Network Output Measures Health & Risk Reporting Methodology & Framework

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

Title	Network Output Measures Health & Risk Reporting Methodology & Framework
Version Date	30/09/2015
Current Version Number	V2.0

Confidentiality

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 NOMs methodology cohorts are defined specifically for planning and assessing investment interventions to quantify health and monetised risk benefits.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

GDN – Gas Distribution Networks (Distribution network operators).

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

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

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

LTS – Local Transmission System (pipeline network)

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

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

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

PE – polyelthylene 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.

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.

1. Introduction

1.1 Purpose

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

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

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

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

1.2 Background

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

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

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

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

1.3 Objectives

In developing this methodology the following objectives have been targeted:

- comparative analysis:
    - over time;
    - between geographical areas; and
    - between network assets;
- the evaluation of:
    - Probability of Failure (PoF) of an asset failing to fulfil its intended purpose during any year (see glossary for definition of Probability of Failure) ;
    - the rate of deterioration to forecast future Probability of Failure;
    - asset criticality (safety, environmental, reliability, financial); and
    - network risk, taking into account Probability of Failure, asset criticality and, if feasible, asset inter-dependence.

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

2 Methodology Overview

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

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

2.1 Principles

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

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

BS EN ISO 31010, 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 ISO 31010, 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).

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

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

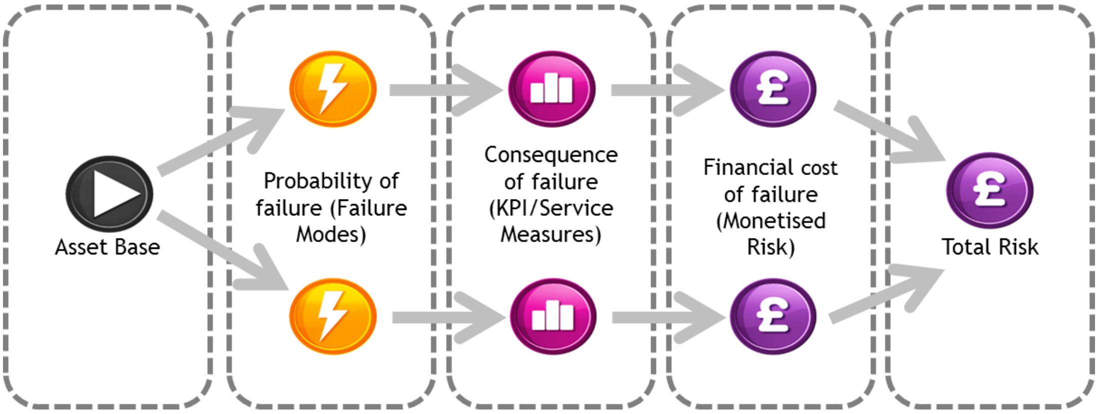


Fig 1: Broad Monetised Risk Process.

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/maintained in line with the type of investment activity whilst PoC will generally remain unchanged, with the exception of system or network design alterations. This will in turn result in a reduction in the Asset Risk Value enabling the comparison of with/without Intervention scenarios in the form of Network Output Measures as defined in licence condition 4G part C. This is described in detail in section 4.5.

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 Section 7.

2.2 Asset Base

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

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

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

2.3 Grouping of Assets

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

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

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

Asset Groups

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

Asset Sub-group

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

Asset Cohort

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

Asset Cohort groupings will be formed with regard to;

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

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

- Material
- Pressure
- Diameter Band
- Age

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

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

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

Asset Stratification

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

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

Figure 2 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.

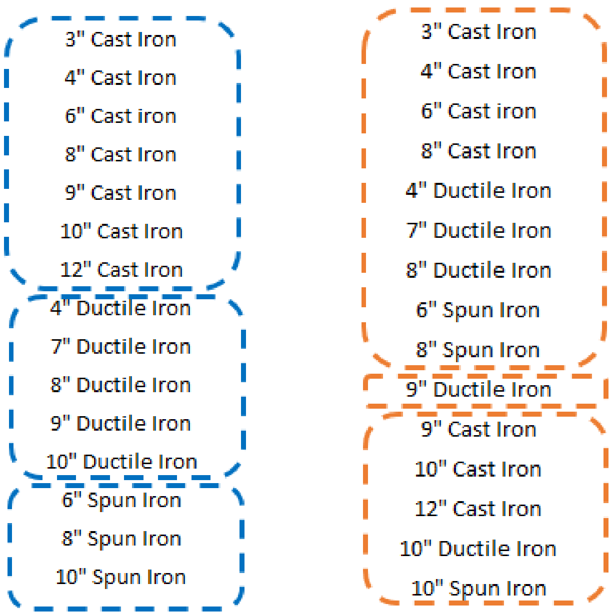


Fig 2: Asset Cohort/Stratification

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

Fig 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). See Worked Example, section 2.8 below.

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

2.4 Probability of Failure

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

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

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

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

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

generally be resolved through a maintenance process, rather than full asset replacement. The frequency of failures is estimated using counting process regression models. Where data is not available the parameters of these models will be estimated using Expert Elicitation.

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

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

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

2.5 Consequence of Failure

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

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

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

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

2.6 Financial Cost of Failure

Each Consequence of Failure event will 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 as defined in the Data Reference Libraries.

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.

3 Event Tree Development

3.1 Development Overview

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

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

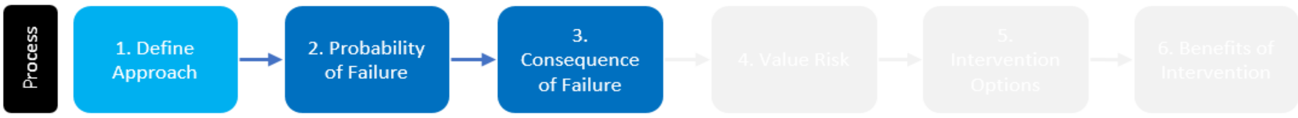
This is summarised in Figure 4 below:

Fig 4: Event Tree Development Flow Chart

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

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

3.2 Define Approach



3.2.1 Determine Asset Groups

A common suite of Asset Groups to be used as a basis for risk assessment and reporting has been developed and agreed between all GDNs. These are defined based upon the key operational components within the gas supply system and have been selected based on planned investment with a view to having 95% of asset intervention spend covered by monetised risk models.

The Asset Groups will be 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 10 primary Asset Groups, for which Event Trees will be developed, as per Table 1 below:

Primary Assets for Event-Tree Analysis
1. LTS Pipelines
2. Distribution Mains
3. Services
4. Risers
5. Offtake/PRS Filters
6. Offtake/PRS Pre Heating
7. Offtake/PRS Slamshut & Regulators
8. Offtake Odorant
9. Offtake Metering
10. District, I&C and Service Governors

Table 1: Primary Asset Groups

Secondary assets, such as E&I and civils, are considered and included within primary Event Trees where there is a quantifiable effect on the risk value of the primary asset.

Asset-specific detail related to Event Tree structure, PoF calculations/values, CoF calculations/values, deterioration and associated costs are included within the Appendices to this document.

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

3.2.2 Develop Risk Map

A key part of the design phase is to determine the optimum level of detail required for each Asset Group It is recognised that GDNs hold data at different levels of detail, but a consistent level of detail required for each Asset Group will be agreed by the SRWG (See section 4.1). **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 are developed using the following generic process. This is normally undertaken through a series of facilitated workshops, supported by meetings with asset or financial experts

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

- Apply interventions to baseline model to test impact on monetised risk
- Use the difference between baseline and with-intervention monetised risk profile to determine the benefit of each intervention
- Model is now ready for reporting or investment targeting applications
- Generate Asset Health and Risk Reports

Data sources to populate the risk map will be 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 must be 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.

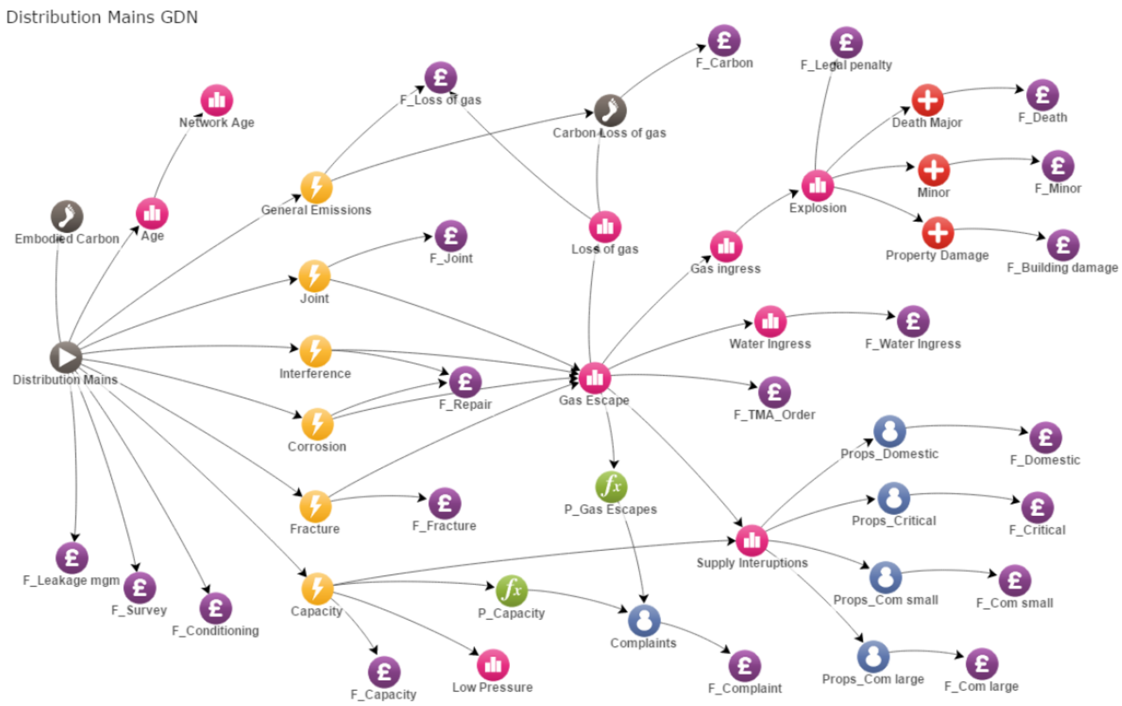


Fig 5: Example Final Risk Tree

3.3 Worked Example

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

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

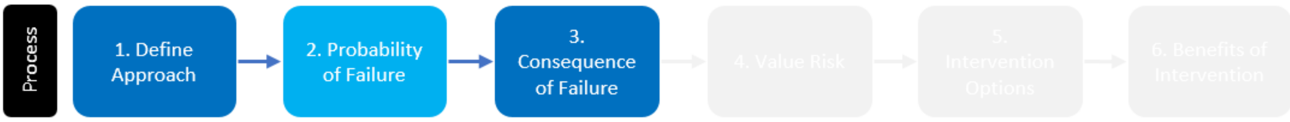
The base year length of the DI/NO/1 cohort is 1,096 kilometres. The total base year monetised risk value is £1,721,370. The overall levels of monetised risk for the DI/NO/1 cohort, broken down by individual monetised risk elements, are illustrated in Figure 6.

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

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

Fig 6: Base year monetised risk values for the DI / NO / 1 cohort

3.4 Derive Probability of Failure



3.4.1 Identify Failure Modes for each Asset Group

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

Failure Modes are defined as a specific deviation in the performance of the asset which will give rise to a Consequence (cost, service, safety or environment). Clearly, Failure Modes are highly asset specific. It is essential that all modes of failure that are likely to generate a significant consequence are identified up front. At this stage the availability of data to quantify both the current rate of failure (and future changes in the rate of failure due to asset deterioration) is confirmed and to a specific Failures linked to resulting Consequences. If appropriate failure data is not available and the failure and consequences are judged to be significant, then gaps can be filled through judgement 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	Water discharge 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 and type.

3.4.2 Identify asset configuration for each Asset Group

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

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

When an asset is operating in **parallel** an asset will consist of two (or more) components that need only one of them in functional state to operate. If one component fails then the asset will continue to operate unless all components fail at the same time. A simple parallel system can be approximated as the multiplication of all the component failure rates, thereby reducing the overall asset PoF. **POF (Asset in parallel) = POF (component 1) * POF(component 2)**

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

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

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

3.4.3 Worked Example – Failure Modes

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

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

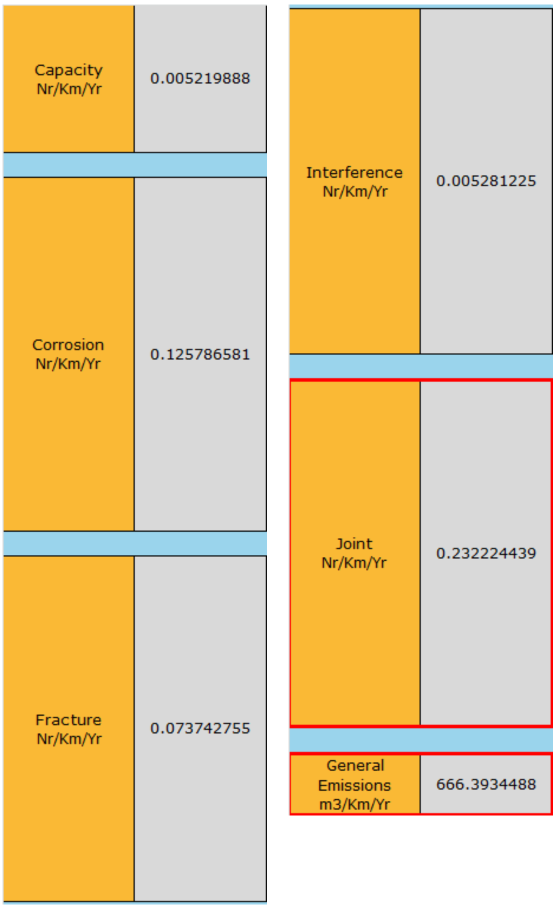
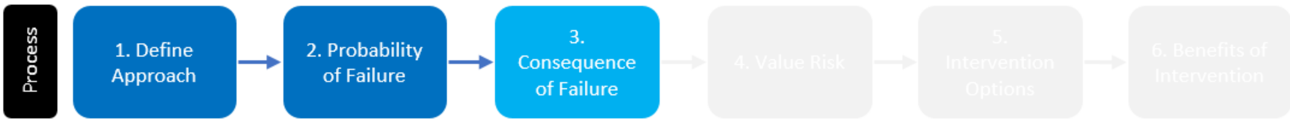


Fig 7. Worked Example - DI/NO/1 cohort Failure Modes and Year 0 probabilities of failure

3.5 Derive Consequence of Failure



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

3.5.1 Define list of Consequence measures

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

The Consequence measure can be defined in the following categories:

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

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

Primary Consequence Measure		Secondary Consequence measure		Metric
1	Public Risk (Health & Safety, 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.

