Network Asset Risk Metric Reporting Methodology & Framework

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

Version Number	Version Date	Title	Description
V3.2	31st July 2017	Network Output Measures Health & Risk Reporting Methodology & Framework	Original NOMs Methodology
V4	23rd December 2022	Network Asset Risk Metric Reporting Methodology & Framework	Methodology updates for: NOMs to NARMs, NARMs reporting, interdependencies, data assurance, fixed parameters review and mains deterioration.
V5		Network Asset Risk Metric Reporting Methodology & Framework	Methodology updates for: asset deterioration, long term risk, testing and validation, previously recognised limitations, engineering assessments, transparency publicly available, transparency demand mix, transparency parameters, Category 1 Feedback
V6			Updates for Long Term Risk calculations and improvements to the PRS/Offtakes and Governor deterioration models

Contents

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 NMs 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.

(NARMs) Intervention Life – the fixed time (per asset and intervention type) that the Monetised Risk benefit is accumulated to derive the LTRB metric for a specific asset and intervention type. Also referred to as the life of an intervention. It is important to state that this is not the same as the asset life used for accounting depreciation, which assumes a typical cycle of maintenance prior to the asset being deemed as having zero asset value.

LTS – Local Transmission System (pipeline network)

Long Term Risk (LTR) and Long Term Risk Benefit (LTRB) – these are used (sometimes interchangeably) to quantify the cumulative Monetised Risk benefit delivered over the defined intervention life, per asset and intervention.

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

NARM Methodology - Network Asset Risk Metric Methodology and Framework (RIIO-2 approach)

NOMs Methodology – Network Output Measures Health & Risk Reporting Methodology and Framework (RIIO-1 approach)

Network Risk Output (NRO) – the regulatory target arising from implementation of the Long Term Risk process. Consists of a Long Term Risk Benefit value (R£) and a cost to deliver (£) which are combined into a Unit Cost of Risk (UCR) metric to measure efficient delivery and support calculation of rewards and penalties through the NARM incentive mechanism. The NRO is a sum of all the LTRB values, per asset and intervention, within a best-value asset health investment programme.

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

Methodology Overview

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 9.2 (Network Asset Risk Metric Methodology). This methodology is called the Network Asset Risk Metric Methodology & Framework, hereafter referred to as the NARM 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 NARM. The methodology can be amended subject to the change process outlined in licence condition 9.2 Part C.

When approved by Ofgem, this methodology will require GDNs to re-align their current processes and practices to this new standard. GDNs may also need to re-baseline their NARM consistent with the methodology detailed within this document for the RIIO-GD2 period.

When adopted, GDNs will be required to report annually against the targets set using the methodology. These reporting requirements are set down in RIIO-2 Regulatory Instructions and Guidance (RIGs) for NARM Tables.

1.2 Background

In the RIIO regulation regime, as first implemented in RIIO-GD1, Ofgem sought to move to a more output based measurement of the drivers for network business plans. One such output was 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 was proposed in order to ensure health management was appropriate to the needs of the Gas Distribution Network and its consumers. This process identified 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 were 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.

This Asset Health and Risk Assessment process was initially badged Network Output Measures (NOMs) and became the NARM for RIIO-2. Itis 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

Prior to RIIO-2, NOMs was used primarily as a regulatory reporting tool to monitor the network companies' asset management outputs and performance. NARM was developed to quantify the benefit, to consumers, of the network companies' asset management activities. In RIIO-2, this will be used as the output to hold the network companies accountable for their investment decisions. NARM is intended not only as a regulatory reporting and monitoring tool, but also as a decision-supporting tool for network companies' asset management investments, and as a way for the network companies to justify past and future investments to Ofgem.

The NARM Objectives are set out in Special Condition 9.2 of the RIIO-2 licence. The network companies' NARM Methodologies should facilitate the achievement of the objectives. However, the NARM Methodologies may not be the only tool needed to achieve the NARM Objectives. The network companies should be continually striving to better achieve the NARM Objectives.

Part B of SpC 9.2 sets out eight NARM Objectives (a to h). These objectives are summarised as follows:

a) To allow Ofgem and other stakeholders to understand the links between the data that a network company collects and utilises and the asset management and investment decisions it makes. The NARM Methodology will therefore help provide assurance that any investment decisions are based on solid evidence and sound reasoning.
b) To enable Ofgem to set outputs for the network company to deliver over a price control period and to ensure that what the network company actually delivers can be compared to the targets on a like-for-like basis.
c) To enable the network company to estimate the Monetised Risk of its network assets both now and in the future.
d) To enable the network company to estimate the Monetised Risk Benefit that would be delivered by different types of interventions on any given asset or group of assets. The objective is to be able to estimate both single-year snapshot risk benefit and long-term risk benefit.
e) The estimated Monetised Risk Benefits should be suitable for use as inputs in Cost Benefit Analyses (CBA) in order to help network companies choose the best value for money investments, and to demonstrate to Ofgem, consumers, and other stakeholders that any investment plans have been optimised. This means that the Monetised Risk Benefits should be realistic with robust probability estimates and correctly valued consequences.
f) To enable the identification and quantification of drivers of changes in Monetised Risk over time.
g) To allow Monetised Risk comparisons to be made between different assets and different networks. In order for this objective to be achieved, the methodologies used for estimating Monetised Risk should be based as little as possible on subjectivity.
h) To enable the network company to report to Ofgem and other stakeholders in a way that can be easily understood and unambiguously interpreted.

2. Methodology Overview

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

- Principles (of the NARM 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)

Methodology Overview

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

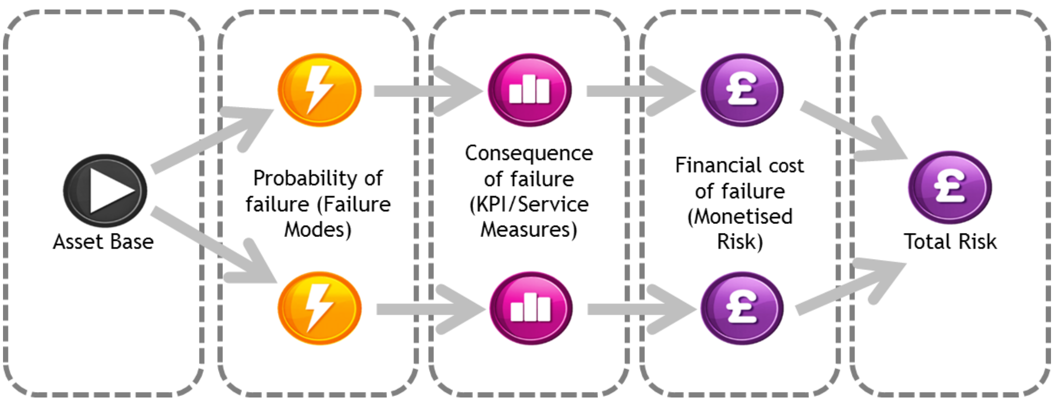

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Figure 1 – Broad Monetised Risk Process

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 NARM as defined in special licence condition 9.2.

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 NARM methodology.

The NARM 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.

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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 e

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

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

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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.

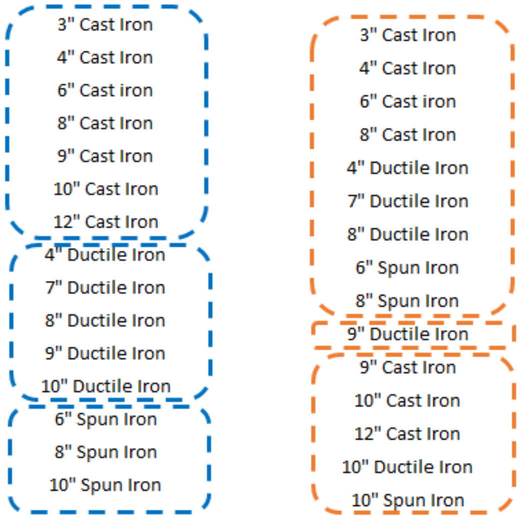

Figure 2 - Asset Cohort/Stratification

The relationships between Asset Groups, Sub-groups, Cohorts and Stratifications are summarised below in Figure 3.

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 the 1960'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.

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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 NARM 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.

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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.

During development of the NARM's models, interdependency was outlined as a key consideration. This is the impact that a primary or secondary asset may have in relation to the Probability of Failure (PoF), or Consequence of Failure (CoF) on assets in the same or different primary or secondary asset groups. This section of this document explains these interdependencies and how they have been accounted for in the modelling process.

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 the following categories:

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

Details of each are described in the sections below.

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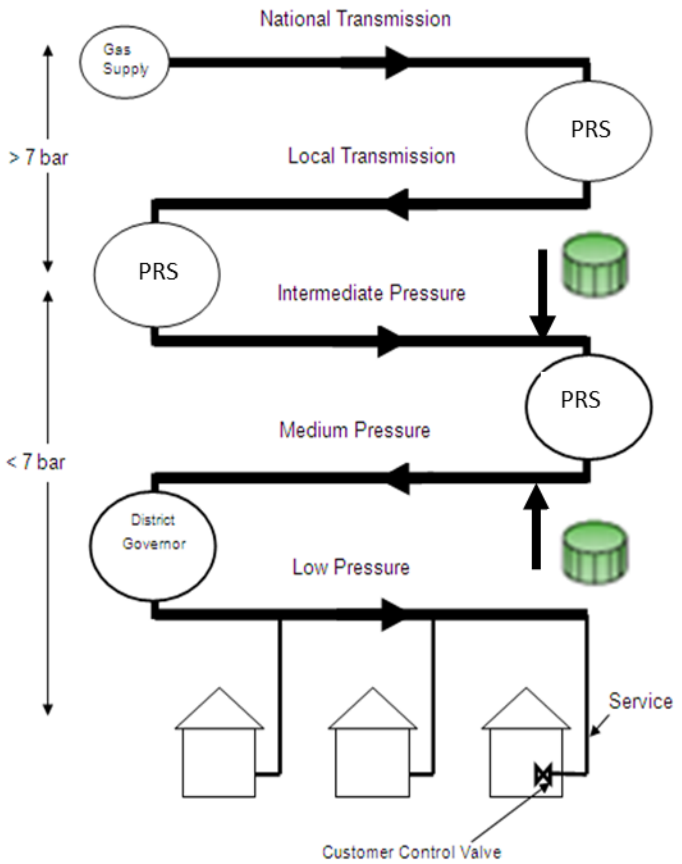
2.8.1 Assets downstream of other assets who would fail to supply gas if the upstream asset failed to supply gas

The UK gas distribution network is linear in nature. Gas enters the distribution network via the National Transmission System (NTS) before being incrementally reduced in pressure to serve industrial or domestic supplies. Below is a diagram to illustrate this:



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. To monitor the impact of such failures, GDNs use network analysis to determine the number and type of consumers impacted.

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

Evaluating the interdependencies of the assets at the start of the distribution system is relatively simple, but in Lower Pressure networks there is much greater dependency on additional assets. 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 (e.g. there are often multiple governors feeding a low pressure network, if one fails, others can support the network to prevent failure of downstream assets).

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Network analysis is a tool utilised to ensure the consequence of these asset failures reflect the reality of supply interruptions. 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

The table below summarises this by asset group. The asset group considered in the leftmost column, and the further columns highlight the impact on other assets. This does not include the failure of upstream assets as described previously.

	Pipelines			Offtakes & PRIs			Governors			Mains			Services			Risers		
Asset Group	PoF	CoF	Costs	PoF	CoF	Costs	PoF	CoF	Costs	PoF	CoF	Costs	PoF	CoF	Costs	PoF	CoF	Costs
Pipelines																		
Offtakes & PRIs					y					y	y							
Governors								y		y	y							
Mains					y			y						y	y			y
Services												y						
Risers												y						

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

Methodology Overview

- 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 both scenarios the simulation considers the impact of gas escaping from the downstream pipe network. It includes an assessment by spatial query, of properties in vicinity of the PRI and the likelihood of failures resulting in Gas tracking into building and causing explosion.
- 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 It includes an assessment by spatial query, of properties in vicinity of the PRI and the likelihood of failures resulting in Gas tracking into building and causing explosion.
- 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 the GDNs have split the model into 3 asset groups due to the negligible impact of their performance on each other – Odorisation & Metering, Filters & Regulators, Preheating
- Governors – no impact
- Mains – no impact
- Services – no impact
- Risers – no impact

2.8.5 Assets with cost of intervention interdependencies

Mains have no interdependencies on PoF and CoF of other assets other than described above. They do however have an impact on costs of services and costs of risers. Mains and services and mains and risers are often replaced together so the costs used in NARM's modelling reflect this.

Services have no interdependencies on PoF and CoF of other assets. They do however have an impact on costs of Mains. Mains and services are often replaced together so the costs used in NARM's modelling reflect this.

Risers have no interdependencies on PoF and CoF of other assets. They do however have an impact on costs of Mains. Mains and risers are often replaced together so the costs used in NARM's modelling reflect this.

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2.9 Data Assurance

NARM is data intensive, using data relating to:

- Assets,
- Faults and failures,
- Consequence
- Likelihood of that consequence and
- Cost/value of consequence.

GDNs are focused on the impact of any inaccurate or incomplete reporting, or any misreporting, of information to the Authority. As such, GDNs have data governance processes in place to ensure data quality.

To ensure compliance with the NARM licence condition, each GDN carries out risk assessments to understand the implications of reporting inaccurate, inconsistent, or incomplete data. These assessments consider both the likelihood of data errors and the impact of those errors. Where improvements can be made to data systems or processes, actions are planned to undertake these to reduce the potential for inaccuracies in the submissions"

In providing data, the GDNs have each developed work instructions for each table to be submitted. Data concerning the asset inventory, condition scoring, and criticality information is specific to each GDN. As such, these work instructions are specific to each GDN and reflect the systems and data repositories used by each network.

Data improvement plans are held by each licensee. These detail the data supporting the NARM assessment, quality of that data and any plans in place to improve the data. Progress is reported annually through the RRP process.

3. Event Tree Development

3.1 Development Overview

This section explains the key principles of the NARM 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:

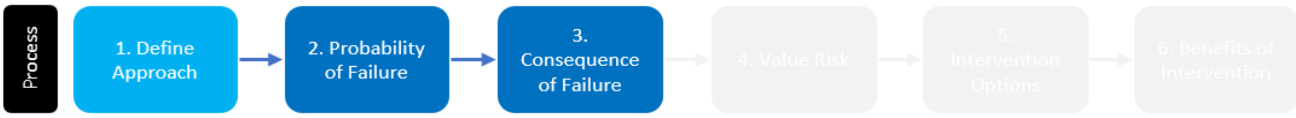
Figure 4 - Event Tree Development Flow Chart

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.

Event Tree Development

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	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. SRWG will, in line with Licence Condition 9.2, keep the NARM Methodology under review

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.)

Event Tree Development

- 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.

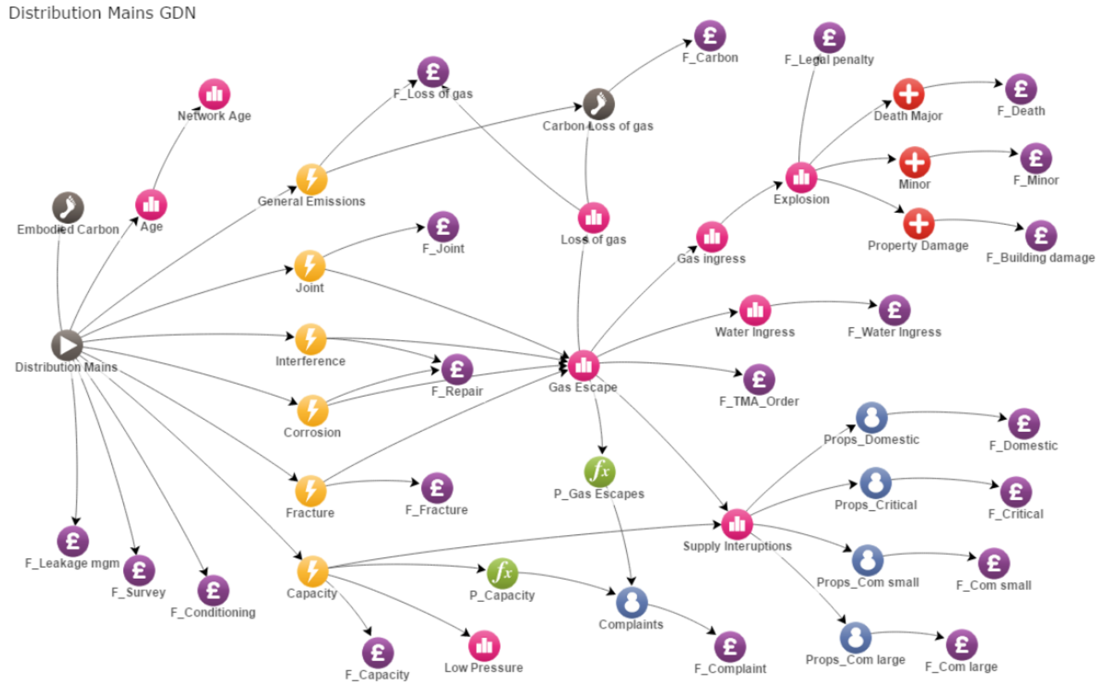


Figure 5 - Example Final Risk Tree

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 deliver 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.

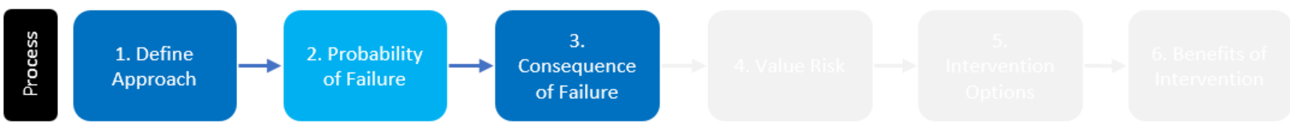
The base year length of the DI/NO/1 cohort is 1,096 kilometres. The total base year monetised risk value is £1,721,370. The overall levels of monetised risk for the DI/NO/1 cohort, broken down by individual monetised risk elements, are illustrated in Figure 6.

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.

Event Tree Development

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 considered 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.

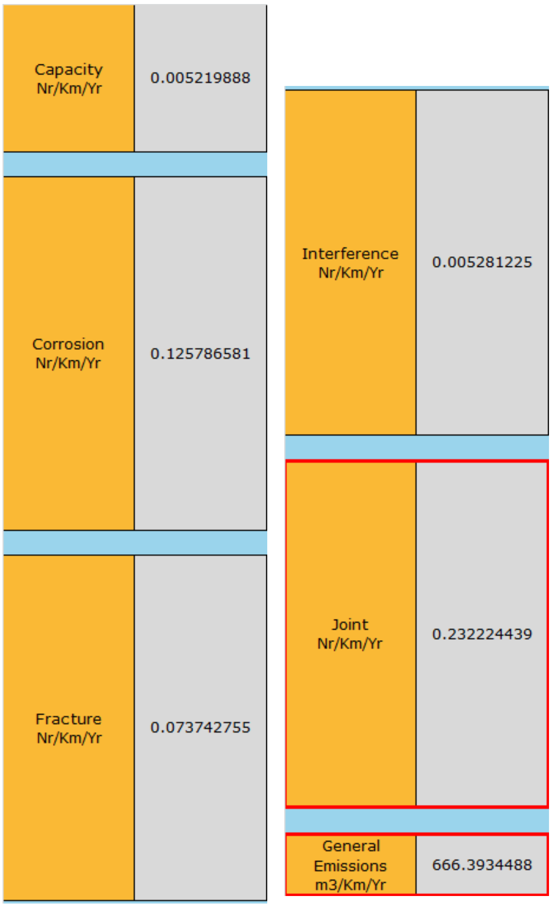
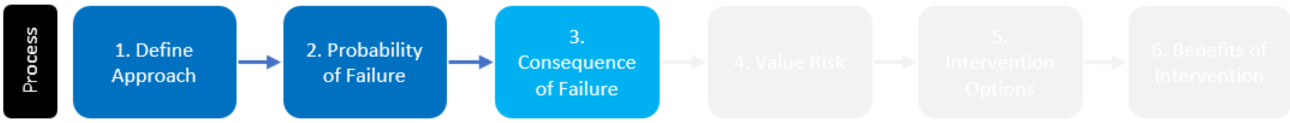


Figure 7 - Worked Example - DI/NO/1 Cohort Failure Modes and Year 0 PoF

Event Tree Development

3.5 Consequence of Failure



One of the key concepts of the NARM 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).

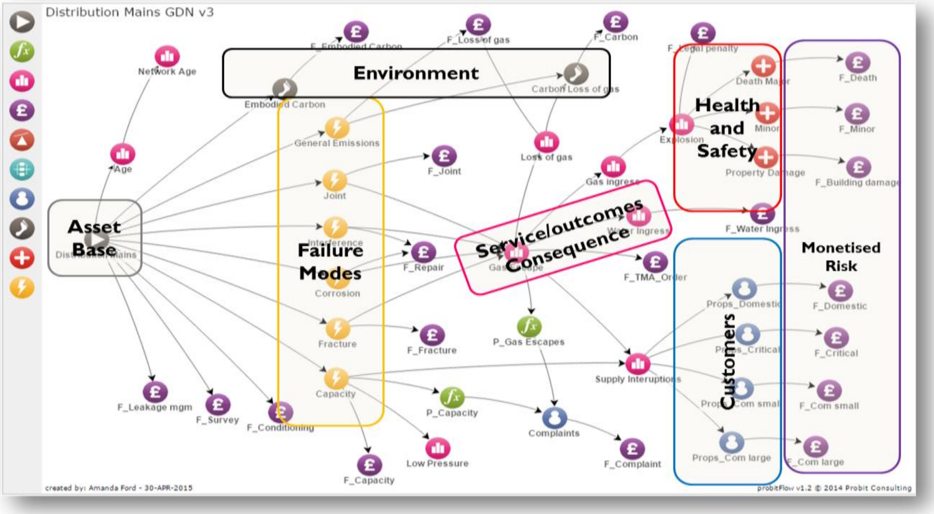


Figure 8 - Example Event Tree Sections

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 and 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.

All prices detailed throughout this document are in 2014/15 prices. These have been uplifted to 2018/19 prices for RIIO-GD2 planning purposes.

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 be 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.

Event Tree Development

Node ID / Variable	Description	Value GD2	Notes / Source	GDN or Common value	GD3 Values (subject to additional change)	Source of Uplift
F_Loss_Of_ Gas	Cost per m3 of loss of gas	£0.22	2p/kWh = £0.22/m3 (QUARTERLY ENERGY PRICES 2015 DECC) [(Shrinkage gas replacement cost {p/kwh}*kWh to GWh conversion)/Natural gas GWh to m3 conversion)]	Common	£0.75	CBA Template
F_Legal_ Penalty	Legal penalty payment	£1M	SRWG estimate based on civil action costs.	Common	£1,374,687.73	Price Base Uplift
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" Box 3.4 Non-traded value of Carbon (£/tCo2e) Scaling factor for methane to be included within volume calculation (see Carbon Loss of Gas)	Common		CBA Template
F_Restore_Supply	Compensation cost for resoration of supply	£100			£137.47	Price Base Uplift
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	£274.94	Price Base Uplift

Event Tree Development

Node ID / Variable	Description	Value GD2	Notes / Source	GDN or Common value	GD3 Values (subject to additional change)	Source of Uplift
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	£274.94	Price Base Uplift
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	£618.61	Price Base Uplift
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	£274.94	Price Base Uplift
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	£206.20	Price Base Uplift
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	GDN Specific	£259,815.98	Price Base Uplift

Event Tree Development

Node ID / Variable	Description	Value GD2	Notes / Source	GDN or Common value	GD3 Values (subject to additional change)	Source of Uplift
F_Minor	Cost of minor injury	£ 185,000.00	Sum historically agreed based on legacy Business Plan submissions and discussions with Ofgem/HSE ([Cost per Non Fatal/ Major injury (£m)]*[safety disproportion factor])	Common	£150,672.43	CBA Template
F_Death	Cost of death	£16,000,000.00	Sum historically agreed based on legacy Business Plan submissions and discussions with Ofgem/HSE ([Cost per Fatality (£m)]*[safety disproportion factor])	Common	£22,401,506.47	CBA Template
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		CBA Template
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. 0.00076*[Carbon equivalent per network]	Value calculated by each GDN based on actual gas composition in the network. [Methane m3 to tonnes conversion]*[Carbon equivalent per network]	GDN Specific	0.00066*[Carbon equivalent per network]	CBA Template
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		

Event Tree Development

Node ID / Variable	Description	Value GD2	Notes / Source	GDN or Common value	GD3 Values (subject to additional change)	Source of Uplift
Base Price Year	Base Price Year	Current RRP year	Current RRP year	Common	23/24	Current RRP year
Discount Rate <= 30 years		3.50%		Common	3.50%	HMRC Green Book (see Discount Factors spreadsheet 'Standard Discount Factors' tab
Discount Rate > 30 years		3.00%		Common	3.00%	HMRC Green Book (see Discount Factors spreadsheet 'Standard Discount Factors' tab
Discount rate for safety <= 30 years		1.50%		Common	1.50%	HMRC Green Book (see Discount Factors spreadsheet 'Standard Discount Factors' tab

Event Tree Development

Node ID / Variable	Description	Value GD2	Notes / Source	GDN or Common value	GD3 Values (subject to additional change)	Source of Uplift
Discount rate for safety > 30 years		1.29%		Common	1.29%	HMRC Green Book (see Discount Factors spreadsheet 'Standard Discount Factors' tab
Assumed Asset Life (Years)		45		Common	45	Assumption (above) consistent with Ofgem's RIIO-2 CBA tool.
Safety Disproportion Factor		10		Common	10	https://www.ofgem.gov.uk/sites/default/files/docs/2021/04/dno_common_network_asset_indices_methodology_v2.1_final_01-04-2021.pdf
Methane GWP	Global Warming Potential of Methane (tCO2e)	28		Common	28	https://ghgprotocol.org/sites/default/files/Global-Warming-Potential-Values%20%28

Node ID / Variable	Description	Value GD2	Notes / Source	GDN or Common value	GD3 Values (subject to additional change)	Source of Uplift
						Feb%2016%20 2016%29_0.pdf
Methane m3 to tonnes conversion				Common	0.00066	Leakage & Shrinkage Model
Natural gas GWh to m3 conversion				Common	90909.1	Leakage & Shrinkage Model
Natural gas CO2 content - tonnes per GWh				Common	4.32	Leakage & Shrinkage Model
Shrinkage gas replacement cost (p/kwh)		6.01		Common	6.83	2023 RRPs

Table 5 - Global Values

- - GD3 values are subject to change at the point of updating this table

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:

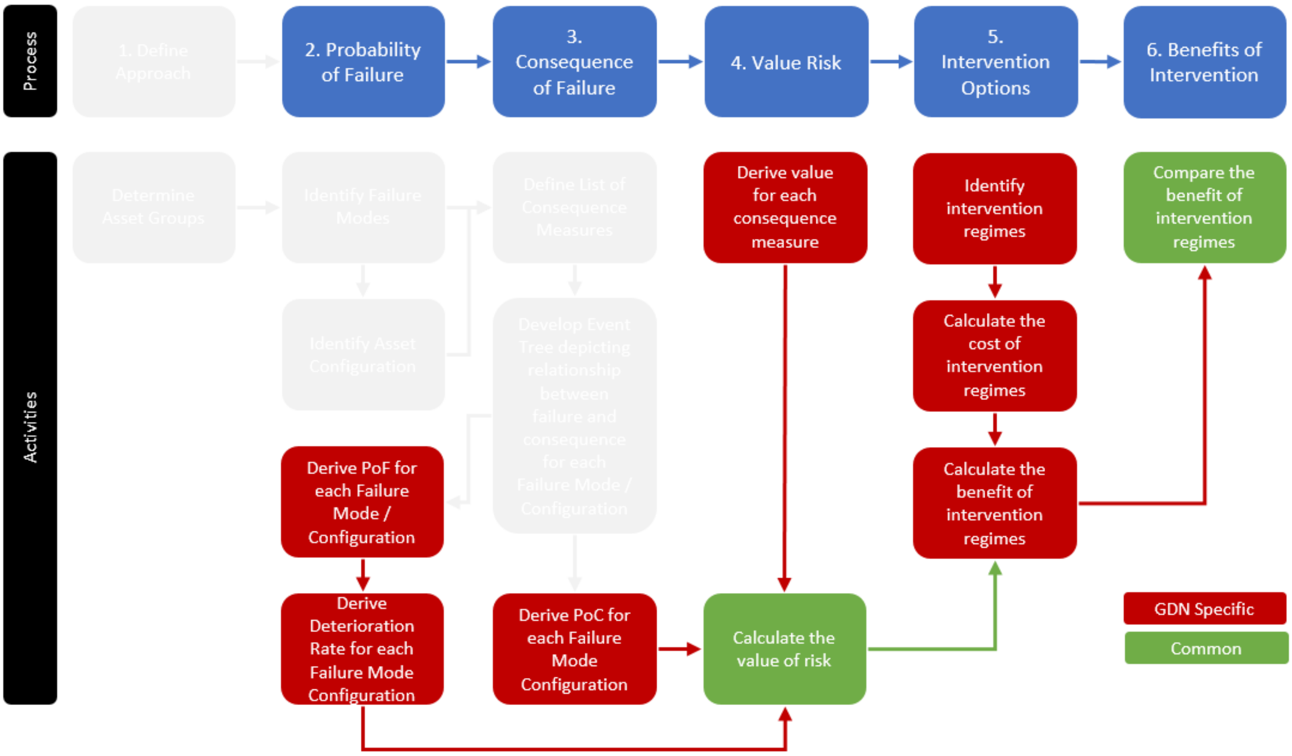


Figure 9 - Event Tree Utilisation Flow Chart

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 Utilisation

Event Tree analysis. It is recognised that the GDNs will have data gaps and will not hold the same level of asset data and 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.

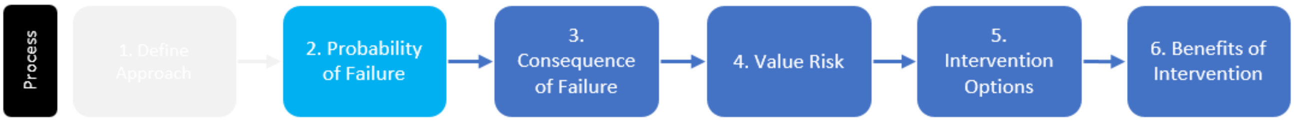
Table 6 below depicts the options available for each element of an event-tree:

	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)

Event Tree Utilisation

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 norm

alised 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.

Event Tree Utilisation

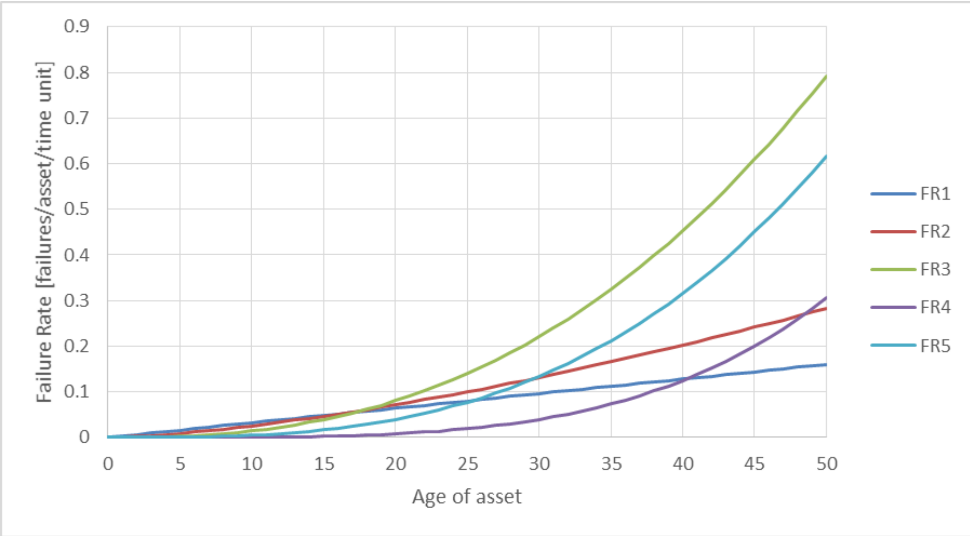


Figure 10 - Example PoF Curves

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.

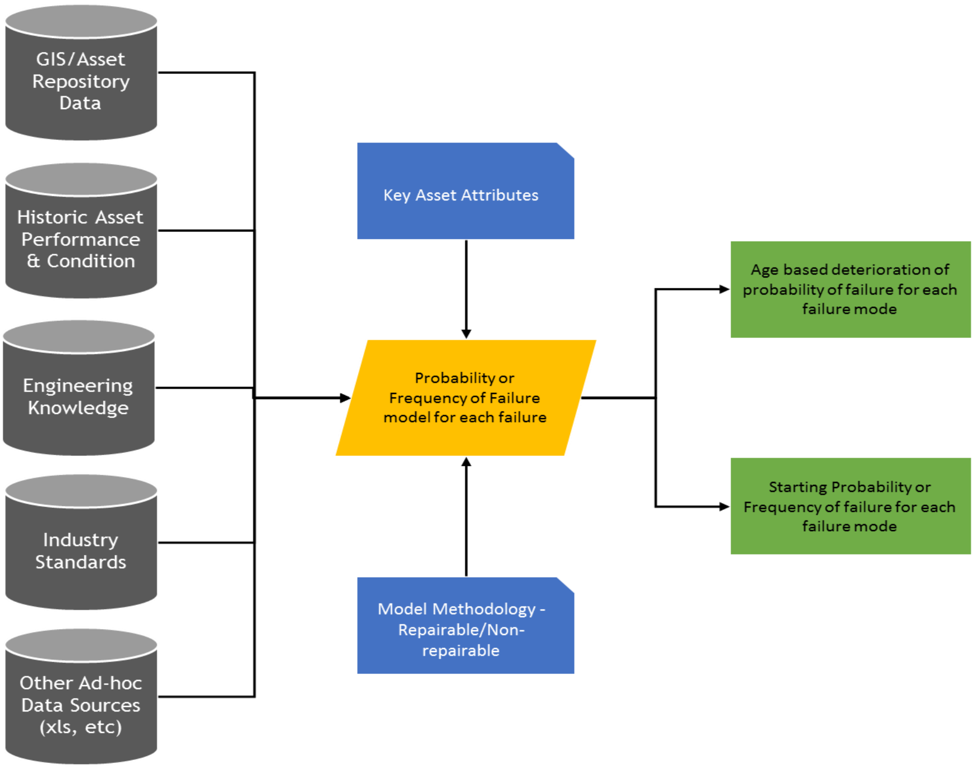


Figure 11 - Data Sources

Event Tree Utilisation

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.

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.

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.

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.

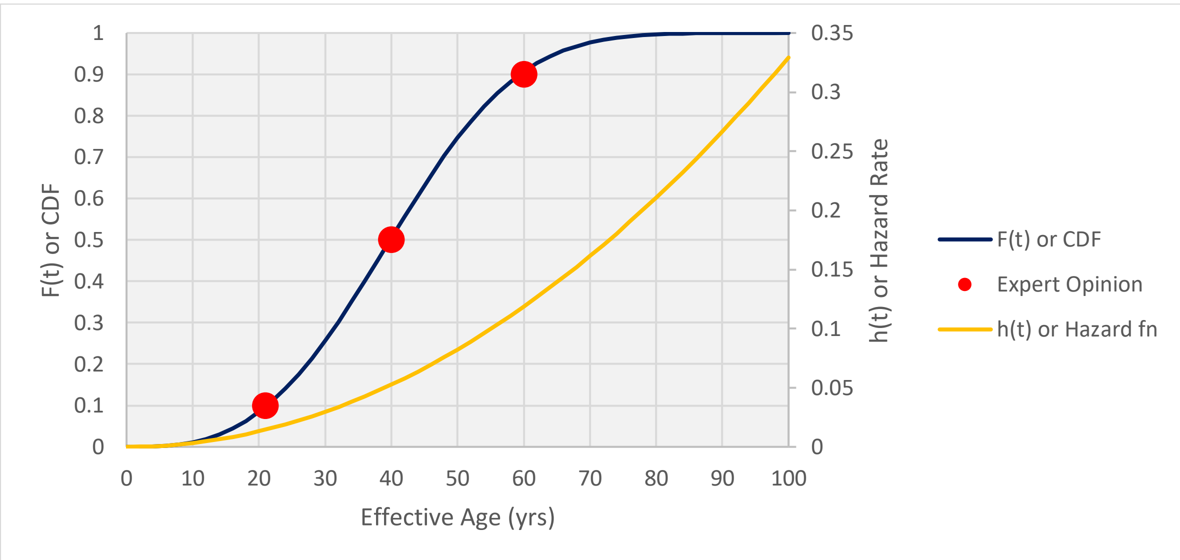


Figure 12 - Derived Failure Curve

Event Tree Utilisation

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.

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

Event Tree Utilisation

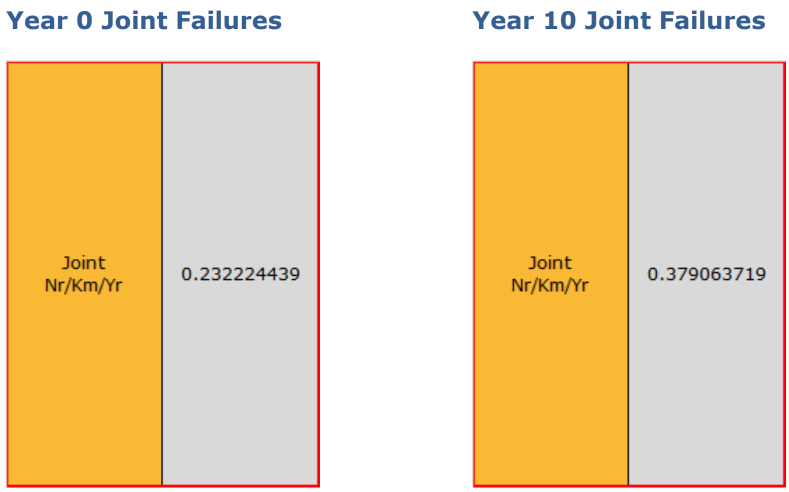


Figure 13 - Worked Example - Joint Failure Figures

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

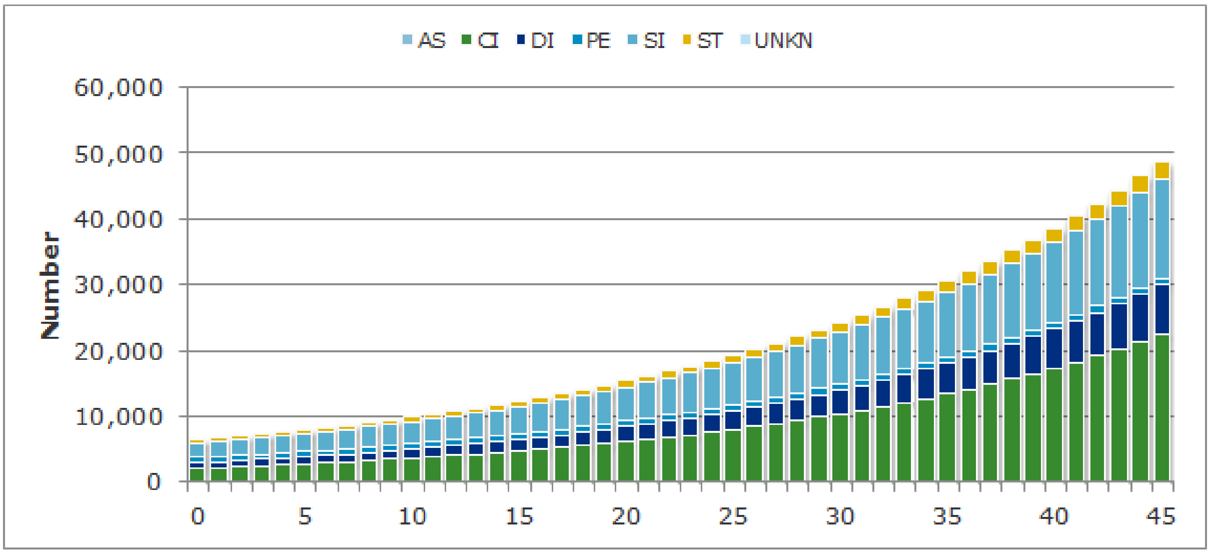


Figure 14 - Worked Example - Total numbers of joint failures per year given reactive only maintenance (all materials and all cohorts)

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.

Event Tree Utilisation

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

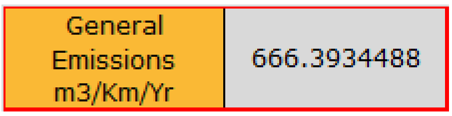
Deterioration of general emissions assumes a simple linear annual increase according to the equation below:

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



Year 10 General Emissions

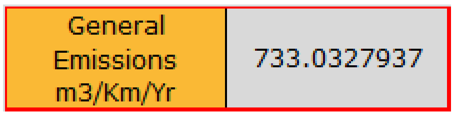


Figure 15 - Worked Example - General Emissions Figures

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

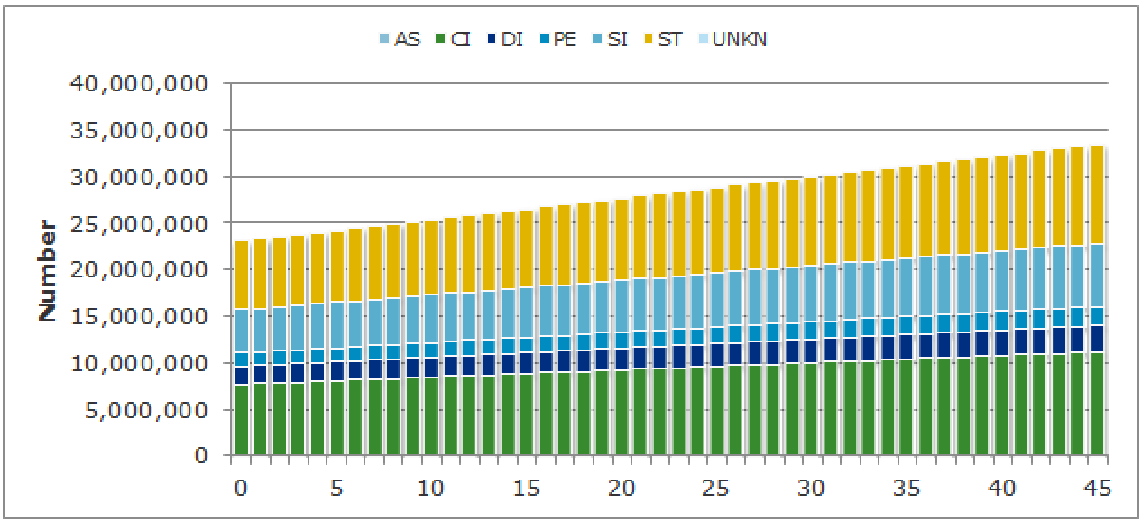


Figure 16 - Worked Example - Total general emissions given reactive only maintenance (all materials and all cohorts). Units are in cubic metres per year

1.1.1 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.

1.1.1.1 Example

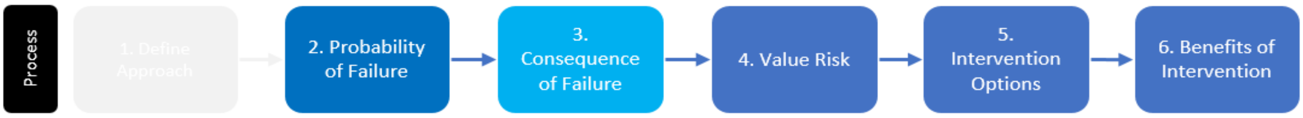
Following on from the example above, the Asset Health is considered to be the sum of all the PoF modes (where expressed in common units, in this case the number of failures per kilometre per year).

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

Event Tree Utilisation

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, poor quality or simply non-existent 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.

Event Tree Utilisation

4.4.2 Worked Example – Probability of Consequence

Joint

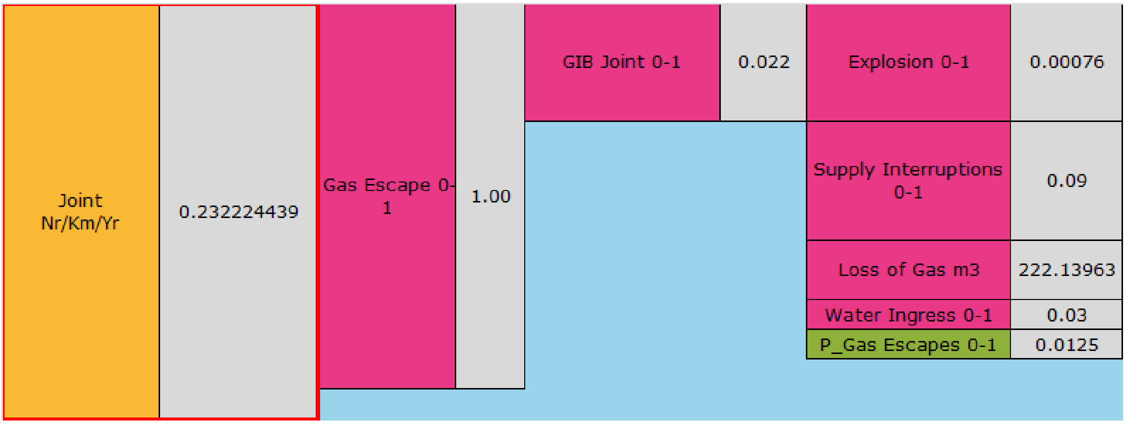


Figure 17 - Worked Example – Joint PoC Figures

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:

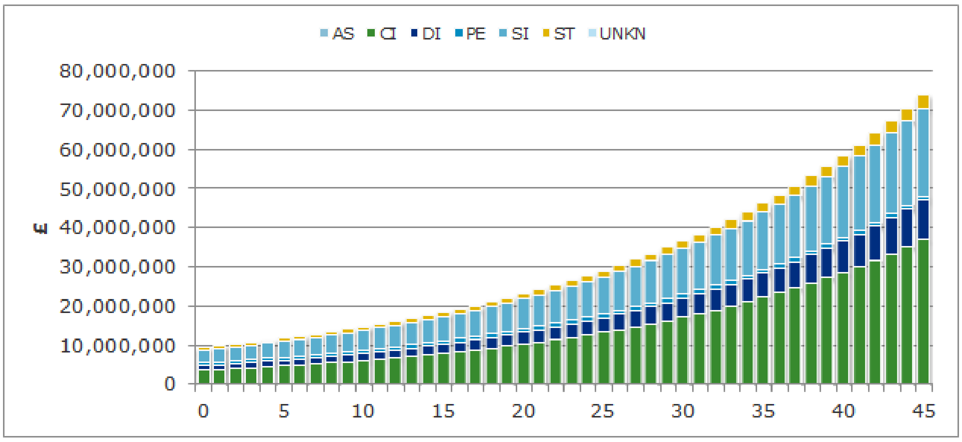


Figure 19 - Worked Example - Joint consequence values over life of asset given reactive only maintenance (all materials and cohorts)

Event Tree Utilisation

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)

Event Tree Utilisation

- 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 (m³)	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:

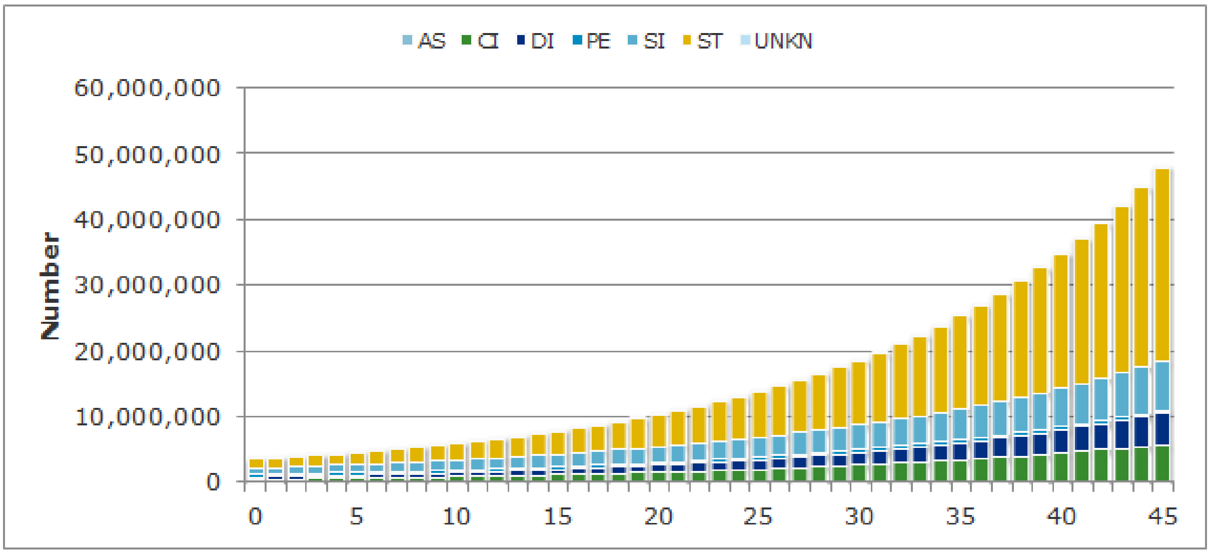


Figure 21 - . Worked Example - Loss of Gas consequence values over life of asset given reactive only maintenance (all materials and cohorts). Units are £/year

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:

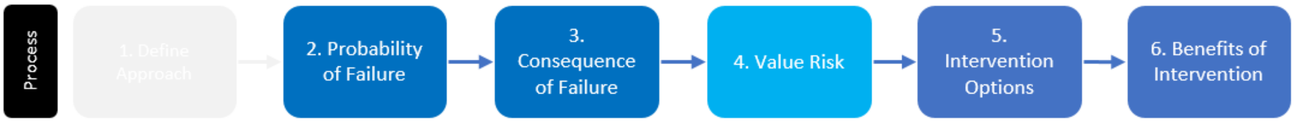
F_Carbon (Year 0) = 666.3 m3/km/year x 0.0134 x £59 per tonne = £528.81per km per year

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 in Figure 22 and 23.

