taken from company systems.	GDN Specific
Capacity	Low outlet pressure caused by inability of pre-heating downstream demand for gas due to under sizing	Binary value used at asset level where known capacity issues from network modelling. Capacity issues flagged in data with a 'Y'	GDN Specific
Carbon Heating	Carbon associated with gas burnt or electricity consumed in pre-heating system	Based on shrinkage costs for pre-heating. For gas fired pre-heating systems then taken as 0.0013% site throughput and consideration of pre-heating efficiency. Electrical pre-heating to be taken from site electricity supply invoices.	GDN Specific
Death Major	Probability of death following an explosion (caused by ignition of a pipeline leak/rupture).	Probability of death of people in surrounding houses and immediate vicinity Assumes everyone in the properties in the inner zone are killed	GDN Specific
DS Gas Escapes	Properties downstream of PRS/Offtake at risk of explosion (i.e. number of downstream gas escapes)	Data taken from company systems.	GDN Specific
Explosion	Probability of explosion given a GIB	Value of 1 used as a multiplier to enable the grouping/summation of the probability of leak and rupture ignitions	Common
F_Compensation	Customer compensation payments resulting from explosion of station	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific
F_Compliance	HSE; Working at Height; DSEAR; Asbestos etc.	Data taken from company systems.	GDN Specific
F_CS Maintenance	Routine maintenance of PLC and Control Systems	Data taken from company systems.	GDN Specific
F_General	Routine & non-routine maintenance costs (as per Governors)	Data taken from company systems.	GDN Specific
F_Heating	Pre-heating energy consumption (electrical costs of operating site). Cost of lost product (gas burnt)	Data taken from company systems.	GDN Specific
F_Heating Carbon	Cost of carbon associated with gas burnt or electricity consumed in pre-heating system	Data taken from company systems.	GDN Specific
F_Inspection	PSSR and any inspection costs, including any maintenance carried out during surveys	Data taken from company systems.	GDN Specific
F_Major_General	Costs of major repairs/replacements following	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	on from General Failures (only financial consequences)		
F_Major_High_ Temp	Costs of major repairs/replacements in response to High Temperature failure	Data taken from company systems.	GDN Specific
F_Major_Low Temp	Costs of major repairs/replacements in response to Low Temperature failure	Data taken from company systems.	GDN Specific
F_Major_Release	Costs of heat exchanger replacement (or other HP failure)	Data taken from company systems.	GDN Specific
F_Minor_General	Costs of minor repairs/replacements following on from General Failures (only financial consequences)	Data taken from company systems.	GDN Specific
F_Minor_High_ Temp	Costs of minor repairs/replacements in response to High Temperature failure	Data taken from company systems.	GDN Specific
F_Minor_Low_ Temp	Costs of minor repairs/replacements in response to Low Temperature failure	Data taken from company systems.	GDN Specific
F_Minor_Release	Leak on supply to burners (LP) plus any other failures resulting in Loss of Gas	Data taken from company systems.	GDN Specific
F_Protection	Kiosk and Fence costs (including CCTV; site security). Painting to prevent pipework corrosion	Data taken from company systems.	GDN Specific
F_Repair_Heave	Costs of repairing consequences of ground heave (e.g. damage to highways)	Data taken from company systems.	GDN Specific
F_Restore Supply	Costs of restoring supply following supply interruption (per property)	Data taken from company systems.	GDN Specific
F_Surrounding Assets	Costs of repair/restoration to surrounding assets following an explosion. These are company assets (i.e. Governor sharing same site) not 3rd party assets (buildings etc.)	Data taken from company systems.	GDN Specific
General Failure	Frequency of alarms that result in an action (and cost) but no impact on downstream service (e.g. boiler alarm and security alarm)	Data taken from company systems.	GDN Specific
Ground Heave	Events resulting in damage requiring remediation (structure; road; assets)	Data taken from company systems.	GDN Specific
Heating Gas	Volume of gas burnt in pre-heating	Data taken from company systems.	GDN Specific
High Outlet Temp	High outlet temperatures caused by poor control or various E&I failures. Alarms based on site specific thresholds.	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
Loss of Gas	Release of gas on site (unburnt gas)	Same as LTS Model - A value calculated using pressure to estimate the volume of gas lost over a given duration. This value was calculated using DNV GL's PIPESAFE model for a sample data set and a 40mm hole and a linear model fitted. The hole size and leak duration can be adjusted in the model to recalculate the gas leak value.	GDN Specific
Low Outlet Temp	Frequency of low outlet temperatures caused by poor control or various E&I failures. Alarms based on site specific thresholds.	Data taken from company systems.	GDN Specific
P_Explosion_Esc	Probability of an onsite release of gas leading to an explosion	From company fault data /Elicitation	Common
P_Explosion_GIB	Probability of a downstream GIB resulting in an explosion	From company fault data /Elicitation	GDN Specific
P_Gas Release Dur	Probability of loss of gas given release factored to include duration of loss	From company fault data /Elicitation	GDN Specific
P_High_Fail	Probability of a high outlet temperature leading to a site failure (dependent on telemetry presence)	From company fault data /Elicitation	GDN Specific
P_High_Temp_ Dur	Probability of telemetry detecting high temperature within scan period	From company fault data /Elicitation	GDN Specific
P_Low_Fail	Probability of a low outlet temperature leading to a site failure (dependent on telemetry presence)	From company fault data /Elicitation	GDN Specific
P_Low_Temp_ Dur	Probability of telemetry detecting low temperature within scan period	From company fault data /Elicitation	GDN Specific
P_SI_Capacity	Probability of a supply interruption resulting from a capacity issue	Data taken from company systems.	GDN Specific
Property Damage	Probability of property damage due to ignition/explosion impact	Assumes 100% of properties in inner zone and 25% in middle zone are destroyed	GDN Specific
Props SI	Number of properties requiring supply restoration support following a supply interruption. **SI** is the sum of all modelled supply interruption events.	Value of 1 used as a multiplier to enable the grouping/summation of props_domestic, props_com small, props_com large and props_critical	GDN Specific
Props Surrounding	Number of properties surrounding Offtake or HP PRS installations on which are at risk of damage by explosion of the installation itself following a loss of gas.	Defined as Properties within the inner zone of the offtake or HP PRS. Derived from GIS analysis or other company records where available. The probability of explosion given a loss of gas at a Governor is based on SRWG estimates.	GDN Specific
Props_Com large	Number of large commercial properties at risk of supply	Data taken from company systems based on either network	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	interruption (C3 and C4 type properties)	analysis or assumptions based on demands, flow & redundancy	
Props_Com small	Number of small commercial properties at risk of supply interruption (C1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Critical	Number of critical commercial properties at risk of supply interruption (C2 and I2 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Domestic	Number of domestic properties at risk of supply interruption (D1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
PRS Site Failure	Total number of properties experiencing a supply interruption following a total PRS/Offtake site failure	This is a function of the average site demand and network criticality. Assumed that gas demand per property is 0.8m^3/hr	GDN Specific
Release of Gas	Probability of a Catastrophic failure of heating systems (heat exchanger), including boilers	Taken from company systems	GDN Specific
Surrounding Assets	Number of surrounding assets impacted by on-site explosion	Defined as a probability of assets within inner zone. Derived from GIS analysis or other company records where available. Includes the installation itself including plant, equipment and civils.	GDN Specific

E2.5.3 Filters & Pressure Control Data Reference Library

Node ID / Variable	Description	Data Source	GDN or Common Value
Capacity	Flag to define whether a LTS pipeline has a known capacity issue. **P_SI_Capacity** is the probability of a supply interruption given a capacity exceedance event.	Binary value used at asset level where known capacity issues using off-line sizing/capacity analysis. Capacity issues flagged in data with a 'Y'	GDN Specific
Carbon Use of Gas	Unburnt gas associated with hydraulic driving force to open/close control valves; odorant kit etc.	Carbon Loss of Gas = relative density x carbon equivalent. Value calculated by each GDN based on actual gas composition in the network	GDN Specific
DS Gas Escapes	Properties downstream of PRS/Offtake at risk of explosion (i.e. number of downstream gas escapes)	Taken from company systems/elicitation	GDN Specific
Explosion	Probability of explosion given a GIB or release of gas in vicinity of Offtake/PRS	Value of 1 used as a multiplier to enable the grouping/summation of events downstream and in the vicinity of the Offtake/PRS	GDN Specific
F_Compensation	Customer compensation payments resulting from explosion of station	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific
F_Compliance	HSE; Working at Height; DSEAR; Asbestos etc.	Data taken from company systems.	GDN Specific
F_CS_Maintenance	Control system maintenance costs	Data taken from company systems.	GDN Specific
F_General	Routine & non-routine maintenance costs (as per Governors)	Data taken from company systems.	GDN Specific
F_Inspection	PSSR and any inspection costs, including any maintenance carried out during surveys	Data taken from company systems.	GDN Specific
F_Major_General	Costs of major repairs/replacements following on from General Failures (only financial consequences)	Data taken from company systems.	GDN Specific
F_Major_HOP	Costs of resolving major over-pressurisation events	Data taken from company systems.	GDN Specific
F_Major_LOP	Costs of resolving major under-pressurisation events	Data taken from company systems.	GDN Specific
F_Major_Release	Costs of major repairs/replacements following on from a release of gas failure (only financial consequences)	Data taken from company systems.	GDN Specific
F_Minor_General	Costs of minor repairs/replacements following on from General Failures (only financial consequences)	Data taken from company systems.	GDN Specific
F_Minor_HOP	Costs of resolving minor overpressurisation events	Data taken from company systems.	GDN Specific
F_Minor_LOP	Costs of resolving minor underpressurisation events	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
F_Minor_Release	Costs of minor repairs/replacements following on from a release of gas failure (only financial consequences)	Data taken from company systems.	GDN Specific
F_Own_Use	Cost of Shrinkage gas	Data taken from company systems.	GDN Specific
F_Protection	Costs of fence and kiosk maintenance. Include costs of pipework painting to mitigate corrosion	Data taken from company systems.	GDN Specific
F_Restore Supply	Costs of restoring supply following supply interruption (per property)	Data taken from company systems.	GDN Specific
F_Surrounding Assets	Costs of repair/restoration to surrounding assets following an explosion. These are company assets (i.e. Governor sharing same site) not 3rd party assets (buildings etc.)	Data taken from company systems.	GDN Specific
F_Use of Gas	Carbon value of own use gas (shrinkage)	Data taken from company systems.	GDN Specific
General Failure	Probability of failure not leading to a downstream consequence but incurring costs to prevent a consequence occurring	Data taken from company systems.	GDN Specific
High Outlet Pressure	As per Governor Fail Open	Data taken from company systems.	GDN Specific
Loss of Gas	Financial value of loss of gas through corrosion of pipework	Same as LTS Model - A value calculated using pressure to estimate the volume of gas lost over a given duration. This value was calculated using DNV GL's PIPESAFE model for a sample data set and a 40mm hole and a linear model fitted. The hole size and leak duration can be adjusted in the model to recalculate the gas leak value.	GDN Specific
Low Outlet Pressure	Frequency of component failures (slamshuts firing; stiction; blocked filters etc.) leading to downstream supply losses	Data taken from company systems.	GDN Specific
P_Explosion	Probability of explosion following DS gas escape	From company fault data /Elicitation	Common
P_Explosion_Esc	Probability of an onsite release of gas leading to an explosion	From company fault data /Elicitation	GDN Specific
P_Gas Release Dur	Probability of loss of gas given release factored to include duration of loss	From company fault data /Elicitation	GDN Specific
P_High_Fail	Probability of a high pressure event resulting in site failure (closedown)	From company fault data /Elicitation	GDN Specific
P_HOP_Dur	Probability of telemetry detecting high pressure (if available) and associated duration of failure event	From company fault data /Elicitation	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
P_LOP_Dur	Probability of telemetry detecting low pressure (if available) and associated duration of failure event	From company fault data /Elicitation	GDN Specific
P_Low_Fail	Probability of a low pressure event causing a site failure (closedown)	From company fault data /Elicitation	GDN Specific
P_SI_Capacity	Probability of a supply interruption resulting from a capacity issue	Data taken from company systems.	GDN Specific
Property Damage	Probability of property damage due to ignition/explosion impact	Assumes 100% of properties in inner zone and 25% in middle zone are destroyed	GDN Specific
Props SI	Number of properties requiring supply restoration support following a supply interruption. **SI** is the sum of all modelled supply interruption events.	Value of 1 used as a multiplier to enable the grouping/summation of props_domestic, props_com small, props_com large and props_critical	GDN Specific
Props Surrounding	Number of properties surrounding Offtake or HP PRS installations on which are at risk of damage by explosion of the installation itself following a loss of gas.	Defined as Properties within the inner zone of the offtake or HP PRS. Derived from GIS analysis or other company records where available. The probability of explosion given a loss of gas at a Governor is based on SRWG estimates.	GDN Specific
Props_Com large	Number of large commercial properties at risk of supply interruption (C3 and C4 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Com small	Number of small commercial properties at risk of supply interruption (C1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Critical	Number of critical commercial properties at risk of supply interruption (C2 and I2 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
Props_Domestic	Number of domestic properties at risk of supply interruption (D1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
PRS Site Failure	Site shutdown resulting from over-pressurisation causing DS supply interruptions		
Release of Gas	Probability of release of gas associated with corrosion defects on site pipework	Data taken from company systems.	GDN Specific
Shrinkage Gas	Volume of unburnt gas associated with hydraulic driving force to open/close control valves; odorant kit etc.	Data taken from company systems.	GDN Specific
Surrounding Assets	No of properties within a defined explosion radius of the PRS station	Defined as a probability of assets within inner zone. Derived from GIS analysis or other company records where available. Includes the	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		installation itself including plant, equipment and civils.	