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).

Event Tree Development

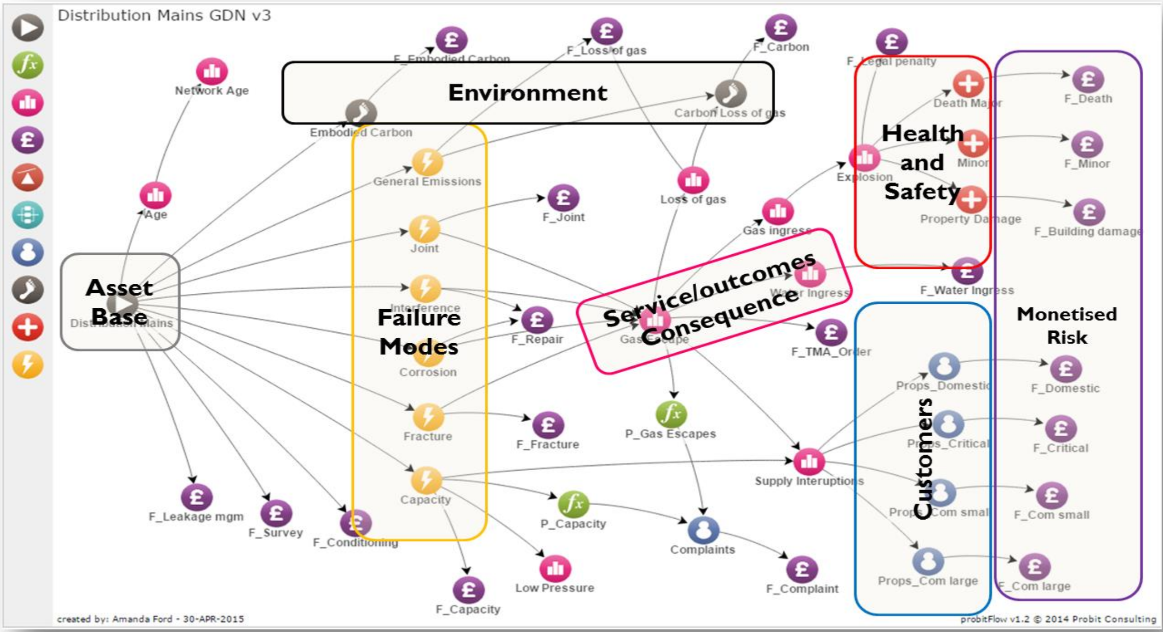


Fig 8: Example Event Tree Sections

The table below expands on those sections further, providing a description of each section, examples of the types of data used and which elements are GDN specific (Joint/Global values apply where not).

	Description	Examples	GDN Specific
Asset Base	Asset data and attributes from company asset repositories	List of individual distribution mains including diameter, material and location	Yes
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	Failure Modes - No PoF Values - Yes
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	Outcome Types - No PoC Values - Yes
Environmental Consequence	Environmental outcomes resulting from a failure, each with a calculated volume (value >=0)	Carbon Loss of Gas, Embodied Carbon	Outcome Types - No Consequence Values – Yes (Cost of Carbon – No)
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	Outcome Types - No Consequence Values - Yes
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)	Outcome Types - No Consequence Values - Yes
Monetised Risk Value	Applicable costs associated with consequences, failure resolution and asset management (value in £)	Repair costs, restoration of supplies, cost of complaints	Outcome Types - No Cost Values – Yes (Cost of death/injury – No)

Table 4: Event Tree Section Detail

3.7 Data Reference Libraries

3.7.1 Overview

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

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

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

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

Any changes to the data values or the methods for deriving the data values will be subject to the governance process as per section 7. Node values defined as High sensitivity can be subject to the modification process at any time.

3.7.2 Global Values

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

Sensitivity	Node ID / Variable	Description	Unit	Value Used	Notes / Source	GDN or Common value
H	**F_Loss_Of_ Gas**	Cost per m3 of loss of gas	£/m3	£0.22	2p/kWh = £0.22/m3 (QUARTERLY ENERGY PRICES 2015 DECC)	Common
L	**F_Legal_ Penalty**	Legal penalty payment	£/event	£1,000,000	SRWG estimate based on civil action costs.	Common
H	**F_Carbon**	Cost of carbon	£/tonne	Formula to model bi-linear increase over time. if(Dyear+2015<2030,Dyear	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	Common

Sensitivity	Node ID / Variable	Description	Unit	Value Used	Notes / Source	GDN or Common value
				+2015-1956,6.9606*(2015+Dyear)-14056)	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)	
L	**F_Com_large**	Cost of large commercial supply interruption	£/event	GDN specific or £200 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £100 compensation payment cost + £100 visit cost;	GDN Specific
L	**F_Com_small**	Cost of small commercial supply interruption	£/event	GDN specific or £200 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £100 compensation payment cost + £100 visit cost;	GDN Specific
L	**F_Complaint**	Cost of complaint	£/complaint	GDN specific or £450 per complaint	Complaint cost based on data from company systems, or (where no data available) default cost based on £450 complaint cost;	GDN Specific
L	**F_Critical**	Cost of critical customer supply interruption	£/event	GDN specific or £200 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £100 compensation payment cost + £100 visit cost;	GDN Specific
M	**F_Domestic**	Cost of domestic customer supply interruption	£/event	GDN specific or £150 per Customer default.	Compensation cost + visit cost based on data from company systems, or (where no data available) default cost based on £50 compensation payment cost + £100 visit cost;	GDN Specific
L	**F_Building_ damage**	Cost of building damage	£/event	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)	GDN Specific
L	**F_Minor**	Cost of minor injury	£/event	£ 185,000.00	Sum historically agreed based on legacy Business Plan submissions and discussions with Ofgem/HSE	Common
M	**F_Death**	Cost of death	£/event	£16,000,000.00	Sum historically agreed based on legacy Business Plan submissions and discussions with Ofgem/HSE	Common
Calculation	**Discount Rate**	Financial discount rate	%	3.50%	Assumption agreed with SRWG	Common

Sensitivity	Node ID / Variable	Description	Unit	Value Used	Notes / Source	GDN or Common value
H	**Carbon_ Equivalent**	Scalar value for carbon methane uplift	Nr	17.697	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. dioxide Agreed with SRWG as per Business Plan submissions	Common
Calculation	Carbon_Loss _Of_Gas	m3 of carbon equivalent from loss of gas	$m^3 CO_2e$	1 m3 of carbon equivalent from Loss of Gas (i.e. 0.00076 x 17.697 = 0.0314 m3 CO2e.)	Will vary from network to network so appears in individual DRLs as well. Importance is due to the differences in gas composition across individual networks.	GDN Specific

Table 5. Global Values

4 Event Tree Utilisation

4.1 Utilisation Overview

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

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

This is summarised in Figure 9 below:

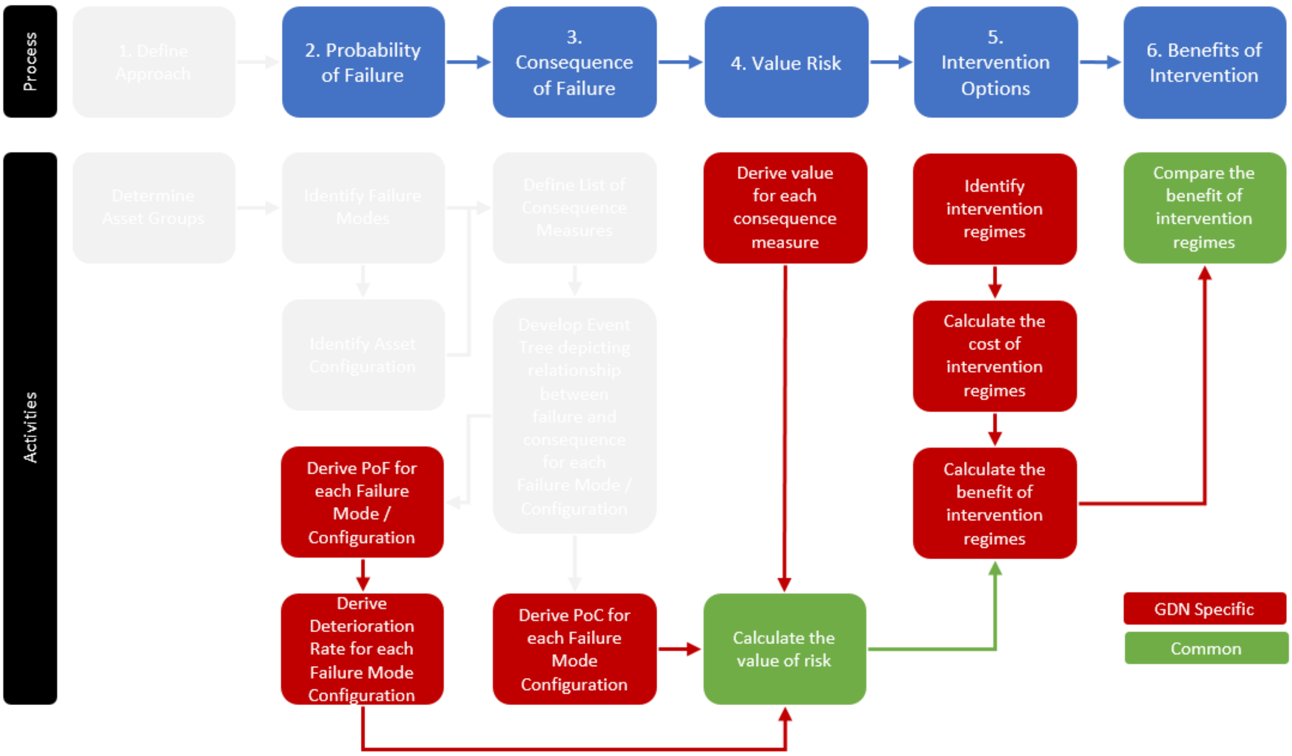


Fig 9. Event Tree Utilisation Flow Chart

4.2 Data Assessment

Each derived asset category and associated Event Tree Analysis will be accompanied with details of Global Values applied (see section 3.6.2) and a Data Reference Library (see section 3.6). 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 Utilisation

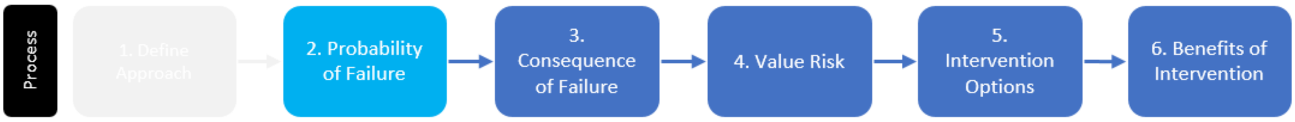
Event Tree analysis will be undertaken using asset level data where such data exists in company systems however, a number of sub-population and global values may be used to complete the Event Tree analysis. It is recognised that the GDNs will have data gaps and will not hold the same level of asset data,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

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

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

Table 6. Data Options

4.3 Probability of Failure, Deterioration & Asset Health



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

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

4.3.1 Probability of Failure (PoF) Calculation

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

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

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

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

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

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

Statistical fitting methods will 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.

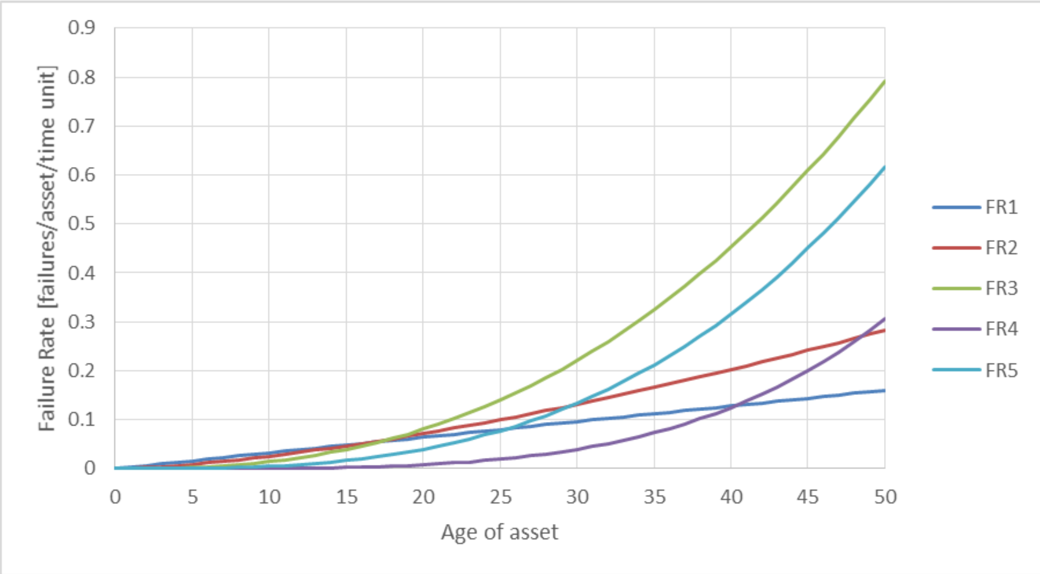


Fig 10. Example PoF curves.