Event Tree Utilisation

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.

Event Tree Utilisation

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).

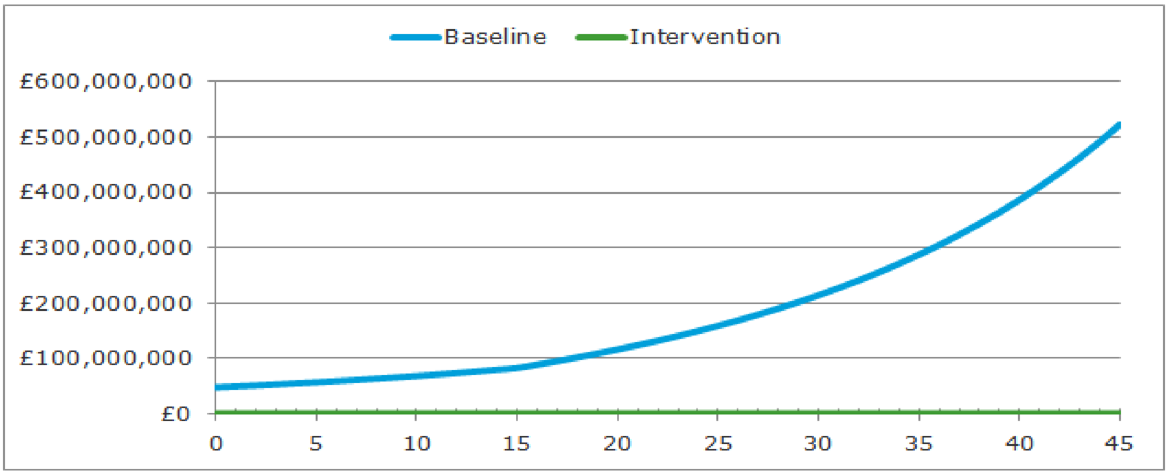
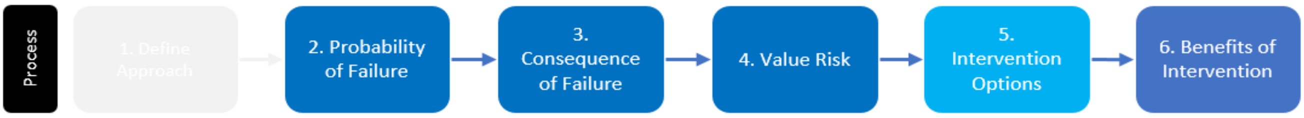


Figure 25- Worked Example - Total monetised risk values for the DI/NO/1 cohort with no intervention (reactive maintenance only)

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-GD requirements.

Event Tree Utilisation

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

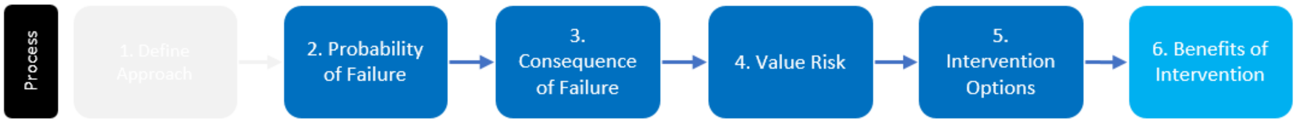
Example 2 - Spray-lining intervention

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

Event Tree Utilisation

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.

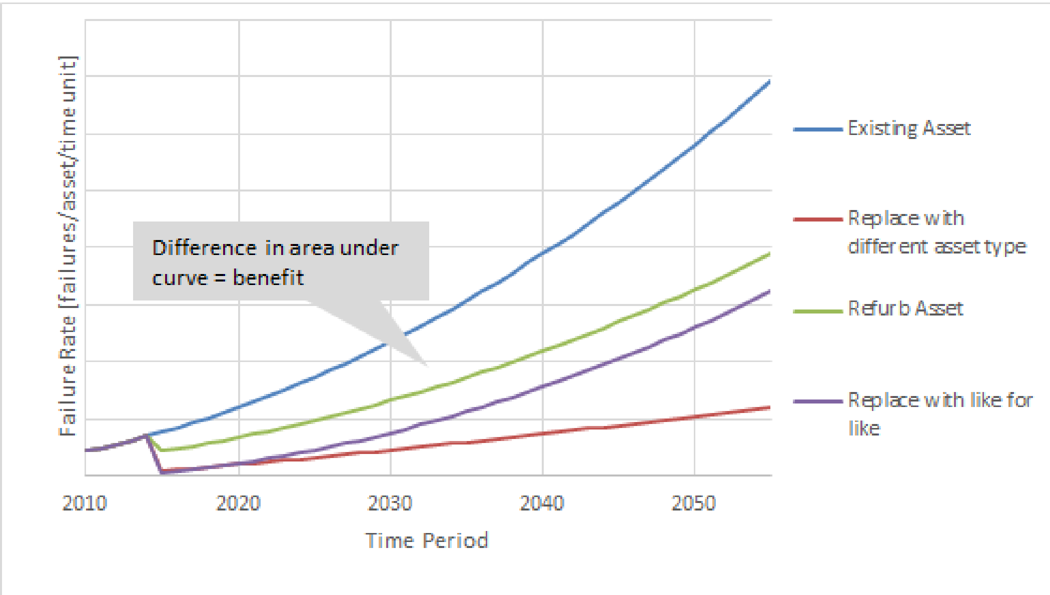


Figure 26 - Example Intervention Curves

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	£1.72M	£1.95M	£2.17M

Monetised risk			
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.

4.7.2 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
Cohort Number	Cohort Name	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

		5	6	7	8
Cohort Number	Cohort Name	Risk Value	Risk Value	Risk Value	Risk Value
11	DI / NO / 1	£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)

4.7.3 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).

Event Tree Utilisation

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

4.7.4 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

Event Tree Utilisation

Table 15- Worked Example – Risk Comparison

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

5. Regulatory Reporting

RIIO-GD2 regulatory reporting to Ofgem saw the introduction of a requirement of a NARM Regulatory Reporting Pack (RRP) which is different to the RIIO-GD1 approach whereby Monetised Risk was reported as a table within the main cost and volumes RRP (Table 7.3). NARM RRP is part of a wider suite of regulatory reporting and monitoring tools that are submitted annually to Ofgem.

There are several purposes to NARM annual reporting, including:

- to collect outturn and forecast data so that Ofgem can take a view on the likely end of period outcome of the NARM Funding Adjustment and Penalty Mechanism. This means that each network company's annual reporting should include its best forecasts of data that will be provided as part of its NARM Closeout Report (see below);
- to help identify emerging issues that might need to be addressed ahead of the next price control period or at RIIO-2 closeout;
- to collect data and information to inform future development of the NARM methodologies and NARM mechanisms in future price controls;
- to collect data that will be needed to facilitate robust assessment of the network companies' RIIO-3 business plans.
- to understand the costs associated with delivering NARM's interventions

In RIIO-GD1, regulatory reporting saw assets reported by asset group and sub-group level. For RIIO-GD2, assets are reported by asset group only.

The NARM Regulatory Instructions and Guidance (NARM RIGs), sets out the instructions and guidance applicable to the relevant network companies for completing and submitting the NARM RRP and must be adhered to.

The submission is risk assessed by each GDN for likelihood of error and the impact of an error. The risk score determines the level of assurance applied to the NARM's tables and will be specific to each GDN.

The previous version of the Methodology stated that the GDNs were currently unable to report the long-term risk benefit and therefore it has been agreed with Ofgem that the reporting and target associated with monetised risk for GDNs will only include the single year risk change at the end of the RIIO period.

This revision to the Methodology documents the new GDN approach for reporting the monetised risk reductions delivered by investments beyond a single year, which will provide a more realistic view of the longer-term benefits delivered to customers through asset health investments and a more nuanced approach to NARMs target setting and application of the NARM incentive mechanism. This approach is discussed in Section 7 and in the relevant Appendices for different asset types.

6. Governance

The publication and maintenance of NARM 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 as set out in Section 1.3.

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
- 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 as appropriate.

6.2 SRWG Annual Work Programme

The Gas Distribution Networks (GDNs) will collectively assess the performance and effectiveness of the NARM Methodology and monitor the activities as agreed in the NARM audit workplan with Ofgem. The Gas SRWG will be responsible for the following:

- Monitoring the performance and effectiveness of the NARM 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 NARM 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 NARM Methodology and Outputs.

6.3 Modification Process

The SRWG can at any time propose a modification to the NARM methodology that it believes would better meet the NARM Objectives and wider Licence Obligations prompting an audit. The timeframe for executing an audit will be agreed in consultation with all GDNs and Ofgem. Factors which will dictate the timeliness of an audit will be considered, these include:

- Legislative changes that must be included within the current or following price controls
- Business planning timeframe requirements
- RRP Reporting cycle requirements

The GDNs will jointly publish a consultation via the SRWG on any proposed changes as required by the Gas Transporters Licence, this will be undertaken in consultation with Ofgem with the GDNs as the lead. 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.

6.4 Publication of Methodology Statement

The GDNs will make publicly available the most recent NARM Methodology Statement and all associated appendices.

6.5 Fixed Parameters

It is envisioned that Global values, in particular those listed below, will not be updated within a regulatory price control period, unless there is a significant need to do so. The rationale for this is set out in Table 20. All costs will be updated from 2014/15 prices to a base price year agreed with Ofgem for each Price Control. The values outlined in the table 20 below will not align to global values in section 3.7.2 for newly updated RIIO-GD3 values.

As discussed in Section 3.7.2 all Global values will be subject to an annual review and identified changes to values and/or data sources will be agreed by SRWG. Significant changes to any of these parameters which have an associated impact of +/-10% on overall baseline monetised risk will be considered for change at annual review. +/-10% has been chosen as it represents a standard measure of statistical robustness.

If changes are identified and approved for inclusion, any potentially significant changes to individual GDN investment programmes will be 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.

Governance

Parameter	Parameter Description	Common to Sector of Licensee Specific	Reference to Methodology	Rationale for fixing over RIIO-2	Is this parameter updated for investment planning purposes?	Units	Fixed Values*[1]	Next Proposed Review and/or Update
F_Loss_Of_Gas	Cost per m3 of loss of gas	GDN	3.7.2 Global Values	Are values outside of GDN control and should be fixed as they are not affected by intervention. Although they are considered in investment decisions, they typically are not the main driver. Non-intervention risk changes would not be the appropriate mechanism for handling changes in this parameter due to the impact and level of control that GDNs have over them. There are also practical issues as this parameter affects all GDNs as it is a 'common' value, therefore a common consensus has to be made which is difficult to implement when the parameter has already been agreed by the group.	The decision on whether this is updated for investment planning purposes is GDN specific.	£	£0.22	Should be reviewed and updated as part of RIIO-3 CBA and NARM target setting.

[1] All cost values listed are as set out in the NARMS methodology. As costs were inflated to 2018/19 prices by GDNs for their GD2 submissions, any cost values need to be inflated to 2018/19 prices to determine the value that has been used for GD2 NARMs target setting.

Governance

Parameter	Parameter Description	Common to Sector of Licensee Specific	Reference to Methodology	Rationale for fixing over RIIO-2	Is this parameter updated for investment planning purposes?	Units	Fixed Values*[1]	Next Proposed Review and/or Update
F_Legal_Penalty	Legal penalty payment	GDN	3.7.2 Global Values	Are values outside of GDN control and should be fixed as they are not affected by intervention. Although they are considered in investment decisions, they typically are not the main driver. Non-intervention risk changes would not be the appropriate mechanism for handling changes in this parameter due to the impact and level of control that GDNs have over them. There are also practical issues as this parameter affects all GDNs as it is a 'common' value, therefore a common consensus has to be made which is difficult to implement when the parameter has already been agreed by the group.	The decision on whether this is updated for investment planning purposes is GDN specific.	£	£20m Offtake/ PRS/ LTS £1m Mains/ Services/ Governors/ Risers	Should be reviewed and updated as part of RIIO-3 CBA and NARM target setting.

Governance

Parameter	Parameter Description	Common to Sector of Licensee Specific	Reference to Methodology	Rationale for fixing over RIIO-2	Is this parameter updated for investment planning purposes?	Units	Fixed Values*[1]	Next Proposed Review and/or Update
F_Carbon	Cost of Carbon	GDN	3.7.2 Global Values	Are values outside of GDN control and should be fixed as they are not affected by intervention. Although they are considered in investment decisions, they typically are not the main driver. Non-intervention risk changes wouldn't be the appropriate mechanism for handling changes in this parameter due to the impact and level of control that GDNs have over them. There are also practical issues as this parameter affects all GDNs as it is a 'common' value, therefore a common consensus has to be made which is difficult to implement when the parameter has already been agreed by the group.	The decision on whether this is updated for investment planning purposes is GDN specific.	£	Formula to model bi-linear increase over time. if(Dyear+2015<=2030,Dyear+2015-1953,7.3587*(2015+Dyear)-14860)	Should be reviewed and updated as part of RIIO-3 CBA and NARM target setting.

Governance

Parameter	Parameter Description	Common to Sector of License Specific	Reference to Methodology	Rationale for fixing over RIIO-2	Is this parameter updated for investment planning purposes?	Units	Fixed Values*[1]	Next Proposed Review and/or Update
F_Minor	Cost of minor injury	GDN	3.7.2 Global Values	Are values outside of GDN control and should be fixed as they are not affected by intervention. Although they are considered in investment decisions, they typically are not the main driver. Non-intervention risk changes would not be the appropriate mechanism for handling changes in this parameter due to the impact and level of control that GDNs have over them. There are also practical issues as this parameter affects all GDNs as it is a 'common' value, therefore a common consensus has to be made which is difficult to implement when the parameter has already been agreed by the group.	The decision on whether this is updated for investment planning purposes is GDN specific.	£	185,000	Should be reviewed and updated as part of RIIO-3 CBA and NARM target setting.

Governance

Parameter	Parameter Description	Common to Sector or Licensee Specific	Reference to Methodology	Rationale for fixing over RIIO-2	Is this parameter updated for investment planning purposes?	Units	Fixed Values*[1]	Next Proposed Review and/or Update
F_Death	Cost of death	GDN	3.7.2 Global Values	Are values outside of GDN control and should be fixed as they are not affected by intervention. Although they are considered in investment decisions, they typically are not the main driver. Non-intervention risk changes would not be the appropriate mechanism for handling changes in this parameter due to the impact and level of control that GDNs have over them. There are also practical issues as this parameter affects all GDNs as it is a 'common' value, therefore a common consensus has to be made which is difficult to implement when the parameter has already been agreed by the group.	The decision on whether this is updated for investment planning purposes is GDN specific.	£	16,000,000	Should be reviewed and updated as part of RIIO-3 CBA and NARM target setting.

Governance

Parameter	Parameter Description	Common to Sector of Licensee Specific	Reference to Methodology	Rationale for fixing over RIIO-2	Is this parameter updated for investment planning purposes?	Units	Fixed Values*[1]	Next Proposed Review and/or Update
Discount Rate	Financial discount rate	Licensee Specific	3.7.2 Global Values	Are values outside of GDN control and should be fixed as they are not affected by intervention. Non-intervention risk changes would not be the appropriate mechanism for handling changes in this parameter due to the impact and level of control that GDNs have over them, discount rates to be applied would be determined by Ofgem.	The decision on whether this is updated for investment planning purposes is GDN specific.	%	0	Should be reviewed and updated as part of RIIO-3 CBA and NARM target setting.

Governance

Parameter	Parameter Description	Common to Sector of Licensee Specific	Reference to Methodology	Rationale for fixing over RIIO-2	Is this parameter updated for investment planning purposes?	Units	Fixed Values*[1]	Next Proposed Review and/or Update
Base Price Year	Base Price Year	GDN	3.7.2 Global Values	Are values outside of GDN control and should be fixed as they are not affected by intervention. Although they are considered in investment decisions, they typically are not the main driver. Non-intervention risk changes would not be the appropriate mechanism for handling changes in this parameter due to the impact and level of control that GDNs have over them. There are also practical issues as this parameter affects all GDNs as it is a 'common' value, therefore a common consensus has to be made which is difficult to implement when the parameter has already been agreed by the group.	The decision on whether this is updated for investment planning purposes is GDN specific.	Year	2018/19	Should be reviewed and updated as part of RIIO-3 CBA and NARM target setting.

Table 20- Fixed Parameters for NARM GDN Methodology (Aligned to GD2)

Governance

6.6 Continuous improvement

This section summarises model and methodology improvements made since NOMs went live in 2017. Areas for future exploration are listed in appendix I and will be annually reviewed by SRWG. This section will be updated for each new price control period.

Since NOM conception and development in RIIO1, we have reviewed our methodology for improvement opportunities and for weaknesses.

In RIIO1 we focused on addressing key weaknesses identified following implementation of the first version of the NOMs models.

The first significant challenge was forecasting of failure and subsequent consequence for Local Transmission System (LTS) pipelines. It became clear in 2018 that the model results needed review. We employed leading UK experts, PIE (Pipeline Integrity Engineers Ltd), a professional pipeline engineering consultancy to undertake a model review and suggest improvements. These were accepted and implemented in 2018

In 2019 the SRWG reviewed the riser risk model. This was due to a shared view that riser risk was underrepresented in the NOM's calculations. This resulted in a number of changes to modelled assumptions and to failure data. The result were risk levels that were more comparable to risk levels of other asset groups, as experienced in reality

In 2019 we adopted and implemented the revised NOM's methodology, NARMs. We applied NOM's modelling to the NARM framework and tables, submitting NARMs Business Plan Data Templates (BPDTs) to Ofgem in December 2019.

In 2022, following RIIO2 Final Determinations and embedding the new NARM's approach, SRWG conducted a full review of our methodology in parallel with an Ofgem review. Results were compared and a list of proposed improvements were agreed. These were labelled as category 1 or 2.

Category 1 improvements were implemented and methodology updated by November 2023. Category 2 improvements and methodology updates are being completed in 2024 in readiness for RIIO3 Business Plan submission. This includes the development of a long term risk methodology, a substantial change to GDN NARM. This required external expert support, a validation and assurance process and significant modelling and methodology updates.

Details of the 2022 – 2024 category 1 and 2 improvements can be found in appendix J

7. Long Term Risk and Network Risk Outputs

This section of the document outlines the general approach taken for the calculation of long-term monetised risk benefits associated with asset health investments. Where this approach differs between asset classes it will be discussed in the relevant Appendix.

7.1 Introduction

This section outlines the GDN approach for calculating the long-term monetised risk benefit (LTRB, or LTR) arising from alternative asset interventions. GDNs had developed the capability to undertake LTR calculations for the GD2 price control submission, but due to uncertainties in some of the asset deterioration assumptions, only a single-year monetised risk benefit target was adopted for GD. Improvements have been made to how deterioration rates are estimated for Governor and PRS/Offtakes assets and Mains and Services deterioration rates have been recalculated using a further 7 years' worth of data since the previous Methodology submission, accounting for mains replacement activity carried out over this period.

The LTR calculation uses different time-periods for cumulative intervention benefit assessments, based on the asset type and scale of the specific intervention adopted. This provides a basis for:

- Comparing the costs and monetised risks of alternative interventions over a longer period, prior to regulatory submissions.
- Allowing the benefits delivered through funded investments to be tracked and enable regulatory rewards and/or penalties to be applied in a consistent and quantified manner (across gas networks and other energy sectors).

7.2 Definitions

Term	Definition
Monetised Risk (£MR)	The absolute level of risk, expressed in monetary terms in a reporting year. Generally, increases with deterioration and is reduced by proactive investment. Is split into different risk categories for reporting (Financial, Environment, Safety and System).
Long Term Risk (£LTR)	The cumulative monetised risk, pre- and post-intervention for a specific asset and intervention type.
Intervention Life	Should an intervention be implemented, the elapsed time until another intervention (of any type) is needed on the same asset.
Long Term Risk Benefit (£LTRB)	The difference between the pre- and post- LTR over the Intervention Life, for a specific asset and intervention.

7.3 Approach

There are five key data requirements to enable the LTR of an investment (on a specific asset or grouped cohort) to be assessed:

- The rate of deterioration of the asset, pre-investment (assuming only reactive interventions are carried out to maintain condition "as good as old".
- The rate of deterioration of the asset, post-investment (assuming that the intervention has extended the life of the asset and reduced the rate of deterioration).
- The reduction in the probability of failure of the asset, post intervention (for each failure mode associated with the asset).
- The time (number of years) until a subsequent intervention is required on the same asset (or life of an intervention). This could be a further refurbishment, or replacement but the nature of this subsequent intervention is not relevant.
- The financial discount rate, which allows investment costs and benefits to be compared on equal terms (through a simple benefits/cost ratio), This has a secondary effect of devaluing benefits in later years of the analysis (as a surrogate for uncertainty of benefits delivery in the future).

A combination of these data requirements allows an LTR value to be calculated for all assets and investments and these to be aggregated or disaggregated as required for planning, benefits tracking, and regulatory reporting.

This document describes a generic approach for LTR calculation for all asset types which will allow configuration of Asset Risk Decision Support Tools (DSTs). It also identifies what new asset and investment level data that needs to be provided to enable this process (Figure 28). Please note that the reference to "Other Non-NARM Consequences" is to allow for future changes to the Methodology, for example to include the societal costs and benefits of disruption to transportation (due to work in the highway etc.).

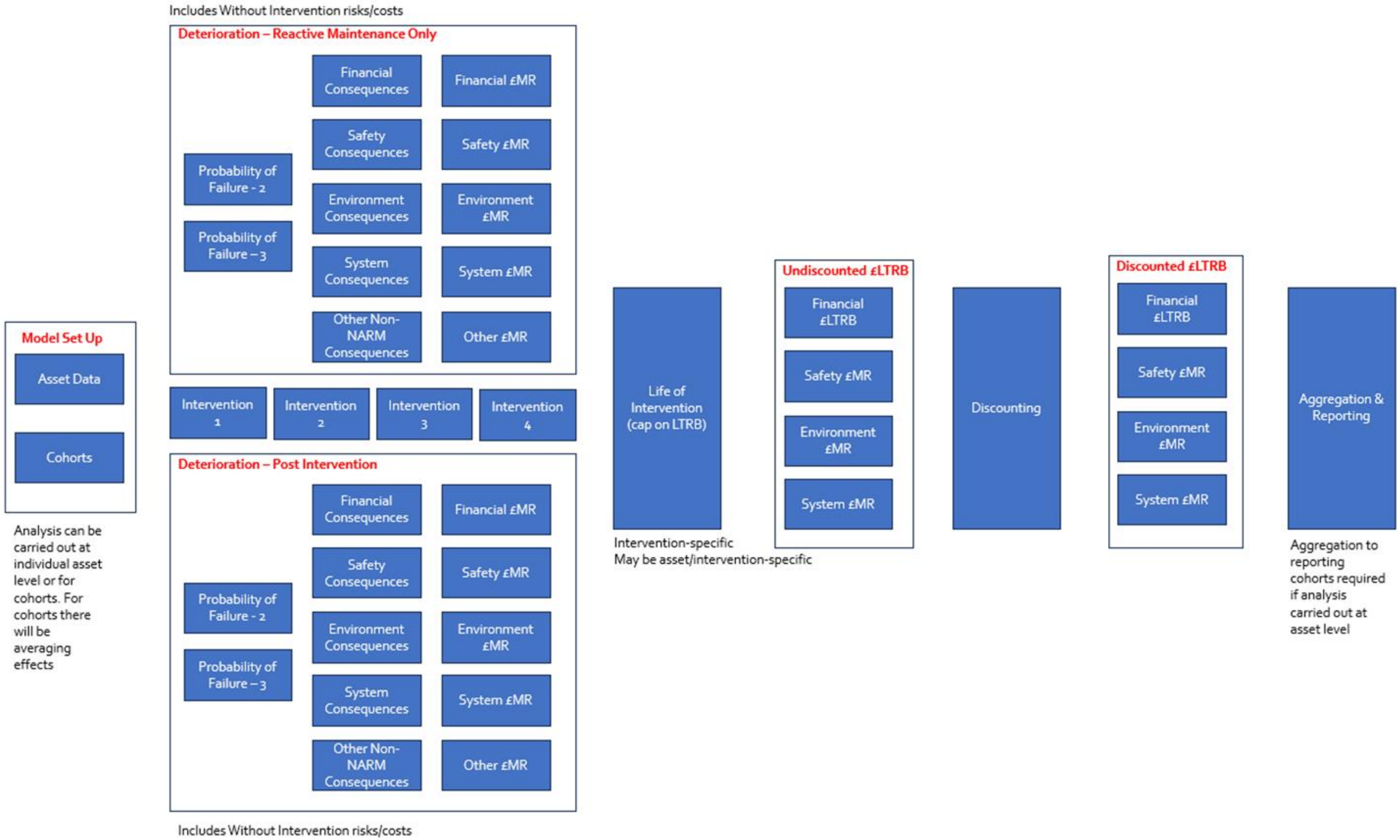


Figure 28 - Overview of LTR calculation process

7.4 Process Description

This section describes the process using the steps shown in Figure 28. A simple worked example has been produced covering mains replacement and refurbishment (by material type) showing how different deterioration and intervention life assumptions can impact on LTR. This is referenced throughout this section.

Please note, the examples presented in this, and subsequent questions are for illustration purposes only and do not represent real network data. Monetised risk values, deterioration rates and intervention benefits for the example shown are arbitrary.

The example includes model simulations from 2026 to 2074, with a single intervention in 2030 (no subsequent intervention). For LTR assessment, model runs will be needed corresponding to the maximum identified life of an intervention. It is currently assumed that this will be no greater than 50 years..

The outlined LTR calculation is similar for all asset types, as DST risk modelling tools can already calculate, and report on, the annualised monetised risk values for the four NARM risk reporting categories (Financial. Environment, Safety and System).

7.5 Model Set Up

All GDNs have developed asset risk calculation and optimisation models, and specific asset units of measure have been defined for NOMs/NARMs reporting and processes are in place to group from individual asset/system to these defined reporting cohorts. Some networks calculate risk at asset level, prior to cohorting, whereas others aggregate to cohorts prior to calculating risk. The outlined approach will work for both if the impact of averaging is considered during the cohorting process.

Asset risk models should be run to reflect the proposed programme of work, plus any alternative options. This could be through optimisation or by submitting a pre-defined works programme and then reporting on how this changes risk over time. Ideally, multiple different works programmes (for example, different blends of replacement and refurbishment), should be analysed to understand the sensitivity to investment costs and business targets/outcome assumptions.

7.6 Deterioration Analysis – Reactive Maintenance Only

The first stage in LTR calculation is to understand how the value of risk changes over time assuming only reactive interventions are conducted (for example, repairs and planned maintenance).

As previously described, GDNs split risk into 4 categories for use in NARM reporting). These are:

Financial Risk – cost incurred by the network in managing its assets.

Safety Risk - the costs of mitigating health and safety impacts of asset failure on employees and the public, including fines or penalties.

Environmental Risk – the costs of environmental damage due to inefficient asset operation and/or failure[2]

System Risk – the costs of a loss of gas supply to customers, including customer contact handling and supply restoration costs.

Where the deteriorating condition of assets increases the costs of planned maintenance activities this may be considered as Financial Risk for LTR assessment.

The first stage of LTR assessment is to calculate an annual Monetised Risk value (£MR) for each of these categories as a baseline for benefits calculation, for reactive-only interventions (fix-on-failure).

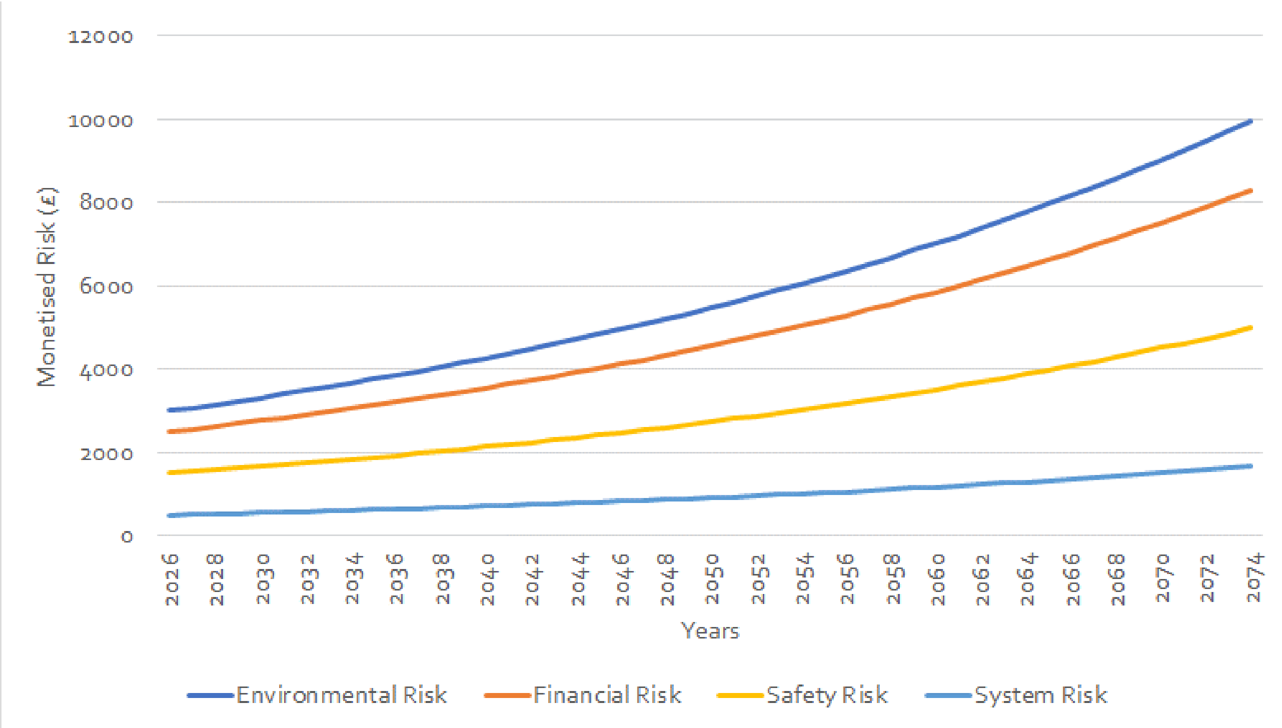


Figure 29 - Monetised Risk by year for reactive interventions only.

7.7 Deterioration Analysis – Post Intervention

An identical process is then followed for all the relevant NARM interventions for each asset class. This requires the intervention (or alternative) and intervention benefits to be configured in asset risk modelling tools. Where new interventions are identified, or where changes to existing interventions are needed, these will need to be configured and evaluated prior to LTR analysis.

Figure 30 and Figure 31 show how the intervention reduces the monetised risk and deterioration rate for a Replace and Refurbish intervention, respectively. It can be seen that the Replace option delivers both a higher reduction in PoF and deterioration rates. For LTR assessment, all

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[2] Where the environmental costs of asset operation are fixed, they are generally excluded from LTR (for example, travel to site or routine maintenance such as valve operations)

interventions are assumed to take place in the same year (the final year of the GD period) as per Ofgem guidance.

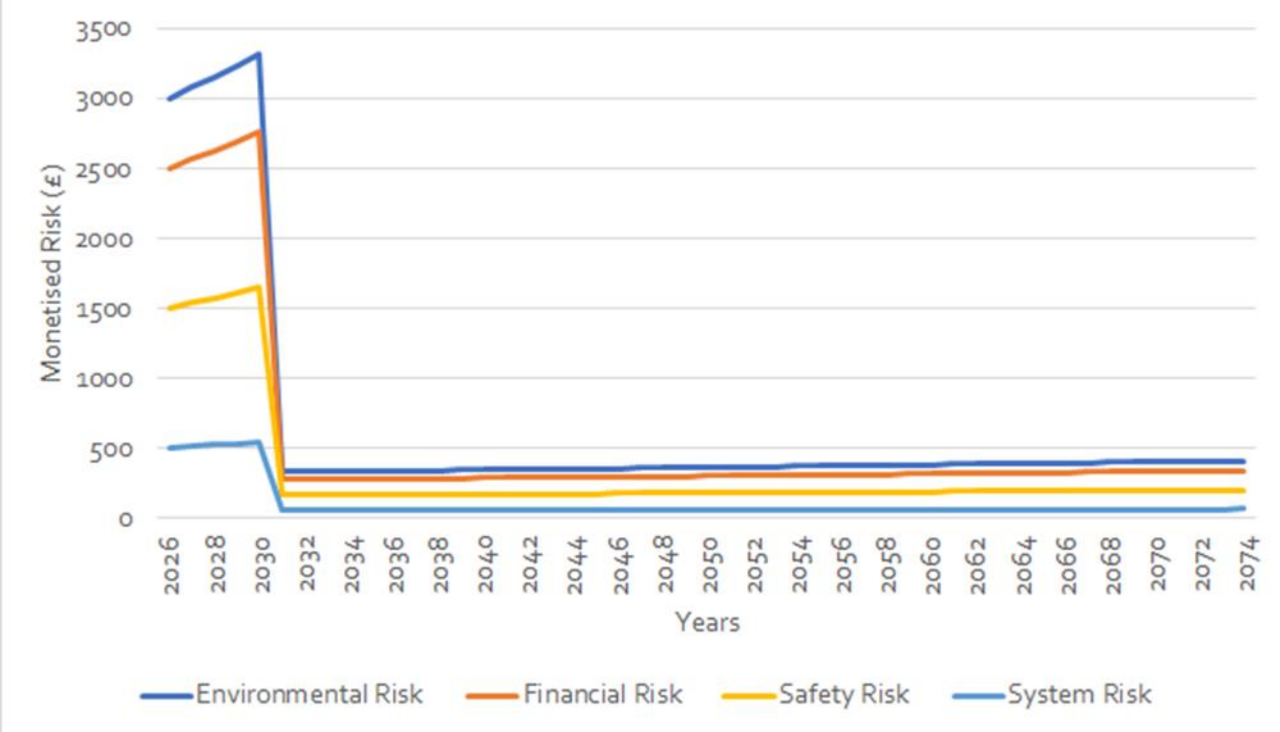

Figure 30 – Monetised risk with Replace intervention in 2030

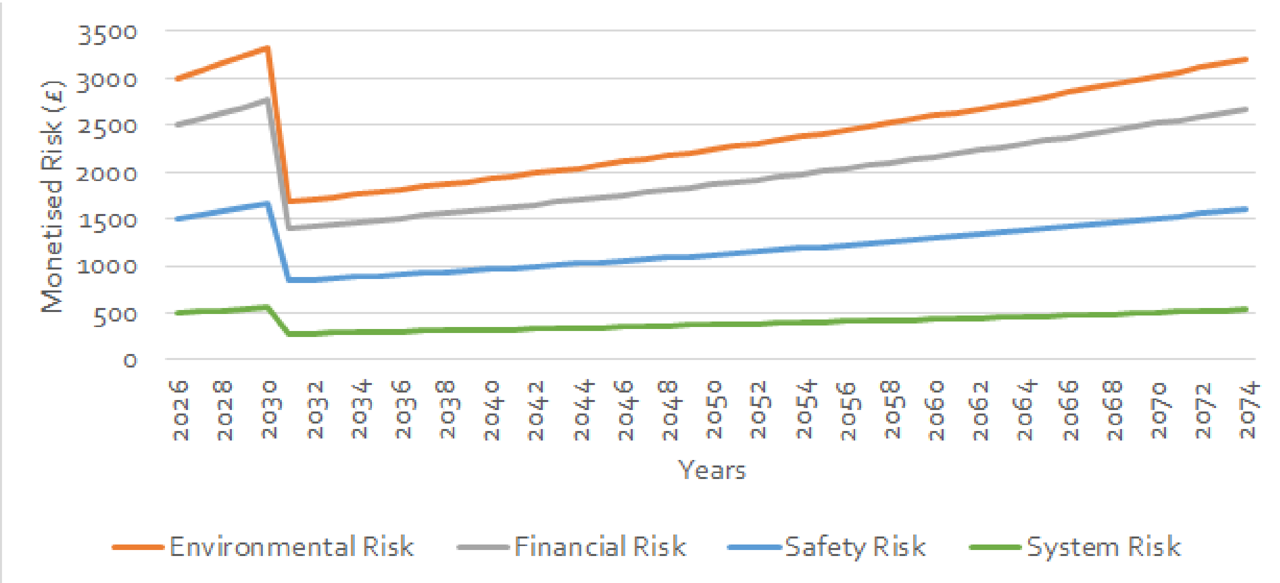

Figure 31 - Monetised Risk with a Refurbish intervention in 2030

An annual monetised risk value (£MR) for each of these categories post-intervention is calculated for each intervention type over the same time period (the life of an intervention is not relevant at this stage). The intervention is assumed to occur in the last year of the GD period, 2030 in this case with the first benefit being observed in 2031, regardless of when the actual intervention takes place during the GD period. This is in line with Ofgem guidance. For simplicity it is recommended that discounting of costs and benefits also takes place from this final year, which may result in some minor misalignment with other cost-benefit analysis (CBA) which may use different price base years.

Please note, this is not Long-Term Risk at this stage; it is just the absolute level of risk expressed in monetised risk terms, pre- and post- alternative investments (£MR).

7.8 Intervention Life

The NARMs intervention life, or the life of a (NARM) intervention, is the core principle underpinning the LTR approach. For assets/interventions with large benefits (either due to a large reduction in PoF and/or reduction in deterioration, post-intervention), an appropriate and justified choice of the value of the NARM intervention life is essential.

It is important to distinguish this value which has been defined to support the NARM incentive mechanism from the "accounting" asset life (which is used for asset depreciation analysis). It is also an Expected Value and individual assets may require intervention before or after this stated NARM intervention life period.

A key principle of the Network Risk Output (NRO) approach requires that a specific **intervention type**, on a specific **asset type** has a defined (and fixed) period until the next intervention is needed on the **same asset**. From an asset management perspective this is clearly flawed as some assets will deteriorate quicker than others, random failures will happen, and other factors (such as resources/budget or policy) will result in earlier or later intervention than the fixed intervention period defined by the NARM approach. As stated previously, the LTR calculation process does not need to consider the size or scale of any subsequent intervention, beyond the current GD period.

To achieve this, a fixed NARM intervention life must be estimated and fixed in the NARM Methodology. The choice of intervention life is sensitive to the calculated LTR values, and this sensitivity has been explored through the Testing and Validation process. These calibrated intervention lives are defined in the relevant Appendix for each asset type and will be under ongoing review as part of annual Methodology reviews. However, changes will only be made as party of price control submissions to avoid the need to rebase targets within a price control period.

For the purposes of the worked example the following intervention life values are used. A specific value will be stated for each asset and intervention type.

Asset	Intervention	Life
Mains	Replace	45 years
	Refurbish	25 years

Table 16 – Intervention lives for worked example

Figure 32 and Figure 33 illustrate how the defined intervention life caps the value of the LTR based on the monetised risk profile, pre- and post-intervention, for a Replace and Refurbish intervention, respectively.

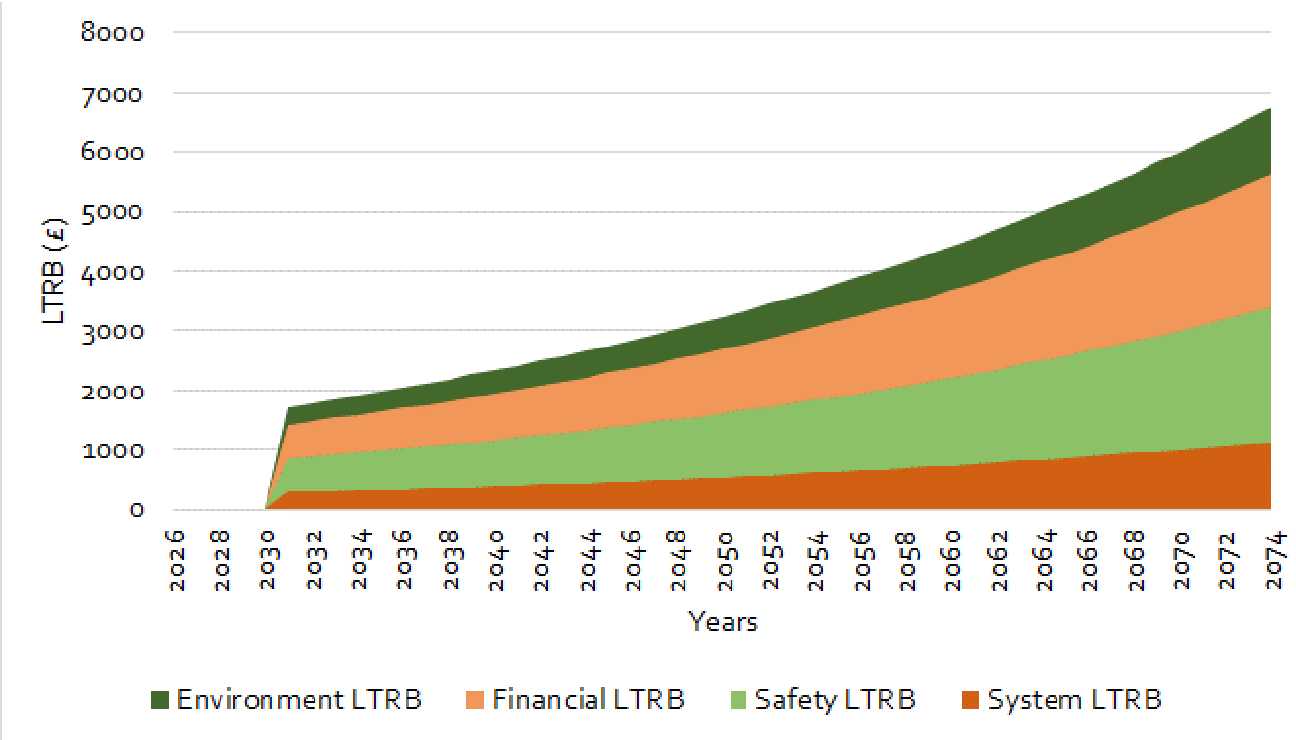

Figure 32 - LTRB for Replace intervention (cumulative over 45 years)

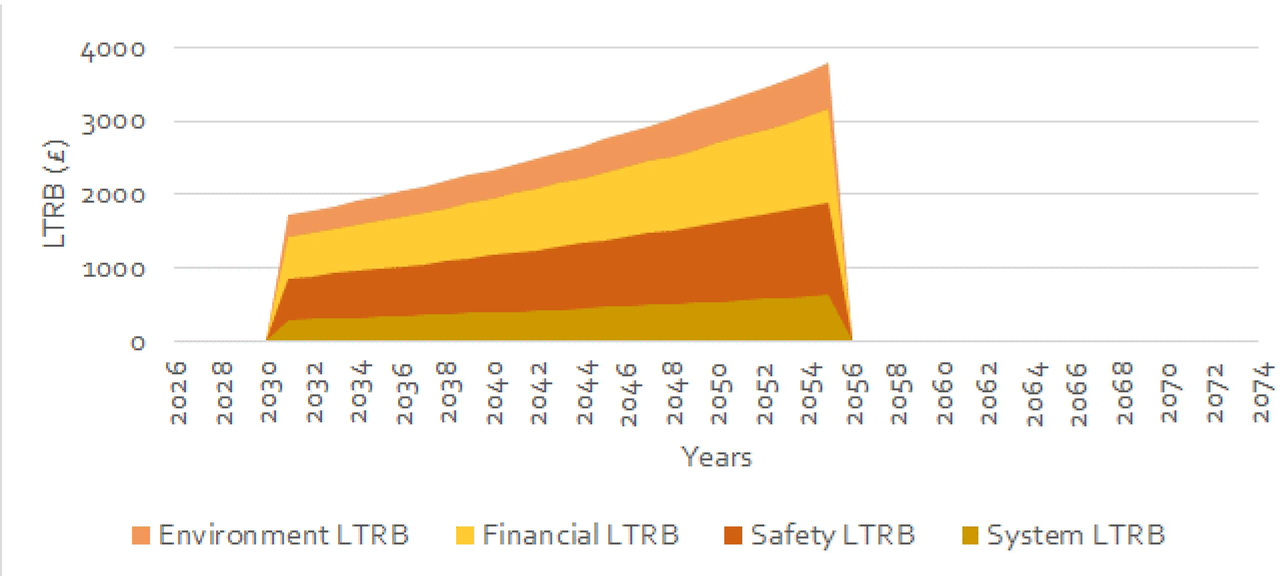

Figure 33 - LTRB for a Refurbish intervention (cumulative over 25 years)

For the replacement and refurbishment interventions shown, Replacement clearly delivers more LTR as:

- The intervention benefit persists for longer (45 years, versus 25 years for Refurbishment).
- The magnitude of the PoF and deterioration is greater, increasing the size of the area between the with- and without-intervention lines.

A final decision as to which is the better option to choose requires consideration of both the delivery costs and the true timing and size/scale of any future (repeating) interventions (using a traditional cost/benefit analysis).

7.9 Calculating the Undiscounted Long Term Risk Benefit

The LTRB delivered is the cumulative difference between the reactive-only monetised risk value and the monetised risk value post-intervention.

These cumulative post-intervention monetised risk values are subtracted from the cumulative reactive-only monetised risk values over the same period (45 years for replacement; 25 years for refurbishment). So, for a specific asset (or cohort) and Intervention the calculation would be:

$$LTRB\ (Intervention) = \sum_{Int\ Start}^{Int\ Start + Int\ Life} \text{R£}\ (Reactive\ only) - \sum_{Int\ Start}^{Int\ Start + Int\ Life} \text{R£}(Intervention)$$

Where *£LTRB* is the LTRB for the specified intervention; R*£ (Reactive only)* is the yearly monetised risk value for the reactive-only scenario; and R*£ (Intervention)* is the yearly monetised risk value for the specified intervention scenario. *Int Start* is the start year for counting risk benefits (end of GD period) and *Int Life* is the intervention life.

7.10 Calculating the Discounted Long Term Risk Benefit

Discounting is the process of determining the present value of a payment or a stream of payments that is to be received in the future (or in this case benefits of investment). Given the time value of money, a pound is worth more today than it would be worth tomorrow. Discounting is the primary factor used in pricing a stream of tomorrow's cash (or benefits) flows. Discounting for LTR monetised benefits "cash" flows is stipulated by Ofgem to account for benefits delivery becoming increasingly uncertain over time. Its application is identical to that used for traditional cost benefit analyses.

A discount rate is used to calculate the magnitude by which benefits are devalued over time. Discounting to the LTR is applied in accordance with the NARM Handbook and Ofgem guidelines.

Asset risk modelling tools typically allow both discounted and undiscounted values to be reported directly. Care should be taken not to discount twice (for example, build discounting into a risk/value calculation and then allow the Asset Risk tool to discount again when a report is generated.

The discounted LTR value is calculated for each time step using the following equation.

$$£LTR\ (discounted) = \frac{£LTR(undiscounted)}{(1 + Discount\ Rate)^{(Current\ Year\ -\ Benefits\ Year)}}$$

Where the Current Year is the year the LTR value is to be calculated for and the Benefits Year is the first year that the benefit is delivered (this is the end GD period year for LTR). To give an idea of how quickly the discounting process devalues the LTR value, Figure 34 shows the value of the divisor as time progresses, using 2025 as the Benefits Year (as per GD1).

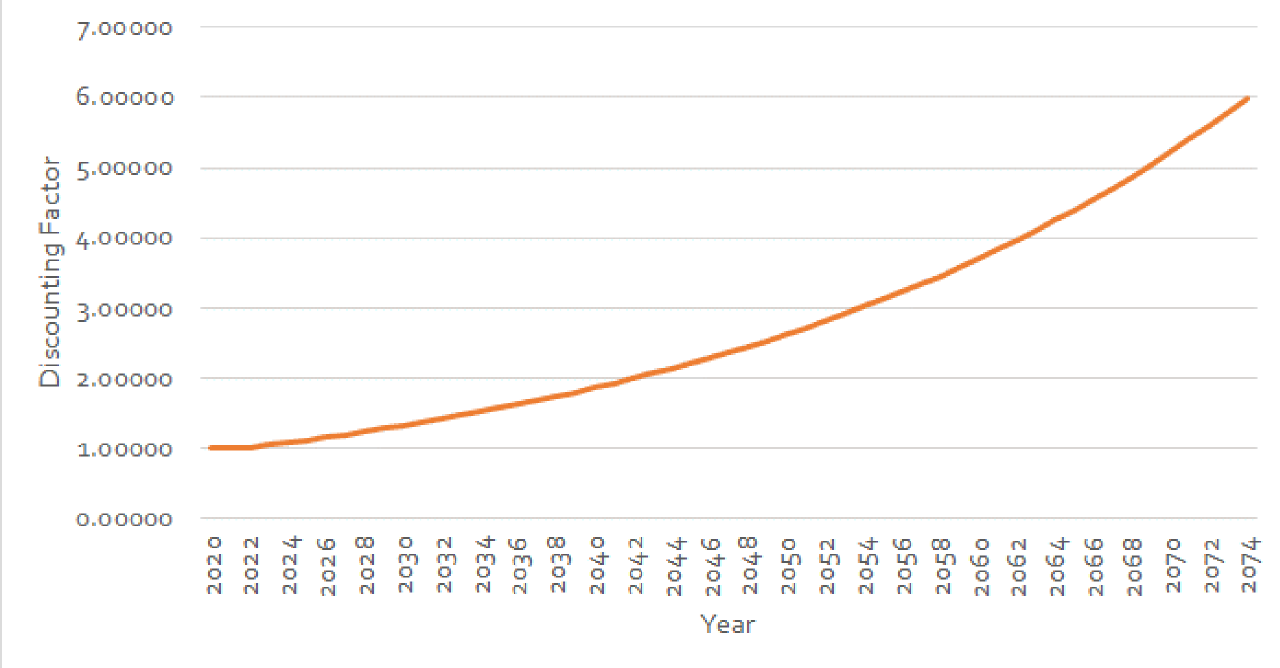

Figure 34 - Discounting factor based on a Benefits Year of 2025 and a Discount Rate of 3.5%

By 2074, the value of benefits is reduced by a factor of nearly 6. This process is repeated for each of the risk categories and then summed to give the overall LTR for the asset and intervention type.