E3. Offtake & PRS Event Tree Utilisation

E3.1. Offtake & PRS Base Data

The Offtake & PRS base data will be created from company asset databases, financial systems and other data sources. Where available, condition assessment of assets and ancillaries (such as kiosks and fencing) can be used to improve the starting failure rate assessments. An example of data input format is shown below. A single base data template covers all asset groups to allow future combination of monetised risk models, if required.

ICS_SYSTEMS_ID	ASSET_TYPE	ASSET_CAT	ASSET_CAT_DESC	OBSOLETE_YEAR	INSTALL_YR	CITY	NETWORK	POST_CODE	WORK_CENTRE	WORK_CENTRE_DESCRIPTION	DISTANCE_TO_COAST
D40B8D851FB042F3BEA95D0EFA7F9D5A	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	WINKFIELD	NL	SL4 4RZ	UNKN	UNKN	2983.774659
E685AC90600441E2AC300EB166CC998B	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	MALPAS	NW	SY14 8JE	UNKN	UNKN	28080.15037
D32F551E67D44F3F9295259750256967	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	CHESTER	NW	CH2 4EN	UNKN	UNKN	7396.479446
C54D8A3EB04F469188CAD7154D957BD3	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	PRESTON	NW	PR5 4EN	UNKN	UNKN	17105.04701
4C8571FF8AE246BBBEDFBAEF63E8A6D4	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	STANFORD LE HOPE	NL	SS17 8PU	UNKN	UNKN	72653.34722
6364AE16B89C43D8BB1992BFC095DE43	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	WOODHALL SPA	EM	LN10 6XT	UNKN	UNKN	23467.10078
1E7C007A74CE4F4BB9F90C48BC1E37C1	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	Runcorn	NW	WA7 4FZ	UNKN	UNKN	1791.238901
C73C40F01C5E4E099C4D106C615A436E	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	HARLOW	EA	CM17 0PR	UNKN	UNKN	30015.48509
22687576A2F24ABDACC8DE735F67EDD3	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	NORTH KILLINGHOLME	EM	DN40 3JY	UNKN	UNKN	5123.181986
C46C8E3A2CF04078903C83D3E13F37E6	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	SLEAFORD	EM	NG34 0BL	UNKN	UNKN	25286.19739
6EC175A9DF2E477FB0185BDFA524090D	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	CHIGWELL	NL	IG7 5BT	UNKN	UNKN	25939.91913
BBEBF2ED86E14422970EBF3AAB7060B6	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	CREWE	NW	CW4 7ET	UNKN	UNKN	23930.30606
6E4E31D3993F475AB9B601182AF619BA	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	BACTON	EA	NR12 0JD	UNKN	UNKN	787.0944156
B4F1197AD11949F1BF4EAE55452CB223	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	HARLOW	EA	CM17 0PR	UNKN	UNKN	30015.48509
BF6972913CC542B7B39B742A7EBDFBA1	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	TAMWORTH	WM	B79 0HB	UNKN	UNKN	36278.15525
81F2FF865C7B4F6E99FE0FB62B291D77	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	STANFORD LE HOPE	NL	SS17 8PU	UNKN	UNKN	72653.34722
941303B4AB1B4E738B85747144B032F4	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	BLYBOROUGH	EM	DN21 4HH	UNKN	UNKN	29722.89965
FC55CCF494F94289834D43D7522C76A7	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	NEAR ADLINGTON	NW	BL6 5LB	UNKN	UNKN	23852.64876
63737ED6E8194992AA1FB88C415260B7	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	LEICESTER	EM	LE8 6LD	UNKN	UNKN	85210.77544
BC46C4E9BB9E4BE1BEFA4ECDE76F6D4E	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	NR LUPTON	NW	LA6 2PT	UNKN	UNKN	8874.083447
4CBB9B1BFCFE4E1684426C30E659C411	OFFTAKES	RGI	ODORISATION AND CHROMATOGRAPH GAS SUPPLY SYSTEM	9999	1965	SLEAFORD	EM	NG34 0BL	UNKN	UNKN	25286.19739
682F613614AE4EA6B6B2DA7464AA43C9	OFFTAKES	LGT	ODORISATION SYSTEM	9999	1965	HINCKLEY	WM	LE10 3DP	UNKN	UNKN	36278.15525

ICS_SYSTEMS_ID	HOUSING	KIOSK_COND	FENCE_COND	CONDITION_SCORE	CLIENT_SITE_ID	CLIENT_PROCESS_ID	CLIENT_SYSTEM_ID	SITE_NAME	PROCESS_TYPE	SYSTEM_TYPE	NUMBER_OF_STREAMS	NUMBER_OF_EQUIPMENT	ASSET_SUBTYPE	PROP_DENSITY
D40B8D851FB042F3BEA95D0EFA7F9D5A	UNKN	1	1	2	7016NS	7016NS-NO1	7016NS-NO1-LGT1	WINKFIELD AGI	Offtake	LGT	1	19	ODOUR	0.000245895
E685AC90600441E2AC300EB166CC998B	UNKN	1	1	2	3713NS	3713NS-NO1	3713NS-NO1-LGT1	MALPAS OFFTAKE AGI	Offtake	LGT	1	19	ODOUR	3.88382E-05
D32F551E67D44F3F9295259750256967	UNKN	1	1	2	4113NS	4113NS-NO1	4113NS-NO1-LGT1	MICKLE TRAFFORD OFFTAKE AGI	Offtake	LGT	1	19	ODOUR	6.27417E-05
C54D8A3EB04F469188CAD7154D957BD3	UNKN	1	1	2	4357NS	4357NS-NO1	4357NS-NO1-LGT1	SAMLESBURY OFFTAKE AGI	Offtake	LGT	1	19	ODOUR	0.000160352
4C8571FF8AE246BBBEDFBAEF63E8A6D4	UNKN	1	1	2	8117NS	8117NS-NO1	8117NS-NO1-LGT1	HORNDON PRS STN 219	Offtake	LGT	1	19	ODOUR	0.000159934
6364AE16B89C43D8BB1992BFC095DE43	UNKN	1	1	2	1737NS	1737NS-NO1	1737NS-NO1-LGT1	KIRKSTEAD PRS	Offtake	LGT	1	19	ODOUR	1.0519E-06
1E7C007A74CE4F4BB9F90C48BC1E37C1	UNKN	1	1	2	4119NS	4119NS-NO1	4119NS-NO1-LGT1	WESTON POINT OFFTAKE (RUN 13)	Offtake	LGT	1	19	ODOUR	0.000507249
C73C40F01C5E4E099C4D106C615A436E	UNKN	1	1	2	2815NS	2815NS-NO1	2815NS-NO1-LGT1	MATCHING GREEN PRS	Offtake	LGT	1	19	ODOUR	0
22687576A2F24ABDACC8DE735F67EDD3	UNKN	1	1	2	1121NS	1121NS-NO1	1121NS-NO1-LGT1	THORNTON CURTIS 'A' PRS	Offtake	LGT	1	19	ODOUR	2.52177E-05
C46C8E3A2CF04078903C83D3E13F37E6	UNKN	1	1	2	1915NS	1915NS-NO1	1915NS-NO1-LGT1	SILK WILLOUGHBY PRS	Offtake	LGT	1	19	ODOUR	5.87873E-05
6EC175A9DF2E477FB0185BDFA524090D	UNKN	1	1	2	2821NS	2821NS-NO1	2821NS-NO1-LGT1	LUXBOROUGH LANE PRS STN 260	Offtake	LGT	1	19	ODOUR	0.000482695
BBEBF2ED86E14422970EBF3AAB7060B6	UNKN	1	1	2	3623NS	3623NS-NO1	3623NS-NO1-LGT1	HOLMES CHAPEL OFFTAKE AGI	Offtake	LGT	1	19	ODOUR	0.000091584
6E4E31D3993F475AB9B601182AF619BA	UNKN	1	1	2	1211NS	1211NS-NO1	1211NS-NO1-RGI1	BACTON (1213NS)	Offtake	RGI	1	16	ODOUR	6.7186E-06
B4F1197AD11949F1BF4EAE55452CB223	UNKN	1	1	2	2815NS	2815NS-NO1	2815NS-NO1-RGI3	MATCHING GREEN PRS	Offtake	RGI	1	16	ODOUR	0
BF6972913CC542B7B39B742A7EBDFBA1	UNKN	1	1	2	3516NS	3516NS-NO1	3516NS-NO1-RGI1	AUSTREY	Offtake	RGI	1	16	ODOUR	0
81F2FF865C7B4F6E99FE0FB62B291D77	UNKN	1	1	2	8117NS	8117NS-NO1	8117NS-NO1-RGI2	HORNDON PRS STN 219	Offtake	RGI	1	0	ODOUR	0.000159934
941303B4AB1B4E738B85747144B032F4	UNKN	1	1	2	1743NS	1743NS-NO1	1743NS-NO1-RGI1	BLYBOROUGH PRS	Offtake	RGI	1	16	ODOUR	0
FC55CCF494F94289834D43D7522C76A7	UNKN	1	1	2	4361NS	4361NS-NO1	4361NS-NO1-RGI2	BLACKROD OFFTAKE AGI	Offtake	RGI	1	0	ODOUR	0.00024216
63737ED6E8194992AA1FB88C415260B7	UNKN	1	1	2	1439NS	1439NS-NO1	1439NS-NO1-RGI2	BLABY PRS	Offtake	RGI	1	0	ODOUR	0.000165915
BC46C4E9BB9E4BE1BEFA4ECDE76F6D4E	UNKN	1	1	2	4345NS	4345NS-NO1	4345NS-NO1-RGI2	LUPTON OFFTAKE AGI	Offtake	RGI	1	0	ODOUR	0
4CBB9B1BFCFE4E1684426C30E659C411	UNKN	1	1	2	1915NS	1915NS-NO1	1915NS-NO1-RGI2	SILK WILLOUGHBY PRS	Offtake	RGI	1	0	ODOUR	5.87873E-05
682F613614AE4EA6B6B2DA7464AA43C9	UNKN	1	1	2	HY10WM	HY10WM-PH1	HY10WM-PH1-LGT1	HYDES PASTURES	HP PRS	LGT	1	14	ODOUR	0

Table E1 - Example of the base data format for the Offtake/PRS risk models showing sub-types and attributes as discussed above

E3.2. Offtake & PRS Probability of Failure and Deterioration Assessment

As maintainable assets with a high consequence of failure, significant proactive investment is incurred to prevent Offtake & PRS assets from failing. Therefore it would be expected that for failure modes with the highest consequences of failure the observed failure rates will be very low. Company fault data is available but, to improve PoF assessments, elicitation workshops were held to provide additional data to support that which can be directly taken from company systems.

E3.2.1 Overview

The failure modes for Offtakes & PRSs are based on a 'bathtub' failure rate consisting of two components, a flat portion and a deteriorating portion, as shown in Figure E15 below. Figure E15 shows that after the initial flat portion, where failure rates are relatively constant (although in reality random failures will occur causing spikes in failure rates), and a threshold may be reached whereby the asset begins to shows observable deterioration.

The flat portion is estimated using observed data from company systems over a number of years, and ratified with experts. The threshold at which deterioration becomes observable was estimated through the elicitation process described above.

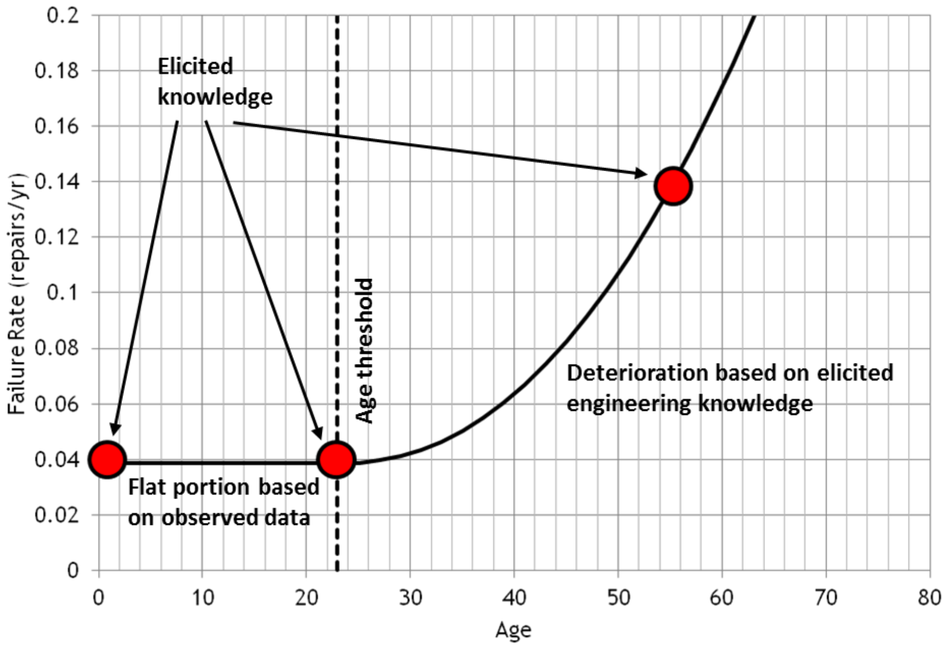


Figure E15 – Bathtub model used for Offtake/PRS PoF and deterioration assessment

The basic model used for the curve can be described as follows:

PoF (Flat portion) = 0.8*Population_Failure_Rate+ 0.2*Observed_Failure_Rate

PoF (Deteriorating portion, where Age>threshold) = Flat portion * exp(Rate of Deterioration * time)

E3.2.2 Elicited Failure Results

A structured and formal elicitation workshop was undertaken with experts and the outputs were analysed. Final results are provided in the Table E2 below. The parameter B is the estimated deterioration coefficient. Parameter A is the elicited flat portion of the failure rate, which typically will be replaced with observed failure rates from company systems.