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.

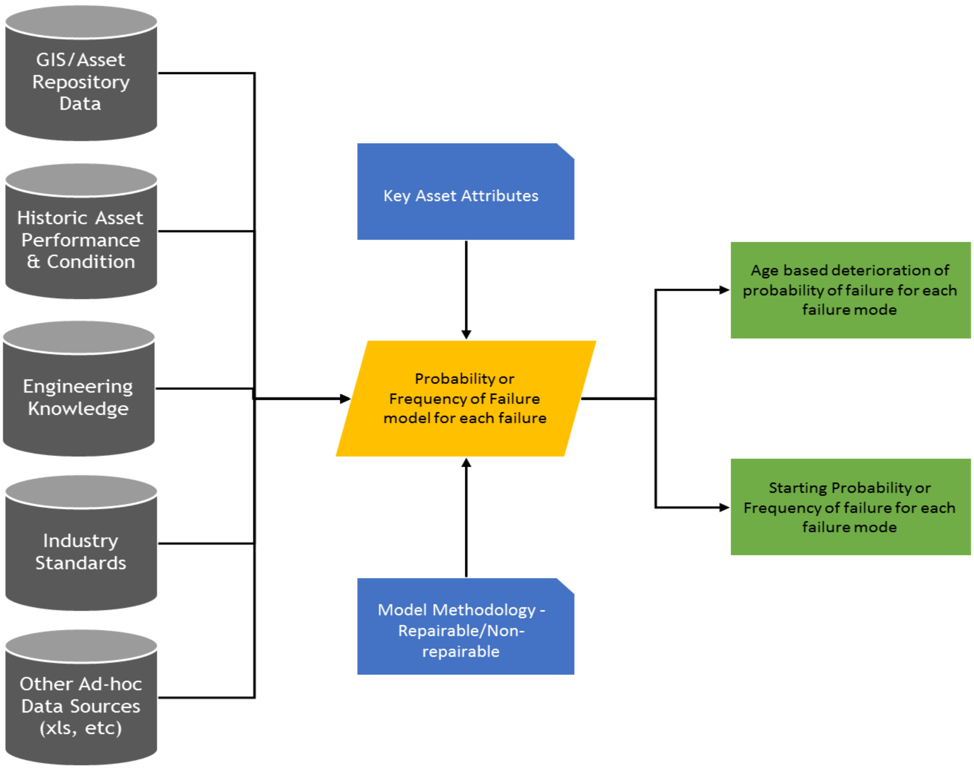


Fig 11. Data Sources.

Where a GDN has inconsistent, incomplete and/or poor quality data for a particular Failure Mode, the methodology allows for the utilisation of either an agreed standard PoF curve with derived starting-point (Option C) or pooled/shared PoF values and deterioration rates (Option B). Data Improvement plans will be established to move to 'Option A' data, away from a reliance on either engineering judgement or other GDN values, ensuring each GDN has consistent and complete data for accurate and comparable reporting.

4.3.1.1 Option A (Data Driven)

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

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

4.3.1.2 Option B (Pooled/Industry Accepted Model)

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

4.3.1.3 Option C (Expert Elicitation)

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

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

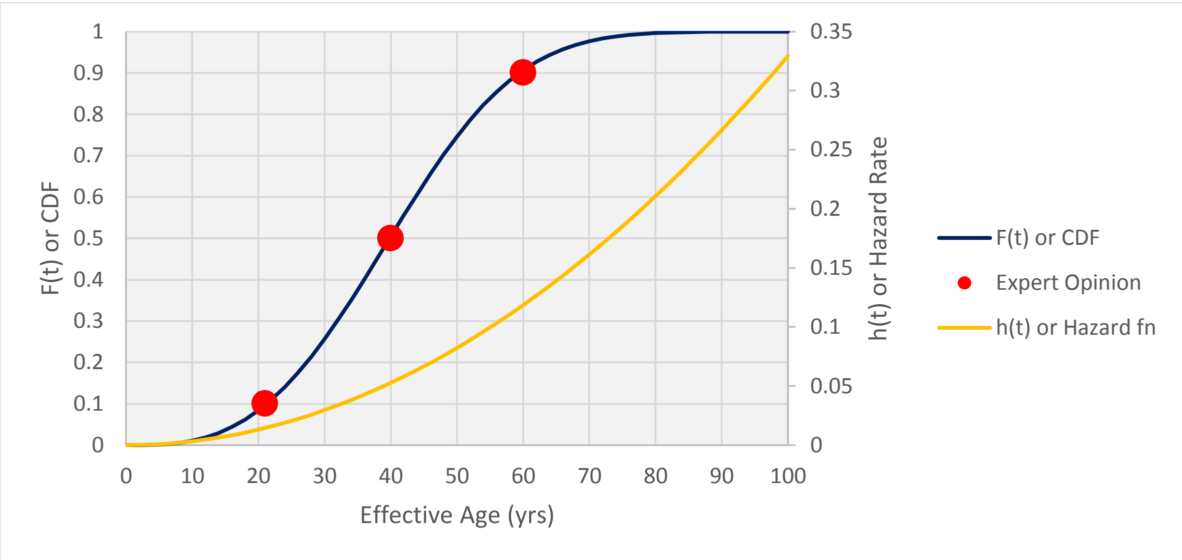


Fig 12. Derived Failure Curve.

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

4.3.2 Worked Example – PoF and Deterioration

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

4.3.2.1 Joint

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

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

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

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

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

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

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

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

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

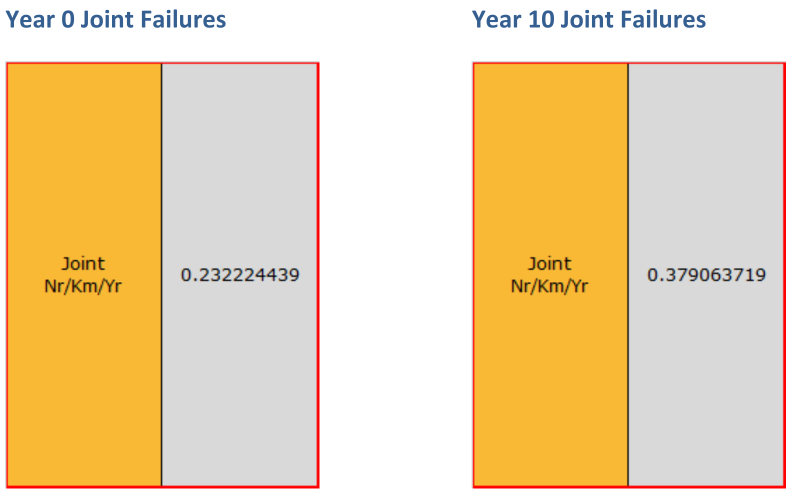


Fig 13. Worked Example - Joint Failure Figures.

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

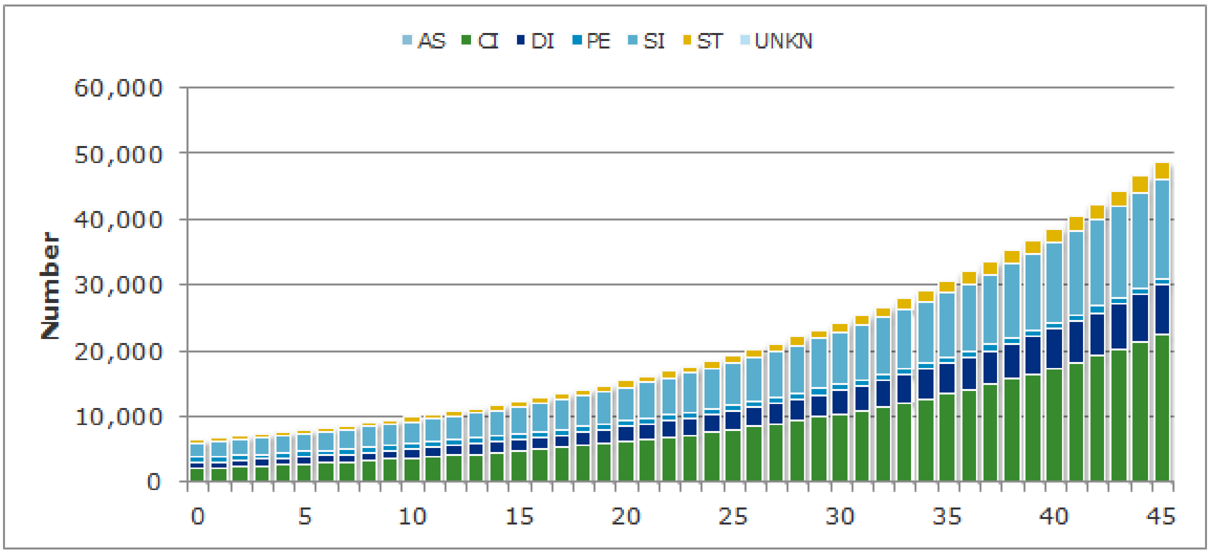


Fig 14. Worked Example - Total numbers of joint failures per year given reactive only maintenance (all materials and all cohorts)

4.3.2.2 General Emissions

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

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

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

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

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

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

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

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

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

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

Year 0 General Emissions

General Emissions m3/Km/Yr	666.3934488

Year 10 General Emissions

General Emissions m3/Km/Yr	733.0327937

Figure 15. Worked Example – General Emissions Figures.

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

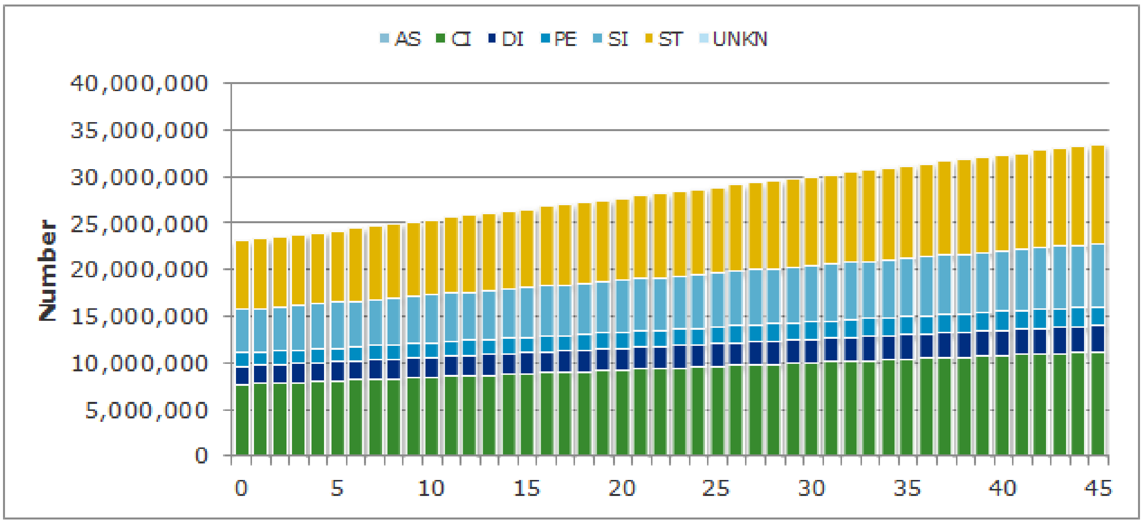


Fig 16. Worked Example - Total general emissions given reactive only maintenance (all materials and all cohorts). Units are in cubic metres per year

4.3.3 Derived Asset Health

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

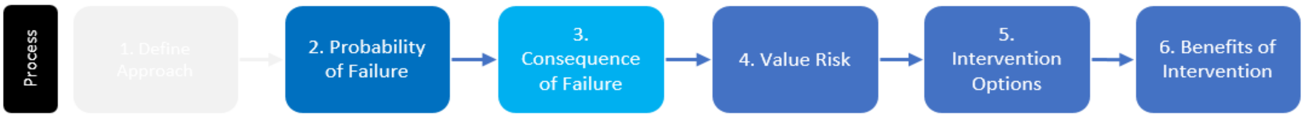
4.3.3.1 Example

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

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

Table 8. Example Asset Health Figure.

4.4 Consequence of Failure & Derived Criticality



4.4.1 Probability of Consequence (PoC) Calculation

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

Gap analysis will be undertaken for consequence data that will be used in the determination of these values. The applicable method for determining each value will be dependent on the level of data availability and quality derived from this analysis, as per the options in section 4.1.

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

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

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

4.4.1.1 Option A

Consequence values derived from GDN specific data sources.

4.4.1.2 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.