The Unit Cost of Risk Benefit (UCR) for each intervention would then be calculated by dividing the investment costs (to deliver the above LTRB) by the R£LTRB value. All costs and benefits must be stated in the same price base and both the costs and the benefits would be applied from the final year of the price control for reporting purposes, unless modified by Ofgem. The rationale for this approach was to stop potential gaming of UCR by backloading programmes relative to original plan / targets to capture greater benefits due to deterioration. The present value of the LTRB should be consistent with the costs due to the use of the same price base and discounting.

7.11 Capping of Monetised Risk Benefits

The process to be adopted for the calculation of Long-Term Risk (LTR) benefits aligns to the Ofgem definition of a Network Risk Output (NRO), taken from the NARM Handbook.

The NARM Handbook (Appendix 1, page 19) defines the Network Risk Output as:

> *The risk benefit delivered or expected to be delivered by an asset intervention, and: is the difference between without intervention and with intervention Monetised Risk;* ***can be measured over one year or over a longer period of time****; and includes both direct (i.e., on the asset itself) and indirect (i.e., on adjacent assets or on the wider system) risk benefit.*

Previous versions of the Methodology capped monetised risk benefits to a single year due to lack of confidence in the longer-term monetised risk forecasts, with- and without-intervention. The purpose of this GDN LTR project is to improve these risk deterioration estimates and define the period by which these benefits persist before **a subsequent intervention is needed on the same asset**. This is subsequently referred to as the **life of an intervention** or **intervention life**.

An example of the use of the intervention life to calculate the LTR metric would be where an asset is periodically refurbished (e.g., painted), but ultimately replacement would be needed. This could be due to 1) costs/benefits of replacement outweighing costs/benefits of ongoing refurbishment; 2) inability to continue to refurbish due to asset obsolescence or changing policy/legislation drivers 3) other justified drivers. The life on an intervention in this case is either:

- The time between subsequent refurbishments.
- The time between the final economic/feasible refurbishment and asset replacement.

The choice of an investment strategy for a specific asset (or group of assets) is part of the periodic investment planning cycle and is beyond the scope of this Methodology. The selected investment may be accompanied with a NARM regulatory output, and this is quantified using:

- The change in risk post-intervention.
- The change in the rate of deterioration post-investment.
- The life of the intervention, which in accordance with the NRO definition, is the period over which the monetised risk benefit cumulates before a subsequent intervention is implemented.

7.12 Defining NARM Interventions

The list of interventions listed in the current Methodology has been reviewed. A full list for each asset type has been updated in the relevant Appendices (A-F). There are two categories of intervention defined:

- **With Intervention** – these interventions generate a change in asset risk and deterioration through an improvement in overall asset condition (and performance)[3].
- **Without Intervention** – these are generally interventions that maintain the asset at the current level of condition/performance and/or are surveys/investigations to assess asset condition and prioritise "proactive" work. This includes reactive repairs, to return the asset to its "good as old" condition/performance, and planned maintenance.

Interventions to be applied for LTR assessment are restricted to **With Intervention** only. Without Intervention activities are assumed to only apply to Financial Risk and are either non-time-varying or changes over time are not asset condition related.

7.13 Practical Considerations

Assets are not intervened upon at fixed intervals, but a decision is made based on a full assessment of asset performance, current/future risk, deliverability and intervention costs by engineering experts and investment teams. It is essential that the assumptions underpinning LTR are clearly defined, tested, and fixed, such that specific asset/intervention combinations do not over- or under-estimate the cumulative monetised risk benefits and distort the NRO targets in the real world of asset investment decision-making and delivery.

This is further discussed in the Testing and Validation report.

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[3] Where condition is a lead indicator of future performance issues. Performance is a lag measure where actual faults/failures can be used to inform investment decisions on similar assets.

Appendices - Detailed Asset Assessments

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 – failure of the pipe due to corrosion. Corrosion occurs on metallic pipes due to the presence of moisture either on the inside or outside surface of the pipe.
- Fracture failure – failure of the pipe due to fracture. This principally affects cast iron pipes.
- Interference failure – for example 3rd party damage
- Joint failure – failure of the pipe due to 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

Appendices - Detailed Asset Assessments

A2.3. Distribution Mains Risk Map

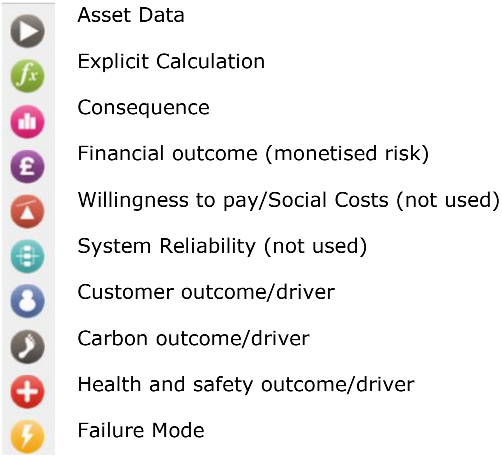

Figure A- 1 - Risk Map Key

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.

Appendices - Detailed Asset Assessments

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

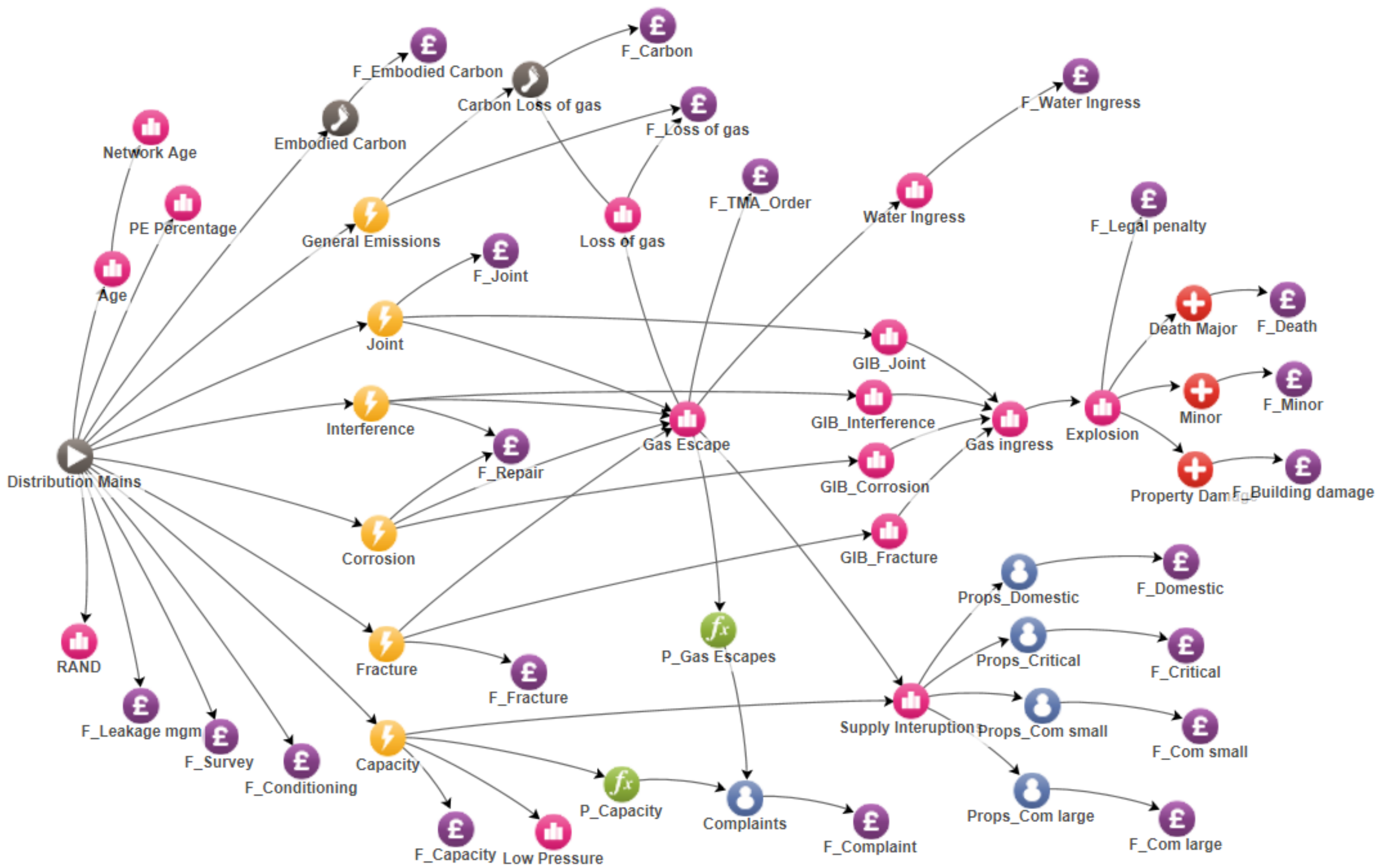

Figure A- 2 - Distribution Mains Risk Map

Appendices - Detailed Asset Assessments

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.

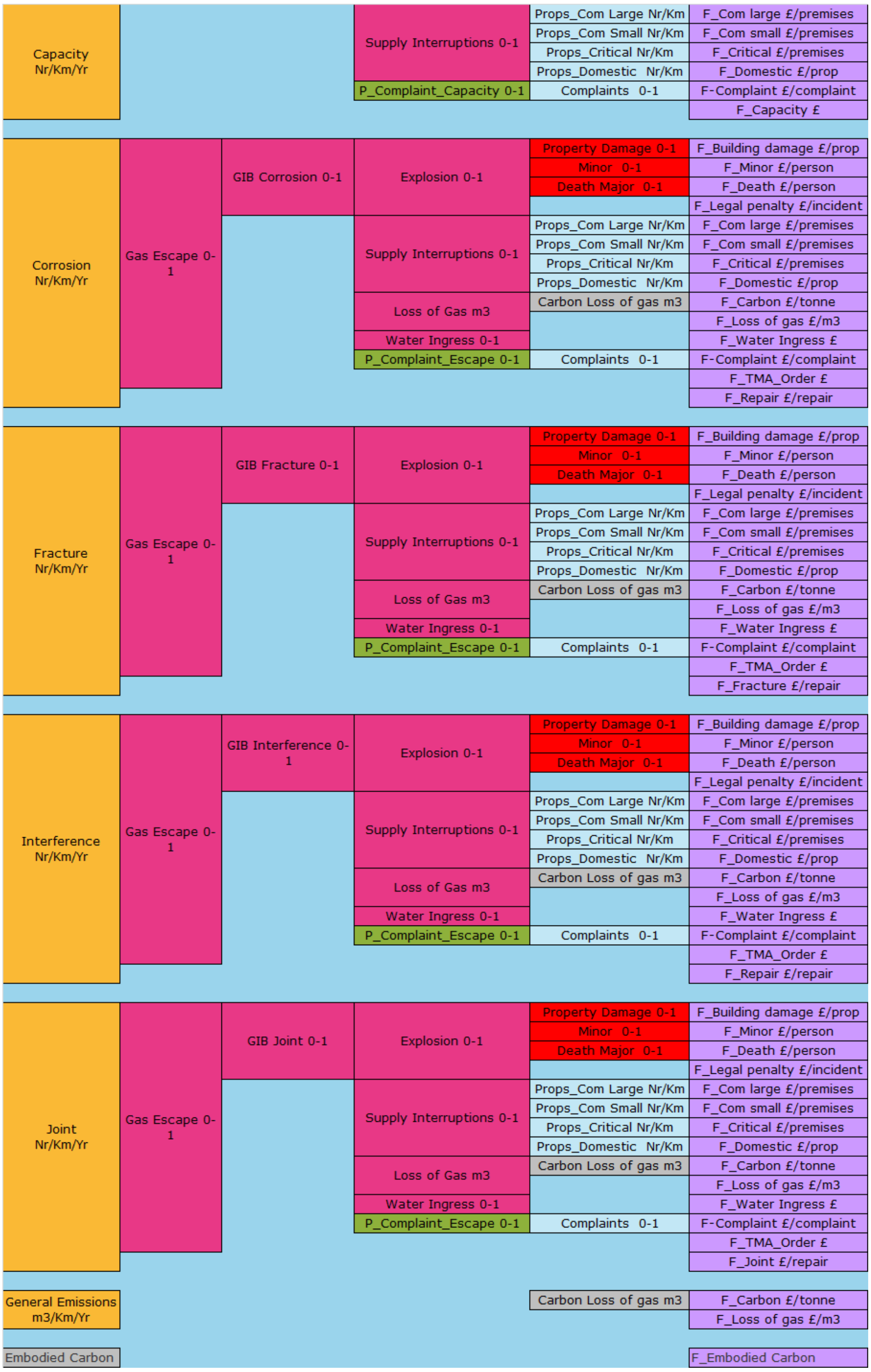

Figure A- 3 - Distribution Mains Risk Map Template

Appendices - Detailed Asset Assessments

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. Demand mix generation is a longer-term evolutionary piece which GDNs will need to consider due to the inherent adjustment to baseline monetised risk as a result of customer demand changing. Customer number updates can be reflected in the modelling base data that supports asset investment decision making, therefore it can be undertaken periodically where required. A customer base data refresh will be undertaken after the completion of the current GD2 price control and at the completion of later price controls as net zero impacts effect methane gas distribution use.

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 (CO_2e) 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	GDN Specific

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	Source
		be estimated for each Failure Mode and Material using the statistical relationship between estimated pipe failure rates and installed Age.	
Death_Major	Number of deaths or major injuries given an explosion	0.45 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 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.	GDN Specific Common

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Node ID / Variable	Description	Data Source	Source
		Nil costs reported for services. Cost of leakage management (e.g. profiling) captured under Governors model	
F_Legal_Penalty	Cost of legal enforcement and penalty payments following ignition/explosion	£1m 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

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Node ID / Variable	Description	Data Source	Source
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 which no data currently exists	Common
Minor	Number of minor injuries given an explosion in a property	1.0 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

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Node ID / Variable	Description	Data Source	Source
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	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	Source
	given a failure has occurred		
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

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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:

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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 – low pressure (LP) 0-75mbar, medium pressure (MP) 75mbar-2bar, or intermediate pressure (IP) 2bar-7bar.
- Distribution Zone – zonal distribution area for the transportation of gas. Distribution Zones will vary according to each individual GDN.

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.

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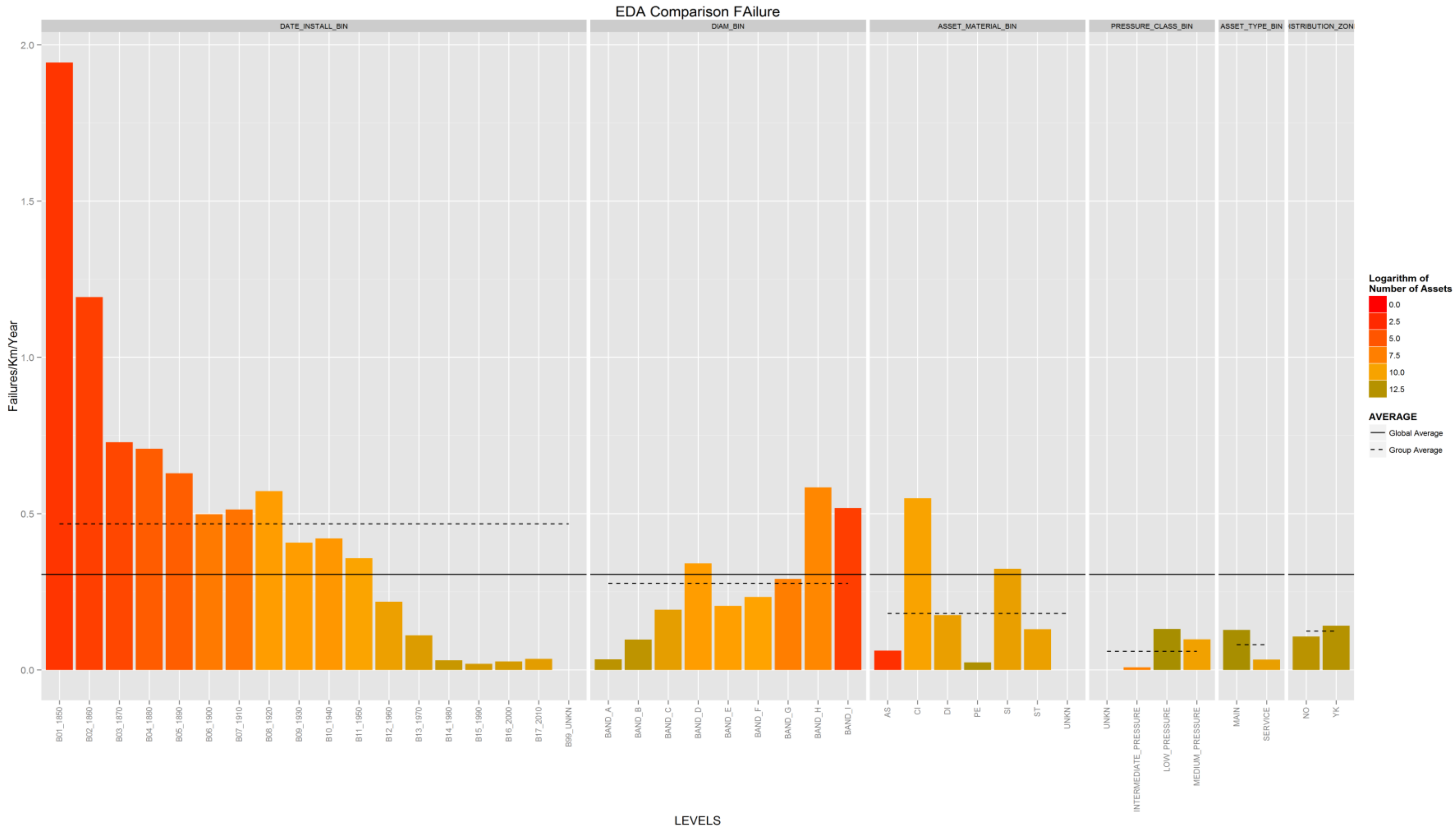

Figure A-4 Initial Joint failure rates for Mains by asset cohort. This illustrates the explanatory factors explored in deriving the predictive function.

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

The mains asset deterioration analysis has been completely updated for this update to the Methodology. The previous analysis only used a single network's asset and failure data. For this new analysis, seven of the eight networks provided data, comprising:

- Mains pipe data and attributes (from GIS). This was at individual pipe section level.
- 10 years of failure data, by failure mode, allocated to individual pipe sections.

A change to the analysis was that both live and abandoned pipe data (and associated historic failures) were included in the analysis. Abandoned pipe data is where the asset has been replaced with PE. Use of abandoned as well as live pipe data both increases the sample size and allows any performance differences between replaced and non-replaced assets (of a similar type) to be assessed. Profiles of the time-varying asset failure data used in the analysis are shown in the chart below. The 10 year cut-off was applied as collected failures become sparse beyond this point (due to changes in company systems etc.).

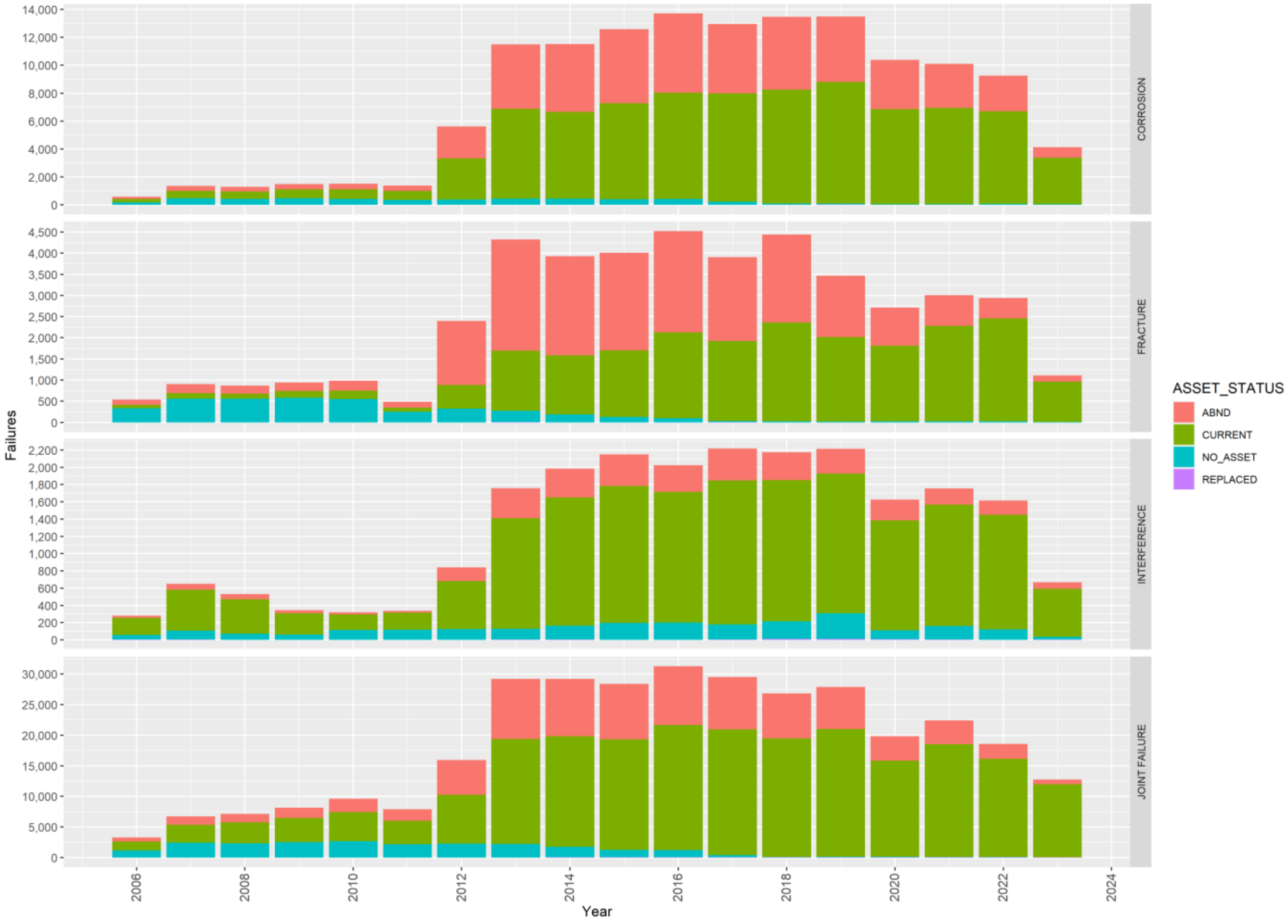

Figure A-5 Observed failure numbers by year, for live and abandoned pipes

Once the data was received from the seven participating networks, it was combined into a single repository and a data cleansing and gap-filling process implemented. In total, over 4.5 million individual assets, with 72 attributes for each, were used in the analysis. This process:

- Identified and removed (or cleansed) any obvious bad data (e.g. PE mains installed in 1900).
- Filled gaps in key attributes to be used for deterioration analysis, such as material, size, and age.
- Checked the failure to asset data allocation to ensure consistency across networks.
- Pipes were grouped into material and age (decade) bandings to mitigate the impact of outlier assets and time-periods (such as the drop in repairs during COVID-10 lock-downs).

Once this data preparation was completed, a series of statistical analyses were carried out to understand the underlying reasons for variations in failure rates between different network, material, and age asset groupings. Two models were prepared for each mains failure model (Joint, Corrosion, Fracture, and Interference), a Polyethylene (PE) and non-PE model, with the following key statistical performance indicators:

- Network / Distribution Zone.
- Material.

- Diameter (size).
- Installation date (age).
- Pressure class.
- Property density (various indicators).

An example of asset data profiling for Install Date is shown below.

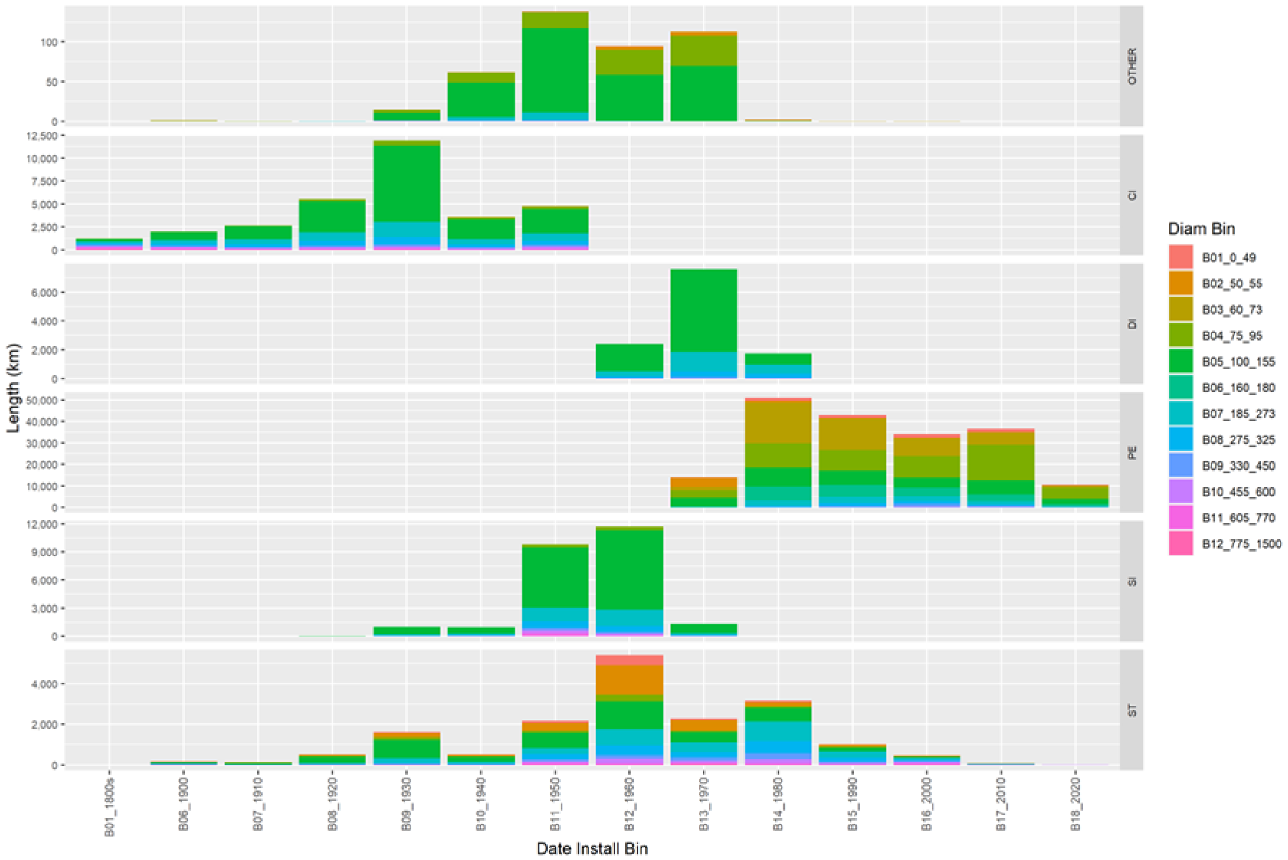

Figure A-6 Length of asset by Install Date and Material type (all networks)

Several other parameters were tested but had no significance on observed failure rates. An example of the significance fits for Joint failures is shown below.

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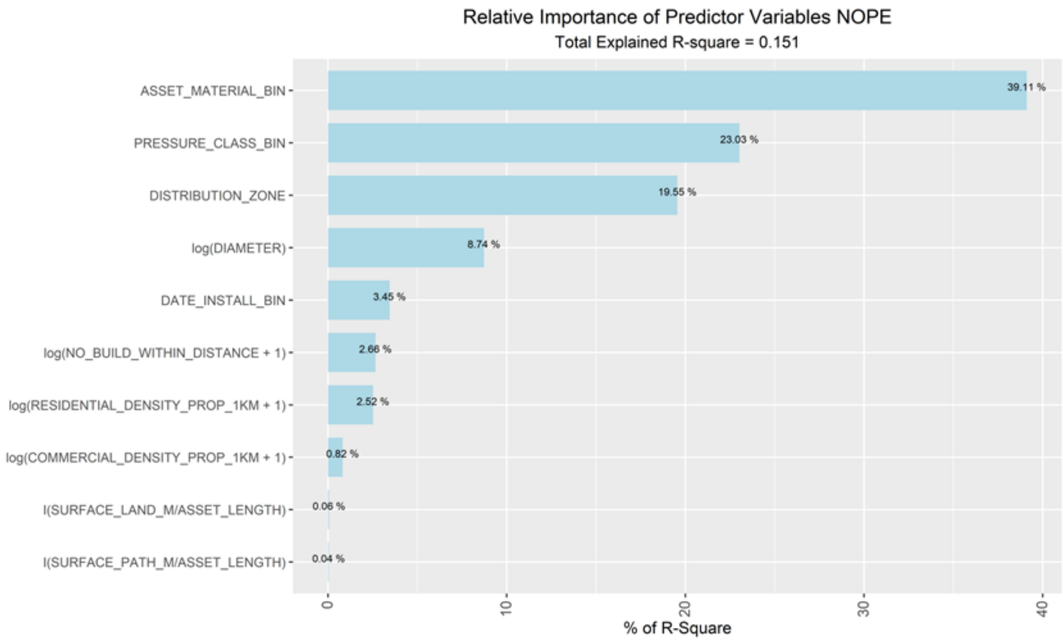

Figure A-7 Joint failure rate predictor variables. A high percentage indicates a greater significance for prediction of joint failures per asset.

Once the failure models were built and tested for each failure mode, the Install Date indicator was used to construct a deterioration model for each.

It was decided to exclude all asset age data beyond 80 years as the failure rates of these pipes was judged to be unrepresentative. This is either due to incorrect age allocation or the fact these assets are unusually resilient compared to the wider population.

Examples of the Joint failures Non-PE and PE deterioration modelling curve fits are shown below.

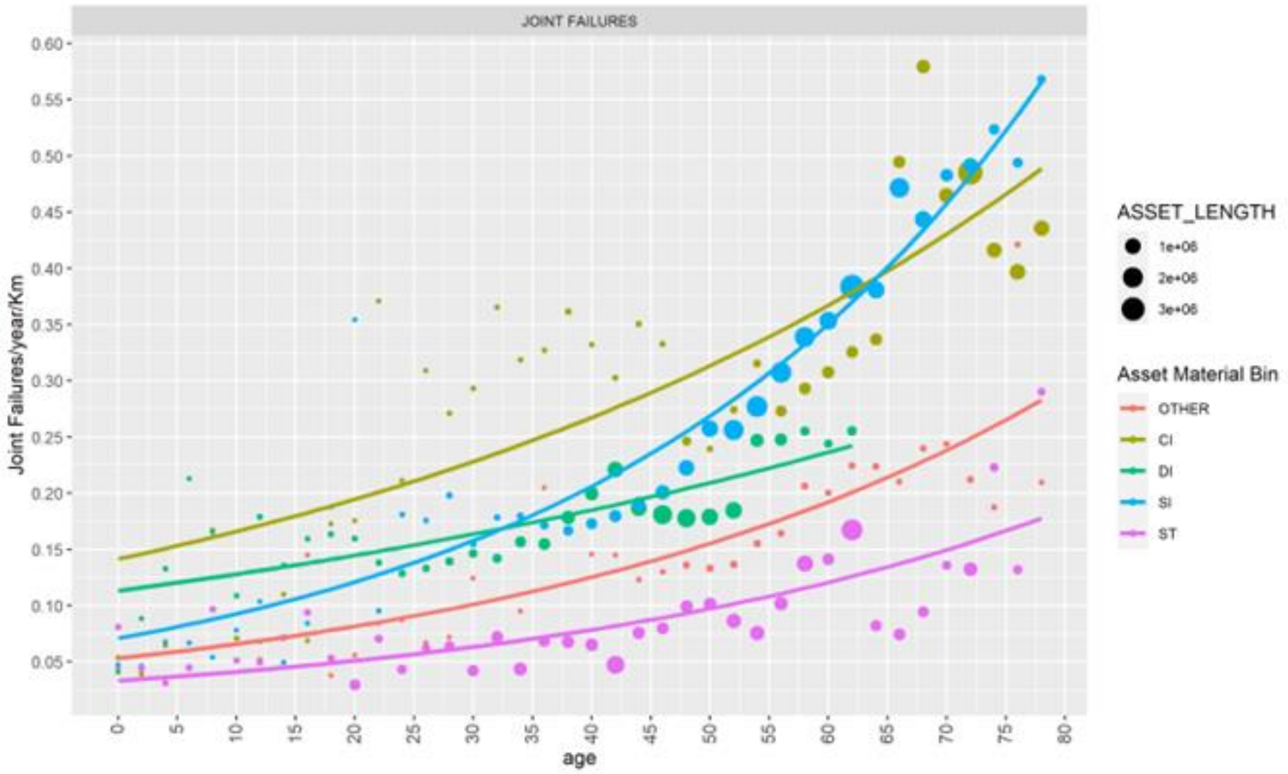

Figure A-8 Predicted deterioration rates for Joint failures, by material type (non-PE assets)

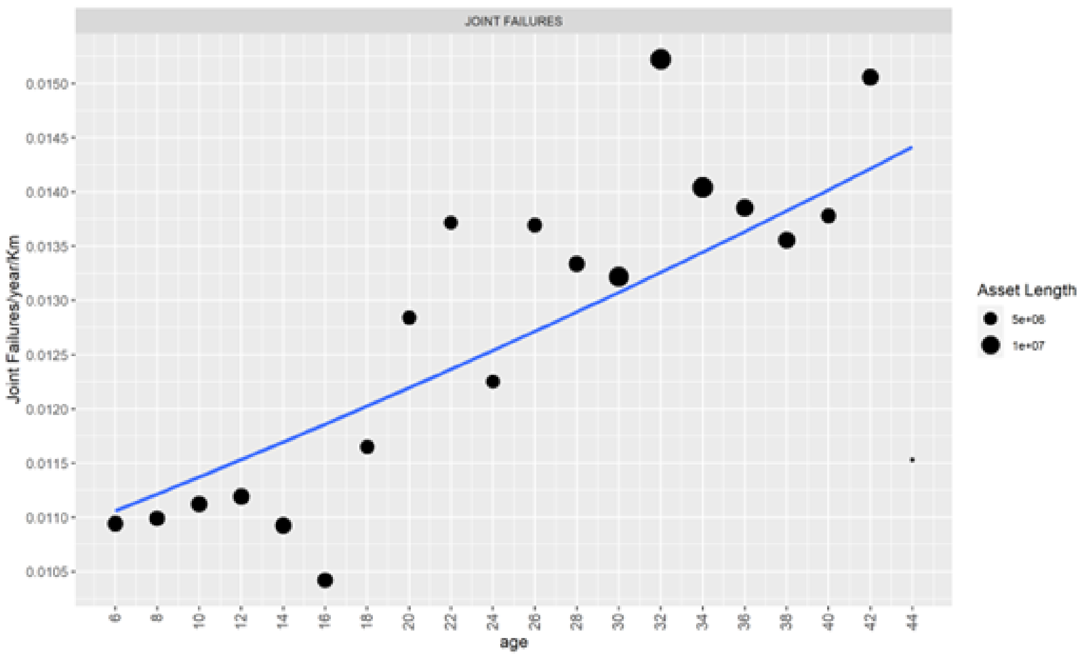

Figure A-9 Predicted deterioration rates for PE Joint failures

It should be noted that the derived deterioration rates are not from fitting an exponential equation to these curves, but from the failure model itself which uses Install Date (age) as an input parameter (DATE_INSTALL_BIN) . An example model for Joint non-PE failures is shown below:

```
JOINT_FAILURE_TOTAL ~ ASSET_MATERIAL_BIN + PRESSURE_CLASS_BIN+ log(DIAMETER) + DATE_INSTALL_BIN +
(SURFACE_PATH_M/ASSET_LENGTH) + I(SURFACE_LAND_M/ASSET_LENGTH) + DISTRIBUTION_ZONE+
log(NO_BUILD_WITHIN_DISTANCE ) + log(RESIDENTIAL_DENSITY_PROP_1KM) + log(COMMERCIAL_DENSITY_PROP_1KM)
+offset(log(ASSET_LENGTH * TTT))
```

The same model fitting process was carried out for Corrosion, Fracture, and Interference failure models. Due to small sample sizes, it was not possible to split Fracture deterioration rates by material and a single rate for non-PE and PE materials is used.

The new deterioration rates are presented in the table below. The "Global" failure rate has been replaced with an "Other" category, which includes smaller population of mains materials such as Asbestos Cement (AC) and PVC. The previous values are included in brackets for comparison.

Material	**Deterioration Rates**		
	Corrosion	**Fracture**	**Joint**
Cast iron (CI)	2.1% (5.3%)	5.0% (5.0%)	2.9% (5.1%)
Ductile Iron (DI)	3.0% (7.3%)		2.1% (4.9%)
Spun Iron (SI)	2.1% (4.6%)		3.0% (4.3%)
Steel (ST)	3.6% (7.9%)		1.4% (4.1%)
PE (PE)	0.0% (0.5%)	2.2% (0.5%)	1.1% (0.5%)
Other	1.9% (2.0%)	5.0% (5.0%)	2.1% (2.0%)

Table A- 3 – New Mains deterioration rates (based on 7 networks data)

With the exception of Fractures (which are similar), the new deterioration rates are lower than previously estimated. This is partially due to a significantly larger sample size, which increases confidence in the analysis. However, this result could have been expected if the worst-condition, faster-deteriorating assets have been replaced through the ongoing mains replacement programmes.

The values for PE assets are higher, but this is due to the new analysis calculating statistically significant deterioration rates for PE failures, which was not possible with the previous single network analysis. Corrosion is not a known failure mode for PE and as such a value of zero applied.

The improved deterioration rates provide much greater confidence in the LTR results for mains, where monetised risk benefits of intervention will be accumulated for up to 50-years.

Interference rates were similar to those calculated previously (0.0078 per km, versus 0.006 per km) and do not deteriorate.

7.13.1 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 Health and Safety Executive (HSE) or Customer consequences are also included as internal costs, as are the costs of managing work in the highway (Traffic Management Agency (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.). Monetised risk is calculated for each consequence using the principle that monetised risk is the multiplication of probability of failure x probability of consequence x cost of consequence (reference Section 2.1). The sum of all monetised risk relating to consequences of a gas leak due to corrosion is the monetised risk for the Corrosion Failure Mode.

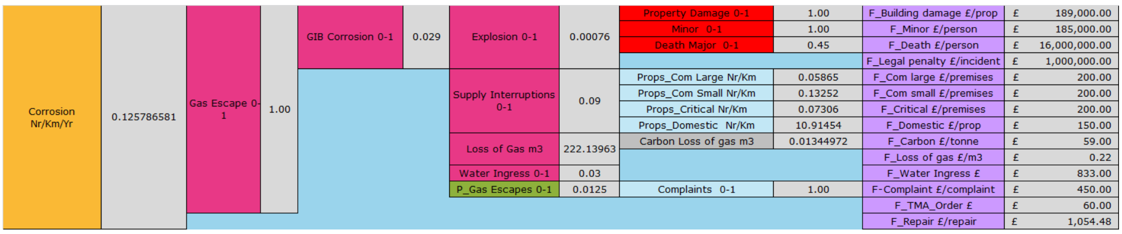

Figure A- 8 - Modelled consequences and values for Mains Corrosion failure.

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.
Intervention 2	Decommissioning	Decommissioning/abandonment of existing main.
Intervention 3	CIPP Lining	Decommissioning/abandonment of existing main (no replacement).
Intervention 4	Planned internal repairs (e.g. CISBOT)	Internal repair/refurbishment of mains e.g. joint.

Table A- 4 - Potential With- and Without Investment interventions for Mains

Intervention lives for Mains assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1	Replacement		

Intervention 2	Decommissioning		
Intervention 3	CIPP Lining	Removed, as no longer used.	
Intervention 4	Planned internal repairs (e.g. CISBOT – cast iron sealing robot)		

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, based on an analysis of 10-years failure data from seven networks, 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	1.1%
Corrosion	0.00431	0.0%
Fracture	0.000879	2.2%

Table A- 54 - Applied PoF and PoF deterioration for new PE mains

The deterioration rates for CISBOT intervention are assumed to be the same for the underlying material of the main.

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)

Where Cohort Name is Material / Distribution Zone Reference / Mains Tier (dependent on risk and diameter)

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)

Where:

Scalar_Corrosion – is a scalar coefficient scaling modelled failures by corrosion to actual failures observed.

Corrosion – is the initial probability of failure of the main due to corrosion based on the factors described in Section A3.2.

Material_Corrosion – is the deterioration rate of the main failing by corrosion based on material type as described in Section A3.3.

Scalar_Fracture – is a scalar coefficient scaling modelled failures by fracture to actual failures observed.

Fracture – is the initial probability of failure of the main due to fracture based on the factors described in Section A3.2.

Material_Fracture – is the deterioration rate of the main failing by fracture based on material type as described in Section A3.3.

Leakage Rate – is the leakage rate as defined by the National Leakage Reduction Monitoring Model.

Scalar_interference – is a scalar coefficient scaling modelled failures by interference to actual failures observed.

Interference – is the initial probability of failure of the main due to interference based on the factors described in Section A3.2.

Scalar_joints – is a scalar coefficient scaling modelled failures by joint failure to actual failures observed.

Failure – is the initial probability of failure of the main due to joint failure based on the factors described in Section A3.2.

Material_joint – is the deterioration rate of the main failing by joint failure based on material type as described in Section A3.3.

Corrosion_new_pipe – is the initial probability of failure of a new PE main due to corrosion based on the factors described in Section A3.2.

Corrosion_PE – is the deterioration rate of a PE main failing by corrosion based on material type as described in Section A3.3.

Fracture_new_pipe – is the initial probability of failure of a new PE main due to fracture based on the factors described in Section A3.2.

Fracture_PE – is the deterioration rate of a PE main failing by fracture based on material type as described in Section A3.3.

Joint_new_pipe – is the initial probability of failure of a new PE main due to joint failure based on the factors described in Section A3.2.

Joint_PE – is the deterioration rate of a PE main failing by joint failure based on material type as described in Section A3.3.

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.

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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 NARM 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 – failure of the pipe due to corrosion. Corrosion occurs on metallic pipes due to the presence of moisture either on the inside or the outside surface of the pipe.
- Fracture failure – failure of the pipe due to fracture. As services are typically PE or steel, there is a relatively low probability of failure by this failure mode.
- Interference failure – for example 3rd party damage
- Joint failure – failure of the pipe due to joint failure, principally where the service joins the mains pipe.

- 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

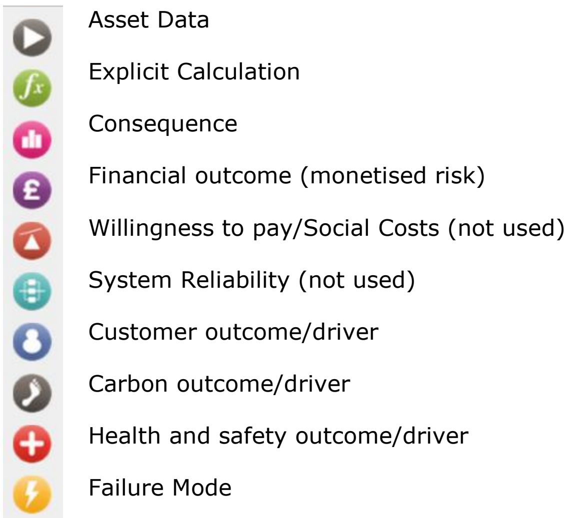

Figure B- 1 - Risk Map Key

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.

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

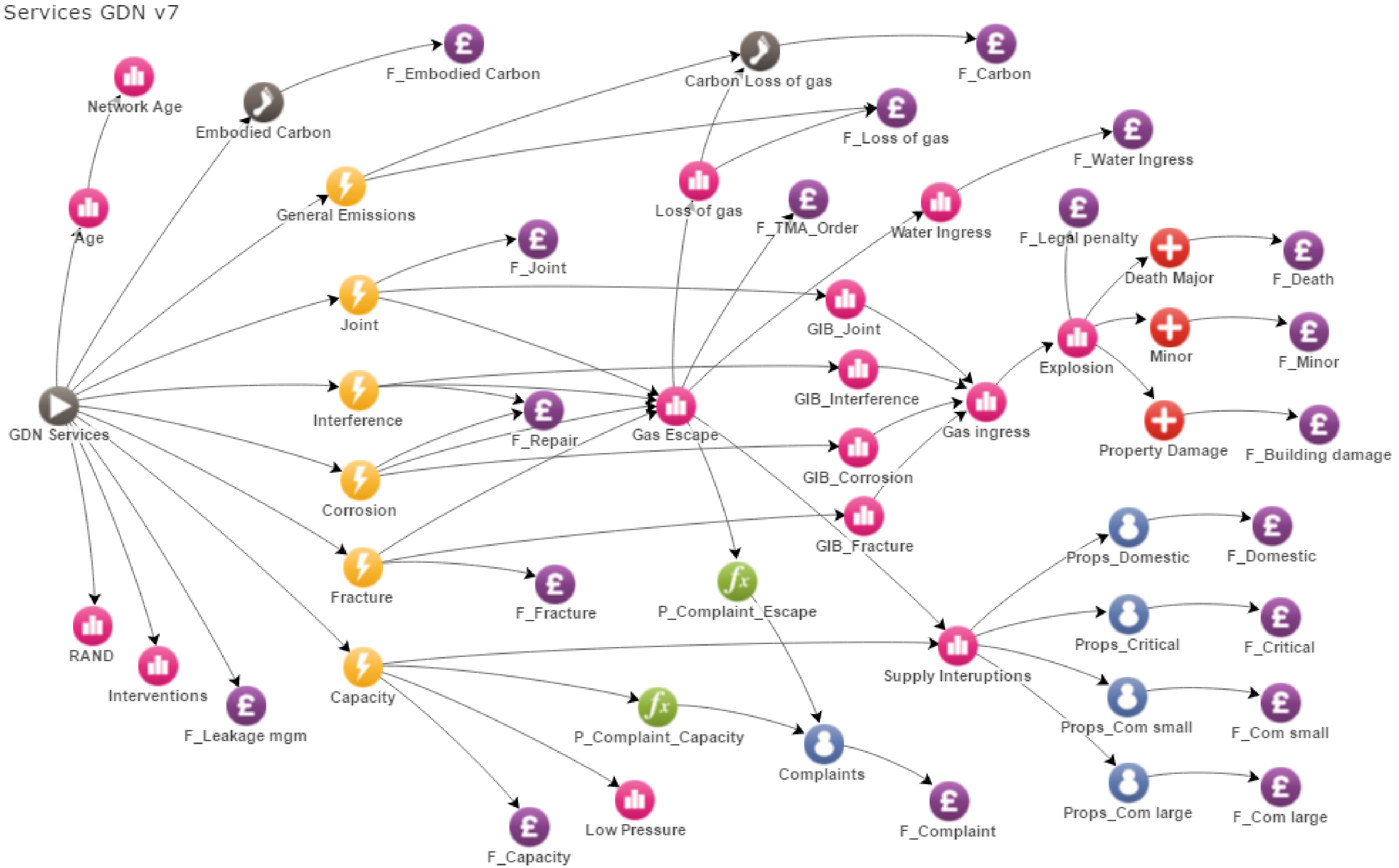

Figure B- 2 - Services Risk Map

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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.

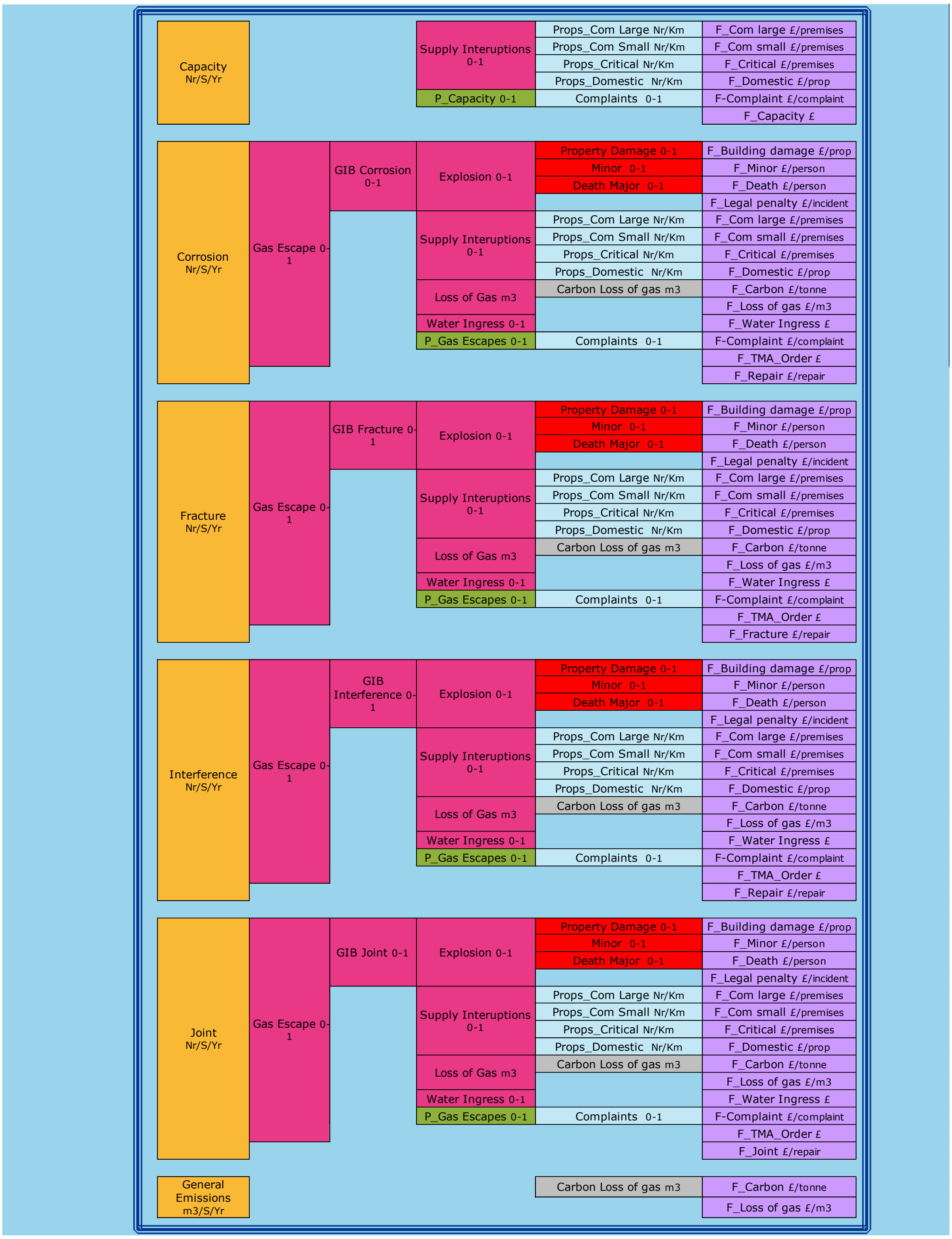

Figure B- 3 - Services Risk Map Template

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. Demand mix generation is a longer-term evolutionary piece which GDNs will need to consider due to the inherent adjustment to baseline monetised risk as a result of customer demand changing. Customer number updates can be reflected in the modelling base data that supports asset investment decision making, therefore it can be undertaken periodically where required. A customer base data refresh will be undertaken after the completion of the current GD2 price control and at the completion of later price controls as net zero impacts effect methane gas distribution use.