The Age Threshold **(γ)** is the point at which noticeable deterioration may be observed. The Condition Scale and Shape are Weibull coefficients allowing actual asset Age to be modified to an Effective Age through a visual condition assessment (see Section E3.2.3.).

Elicitation Model Group	A	B (Deterioration)	Cond Scale (k)	Cond Shape (λ)	Age Threshold (γ)
Odorant & Metering - Control system	0.018	0.132	10.776	2.128	15
Odorant & Metering - Metering	0.012	0.161	9.269	2.019	15
Odorant & Metering - Odorant Injection	0.040	0.161	8.831	2.190	10
Odorant & Metering	0.051	0.092	9.678	1.887	15
Preheaters - Electrical Heating System	0.054	0.091	10.430	1.695	11.5
Preheaters - Modular Boiler Systems	0.002	0.322	8.831	2.190	15
Preheaters - Waterbath Control System	0.089	0.080	9.678	1.887	10
Preheaters - Waterbath Heating System	0.008	0.161	10.430	1.695	20
Preheaters	0.040	0.107	10.430	1.695	15
Pressure Reduction and Control - Control System	0.051	0.092	10.430	1.695	15
Pressure Reduction and Control - Filters	0.002	0.110	16.721	2.424	30
Pressure Reduction and Control - Regulators	0.008	0.139	10.430	1.695	20
Pressure Reduction and Control - Slamshuts	0.029	0.096	10.430	1.695	17.5
Pressure Reduction and Control	0.004	0.161	10.430	1.695	20

Table E2 – PoF and deterioration coefficient applied in the model, along with factors to allow adjustments for observed condition

Note: Individual age thresholds (the point at which noticeable deterioration may be observed) have only been applied at the asset group level e.g. an individual gamma value exists for meters, odourant, filters and pressure control and pre-heaters.

In line with Governors, a Fault Detection Factor was applied to factor the observed number of faults to the expected number of faults given that not all faults are detected.

Fault Detection Rate = 1 / (Fault Detection Factor)

E3.2.3 Factors Applied to Initial PoF Values

Similar adjustment methods and factors used in the Governor methodology are used on Offtakes and PRS assets. The initial PoF is scaled by a number of factors, such as housing condition, kiosk condition, distance to coast and the fault detection rate, to achieve a more accurate estimate for the initial likelihood of failure at individual assets. This is necessary as due to the low numbers of actual failures initial PoF estimates are taken from population level estimates.

The derived factors are each discussed below:

Condition Risk (Effective Age)

To allow the initial failure rate to be adjusted, based on assessed condition, a concept of Effective Age was introduced. Effective Age is the modified default age of the asset according to its assessed condition; it applies where the Effective Age is greater than the Age Threshold **(γ)**.

This concept is illustrated in Figure E16 below:

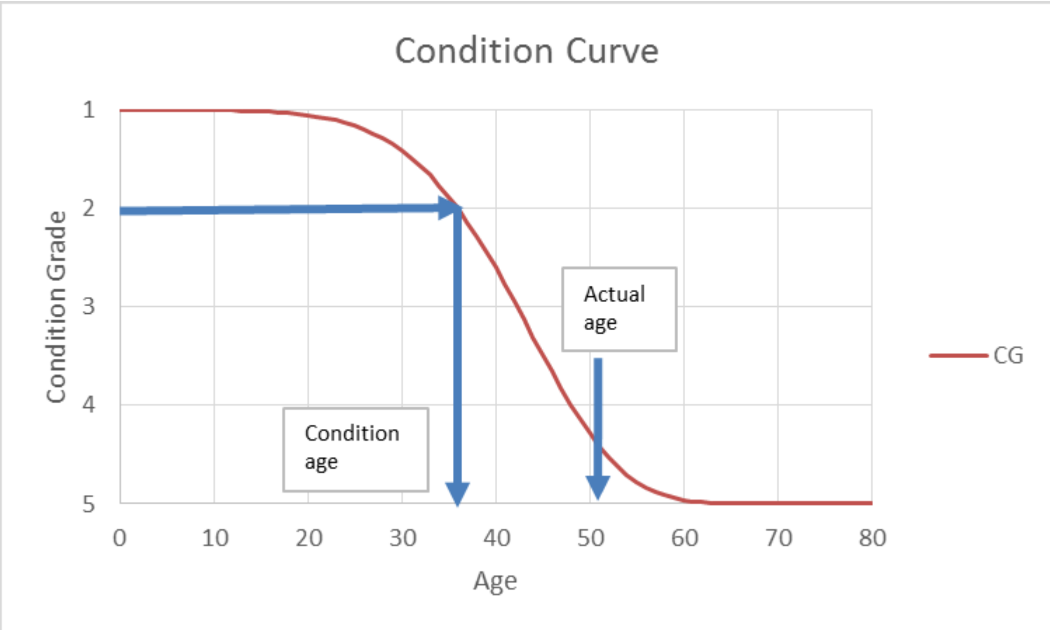


Figure E16 – Derivation of the Effective Age of an asset from assessed Condition Grade

The assessed condition is determined via GDN-specific visual condition surveys, where available, aligned to common Condition Grades 1 to 5 to be applied as follows:

Condition Grade	Description	Factor (c)
1	As new, no corrosion	0.005
2	Superficial corrosion to asset	0.1
3	Minor corrosion to asset	0.25
4	Moderate corrosion to asset (intervention considered).	0.4
5	Severe corrosion to asset (intervention required)	0.75

Table E3 – Condition Grade factors used to calculate Effective Age of asset from actual (or population) age

The age of an individual asset is calculated and an initial default Condition Grade 2 is applied. To determine the Effective Age, the actual Condition Grade is used to adjust the age using the following equation.

$$Effective\ Age = Default\ Age \times \left((k \times (-\ln(1-c))^{1/\lambda}\right)/\left((k \times (-\ln(0.9))^{1/\lambda}\right)$$

Please note, where there are multiple components/sub-assets, the worst-case condition assessment will be applied.

Note: Where the condition grade is unknown, perhaps as a result of no visual survey being conducted, then a default of condition grade 3 should be utilised.

Location Risk (Coastal Factor)

Model Report 1569 *(SEAMS Ltd, November 2014*) explored how the geographical location could potentially impact the remaining life of the asset. It has been agreed that a coastal factor is applicable across all asset types on an Offtake/PRS site.

The derived PoF multiplication factor is shown in the table below:

Type	Location Factor
Coastal	1.667

Table E4 – Coastal location PoF multiplier

The distance from the coast at which the coastal factor applies was not documented in Report 1569. This can be applied flexibly in the analysis using a 'Distance to Coast' attribute in the base data. A value of 3km has been applied initially.

Housing Risk (Housing Factor)

The assessed condition of the building/housing is used as an adjustment factor, where applicable. The derived PoF multiplication factors are shown in the table below:

Condition Grade	Description	Housing Factor
1	As new	0.5
2	minor cosmetic damage to housing	0.8
3	some damage to housing (assessment/monitoring required)	1
4	considerable damage to housing (intervention considered).	1.5
5	severe damage to housing (intervention required)	2

Table E5 – Housing condition PoF multipliers

Fencing/Security Risk (FS Factor)

The assessed condition of the fencing and security is used as an adjustment factor, where applicable. The derived PoF multiplication factors are shown in the table below, note: where two sub assets measured, the worst case assessment score will be taken.

Condition Grade	**Description**	**Housing Factor**
1	As new, no issues	0.5
2	minor cosmetic damage to fencing, no security issues	0.8
3	Low security concerns/issues, some damage to fencing (assessment/monitoring required).	1
4	Medium security concerns/issues, considerable damage to fencing (intervention considered).	1.5
5	High security concerns/issues, severe damage to fencing (intervention required).	2

Table E6 – Fencing/security condition PoF multipliers

Please note, where there are multiple components/sub-assets, the worst-case condition assessment will be applied.

Flood Risk (Flood Factor)

In a 2009 Environment Agency report titled "Flooding in England – a national assessment of flood risk", the EA identified that some "28% of gas infrastructure assets were identified as being at significant risk of flooding".

As part of the EA's approach to managing flood risk they provide mapping datasets for classifications/risk levels in relation to flooding as follows:

- **Zone 3 (significant)** – Land assessed, ignoring the presence of flood defences, as having a 1% or greater annual probability of fluvial flooding or a 0.5% or greater annual probability of tidal flooding.
- **Zone 2 (moderate)** – Land assessed, ignoring the presence of flood defences, as having between a 1% and 0.1% annual probability of fluvial flooding or between a 0.5% and 0.1% annual probability of tidal flooding.
- **Zone 1 (low risk)** – Less than 0.1% probability.

For the purposes of the methodology, the following flood risk factors apply:

Zone	Flood Factor
1	1
2	1.5
3	2

Table E7 – Flood risk PoF multipliers

Please note, if sufficient flood protection or defences are in place, ensuring the asset is fully protected from flooding, then a Zone 1 factor applies.

Final Calculation

The calculation applied to the Initial Failure Rate, to include condition, flood and location adjustments, is as follows:

PoF = Initial Failure Rate x (exp[(Effective Age – Default Age) x Deterioration Rate]) x Coastal Factor x Housing Factor x FS Factor x Flood Factor

E3.3. Offtake & PRS Consequence of Failure Assessment

There are several consequences of failure identified for Offtakes & PRSs. These can be viewed in the risk maps and Data Reference Library in section E2.4. For simplicity each consequence of failure has been categorised as Internal Costs, Environmental, and Health & Safety consequences.

As maintainable assets it is important to consider the consequences of obsolescence within the Offtake and PRS models. As the probability of failure does not automatically increase when an asset becomes obsolete, we have adopted asset management best practice which suggests that the consequence of failure (not the probability of failure) increases when an asset becomes obsolete. For example, when an asset becomes obsolete the cost and/or time and/or impacts of failure are correspondingly greater than when this asset is serviceable (e.g. spare parts are readily available) which may impact on response time/cost and the potential length of any service outage. The magnitude of these obsolescence factors was initially estimated using expected values of failure consequence, derived through workshops with asset experts. As companies spend significant sums of proactive maintenance to avoid potentially catastrophic failures, the impact of obsolescence is a significant factor driving investment as would be expected.

Similarly, it is important to consider the condition of any associated electrical, instrumentation and telemetry equipment within the Offtake & PRS models.

Obsolescence factors and E&I Condition factors are applied to the following **Odorant & Metering** nodes:

- **P_Gas_Release_Dur –** The duration of a Loss of Gas consequence as a result of a Release of Gas failure.
- **P_Low_Dur –** The duration of undetected downstream escapes as a result of a Low Odorant failure.
- **P_High_Dur –** The duration of an increase in Public Reported Escapes as a result of a High Odorant failure.

Obsolescence factors and E&I Condition factors are applied to the following **Pre-heating** nodes:

- **P_Gas_Release_Dur –** The duration of a Loss of Gas consequence as a result of a Release of Gas failure.
- **P_Low_Temp_Dur –** The duration of undetected downstream escapes and ground-heave events, **plus** the increase in probability of PRS Site Failure as a result of a low temperature failure.
- **P_High_Temp_Dur –** The duration of an increase in probability of PRS Site Failure as a result of a High Odorant failure.

Obsolescence factors and E&I Condition factors are applied to the following **Filters & Pressure Control** nodes:

- **P_Gas_Release_Dur –** The duration of a Loss of Gas consequence as a result of a Release of Gas failure.
- **P_HOP_Dur –** The duration of undetected downstream escapes, plus the increase in probability of PRS Site Failure as a result of a High Outlet Pressure failure.
- **P_LOP_Dur –** The duration of an increase in probability of PRS Site Failure as a result of a Low Outlet Pressure failure.

For Electrical, Instrumentation & Telemetry ancillary assets, the assessed Condition Grade is used as an adjustment factor, where applicable. The derived consequence of failure multiplication factors is shown Table E8 below:

Condition Grade	Description	E&I Factor
1	As new	0.5
2	No signs of deterioration to equipment	0.8
3	Minor signs of deterioration to equipment leading to occasional faults	1
4	Significant signs of deterioration to equipment leading to increasing numbers of faults	1.5
5	Severe issues, unable to operate, unable to monitor or transmit system faults	2

Table E8 – Consequence of failure multipliers for electrical, instrumentation and telemetry assets

Note, where there are multiple components/sub-assets, the worst-case condition assessment will be applied.