4.4.1.3 Option C

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

4.4.2 Worked Example – Probability of Consequence

4.4.2.1 Joint

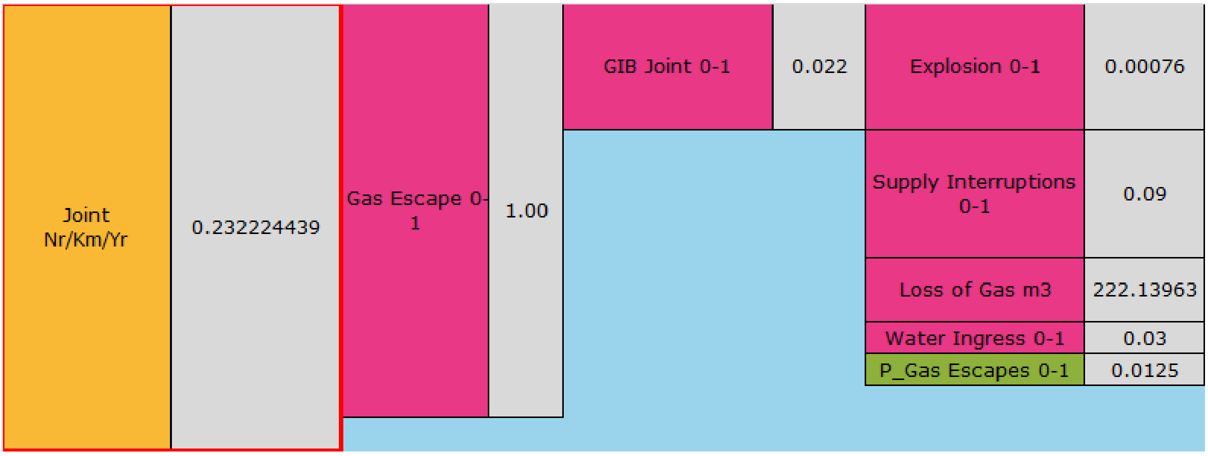


Fig 17. Worked Example – Joint PoC Figures

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)

4.4.2.2 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 (£)

4.4.4.1 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

Fig 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:

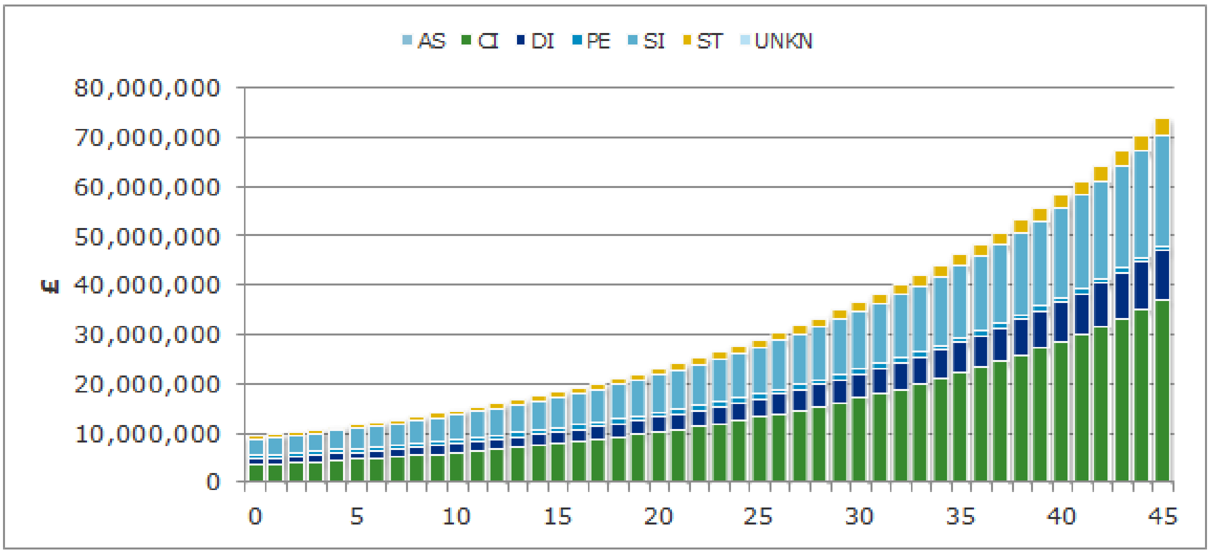


Fig 19. Worked Example - Joint consequence values over life of asset given reactive only maintenance (all materials and cohorts)

F_Joint

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

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

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

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

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

F_Carbon

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

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

- The Year 0 value of carbon is £59 per tonne of carbon dioxide. This is inflated in future years according to HM Treasury guidelines
- This is converted to a value in cubic metres (to align with the loss of gas estimate) and uplifted to account for the higher greenhouse impact of natural gas

- 1 cubic metre of CO_2 = 0.00076 tonnes
- Correction tonnes of CO_2 to tonnes of natural gas = 17.697
- Conversion factor (tonnes CO_2 to m3 natural gas) = 0.00076 x 17.697 = 0.0134

- The annual volume of the loss of gas due to joint failures is calculated by multiplying the predicted joint PoF by the loss of gas per joint failure (222.14 m3)
- The total annual loss of gas is multiplied by the value of carbon emissions associated with the calculated loss of gas

The calculation is shown below:

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

F_Death

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

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

The calculation for F_Death is as follows:

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

4.4.4.2 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

Fig 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:

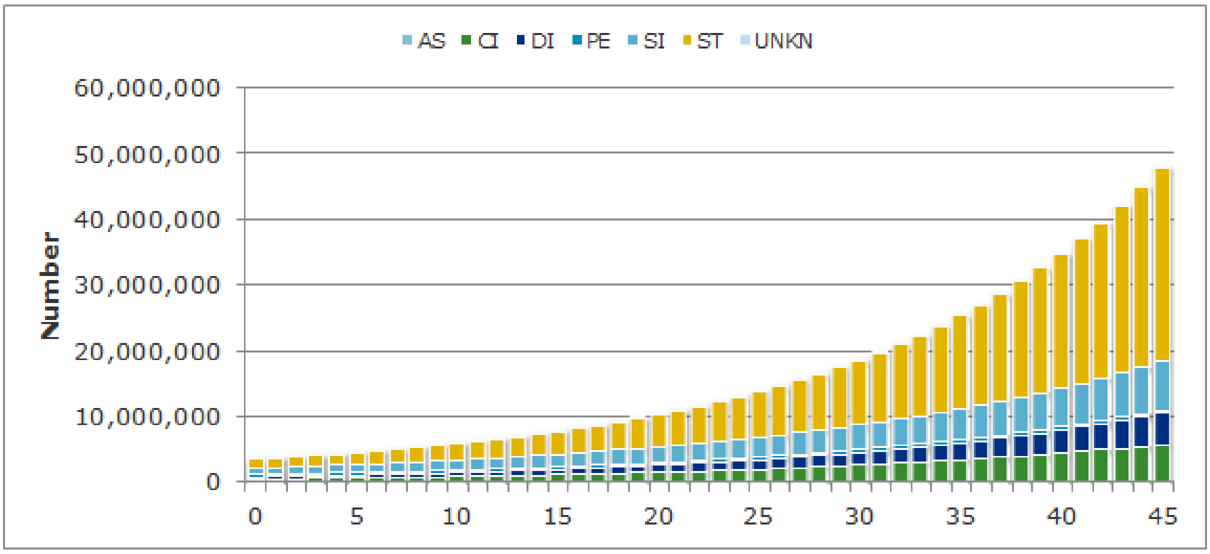


Fig 21. Worked Example - Loss of Gas consequence values over life of asset given reactive only maintenance (all materials and cohorts). Units are £/year

F_Carbon

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

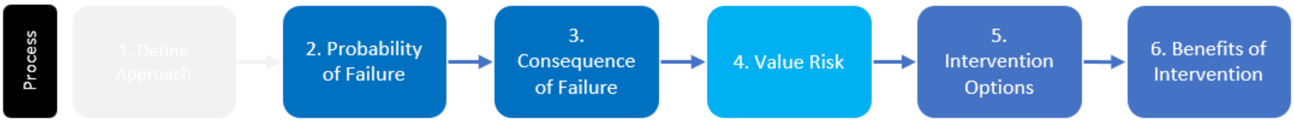
F_Carbon (Year 0) = 666.3 m3/km/year x 0.0134 x £59 per tonne = £528.81per km per year

F_Loss of Gas

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

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

4.5 Calculate Risk Values



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

4.5.1 Worked Example – Monetised Risk Calculation

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

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

4.5.1.1 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**

Fig 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.

4.5.1.2 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**

Fig 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.

4.5.1.3 Total Monetised Risk

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

Year 0 Total Monetised Risk

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

Year 10 Total Monetised Risk

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

Fig 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):

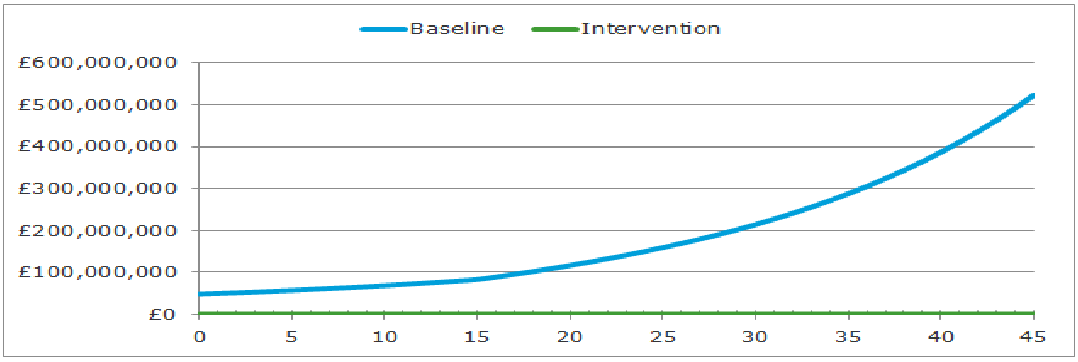
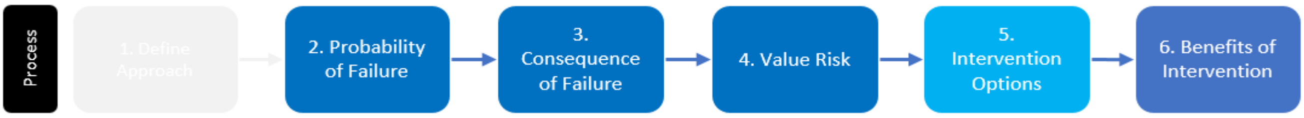


Fig 25. Worked Example - Total monetised risk values for the DI/NO/1 cohort with no intervention (reactive maintenance only).

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.

4.6.1.1 Worked Example - Types of Intervention

Appendix A describes how intervention options are identified for Mains (and other Asset Group) interventions. For the purposes of this worked example we will consider 2 simple (and exaggerated) interventions for the DI/NO/1 cohort and then compare them.

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

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

4.6.2 Calculate intervention strategy costs

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

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

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

4.6.2.1 Worked Example - Types of Intervention

Mains replacement

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

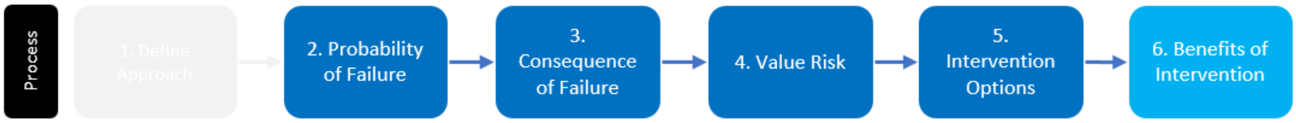
Unit cost of mains replacement = £128,084 per km

Spray-lining

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

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

4.7 Impact of Intervention



The benefit (value) of each intervention will be established to calculate the net effect of applying an intervention across the planning horizon. An example is given in the plot below where the asset is either completely replaced with a new and different asset and the PoF is reset to zero (red), or the asset is refurbished and the age is only partially reset, on the same failure curve but shifted towards the left.

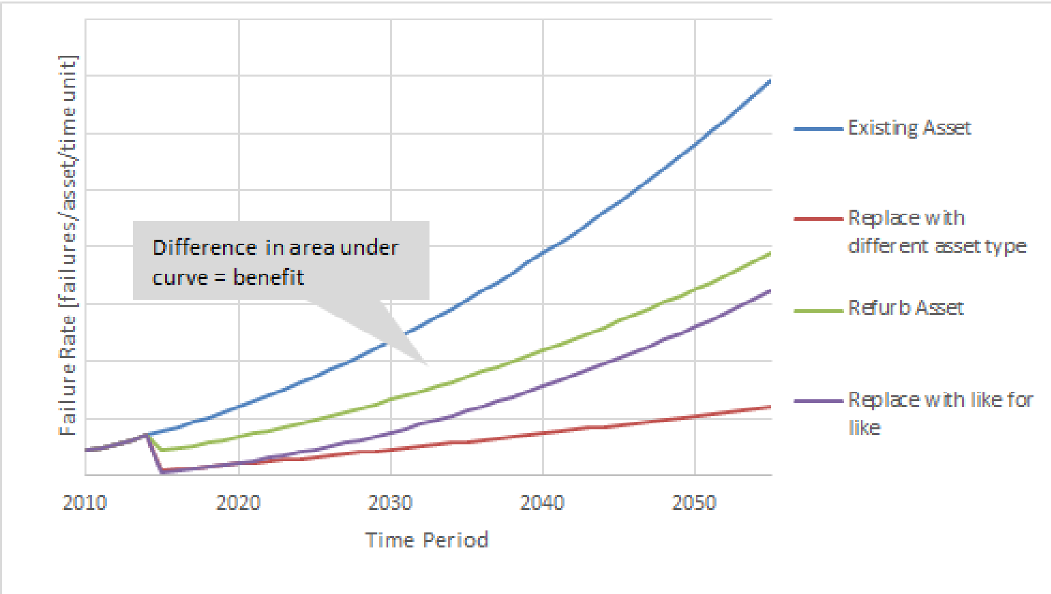


Fig 26. Example Intervention Curves

4.7.1.1 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)

Mains replacement

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

Spray-lining

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

For spray-lining, benefits are modelled as:

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

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

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

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

Comparison of Monetised Risk Reduction Benefits

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

Costs of intervention are discussed in further sections.

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 mid- and end-points of the RIIO GD1 period.

4.7.2.1 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

Fig 27. Worked Example - Monetised risk for DI/NO/1 cohort without intervention (Years 0-8)

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 mid and end points of the RIIO GD1 period are 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 identify opportunities for risk trading where investment can be re-targeted to deliver better returns on investment.

4.7.3.1 Worked Example – With-Intervention Risk Values

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

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

Spray-lining

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

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

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

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

4.7.4 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.