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	0.45 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

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Node ID / Variable	Description	Data Source	Source
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	GDN Specific

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Node ID / Variable	Description	Data Source	Source
		corrosion / no. of corrosion 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	1.0 Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common

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Node ID / Variable	Description	Data Source	Source
Non_PE_Det	Deterioration rate of Non_PE pipes	Limited data was available to estimate the deterioration of services over time. 5% Default/assumed value agreed with SRWG – see Section B3.3	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. 0.5% Default/assumed value agreed with SRWG – see Section B3.3	Common
Property_Damage	Number of property damage given explosion	1.0 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
Props_Critical	Number of critical properties at risk of supply interruption	Data taken from company systems or assumed based on network/geographic	GDN Specific

Node ID / Variable	Description	Data Source	Source
		analysis and proportion of property types.	
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 will 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

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B3. Services Event Tree Utilisation

B3.1. Services Base Data

The definition of Services cohorts within the NARM 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 NARM methodology.

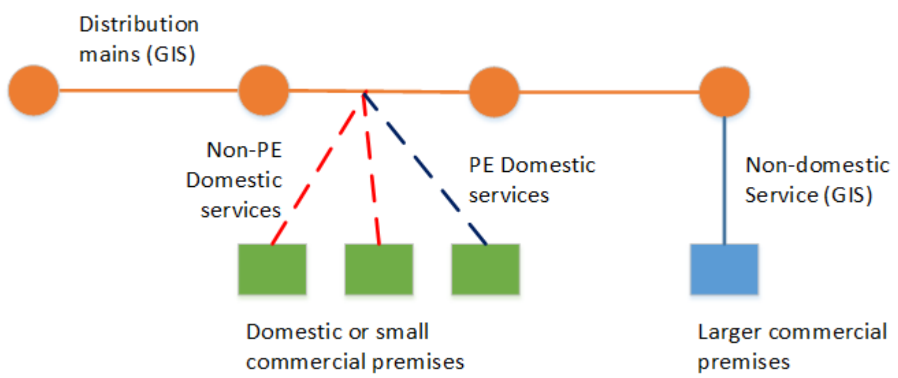

Figure B-4 - representation of Services with respect to Mains in the base data

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

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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

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ASSET_	CUSTOMER_TY	ASSET_TYPE_B	DIAMET	DIAM_B	ASSET_MATERIAL_B	TOTAL_SERVICE_LENGTH_	NO_OF_METERS_ON_ASSI	ASSET_LENGT	PRESSURE_CLASS_B	POSTCOI	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 NARM 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 a 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 non-digitised Services will be the weighted average of the PE and non-PE PoF values for that Service group. Where Services are digitised they will have their own individual asset records and will have a PoF directly related to their material type. The definition of digitised Services are those that have full records.

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 serice

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.). Monetised risk is calculated for each consequence using the principle that monetised risk is the multiplication of probability of failure x probability of consequence x cost of consequence (reference Section 2.1). The sum of all monetised risk realating to consequences of a gas leak due to corrosion is the monetised risk for the Corrosion Failure Mode.

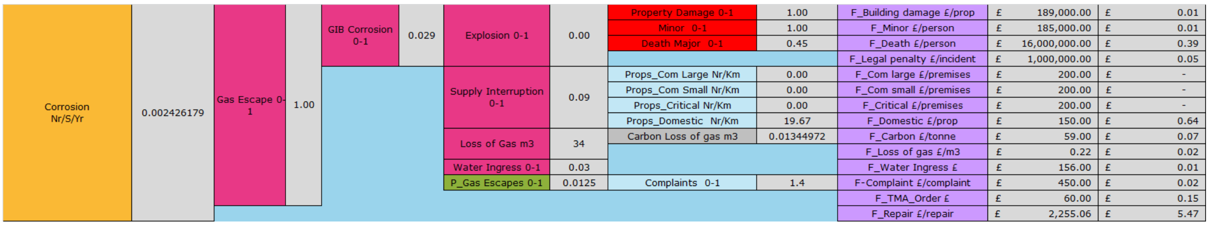

Figure B- 5 - Modelled consequences and values for Services Corrosion failure

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.

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 NARM 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.

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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 (or in Steel if regulations/policy requires).
Intervention 2	Bulk service replacements	Bulk replacement of services with PE Replaced by Intervention 1.
Intervention 3	Alteration	Customer driven service/meter move Associated with extensions and property development. Replaced by Intervention 1.
Intervention 4	Decommission	Decommission/abandonment of services (no replacement).

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

Intervention lives for services assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1	Service relays		
Intervention 2	Bulk service replacements		
Intervention 3	Alteration		
Intervention 4	Decommission		

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.

Where Cohort Name is Material / Type of Service (domestic or non-domestic)

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)

Where

Scalar_Corrosion – is a scalar coefficient scaling modelled failures by corrosion to actual failures observed.

Scalar_Unmatched – is a secondary scalar coefficient scaling modelled number of failures to actual number of failures.

Corrosion_Non_PE and Corrosion_PE – are the initial probability of failures of the non_PE or PE service due to corrosion based on the factors described in Section B3.2.

Non_PE Det and PE_Det – are the deterioration rates of the main failing by any failure mode based on material type as described in Section B3.3.

Scalar_Fracture – is a scalar coefficient scaling modelled failures by fracture to actual failures observed.

Fracture_Non_PE and Fracture_PE – are the initial probability of failure of the non-PE and PE service due to fracture based on the factors described in Section B3.2.

Leakage Rate – is the leakage rate as defined in the National Leakage Reduction Monitoring Model.

Scalar_interference – is a scalar coefficient scaling modelled failures by third party interference to actual failures observed.

Interference_Non_PE and Interference_PE – are the initial probability of failure of the non_PE and PE services due to third party interference based on the factors described in Section B3.2.

Scalar_joints – is a scalar coefficient scaling modelled failures by joint failure to actual failures observed.

Failure_Non_PE and Failure_PE – are the initial probability of failure of the non-PE and PE services due to joint failure based on the factors described in Section A3.2.

Corrosion_new_pipe – is the initial probability of failure of a new PE service, following a replacement intervention, due to corrosion based on the factors described in Section B3.2.

Fracture_new_pipe – is the initial probability of failure of a new PE service, following a replacement intervention, due to fracture based on the factors described in Section B3.2.

Joint_new_pipe – is the initial probability of failure of a new PE service, following a replacement intervention, due to joint failure based on the factors described in Section B3.2.

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

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

Where Cohort Name is Material / Type of Service (domestic or non-domestic)

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).

Where

Scalar_Corrosion – is a scalar coefficient scaling modelled failures by corrosion to actual failures observed.

Scalar_Unmatched – is a secondary scalar coefficient scaling modelled number of failures to actual number of failures.

Corrosion_Non_PE and Corrosion_PE – are the initial probability of failures of the non_PE or PE service due to corrosion based on the factors discussed in Section B3.2.

Non_PE Det and PE_Det – are the deterioration rates of the main failing by any failure mode based on material type as discussed in Section B3.3.

Scalar_Fracture – is a scalar coefficient scaling modelled failures by fracture to actual failures observed.

Fracture_Non_PE and Fracture_PE – are the initial probability of failure of the non-PE and PE service due to fracture based on the factors described in Section B3.2.

Leakage Rate – is the leakage rate as defined in the National Leakage Reduction Monitoring Model.

Scalar_interference – is a scalar coefficient scaling modelled failures by third party interference to actual failures observed.

Interference_Non_PE and Interference_PE – are the initial probability of failure of the non_PE and PE services due to third party interference based on the factors described in Section B3.2.

Scalar_joints – is a scalar coefficient scaling modelled failures by joint failure to actual failures observed.

Failure_Non_PE and Failure_PE – are the initial probability of failure of the non-PE and PE services due to joint failure based on the factors described in Section A3.2.

Corrosion_new_pipe – is the initial probability of failure of a new PE service, following a replacement intervention, due to corrosion based on the factors described in Section B3.2.

Fracture_new_pipe – is the initial probability of failure of a new PE service, following a replacement intervention, due to fracture based on the factors described in Section B3.2.

Joint_new_pipe – is the initial probability of failure of a new PE service, following a replacement intervention, due to joint failure based on the factors described in Section B3.2.

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

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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

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- **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

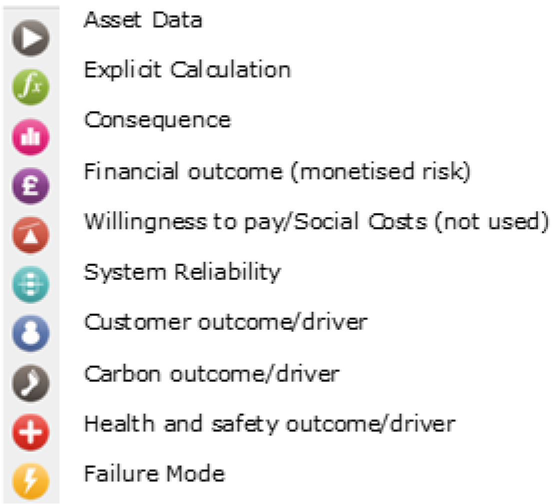

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Figure C- 1 - Risk Map Key

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.

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

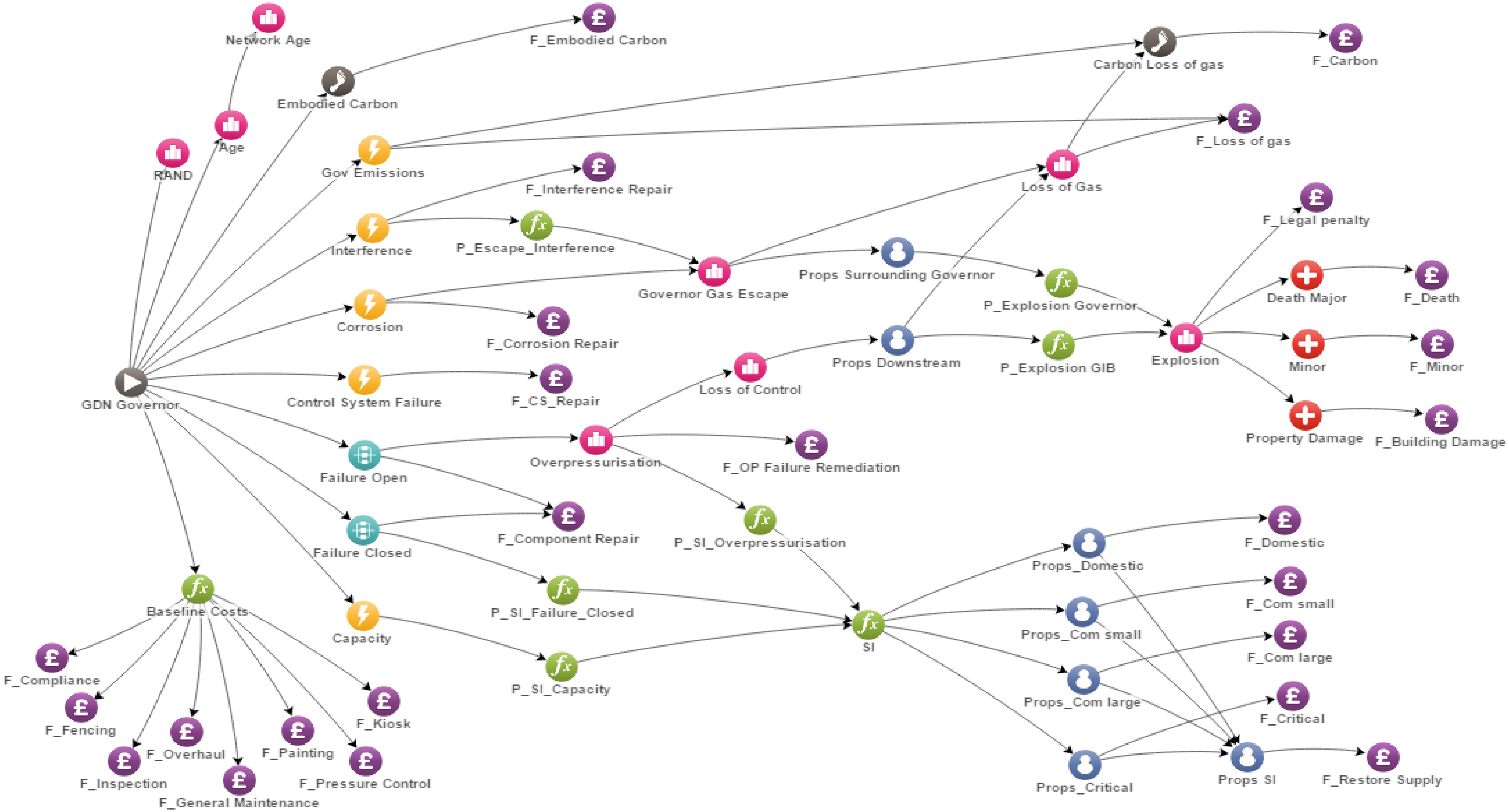

Figure C- 2 -Governors Risk Map

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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.

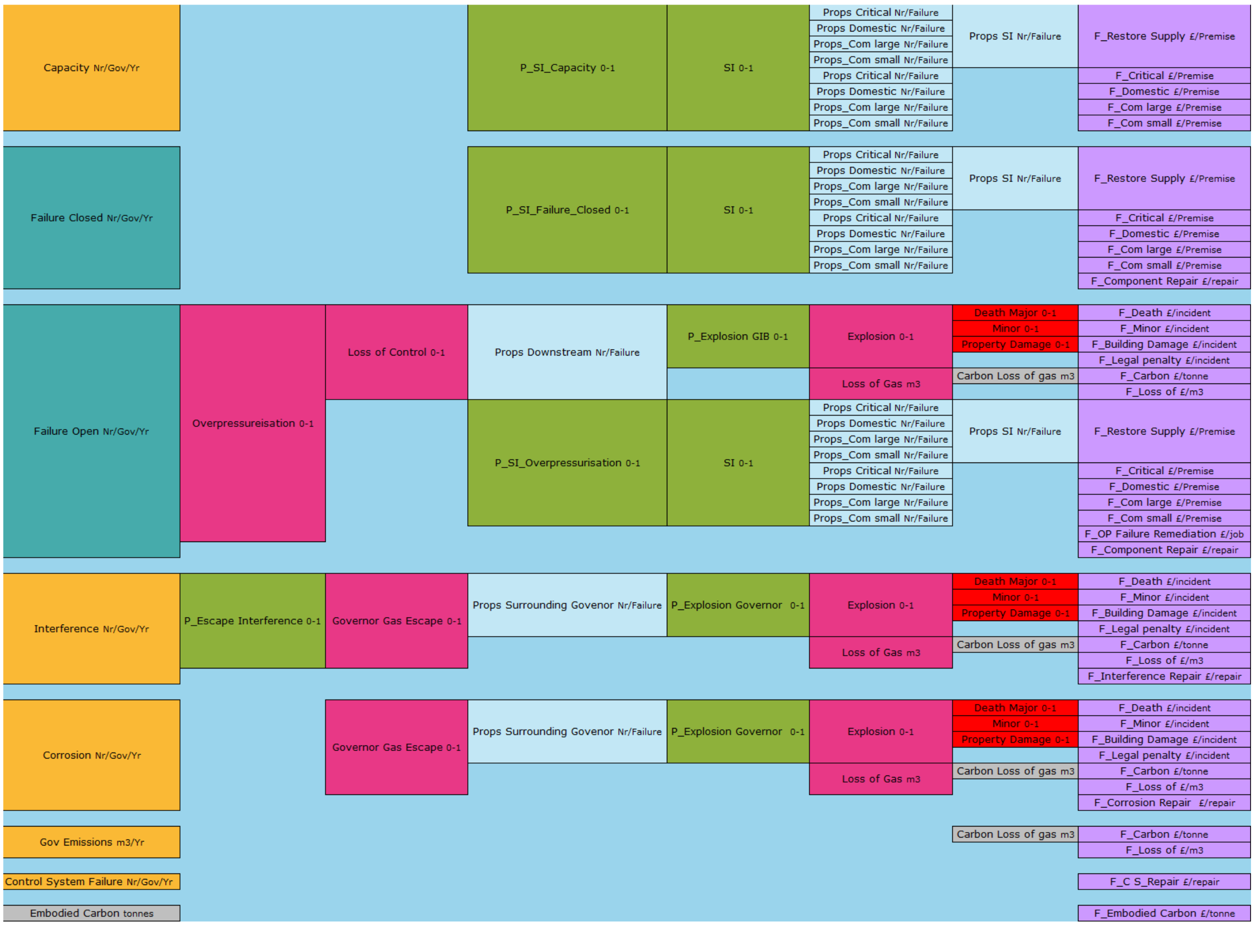

Figure C-3 - Governors Risk Map Template

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. Demand mix generation is a longer-term evolutionary piece which GDNs will need to consider due to the inherent adjustment to baseline monetised risk as a result of customer demand changing. Customer number updates can be reflected in the modelling base data that supports asset investment decision making, therefore it can be undertaken periodically where required. A customer base data refresh will be undertaken after the completion of the current GD2 price control and at the completion of later price controls as net zero impacts effect methane gas distribution use.

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.	GDN Specific
Carbon Loss of gas	m^3 of carbon equivalent (CO2e) 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	GDN Specific

		point on the deterioration curve is estimated using the Effective Age of the asset, which can be determined through condition surveys.	
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	Failure rate of faults 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. The probability of a supply interruption given a Failure Closed event is based on SRWG estimates developed through elicitation with GDN experts, ICS and DNV GL and calibrated to the expected numbers of annual failures.	GDN Specific
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	GDN Specific

		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 C3.2.1 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.	
Gov Emissions	General emissions associated with the Governor station	Consistent with common leakage assessment model as approved by Ofgem – National Leakage Reduction Monitoring Model (NLRMM)	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	A Loss of Control value of 0.5 represents 50% reduction in	Common

	system on the downstream loss of gas and explosion risk.	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).	
Minor	Probability of minor injury following an explosion. This includes explosions at, or downstream of, the Governor station.	Default/assumed value agreed with SRWG consistent with RIIO GD1 CBA analyses	Common
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. Set at 20%.	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 (e.g. GDN engineer undertaking purge and relight operation) 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 a 50-metre radius 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 developed through elicitation with GDN experts, ICS and DNV GL.	GDN Specific
Props_Com large	Number of large commercial properties affected by supply interruption (Xoserve categories: 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 (Xoserve Category: 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 (Xoserve Categories: 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 (Xoserve Category: 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 engineering inspection methods used across GDNs are broadly aligned and so no GDN specific annexes have been created for this document. In the case of visual surveys all GDNs have their own processes, following asset management best practices, which are then aligned to a NARM condition score using guidance in the tables within this document. For governor failure modes the RCM fault data process is used.

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 C-1 below:

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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
11986C5F497C48F79CD90FB035205C66	COMMERCIAL_CRITICAL	M875	AINTREE	IGA	1800	2MASa	2025	35	K
0DD20DEAB91740DAAADBB02C9B471FF7	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
A3B46B5B5E9A4557871 6CF0CE8802964	COMMERCIAL_LARGE	M352	LIVERPOOL	IGA	3000	2ASWa	2025	35	K
80D074A244D44E3C9C2908448290FA66	COMMERCIAL_LARGE	M850	RICKMANSWORTH	DONKIN	280	2ASWa	2025	35	K
C726FC0E68824842B4EDA14A34143C87	COMMERCIAL_LARGE	M126	DROITWICH	DONKIN	270	2ASWd	2025	35	K
891E036746E145648D93D5FEB6C04D7F	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
A68B618C88B14E42A1E5F17718008FF6	DOMESTIC	M1555	WEMBLEY	ORPHEUS 10	ORPHEUS 10	2ASa	2055	5	MODULE
03D043681EBB4D9084AC7A5C1A320BEC	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
11986C5F497C48F79CD90FB035205C66	0.000773644	1	1	2	0.001988884	0.001257795	0.000261786	0	0.000262554	0.002319814
0DD20DEAB91740DAAADBB02C9B471FF7	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
A3B46B5B5E9A4557871 6CF0CE8802964	0.000875896	1	1	2	1	0.001257795	0.000261786	0.000102082	0.000262554	1
80D074A244D44E3C9C2908448290FA66	0.000557438	1	1	2	1	0.001257795	0.000261786	0.000102082	0.000262554	1
C726FC0E68824842B4EDA14A34143C87	0.000100276	1	1	2	1	0.001257795	0.000261786	0.000102082	0	1
891E036746E145648D93D5FEB6C04D7F	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
A68B618C88B14E42A1E5F17718008FF6	0.0018408	805	1	2	1	0.001257795	0.000261786	0	0.000262554	1
03D043681EBB4D9084AC7A5C1A320BEC	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

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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.

The method for calculating site-level Governor probability of failure and deterioration has changed significantly for this version of the Methodology:

- **Failure Open & Failure Closed** – have been derived from reliability modelling (see Appendix G) or where suitable data exists, from asset-specific failure rate asssesements, such as RCM (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:

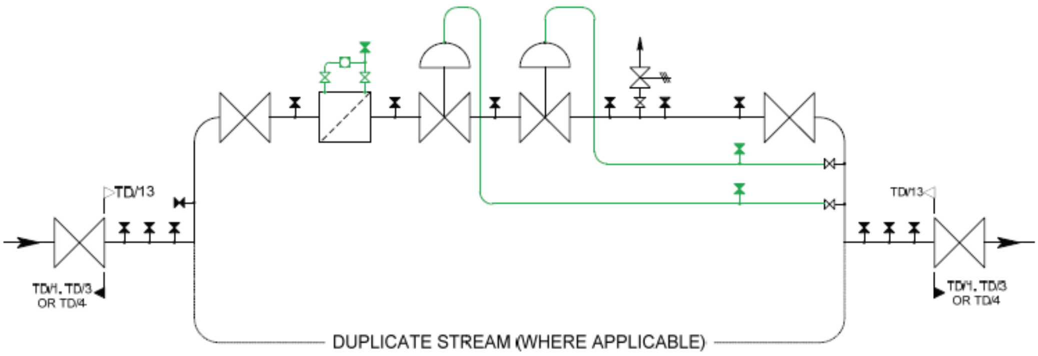

Figure C4 - Typical Monitor and Active Regulator arrangement (from IGEM TD/13)

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.

Previously, the likelihood of a Failure Open and Failure Closed was derived from RCM data collected over a number of years by each company. This has been replaced by the reliability modelling approach (Appendix G). A Failure Open and Failure Closed starting PoF value and deterioration rates is calculated for each site configuration, pre- and post-intervention. RCM data is no longer used, other than to obtain the inspection/maintenance frequency which is a key element of the reliability modelling analysis.

These initial failure rates calculated from reliability modelling 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.

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 National Leakage Reduction Monitoring Model (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

Initially derived failure rates are based on the assessed effective (or condition-adjusted) age at a site level using the deterioration curves derived through the reliability modelling process. A separate curve has been derived for each site configuration and maintenance frequency.

The Initial Failure Rate is calculated as follows:

Initial Failure Rate = Fault Detection Rate x Probability of a Failure event x Total Number of Assets that can Fail

Where:

Probability of Failure in a given year is derived from RCM faults over a period of time, based on configuration type (C3.2.1).

Total number of assets that can fail is determined by configuration type.

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 and C3.2.3.

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 location factor of (2.5 x 1.667 = 4.168) applies to the derived failure rate.

Condition Risk (Effective Age)

Reliability modelling initially assumes that the asset age is zero (new asset) as a basis for ongoing deterioration. Each configuration of assets is then modelled to account for additional risk factors (Monitor and Active regulatorsin series, presence of a slamshut valve) and resilience (number of streams). These results are then adjusted for specific assets based on the concept of Effective (or condition-adjusted) age. 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:

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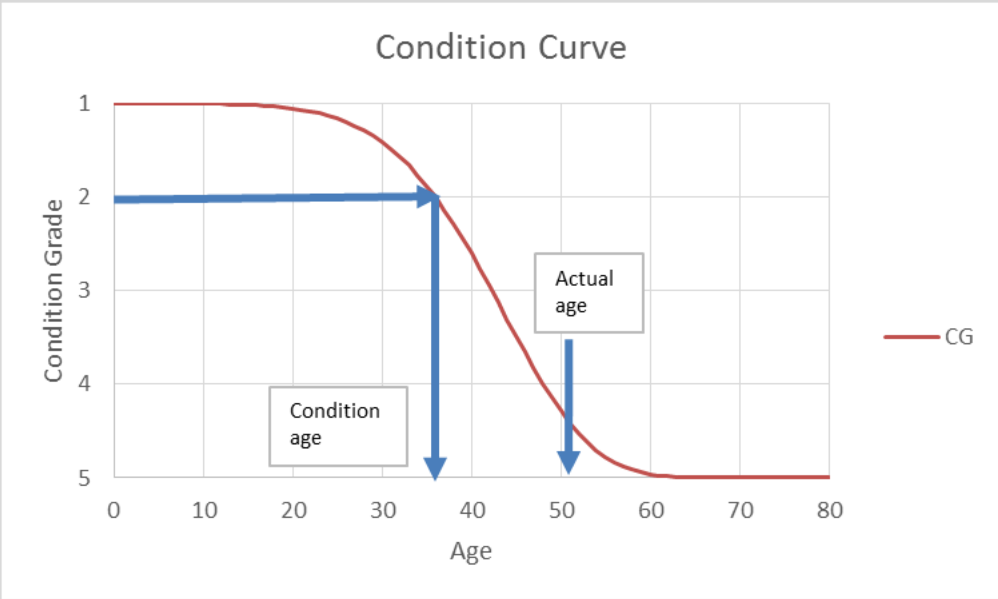

Figure C5 – Derivation of Effective Age from assessed Condition Grades

The assessed condition is determined via GDN-specific visual condition surveys, where available, aligned to common condition grades 1 to 5 with factors derived through expert elicitation as follows and used in the equation as shown under Final Adjustment Calculation below:

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 as per table C3 is used to adjust the Age to an Effective Age using the equation below.

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

Where:

Age is the mean (average) or actual age of the asset.

k is the Weibull Scale and λ is the Weibull Shape as outlined in Table C2

c is the Condition Factor as outlined in Table C3

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Kiosk Risk (Kiosk Condition)

The assessed condition of the building/housing is used as an adjustment factor, where applicable. The derived failure rate multiplication factors are shown in the table below and used in the equation as shown under final adjustment calculation below:

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

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

Fencing/Security Risk (FS Factor)

The assessed condition of the fencing and security is used as an adjustment factor, where applicable. The fencing/security factor only affects the interference failure mode. The derived failure rate multiplication factors are shown in the table below and used in the equation as shown under Final Adjustment Calculation 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

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 1 (low risk) – Less than 0.1% probability of fluvial or 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 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.

For the purposes of the methodology, the following flood risk factors apply which have been derived through expert elicitation and are used in the equation as shown under Final Adjustment Calculation below:

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 Kiosk Factor x FS Factor x Housing Factor x Coastal Factor x Flood Factor

Where:

Initial Failure Rate is derived as shown at the start of C3.2.3

Effective Age is as described under Condition Risk (Effective Age) in Section C3.2.3

Mean age is the average (mean) age of the asset

Deterioration Rate is the rate of deterioration of the asset by failure mode, as set out in C3.3

Housing Factor, **FS Factor**, **Location Factor** and **Flood Factor** are as described in Section C3.2.3

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 approach taken to model the deterioration in the rate of Fail Open and Fail Closed events over time has changed in this version of the Methodology.

Deterioration rates for each site configuration, pre- and post-intervention, are derived directly from the reliability analysis (detailed in Appendix G) using:

- The derived relationship between asset condition and effective age
- A simulation of how failure rates change over time, considering the interaction between regulator and slam-shut assets for site of varying configurations and accounting for system resilience (such as Active/Monitor arrangements and multiple streams).

This is an identical approach as adopted for PRS Pressure Control assets, except Governors is a site-level analysis while PRS Pressure Control is by system.

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

A deterioration rate of 1% per annum applies to General Emissions in the Governor model. This figure was derived through discussion with asset experts, DNV GL and ICS.

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 (refer to Global Values in Section 3.7.2). 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 – National Leakage Reduction Monitoring Model (NLRMM).

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	Post Intervention Change in PoF
Intervention 1	Governor Replacement	Replacement of complete unit including kiosk and control system.	Age=0 Capacity = 0 Corrosion = 0.0006

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			DYear=> Int_Year Fence Interference=0.5 Kiosk Interference=0.5 Obsolete factor=1
Intervention 2	Fencing replacement	Includes installation or replacement of a fence and reduces the interference,	Fence Interference=0.5
Intervention 3	Kiosk replacement	Replacing the entire kiosk/housing of the governor.	Kiosk Corrosion = 0.5 Kiosk Interference=0.5
Intervention 4a	Governor Major Refurbishment	Site overhaul: full painting + soft parts + minor component replacement or replacement of components(s) (filter/valve) which are the key source of condition issues	Age Effective => 0.2*Age Effective
Intervention 4b	Governor Minor Refurbishment	Improving the governor site condition by whole site painting (reducing corrosion) and reducing overall site deterioration.	Age Effective => 0.8*Age Effective
Intervention 5	Regulator replacement (pressure regulation systems only, all streams)	Replacement of whole regulation stream including control system. Excludes kiosk. Includes regulators, filters, and active slams.	Age=0 Corrosion=0.0006 Capacity = 0 DYear=> Int_Year Obsolete factor=1
Intervention 6	ERS Replacement (Governor relocation)	Replacement of underground module with an above ground governor,	Age=0 Capacity = 0 Housing = 1 Corrosion = 0.0006

			DYear=> Int_Year Fence Interference=0.5 Kiosk Interference=0.5 Obsoletefactor=1
Intervention 7	Service Governor Replacement	Replacement of complete unit within kiosk	Capacity = 0 Kiosk Corrosion = 0.5 DYear=> Int_Year Kiosk Interference=0.5 Obsoletefactor=1
Intervention 8	Governor Decomissioning	Decommissioning of Governor (no replacement)	Total Risk => 0
Intervention 9	Kiosk Refurb	Refurbishing the entire kiosk/housing of the governor	Age = Age Effective Kiosk Corrosion = 0.8 Kiosk Int = 0.8
Intervention 10	Regulator (pressure reduction systems only, single stream) replacement	Replacement of one of multiple regulation streams (assumes all streams carry equivalent risk. All components on the stream. Includes regulators, filters and active slams.	Derived from reliability modelling (see Appendix G)
Intervention 11	Corrosion remediation	Intervention specifically to resolve corrosion issues on site	Age=0 Corrosion=0.0006 Capacity = 0 DYear=> Int_Year Obsolete factor=1
Intervention 12	Capacity Refurb	Intervention specifically to remove capacity constraints.	Capacity = 0 Age Effective => 0.65*Age Effective (Corrosion only)

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

The currently assumed intervention lives for Governor assets, for use in LTR calculations are listed below.

Number	Description	Intervention Life	Rationale
Intervention 1	Governor Replacement		
Intervention 2	Fencing replacement		
Intervention 3	Kiosk replacement		
Intervention 4a	Governor Major Refurbishment		
Intervention 4b	Governor Minor Refurbishment		
Intervention 5	Regulator Replacement		
Intervention 6	ERS Replacement (Governor relocation)		
Intervention 7	Service Governor Replacement		
Intervention 8	Governor Removal		
Intervention 9	Kiosk Refurb		
Intervention 10	Partial Site (Stream) Replacement		
Intervention 11	Corrosion remediation		
Intervention 12	Capacity Refurb		

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 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.

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Intervention lives for Governor assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1	Governor Replacement		
Intervention 2	Fencing replacement		
Intervention 3	Kiosk replacement		
Intervention 4a	Governor Major Refurbishment		
Intervention 4b	Governor Minor Refurbishment		
Intervention 5	Regulator Replacement		
Intervention 6	ERS Replacement		
Intervention 7	Service Governor Replacement		
Intervention 8	Governor Removal		
Intervention 9	Kiosk Refurb		
Intervention 10	Partial Site (Stream) Replacement		
Intervention 11	Corrosion remediation		
Intervention 12	Capacity Refurb		

C3.5.2. Example Governors Interventions

Two examples of Governor 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:

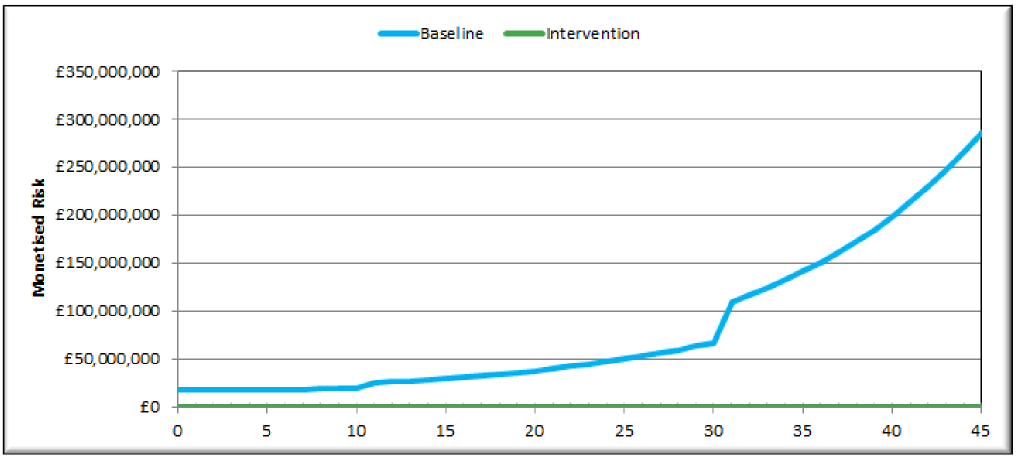

Figure C6 – Example baseline monetised risk for Governors over 45 years

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.

Appendices - Detailed Asset Assessments

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

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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 & COMMERCIAL / 15			2								
2-7BAR INDUSTRIAL & COMMERCIAL / 25			16								
2-7BAR INDUSTRIAL & COMMERCIAL / 35			18								
2-7BAR INDUSTRIAL & COMMERCIAL / 40			51								
2-7BAR INDUSTRIAL & COMMERCIAL / 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

Where:

Fault Detection Rate, **Fail Open** and **Fail Closed** are described under Section C.3.2.1

Age Effective is as described under Condition Risk (Effective Age) in Section C.3.2.3

DYear is the number of years that deterioration is applied for.

Gov_system_deterioration is deterioration as described in Section C3.3

Housing is Housing Factor and **Coast** is Coastal Factor, both described in Section C.3.2.3

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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.

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			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 & COMMERCIAL / 15	Intervention 10	KIOSK - Negative Inte	2	2
2-7BAR INDUSTRIAL & COMMERCIAL / 25	Intervention 10	KIOSK - Negative Inte	16	16
2-7BAR INDUSTRIAL & COMMERCIAL / 35	Intervention 10	KIOSK - Negative Inte	18	18
2-7BAR INDUSTRIAL & COMMERCIAL / 40	Intervention 10	KIOSK - Negative Inte	51	51
2-7BAR INDUSTRIAL & COMMERCIAL / 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 C12 - Intervention plan modelling impact of stopping painting and kiosk maintenance interventions

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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, ground beds 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 diameter (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 several consequences such as:

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

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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

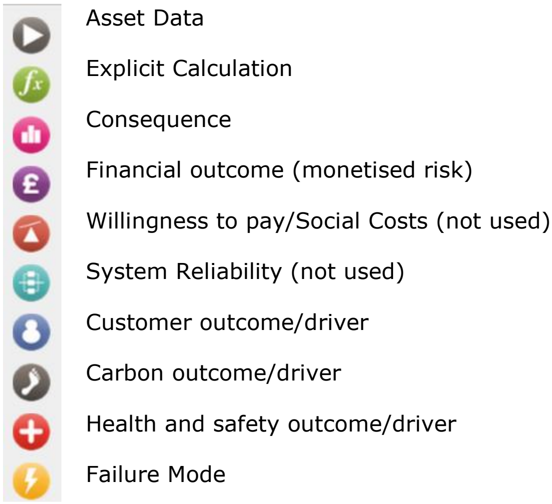

Figure D- 1 - Risk Map Key

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.

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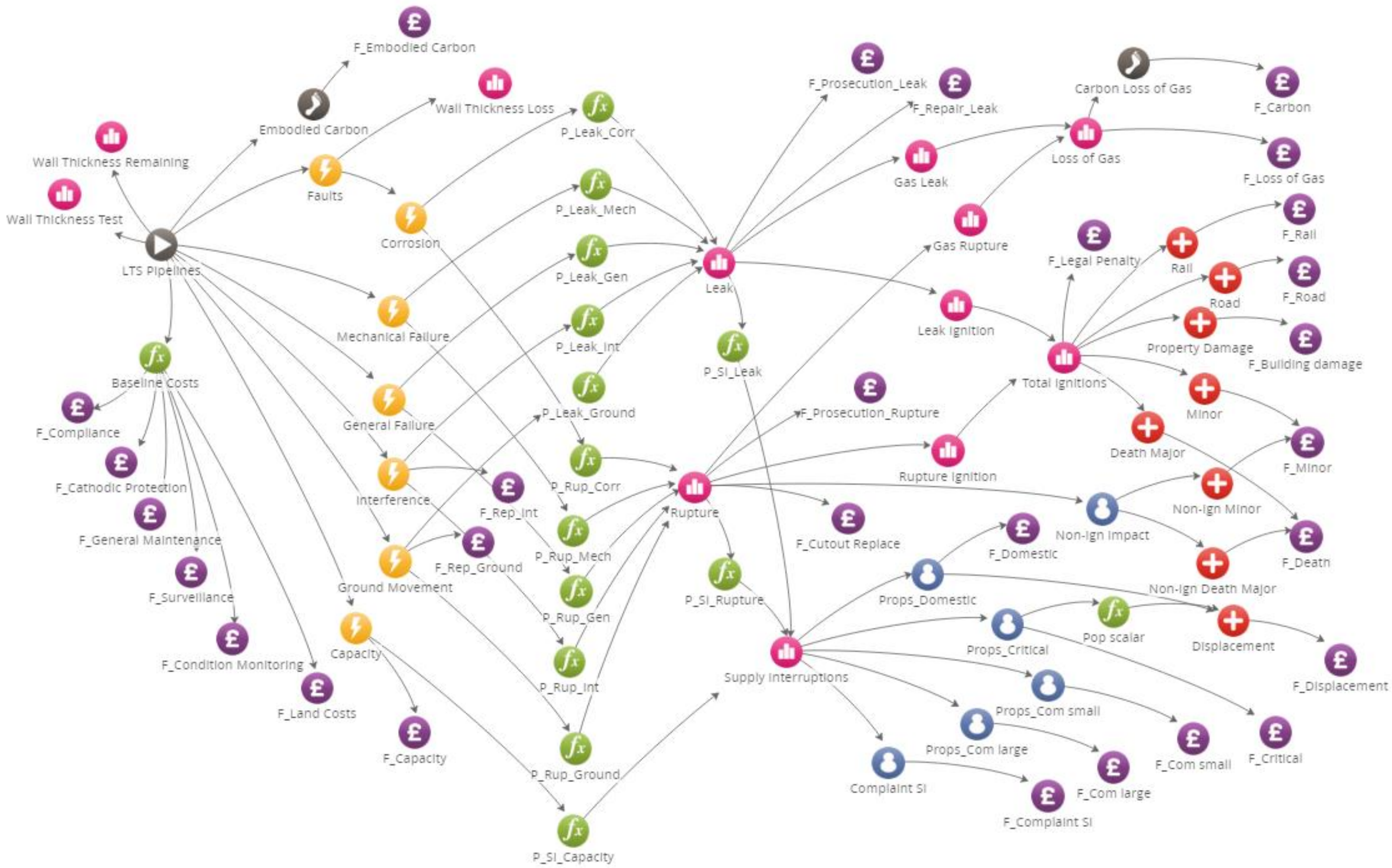
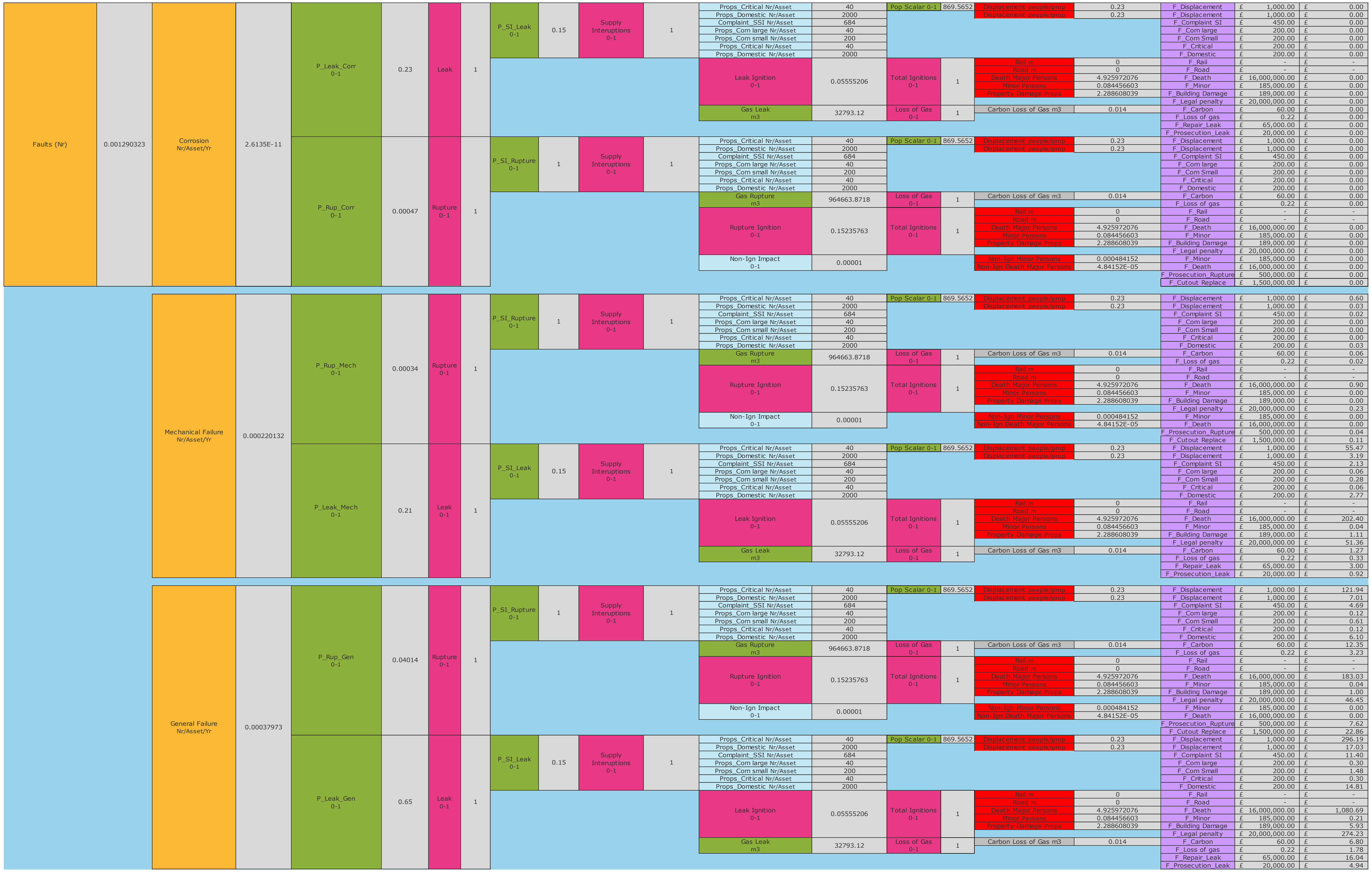


Figure D- 2 -LTS Risk Map

Appendices - Detailed Asset Assessments

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.



Appendices - Detailed Asset Assessments

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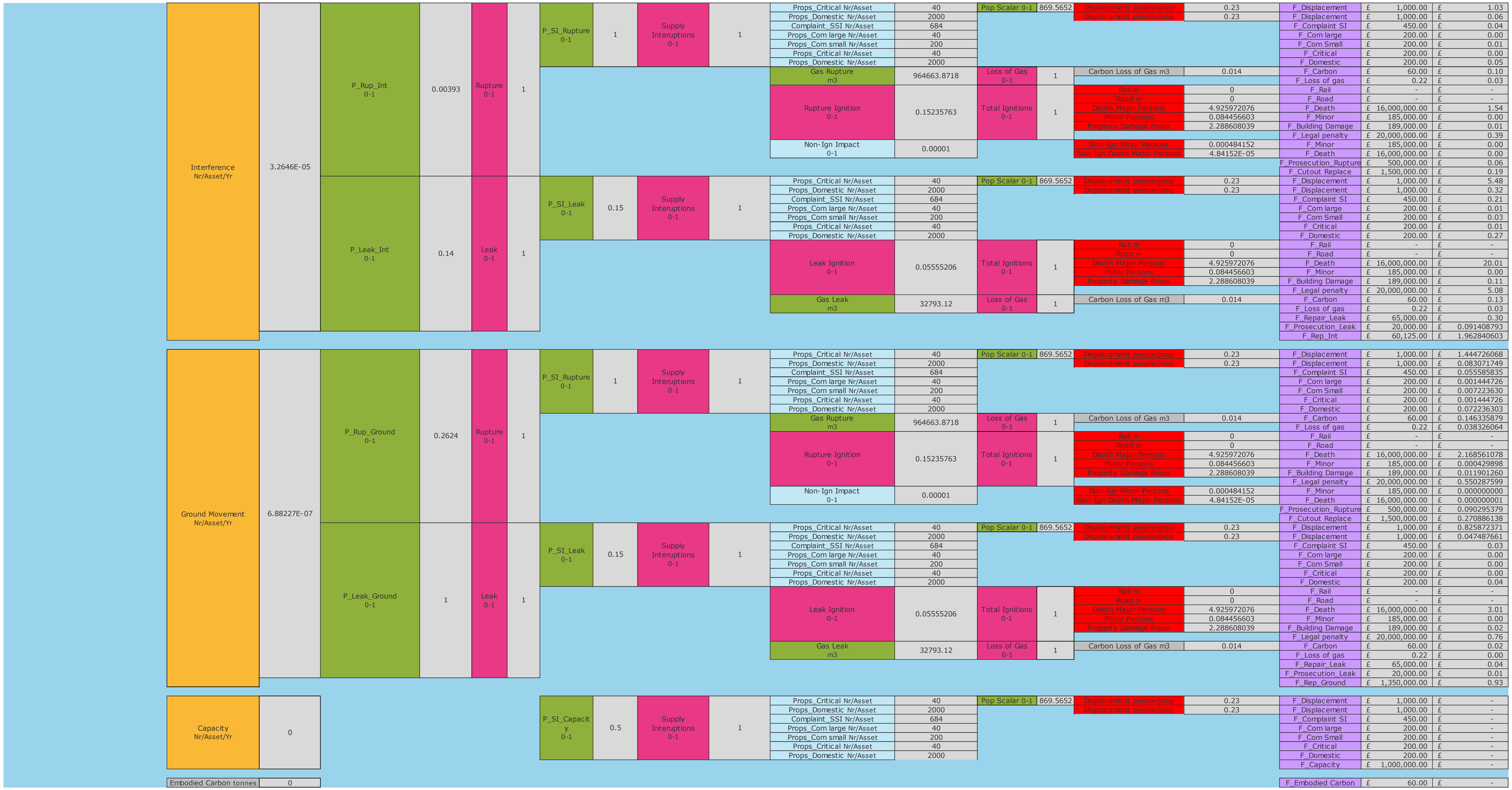

Figure D- 3 - LTS Risk Map Template

Appendices - Detailed Asset Assessments

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). Demand mix generation is a longer-term evolutionary piece which GDNs will need to consider due to the inherent adjustment to baseline monetised risk as a result of customer demand changing. Customer number updates can be reflected in the modelling base data that supports asset investment decision making, therefore it can be undertaken periodically where required. A customer base data refresh will be undertaken after the completion of the current GD2 price control and at the completion of later price controls as net zero impacts effect methane gas distribution use.