Until internal processes can be put in place across GDN's to capture E&I condition in accordance with table E8, the following default classification should be used which will take into consideration the reliability of the electrical, instrumentational and telemetry systems as the adjustment factor to the consequences of failure. This is agreed to be a more robust method for measuring the impact of any loss of telemetry.

- ≥99% Uptime = A factor of 1
- <98% Uptime = A factor of 2

E3.3.1. Internal Consequence Costs

Internal consequences refer both to the proactive costs of preventing failure (or maintaining the asset to an acceptable level or risk) and the reactive costs of responding to failure. Proactive consequences modelled include the costs of:

- **Inspections** – PSSR, ME2, and any inspection costs, including any maintenance carried out during surveys, pre-heater revalidation inspection costs and DAM1 assessments
- **Compliance** – costs of compliance with HSE and other legislative requirements (e.g. DSEAR; COMAH, working at height)
- **General Maintenance** – Routine & non-routine maintenance costs
- **CS Maintenance** - Control system & E&I maintenance costs
- **Protection** - Costs of fence and kiosk maintenance. Include costs of pipework painting to mitigate corrosion. Cost of security (i.e. CCTV, patrols).

E3.3.2. Environment Consequence Costs

Environmental consequences include the monetary value of product lost due to failures or leakage plus the shadow cost of carbon associated with failure or emissions. In particular, the shadow cost of carbon increases annually (and hence the consequence value increases) in line with government carbon valuation guidelines. Environmental consequences modelled include:

- **Carbon** – the external cost of carbon associated with general emissions and loss of gas following failures. The environmental costs of burnt and unburnt gas are treated separately
- **Loss** of **Gas** – the product value of the loss of gas due to failure and general emissions. These volumetric values are taken from standard industry models
- **Verometer Carbon -** carbon associated of unburnt gas associated with operation of verometers
- **Carbon Heating -** carbon associated of burnt gas associated with operation of pre-heaters
- **Own-use Gas –** Own use gas for site pre-heating requirements

E3.3.3. Health & Safety Consequence Costs

Health & Safety consequences are primarily associated with the damage caused by ignition following asset failure and subsequent entry into customer properties. The largest HSE consequence is associated with loss of life, but minor injury and property damage are also considered. The HSE consequences are similar to the Mains and Services models, but include potential injury and loss of life at the Offtake/PRS itself.

E3.4. Offtake & PRS Intervention Definitions

Intervention activities can be flexibly defined within the monetised risk trading methodology by modelling the change in risk enabled by the intervention activity.

Some interventions, such as replacing a defective filter, will reduce both the Probability of Failure and deterioration of the overall asset base, thus changing the monetised risk value over the life of the asset. This is called a **With Investment** activity below.

Other types of intervention may just represent the base costs of maintaining the asset at an acceptable level of performance, for example fencing maintenance or painting to arrest corrosion. This is called a **Without Investment** action below.

Definitions of activities undertaken as part of normal maintenance (i.e. 'without intervention') and interventions for Offtakes & PRSs are listed below.

Odourant and metering

'Without intervention' activities:

- System Repair
- System Maintenance
- System Testing
- Odorant purchasing
- Functional check
- Routine Maintenance (calibration)
- Soft Spare replacement

'With intervention' activities:

Number	Description	Definition
Intervention 1	Odorant Refurb	Refurb of odorant system (inc pumps)
Intervention 2	Meter Refurb	Refurb of meter system
Intervention 3	Odorant Replace	Replacement of odorant system (inc pumps)
Intervention 4	Meter Replace	Replacement of metering system
Intervention 5	Full System E&I Upgrade	Full Upgrade of E&I equipment on site. If a loop is only upgraded on site then the intervention should only be applied to the relevant system
Intervention 6	Civils Upgrade (Fence and Building replacement)	Replacement of fence and building on site. Intervention should only be applied to systems that the building applies too.
Intervention 7	Civils Upgrade (Fence replacement)	Replacement of fence on site
Intervention 8	Civils Upgrade (Building replacement)	Replacement of building on site. Intervention should only be applied to systems that the building applies too.
Intervention 9	Full System Rebuild	Full upgrade of relevant system, fence, civils and E&I

Pre-heating

'Without intervention' activities:

- Heater System Repair
- Heater System Maintenance
- Heater System Testing

- Heater Water sampling
- Heater PSSR checks

'With intervention' activities:

Number	Description	Definition
Intervention 1	Preheater Replace	Replacement of heating system
Intervention 2	Preheater Refurb	Refurb of heating system
Intervention 3	Full System E&I upgrade	Full Upgrade of E&I equipment on site. If a loop is only upgraded on site then the intervention should only be applied to the relevant system
Intervention 4	Civils Upgrade (Fence and Building replacement)	Replacement of fence and building on site. Intervention should only be applied to systems that the building applies too.
Intervention 5	Civils Upgrade (Fence replacement)	Replacement of fence on site
Intervention 6	Civils Upgrade (Building replacement)	Replacement of building on site. Intervention should only be applied to systems that the building applies too.
Intervention 7	Full System Rebuild	Full upgrade of relevant system, fence, civils and E&I

Pressure reduction and filtration

'Without intervention' activities:

- Small Patch Paint applications
- Functional check
- Routine Maintenance
- Soft Spare replacement
- PSSR Inspection
- Routine Functional check
- Attend Fault /Alarms response
- Overhaul following inspection
- DAM 1 assessment
- Patch Painting

'With intervention' activities:

Number	Description	Definition
Intervention 1	PRS Refurb	Refurbishment of main components on pressure reduction stream (monitor, active, slam)
Intervention 2	PRS Replace	Total replacement of all pressure reduction streams on the specific system from inlet to outlet
Intervention 3	Filter Refurb	Filter refurb
Intervention 4	Filter Replace	Total replacement of the filter system

Number	Description	Definition
Intervention 5	Civils Upgrade (Fence and Building replacement)	Replacement of fence and building on site. Intervention should only be applied to systems that the building applies too.
Intervention 6	Civils Upgrade (Fence replacement)	Replacement of fence on site.
Intervention 7	Civils Upgrade (Building replacement)	Replacement of building on site. Intervention should only be applied to systems that the building applies too.
Intervention 8	Full System E&I Upgrade	Full Upgrade of E&I equipment on site. If a loop is only upgraded on site then the intervention should only be applied to the relevant system.
Intervention 9	Full System Rebuild	Full upgrade of relevant system, fence, civils and E&I.

Table E9 – With and Without Investment interventions for Offtake/PRS assets

E3.4.1. Offtake/PRS Intervention Benefits

The risk modelling tools developed provide the ability and flexibility to model any intervention by adjusting the values of the calculated risk nodes to match the expected performance of the asset following intervention. For example, painting of internal pipework will reduce the probability of a corrosion failure and potentially the deterioration of the rate of corrosion. This allows the new risk value to be calculated post-intervention and compared with the pre-intervention (do nothing) monetised risk.

Compared to Mains and Services, there are many alternative interventions possible for Offtake and PRSs assets. Because of the degree of redundancy built into Offtake & PRS assets and the high level of proactive maintenance activities, failures are highly infrequent, but have a very high consequence of failure.

The developed models allow "negative" interventions to be modelled to test the benefits of existing (and ongoing) proactive maintenance work. For example the benefit of fencing and housing maintenance programmes can be tested by removing these costs from the programme (and thereby reducing the baseline level of monetised risk). By assessing the increased failure rate (or consequences) arising from this lack of proactive maintenance the cost-effectiveness of these interventions can be quantified.

E3.4.2. Example Offtake/PRS Interventions

An example Offtake intervention, namely replacement of five Odorisation systems per year, is provided for illustration of the process. An example replacement cost of £140,000 per system, total cost of £700,000, has been applied. This is shown in Figure 17 below.

This type of intervention will include benefits including;

- Reduce the number of low/high odorant events by installing a new LGT Pump system
- Reduce the probability of a release of gas by corrosion on the pump system
- Reduce the probability of odorant spillage on the odorant tank due to corrosion

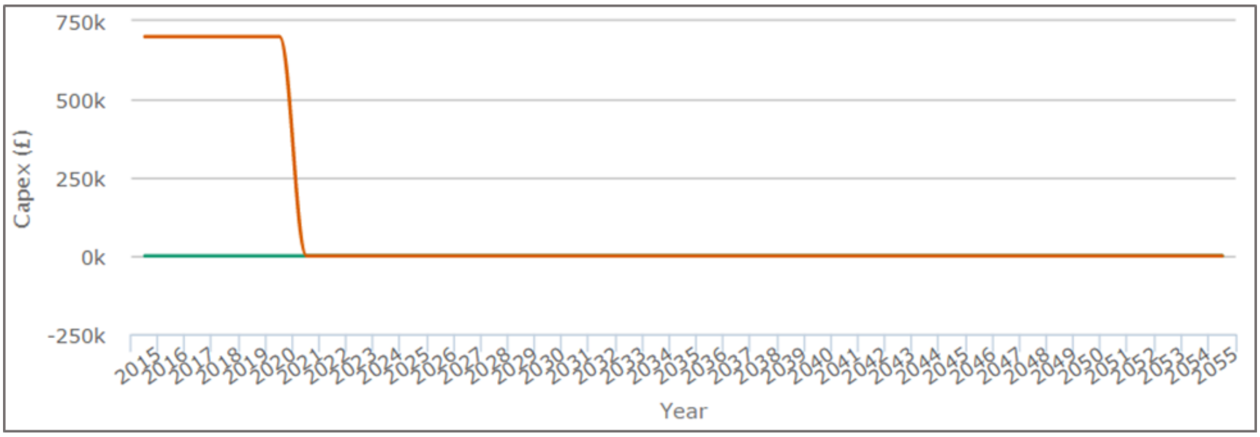


Figure E17 – Example Annual Capital Expenditure for Replacement of Odorisation Systems

The baseline level of cumulative monetised risk for each financial risk node is shown below for both with and without intervention.

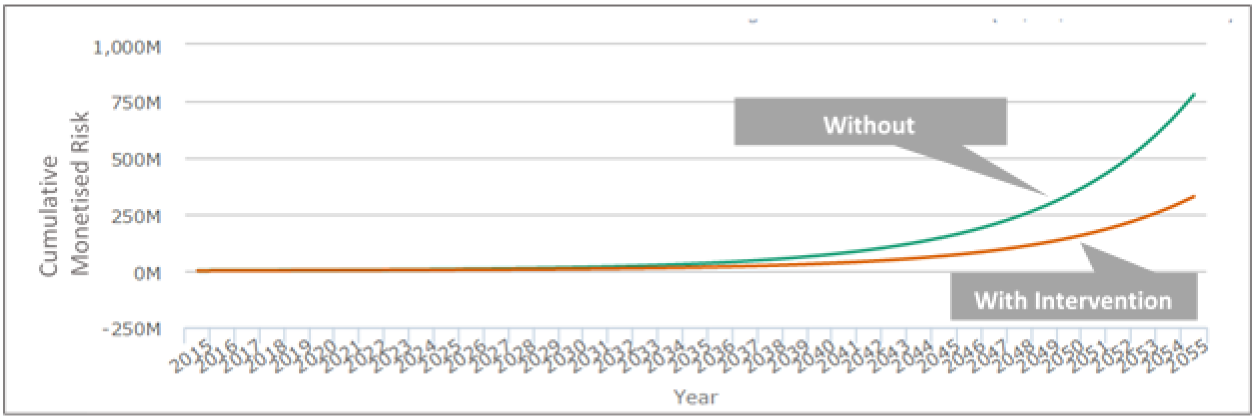


Figure E18– Example Pre and Post cumulative Monetised Risk value of Odorisation Systems

This gives a discounted net benefit that has a payback of approximately 14 years. A full set of results is provided in table 10 below.