4.7.4.1 Worked Example

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

	Without Intervention (£M)	With Intervention (£M)	Delta (±£M)
Mains replacement			
50km pa	63.72	63.23	-0.49
10km pa	63.72	63.62	-0.10
Spray-lining			
50km pa	63.72	63.53	-0.19

Table 15. Worked Example – Risk Comparison

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

5 Regulatory Reporting

5.1 Overview

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

- be able to communicate to a general audience the overall state of each Asset Group in a consistent and comparable manner across a number of key performance measures;
- illustrate movement in key performance measures with and without interventions;
- illustrate movement in key performance measures over time;
- demonstrate the monetised value of investment on key performance measure;
- incorporate asset health expressed as the number of failures per annum, and
- be visual, but with supporting tables and a level of drill-downs that allow more in depth comparison if required.

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

5.2 Asset Groups

There are Event Trees for 10 primary Asset Groups. These primary Asset Groups will be split into 19 sub-groups for regulatory reporting, as per the table below:

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

Table 16. Asset Groups & Sub-Groups for Reporting

5.3 Health & Risk Reporting

GDNs will report on six key performance measures for each of the 19 Asset Groups and Asset Sub-groups. This provides an overall view of the health, criticality (customer, environmental and health & safety) and risk and a breakdown of the key components. The six performance measures are provided in the table below. Data will be provided as absolute and normalised by the appropriate unit.

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

Table 17. Reporting Performance Measures

The following table provides example output for Distribution Mains in tabular format for normalised values (sample data only). Normalised data can be directly derived from dividing the absolute values by the appropriate unit, length or numbers of assets in each Asset Group. Each table provides the measures with and without intervention (investment).

Primary Asset	Secondary Asset	Scenario	2015						
			Asset Count	Length(km)	Asset Health (failures/km)	Customers Risk (£/km)	Health & Safety Risk (£/km)	Carbon Risk (£/km)	Monetised Risk (£/km)
Distribution Mains	IRON	Without Investment	93,076	9,831	0.85	£138.68	£133.81	£1,312.04	£3,415.96
		With Investment	88,906	9,383	0.84	£139.57	£132.06	£1,301.15	£3,417.98
	OTHER	Without Investment	23	3	42.49	£6,782.65	£7,180.70	£5,634.89	£66,756.79
		With Investment	23	3	42.49	£6,782.65	£7,180.70	£5,634.89	£66,756.79
	PE	Without Investment	331,660	22,979	0.05	£9.25	£6.47	£62.32	£171.34
		With Investment	336,493	23,461	0.05	£9.16	£6.43	£61.17	£292.80
	ST	Without Investment	29,548	1,999	0.56	£60.87	£86.21	£3,140.91	£5,047.77
		With Investment	28,885	1,966	0.56	£61.45	£85.92	£3,145.53	£5,058.91

Table 18. Reporting Health, Criticality & Risk (Normalised Values)

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

The underlying continuous values of asset health (i.e. the failure rate) in this instance are banded into 11 bands, 10 bands of equal measure and a spill over band. Each health index (HI) band is defined for each asset and is consistent across GDNs to allow for easy visual comparison.

For asset health, the data should be generated to reflect the key factors that influence the underlying Failure Rate and the asset attributes used to determine the asset Failure Modes – as described in Section 4.3.1 and example in Appendix 3.2.

An example histogram is provided below for Distribution Mains that uses the attributes described in Appendix 3.2. This clearly shows the spread of cohorts with and without intervention/investment for any given year.

Fig 28. Asset Health Distribution Report

A histogram of asset risk (RI) will also be generated to help understand the distribution of the underlying cohorts. The bands are also split into 10 equal bands and one spill over band.

Fig 29. Asset Risk Distribution Report

6 Governance

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

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

6.1 SRWG Membership

The Gas SWRG Membership will include;

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

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

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

6.2 SRWG Annual Work Programme

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

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

6.3 SRWG Annual Report

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

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

The Annual Report will include;

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

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

6.4 Modification Process

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

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

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

- A detailed explanation of the proposed modification and how it will better meet the relevant obligations
- Any impact on the Risk baselines previously agreed with Ofgem and contained within any Licence 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.

Following the implementation of any approved modification to the methodology the GDNs will appoint an independent expert to review and report on that implementation. This report will be submitted to the Authority and made publically available.

6.5 Publication of Methodology Statement

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

Appendix A – 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. Event Tree Development

A2.1. Distribution Mains Failure Modes

As per the process in section 3.3, the following Failure Modes have been identified for Distribution Mains. Failure modes were identified through a number of workshops with asset experts and through careful analysis of available data held by companies to assess and quantify the rate of failures and future asset deterioration.

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

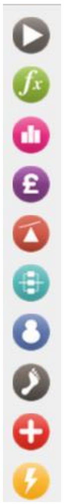
Values are typically expressed per kilometre of pipe. The Failure Modes are highlighted in yellow on the risk map below.

A2.2. Distribution Mains Consequence Measures

As per the process in section 3.4, the following consequence measures have been identified for Distribution Mains.

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

A2.3. Distribution Mains Risk Map



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

As per the process within section 3.5, the final risk map for Distribution Mains is below:

Distribution Mains GDN v5

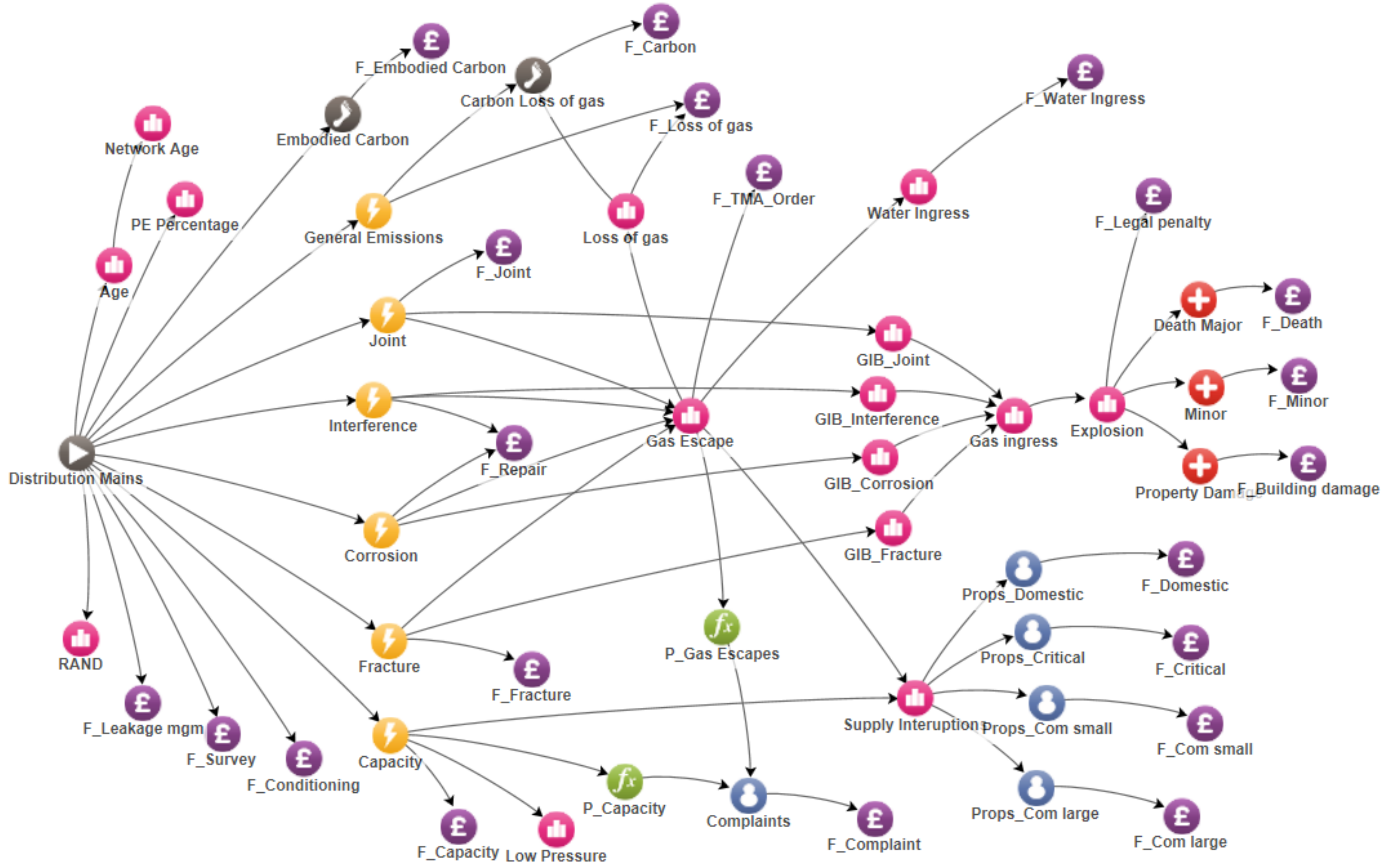


Fig 30. Final Distribution Mains Risk Map

A2.4. Distribution Mains Risk Template

The following table demonstrates how the total risk value is derived for any given Distribution Mains 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.

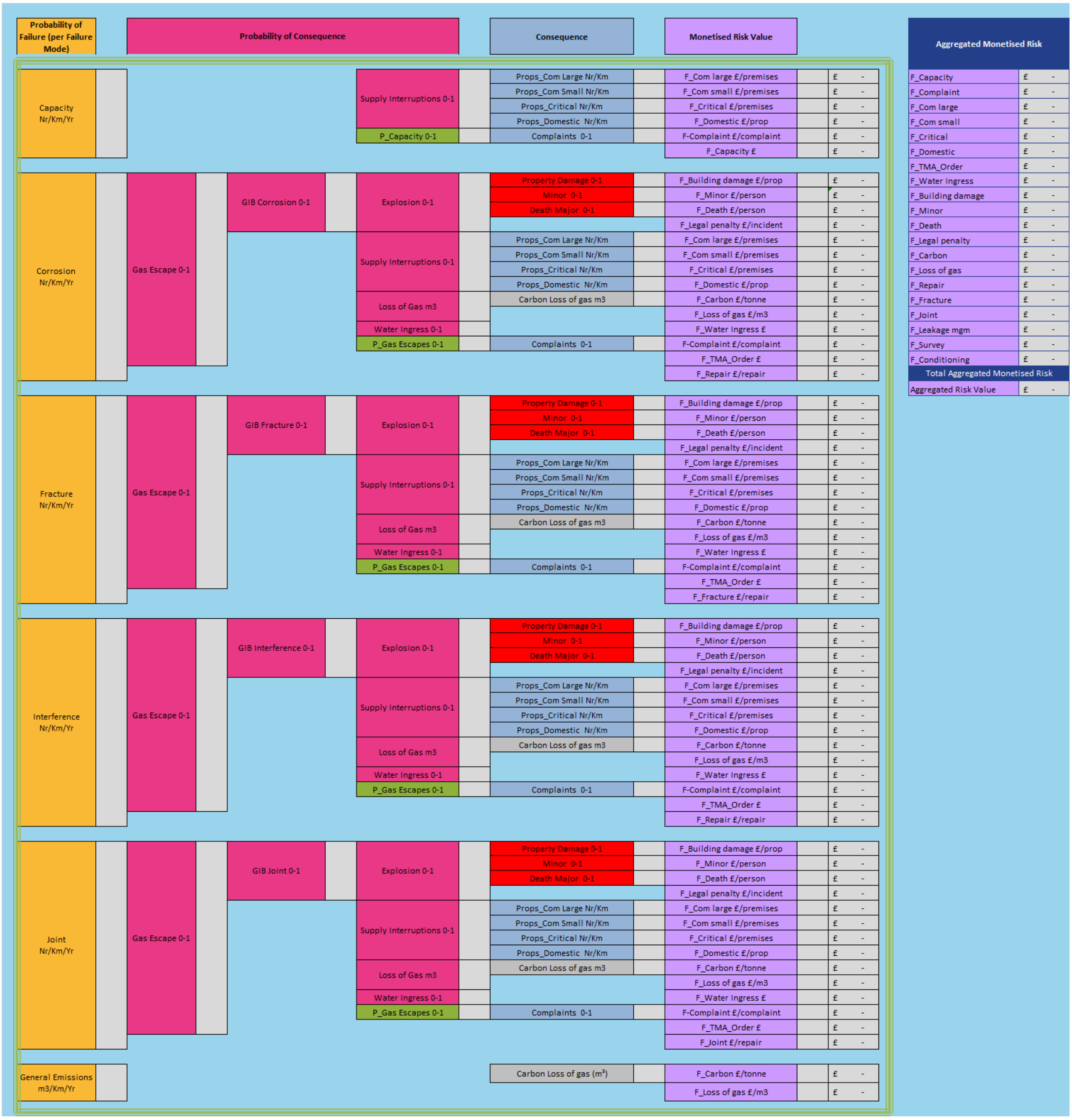


Fig 31. Final Distribution Mains Template

A2.5. Distribution Mains Data Reference Library

As per section 3.6, the following table gives a description of data required for nodes on the Event Tree. It includes data source, update frequency, sensitivity. It also includes the plan for data improvement which is proportionate based on the sensitivity in the model to that data item.