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	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		resistance (high, average, low). Other calculation factors include type of coating, history of town gas usage, defects and sleeve condition.	
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 Building Burning Distance is closest to the pipeline. 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 Building Burning Distance (Inner Zone: pipeline to the Building Burning Distance). The Escape Distance is further away. The zone from the Building Burning Distance to the Escape Distance is termed the Middle Zone. 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 on TD1 and advice from DNV GL. . GDNs can perform own analysis and change these values if required. Building Burning Distance (BBD) - Distance to thermal radiation flux (heat radiation from ignition) causing piloted ignition of wood, for almost all assessments this is assumed to be from piloted ignition. BBDs for ruptures in metres are given	GDN Specific

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Node ID / Variable	Description	Data Source	GDN or Common Value
		for four case study pipelines of varying diameter and wall thickness in TD2 Appendix 6. Escape Distance (ED) - Closest distance at which people moving away from the fire receive less than the dangerous dose without resort to shelter. EDs for ruptures in metres are given for four case study pipelines of varying diameter and wall thickness in TD2 Appendix 6	
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 Based on elicitation by ICS, DNV GL and GDN experts.	GDN Specific
F_Cathodic Protection	Annual Cost of maintaining compliant Cathodic Protection schemes	Data taken from company systems.	GDN Specific

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Node ID / Variable	Description	Data Source	GDN or Common Value
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 Based on elicitation by ICS, DNV GL and GDN experts.	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 Based on elicitation by ICS, DNV GL and GDN experts.	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 Based on elicitation by ICS, DNV GL and GDN experts.	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

Node ID / Variable	Description	Data Source	GDN or Common Value
		Based on elicitation by ICS, DNV GL and GDN experts.	
F_Prosecution_Leak	Cost of legal enforcement and penalty payments following gas leak	Default/assumed value agreed with SRWG Based on elicitation by ICS, DNV GL and GDN experts.	Common
F_Prosecution_Rupture	Cost of legal enforcement and penalty payments following pipe rupture	Default/assumed value agreed with SRWG Based on elicitation by ICS, DNV GL and GDN experts.	Common
F_Rail	Cost of damage to network rail infrastructure	Default/assumed value agreed with SRWG for regional railways. Based on elicitation by ICS, DNV GL and GDN experts. 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. Based on elicitation by ICS, DNV GL and GDN experts. 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. Based on elicitation by ICS, DNV GL and GDN experts. This value is multiplied by (1-probability of interference leading to a rupture-probability of interference leading to leak)	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		to ensure there is no double counting with F_Cutout_Replace and F_Repair_Leak	
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. Based on elicitation by ICS, DNV GL and GDN experts.	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. Based on elicitation by ICS, DNV GL and GDN experts.	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. Based on elicitation by ICS, DNV GL and GDN experts.	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 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.	GDN Specific

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Node ID / Variable	Description	Data Source	GDN or Common Value
		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. Based on elicitation by ICS, DNV GL and GDN experts.	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

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Node ID / Variable	Description	Data Source	GDN or Common Value
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 houses and immediate vicinity	See Death and Major. We assume that 5% of population in the Middle Zone suffer a minor injury (the other 5% is killed or suffers a major injury).	GDN Specific
Non-Ign Death Major	Number of death / major injury from non-ignition	See Death and Major. Assumes 1% of the people living in the Building Burning Distance (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	Probability of a blast impact assumed to be negligible compared to fire effects p12 TD2, therefore a small value has been used, 0.00001)	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	immediately; missiles generated from overlying soil or from pipe fragments (IGEM TD2 pg12)		
Non-Ign Minor	Number of minor injuries from non-ignition	Assumes 1% of the people living in the Building Burning Distance (Inner Zone) would be in the immediate vicinity and there is a 1% likelihood of them suffering a minor injury. As a default, use 2.3 people per hectare for Rural and 23 people per hectare for Suburban – based on TD1 and advice from GL (Phil Baldwin). However, GDNs can perform own analysis. Building Burning Distance (BBD) - Distance to thermal radiation flux (heat radiation from ignition) causing piloted ignition of wood, for almost all assessments this is assumed to be from piloted ignition. BBDs for ruptures in metres are given for four case study pipelines of varying diameter and wall thickness in TD2 Appendix 6.	GDN Specific
Property Damage	Number of property damage due to ignition/explosion impact	Assumes 100% of properties in the Building Burning Distance (inner zone) and 25% in middle zone are destroyed/damaged. However, GDNs can perform own analysis. Multiply by property density (depends on rural /suburban). As a default value we use 1 property per hectare for Rural and 10 properties per hectare	Common

Node ID / Variable	Description	Data Source	GDN or Common Value
		for Suburban areas – based on TD1 and advice from DNV GL. GDNs can perform own analysis and change these values if required.	
Props_Com large	Number of large commercial properties affected by supply interruption (Xoserve categories: 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 (Xoservce category: 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 (Xoserve categories: 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 domesticproperties affected by supply interruption (Xoserve category: D1 type properties)	Data taken from company systems based on either network analysis or assumptions based on demands, flow & redundancy	GDN Specific
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	Value of 1 used as a multiplier to enable the grouping/summation	Common

Node ID / Variable	Description	Data Source	GDN or Common Value
	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)	of the probability of mechanical, general, interference and ground movement failures	
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

Node ID / Variable	Description	Data Source	GDN or Common Value
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 of the eruptive and steady-state flow durations can be changed in the model.	GDN Specific
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). Based on elicitation by ICS, DNV GL and GDN experts.	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. Based on elicitation by ICS, DNV GL and GDN experts.	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.

The engineering inspection methods used across GDNs are broadly aligned and so no GDN specific annexes have been created for this document. In the case of visual surveys all GDNs have their own processes, following asset management best practices, which are then aligned to a NARM condition score using guidance in the tables within this document.

Sub-type assets

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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:

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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

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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 (United Kingdom Onshore Pipeline Operators' Association) 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.[4]
- Assessing the risks from high pressure Natural Gas pipelines, IGEM/TD/2 Edition 2 with amendments July 2015 Communication 1779.[5]
- Technical Note PIE/14/TN113:-Development of a model for classifying the health index of non-piggable pipelines. PIE (Pipeline Integrity Engineers)
- 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)[6]

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 as a starting point and to the fault equation generates predicted future faults on top of that
- For non-piggable pipes, a default starting number of faults is derived based on age, and as per piggable pipes this number grows annually within the formula
- Fault growth rate is then based on age
- Diameter, coating and depth scalars are used on a pipe 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)

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4 https://www.ukopa.co.uk/wp-content/uploads/2015/02/UKOPA-14-0031-Product-Loss-Incidents-Faults-Report-1962-2013-Final2.pdf

5 https://www.igem.org.uk/resource/igem-td-2-edition-2-a-2015-assessing-the-risks-from-high-pressure-natural-gas-pipelines.html

6 https://www.egig.eu/reports/$60/$63

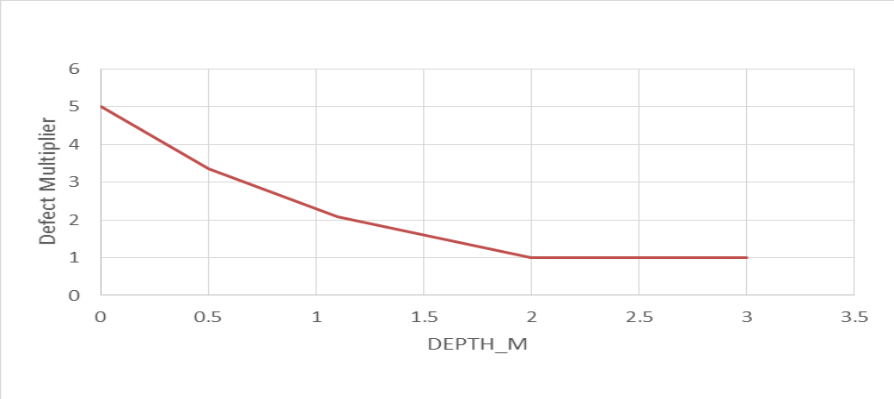

Figure D4 – Use of defect frequency multiplier to account for impact of pipeline depth

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).

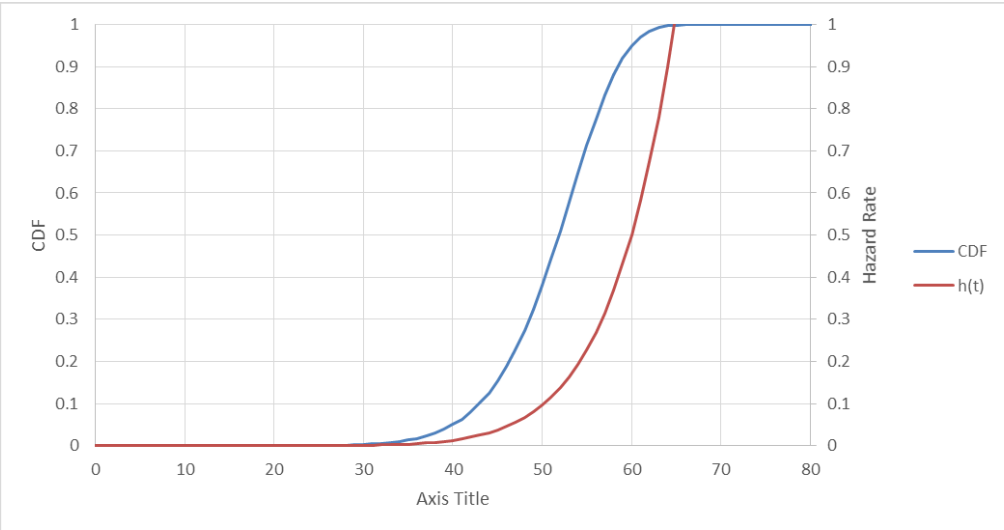

Figure D5 – Weibull model for block valve defects

The Weibull curve's shape and scale values are as detailed in section D3.2.5.

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 to give Condition_Age

- 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.

AGE_EFFECTIVE = w * Condition_Age + (1-w) * Actual_Age

Where w is a percentage weighting factor.

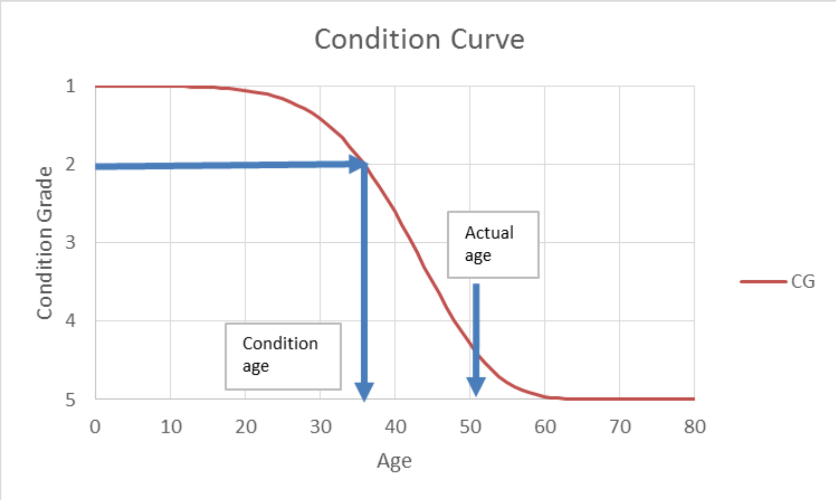

Figure D6 – Derivation of Effective Age from assessed Condition Grade

D3.2.5. Pipe Corrosion

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

- Wall thickness deterioration coefficients are based on high, moderate or low corrosion resistance condition as reported in Intervals and PIE(Pipeline Integrity Engineers).
- 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 thickness 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).

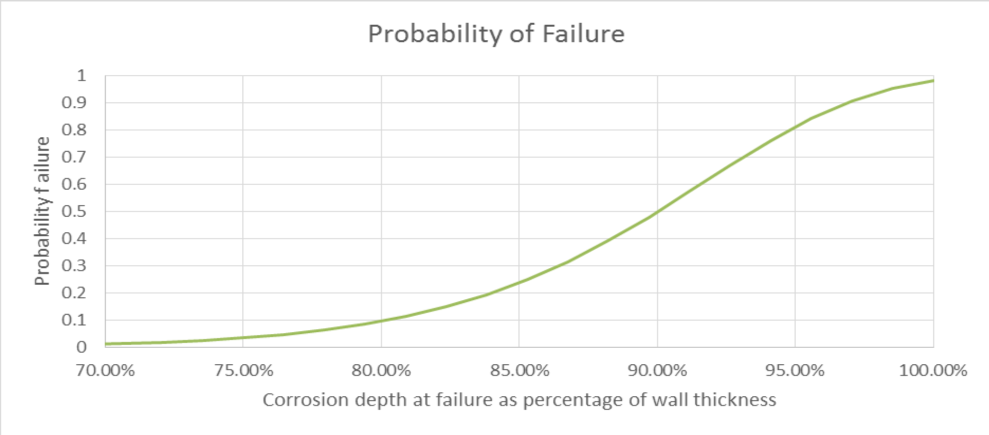

Figure D7 – Relationship between corrosion depth and PoF – for piggable pipes

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

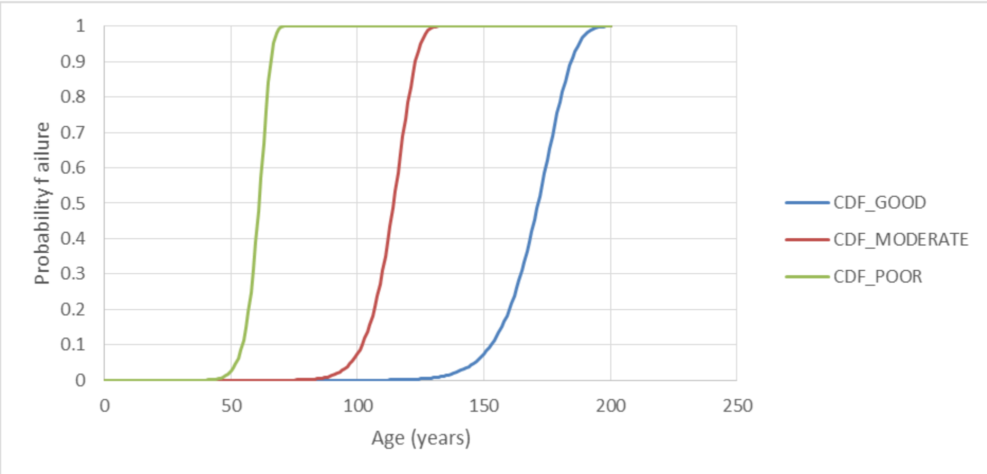

Figure D8 – Relationship between Effective Age and PoF – for non-piggable pipes

The Weibull shape and scale values are derived as per section D3.2.5 below 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.

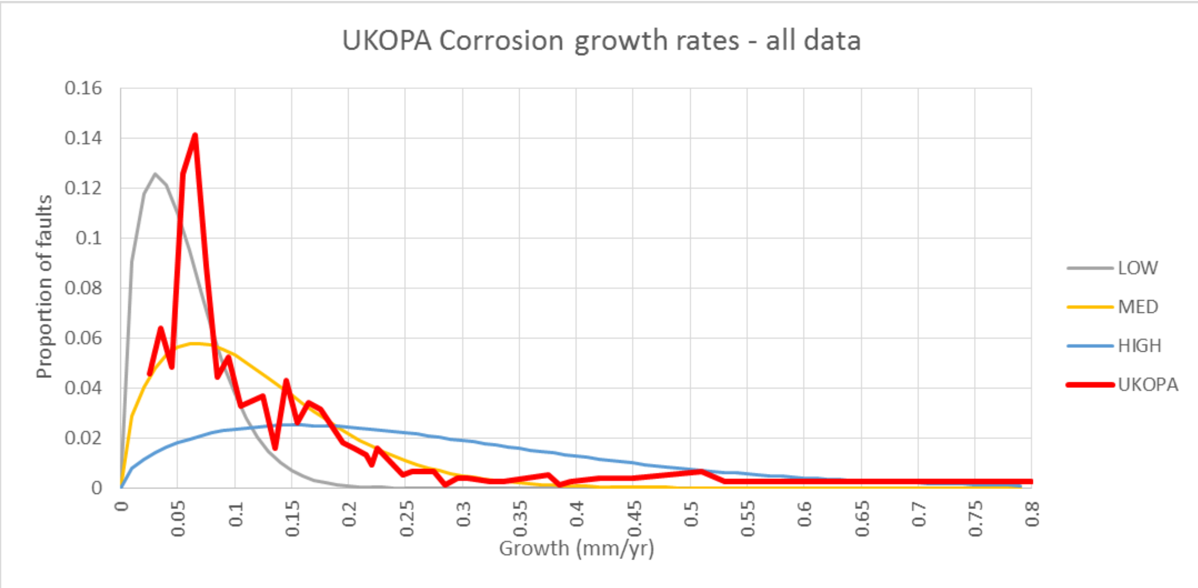

Figure D-9 Analysis of UKOPA data has been undertaken to determine corrosion growth

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[7] 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 failure 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).

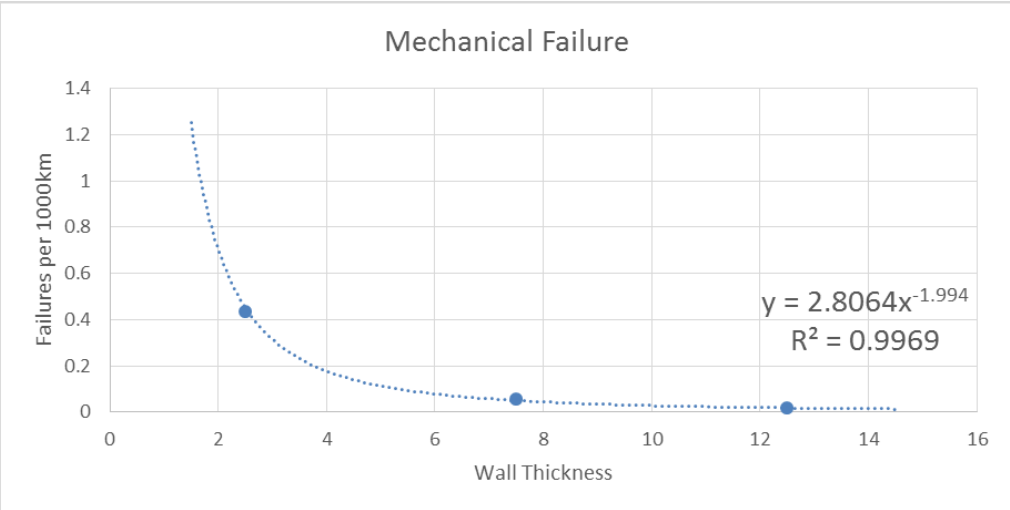

Figure D10 – Frequency of mechanical failure as a function of wall thickness as applied in model

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.

7 https://www.igem.org.uk/resource/igem-td-2-edition-2-a-2015-assessing-the-risks-from-high-pressure-natural-gas-pipelines.html

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 is 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 the 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)[8]

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 diameter of 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 – cost of OLI4,OLI1, valve, sleeve condition monitoring (**F_Condition Monitoring**)
- Land Costs – cost of easement and access rights (**F_Land Costs**)
- General Maintenance – cost of general maintenance on pipes, sleeves and valves etc. (**F_General Maintenance**)
- Compliance – cost of aerial surveys, river surveys, access prevention measures, anti-vandal guards (**F_Compliance**)
- Cathodic Protection – cost of inspections and new ground beds (**F_Cathodic Protection**)

Reactive consequences of failure include:

[8] https://www.egig.eu/reports/$60/$63

- 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.

Building Burning Distance (BBD) - Distance to thermal radiation flux (heat radiation from ignition) causing piloted ignition of wood, for almost all assessments this is assumed to be from piloted ignition. BBDs for ruptures in metres are given for four case study pipelines of varying diameter and wall thickness in TD2 Appendix 6.

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.

Escape Distance (ED) - Closest distance at which people moving away from the fire receive less than the dangerous dose without resort to shelter. EDs for ruptures in metres are given for four case study pipelines of varying diameter and wall thickness in TD2 Appendix 6.

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** (Xoserve category: D1 type properties compensation payments and cost of restoring supply)
- **F_Displacement** (Xoserve categories: D1 and C2 type properties cost of alternative accommodation & travel)
- **F_Critical** (Xoserve categories: C2 and I2 type properties compensation payments and cost of restoring supply)
- **F_Com Large** (Xoserve categories: C3 and C4 type properties compensation payments and cost of restoring supply)
- **F_Com Small** (Xoserve category: 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

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- Above Ground Crossings Surveys
- River Bank/Bed Survey (when in proximity / crossing with a pipeline)
- OLI1/4 Surveys

'With intervention' activities:

Number	Description	Definition	Post Intervention Change in Failure Rate
Intervention 1	Diversions	Abandon old pipe and new pipe in new route.	Modelled by taking the original likelihood + laid likelihood – abandoned likelihood
Intervention 2	Pipe Refurbishment	Pipe remedial, eg recoating, sleeving	Reduces the failure rates and number of faults
Intervention 3	CP Major Refurb	New transformer install and/or new anode ground bed.	Reduces the corrosion failure rate.
Intervention 4	Above Ground Crossings Remedial (Structural, Painting, Anti-vandal Guards)	Remediate exposed crossings (above ground sections only) - support and coatings.	Reduces the corrosion failure rate.
Intervention 5	Resolve Capacity	Resolve a capacity issue on a pipeline.	Capacity Nr/Asset/Yr failure rate changed to 0
Intervention 6	Decommission	Removal of pipeline that is no longer required.	All risk removed, outcome risk of 0
Intervention 7	OLI 1 conversion	Reconfiguration of pipeline system to allow pigging.	Failure rates changed to match pigged pipelines. Still required

Table D6 – With Investment interventions for LTS Pipelines

Intervention lives for LTS assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1			
Intervention 2			
Intervention 3			

Intervention 4			
Intervention 5			
Intervention 6			
Intervention 7			

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:

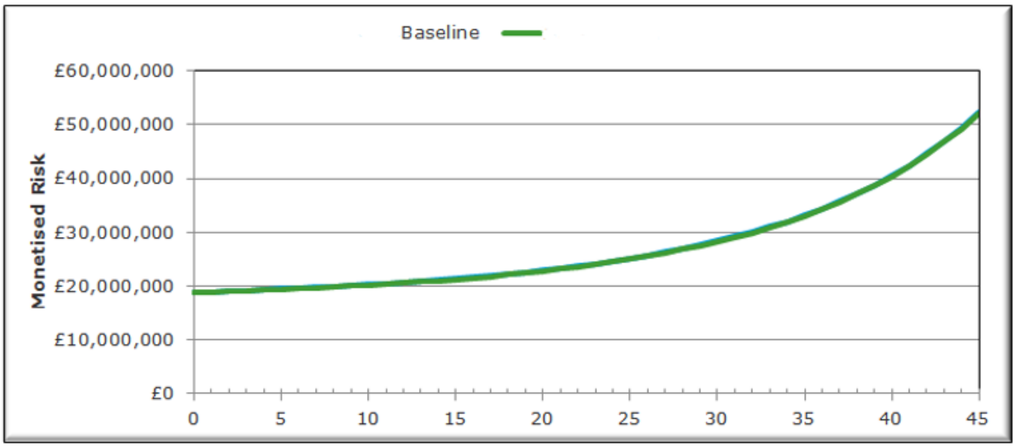

Figure D11 - Baseline monetised risk for LTS Pipelines over 45 years

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 £20million 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 reduce the corrosion deterioration rate in the model to low. It does not change the condition of the pipe, just the future deterioration.

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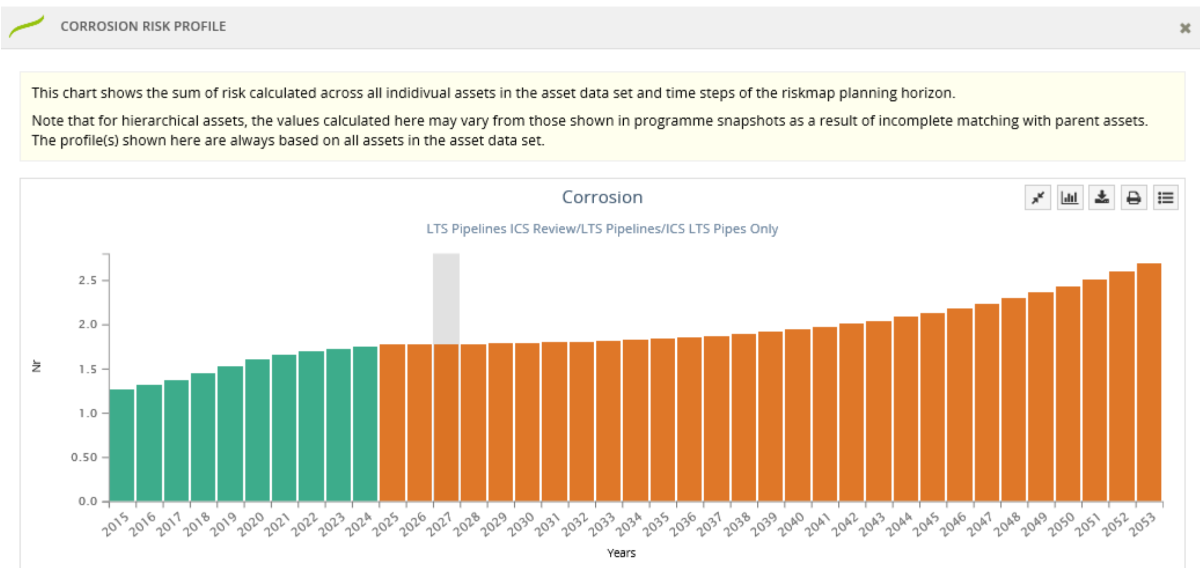

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Appendix E – Offtakes & PRSs

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.

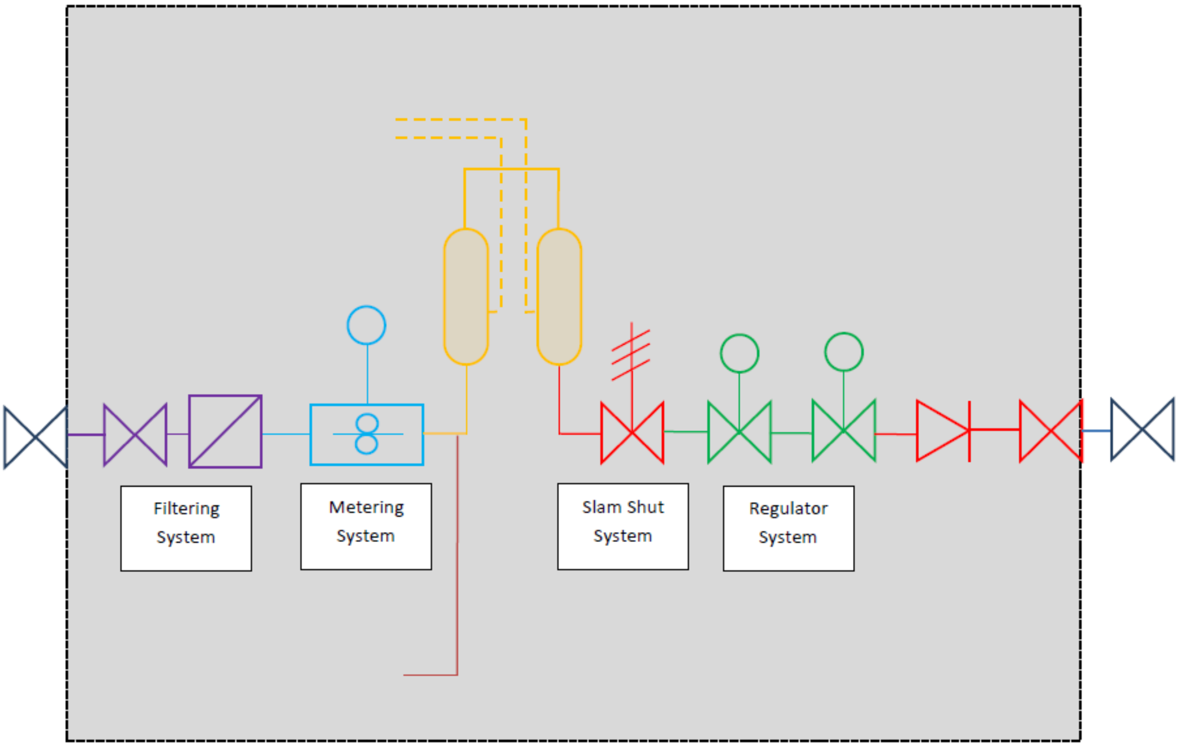

Figure E1 – Schematic of typical PRS/Offtake station (excluding odorant)

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.

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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):

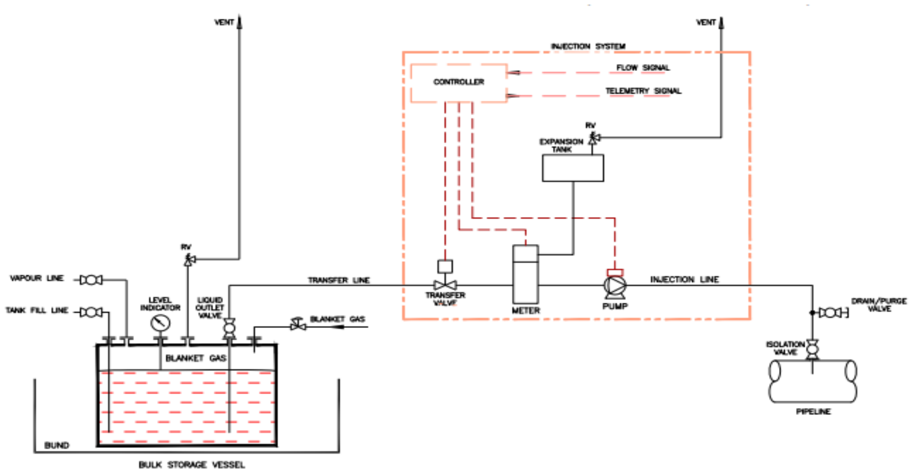
- Electrical supplies, distribution boards and earthing systems
- Offtake telemetry systems including back-up ISDN communications to provide constant communication back to Gas Control Centres. These will generally report flow rates, both energy and volume, and pressure from the Meter, whilst Odorant 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

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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.

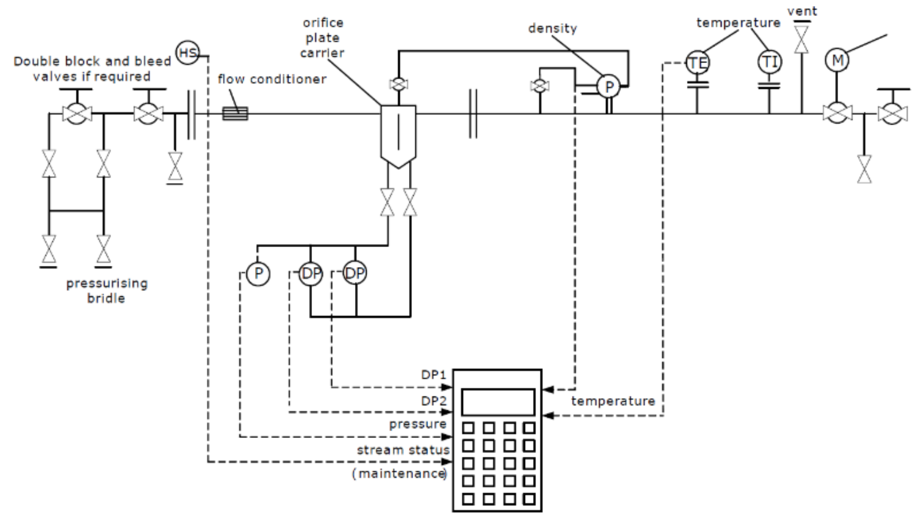

Figure E3 – Schematic of Metering facility

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.

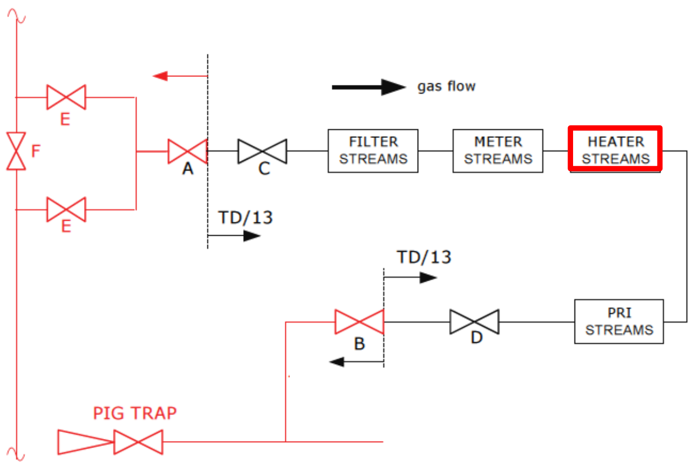

Figure E4 – Schematic of Pre-heating facility

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.

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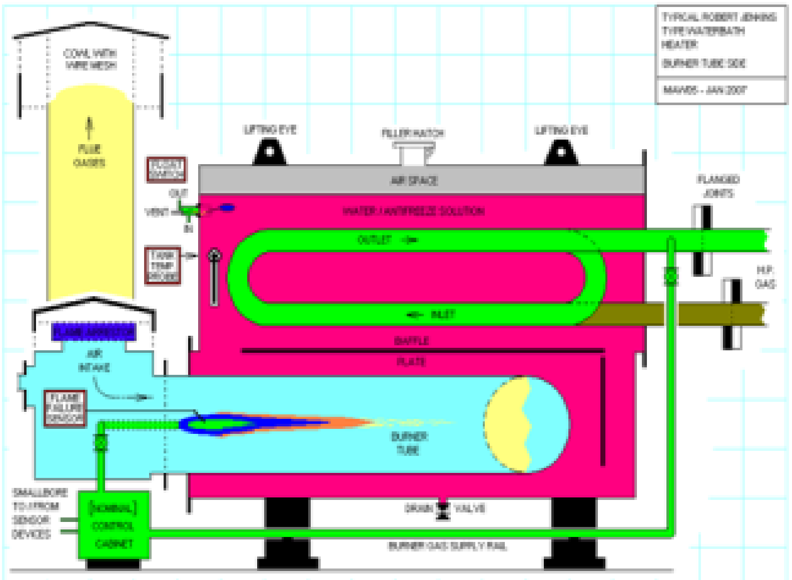


Figure E5 – Water Bath Heater

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.

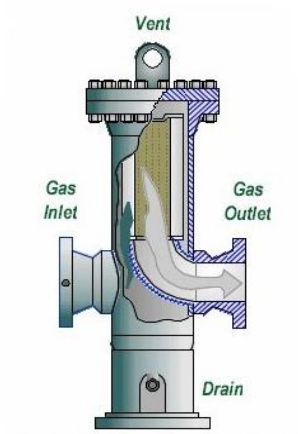
Figure E5 – Electrical Heating System

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:

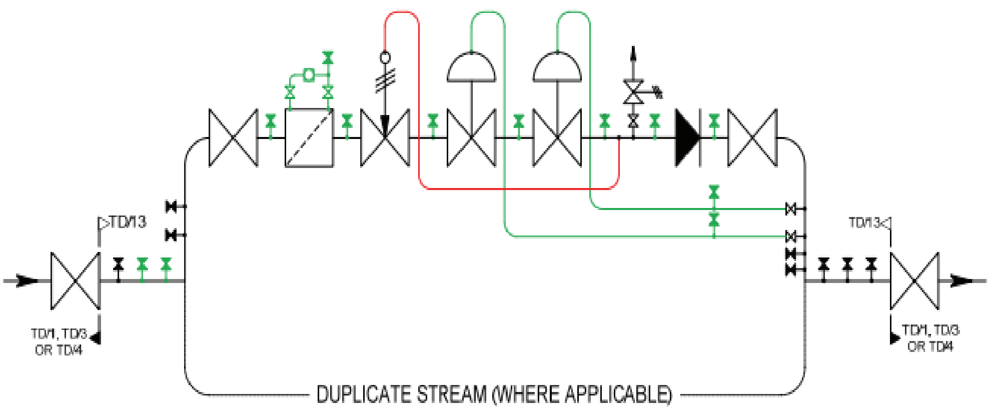


Fig E6: Typical slamshut, valve, monitor and active regulator arrangement

- 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.

E2.1.1 Odorant & 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 off the 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:

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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:

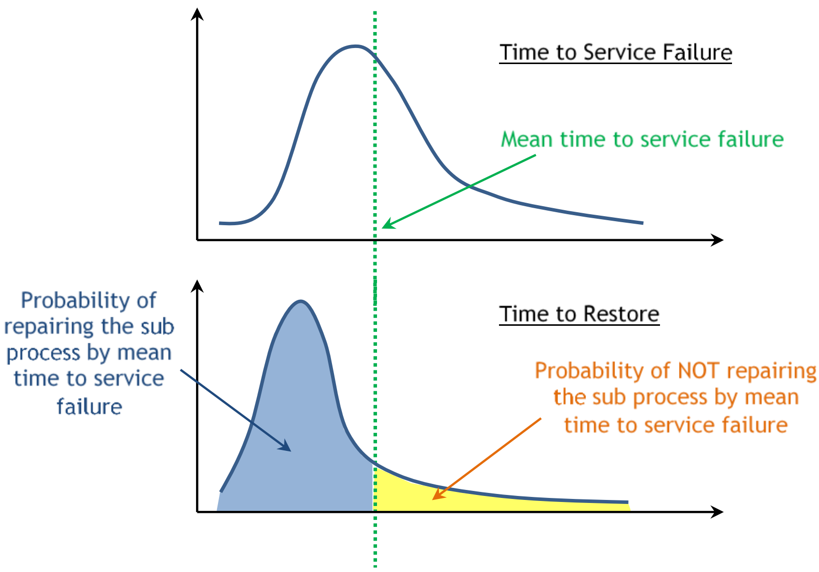

Figure E7 – Statistical modelling of TTSR and TTR

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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

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E2.3. Offtake & PRS Risk Map

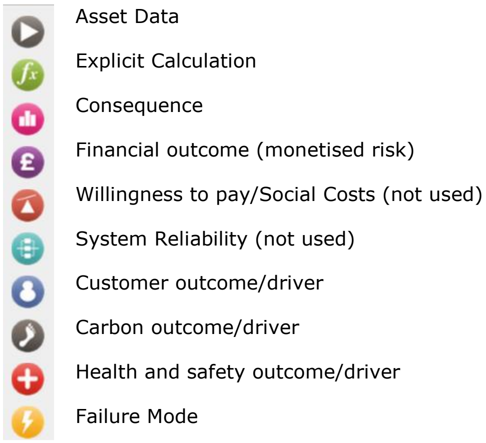

Figure E- 8 - Risk Map Key

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.

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E2.3.1 Odorant & Metering Risk Map

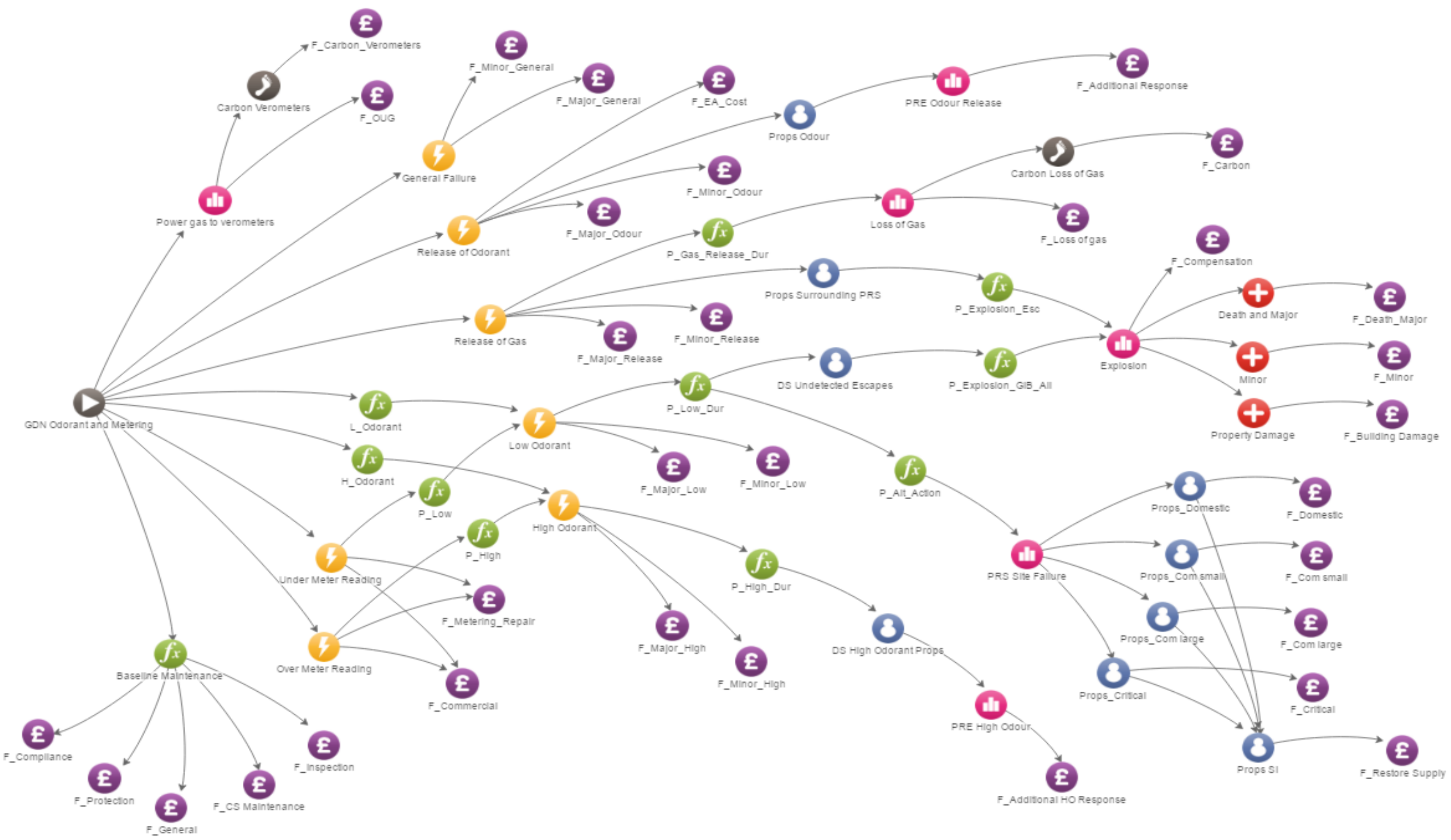

Figure E- 9 Odorant Risk Map

E2.3.2Pre-heating Risk Map

PRS - Pre Heating v4

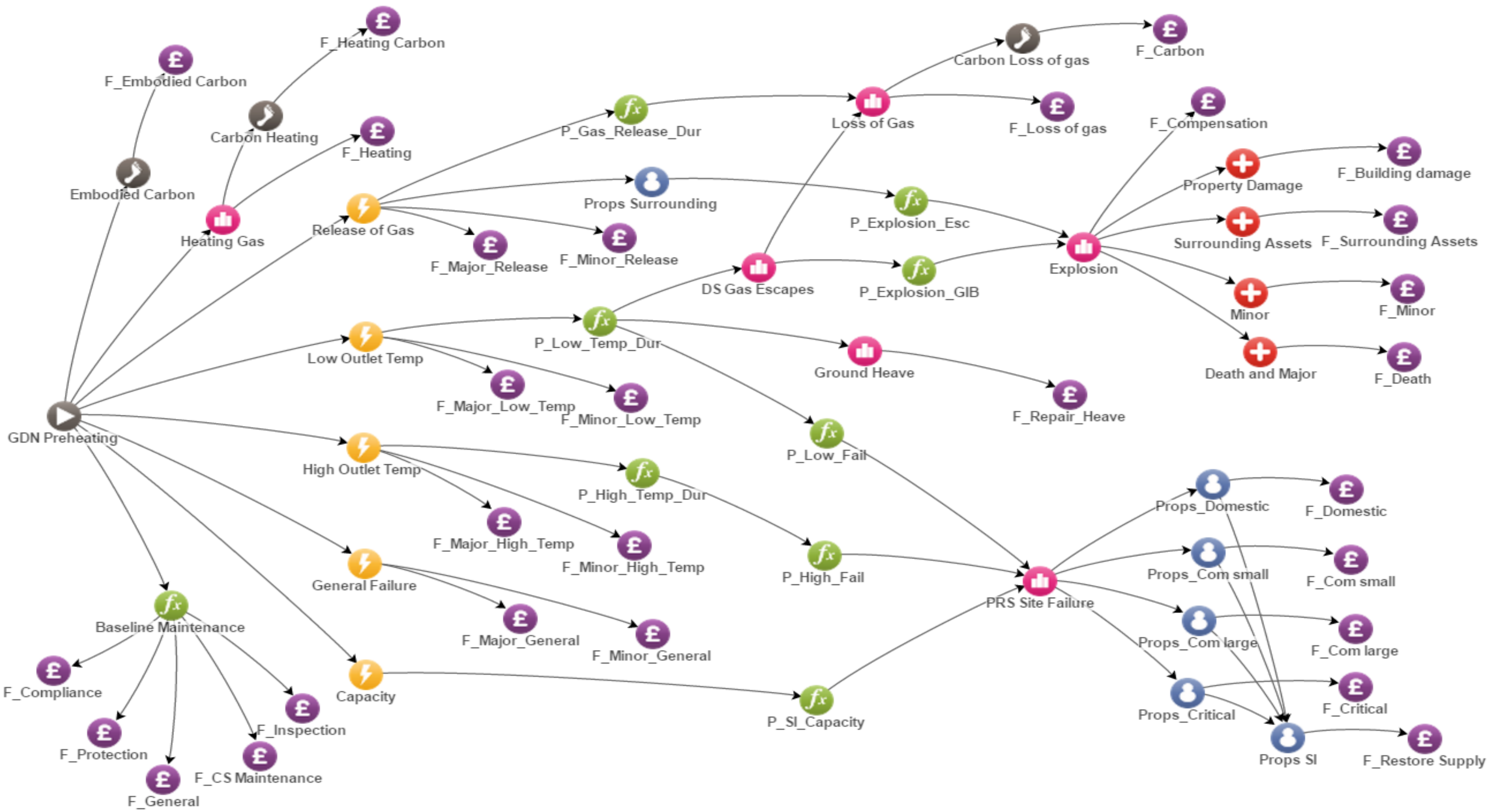

Figure E- 10 Pre-Heating Risk Map

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E2.3.3 Filters & Pressure Control Risk Map

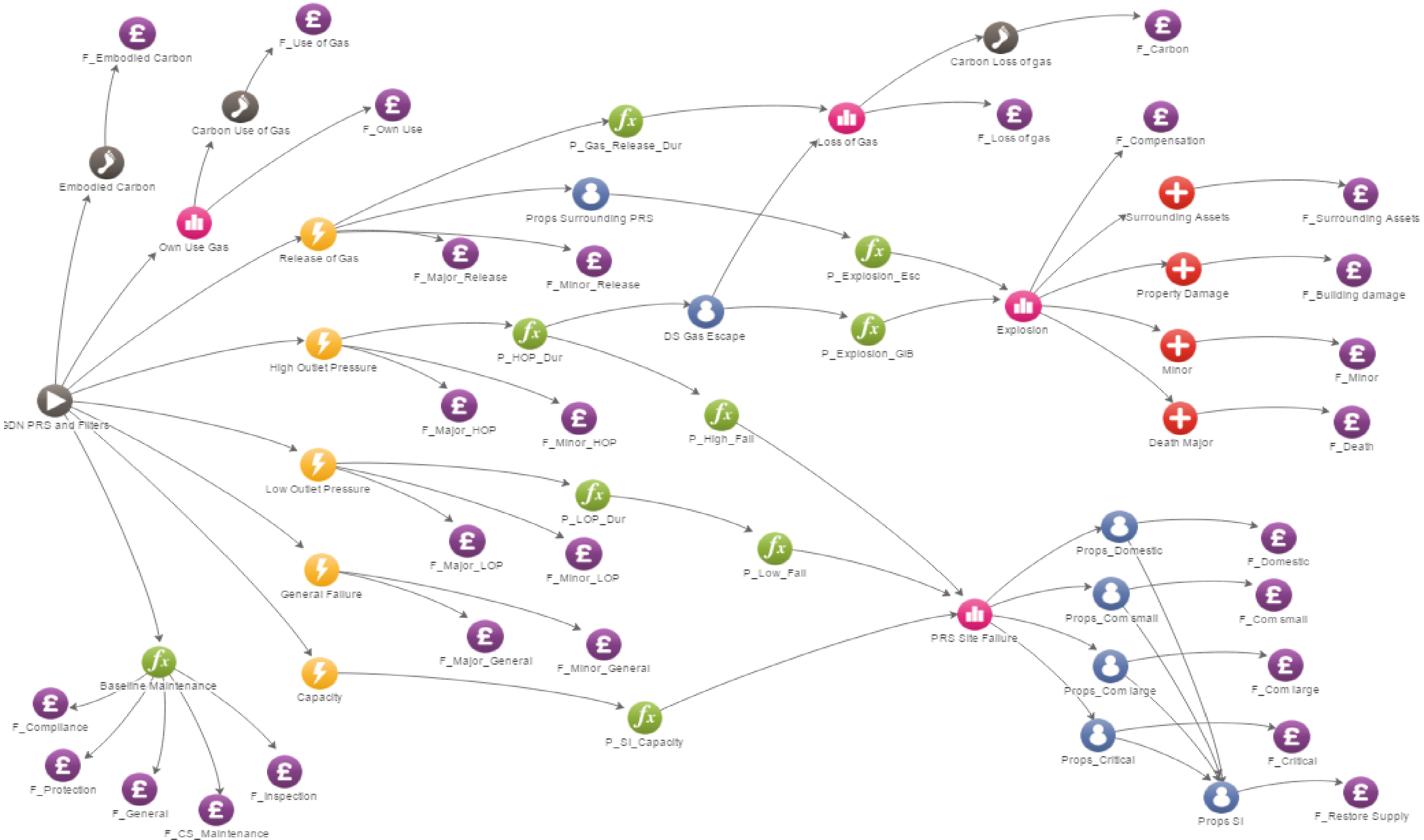

Figure E- 11 Filter and Pressure Control Risk Map

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.