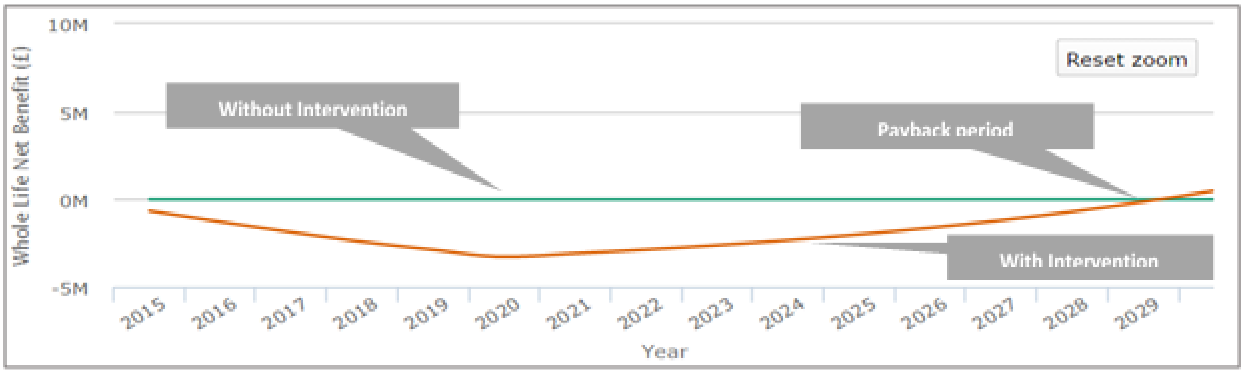


Figure E19– Example Discounted benefits per annum for planned Odorisation System replacement

Period	Year	Interventions	Baseline Monetised Risk	Intervention Monetised Risk	Change in value due to intervention	Discount Factor (3.5%)	Discounted change in risk value due to intervention	Cumulative discounted change due to intervention
1	2015	700000	£ 483,426.35	£ 463,005.39	£ 20,420.96	1	£ 20,420.96	£ 20,420.96
2	2016	700000	£ 490,229.67	£ 456,595.31	£ 33,634.37	0.9662	£ 32,496.97	£ 52,917.93
3	2017	700000	£ 504,464.82	£ 464,462.12	£ 40,002.70	0.9335	£ 37,342.95	£ 90,260.88
4	2018	700000	£ 522,611.23	£ 449,473.02	£ 73,138.21	0.9019	£ 65,966.48	£ 156,227.36
5	2019	700000	£ 549,357.57	£ 398,444.32	£ 150,913.26	0.8714	£ 131,512.18	£ 287,739.54
6	2020	700000	£ 585,244.19	£ 372,522.18	£ 212,722.02	0.8420	£ 179,106.23	£ 466,845.77
7	2021	0	£ 630,673.62	£ 385,811.06	£ 244,862.55	0.8135	£ 199,195.85	£ 666,041.62
8	2022	0	£ 700,207.17	£ 408,736.80	£ 291,470.36	0.7860	£ 229,093.07	£ 895,134.69
9	2023	0	£ 782,354.70	£ 436,187.56	£ 346,167.14	0.7594	£ 262,883.33	£ 1,158,018.02
10	2024	0	£ 879,425.16	£ 469,066.97	£ 410,358.20	0.7337	£ 301,092.52	£ 1,459,110.53
11	2025	0	£ 993,294.67	£ 507,628.88	£ 485,665.79	0.7089	£ 344,297.62	£ 1,803,408.15
12	2026	0	£ 1,131,779.92	£ 558,222.24	£ 573,557.68	0.6849	£ 392,855.88	£ 2,196,264.03
13	2027	0	£ 1,309,816.10	£ 628,363.99	£ 681,452.10	0.6618	£ 450,973.62	£ 2,647,237.65
14	2028	0	£ 1,518,737.86	£ 711,984.36	£ 806,753.49	0.6394	£ 515,841.53	£ 3,163,079.18
15	2029	0	£ 1,763,928.99	£ 811,888.25	£ 952,040.73	0.6178	£ 588,153.43	£ 3,751,232.61
16	2030	0	£ 2,051,720.51	£ 930,777.04	£ 1,120,943.48	0.5969	£ 669,080.64	£ 4,420,313.25
17	2031	0	£ 2,390,637.44	£ 1,075,061.06	£ 1,315,576.38	0.5767	£ 758,700.67	£ 5,179,013.93
18	2032	0	£ 2,788,597.25	£ 1,244,415.21	£ 1,544,182.04	0.5572	£ 860,424.07	£ 6,039,437.99
19	2033	0	£ 3,255,984.66	£ 1,443,230.13	£ 1,812,754.53	0.5384	£ 975,916.59	£ 7,015,354.59
20	2034	0	£ 3,805,038.90	£ 1,676,672.77	£ 2,128,366.13	0.5202	£ 1,107,081.75	£ 8,122,436.34
21	2035	0	£ 4,450,202.53	£ 1,950,831.06	£ 2,499,371.47	0.5026	£ 1,256,098.83	£ 9,378,535.17
22	2036	0	£ 5,208,534.70	£ 2,272,883.41	£ 2,935,651.29	0.4856	£ 1,425,466.85	£ 10,804,002.02
23	2037	0	£ 6,100,208.06	£ 2,651,301.47	£ 3,448,906.58	0.4692	£ 1,618,056.70	£ 12,422,058.72
24	2038	0	£ 7,149,108.08	£ 3,096,093.07	£ 4,053,015.01	0.4533	£ 1,837,173.48	£ 14,259,232.20
25	2039	0	£ 8,383,558.90	£ 3,619,094.50	£ 4,764,464.39	0.4380	£ 2,086,631.17	£ 16,345,863.37
26	2040	0	£ 9,837,206.04	£ 4,234,323.37	£ 5,602,882.67	0.4231	£ 2,370,842.93	£ 18,716,706.30
27	2041	0	£ 11,550,095.05	£ 4,958,406.08	£ 6,591,688.97	0.4088	£ 2,694,930.77	£ 21,411,637.07
28	2042	0	£ 13,569,995.98	£ 5,811,098.22	£ 7,758,897.76	0.3950	£ 3,064,859.60	£ 24,476,496.67
29	2043	0	£ 15,954,038.81	£ 6,815,920.85	£ 9,138,117.96	0.3817	£ 3,487,602.38	£ 27,964,099.05
30	2044	0	£ 18,770,744.17	£ 8,000,942.65	£ 10,769,801.52	0.3687	£ 3,971,344.44	£ 31,935,443.50
31	2045	0	£ 22,102,560.22	£ 9,399,746.41	£ 12,702,813.81	0.3563	£ 4,525,738.31	£ 36,461,181.81
32	2046	0	£ 26,049,051.42	£ 11,052,630.52	£ 14,996,420.90	0.3442	£ 5,162,223.19	£ 41,623,405.00
33	2047	0	£ 30,730,932.39	£ 13,008,111.33	£ 17,722,821.06	0.3326	£ 5,894,427.89	£ 47,517,832.89
34	2048	0	£ 36,295,203.32	£ 15,324,813.66	£ 20,970,389.67	0.3213	£ 6,738,681.92	£ 54,256,514.81
35	2049	0	£ 42,921,730.01	£ 18,073,864.91	£ 24,847,865.10	0.3105	£ 7,714,667.05	£ 61,971,181.87
36	2050	0	£ 50,831,727.57	£ 21,341,946.31	£ 29,489,781.26	0.3000	£ 8,846,252.03	£ 70,817,433.90
37	2051	0	£ 60,298,765.95	£ 25,235,206.62	£ 35,063,559.33	0.2898	£ 10,162,566.65	£ 80,980,000.55
38	2052	0	£ 71,663,130.68	£ 29,884,313.55	£ 41,778,817.13	0.2800	£ 11,699,389.43	£ 92,679,389.99
39	2053	0	£ 85,350,666.26	£ 35,451,013.35	£ 49,899,652.91	0.2706	£ 13,500,947.01	£ 106,180,337.00
40	2054	0	£ 101,897,631.18	£ 42,136,698.60	£ 59,760,932.58	0.2614	£ 15,622,255.06	£ 121,802,592.06

Table E10 Discounted costs and benefits per annum of replacing 5 odorant systems per year from 2015-2020.

In simple terms, the benefit of replacing 5 odorant systems is to reduce the initial probability of failure to the value of an asset with an effective age of zero (i.e. new asset). The failure rate of the pre-intervention asset is based on its effective age, location (coastal or non-coastal) and housing type. The deterioration rate of odorisation systems pre and post intervention is assumed to be the same at present, but as initial failure rates of the new asset is very low the impact of this deterioration assumption is minor.

Applying these rules and modelling the costs and benefits over a 45 year period delivers the following risk reduction profile; a cumulative monetised risk reduction of £895,134 over 8 years.

Interventions for other Offtake and PRS assets will be similar due to the consistent structure of the monetised risk models.

Appendix F –Risers

F1. Risers Definition

This appendix refers to gas transporting assets that are present on or in Multi-Occupancy Buildings (MOBs), e.g. risers and laterals (or above ground (AG) services). Multi-Occupancy Buildings contain multiple individual dwellings (i.e. more than two dwellings within a single building). These are typically residential tower blocks of flats. MOBs exclude detached, semi-detached and terraced houses or bungalows predominantly occupied by a single family.

- The building must be three storeys or higher or two storeys with basement
- Where a building has two floors or less, all of the pipes should be treated as mains & services based upon the relevant definitions and the risks calculated in accordance with the Mains Risk model and the Services Risk model.

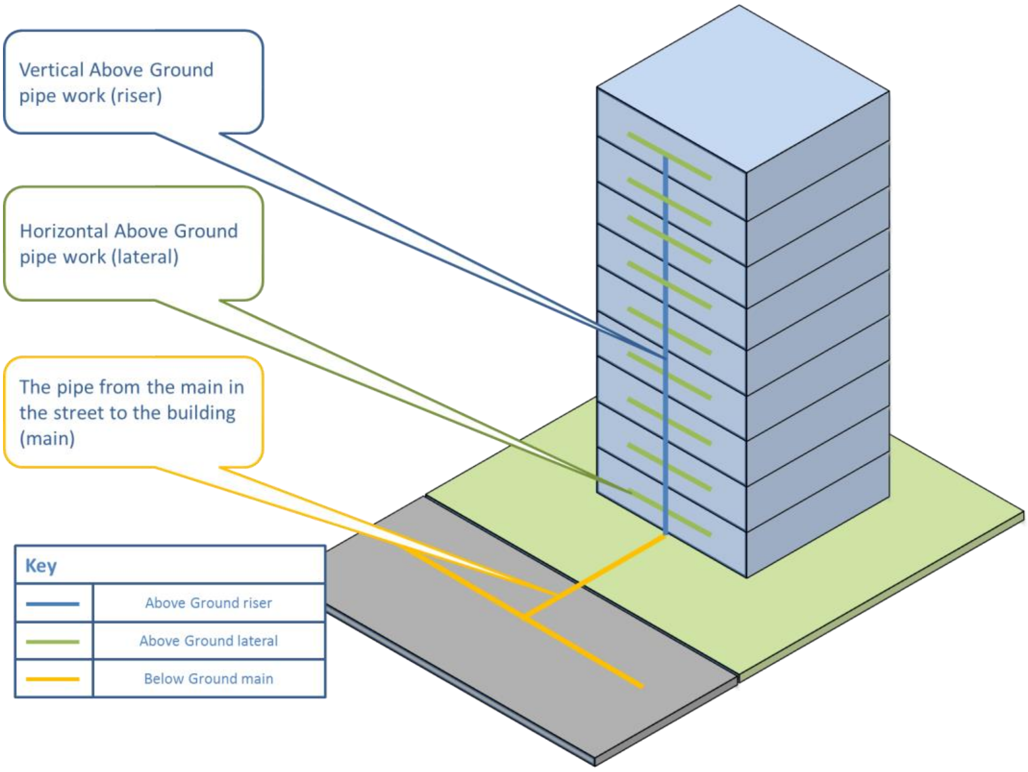


Figure F1 – Riser configuration and definitions

Riser – a vertical pipe that carries gas between floors within a building. *A Riser is a network pipeline, typically vertical, serving one or more dwellings* (IGEM/G/5 Edn2).

Lateral (AG Services) – a horizontal pipe connected to a riser that conveys gas along one floor level within a building. *A Lateral is a network pipeline, typically horizontal, serving one dwelling and connected to a riser* (IGEM/G/5/Edn2).

F2. Risers Event Tree Development

F2.1. Risers Failure Modes

Failure modes have been identified for risers and laterals that are consistent with the process outlines in Section 3.4 of the main methodology. The failure mode for risers includes the following:

- **General Emissions** – background leakage or shrinkage from the Riser
- **Joint failure** – including welding, fittings.
- **Interference failure** – external interference caused by third parties.
- **Corrosion failure** – corrosion of the pipe containing gas

Values are typically expressed per Riser or per Lateral.

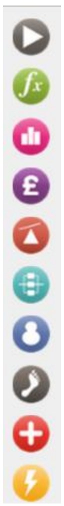
F2.2. Risers Consequence Measures

Consequence measures have been identified in relation to Risers in accordance with the process identified in section 3.5 of the main methodology and include the following:

- Gas escape
- Loss of gas – volume of gas lost due to failure
- GIB – Gas escape leading to a Gas in Building event
- Supply interruption
- Explosion – Probability of explosion given a gas ingress event
- Structural and Fire Hazard – explosion leading to structural collapse and/or subsequent fire

Consequences values are dependent on the consequences being assessed. Some of these consequences are clearly inter-related, as detailed in the risk map.

F2.3. Risers Risk Map



Asset Data
Explicit Calculation
Consequence
Financial outcome (monetised risk)
Willingness to pay/Social Costs (not used)
System Reliability (not used)
Customer outcome/driver
Carbon outcome/driver
Health and safety outcome/driver
Failure Mode

Figure F2 – Risk Map Key

As per the process described within Section 3.6 of the main methodology, the risk map for Risers is shown below.

Figure F-2 outlines the risk map key for LTS. The risk map is colour coded for each node of the event tree to indicate which values are associated with each node. The colours are reflected in both the risk map and risk map template in Figures D3 and D4.