Node ID / Variable	Node Type	Description	Unit	Data Source	Sensitivity	Governance Trigger
Carbon_Loss_Of_Gas	Calculation	m3 of carbon equivalent from loss of gas	m^3	1 m3 of carbon equivalent from Loss of Gas is 0.00076 x 17.697 = 0.0314 m3 CO2e. Sensitivity is due to the differences gas composition in each network	**High**	Annual review
Loss_of_Gas	Consequence	m3 of gas lost from a failure or Failure Mode	m^3	Taken from standard gas industry leakage models Linear extrapolation utilised for Intermediate pressure for which no data currently exists	**High**	Annual review
Fracture	Failure Mode	Frequency of fracture failures	Nr/km/yr	Statistical models developed for each Failure Mode by segmenting 7 worth years of NGN actual failure data by Diameter, Material, Pressure Class, Age and Distribution Zone. Models were created for each Failure Mode based on these explanatory factors and 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 was estimated for each Failure Mode and Material using the statistical relationship between estimated pipe failure rates and installed Age.	**High**	Annual review
Joint	Failure Mode	Frequency of joint failures	Nr/km/yr	As Fracture	**High**	Annual review
Corrosion	Failure Mode	Frequency of corrosion failures	Nr/km/yr	As Fracture	**High**	Annual review
General Emissions	Failure Mode	Leakage	Nr	Uses standard industry emissions models.	**High**	Annual review
F_Joint	Financial	Average cost of repairing a joint	£/repair	Data taken from company systems. A statistical model was developed to relate unit cost to pipe diameter.	**High**	Annual review
F_Fracture	Financial	Average cost of repairing a fracture	£/repair	Data taken from company systems. A statistical model was developed to relate unit cost to pipe diameter.	**High**	Annual review
F_Repair	Financial	Average cost of a general repair due to corrosion / Interference	£/repair	Data taken from company systems. A statistical model was developed to relate unit cost to pipe diameter.	**High**	Annual review
F_Survey	Financial	Cost of survey of iron pipes, assume survey every 5 years	£/km	Agreed with SRWG based on cost data and historic activity taken from company systems.	**High**	Annual review
F_TMA_Order	Financial	Cost of compliance with local authority traffic management order	£	Agreed with SRWG based on cost data and historic activity taken from company systems.	**High**	Annual review
Death_Major	Consequence	Percentage Level of deaths given explosion	Nr	Value based on research values (Newcastle University)	**Medium**	Review every 4 years
Props_Domestic	Consequence	Number of domestic properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (See A2.6). These overall meter counts are split into Property type based on proportions provided by NGN	**Medium**	Review every 4 years

Node ID / Variable	Node Type	Description	Unit	Data Source	Sensitivity	Governance Trigger
Explosion	Consequence	Probability of explosion given gas ingress	0-1	DNV GL estimate Estimate based on average number of explosions over an extended period (all DNs)	**Medium**	Review every 4 years
GIB_Fracture	Consequence	Probability of gas ingress given failure – Fracture	0-1	Based on reported GIB's over 5 year period across whole industry.	**Medium**	Review every 4 years
GIB_Interference	Consequence	Probability of gas ingress given failure – Interference	0-1	Based on reported GIB's over 5 year period across whole industry.	**Medium**	Review every 4 years
GIB_Joint	Consequence	Probability of gas ingress given failure – Joint Failure	0-1	Based on reported GIB's over 5 year period across whole industry.	**Medium**	Review every 4 years
F_Leakage_mgm	Financial	Cost of leakage management per unit length	£/km	Agreed with SRWG based on cost data and historic activity taken from company systems.	**Medium**	Review every 4 years
Minor	Consequence	Percentage Level of minor injury given explosion	Nr	Assumed value consistent with RIIO GD1 CBA analyses	**Low**	Review every 8 years
Property_Damage	Consequence	Percentage Level of property damage given explosion	Nr	Assumed value consistent with RIIO GD1 CBA analyses	**Low**	Review every 8 years
Props_Critical	Consequence	Number of critical properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (See A2.6). These overall meter counts are split into Property type based on proportions provided by NGN	**Low**	Review every 8 years
Props_Com_Small	Consequence	Number of commercial small properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (See A2.6). These overall meter counts are split into Property type based on proportions provided by NGN	**Low**	Review every 8 years
Props_Com_Large	Consequence	Number of commercial large properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (See A2.6). These overall meter counts are split into Property type based on proportions provided by NGN	**Low**	Review every 8 years
P_Gas_Escapes	Consequence	Probability of complaints given a failure has occurred	0-1	Agreed with SRWG based on data from company systems.	**Low**	Review every 8 years
Supply_Interuptions	Consequence	Probability of supply interruptions given a failure has occurred	0-1	Agreed with SRWG based on data from company systems.	**Low**	Review every 8 years
Water_Ingress	Consequence	Probability of water ingress given a failure has occurred	0-1	Agreed with SRWG based on data from company systems.	**Low**	Review every 8 years
Interference	Failure Mode	Frequency of interference failures	Nr/km/yr	As Fracture	**Low**	Review every 8 years
F_Conditioning	Financial	Cost of conditioning of iron pipes	£/km	Agreed with SRWG based on cost data and historic activity taken from company systems.	**Low**	Review every 8 years
F_Capacity	Financial	Cost of responding to capacity issues (not this is not the cost of resolving capacity issues)	£/km	Agreed with SRWG based on cost data and historic activity taken from company systems.	**Low**	Review every 8 years
P_Capacity	Consequence	Probability of customer complaints given a network capacity issue	0-1	Assumed value agreed with SRWG	**Low**	Review every 8 years
F_Complaints	Financial	Cost of handling customer complains		Agreed with SRWG based on cost data and historic activity taken from company systems.	**Low**	Review every 8 years
Complaints	Calculation	Number of customer complaints	Nr	Calculated value from other parameters	**Low**	Review every 8 years
F_Water_Ingress	Financial	Cost of water ingress	£	Agreed with SRWG based on cost data and historic activity taken from company systems.	**Low**	Review every 8 years

Table 19. Distribution Mains Data Reference Library

A3. 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:

- Pipe length
- Diameter
- Material
- Distribution Zone
- Pressure Tier
- Installation date
- MRPS risk scores
- etc.

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

An example of data input format is shown below:

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

Table 20. 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

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 to derive a mathematical relationship between the PoF and the explanatory factors for each Failure Mode. In statistical terms this is described as a counting process regression model.

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

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

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

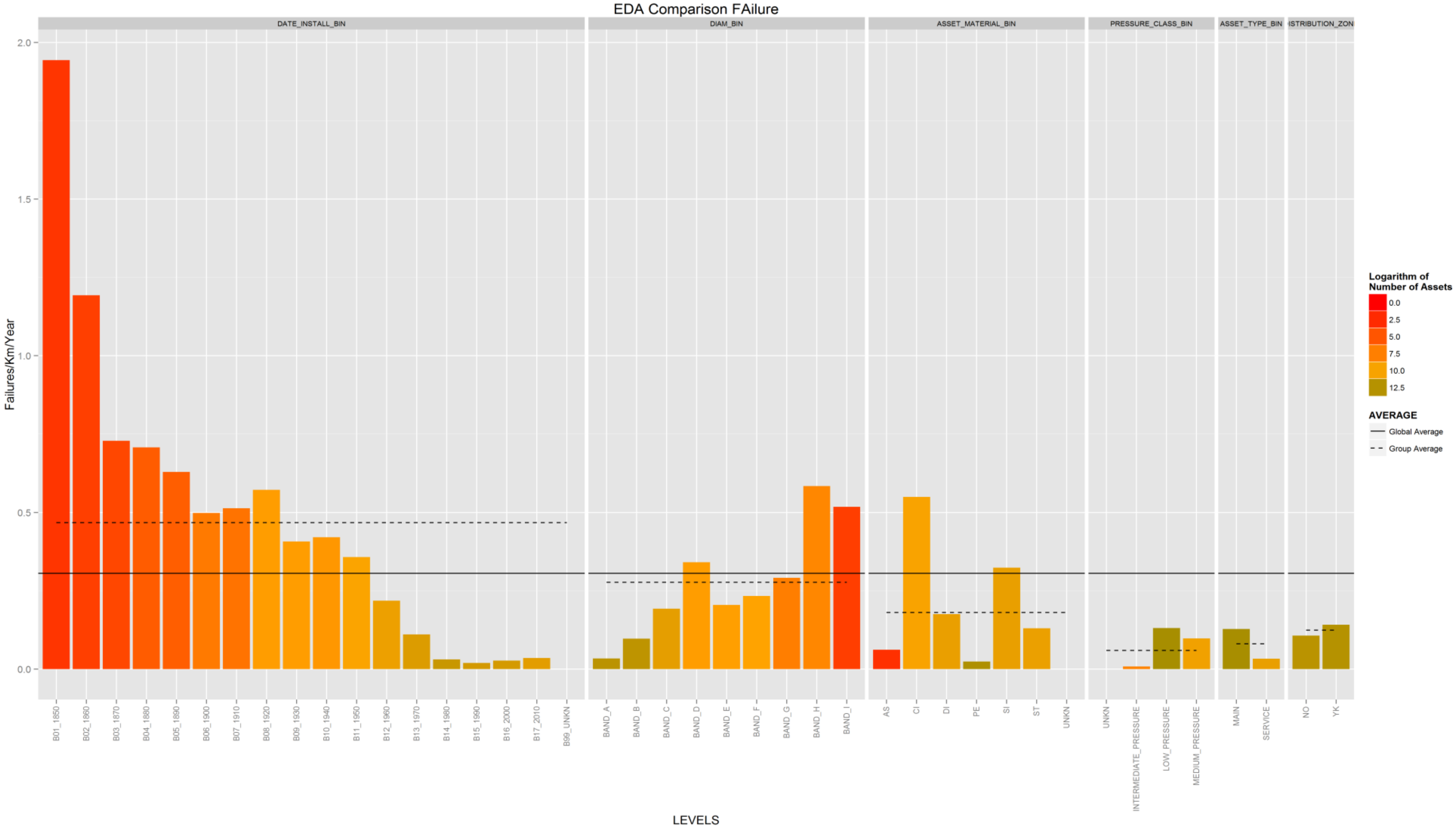


Fig 32. Initial Joint failure rates for Mains by asset cohort. This illustrates the explanatory factors explored in deriving the predictive function. The height of the bars indicates the contribution of each explanatory factor to the overall predicted Joint failure rate.

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 failures per year per pipe length. 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
- Interference (no age relationship modelled)
- Corrosion
- Fracture

These 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.

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

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

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

A3.3. Distribution Mains Deterioration Assessment

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

Two alternative scenarios were initially explored for testing the sensitivity of the applied deterioration rates on risk value. Initially, a global 2% exponential deterioration rate was tested, taken from the 2-4% range suggested in the Ofgem/HSE sponsored CEPA report.

This is in line with previous assumptions; an insufficient time series of data was available to derive the true shape of the deterioration curve. Annual validation will be carried out to test the predictive ability of the deterioration model, for example by using the derived deterioration rate to back-calculate historic failure rates. Sensitivity as to the impact of the assumed shape of the deterioration curve on modelled interventions should be carried out. As the benefits are discounted significantly in the later years of the cost-benefit analysis the impact of an exponential versus linear deterioration curve is dampened.