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E2.4.1Odorant & Metering Risk Template

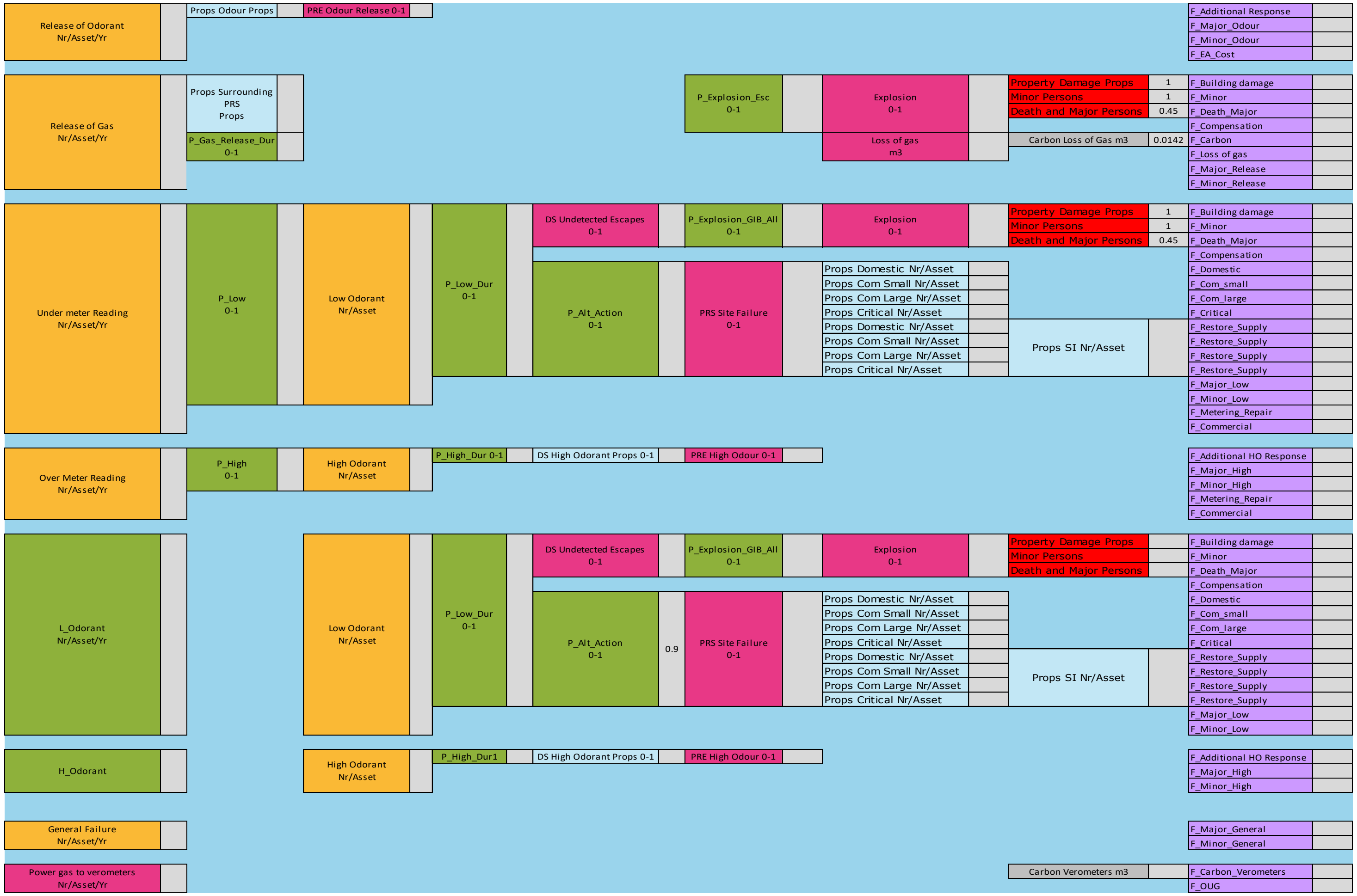

Figure E- 12 Odorant & Metering Risk Template

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E2.4.2Pre-heating Risk Template

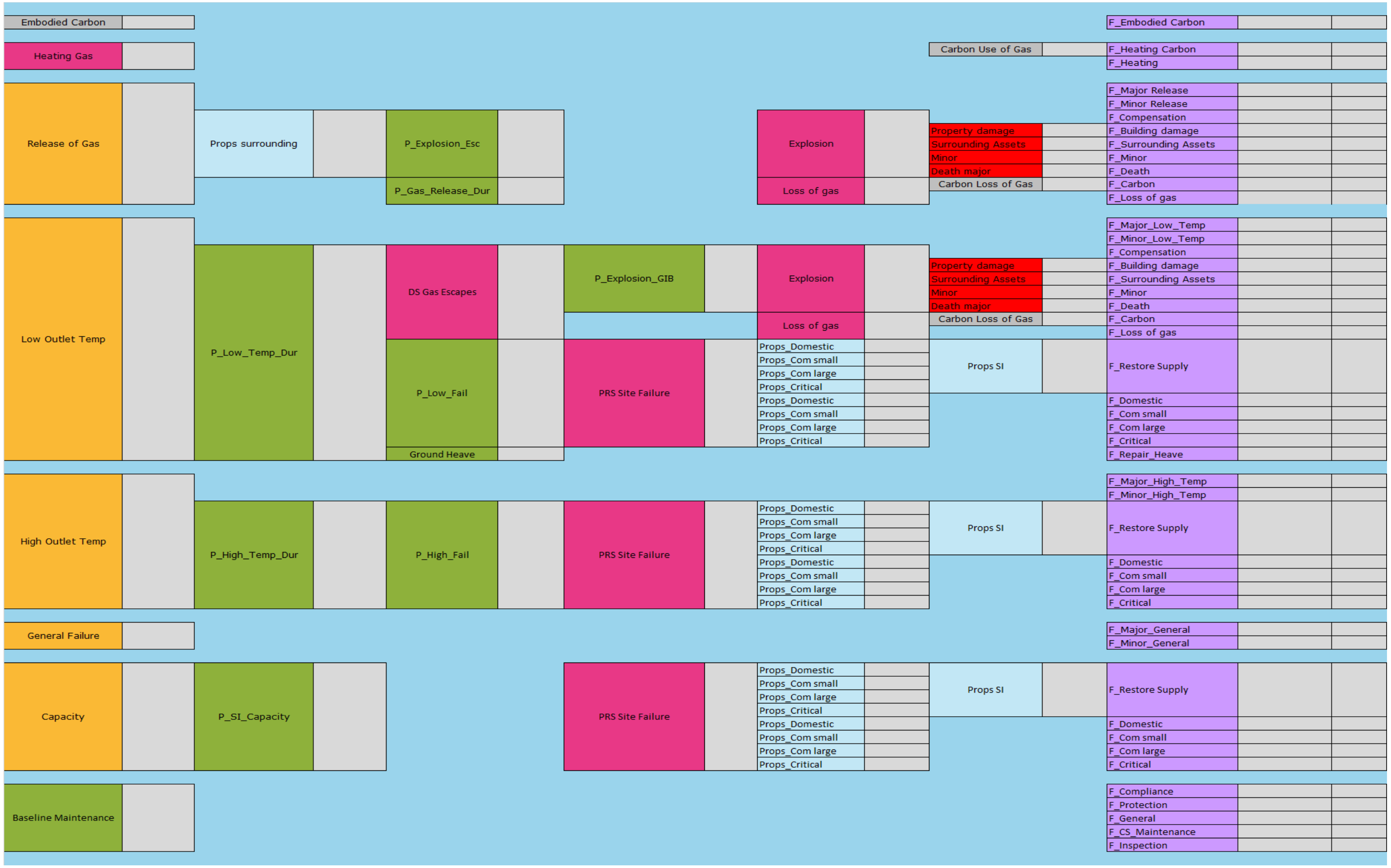

Figure E- 13 - Pre-heating Risk Template

E2.4.3 Filters & Pressure Control Risk Template

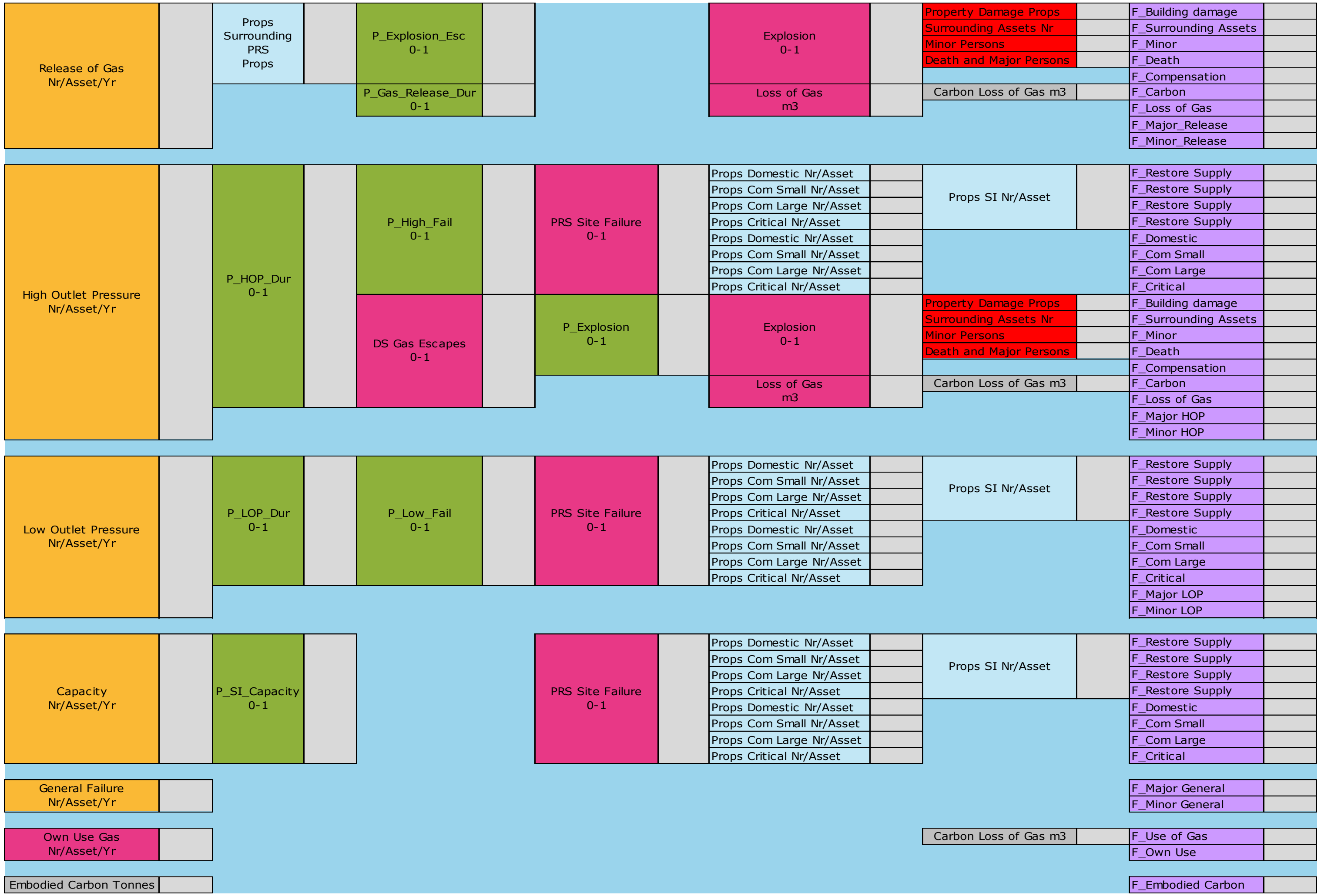

Figure E- 14 - Filters & Pressure Control Risk Template

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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. Demand mix generation is a longer-term evolutionary piece which GDNs will need to consider due to the inherent adjustment to baseline monetised risk as a result of customer demand changing. Customer number updates can be reflected in the modelling base data that supports asset investment decision making, therefore it can be undertaken periodically where required. A customer base data refresh will be undertaken after the completion of the current GD2 price control and at the completion of later price controls as net zero impacts effect methane gas distribution use.

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	0.45 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

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Node ID / Variable	Description	Data Source	GDN or Common Value
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
F_Inspection	Inspection costs, including any maintenance carried out during surveys	Data taken from company systems.	GDN Specific
F_Major_General	Cost of repair given a major general failure. Repairs greater than 12 hrs - everything not in minor (replacement, can't fix)	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	requiring a component replacement		
F_Major_High	Cost of repair given a major failure resulting in high odorant. 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	Cost of repair given a major failure resulting in low odorant. 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	Cost of repair given a major failure resulting in a release of odorant. 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	Cost of repair given a major failure resulting in a release of gas. 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

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Node ID / Variable	Description	Data Source	GDN or Common Value
F_Minor_General	Cost of repair given a minor general failure. 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	Cost of repair given a minor failure resulting in high odorant. 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	Cost of repair given a minor failure resulting in low odorant. 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	Cost of repair given a minor failure resulting in a release of odorant. 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

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Node ID / Variable	Description	Data Source	GDN or Common Value
F_Minor_Release	Cost of repair given a minor failure resulting in a release of gas. 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_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). Reference E.2.1.1	Data taken from company systems.	GDN Specific
High Odorant	Where high levels of odorant are injected into the gas supply. Reference E.2.1.1	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	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common 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.	
Low Odorant	Where levels of odorant are too low to meet the flows of gas going through a site. Reference E.2.1.1	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 affecting the measurement of odorant being injected into the gas system. Reference E.2.1.1	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 undertaken between GDNs and led by	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		consultants ICS and DNV GL.	
P_Explosion_GIB_All	Probability of explosion given a GIB resulting from a low odorant event	Taken from fault data/elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	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 undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_High Dur	Probability of high odour resulting in PRE. Duration weighted based on E&I equipment on site	Taken from fault data/elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	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 undertaken between GDNs and led by consultants ICS and DNV GL.	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 undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
PRE Odour Release	Probability of Public Reported Escape per property	Taken from fault data/elicitation undertaken between GDNs and led by	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		consultants ICS and DNV GL.	
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 undertaken between GDNs and led by consultants ICS and DNV GL.	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 undertaken between GDNs and led by	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
		consultants ICS and DNV GL.	
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

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Node ID / Variable	Description	Data Source	GDN or Common Value
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 £20m	GDN Specific
F_Compliance	Cost of HSE; Working at Height; DSEAR; Asbestos etc.	Data taken from company systems.	GDN Specific
F_CS Maintenance	Cost of 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

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	GDN or Common Value
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_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 major failure resulting in release of gas)	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	Cost of 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	Data taken from company systems.	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	security). Painting to prevent pipework corrosion		
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. Factor from Leakage Reduction Management tool (LRMM), percentage of gas loss attributed to heating gas and site demand used to calculate own use of gas.	GDN Specific
High Outlet Temp	Number of 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

Appendices - Detailed Asset Assessments

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 undertaken between GDNs and led by consultants ICS and DNV GL.	Common
P_Explosion_GIB	Probability of a downstream gas in building (GIB) resulting in an explosion	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_Gas Release Dur	Probability of loss of gas given release factored to include duration of loss	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	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 undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_High_Temp_ Dur	Probability of telemetry detecting high	From company fault data /Elicitation undertaken	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	temperature within scan period	between GDNs and led by consultants ICS and DNV GL.	
P_Low_Fail	Probability of a low outlet temperature leading to a site failure (dependent on telemetry presence)	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_Low_Temp_ Dur	Probability of telemetry detecting low temperature within scan period	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	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 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	Data taken from company systems based on either network analysis or assumptions based on	GDN Specific

Node ID / Variable	Description	Data Source	GDN or Common Value
	(C3 and C4 type properties)	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. Networks do network analysis to determine number of customers experiencing a supply interruption.	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 undertaken between GDNs and led by consultants ICS and DNV GL.	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 (£20m)	GDN Specific
F_Compliance	Cost of 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

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	GDN or Common Value
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
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	Data taken from company systems.	GDN Specific

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	GDN or Common Value
	costs of pipework painting to mitigate corrosion		
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	Number of high outlet pressure events	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

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	GDN or Common Value
Own use of Gas	Gas used in pressure control systems.	Factor from LRMM, percentage of gas loss attributed to pressure controller and site demand used to calculate own use of gas.	GDN Specific
P_Explosion	Probability of explosion following DS gas escape	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	Common
P_Explosion_Esc	Probability of an onsite release of gas leading to an explosion	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_Gas Release Dur	Probability of loss of gas given release factored to include duration of loss	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_High_Fail	Probability of a high pressure event resulting in site failure (closedown)	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_HOP_Dur	Probability of telemetry detecting high pressure (if available) and associated duration of failure event	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_LOP_Dur	Probability of telemetry detecting low pressure (if available) and associated duration of failure event	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific
P_Low_Fail	Probability of a low pressure event causing a site failure (closedown)	From company fault data /Elicitation undertaken between GDNs and led by consultants ICS and DNV GL.	GDN Specific

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	GDN or Common Value
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	GDN Specific

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	GDN or Common Value
		demands, flow & redundancy	
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, under-pressurisation and capacity issues causing downstream supply interruptions. This is a function of the average site demand and network criticality. Networks undertake network analysis to determine the number of customers that could experience a supply interruption. In addition, the criticality of the site in terms of whether it provides a single feed, is part of a weak multi-fed system or a strong multi-fed system is also analysed.	This is a function of the average site demand and network criticality. Networks do network analysis to determine number of customers experiencing a supply interruption.	
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

Appendices - Detailed Asset Assessments

Node ID / Variable	Description	Data Source	GDN or Common Value
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 installation itself including plant, equipment and civils.	GDN Specific

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.

Appendices - Detailed Asset Assessments

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

The approach taken to model the Offtakes and PRS asset probabilities of failure and age (or condition) related deterioration has fundamentally changed for this version of the Methodology and now aligns more closely with the approach used for Governors This is extensively documented in Appendices G and H.E3.2.1 Capture of fault numbers

The actual faults seen on our systems, as outlined in section E2.1, are monitored through various systems such as the SCADA (Supervisory Control and Data Acquisition) for telemetry data and PSSR (Pressure Systems Safety Regulation) fault data, etc. A process is undertaken to align and translate these fault logs into the type of NARM modelled failure they are reporting.

The faults captured within these systems are as follows:

- High outlet temperature
- Low outlet temperature
- High outlet pressure
- Low outlet pressure
- High odorant
- Low odorant
- Under meter reading
- Over meter reading
- General failure

The number of gas release faults seen on site is not captured in the same way. Gas releases are rare and furthermore, gas releases not leading to immediate replacement of an asset are even more rare. Number of gas releases is instead based on corrosion or crack propagation identified via a defect assessment as these assets are at high risk of leading to a gas escape.

E3.2.3 Factors Applied to Failure Rate Excluding Factors Values

Similar adjustment methods and factors used in the Governor methodology are used on Offtakes and PRS assets. The failure rate (excluding factors) is scaled by a number of parameters, such as housing condition, fencing/security condition, distance to coast, flood risk zone 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 failure rate excluding factors estimates are taken from population level estimates.

The engineering inspection methods used across GDNs are broadly aligned and so no GDN specific annexes have been created for this document. In the case of visual surveys all GDNs have their own processes, following asset management best practices, which are then aligned to a NARM condition score using guidance in the tables within this document. 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.

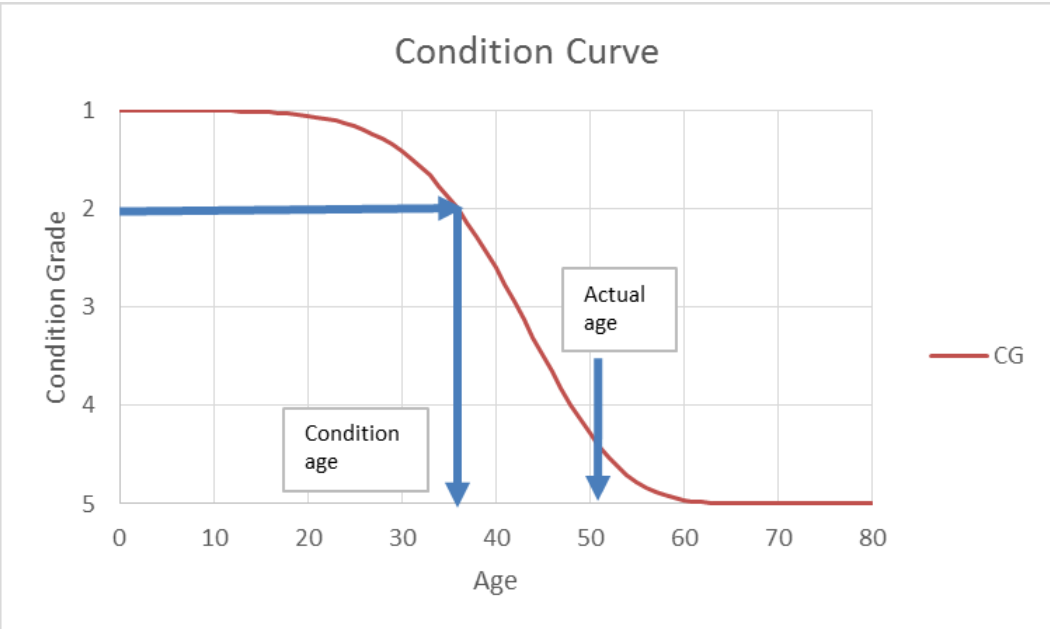

Figure E16 – Derivation of the Effective Age of an asset from assessed Condition Grade

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:

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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 to the system.

Note: Where the condition grade is unknown, 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
Non-Coastal	1
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 and continues to be used by all GDNs.

Housing Risk (Housing Factor)

As outlined in the Governors section C3.2.3, whether an asset is installed above or below ground can increase its probability of failure. For Offtake and PRS assets this is referred to as its housing factor. This housing factor refers to whether the housing of the asset is above or below ground.

The factors are outlined in the Table below:

Description	Housing Factor

Above ground, asset in open air or kiosk	1
Below ground, asset in pit, potentially liable to flooding	2.5

Table E5 – Housing type PoF multipliers

Kiosk Risk (Kiosk Condition)

The assessed condition of the kiosk/building 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	1
2	minor cosmetic damage to kiosk/building	1.05
3	some damage to kiosk/building (assessment/monitoring required)	1.1
4	considerable damage to kiosk/building (intervention considered).	1.15
5	severe damage to kiosk/building (intervention required)	1.2

Table E6 – kiosk 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:

Condition Grade	Description	FS Factor
1	As new, no issues	1
2	minor cosmetic damage to fencing, no security issues	1.05
3	Low security concerns/issues, some damage to fencing (assessment/monitoring required).	1.1
4	Medium security concerns/issues, considerable damage to fencing (intervention considered).	1.15
5	High security concerns/issues, severe damage to fencing (intervention required).	1.2

Table E7 – 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 of fluvial or tidal flooding.

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

Zone	Flood Factor
1	1
2	1.5
3	2

Table E8 – 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:

Failure Rate Including Factors = Failure Rate Excluding Factors x Fault Detection Rate x Coastal Factor x Housing Factor x FS Factor x Flood Factor x Kiosk Factor

Where:

Failure Rate Excluding Factors is defined in Section E3.2.1.

Fault Detection Rate is defined in Section E3.2.2.

Coastal Factor, Housing Factor, FS Factor, Kiosk Factor and Flood Factor are all defined in Section E3.2.3.

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.

E3.3.1. Obsolescence and E&I factors

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 because of a Release of Gas failure.
- **P_Low_Dur –** The duration of undetected downstream escapes because of a Low Odorant failure.
- **P_High_Dur –** The duration of an increase in Public Reported Escapes because 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 because 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 because 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 because 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 because of a Low Outlet Pressure failure.

E3.3.2. E&I Risk (E&I condition)

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 in the table 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 E9 – 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

E3.3.3. Obsolescence Risk

The asset type, manufacturer, and availability of spares can be used to estimate the year that the asset will no longer be like for like repairable, this is defined as the obsolete year.

IF(current year > Obsolete year, Obsolescence factor,1)

As per the above equation if it is beyond the obsolete year then an obsolescence factor is applied to the duration calculations outlined in E3.3.1.

E3.3.4. 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).

E3.3.5. 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

E3.3.6. 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.

E3.3.7. 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 Offtake and PRS failure is a supply interruption, which can be due to high or low outlet pressure events. Over-pressurisation could arise from a failure in the pressure control of the system and could lead to downstream damage to assets and a subsequent loss of supply. Low outlet pressure could also lead to a loss of supply.

Capacity, Low/High Outlet temperature and Release of Gas failure modes could potentially result in supply interruptions. The number of properties downstream of the Offtake or PRS 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.

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.

E3.4.1. Odorant 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	Post intervention change in Failure Rate
Intervention 1	Odorant Refurb	Major refurbishment of odorant system (Inc. pumps; odorant tanks)	OM Condition score is the only factor affected. Condition score is reduced by 2 grades, to a maximum post-intervention CG of 2.
Intervention 2	Meter Refurb	Major refurbishment of metering system.	OM Condition score is the only factor affected. Condition score is reduced by 2 grades, to a maximum post-intervention CG of 2.
Intervention 3	Odorant Replace	Full upgrade of E&I equipment on site. If a loop	OM Condition score = 1

		is only upgraded on site then the intervention should only be applied to the relevant system.	
Intervention 4	Meter Replace	Replacement of metering system	OM Condition score = 1
Intervention 5	Full System E&I Upgrade	Full upgrade of E&I equipment on site.	Control System Cond = 0.5
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 to.	OM Fence Cond = 1 OM Kiosk Cond= 1
Intervention 7	Civils Upgrade (Fence replacement)	Replacement of fence on site.	OM Fence Cond = 1
Intervention 8	Civils Upgrade (Building replacement)	Replacement of building on site. Intervention should only be applied to systems that the building applies to. .	OM Kiosk Cond= 1
Intervention 9	Full System Rebuild	Full replacement of relevant system, fence, civils and E&I.	OM Condition score = 1 OM Fence Cond = 1 OM Kiosk Cond= 1 Control System Cond = 0.5
Intervention 10	Odorant Decommissioning	Decommissioning of odorant system (no replacement)	All Odorant failure rates assumed to be zero
Intervention 11	Meter Decommissioning	Decommissioning of metering system (no replacement)	All Meter failure rates assumed to be zero

Table E11 – Odorant and Metering intervention definition and change in failure rate.

Intervention lives for Odour and Meter assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1	Odorant Refurb		
Intervention 2	Meter Refurb		

Intervention 3	Odorant Replace		
Intervention 4	Meter Replace		
Intervention 5	Full System E&I Upgrade		
Intervention 6	Civils Upgrade (Fence and Building replacement)		
Intervention 7	Civils Upgrade (Fence replacement)		
Intervention 8	Civils Upgrade (Building replacement)		
Intervention 9	Full System Rebuild		

E3.4.2. 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	Post intervention change in Failure Rate
Intervention 1	Preheater Replace	Replacement of all heating components on system (heater type specific). Excludes civils asset interventions.	PH Condition score = 1 PH Capacity = 0 Control System Cond = 0.5
Intervention 2	Preheater Major Refurb	Major refurbishment of heating systems (heater type specific). WBH - all heating components replaced or full refurbishment (exc. E&I) MB - >=50% of boilers replaced EHS - all heating components replaced. Replacement of HEX.	PH Condition score is the only factor affected. Improve CG by 2 grades, to a maximum post-intervention CG of 2.

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	Control System Cond = 0.5
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 to	PH Fence Cond = 1 PH Kiosk Cond = 1
Intervention 5	Civils Upgrade (Fence replacement)	Replacement of fence on site	PH Fence Cond = 1
Intervention 6	Civils Upgrade (Building replacement)	Replacement of building on site	PH Kiosk Cond = 1
Intervention 7	Full System Rebuild	Full upgrade of relevant system, fence, civils and E&I	PH Fence Cond = 1 PH Kiosk Cond = 1 PH Condition score = 1 PH Capacity = 0 Control System Cond = 0.5
Intervention 8	Preheater Decommissioning	Decommissioning (no replacement)	All PH failure rates assumed to be zero
Intervention 9	Preheater Minor Refurb	Minor refurbishment of heating systems (heater type specific). WBH - some heating components refurbed (exc. E&I) MB - <50% of boilers replace or partial refurbishment EHS - some heating components refurbed. Corrosion remediation & painting of HEX	PH Condition score is the only factor affected. Improve CG by 2 grades, to a maximum post-intervention CG of 2.

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Table E12 – Preheating intervention definition and change in failure rate.

Intervention lives for Preheating assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1	Preheater Replace		
Intervention 2	Preheater Major Refurb		
Intervention 3	Full System E&I upgrade		
Intervention 4	Civils Upgrade (Fence and Building replacement)		
Intervention 5	Civils Upgrade (Fence replacement)		
Intervention 6	Civils Upgrade (Building replacement)		
Intervention 7	Full System Rebuild		
Intervention 8	Preheater Decommissioning		
Intervention 9	Preheater Minor Refurb		

E3.4.3. 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	Post intervention change in Failure Rate

Intervention 1	PRS Major Refurb	Full refurbishment of all main components on pressure reduction system (monitor, active, slam).	PH Condition score is the only factor affected. Improve CG by 2 grades, to a maximum post-intervention CG of 2.
Intervention 2	PRS Replace	Total replacement of all pressure reduction streams on the specific system from inlet to outlet	PC Condition score = 1 PC Capacity = 0 Control System Cond = 0.5
Intervention 3	Filter (Minor) Refurb	Filter minor refurbishment (grinding & painting)	Filter Condition score is the only factor affected. Improve CG by 1 grade, to a maximum post-intervention CG of 2.
Intervention 4	Filter Replace	Total replacement of the filter system	Filter Condition score = 1 PC Capacity = 0
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 to	PC Fence Cond = 1 PC Kiosk Cond= 1
Intervention 6	Civils Upgrade (Fence replacement)	Replacement of fence on site	PC Fence Cond = 1
Intervention 7	Civils Upgrade (Building replacement)	Replacement of building on site. Intervention should only be applied to systems that the building applies to	PC Kiosk Cond= 1
Intervention 8	Full System E&I Upgrade	Full upgrade of E&I equipment on site. If a loop is only upgraded on site	Control System Cond = 0.5

		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.	PC Fence Cond = 1 PC Kiosk Cond= 1 PC Condition score = 1 PC Capacity = 0
Intervention 10	PRS Minor Refurb	Partial refurbishment of all main components on pressure reduction system (monitor, active, slam).	PC Condition score is the only factor affected. Improve CG by 1 grade, to a maximum post-intervention CG of 2.
Intervention 11	PRS Decommissioning	Decommissioning of all PC and Filter systems	All PH failure rates assumed to be zero

Table E13 – Pressure Control and Filter intervention definition and change in failure rate

Intervention lives for PRS and Filter assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1	PRS Major Refurb		
Intervention 2	PRS Replace		
Intervention 3	Filter Refurb		
Intervention 4	Filter Replace		
Intervention 5	Civils Upgrade (Fence and Building replacement)		
Intervention 6	Civils Upgrade (Fence replacement)		
Intervention 7	Civils Upgrade (Building replacement)		
Intervention 8	Full System E&I Upgrade		
Intervention 9	Full System Rebuild		
Intervention 10	PRS Minor Refurb		
Intervention 11	PRS Decommissioning		

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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 E17 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

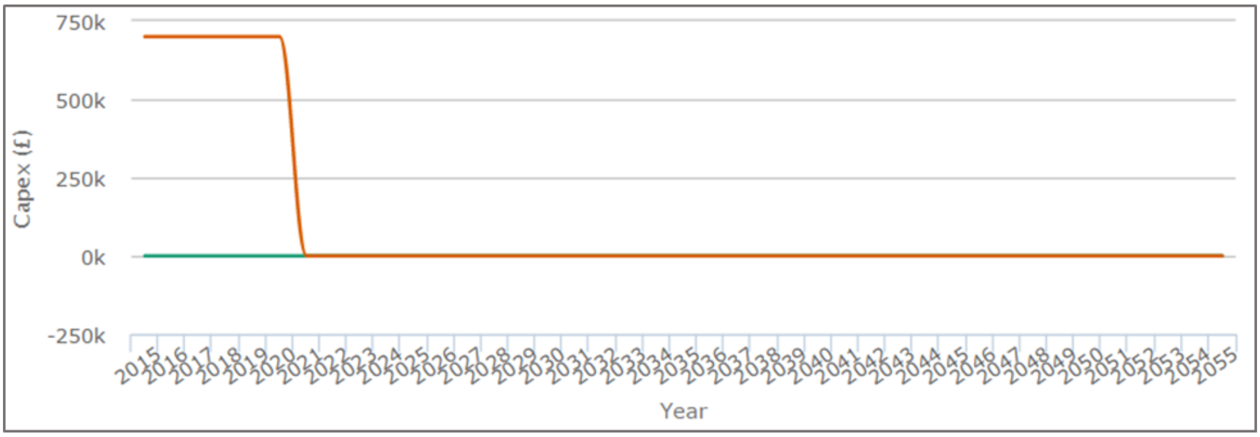


Figure E17 – Example Annual Capital Expenditure for Replacement of Odorisation Systems

The baseline level of cumulative monetised risk for each financial risk node is shown below for both with and without intervention.

Appendices - Detailed Asset Assessments

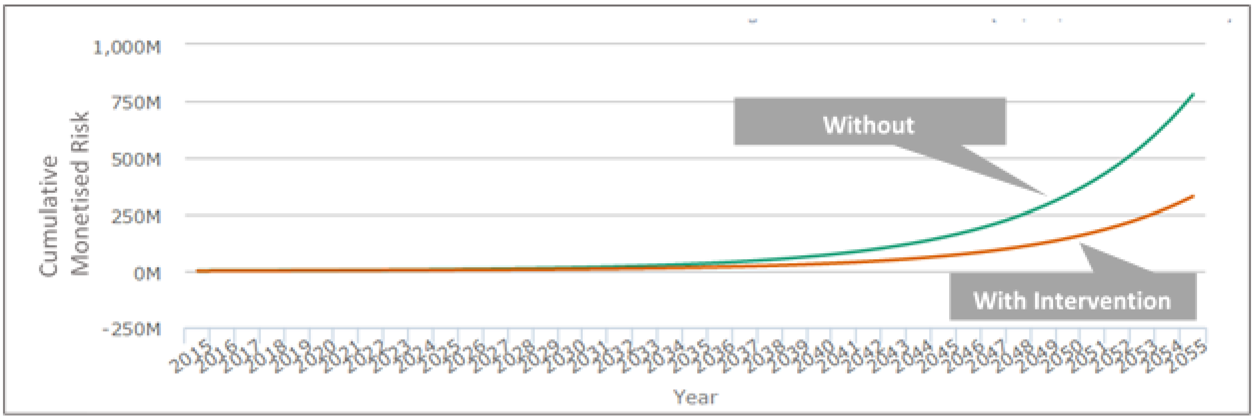


Figure E18– Example Pre and Post cumulative Monetised Risk value of Odorisation Systems

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.

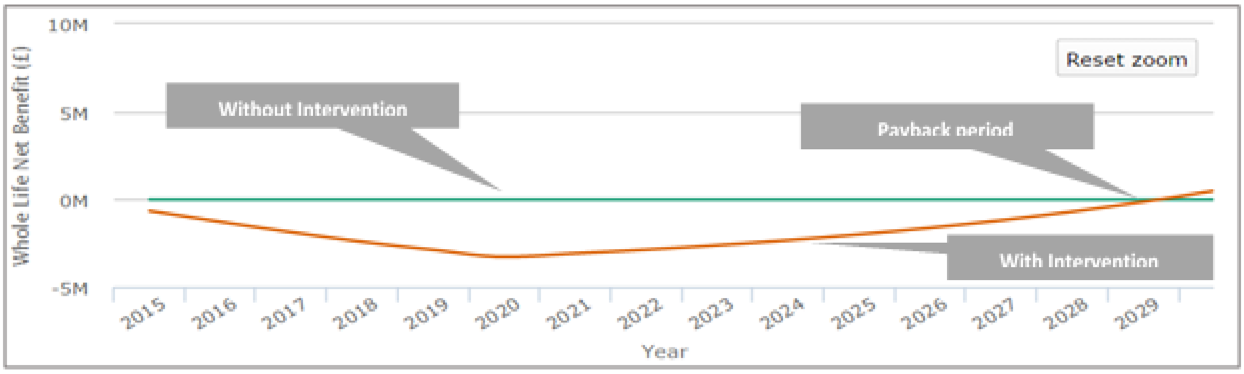


Figure E19– Example Discounted benefits per annum for planned Odorisation System replacement

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.

Appendices - Detailed Asset Assessments

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.

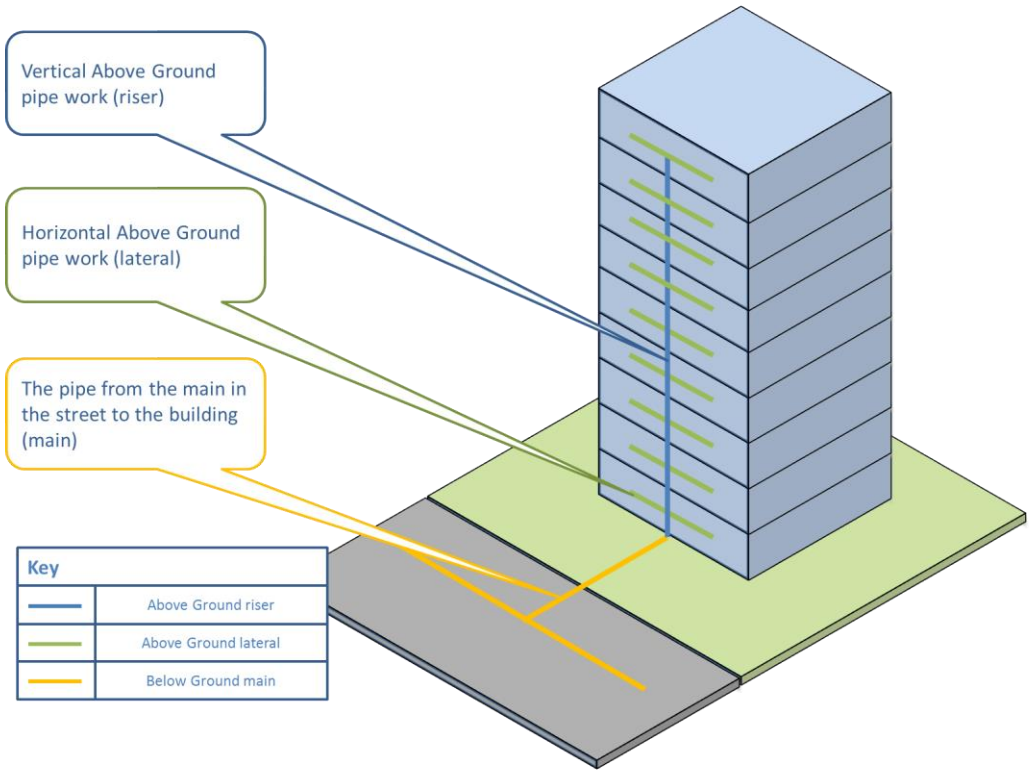


Figure F1 – Riser configuration and definitions

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).

Appendices - Detailed Asset Assessments

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.

Please note that a riser fracture failure is rare and so it is not modelled in NARMs.

F2.2. Risers Consequence Measures

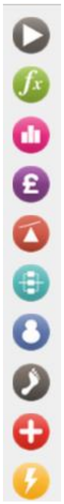
Consequence measures have been identified in relation to Risers in accordance with the process identified in section 3.5 of the main methodology and include the following:

- 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.

Appendices - Detailed Asset Assessments

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 Risers. 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.

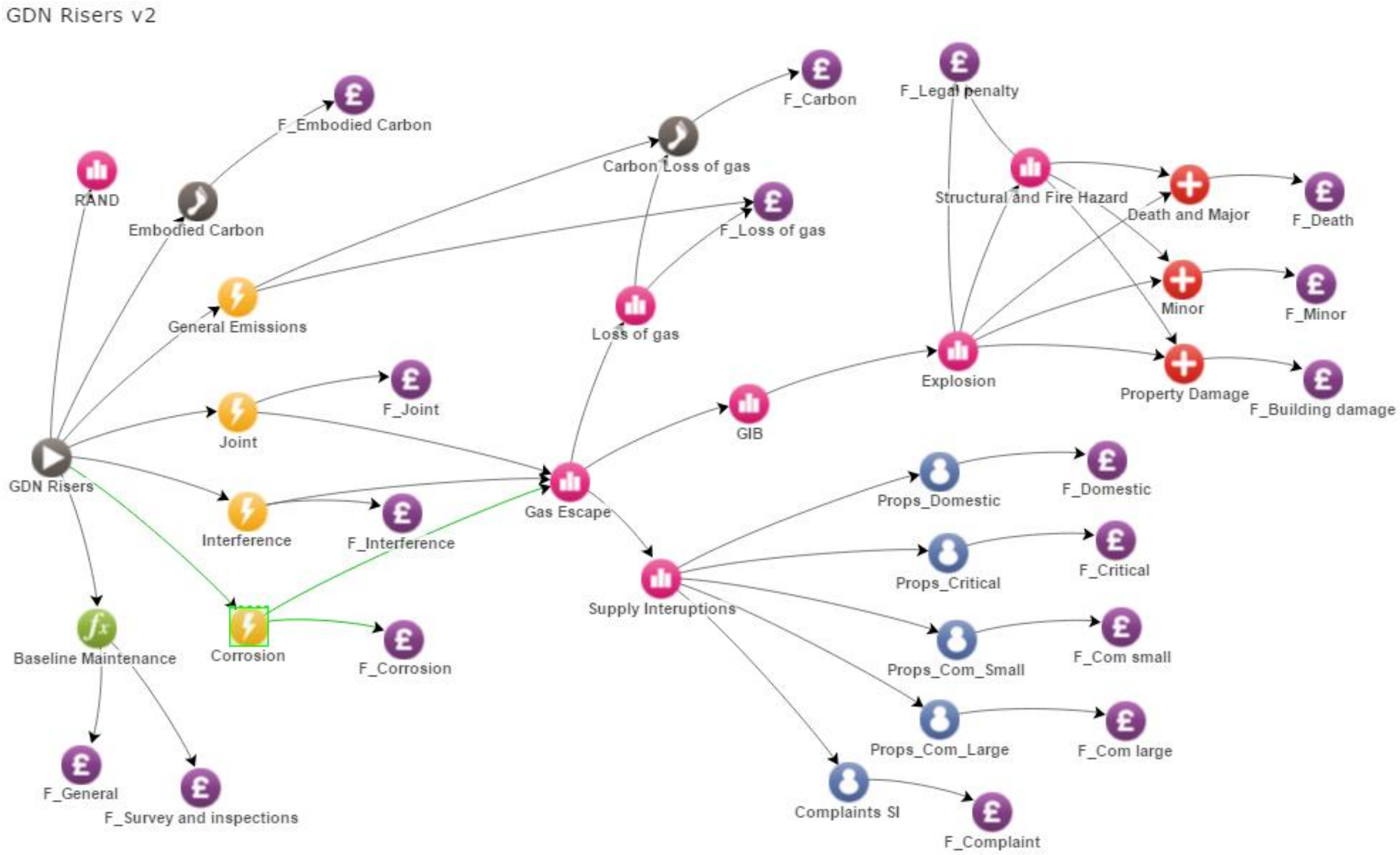


Figure F3 – Risers Risk Map

Appendices - Detailed Asset Assessments

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.

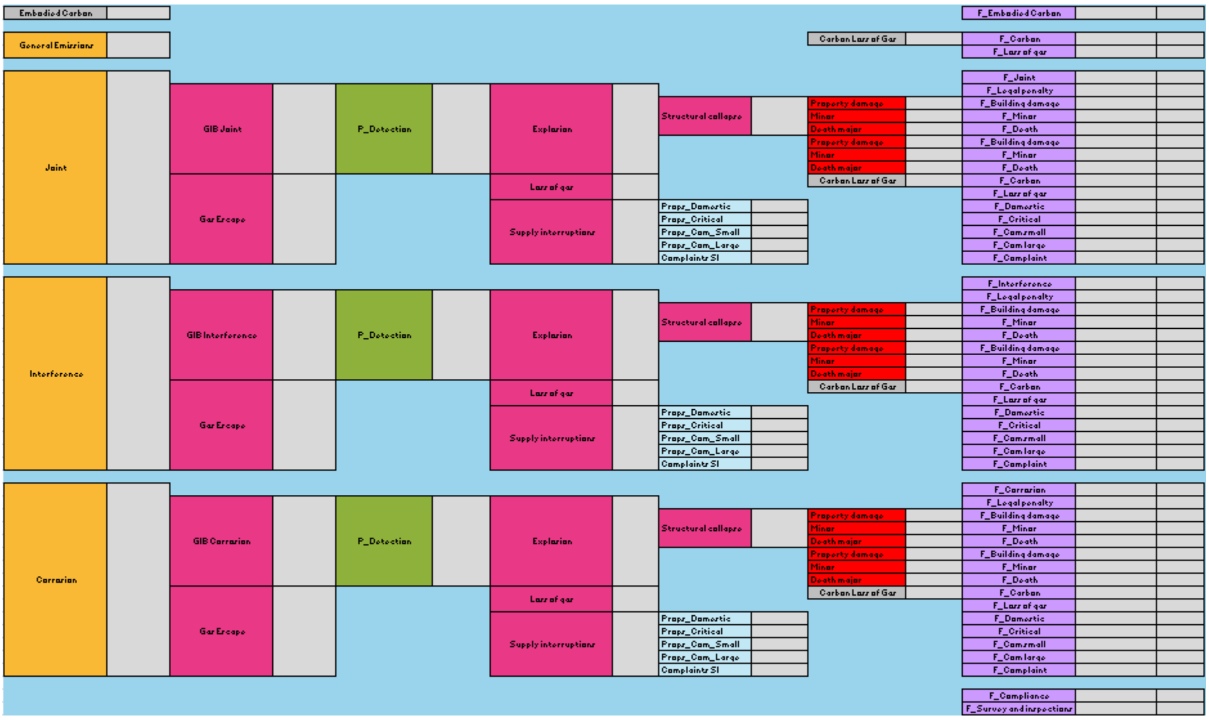


Figure F4 – Risers Risk Template

Appendices - Detailed Asset Assessments

F2.5. Risers Data Reference Library

As per Section 3.7 of the main methodology, the following table gives a description of data required for nodes on the Risers Risk Map (Event Tree). Demand mix generation is a longer-term evolutionary piece which GDNs will need to consider due to the inherent adjustment to baseline monetised risk as a result of customer demand changing. Customer number updates can be reflected in the modelling base data that supports asset investment decision making, therefore it can be undertaken periodically where required. A customer base data refresh will be undertaken after the completion of the current GD2 price control and at the completion of later price controls as net zero impacts effect methane gas distribution use.

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 Riser properties assumed to be domestic.	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	Common

		for payments under GS1 is £1,000. 5 properties x £1,000 = £5,000	
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 the cost of repair following the failure of a to riser orand lateral due to corrosionby 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 Riser properties assumed to be domestic.	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 £1,000. 5 properties x £1,000 = £5,000	Common
F_Interference	GDN specific cost data relating to the cost of repair following the failure forof a riser or lateral due to interference damageby 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	GDN specific cost data relating to the cost of repair following the failure of a riser or lateral due to a joint failure. (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_Legal penalty	Cost of legal enforcement and penalty payments following ignition/explosion	Default/assumed value agreed with SRWG based on historical incidents (£1m).	Common
F_Survey and inspections	Cost of 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, interference or joint failure	Value of 1 used as a multiplier to enable the grouping/summation of the probability of corrosion, 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 Intermediate pressure for which no data currently exists.) Value used is 33.2m^3.	Common
Minor	Number of minor injuries given explosion	Data taken from company riser surveys (based on type of building and number of stories).	Common
Property Damage	Number of properties damaged given explosion. Based on number of storeys. Outlined as [PROPERTY_DAMAGE] in section F3.4.8.	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
People at Risk	Number of people at risk of Death or injury within the building linked to the riser. This is outlined as [PEOPLE_AT_RISK] in section F3.4.8.	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. Outlined as [SCORE_GAS_RELEASE] in section F3.4.7.	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.

The surveys undertaken by GDNs are consistent and aligned with best practice outlined in (IGEM/G/5 Edn2). This consistency and alignment between GDNs mean there is not perceived to be any benefit to GDN specific annexes for risers.

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_STRENGHTENED	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 leakage data for each GDN varied, from 4 years for Cadent to 6 years for SGN and WWU. Leakage 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 Cadent. 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)

Where:

- 0.000002403 and 0.000013265 are initial leakage rates (Number/Asset/Year) depending on material type of riser asset (PE or non-PE) where the failure is by joint failure.
- 0.00001 and 0.00000365 are initial leakage rates (Number/Asset/Year) depending on material type of riser asset (PE or non-PE) where the failure is by third party interference.
- 0 and 0.00027562 are initial leakage rates (Number/Asset/Year) depending on material type of riser asset (PE or non-PE) where the failure is by corrosion.
- Asset length – length of riser.
- Joint_det_pe – deterioration in the numbers of leaks per asset by joint failure for PE risers (% per year).
- Joint_det_nonpe – deterioration in the numbers of leaks per asset by joint failure for non-PE risers (% per year).
- DYear – number of years since initial failure rates determined.
- Leakage rate – initial leakage of gas in m^3/ year for the riser.
- Emissions_det – deterioration in the loss of gas (%/year).

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 and failure rate for Corrosion on PE 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 gas in building (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.

The Hazard Point score is calculated using the below function, based on the C-R258 Riser Risk Ranking Model Version 2 used by Northern Gas Networks:

Probability of an explosion given a gas in building (GIB) = score_param_a_haz*exp(score_param_b_haz*SCORE_HAZARD_POINTS / hazard_normal)

Where:

score_param_a_haz = 0.0002

score_param_b_haz = 5

hazard_normal = 331

SCORE_HAZARD_POINTS is calculated for each riser from the flowchart in Appendix 3 of the PIE report (Risk Ranking Model for Prioritization of Risers in High Rise Buildings Version 2).

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)

Where:

- Ronan Point Construction types – multi-occupancy building construction types which are susceptible to successive collapse on explosion.

- Wall strengthening – mitigation used to limit successive collapse of Ronan Point Construction types on explosion.

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 multiplied by 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 with a reduced find and fix time. Refer to data reference library in Section F2.5 for more details on loss of gas.

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.

Appendices - Detailed Asset Assessments

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 – repair of a riser or lateral following leakage.
- Survey – survey carried out on riser and laterals to determine base data required for monetised risk calculations.