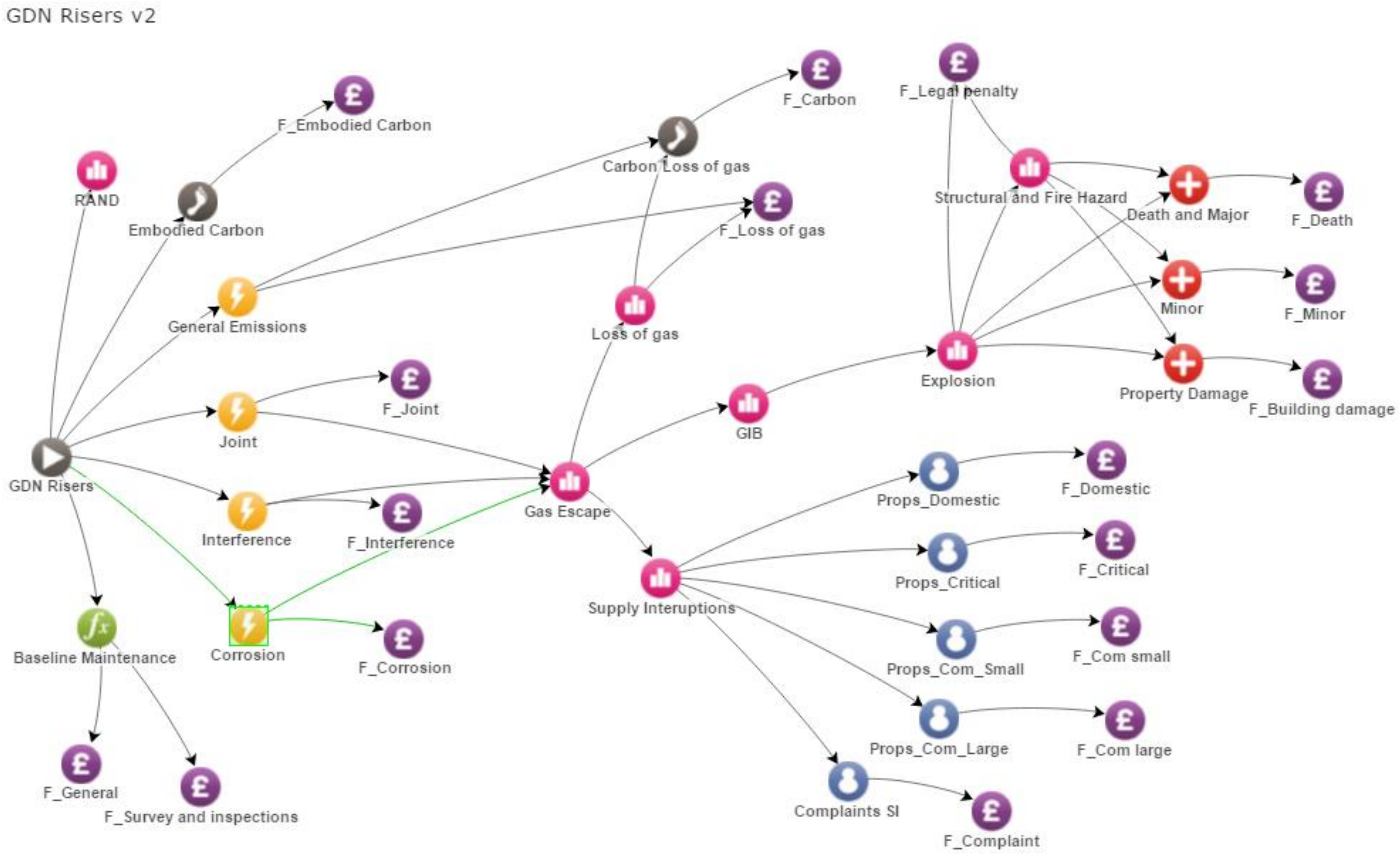


Figure F3 – Risers Risk Map

F2.4. Risers Risk Template

The following table demonstrates how the total risk value is derived for any given Riser cohort. An individual, populated risk map is developed for every asset to be modelled to deliver a baseline monetised risk value prior to intervention modelling.

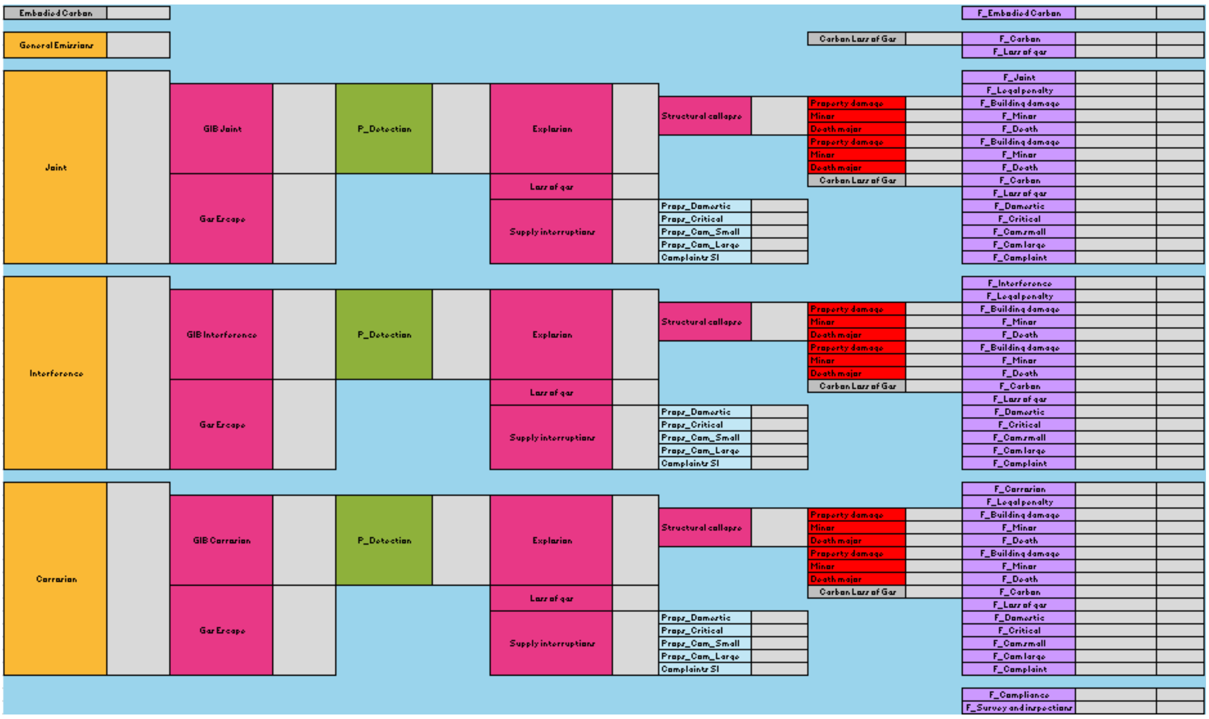


Figure F4 – Risers Risk Template

F2.5. Risers Data Reference Library

As per Section 3.7 of the main report, the following table gives a description of data required for nodes on the Risers Risk Map (Event Tree).

Node ID / Variable	Description	Data Source	GDN Specific or Common
Complaints SI	Number of customer complaints arising from supply interruptions.	Data taken from company systems.	GDN Specific
Corrosion	Frequency of corrosion failures.	Data taken from company riser surveys.	GDN Specific
Death_Major	Number of deaths given explosion	Data taken from company riser surveys (based on type of building and number of stories).	Common
Explosion	Probability of explosion given gas ingress, including probability of gas leak detection given GIB	Data taken from company riser surveys & systems.	GDN Specific
F_Com large	Financial cost of supply interruption of riser or lateral for a large commercial customer.	Regulatory penalty payment	Common
F_Com small	Financial cost of supply interruption of riser or lateral for a small commercial customer. To includethe cost of customer buy-out in the event of supply interruption	Regulatory penalty payment Based on GS1 regulation 7 – supply restoration. Average of 5 domestic properties per riser at domestic building (WWU figures), cap for payments under GS1 is £1,000. 5 properties x £1,000 = £5,000	Common
F_Complaint	Cost of handling customer complaints relating to a supply interruption on a riser or lateral	Data taken from company systems where available, or a default/assumed value agreed with SRWG	GDN Specific
F_Corrosion	GDN specific cost data relating to riser and lateral by failure mode (with back office cost uplift to be included)	Data taken from company systems where available.	GDN Specific
F_Critical	Financial cost of supply interruption of riser or lateral for a critical customer.	Regulatory penalty payment	Common
F_Domestic	Financial cost of supply interruption of a riser or lateral for a domestic customer. To includethe cost of customer buy-out in the event of supply interruption	Regulatory penalty payment Based on GS1 regulation 7 – supply restoration. Average of 5 domestic properties per riser at domestic building (WWU figures), cap for payments under GS1 is £1,000.	Common

Node ID / Variable	Description	Data Source	GDN Specific or Common
		5 properties x £1,000 = £5,000	
F_Interference	GDN specific cost data for a riser or lateral by failure mode (with back office cost uplift to be included)	Data taken from company systems. A statistical model can be used to relate unit cost to pipe diameter.	GDN Specific
F_Joint	Average cost of repairing a joint for a riser or lateral.	Data taken from company systems. A statistical model can be used to relate unit cost to pipe diameter.	GDN Specific
F_Legal penalty	Cost of legal enforcement and penalty payments following ignition/explosion	Default/assumed value agreed with SRWG based on historical incidents.	Common
F_Survey and inspections	LC20 surveys (used to assess building risers and laterals - to ensure full compliance with IGEM standard IGEM/G/5: Gas in mutli-occupancy buildings. Plus, LC23 inspections - in order to comply with Regulation 13 of Pipeline Safety Regulations.	Data taken from company systems.	GDN Specific
Gas Escape	Gas Escapes due to corrosion, fracture, interference or joint failure	Value of 1 used as a multiplier to enable the grouping/summation of the probability of corrosion, fracture, interference and joint failures	Common
General Emissions	Amount of leakage per pipe in m3.	Industry leakage model. Risers – as per Mains; Laterals – as per Services. See also Loss of Gas.	Common
GIB	Probability of gas ingress into MOB given failure of risers or laterals	Data taken from company systems where available (i.e. no. of gas ingress events due to interference / no. of interference failures) or a default/assumed value agreed with SRWG	GDN Specific
Interference	Frequency of interference failures of risers or laterals	Data taken from company riser surveys.	GDN Specific
Joint	Frequency of joint failures of risers or laterals	Data taken from company riser surveys.	GDN Specific
Loss of gas	M3 of gas lost from a failure or failure mode	Taken from standard gas industry leakage models. Risers – as per Mains; Laterals – as per Services. (Linear extrapolation utilised for	Common

Node ID / Variable	Description	Data Source	GDN Specific or Common
		Intermediate pressure for which no data currently exists.)	
Minor	Number of minor injury given explosion	Data taken from company riser surveys (based on type of building and number of stories).	Common
Property Damage	Number of property damage given explosion. Based on number of storeys.	Data taken from company riser surveys.	GDN Specific
Props_Com_Large	Number of commercial large properties at risk of supply interruption from riser or lateral failure.	Data taken from company riser surveys.	GDN Specific
Props_Com_Small	Number of commercial small properties at risk of supply interruption from riser or lateral failure.	Data taken from company riser surveys.	GDN Specific
Props_Critical	Number of critical properties at risk of supply interruption from riser or lateral failure.	Data taken from company riser surveys.	GDN Specific
Props_Domestic	Number of domestic properties at risk of supply interruption from riser or lateral failure.	Data taken from company riser surveys.	GDN Specific
Structural and Fire Hazard	Probability of structural collapse or fire hazard. This takes into account building structural type e.g. Ronan Point.	Data taken from company riser surveys and industry reports.	Common
Supply Interruptions	Probability of supply interruptions given a failure has occurred	Data taken from company systems.	GDN Specific

F3. Risers Event Tree Utilisation

F3.1. Risers Base Data

The Risers base data has been created from company asset databases, financial systems, riser survey information and other data sources. Where available, condition assessment of risers (i.e. survey information) provides the starting point for the PoF analysis.

The analysis assumes the overall riser is split into two sub-assets:

- Vertical (riser)
- Lateral (above ground service)

The key data source is the survey information. Each company currently undertakes comprehensive surveys at asset level that provide condition scores for both the vertical and laterals for various failure modes, as well as risk scores for potential consequence of failure. Where surveys have not yet been undertaken, default values will be used.