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

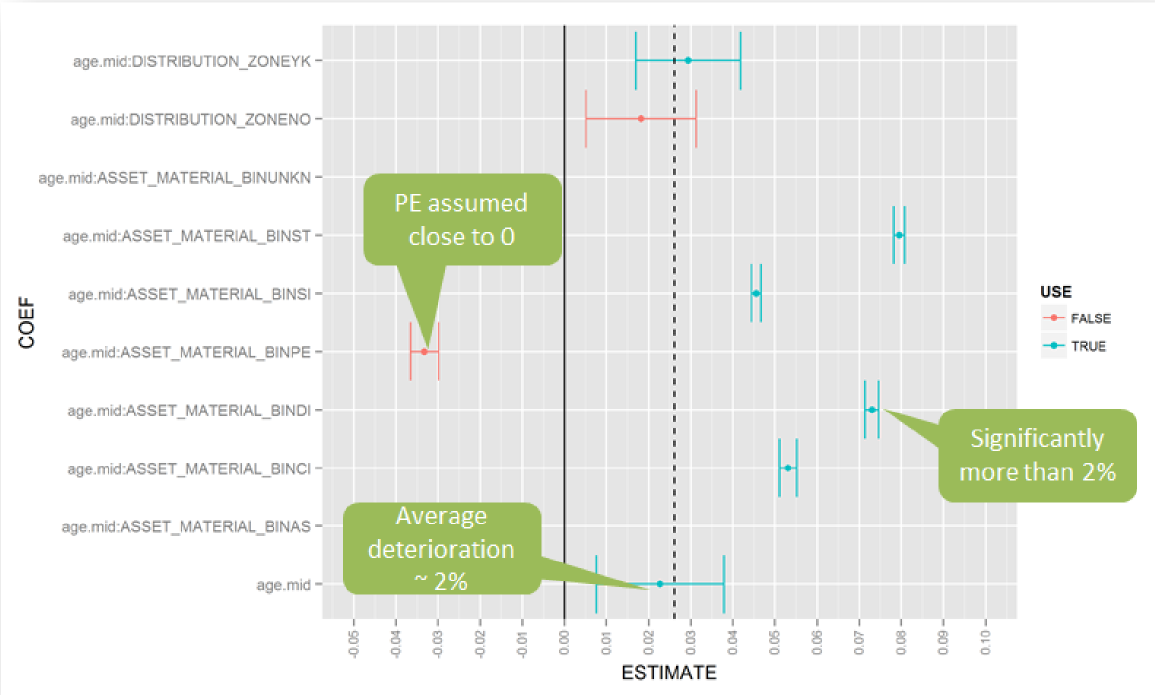


Fig 33. NGN corrosion failure rates by Material and Zone

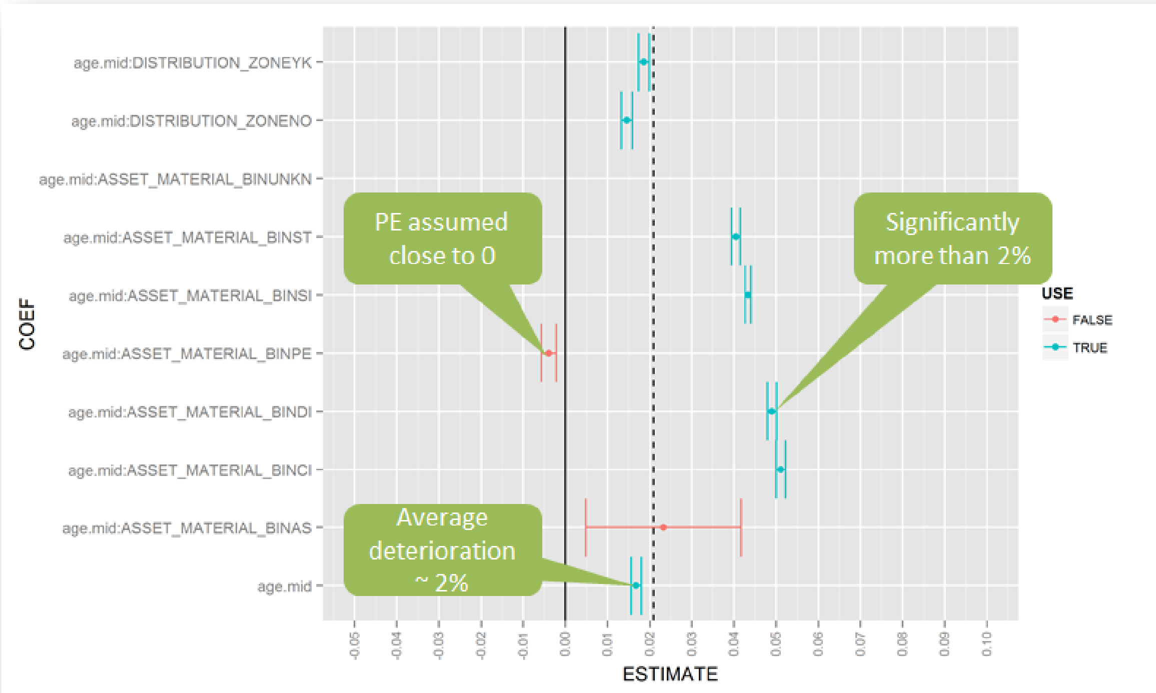


Fig 34. NGN joint failure deterioration rates by Material and Zone

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

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

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

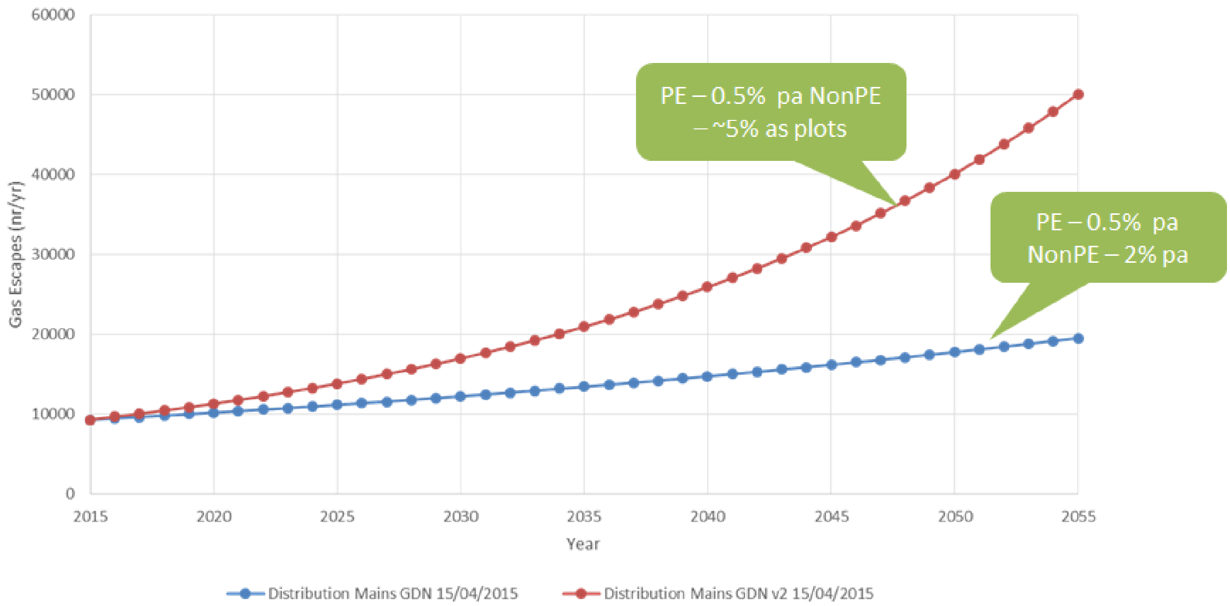


Fig 35. Comparison of 2% and derived deterioration rates on predicted gas escapes

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

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

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

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

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 A2.4. For simplicity each

Consequence of Failure for mains has been categorised as Internal Costs, Environmental, Health & Safety or Customer consequences. Examples of Distribution Mains consequence modelling are also illustrated. The data source and derivation for all Costs of Failure are explained in the Data Reference Library.

A3.4.1. Internal Consequence Costs

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

A3.4.2. Environment Consequence Costs

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

A3.4.3. Health & Safety Consequence Costs

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

A3.4.4. Customer Consequence Costs

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

A3.4.5. Corrosion Consequences of Failure

For a mains corrosion failure the assessed initial consequence is a loss of gas (PoC=1), which may lead to a gas in building (GIB) event (PoC=0.029). A GIB event may lead to an explosion (PoC=0.00076) which may lead to property damage (PoC=1), a minor injury (PoC=1) or a death (PoC=0.45). Each consequence is then assigned a monetary value (using the cost of consequence calculated as per Section A5.). The sum of all consequences is the monetised risk for the Corrosion Failure Mode.

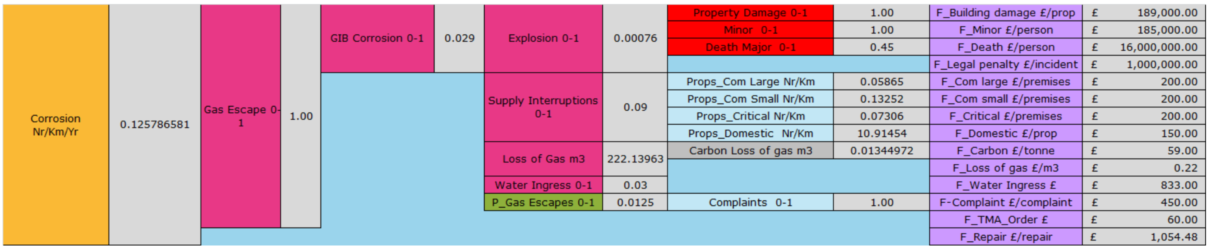


Fig 36. Modelled consequences and values for Mains Corrosion failure.

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

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

A3.4.5. 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.

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

Fig 37. Modelled consequences and values for Mains General Emissions failure

A3.5. Distribution 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 Intervention** 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 Intervention activity below.

Some potential interventions to be modelled for Distribution Mains are listed below.

With Intervention activities	Without Intervention activities
• Replacement	• Gas conditioning
• Decommissioning	
• CIPP lining	• Surveys
• Planned internal repairs (e.g. CISBOT)	• Repairs following leakage/ingress

A3.5.1. Mains Replacement Intervention Benefits

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

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

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

The deterioration rate of the new PE following replacement will be very low, but non-zero. The deterioration rate for PE pipe (derived as above) was used to model the post-intervention PoF deterioration.

Example values used to model post-intervention PoF and deterioration (by Failure Mode)

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

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								

Fig 38. **Example intervention plan for 20km pa mains replacement (CI with PE)**

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

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

Fig 39. Example pre and post intervention rules for the above mains replacement intervention (DI with PE)

Using the example above the pre-intervention DI Fracture rate can be seen to be 0.174 failures/km/year prior to replacement with PE and 0.001 failures/km/year post replacement.

Appendix B – Services

B1. Services Definition

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

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

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

- **Domestic**. Service pipes which are less than 63mm in diameter. There are no company records held of these individual services or their locations and characteristics have needed to be estimated (see A2. below). Please note that **Domestic** is a naming convention used only 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.
- **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.

B2. Event Tree Development

B2.1. Services Failure Modes

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

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

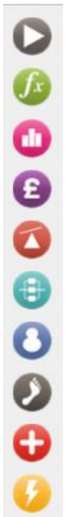
Values are typically expressed in 'per Service' units. The Failure Modes are highlighted in yellow on the risk map below.