'With intervention' activities:

Number	Description	Definition	Change in Failure Rate
Intervention 1	Riser Replacement (with PE)	Replacement of riser/lateral with PE (unlikely to be chosen due to HSE constraints).	Corrosion failures per year = 0. Interference failures set to PE factor Joint factor set to half of PE factor
Intervention 2	Riser Refurbishment (corrosion remediation)	Partial replacement, painting, microstop, nuflow and serviforge.	Deterioration reset to start of curve (Dyear set to Int year) Initial leakage failure rates are halved
Intervention 3	Riser Replacement (Like for Like)	Replacement of riser/lateral (most likely with Steel). Not PE.	Deterioration reset to start of curve (Dyear set to Int year) For non-PE this deterioration resets to half the starting factor.
Intervention 4	Riser Decommissioning	Decommissioning, including buyout (no replacement)	All failure rates set to zero post intervention.

Table F4 – With and Without Investment interventions for Risers

Intervention lives for Riser assets for GD3 will be provided in the NARM GD3 BPDT template in Q3 2024. The below table and methodology will be updated upon the final NARM submission.

Number	Description	Intervention Life	Rationale
Intervention 1	Replace PE		

Intervention 2	Replace like for like		
Intervention 3	Corrosion protection		
Intervention 4	Permanent Isolation		

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 of 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 capital cost (Capex) is variable each year based on the length and number stories of each riser replaced or refurbished and is shown in Figure F5 below.

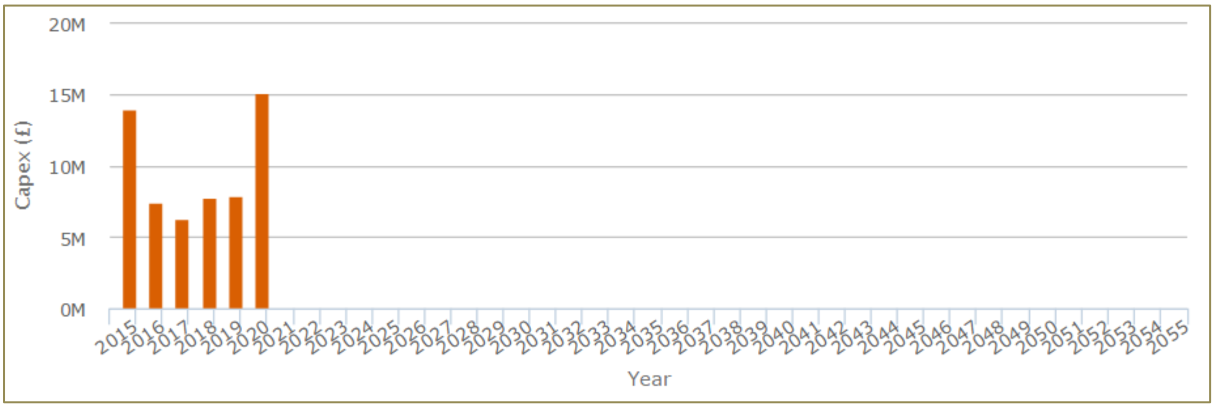


Figure F5 – Example Annual Capital Expenditure for Replacement of Risers

The baseline level of cumulative monetised risk for each financial risk node is shown below for both with and without intervention.

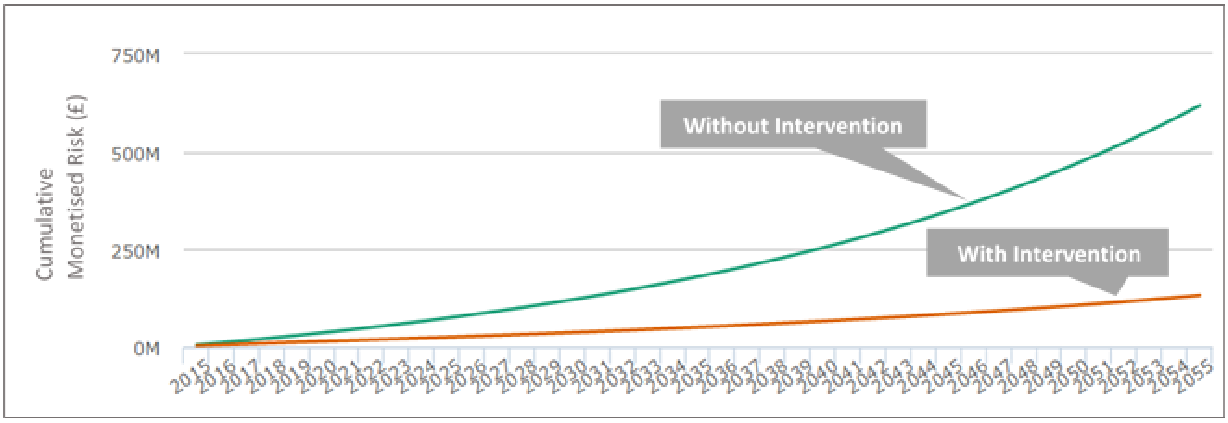


Figure F6– Example Pre and Post cumulative Monetised Risk value of Risers

This gives a discounted net benefit that has a payback of approximately 12 years, where the lines cross in Figure F7. A full set of results is provided in table F5 below.

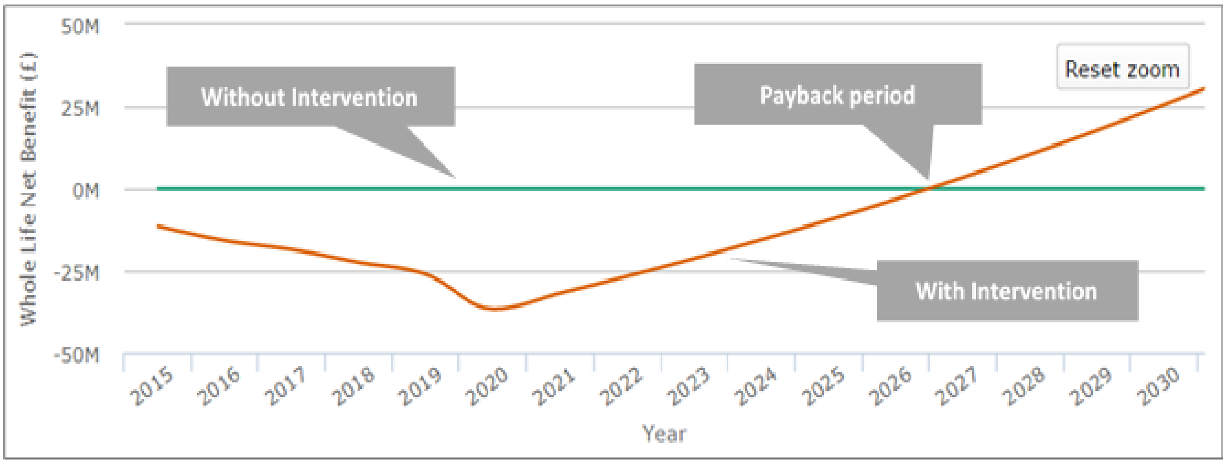


Figure F7 – Example Discounted benefits per annum for planned Riser replacement

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.

Appendices - Detailed Asset Assessments

Appendix G – Improvements to Governor and Pressure Control Failure Rate and Deterioration Modelling

G1. Introduction

G1.1. Background

Gas pressure regulating systems are built with a high degree of redundancy allowing for 1 or more failures to occur on a site before any downstream service impact occurs. According to best practice[9], a reliability modelling approach was developed which can be used to predict service impacts and be used within the existing NARMs (Network Asset Risk Metrics) methodology. The new approach was applied to 4 pilot sites in 2020 for Wales and West Utilities.

This latest development uses a modelling capability called System Dynamics which has a flexible architecture allowing the pressure regulating system operational logic to be expressed and modified easily. Importantly, the tool allows for many different configurations to be modelled in a systemised and automated way with results data exported for further analysis.

The outcome of the reliability modelling approach is to produce over and under pressure performance curves that deteriorate over time and accurately represent the effects of redundancy within a configuration (multiple streams and regulators), fail safes (slam shut), dormant failures, reactive and routine inspections.

This replaces the previous approach adopted for the **Under and Over Pressurisation failure modes** only, for both Governors and the Pressure Control elements of PRS/Offtakes assets. Filters, Preheating, Odorant and Metering use the same approach as documented in previous versions of the Methodology, but with reformulated deterioration curves as per Appendix H. Other failure modes (e.g., emissions, control systems failures, corrosion) that are not included in the reliability model are handled through the same Failure Modes and Effects Analysis (FMEA) approach as used before.

G1.2. Overview of approach

The new approach models the reliability of the pressure regulating function at the system level. Pressure regulating equipment (component level) are modelled at a system level to ensure that any redundancy in the configuration is accounted for and is simulated in daily timesteps to show durations of outages of individual components. This avoids over or under estimating the impacts of component failure.

The components included in the pressure regulating reliability model are

- Active Regulator
- Monitor Regulator
- Slam Shut Valve

[9] Institute of Asset Management, Subject 16: Reliability Engineering (https://theiam.org/knowledge-library/subject-16-reliability-engineering/)

These are arranged in series within a stream. There can be streams with fewer components, and there can also be multiple streams on a system.

Each component has a failure model where the rate of failure is determined based on the age or condition effective age.

The failure events and downtime of components are simulated. The model makes use of rules to represent how the system operates on a daily timestep over a period 60 years.

When certain sequences of component failure occur and coincide on the same day, an under or over pressure event will be recorded in the model. Depending on the configuration rules, a reactive inspection / visit to site may be triggered in response to failure. Otherwise, any "dormant" failures are picked up on routine inspection visits and repaired at that point.

With multiple components that can fail each day, and remain in a dormant failed state, system under or over pressure events can only feasibly be determined using a simulation modelling tool such as System Dynamics. This uses Monte Carlo sampling to evaluate many combinations of different components failing over sequential timesteps.

Other assets that are present on a pressure regulating site have failure impacts themselves but can be treated as having a direct impact when they fail which is not dependent on the system redundancy/reliability and fail-safe configuration of the regulating system. These assets such as valves, filters and pre-heaters that are not part of the regulating function are included in the NARM Long Term Risk assessment using the traditional FMEA (Failure Modes and Effects) approach.

G1.3. Purpose of Document

The purpose of this document is to describe the

- Different system configurations were considered.
- Assumptions and rules used that:
  - alter the reliability of the system.
  - lead to an event that can be classified as either under or over pressure at the outlet of the system (or site)
- Outputs and the analysis to produce curves to be used in the long-term risk assessment.
- Calculation steps to apply the curves to predict over and under pressure from a pressure regulating system on a Governor site or PRS/Offtake system.

G2. Equipment / Component Failure Rates

G2.1. Overview

Both the system reliability simulation model and the FMEA models are built using the same equipment failure models. This ensures consistency when the two approaches are combined within the NARM Long Term Risk assessment process. Fault and consequence data has been pooled from the Networks to derive:

- Failure rate and deterioration models
- Fail open and closed proportions given a component failure.

- Reactive repair times of failed components when detected.

G2.2 Failure rate and deterioration

The curves to predict failure of components are based on formal elicitation of expert views carried out as part of the initial NOMs Methodology development (see Appendix H) where the data are combined to derive a bath-tub curve consisting of:

- Flat and steady state rate of failure, **A**, from new until it reaches an age (effective) that is equal to **gamma***.* At this point, deterioration in the failure rate begins.
- The failure rate deteriorates based on an exponential curve that has been fitted to the same elicited expert data.
- The terminal rate of failure (**FR_EOL**), or the mean time between failure (MTBF) at the end of asset life (EOL): The deterioration curve continues until it reaches a "terminal" rate of failure which is derived from elicited data for expected end of serviceable life or nearing the end of its useful life. At this point, the component has reached its maximum failure rate and remains at this rate.

The derivation of these failure rate and deterioration curves can be found in Appendix H.

G3. Reliability Modelling

G3.1. Overview

Gas pressure regulating installations are built with a large degree of redundancy to allow for varying load demands, equipment failure and maintenance downtime. Because of this, equipment failures do not always lead to downstream impact or consequence. To account for this a reliability approach has been developed and applied to model the frequency of over or under-pressurisation events.

Reliability simulation models within a System Dynamics tool have been built to model the available pressure at the outlet of the site. The models are built up from individual equipment items where every regulator and slam shut is represented and can fail in either an open or closed manner. An over or under pressure event is deemed to occur when the system outlet allows gas to flow through it at a level above or below a required level representing the set point pressure.

The figure below shows a simplified view of the system model for the pressure regulating function of either a Governor site or a PRS/Offtake site.

Each stream consists of key components such as regulators and slam shuts configured in streams which can be "excluded" from the model simulations where appropriate to provide the configuration required. The model is set up so that one or more streams can be included.

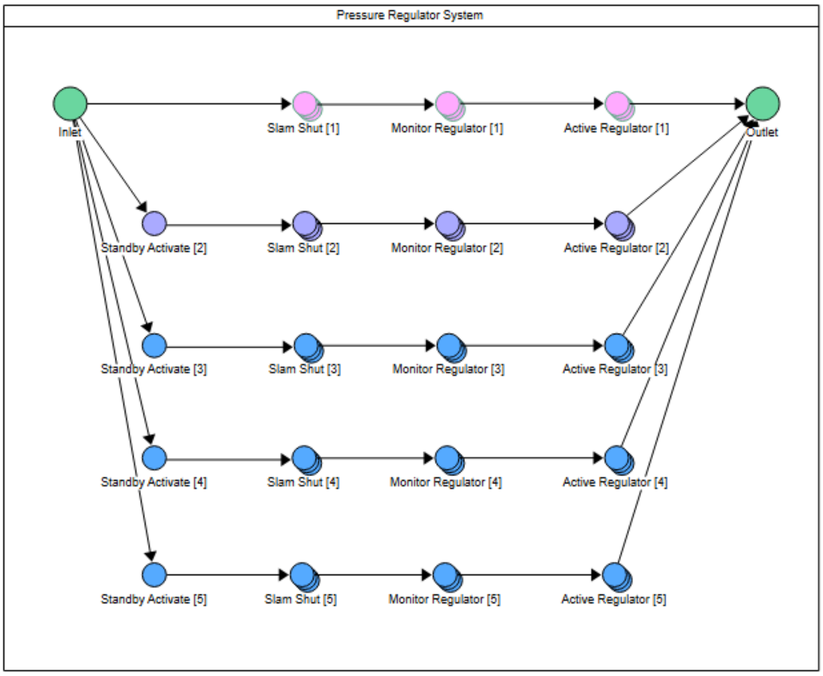


Figure G-1 Example of an RBD for a Pressure Regulating site

A Monte Carlo simulation run of the system model is undertaken in daily timesteps for 21,900 days. 1000 simulation runs are undertaken for each potential configuration. The count of over and under pressure events is recorded from the Monte Carlo runs and an average count of events occurring in each year is calculated across the 1000 runs. This provided the data to generate curve fits to represent how the over and under pressure events (i.e., service impacts) increased over time as the equipment items deteriorate.

G.3.1.1 Physical configuration

- Regulators/slam shuts have two failure modes, they can fail either open or closed each with a different outcome.
- One working (i.e., duty) stream with none, one or more standby streams.
- One active (A) regulator in each stream with potentially the back up of a monitor (M) regulator which is only operated when the active regulator is non-operational i.e., unable to operate and is in a failed open or closed state.
    - Each stream may also have a slam shut (S) to shut the flow of gas when the stream regulators have all failed open.
    - The model starts in year 1 where all components are new and increases in age over the 60-year simulation period. This age is equivalent to the actual age or condition effective age.

G.3.1.2 Operational assumptions

- There is one working stream where the active regulator is sufficient to regulate the pressure on its own. All other streams are standby.
- The monitor regulator will become the working regulator when the active regulator fails open

- If either the active or monitor regulator fail closed, the stream will fail closed and automatically switch to a standby stream if available. If not, then an under-pressure event will be recorded
- If the active and monitor regulator in the working stream both fail open (or in the case where there is only an active regulator) then the slam shut will be activated
  - The slam shut will stop the flow of gas, and an under-pressure event will be recorded.
  - If the slam shut also fails open, then an over-pressure event will be recorded.
- Multi-stage regulators have not been explicitly modelled to keep the number of alternative reliability modelling simulations to reasonable levels. It is assumed that the active or monitor regulator can achieve full pressure reduction without the need for incremental pressure reductions. This was agreed to be a reasonable assumption and more sophisticated pressure reduction arrangements could be implemented through future Methodology updates,

G3.1.3 Dormant Failures

- A dormant failure is when a component (any regulator or slam shut) that is not operating fails but remains "hidden" until the time of inspection or maintenance (at which point the defect is observed), or when it is required to operate (and a fail open or closed failure occurs).
- For example, within a working stream, when the active regulator fails open, the monitor regulator and slam shut may both be lying in a dormant fail open state as a "hidden" failure. In this situation, the system will experience an over pressure event as neither the monitor regulator or the slam shut can regulate or shut down the stream to avoid the over pressure event.
- Dormant failures on either the working or standby streams remain hidden until the next planned or triggered inspection

G3.1.4. Planned or Triggered Inspections

- Planned routine inspections occur on a defined regular interval (one per system or site for simplicity) e.g., every 12 months or 36 months etc.
- Inspections or site visits can also be reactive (triggered) because of detecting abnormal flow in a stream, or at the site level i.e., site output.
- Triggered inspections are assumed to have a 1-day response time.
- During inspection whether routine or triggered, any failures will be "repaired" with a repair time of 25 days. The assumed repair duration is based on information obtained through private correspondence with National Gas Transmission who elicited response times from many operational teams across the company in preparation for their NARMs probability of failure assessment. We looked at the worst case where spares are not readily available, which suggests 30 days for slam shut, 12 days for regulator. The average between the two is 21 days which was rounded up to 25 days to err on the side of pessimism.

G3.1.5. Repair of Failed equipment / Components

- The inspection process evaluates the operational integrity of each stream, identifying any that have deviated from normal.

- Repairs are prioritised to streams in a deviated state.
- To facilitate these repairs, all components within the affected stream are set to an "out of service" status for the repair duration. This strategic pause is designed to minimise the likelihood of under pressure events that could arise during the maintenance period. In scenarios where the site comprises of multiple streams, this protocol serves to almost eliminate service disruptions during repairs, and fully captures the heightened risk level. Conversely, in single-stream configurations, the model presupposes that network management strategies will be implemented to manage any interruptions in service caused by scheduled maintenance activities.
- The repair task brings the equipment back on-line but does not alter its age or probability of failure.

G.3.2. Site and system configurations

G.3.2.1. Configurations Modelled

A review of the configurations present in the GDNs' asset databases was undertaken and a standard set was agreed. The configuration is applicable at site level for Governors and at system level for PRS/Offtakes. Where a Governor is on a PRS site it is treated as a Governor. The key aspects of each configuration are shown below:

Configuration variants	Value	Description
SITE TYPE	Governor or PRS/Offtake	Whether it is a governor or a pressure regulating assets on a PRS/Offtake
STREAMS	1 to 5	The number of streams
ACTIVE	Yes or No	If each stream contains an Active (A) regulator
MONITOR	Yes or No	If each stream contains a Monitor (M) regulator
SLAMSHUT	Yes or No	If each stream contains an Slamshut(S) valve
INSPECTION_MTHS	6, 12, 24, 36, 48, 60, 72, 96	The planned inspection interval in months
DETECTION_LEVEL	Site or Stream	Whether the pressure anomaly due to failures are detectable at site (SITE) or stream (STR) level

Each configuration is modelled separately with a starting age of 0 and simulated for 60 years.

This gives a total of 114 and 128 distinct configurations for governor and PRS/Offtake sites respectively giving a baseline total of 242 distinct configurations to be modelled.

G3.2.2. NARMS Interventions – Post Intervention Models

The following interventions have been identified for inclusion in the NARM LTR assessment which impact on the reliability of the pressure regulating system. **These have been referenced differently to the preceding asset-specific sections to enable a unique reference to be assigned to Governor and PRS interventions**.

Ref.	Intervention	Asset Type	Definition
17a	Governor refurbishment (major)	Governor	Improving the governor condition by painting, reducing corrosion and overall deterioration (whole site).
17b	Governor refurbishment (minor)	Governor	Improving the governor site condition by painting, reducing corrosion and overall deterioration (partial site).
18a	Regulator replacement	Governor	Replacement of complete unit including control system. Resets asset age to 0, failure rate then represents an initial failure rate on deterioration curve. Excludes kiosk.
20	Service Governor replacement	Governor	Replacement of complete unit within kiosk
18b	Regulator (pressure reduction systems - single stream) replacement	Governor	Replacement of one of multiple streams (assumes all streams carry equivalent risk. Resets all assets on working stream to effective age of zero. Other streams continue to deteriorate.
67a	PRS refurb (major)	Pressure Reduction & Filtration	Limited replacement of main components e.g. the slam shuts being replaced.
67b	PRS refurb (minor)	Pressure Reduction & Filtration	Partial refurbishment of all main components on pressure reduction system (monitor, active, slam).
68	PRS replacement	Pressure Reduction & Filtration	Total replacement of all pressure reduction streams on the specific system from inlet to outlet

Note: Other interventions have been specified by the GDNs which can be configured as variations of the above, e.g., full site rebuild which includes replacement of the pressure regulating equipment

G3.2.3. Post Intervention Under and Over Pressure Events

The simulation results from each of the configurations are used to develop curves representing the expected frequency of under and over pressure events versus age (or condition effective age). The age is indicative of the average age of the site (governors) or the system (PRS / Offtakes).

These curves are referred to as Reactive but can be used to represent the reliability of the system post intervention by resetting or modifying the actual age or condition effective age. This is applicable to all interventions in the table above except for Intervention 18b.

The governors have an intervention type (18b) that requires the replacement of all components of a given stream to be undertaken. The reliability and frequency of over / under pressures of the site going forward after intervention will depend on the age of the site at the time of the intervention.

This requires the simulation models to be run from an assumed start age for the site, except for the stream(s) being replaced and reset to zero age. Given the numbers of potential intervention timesteps (60 years), and the number of distinct governor configurations with multiple streams (88 no.) up to 5 streams, the number of additional models is excessive both in terms of simulations required and LTR application practicalities.

It was decided that a pragmatic approach considers replacement of the working (duty) stream only, at 5-year age intervals, i.e. 1 to 5 years (start age assumed to be the mid-point of the band, so age=3 years); 6 to 10 years (start age assumed to be 8); up to 26 to 30 years (start age 28). A final top end start age was also run to test the sensitivity of the model which was 50 to 60 years (start age 55). All ages greater than 50 years were assumed to have a start age of 55 years.

A total of 616 additional models were run to produce data to represent the benefits of intervention 18b alone.

G.3.2.4 Final Configuration List

The final list of configurations and curve fitting results can be found in the specification documents developed to support updates to DST models. There are a total of 858 different combinations where 242 are distinct configurations and the remainder represent the intervention option for working stream replacement for the multi-stream configurations.

G4. Reliability Model Outputs

G4.1. Simulation outputs overview

Each configuration has been run for 1000 simulations over 60 years of daily timesteps.

The flow on the outlet or the active monitor on the working stream is tracked for deviation from normal which is nominally set for the model. When the flow deviates and is higher than normal, a high-pressure event is counted. Similarly, a low-pressure event is counted when the flow deviates and is lower than normal.

An event that has a duration over more than one day is counted as one event.

The average number of low and high events each year is calculated across 1000 simulations. An example of the results data is plotted below for all the single and 2 stream governor sites.

"A" denotes Active regulator only; "AM" denotes Active and Monitor regulators only; "AMS" denotes Active and Monitor regulators with Slam Shut valve.

G4.2. Comparing single and 2 stream configurations

Examples of reliability runs are shown below for GOV_1_AM, Under and Over Pressure, respectively. The dotted line is the modelled curve fitted to these runs where every data point on the solid lines is a single reliability run. Each curve reflects a different period between maintenance inspections.

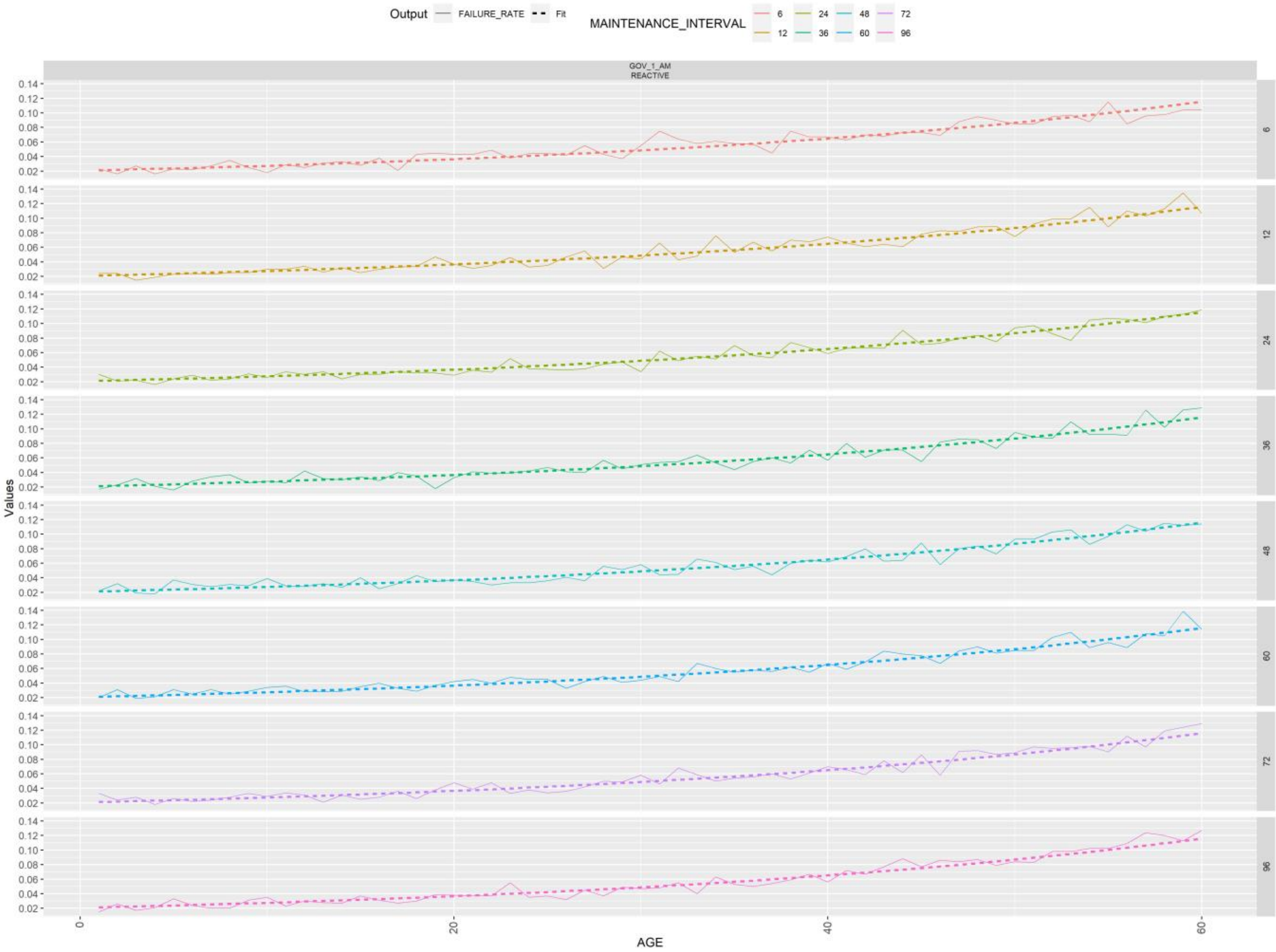


Figure G-2 Examples of reliability modelling runs and curve fits for GOV_1_AM, Under Pressure.

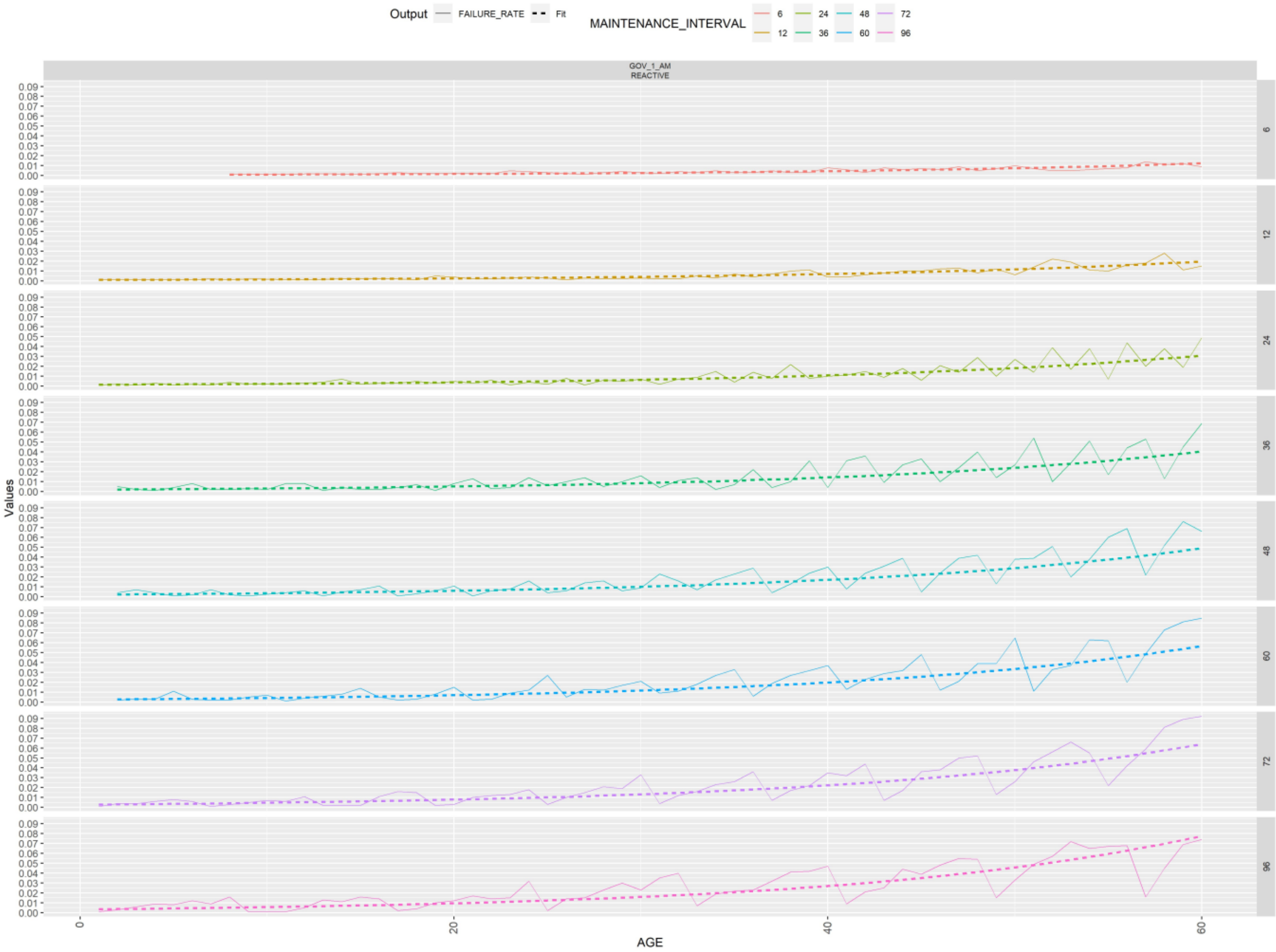


Figure G-2 – Examples of reliability modelling runs and curve fits for GOV_1_AM Over Pressure.

Notable observations on single and 2 stream configurations:

- As planned maintenance interval lengthens, typically frequency of events increases for the multiple stream configurations. This suggests that planned inspections have a positive effect in general on under and over pressure events. Reliability runs become noisier for longer maintenance intervals as a site visit is assumed to identify dormant failures that have arisen since the previous visit.
- Focusing on the single stream configurations and under pressure events, the frequency of events appears highest for AS, then AMS then AM then A. This seems counter intuitive. However, the potential for the stream to “close” increases as there are more components that could fail closed. Also, to protect against high pressure, a slam shut operates and shuts the flow, which is again counted as a low-pressure event, therefore streams with slam shuts have a higher likelihood of a low-pressure event.
- Focusing on the 2 stream configurations, those without slam shuts show hardly any under pressure events. In contrast, the configurations with slam shuts appear to have increased the likelihood of low-pressure events as the slam shut is operated. This suggests that on 2 stream sites, the under-pressure events are occurring due to the slam shuts operating to avoid over pressure events rather than due to equipment failing closed. For equipment

failing closed to cause an under-pressure event requires the standby streams to also fail closed when the working stream has failed closed.

G.4.3 Comparing Active Monitor configurations 1 to 5 Streams

The following charts show the impact of increasing numbers of streams for Governor "AS" sites, for fail open and closed modes respectively.

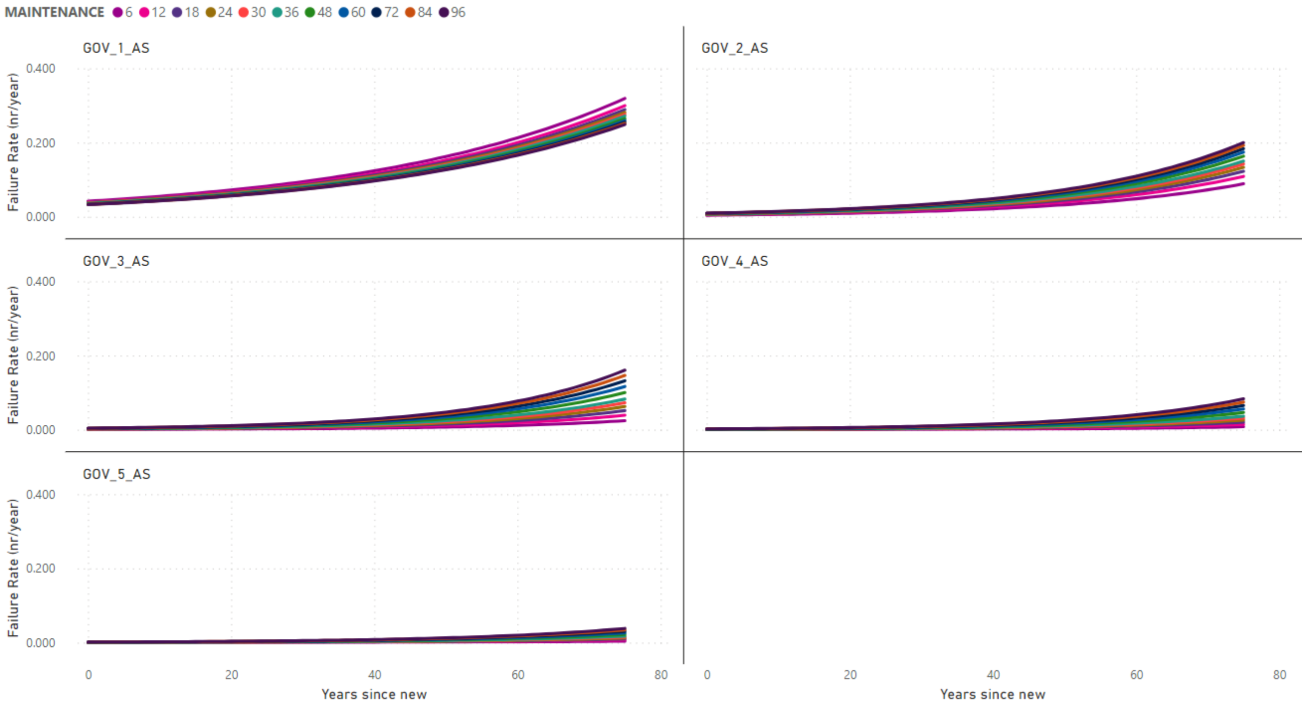


Figure G-4 Fail Closed failure and deterioration rates for Governor "AS" configurations with increasing numbers of streams. Each line represents a different maintenance interval

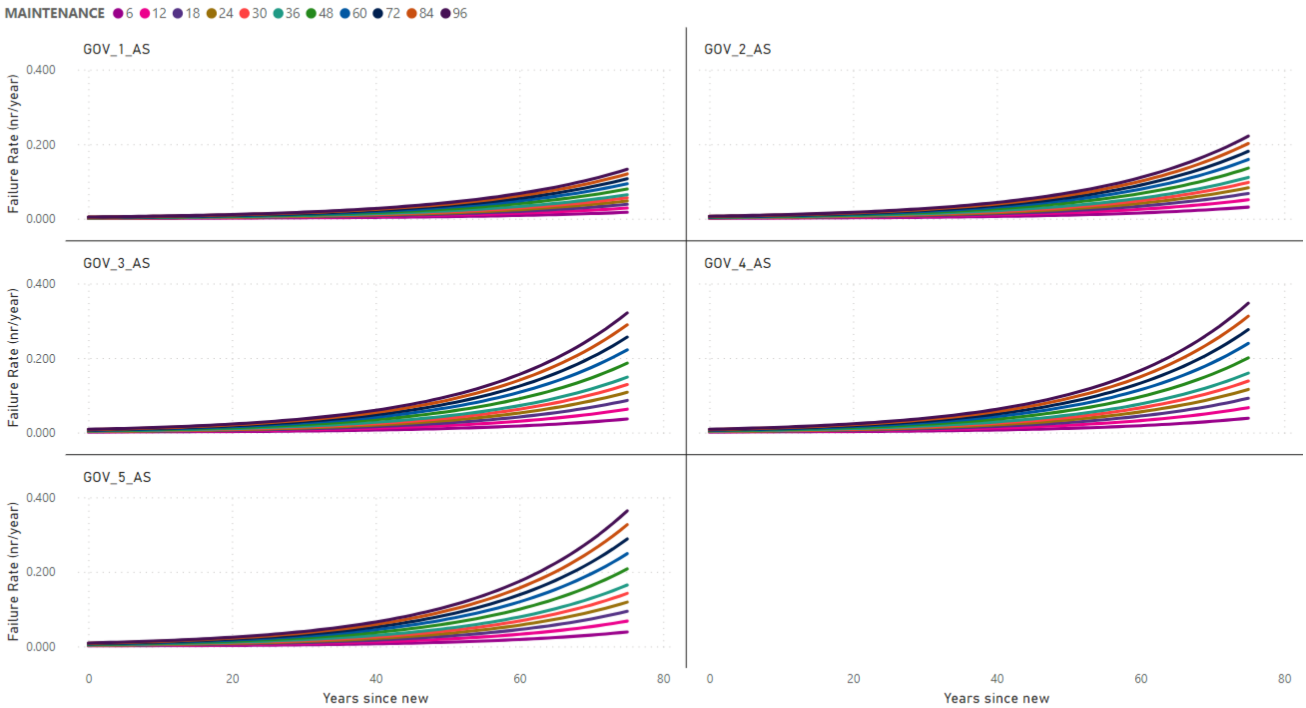


Figure G-5 Fail Open failure and deterioration rates for Governor "AS" configurations with increasing numbers of streams. Each line represents a different maintenance interval

It can be seen that for Fail Open the likelihood of a failure reduces as the number of streams increases, as would be expected due to resilience. For Fail Closed, the opposite trend is observed. This is because there is a modelled interaction between Fail Closed and Fail Open modes. If a Fail Closed occurs, this triggers an additional site visit during which it is assumed that a fault that could result in a Fail Open is identified and resolved. The time between inspection/maintenance visits is more significant when predicting failure rates than the number of streams. This is partially due to the assumption that if a stream fails, the other streams can be readily configured to take the load of the unavailable stream.

G4.4. Benefits of partial site or system replacements (Working Stream)

The Methodology has been set up to model partial replacement of a pressure reduction system, or in other words, replacement of one of multiple streams (where more than one stream exists). The assumption is that this will always be the working stream of the system (or site for Governors), where other streams are in standby mode ready to be switched over should be working stream become unavailable.

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Based on the reliability model runs, the total number of under and over pressure events over the 75-year simulation period, post partial site intervention, increases only marginally with the age of the site at time of intervention.

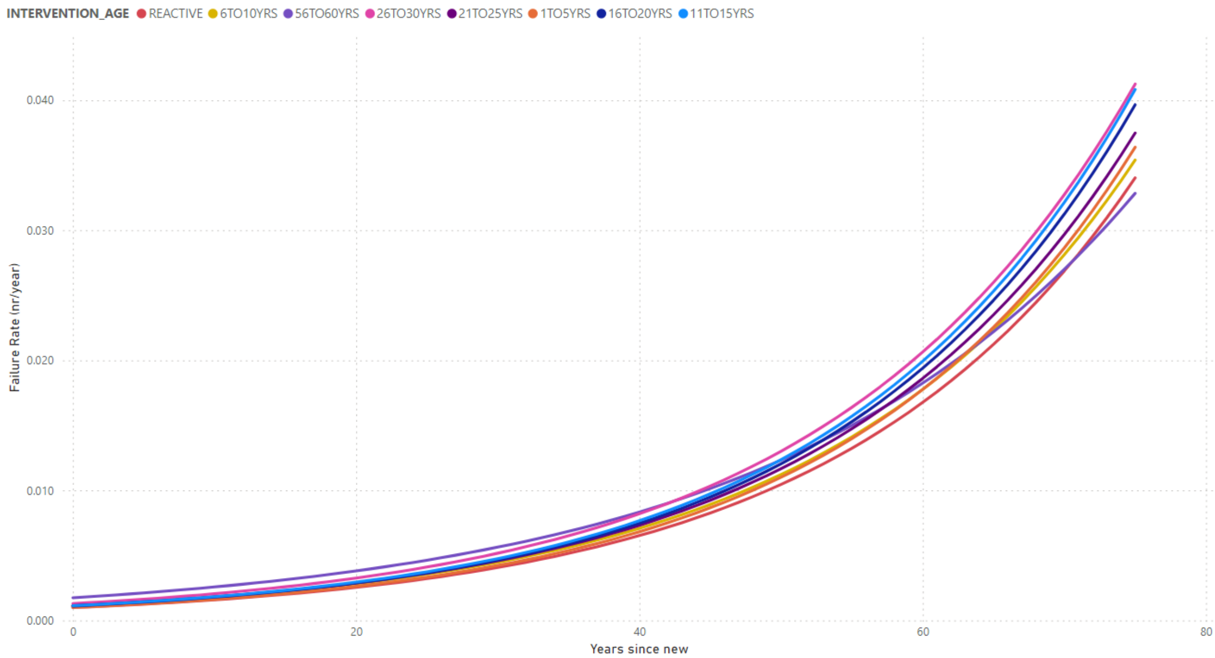

Figure G6 - Fail Open events for Governor 2AMS sites showing the low marginal increase in failure rates post-intervention as the remaining site age at time of intervention increases for partial site replacements.

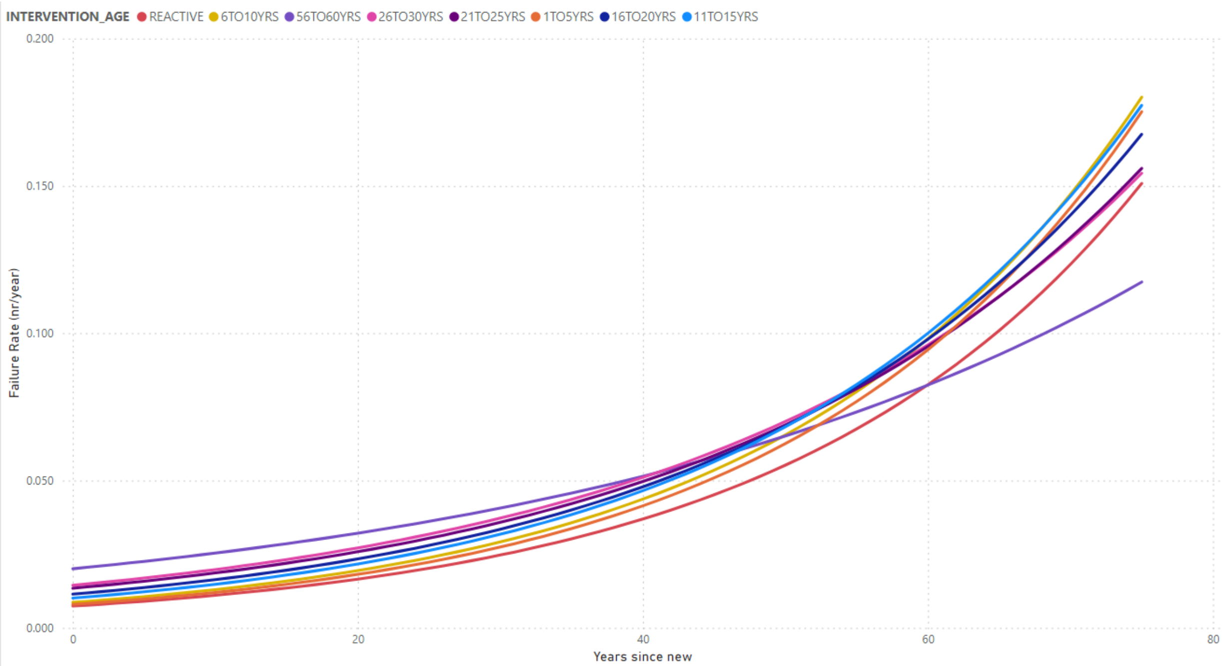

Figure G-8 Fail Closed events for Governor 2AMS sites showing the low marginal increase in failure rates post-intervention as the remaining site age at time of intervention increases for partial site replacements.

This suggests that the benefit of replacing just the working stream is almost as effective as replacing all the assets on the regulating stream. This is predominantly driven by the assumption that all streams other than the working stream are waiting in standby to be available when required. If this is not the case for certain sites, then further modelling may be needed to represent scenarios where loading is shared across multiple streams.

G4.5. Overall impact of Configuration and Variants on over and under pressure performance

The following observations can be made:

- Increasing the number of streams lowers the risk of under pressure events but shows little benefit for over pressure events based on the current modelling assumptions.
- Planned maintenance intervals have a significant impact on prevention of over pressure events and to some degree on under pressure events
- Replacing the working stream has almost the same benefits as full replacement for over pressure but are significantly less for under pressure failures, particularly where a slam shut is present.

G5. Over and under pressure events – Model curves

G5.1. Applying formal statistical fitting process to simulation results

As an example of the curve fitting to the results from the simulation runs, figures below show the data (solid lines) and curve fits (dotted lines) for the configuration 2 Stream, Active Monitor. Each tile represents the results averaged over 1000 simulations with each row representing the maintenance interval and column representing the intervention age. The y-axes are the numbers of predicted over-pressurisation failures per year. The curves become increasingly noisy as maintenance intervals increase as there are more dormant failures identified (as more have had time to accumulate since the previous visit).

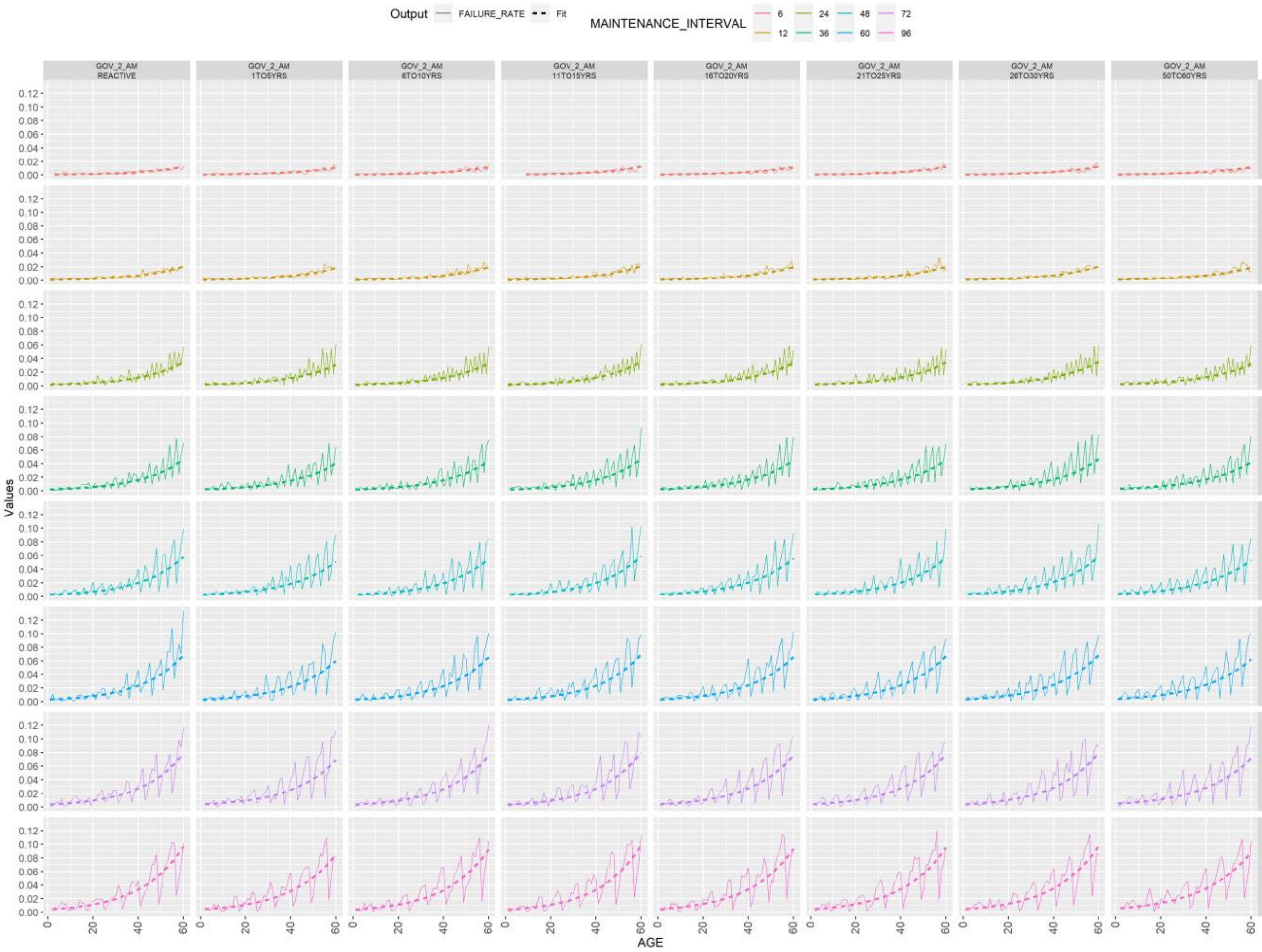

Figure G-9 Over Pressure Simulation Results and Curve Fits by INTERVENTION_AGE and Planned Maintenance Interval for GOV_2_AM

The chart below shows similar information for under-pressure failures. This time the y-axis relates to the predicted annual number of under-pressurisation results with each row representing the specified maintenance interval and each column representing the age of the asset at time of intervention. As before, each data point relates to a single reliability model run.