An example of data input format is shown below:

ABOVE_BELOW_GROUND_ENTRY	ACCESSIBLE	ACCESSIBLE_EMERGENCY_VALVES	AGE_OF_BUILDING	AGS_EMERGENCY_CONTROL_VALVE	AG_INTER_FLOOR_CEILING_MATER	AG_RISER_NUMBER	AG_TOTAL_ABOVE_GROUND_SERVICES	ASSET_LENGTH	ASSET_SUBTYPE	ASSET_TYPE	BRANCH_ISOLATION_VALVE	BUILDING_NO	CELLAR_VENTILATED	CP_COMPLIENT
ABOVE	No	Not assigned	40	Not assigned	Not assigned	408	0	58	RISER	RISER	Not assigned	52604785	NA	No
ABOVE	No	Not assigned	40	Not assigned	Not assigned	409	0	58	RISER	RISER	Not assigned	52604785	NA	No
ABOVE	No	Not assigned	40	Not assigned	Not assigned	410	0	65	RISER	RISER	Not assigned	52604785	NA	No
ABOVE	No	Not assigned	40	Not assigned	Not assigned	412	0	80	RISER	RISER	Not assigned	52604785	NA	No
ABOVE	No	Not assigned	40	Not assigned	Not assigned	414	0	85	RISER	RISER	Not assigned	52604784	NA	No
ABOVE	No	Not assigned	40	Not assigned	Not assigned	415	0	70	RISER	RISER	Not assigned	52604784	NA	No
ABOVE	No	Not assigned	40	Not assigned	Not assigned	416	0	80	RISER	RISER	Not assigned	52604784	NA	No
ABOVE	No	Not assigned	69	Yes	Mastic	2	5	7.5	SERVICES	RISER	No	52604749	Not assigned	No
ABOVE	No	Not assigned	69	Yes	Mastic	4	6	9	SERVICES	RISER	No	52604749	Not assigned	No
ABOVE	No	Not assigned	69	Yes	Mastic	4	6	34	RISER	RISER	No	52604749	Not assigned	No
ABOVE	No	Not assigned	69	Yes	Mastic	10	5	10	SERVICES	RISER	No	52604749	Not assigned	No
ABOVE	No	Not assigned	69	Yes	Mastic	10	5	42	RISER	RISER	No	52604749	Not assigned	No
ABOVE	No	Not assigned	69	Yes	Mastic	14	5	7.5	SERVICES	RISER	Not assigned	52604749	N	No
ABOVE	No	Not assigned	69	Yes	Mastic	14	5	16	RISER	RISER	Not assigned	52604749	N	No
ABOVE	No	Not assigned	69	Yes	Mastic	16	5	5	SERVICES	RISER	No	52604749	N	No
ABOVE	No	Not assigned	69	Yes	Mastic	16	5	16	RISER	RISER	No	52604749	N	No
ABOVE	No	Not assigned	69	Yes	Not assigned	3	5	7.5	SERVICES	RISER	No	52604749	Not assigned	No
ABOVE	No	Not assigned	69	Yes	Not assigned	3	5	22	RISER	RISER	No	52604749	Not assigned	No
ABOVE	No	Not assigned	69	Yes	Not assigned	5	4	4	SERVICES	RISER	No	52604749	Not assigned	No

CP_FITTED	DIAMETER_MM	DUST_TRAPS_FITTED	EXPOSED	EXPOSED_PIPE_WORK	EXTERNAL_RISER_VENTILATED	GARAGE_CELLAR_BASEMENT_UG	ICS_RISER_BUILDING_ID	ICS_RISER_ID	INLET_ISOLATION_VALVES_FITTED	LEAKING_COMPONENTS_JOINT	LEAKING_COMPONENTS_OTHERS	LEAKING_COMPONENTS_PIPE_WALL	LEAKING_COMPONENTS_VALVES	MAR_POST_GAS_OR_G_ON_VALVE_CO
No	76.2	Not assigned	No	No	Yes	Yes	CD459B8B197F430FADCBA55F8E3F6747	270F8DBE780C423B99CE30AA4826DEBF	No	0	0	0	0	Not assigned
No	76.2	Not assigned	No	No	Yes	Yes	CD459B8B197F430FADCBA55F8E3F6747	66B953F2E4344A249CDBB05C390E28B7	No	0	0	0	0	Not assigned
No	76.2	Not assigned	No	No	Yes	Yes	CD459B8B197F430FADCBA55F8E3F6747	67A1CEFE2F6E4547B0B15BB7F6545688	No	0	0	0	0	Not assigned
No	101.6	Not assigned	No	No	Yes	Yes	CD459B8B197F430FADCBA55F8E3F6747	1C7F5972E94244F086ABB10680D6753D	No	0	0	0	0	Not assigned
No	101.6	Not assigned	No	No	Not assigned	Yes	75FA5BDC3C9445F4AB101B699989ACBA	27728F9E59F040E680D5FD295512D386	No	0	0	0	1	Not assigned
No	101.6	Not assigned	No	No	Not assigned	Yes	75FA5BDC3C9445F4AB101B699989ACBA	F0EE62C7849448DE8B9BC8FB3DDDCF0D	No	0	0	0	1	Not assigned
No	101.6	Not assigned	No	No	Yes	Yes	75FA5BDC3C9445F4AB101B699989ACBA	2C87FE6CBE7E45619B2666BFCB26EB2C	No	0	0	0	1	Not assigned
No	25.4	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	ED2AB8BC98874EB9B48FB3CA9D52BC5D	Yes	0	0	0	0	Not assigned
No	25.4	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	08C21F42E55C4AF79B0795639DC38A2A	No	0	0	0	0	Not assigned
No	50.8	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	08C21F42E55C4AF79B0795639DC38A2A	No	0	0	0	0	Not assigned
No	25.4	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	FEE1139623EF489BBBB2EC443CC8681F	No	0	0	0	0	Not assigned
No	50.8	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	FEE1139623EF489BBBB2EC443CC8681F	No	0	0	0	0	Not assigned
No	25.4	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	BF86BF526D324A229879DB919BCBBC92	No	0	0	0	0	Not assigned
No	50.8	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	BF86BF526D324A229879DB919BCBBC92	No	0	0	0	0	Not assigned
No	25.4	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	BD5C6FDF5ABB46EC8FB24F77C441F74C	No	0	0	0	0	Not assigned
No	50.8	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	BD5C6FDF5ABB46EC8FB24F77C441F74C	No	0	0	0	0	Not assigned
No	25.4	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	FDCDEB240D4F4966B34F2FA7FECB9663	No	0	0	0	0	Not assigned
No	50.8	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	FDCDEB240D4F4966B34F2FA7FECB9663	No	0	0	0	0	Not assigned
No	25.4	Not assigned	Yes	No	Yes	Yes	E6E18571FD854A888C882F7EA733E273	C95059ED4ED84D18B207D653D6508B64	No	0	0	0	0	Not assigned

ASSET_MATERIAL	ASSET_MATERIAL_BIN	NO_OF_RISERS	NO_OF_STOREYS	NO_OF_STOREYS_HAVING_GAS	PASSING_THROUGH_SOLID_FLOORS	PIPE_CORROSION	PIPE_ENVIRONMENT	PROTECTION_REQUIRED	PROTECTION_TYPE	RISER_EXTERNAL	RISER_SUPPORT_FITTED	RONAN_POINT_CONSTRUCTION	SERVICE_ISOLATION_VALVES_FTD	SERVICE_VALVE_BOX
Steel	ST	5	9	7	No	None	DRY	No	Not assigned	No	Yes	No	Yes	Not assigned
Steel	ST	5	9	7	No	None	DRY	No	Not assigned	No	Yes	No	Yes	Not assigned
Steel	ST	5	9	7	No	None	DRY	No	Not assigned	No	Yes	No	Yes	Not assigned
Steel	ST	5	9	7	Yes	None	DRY	No	Not assigned	No	Not assigned	No	Yes	Not assigned
Steel	ST	4	19	18	No	None	DRY	No	Not assigned	No	Yes	No	Yes	Not assigned
Steel	ST	4	19	18	No	None	DRY	No	Not assigned	No	Yes	No	Yes	Not assigned
Steel	ST	4	19	18	No	None	DRY	No	Not assigned	No	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	Not assigned	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	Not assigned	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	None	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	Not assigned	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	None	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	Not assigned	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	No	None	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	Not assigned	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	No	None	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	Not assigned	WET	Not assigned	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	No	None	WET	Not assigned	Not assigned	Yes	Yes	No	Yes	Not assigned
Steel	ST	16	6	5	Yes	Not assigned	WET	No	Not assigned	Yes	Yes	No	Yes	Not assigned

SHAFT	SLEEVES__FIREPROOFING	SUPPLIES_PER_STOREY	SUPPLIES_PER_STOREY_HAVING_GAS	TYPE_OF_BUILDING	TYPE_OF_JOINT	UNVENTILATED_VOIDS	VENTILATED	VULNERABLE_RE_WINTER_TRIGGER	WALLS_STRENGTHENED	SCORE_HAZARD_POINTS	SCORE_EXTERNAL_INF	SCORE_CORROSION	SCORE_GAS_RELEASE	SCORE_CONSEQUENCE_GAS_RELEASE	SCORE_JOINT_LEAKAGE	ICS_ASSET_ID	LEAKAGE_RATE
Yes	Not assigned	5	5	Residential	Welded	No	Yes	No	No	90	10	25	181	70	3.5	270F8DBE780C423B99CE30AA4826DEBF_R	3416.34
Yes	Not assigned	5	5	Residential	Welded	No	Yes	No	No	90	10	25	181	70	3.5	66B953F2E4344A249CDBB05C390E28B7_R	3416.34
Yes	Not assigned	5	5	Residential	Welded	No	Yes	No	No	90	10	25	181	70	3.5	67A1CEFE2F6E4547B0B15BB7F6545688_R	3416.34
Yes	Not assigned	5	5	Residential	Welded	No	Yes	No	No	90	15	30	181	70	4.7	1C7F5972E94244F086ABB10680D6753D_R	3854.4
Yes	Not assigned	3	3	Residential	Welded	No	Yes	No	No	140	10	25	341	70	3.7	27728F9E59F040E680D5FD295512D386_R	3854.4
Yes	Not assigned	3	3	Residential	Welded	No	Yes	No	No	140	10	25	341	70	3.7	F0EE62C7849448DE8B9BC8FB3DDDCF0D_R	3854.4
Yes	Not assigned	3	3	Residential	Welded	No	Yes	No	No	90	10	25	291	70	3.7	2C87FE6CBE7E45619B2666BFCB26EB2C_R	3854.4
No	Yes	5	5	Residential	Welded	No	No	No	No	11	5	110	219	40	0	ED2AB8BC98874EB9B48FB3CA9D52BC5D_S	0
No	Yes	5	5	Residential	Not assigned	No	Not assigned	No	No	11	5	110	234	40	0	08C21F42E55C4AF79B0795639DC38A2A_S	0

Table F1 – Example of the base data format for the Risers risk models showing rise level information

F3.2. Risers Probability of Failure Assessment

The failure rate for risers was based upon actual leak and population data from risers from all 4 Gas Distribution Networks (GDNs). The required format of the failure rate was leaks per m per year. Ideally, failure rates for risers and laterals would be generated but this was not available from all data sources. In addition, material groupings by individual material groups was not possible other than metallic (which encompasses steel, copper, ductile iron and spun iron) and PE. Categories of leak type were corrosion, joint leak and interference damage

The time period for each GDN varied, from 4 years for Cadent to 6 years for SGN and WWU. Leak data was not available for NGN.

The average number of leaks per year have been standardised into leaks per m of risers, using an average of 11.1 m per risers, based upon average riser length from NGN and NG. Only WWU had specific data on interference damage events.

Analysis of failure rates was carried out by DNV GL and produced global failure formulae for all GDNs by failure mode as set out below:

Joint Nr/Asset/Yr	IF(ASSET_MATERIAL="PE",0.000002403,0.000013265)*ASSET_LENGTH* exp(DYear*IF(ASSET_MATERIAL="PE",joint_det_pe,joint_det_nonpe))
Interference Nr/Asset/Yr	ASSET_LENGTH*IF(ASSET_MATERIAL="PE",0.00001,0.00000365)
Corrosion Nr/Asset/Yr	IF(ASSET_MATERIAL="PE",0,0.00027562)*ASSET_LENGTH*exp(DYear* IF(ASSET_MATERIAL="PE",joint_det_pe,joint_det_nonpe))
General Emissions m3/Year	LEAKAGE_RATE*exp(DYear*emissions_det)

F3.3. Risers Deterioration Assessment

Risers are assets that are typically not run to failure, as work is prioritised based on regular survey information. There is therefore a very limited amount of data that can be used to derive quantitative estimates of deterioration. Option B is therefore adopted, utilising information from similar assets, in this case Mains and Services. Values were chosen as follows:

- 5% deterioration per annum was assumed for all non-PE material types, for all Failure Modes except Interference
- 0.5% deterioration per annum was assumed for PE and all new risers
- 0% deterioration per annum was assumed for Interference
- 1% per annum was assumed for General Emissions

F3.4. Risers Consequence of Failure Assessment

There are many consequences of failure identified for the Risers Asset Group. These can be viewed in the risk maps and Data Reference Library in Section F2.5. For simplicity, each Consequence of Failure has been categorised as Internal Costs, Environmental, Health & Safety, Customer, Corrosion, Joint, Interference and General failure consequences. The data source and derivation for all Costs of Failure are explained in the Data Reference Library.

F3.4.1. Internal Consequence Costs

This includes the internal costs of responding to or remediating failures. These are generally derived from internal company financial systems. Examples include Joint, Fittings or Corrosion repair costs. Legal costs associated with HSE or Customer consequences are also included as internal costs.

F3.4.2. Environment Consequence Costs

Environmental consequences include the monetary value of product lost due to failures or leakage plus the shadow cost of carbon associated with failure or emissions. In particular, the shadow cost of carbon increases annually (and hence the consequence value increases) in line with government carbon valuation guidelines.

F3.4.3. Health & Safety Consequence Costs

Health & Safety consequences are primarily associated with the damage caused by ignition following asset failure and subsequent entry into customer properties. The largest HSE consequence is associated with loss of life, but minor injury and property damage are also considered.

F3.4.4. Customer Consequence Costs

Customer consequences include compensation payments generated through loss of service caused by asset failure. These are categorised into Domestic, Commercial and Critical customers to account for the differences in the monetary value of these compensation payments.

F3.4.5. Gas Escape

For a mains corrosion failure the assessed initial consequence is a loss of gas (PoC=1), which may lead to a gas in building (GIB) event, 1 if internal and 0.01 if external, representing a small probability of gas migrating in to the building.

F3.4.6. Explosions

The probability of an explosion given a GIB is based on a weighted and normalised hazard score from the survey calibrated against the mains and services value of 0.00076. Where the hazard score is high, the benchmark value is multiplied upwards to represent an increased level of probability of explosion.

This score takes into account the following attributes:

- Material;
- Corrosion Protection;
- Emergency and isolation valves;
- Ventilation and ducting;
- Cellars;
- Sleeving and fireproofing.

F3.4.7. Structural & Fire Hazard

Following an explosion given a GIB, there is the potential for further structural collapse and/or fire damage within adjacent properties/floors, which would increase the health & safety consequence of failure.

Where Ronan Point Construction types have been identified and where walls haven't been strengthened, the risk will be greater.

[SCORE_GAS_RELEASE]= Function (Ronan Point, Wall Strengthening]

F3.4.8. Health and Safety

Health and Safety nodes are similar to Mains and Services. The number of people potentially at risk of Death, Major, or Minor Injury is based on the type of building and the average number of occupants per dwelling and number of storeys.

[PEOPLE_AT_RISK] = Function(People per dwelling, Building Type, Number of storeys, no of supply points) x probability of HSE event

- People per dwelling;
- Building Type – Residential or commercial;
- Number of stories;
- Number of gas supplies per storey.
- Probability of HSE Event - 10% Death and Major, 90% Minor Injury

Property Damage is based on the type of construction and the age of the building.

Ronan Point Construction – Particular type of construction that has been identified by HSE;

Walls strengthened – Structural strengthening of the walls;

Age of building – 5% increase per year of age.

[PROPERTY_DAMAGE] = Function (Ronan Point, Wall Strengthening, Age]

F3.4.9 Supply Interruptions

Supply interruptions are calculated based on the type of customer (residential, commercial, etc) and the number of storeys and supply points in the building.

It is assumed that every customer suffering an interruption arising from a gas escape is recorded as a complaint.

F3.4.10. General Emissions and Loss of Gas

For an emissions failure a simplified approach is adopted as consistent with Mains and Services. The volume per kilometre per year is multiplied by the carbon value of the gas lost through emissions. This is then added to the retail value of the lost gas to give the monetised risk value for the General Emissions Failure Mode.

The loss of gas is calculated as consistent with services but a reduced find and fix time.

F3.5. Risers Intervention Definitions

Intervention activities can be flexibly defined within the monetised risk trading methodology by modelling the change in risk enabled by the intervention activity.

Some interventions, such as replacing the riser, will reduce both the Probability of Failure and deterioration of the overall asset base, thus changing the monetised risk value over the life of the asset. This is called a **With Investment** activity below.

Other types of intervention may just represent the base costs of maintaining the asset at an acceptable level of performance, for example painting to arrest corrosion. This is called a **Without Investment** action below.

Definitions of activities undertaken as part of normal maintenance (i.e. 'without intervention') and interventions for Risers are listed below.

'Without intervention' activities:

- Repair
- Survey

'With intervention' activities:

Number	Description	Definition
Intervention 1	Replace	Replacement of riser and associated laterals with pipes of the same material as existing or with PE.
Intervention 2	Refurbishment	Refurbishment of riser and associated laterals

Table F4 – With and Without Investment interventions for LTS Pipelines

F3.5.1. Risers Intervention Benefits

The risk modelling tools developed provide the ability to flexibly model any intervention by adjusting the values of the calculated risk nodes to match the expected performance of the asset following intervention. For example, painting of internal pipework will reduce the probability of a corrosion failure and potentially the deterioration of the rate of corrosion. This allows the new risk value to be calculated post-intervention and compared with the pre-intervention (do nothing) monetised risk.

F3.5.2. Example Risers Interventions

This is an example Riser interventions provided for illustration purposes only.

As an example, 100 Risers per year are replaced for the 6 years from 2015 to 2020. The replacement of a riser reduces the POF to that of a new pipe and assumes the deterioration of a PE pipe, 0.5% per annum. Numbers are approximate only and each GDN needs to define their own costs and benefits data.

The replacement cost is variable based on the length and number stories of each riser and shown in Figure F5 below.

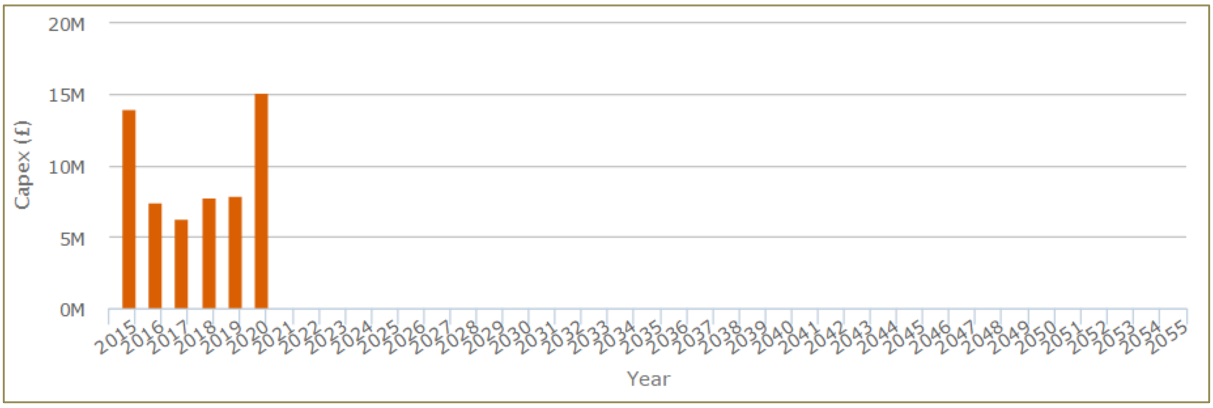


Figure F5 – Example Annual Capital Expenditure for Replacement of Risers

The baseline level of cumulative monetised risk for each financial risk node is shown below for both with and without intervention.

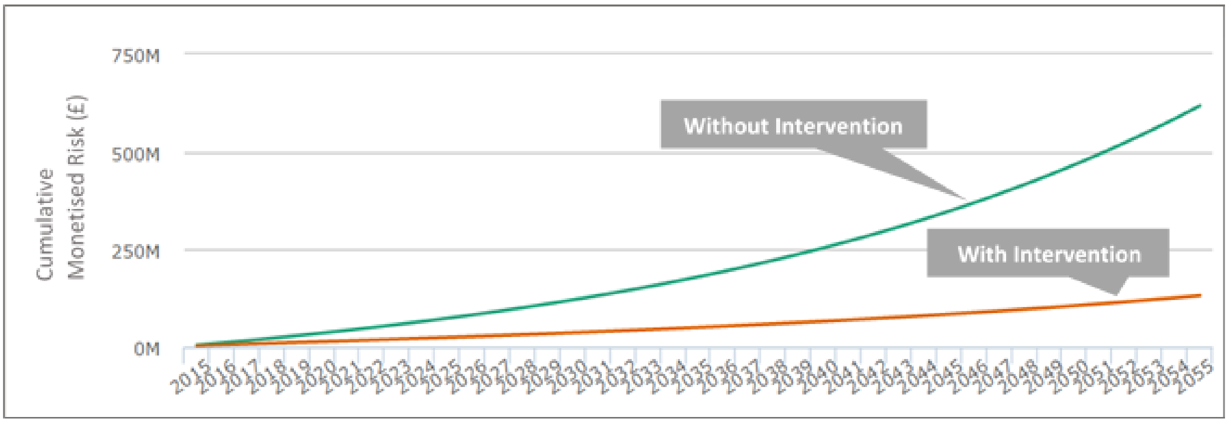


Figure F6– Example Pre and Post cumulative Monetised Risk value of Risers

This gives a net discounted net benefit that has a payback of approximately 12 years. A full set of results is provided in table F5 below.

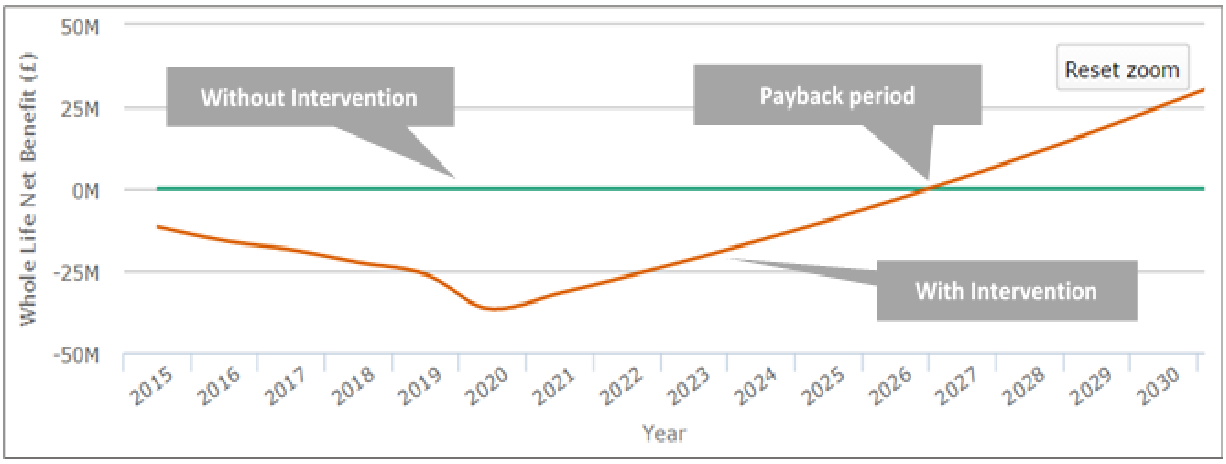


Figure F7 – Example Discounted benefits per annum for planned Riser replacement

Period	Year	Interventions	Baseline Monetised Risk	Intervention Monetised Risk	Change in value due to intervention	Discount Factor (3.5%)	Discounted change in risk value due to intervention	Cumulative discounted change due to intervention
1	2015	13902159.74	£ 5,448,444.35	£ 2,940,326.16	£ 2,508,118.19	1	£ 2,508,118.19	£ 2,508,118.19
2	2016	7432930.743	£ 5,669,896.04	£ 2,608,585.40	£ 3,061,310.64	0.9662	£ 2,957,788.06	£ 5,465,906.24
3	2017	6238392.741	£ 5,902,600.64	£ 2,416,482.00	£ 3,486,118.64	0.9335	£ 3,254,329.05	£ 8,720,235.30
4	2018	7788417.251	£ 6,147,133.63	£ 2,269,593.20	£ 3,877,540.43	0.9019	£ 3,497,319.31	£ 12,217,554.60
5	2019	7934053.746	£ 6,404,100.00	£ 2,140,170.37	£ 4,263,929.63	0.8714	£ 3,715,768.34	£ 15,933,322.94
6	2020	15138328.24	£ 6,674,135.73	£ 2,031,850.97	£ 4,642,284.76	0.8420	£ 3,908,679.20	£ 19,842,002.14
7	2021	0	£ 6,957,909.39	£ 2,069,392.33	£ 4,888,517.06	0.8135	£ 3,976,811.78	£ 23,818,813.92
8	2022	0	£ 7,256,123.81	£ 2,108,739.09	£ 5,147,384.72	0.7860	£ 4,045,797.86	£ 27,864,611.79
9	2023	0	£ 7,569,517.83	£ 2,149,982.63	£ 5,419,535.20	0.7594	£ 4,115,657.66	£ 31,980,269.45
10	2024	0	£ 7,898,868.15	£ 2,193,219.01	£ 5,705,649.14	0.7337	£ 4,186,411.49	£ 36,166,680.94
11	2025	0	£ 8,244,991.29	£ 2,238,549.19	£ 6,006,442.09	0.7089	£ 4,258,079.80	£ 40,424,760.74
12	2026	0	£ 8,608,745.57	£ 2,286,079.31	£ 6,322,666.27	0.6849	£ 4,330,683.16	£ 44,755,443.90
13	2027	0	£ 8,991,033.35	£ 2,335,920.91	£ 6,655,112.44	0.6618	£ 4,404,242.26	£ 49,159,686.16
14	2028	0	£ 9,392,803.19	£ 2,388,191.25	£ 7,004,611.93	0.6394	£ 4,478,777.96	£ 53,638,464.12
15	2029	0	£ 9,815,052.28	£ 2,443,013.61	£ 7,372,038.67	0.6178	£ 4,554,311.25	£ 58,192,775.37
16	2030	0	£ 10,258,828.92	£ 2,500,517.54	£ 7,758,311.39	0.5969	£ 4,630,863.28	£ 62,823,638.65
17	2031	0	£ 10,736,604.24	£ 2,567,444.54	£ 8,169,159.70	0.5767	£ 4,711,202.69	£ 67,534,841.35
18	2032	0	£ 11,236,625.33	£ 2,636,436.32	£ 8,600,189.00	0.5572	£ 4,792,057.82	£ 72,326,899.16
19	2033	0	£ 11,761,850.87	£ 2,708,654.78	£ 9,053,196.09	0.5384	£ 4,873,888.96	£ 77,200,788.13
20	2034	0	£ 12,313,564.32	£ 2,784,259.94	£ 9,529,304.38	0.5202	£ 4,956,721.90	£ 82,157,510.02

Table F5. Discounted costs and benefits per annum of replacing 100 Risers per year from 2015-2020.