Figure G-10 Under Pressure Simulation Results and Curve Fit for GOV_2_AM

G5.2. Applying the curves to predict under and over pressure events

The curve fitting process has been applied to all the results from the simulation runs for the different configurations and variants.

G5.2.1. Model Configuration Variants

The model configuration variants are shown in the table below.

Model variants	Value	Description
CONFIG	GOV_1_A	Governor single stream Active regulator
	GOV_1_AM	Governor single stream Active & Monitor regulators
	GOV_1_AMS	Governor single stream Active & Monitor with Slamshut valve
	GOV_1_AS	Governor single stream Active with Slamshut valve
	GOV_2_A	Governor 2 stream Active regulator
	GOV_2_AM	Governor 2 stream Active & Monitor regulators
	GOV_2_AMS	Governor 2 stream Active & Monitor with Slamshut valve

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Model variants	Value	Description
	GOV_2_AS	Governor 2 stream Active with Slamshut valve
	GOV_3_AM	Governor 3 stream Active & Monitor regulators
	GOV_3_AMS	Governor 3 stream Active & Monitor with Slamshut valve
	GOV_3_AS	Governor 3 stream Active with Slamshut valve
	GOV_4_AM	Governor 4 stream Active & Monitor regulators
	GOV_4_AS	Governor 4 stream Active with Slamshut valve
	GOV_5_AM	Governor 5 stream Active & Monitor regulators
	GOV_5_AS	Governor 5 stream Active with Slamshut valve
	OFFPRS_1_AMS	PRS/Offtake single stream Active & Monitor with Slamshut valve
	OFFPRS_2_A	PRS/Offtake 2 stream Active regulator
	OFFPRS_2_AM	PRS/Offtake 2 stream Active & Monitor regulators
	OFFPRS_2_AMS	PRS/Offtake 2 stream Active & Monitor with Slamshut valve
	OFFPRS_2_AS	PRS/Offtake 2 stream Active with Slamshut valve
	OFFPRS_3_AMS	PRS/Offtake 3 stream Active & Monitor with Slamshut valve
	OFFPRS_4_AMS	PRS/Offtake 4 stream Active & Monitor with Slamshut valve
	OFFPRS_5_AMS	PRS/Offtake 5 stream Active & Monitor with Slamshut valve
INTERVENTION_AGE*	REACTIVE	Reactive only or site / system level replace or refurbishment
	1TO5YRS	Working stream replacement when site age is between 1 and 5 years
	6TO10YRS	Working stream replacement when site age is between 6 and 10 years
	11TO15YRS	Working stream replacement when site age is between 11 and 15 years
	16TO20YRS	Working stream replacement when site age is between 16 and 20 years
	21TO25YRS	Working stream replacement when site age is between 21 and 25 years
	26TO30YRS	Working stream replacement when site age is between 26 and 30 years
	50TO60YRS	Working stream replacement when site age is between 50 and 60 years. Used for sensitivity testing only.
DETECTION_LEVEL**	Site or Stream	Whether the pressure anomaly due to failures are detectable at site (SITEDET) or stream (STRDET) level
MAINT_INTERVAL_MTHS	6, 12, 24, 36, 48, 60, 72, 96	The planned inspection interval in months

* Applicable to Governor (GOV) sites only

** Applicable to Offtake / PRS (OFFPRS) sites only

G5.2.2 Under or Over Pressure Events Per Year

For a given CONFIG, INTERVENTION_AGE for governors, DETECTION_LEVEL for offtakes:

$$\boldsymbol{Nr\ of\ Events\ Per\ Year} = \mathbf{exp}\ (\boldsymbol{b0} + (\boldsymbol{b1} * \boldsymbol{Ln}(\boldsymbol{MAINT\_INTERVAL\_MTHS})) + (\boldsymbol{b2} * \boldsymbol{AGE}))$$

The model coefficients, *b0, b1 and b2*, can be found in the tables in the DST update specifications and are defined for a given:

- Configuration (CONFIG)
- Intervention age for a working stream replacement if it is a multi-stream governor site (INTERVENTION_AGE)
- Detection of abnormal pressure at either site (SITEDET) or stream level (STREAMDET) if it is an Offtake / PRS site (DETECTION_LEVEL)

Having selected the appropriate *b* coefficients*,* the evaluation further requires

- Age (condition effective) in years (AGE), and
- Planned maintenance interval in months (MAINT_INTERVAL_MTHS).

G5.2.3. Pre-Intervention

The pre intervention under and over pressure events can be evaluated using the b0 and b1 appropriate to the configuration with the age (or condition effective age) at the time of intervention and maintenance interval. For governors, there is an added dimension called INTERVENTION_AGE which for pre intervention purposes the REACTIVE category applies.

G5.2.4 Post-Intervention

Where the intervention impact can be expressed as a change to the overall effective age of the site or system, e.g., 80% reduction the post-intervention under and over pressure events can be evaluated using the same curve as for the pre-intervention, with the age (or condition effective age) for the site / system reduced as required. This has the effect of moving back down the over/under pressure event curve.

For governor sites, if the intervention involves replacement of the working stream components, a different set of the *b0, b1* and *b2* are applicable. This set relates to the age of the site when the intervention takes place, INTERVENTION_AGE.

G5.2.5 Examples – Governor site

For a Governor site with 2 streams of Active Monitor regulators and no slamshut, the *b* coefficients to apply to predict under pressure events are shown in the table below.

Parameter	**Parameter Value**
CONFIG	GOV_2_AM
INTERVENTION_AGE	REACTIVE
b0	-8.170016963
b1	0.4229027955
b2	0.046123061

Reactive – pre-intervention

For a site with effective age of 15 years and planned maintenance interval of 24 months:

Under Pressure Events per Year = Exp (-8.170016963+ (0.4229027955 * Ln(24)) + 0.046123061 * **15**))

= 0.002167538 events per year

Proactive – post-intervention (full replacement)

For a site with full replacement of the pressure regulating assets, the effective age is reset to 0. Continuing with the same planned maintenance interval of 24 months:

Under Pressure Events per Year = Exp (-8.170016963+ (0.4229027955 * Ln(24)) + 0.046123061 * **0**))

= **0.00108518** events per year

Proactive – post-intervention (working streams replacement)

For a site with working stream replacement of the pressure regulating assets, the effective age is reset to 0. However, the *b* coefficients are different and relate to the intervention age at the time of replacement. Continuing with the same planned maintenance interval of **24** months, and a working stream replacement at age **27** years:

Parameter	Parameter Value
CONFIG	GOV_2_AM
INTERVENTION_AGE	26TO30YRS
b0	-7.440266131
b1	0.422902796
b2	0.036669192

Under Pressure Events per Year = Exp (-7.440266131 + (0.422902796 * Ln(24)) + (0.036669192 * **0**))

= **0.002251276** events per year

This value is higher than the reactive pre-intervention position as the working stream has aged by a further 12 years and the subsequent intervention is not sufficient to reduce the failure rate down to the rate calculated at an age of 15 years.

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Appendix H – Deterioration Modelling Improvements for PRS/Offtakes Assets

H1. Introduction

NARMS (Network Asset Reliability Measures) is a methodology developed by the Safety and Reliability Working Group (SRWG) for calculating the monetised risk for gas assets and is used for regulatory risk reporting. ICS has been undertaking a review of the methodology and some of the underlying calculations and parameter values to ensure it is fit for purpose and consistent amongst all GDNs for long term risk (LTR) calculations.

This note focuses on the updates relating to the condition deterioration curves and failure rates doesn'tdoes not start deteriorating until the condition is nearly 5 and the end of life is slightly different to condition grade 5.

- The flat period of the failure rate is quite extended and therefore there is little, or no benefit gained from replacing/refurbing an asset until after this point, even though the asset is in condition grade 4.
- Another slight problem is also the condition curve hits an asymptote at 5, and while this can be adjusted by setting the upper limit at 4.9 it can potentially be simplified.

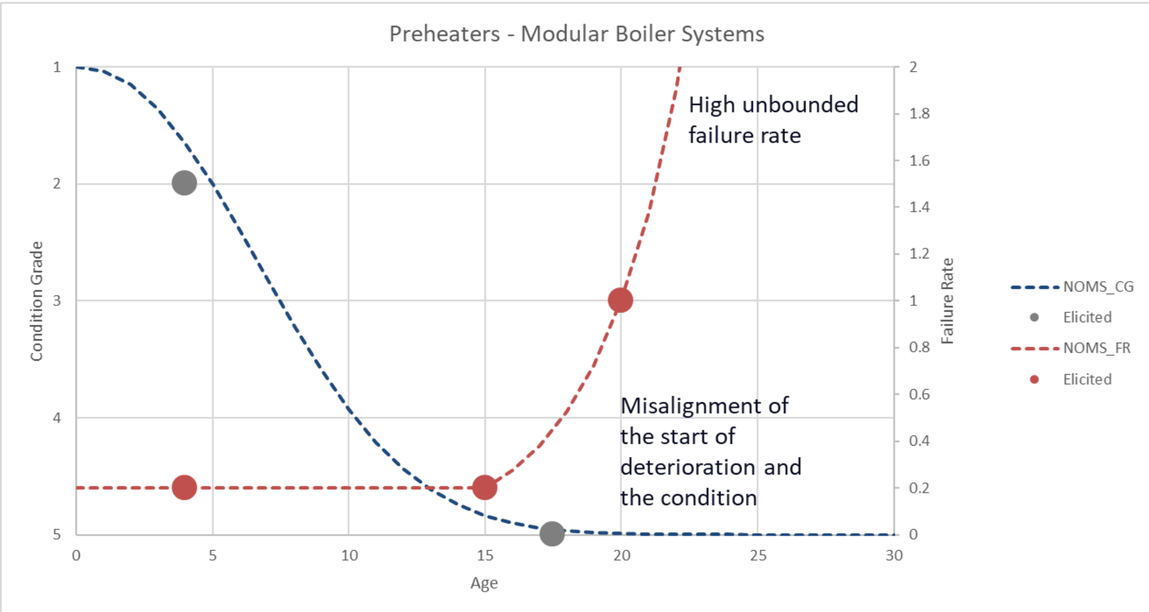

Figure H-3 – Example of the previous inconsistent relationship between start of asset deterioration (at 15 years) and its end of life (at 20 years) which has been addressed through the curve re-fitting process

This graph shows how as assets age (move between condition grades) the effective age increases which in turn increases the failure rate. Where: CG is the condition grade and FR is failure rate (number per year).

Appendices - Detailed Asset Assessments

H3. Updated Methodology

H3.1.Overview

To fix the above-mentioned inconsistencies and potential problems when using the existing elicited NARMS models to LTR we used the current set of elicitation results but re-formulated the models to improve alignment to elicited results. The main advantage of this approach is that it requires minimal changes to any underlying models in Decision Support Tools (DSTs), by simply updating the model fit parameters. This process can be described in a number of simple steps using Modular Boilers as an example.

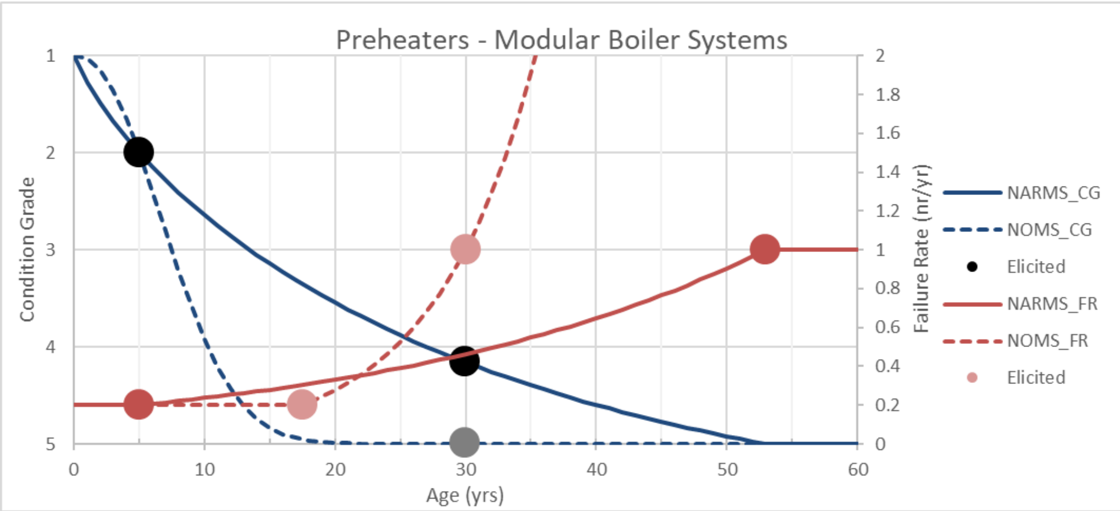

Figure H-4 – Example showing the relationship between the old (NOMs) inconsistent curve fits and the revised NARM versions which: 1) now start deteriorating at Condition Grade 2 (5 years) 2) allow deterioration to continue beyond the elicited end of life at Condition Grade 5 (40 years).

The lines show a comparison between the old (NOMs) and new (NARMs) results from the revised curve. The process for the curve re-fitting was as follows:

1. We change the fitting of the condition curve to fit to a maximum of Condition Grade 6 (CG6) but cap it a CG5. This ensures there are a full 5 condition bins, removing the existing asymptote at CG5 and ensuring condition grade 5 is reached as a whole number.
2. The first condition point stays the same (first black dot).
3. We assume the second condition point (grey dot) is linked to 4.16 instead of 5. Mathematically, this represents the "characteristic life" of a Weibull distribution and practically says that the asset is nearing the end of its life rather than completely ended. This is also approximately the Weibull **Scale** parameter
4. To align the condition with the failure rate this second condition point (second black dot) is calculated as the average of the HI5 and the End of Life. As compared to the grey dot. The curve is expressed as a Weibull Cumulative Distribution Function (CDF) with parameters **Shape and Scale**.
5. The condition curve (blue) can now be seen to extend out to nearly double the original curve. This represents the observed data that shows that when assets begin to deteriorate and are nearing their end of useful life, they can be "sweated" to nearly twice (or some extended period) past their expected life with increased maintenance. Or the accelerated

life (in the negative direction) is considerably less that their actual life due to system reliability/redundancy, i.e., they are only used infrequently.

6. The new condition curve is used to estimate CG5, and this is used instead of the end of useful life point (dark red second point vs the light red second point).
7. Deterioration now starts at CG2 (first red dot and **Gamma**) and a flatter failure rate is fitted between the two points (dark red). This is now the new **A and B**. This reflects the use of Condition Grades to indicate deterioration in asset heath. Gamma is now assumed to be the period between CG1 (a new asset) and CG2, where asset health starts to deteriorate.
8. Finally, the failure rate is capped at the elicited value of the expected time between failures when the asset is nearing its useful life (**FR_EOL**).

The final model can be expressed as before, albeit slightly simplified:

$$\boldsymbol{Failure\ Rate} = \mathbf{if\ Age}_{effective} < \mathbf{Gamma\ then\ A\ \ else\ min}\left(\mathbf{A}.\mathbf{exp}\left[\mathbf{Age}_{effective} - \mathbf{Gamma}\right].\mathbf{B}, \mathbf{FR}_{\mathbf{EOL}}\right)$$

$$\mathbf{Age}_{effective} = \mathbf{WeibullInvCDF}([\mathbf{Condition\ Grade} - \mathbf{1}]/\mathbf{5}, \mathbf{Shape}, \mathbf{Scale})$$

H3.2.Updated Results

A full set of updated model results are shown below with new model parameters given in Section H3.3.

As before, the blue solid and dotted lines refer to the old (NOMs) curve fits; the red solid and dotted lines refer to the new (NARMs) model fits, for condition grade (CG) and failure rate (FR).

The new Weibull coefficients arising from this curve refitting exercise has been applied to the following asset types and is discussed further in the relevant Appendices (A-F).

- Filters
- Preheaters
- Odorant
- Metering

Pressure control and Governor assets use deterioration estimates as derived from the reliability modelling exercise described in Appendix G. As above, comparing the old (NOMs) and new (NARMs) approaches:

- The red/pink dots refer to the failure rates and the gamma point and the end-of life respectively
- The black/grey dots refer to the effective ages at CG2 and C5, respectively.

Appendices - Detailed Asset Assessments

Pressure Reduction and Control

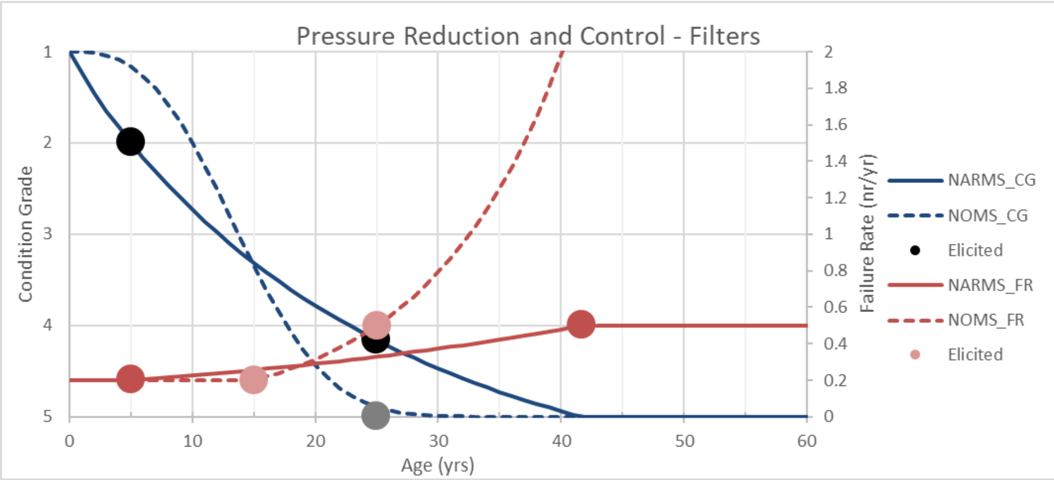

Figure H-5 – Refitted Filters curves

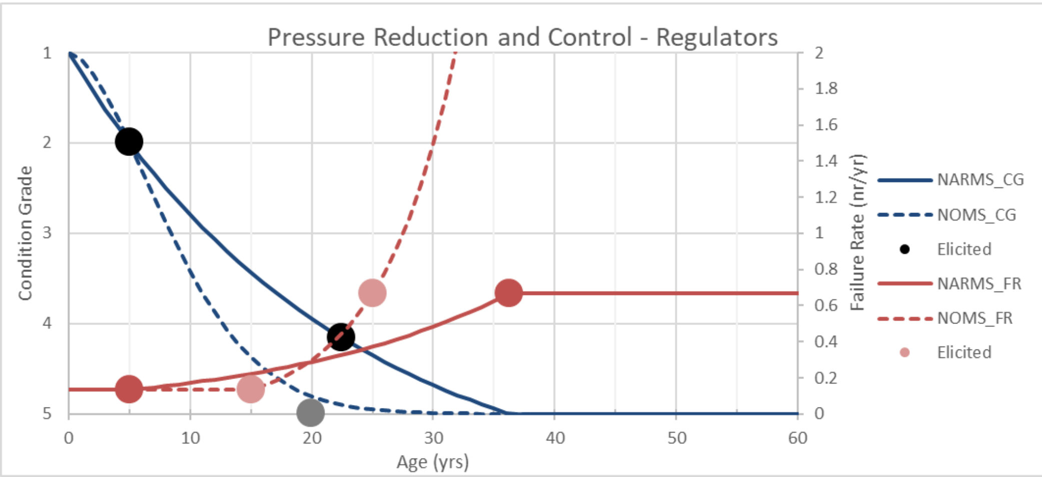

Figure H-6 – Refitted Regulators curves

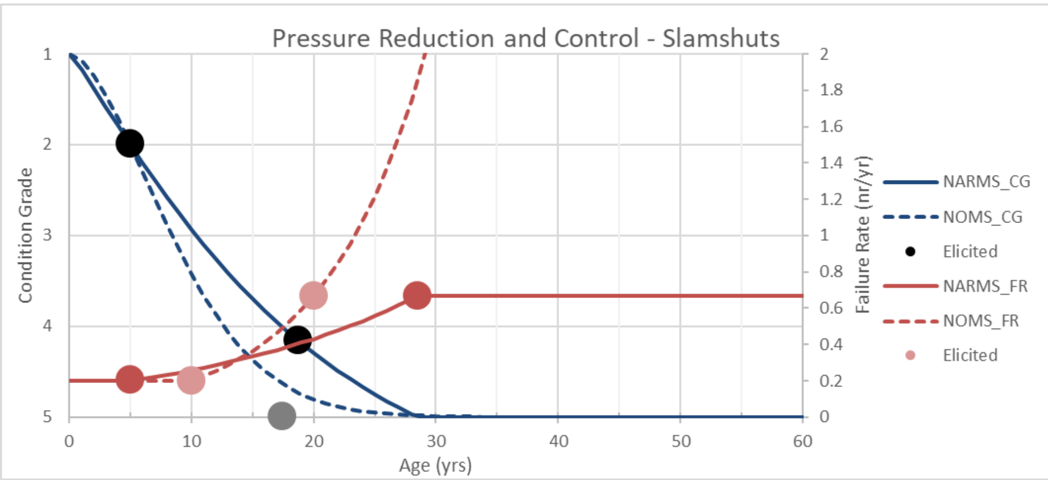

Figure H-7 – Refitted Slam-shuts curves

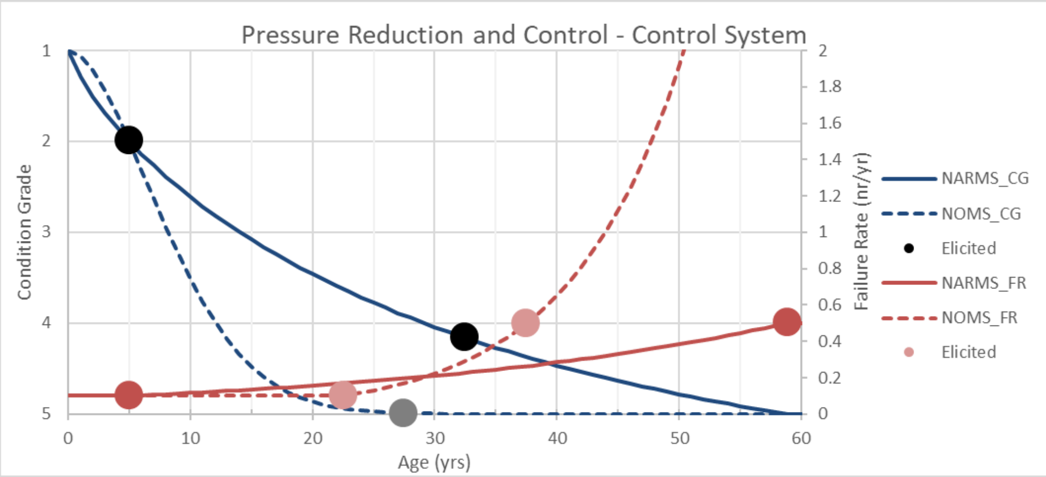

Figure H-8 – Refitted PRS Control Systems curves

Odorant & Metering

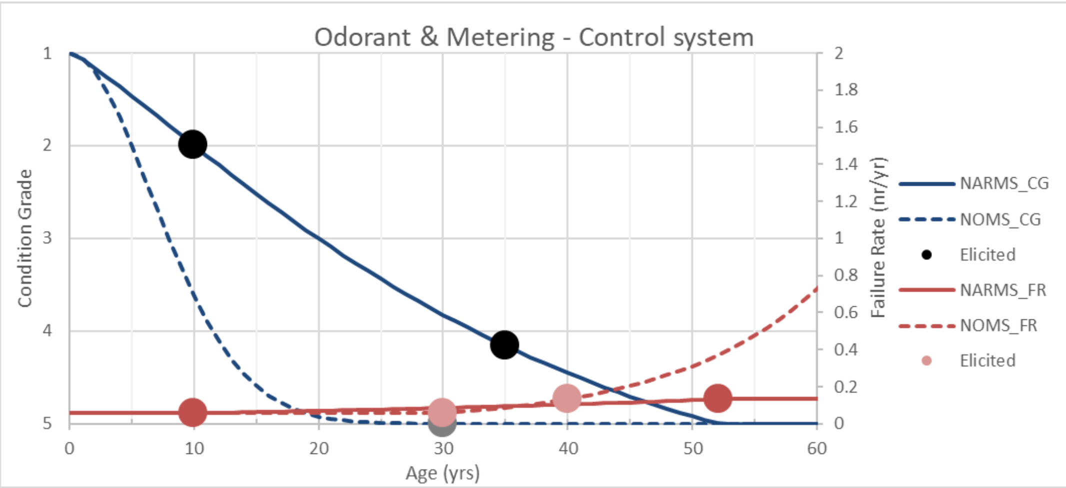

Figure H-9 – Refitted Odorant & Metering Control Systems curves

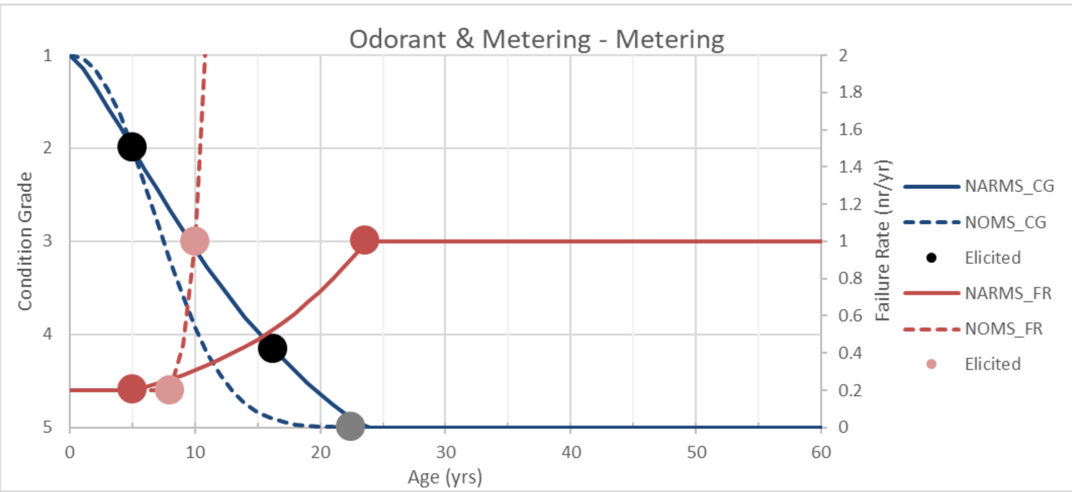

Figure H-10 – Refitted Meters curves

Appendices - Detailed Asset Assessments

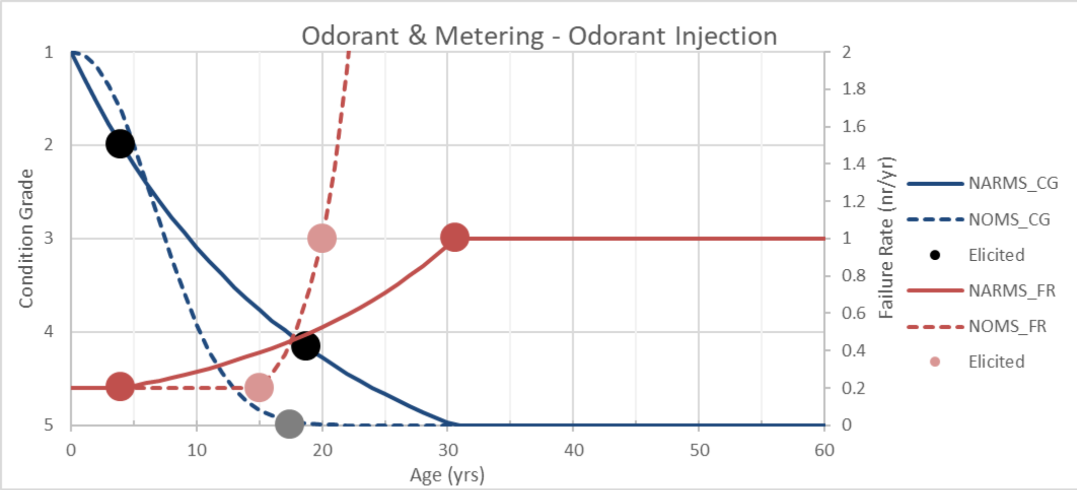

Figure H-11 – Refitted Odorant curves

Pre-heating

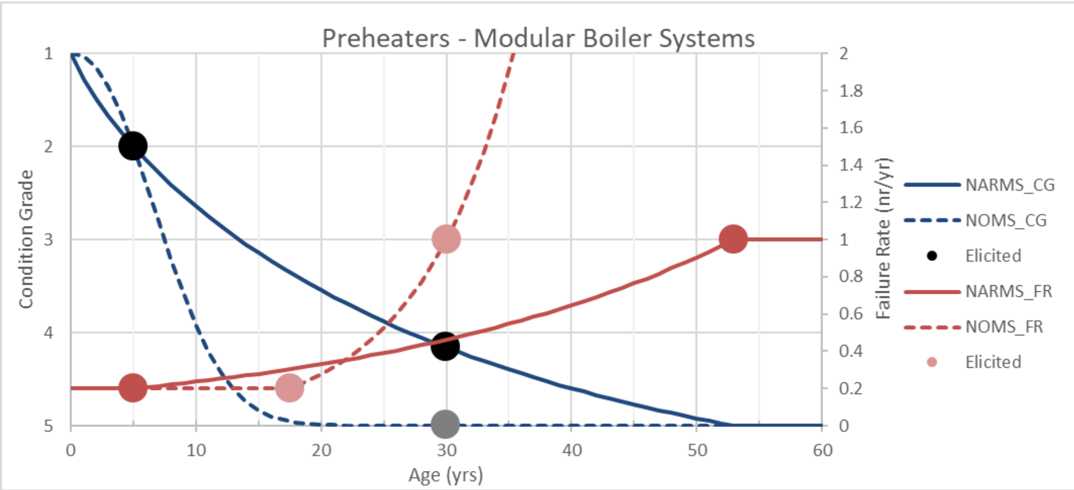

Figure H-12 – Refitted Modular Boiler curves

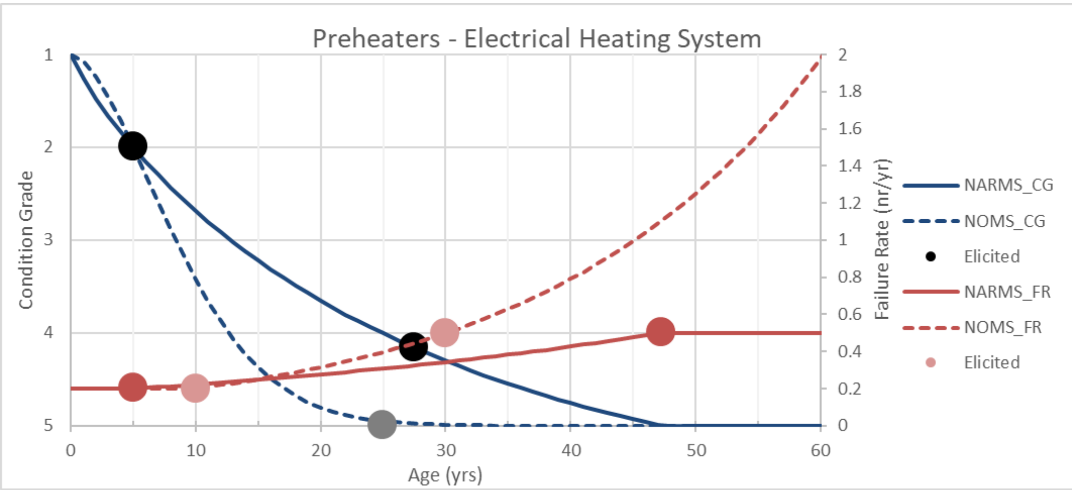

Figure H-12 – Refitted Electrical Heater curves

Appendices - Detailed Asset Assessments

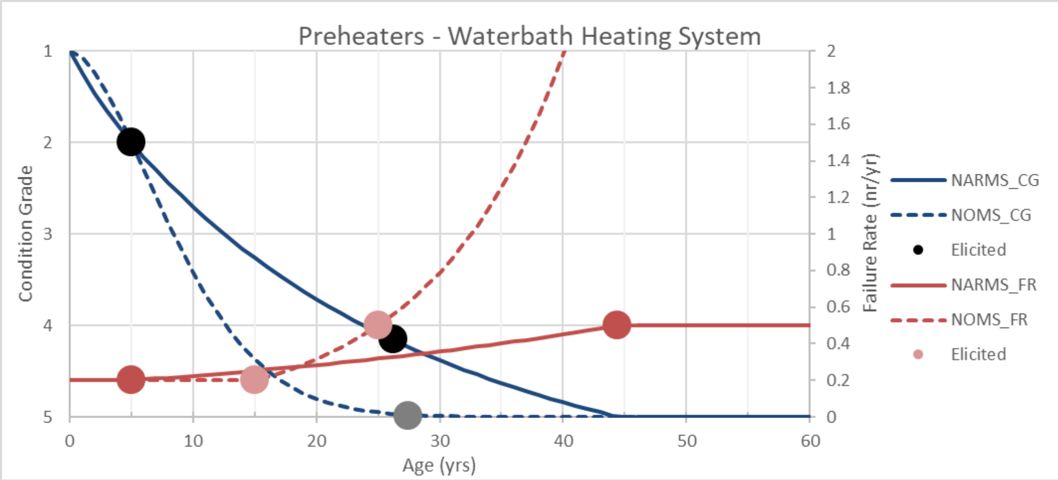

Figure H-13 – Refitted Water Bath Heater curves

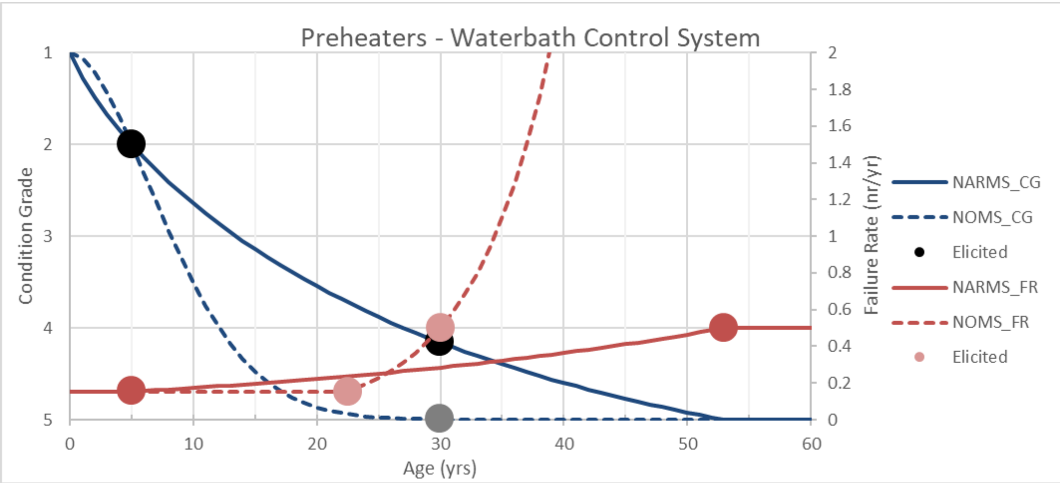

Figure H-14 – Refitted Water Bath Control System curves

7.13.2 H3.3. Refitted Model Coefficients

Table H1.: Elicited Results

Elic Model Group Desc	What is the expected time between failures when the asset is new?	At what age does the asset start to show a noticeable increase in failures?	What is the age when the asset is nearing the end of its useful life?	What is the expected time between failures when the asset is nearing the end of its	HI 2 - Good or serviceable condition.	HI 5 - End of serviceable life. Unreliable & incurring excessive maintenance costs. Requires major
Pressure Reduction and Control - Filters	17.5	30	40	7.5	10	30
Pressure Reduction and Control - Regulators	10	22.5	37.5	2	5	27.5
Pressure Reduction and Control - Slamshuts	6.5	22.5	30	2	5	30
Odorant & Metering - Metering	7.5	15	25	1.5	5	20
Odorant & Metering - Odorant Injection	5	10	20	1.5	5	17.5
Preheaters - Electrical Heating System	5	8	10	1	5	22.5
Preheaters - Modular Boiler Systems	5	15	20	1	4	17.5
Preheaters - Waterbath Heating System	5	17.5	30	1	5	30
Odorant & Metering - Control system	5	15	25	2	5	25
Pressure Reduction and Control - Control System	5	15	25	2	5	27.5
Preheaters - Waterbath Control System	5	10	30	2	5	25

Table H2.: NOMS/NARMS Fitted Model Parameters

Elic Model Group Desc	NOMS/NARMS									
	A	B	Bmaintdoubled	Bmainthalved	Bsaline	Cond Scale	Cond Shape	Gamma (Yrs)	Ttr Logmean	Ttr Logsd
Odorant & Metering	0.0392	0.1271	0.85	1.15	1.15	9.1135	2.089	13.3333	1.7359	1.0338
Odorant & Metering - Control system	0.0506	0.0916	0.85	1.15	1.15	9.678	1.8865	15	1.4675	1.1756
Odorant & Metering - Metering	0.0119	0.1609	0.85	1.15	1.15	8.8312	2.1902	15	2.5039	0.8561
Odorant & Metering - Odorant Injection	0.0552	0.1288	0.85	1.15	1.15	8.8312	2.1902	10	1.2363	1.0697
Preheaters	0.0433	0.1585	0.85	1.15	1.35	9.9388	1.8401	14.125	2.5112	1.0081
Preheaters - Electrical Heating System	0.054	0.091	0.85	1.15	1.25	10.4299	1.6946	11.5	2.7333	1.074
Preheaters - Modular Boiler Systems	0.0016	0.3219	0.85	1.25	1.15	8.8312	2.1902	15	2.5086	1.2106
Preheaters - Waterbath Control System	0.1095	0.0602	0.85	1.15	1.35	10.0641	1.781	10	2.2341	0.8204
Preheaters - Waterbath Heating System	0.008	0.1609	0.85	1.15	1.15	10.4299	1.6946	20	2.5689	0.9275
Pressure Reduction and Control	0.0178	0.1102	0.85	1.15	1.15	11.6549	1.9835	21.875	2.4958	1.1516
Pressure Reduction and Control - Control System	0.0506	0.0916	0.85	1.15	1.15	10.0641	1.781	15	1.8177	0.9627
Pressure Reduction and Control - Filters	0.0045	0.0847	0.85	1.15	1.25	15.6958	2.7637	30	3.4167	1.0798
Pressure Reduction and Control - Regulators	0.0117	0.1073	0.85	1.25	1.15	10.4299	1.6946	20	2.489	1.2019
Pressure Reduction and Control - Slamshuts	0.0045	0.1572	0.85	1.35	1.35	10.4299	1.6946	22.5	2.2598	1.3619

Table H3.: NARMS LTR Fitted Model Parameters

Elic Model Group Desc	NARMS LTR				
	A	B	FR_EOL	Gamma (Yrs)	CG5 (Yrs)
Odorant & Metering	0.1778	0.0425	0.611	5.00	35.49
Odorant & Metering - Control system	0.2000	0.0250	0.500	5.00	41.68
Odorant & Metering - Metering	0.1333	0.0515	0.667	5.00	36.28
Odorant & Metering - Odorant Injection	0.2000	0.0512	0.667	5.00	28.53
Preheaters	0.2000	0.0505	0.875	4.75	38.62
Preheaters - Electrical Heating System	0.2000	0.0864	1.000	5.00	23.63
Preheaters - Modular Boiler Systems	0.2000	0.0605	1.000	4.00	30.62
Preheaters - Waterbath Control System	0.2000	0.0217	0.500	5.00	47.25
Preheaters - Waterbath Heating System	0.2000	0.0335	1.000	5.00	52.99
Pressure Reduction and Control	0.1277	0.0244	0.408	6.25	52.11
Pressure Reduction and Control - Control System	0.2000	0.0232	0.500	5.00	44.44
Pressure Reduction and Control - Filters	0.0571	0.0201	0.133	10.00	52.10
Pressure Reduction and Control - Regulators	0.1000	0.0299	0.500	5.00	58.89
Pressure Reduction and Control - Slamshuts	0.1538	0.0246	0.500	5.00	52.99

Appendix I – Future plan for continuous improvement

There are a number of areas within NARM planned for review by the Gas Distribution Networks under our drive for continuous review and improvement. This appendix will be updated annually to reflect work done and any revision to plans. The table below summarises the future works plan as of May 2024

Appendices - Detailed Asset Assessments

Area for review	Timeline	Impact
Scope of NARMs – assets included in the methodology	Q3 2024	Addition or removal of asset types
PRI consequence modelling	Q2-Q3 2024	Long term risk assessment in GD NARMs
Emissions – modelling of emissions considering use of new technologies such as the Digital Platform for Leakage Assessment (DPLA)	Q2 2025	Potential improvement of impact assessment on emissions benefits
Health assessment – comparing techniques employed across sectors	Q4 2024 -Q2 2025	Potential for common methodology for health and condition assessment
Riser interventions – review model nodes and associated calculations following IGEM/ HSE review	Q4 2025	Changes to the riser risk assessment reflecting changing perceptions from HSE
Complex Distribution Systems (CDS) – assessing risk on commercial MOBs	Q1-2 2026	Potential to include in NARMs, possibly built into the riser risk map

Appendix J – Summary of improvements implemented in the Ofgem and GDN review of NARMs 2022-2024

Priority 1

CRITERIA	AREAS FOR DEVELOPMENT	Suggested Plan of Work	Action	Date completed
016 – ASSET DETERIORATION	Suggested changes:			
Does the methodology fully explain how deterioration (and forecast risk values) are derived. Is the approach to modelling deterioration supported by evidence and appropriate from a technical perspective?	• Ensure approaches to deriving deterioration used in the methodology are clearly set out	Review which areas need more detail as some asset classes are already clearly explained. Main methodology to be refreshed following this review. To be picked up post NARM RRP submission	Methodology update	Dec-22
	• Ensure information is provided for all relevant asset classes			
	• From an evidence perspective, ensure links to relevant documentation are provided (as above)			
019 – INTERDEPENDENCIES	Suggested changes:			

Have relevant interdependences been taken into account in the methodology for the PoF and CoF?	• Ensure an overall consideration of interdependencies including primary/ secondary assets	We have considered interdependencies in the design of NOMs/NARMS but agree this is not explicit in the methodology. Main methodology to be updated with details of interdependencies that were modelled. - To be picked up post NARM RRP submission. If through this exercise we identify any areas not addressed, we will review and make any required model / data updates by end 2023- it is not envisaged to be anything here due to the thorough process used in NOMs/NARMs design.	Methodology update In the event of identifying areas not addressed, model and methodolgy updates to be completed	Dec 22 Nov 23
	• Consider the impact of failure of specific assets on other assets			
	• Interdependence between Mains and Services was previously identified as potential area for further development			
	To note: More focus should be on identifying interdependencies at a higher level rather than their detailed modelling.			
021 – ADDRESSING WEAKNESSES	Suggested changes:			

Has action been taken in areas where the licensee previously signalled they did not have enough information?	• Clearly identify areas for development and actions taken on those areas/ outstanding actions	Review weaknesses previously identified by SRWG with a view to update the methodology to reflect these. Incorporate a section in the methodology where there are limitations due to not having enough information - Target Date December 2022. This will highlight areas where there is opportunity and an ongoing plan to address.	Methodology update	Dec-22
	• Link to data improvement plans and other processes used to include relevant working groups, changes to systems etc.			
023 – ADDRESSING WEAKNESSES				
Has the licensee provided updates to account for any outstanding issues?				
024 – DATA ASSURANCE	Suggested changes:			
Does the approach to data assurance remain appropriate?	• Include short section in the methodology on the DAG process including any specific/ relevant context for NARM	Add section to methodology document on DAG process - Target date December 2022.	Update methodology	Dec-22

Appendices - Detailed Asset Assessments

Priority 2

CRITERIA	AREAS FOR DEVELOPMENT	Suggested Plan of Work	Action	Indicative date (to be firmed up post RRP)
002 – ENGINEERING ASSESSMENTS	Suggested changes:			
Are the engineering parameters within the methodology aligned with, or suitably proxies for, the assessments that the network company should conduct and consider in making its investment decisions? Where parameter scoring requires engineering judgement are the scoring rules unambiguous and robust? **003 – ENGINEERING ASSESSMENTS** Are the engineering assessments supported by relevant technical documentation?	· Outline what other types of engineering assessments impact the methodology and how · Explain the basis behind scoring rules and how these are refined over time · Provide links to relevant technical documentation	All GDNs to review assessment approach by asset type and to review how comparable they are to determine whether a common document update or company specific appendix is required. This would determine the effort involved and timelines. To be picked up post NARM RRP submission when a deadline will be agreed for this update.	Comparison across GDNs Company specific or common section for methodology created Methodology Updated (either company specific appendix or common update)	End Jan 23 April 23 Nov 23
016 – ASSET DETERIORATION	Suggested changes:			

Does the methodology fully explain how deterioration (and forecast risk values) are derived. Is the approach to modelling deterioration supported by evidence and appropriate from a technical perspective?	• Ensure approaches to deriving deterioration used in the methodology are clearly set out	Review which areas need more detail as some asset classes are already clearly explained. Main methodology to be refreshed following this review. To be picked up post NARM RRP submission	Methodology update	Dec-22
	• Ensure information is provided for all relevant asset classes			
	• From an evidence perspective, ensure links to relevant documentation are provided (as above)			
017 – LONG-TERM RISK	Utilising a long-term risk measure remains Ofgem's preferred approach to defining risk outputs as highlighted in RIIO-2 Draft and Final Determinations. This is also reflected in the NARM objectives for RIIO-2 for network companies to be able to estimate both the single-year snapshot risk benefit and long-term risk benefit.			Jul-24

Has the methodology clearly set out the steps for estimating long-term risk?	Given the typical lives of GDNs assets, the full value to consumers of a company's work is better captured by taking a long-term view of risk. This also means that it better reflects the relative benefits of different types of intervention and for different asset types. It also aligns better with cost-benefit analysis used in investment decision making.	Review individual approaches taken to data and agree a work plan to analyse long-term risk. Scope of work to be specified by October 2022. Decision made on third party support requirement and if appropriate, go to market November 2022. Plan to begin work in January 2023 with a 6 month timeline envisaged. This leaves 6 months of GDNs to update their own systems and compare and validate the results in time for GD3 BP.	ToR for the work to be scoped Shared with Ofgem and updated based on feedback Market engaged Work started with preferred partner	end Aug 22 end Sep 22 Oct 22 Dec 22

	Ofgem's expectation is therefore for the GDNs to consider what steps are needed to develop a comprehensive approach to estimating long-term asset risk as part of the methodology and then consider the timelines for carrying out this work. This should be considered a Category 2 priority meaning that it needs to be carried out by the end of 2023 in time for business plan submissions for the RIIO-3 period.	This timeline will support GD3 planning but there is a risk that the solution is not supported by Ofgem. We recommend regular meetings with Ofgem through this project to avoid 11th hour challenges.	Monthly update sessions with Ofgem	to commence Jan 23
022 – ADDRESSING WEAKNESSES				
Has the licensee sought to address previously recognised limitations?				Jul-24
026 – TESTING & VALIDATION	Suggested changes:			
Has a plan been outlined for carrying out recalibration and revalidation of NARM	• Include a specific section outlined the recalibration and validation processes and its link to NARM	Review alongside other updates to models to support GD3 plans. To be incorporated into the activity to validate the models for	Ongoing action dependent on model updates made, particularly related to LTR - To be completed prior to GD3 submission	Nov-23
027 – TESTING & VALIDATION	• Link to RRP, previous processes and to GD3 plans			

Has the licensee demonstrated completion of such testing and identified results?		updates to long-term risk capability (post Jan 2023)		
028 – TRANSPARENCY	Suggested changes:			
With the exception of any elements adhering to the criteria set out in Annex 1, are all parts of the methodology publicly available? (ANNEX 1 TO BE AGREED)	• Ensure that as much information as possible is made publicly available	Review what other sectors have published. Category 1 consultation to be used as an indicator on whether more detail needs to be published. A review across other sectors publications will be completed. We will assess company specific documents against the recent cyber security guidance from Ofgem, commercial impacts and through our own data triage processes. We will then set out a list of planned publications.	Compile list of GDN specific docs Review other sectors publication Follow up with stakeholders who've shown an interest in NARMs and responded to NARMs consultations Update methodology	May 23 June 23 June 23 Nov 23 - Same timeline as updates made for LTR work (need to minimise methodology update cycles)
	• Consider what is provided in other sectors to ensure broad alignment			
	• Review what else may have public value			

	To note: it is recognised that some aspects of the methodology will be confidential/ commercially sensitive and thus should not be made public.	We will add directions in the methodology on how interested parties can engage with individual networks on documents that are not made public but can be considered for release on a case by case basis - Target Date Nov 2023		
031 – TRANSPARENCY	Suggested changes:			
Have all relevant parameters and formulae been presented and fully explained?	• Where parameters/ formulae are presented ensure these are fully explained	To be refreshed following the activity to implement long-term risk as this may lead to significant changes to formulae - Target Date November 2023	Update methodology	Nov-23
	• Ensure appropriate links between model and the methodology			
	• Address issues that are vague and currently rely on interpretation			

	To note: there is a question of proportionality here. It is not a case of capturing every single calculation but there must be sufficient coverage to ensure a clear understanding of the methodology and its outputs.			
35. Has the licensee accounted for future changes in the generation and demand mix and different potential scenarios resulting from future levels of electrification?		The model already handles changes to demand through customer numbers and we see no required changes in the result of step changes in demand. The methodology does not explicitly state triggers to refresh demand. We will update the methodology more explicitly in this area. It should be noted that currently we are seeing no move to electrification in our existing demand base and no indicators of this direction of travel	Methodology update	Nov-23

		which is reflected in the planned date		