B2.2. Services Consequence Measures

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

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

B2.3. Services Risk Map



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

B2.3. Services Risk Map

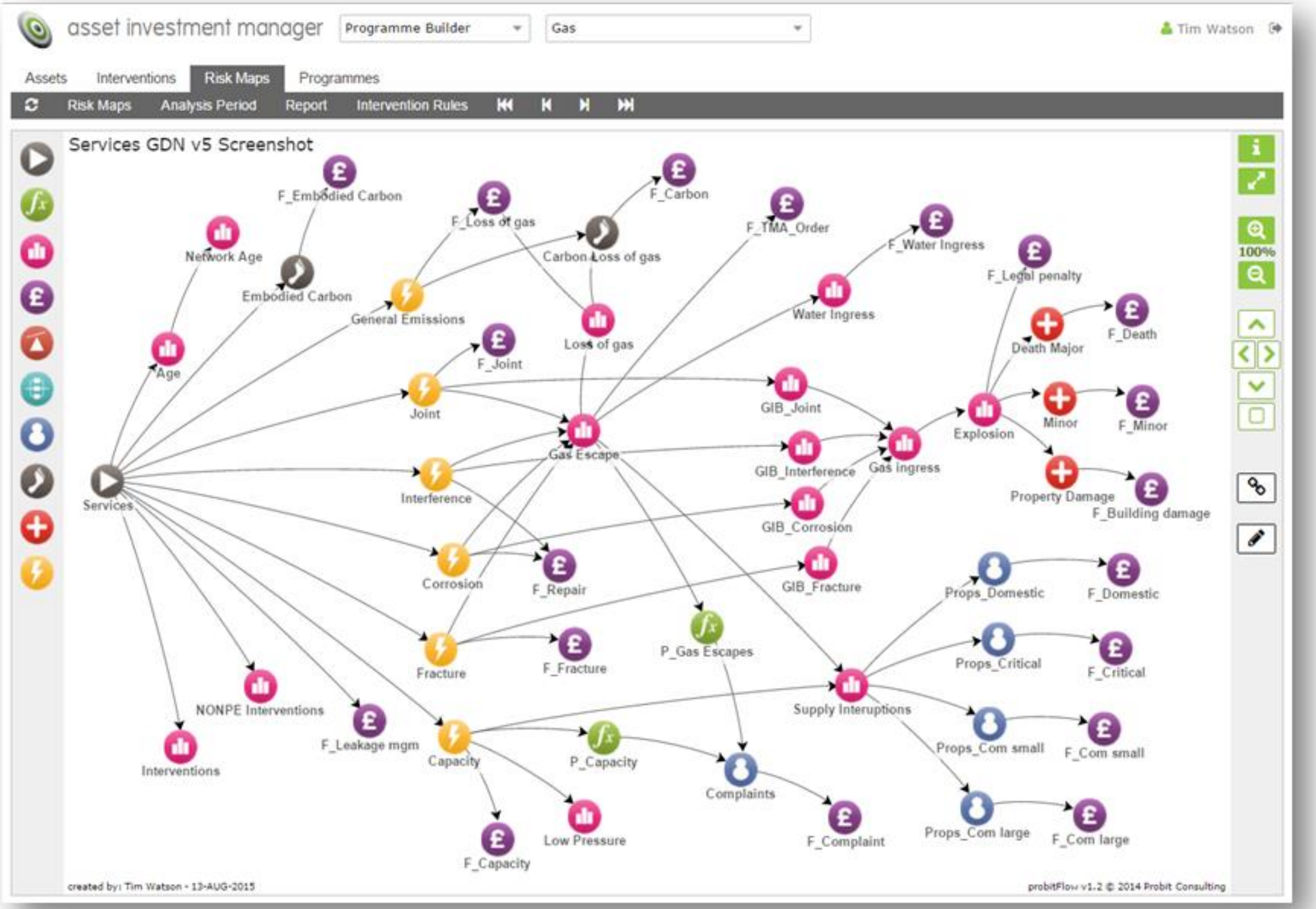


Fig 40. Finalised Services Risk Map

B2.4. Services Risk Template

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

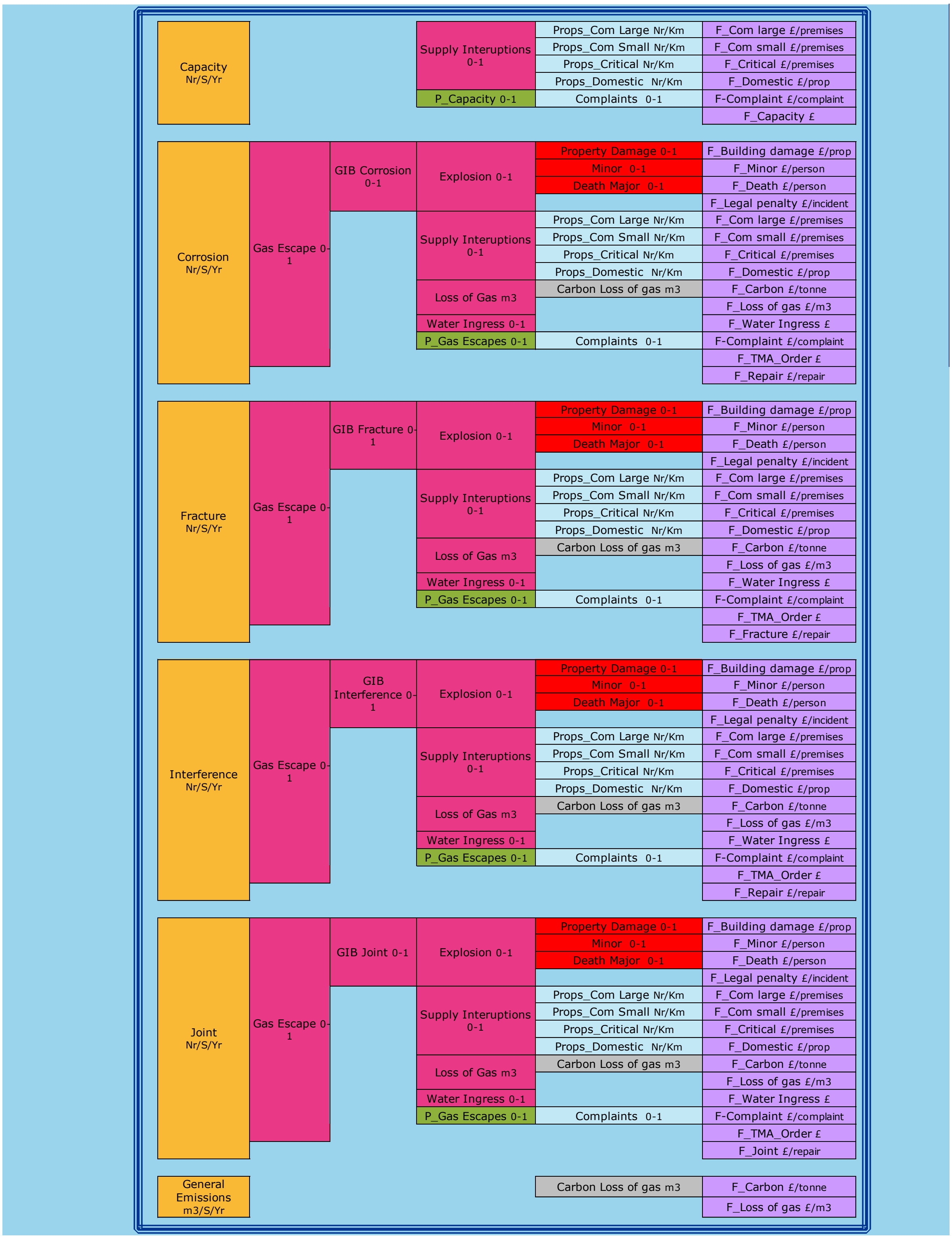


Fig 41. Finalised Services Risk Template

B2.5. Services Data Reference Library

The following table gives a description of data required for nodes on the Event Tree. It includes data source, update frequency, sensitivity. It also includes the plan for data improvement which is proportionate based on the sensitivity in the model to that data item.

Node ID / Variable	Node Type	Description	Unit	Data Source	Sensitivity	Governance Trigger
Props_Domestic	Consequence	Number of domestic properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (see Appendix B2.). These overall meter counts are split into Property type based on proportions provided by NGN. Continue to collect and improve data in company systems. An option is to use an external data-set (such as Ordnance Survey MasterMap property seed points) and then to link these spatially to the closet main using Geographic Information System functionality. This will enable a more accurate assessment of Service density and lengths	**H**	Annual review
Carbon_Loss_Of_Gas	Calculation	m3 of carbon equivalent arising from loss of gas	m^3	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. Carbon Equivalent value is 17.697	**H**	Annual review
Loss_Of_Gas	Consequence	Loss of gas arising from a failure	m^3	Taken from standard gas industry leakage models. Linear extrapolation utilised for Intermediate Pressure	**H**	Annual review
Supply Interruption	Consequence	Probability of supply interruptions given a failure has occurred	0-1	Agreed with SRWG based on data from company systems.	**H**	Annual review
Fracture	Failure Mode	Frequency of fracture failures	Nr/S/Yr	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.	**H**	Annual review
Joint	Failure Mode	Frequency of joint failures	Nr/S/Yr	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.	**H**	Annual review
Corrosion	Failure Mode	Frequency of corrosion failures	Nr/S/Yr	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.	**H**	Annual review
Non_PE_Det	Failure Mode	Deterioration rate of Non_PE pipes	%	Limited data was available to estimate the deterioration of services over time. Assumptions made based on SRWG judgement. Further research to quantify the true deterioration rate of non-PE and PE materials	**H**	Annual review
F_Joint	Financial	Average cost of repairing a joint	£/repair	Data taken from NGN company systems with 50% uplift applied for back office costs	**H**	Annual review

Node ID / Variable	Node Type	Description	Unit	Data Source	Sensitivity	Governance Trigger
F_Fracture	Financial	Average cost of repairing a fracture	£/repair	Data taken from NGN company systems with 50% uplift applied for back office costs	H	Annual review
F_Repair	Financial	Average cost of a general repair due to corrosion or interruption	£/repair	Data taken from NGN company systems with 50% uplift applied for back office costs	H	Annual review
Death_Major	Consequence	Percentage Level of deaths given explosion	%	Value based on research values (Newcastle University)	M	Review every 4 years
Props_Critical	Consequence	Number of critical properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (See Note 1). These overall meter counts are split into Property type based on proportions provided by NGN	M	Review every 4 years
Props_Com_Small	Consequence	Number of commercial small properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (See Note 1). These overall meter counts are split into Property type based on proportions provided by NGN	M	Review every 4 years
Props_Com_Large	Consequence	Number of commercial large properties at risk of supply interruption	Nr	Derived from meter counts at a postcode level (See Note 1). These overall meter counts are split into Property type based on proportions provided by NGN	M	Review every 4 years
P_Gas_Escapes	Calculation	Probability of complaints given a failure has occurred	0-1	Agreed with SRWG based on data from company systems.	M	Review every 4 years
Explosion	Consequence	Probability of explosion given gas ingress	0-1	Agreed with SRWG based on data from company systems.	M	Review every 4 years
GIB_Corrosion	Consequence	Probability of gas ingress given failure - Corrosion	0-1	DNV GL estimate. Based on reported GIB's over 5 year period. These are the same as the Mains values	M	Review every 4 years
GIB_Fracture	Consequence	Probability of gas ingress given failure – Fracture	0-1	DNV GL estimate. Based on reported GIB's over 5 year period. These are the same as the Mains values	M	Review every 4 years
GIB_Interference	Consequence	Probability of gas ingress given failure – Interference	0-1	DNV GL estimate. Based on reported GIB's over 5 year period. These are the same as the Mains values	M	Review every 4 years
GIB_Joint	Consequence	Probability of gas ingress given failure – Joint Failure	0-1	DNV GL estimate. Based on reported GIB's over 5 year period. These are the same as the Mains values	M	Review every 4 years
PE_Det	Failure Mode	Deterioration rate of PE pipes	%	Limited data was available to estimate the deterioration of services over time. Assumptions made based on SRWG judgement. Further research to quantify the true deterioration rate of non-PE and PE materials	M	Review every 4 years
F_Leakage_mgm	Financial	Cost of leakage management per unit length	£/km	Agreed with SRWG based on cost data and historic activity taken from company systems. Applied only to Services that are represented as individual assets in GIS (>=63mm)	M	Review every 4 years
F_TMA_Order	Financial	Local authority management order	£/repair	Agreed with SRWG based on cost data and historic activity taken from company systems.	M	Review every 4 years
Minor	Consequence	Percentage Level of minor injury given explosion	%	Assumed value consistent with RIIO GD1 CBA analyses	L	Review every 8 years
Property_Damage	Consequence	Percentage Level of property damage given explosion	%	Assumed value consistent with RIIO GD1 CBA analyses	L	Review every 8 years
Water_Ingress	Consequence	Probability of water ingress given a failure has occurred	0-1	Agreed with SRWG based on data from company systems.	L	Review every 8 years

Node ID / Variable	Node Type	Description	Unit	Data Source	Sensitivity	Governance Trigger
Interference	Failure Mode	Frequency of interference failures	Nr/s/Yr	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.	**L**	Review every 8 years
F_Capacity	Financial	Cost of responding to capacity issues (not this is not the cost of resolving capacity issues)	£/km	Agreed with SRWG based on cost data and historic activity taken from company systems.	**L**	Review every 8 years
P_Capacity	Calculation	Probability of customer complaints given a network capacity issue	0-1	Applied only to Services that are represented as individual assets in GIS (>=63mm). Assumed value agreed with SRWG	**L**	Review every 8 years
F_Complaints	Financial	Cost of handling customer complains	£	Agreed with SRWG based on cost data and historic activity taken from company systems.	**L**	Review every 8 years
Complaints	Consequence	Number of customer complaints	Nr	Calculated value from other parameters	**L**	Review every 8 years
F_Water Ingress	Financial	Cost of water ingress	£/incident	Agreed with SRWG based on cost data and historic activity taken from company systems.	**L**	Review every 8 years

Table 21. Services Data Reference Library

B3. Event Tree Utilisation

B3.1. Services Base Data

The definition of Services cohorts within the NOMs methodology has been driven by the lack of data for less than 63mm diameter (Domestic) 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.

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 less 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 is 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. The diameter and material (etc.) for Domestic services are unknown and are based on global non-PE/PE proportions.

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

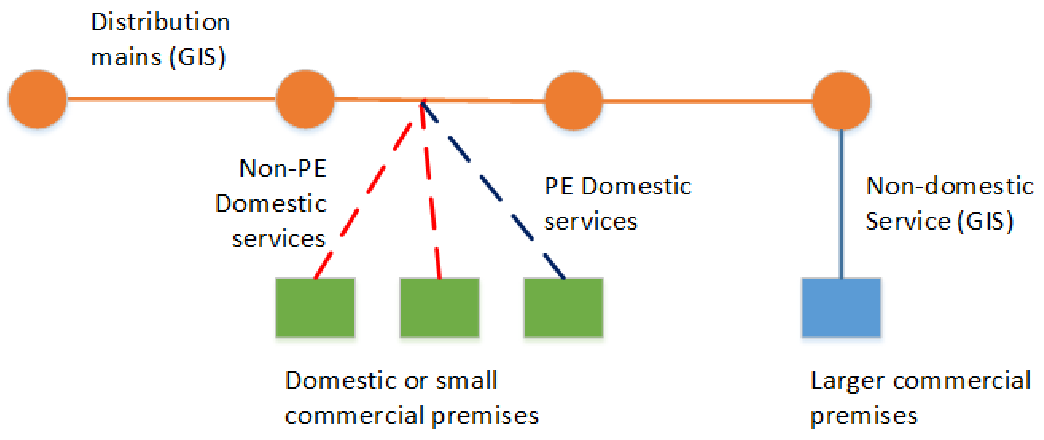


Fig 42. Asset Base Data Modelling

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

ASSET_ID	CUSTOMER_TYPE	ASSET_TYPE_BIN	DIAMETER	DIAM_BIN	ASSET_MATERIAL_BIN	TOTAL_SERVICE_LENGTH_M	NO_OF_METERS_ON_ASSET	ASSET_LENGTH	PRESSURE_CLASS_BIN	NUMBER_OF_PE_SERVICES	NUMBER_OF_NONPE_SERVICES
17353727	NON DOMESTIC	SERVICE	63	BAND_A	PE	30.78437403	1	30.78437403	MEDIUM_PRESSURE	1	0
16798876	NON DOMESTIC	SERVICE	125	BAND_B	PE	1.999612446	1	1.999612446	LOW_PRESSURE	1	0
14514646	NON DOMESTIC	SERVICE	125	BAND_B	PE	14.17185642	1	14.17185642	LOW_PRESSURE	1	0
14606080	NON DOMESTIC	SERVICE	125	BAND_B	PE	8.375	1	8.375	LOW_PRESSURE	1	0
14707401	NON DOMESTIC	SERVICE	50.8	BAND_A	PE	145.7604298	1	145.7604298	LOW_PRESSURE	1	0
14226144	NON DOMESTIC	SERVICE	63	BAND_A	PE	4.475075084	1	4.475075084	LOW_PRESSURE	1	0
16533128	NON DOMESTIC	SERVICE	32	BAND_A	PE	6.648168543	1	6.648168543	MEDIUM_PRESSURE	1	0
14420373	NON DOMESTIC	SERVICE	63	BAND_A	PE	10.61507574	1	10.61507574	LOW_PRESSURE	1	0
14660483	NON DOMESTIC	SERVICE	50.8	BAND_A	ST	16.60808779	1	16.60808779	LOW_PRESSURE	0	1
14527506	NON DOMESTIC	SERVICE	50.8	BAND_A	ST	126.0461644	1	126.0461644	LOW_PRESSURE	0	1
14512197	NON DOMESTIC	SERVICE	90	BAND_B	PE	35.36942447	1	35.36942447	LOW_PRESSURE	1	0
14536462	NON DOMESTIC	SERVICE	63	BAND_A	PE	25.99992152	1	25.99992152	LOW_PRESSURE	1	0
14716795	NON DOMESTIC	SERVICE	200	BAND_D	ST	3.008975352	1	3.008975352	LOW_PRESSURE	0	1
15792872	NON DOMESTIC	SERVICE	63	BAND_A	PE	45.30341685	1	45.30341685	LOW_PRESSURE	1	0
14816406	NON DOMESTIC	SERVICE	63	BAND_A	PE	3.370766572	1	3.370766572	LOW_PRESSURE	1	0
15491029	NON DOMESTIC	SERVICE	125	BAND_B	PE	2.898958641	1	2.898958641	LOW_PRESSURE	1	0
14735776	NON DOMESTIC	SERVICE	63	BAND_A	PE	22.76233918	1	22.76233918	LOW_PRESSURE	1	0

Table 22. Example of data format for Non-domestic services model showing pipe level information One Service per connection is assumed. Material and diameter is taken from GIS

ASSET_	CUSTOMER_TY	ASSET_TYPE_B	DIAMET	DIAM_B	ASSET_MATERIAL_B	TOTAL_SERVICE_LENGTH_	NO_OF_METERS_ON_ASSE	ASSET_LENGT	PRESSURE_CLASS_BIN	NUMBER_OF_PE_SERVICE	NUMBER_OF_NONPE_SERVICE
10172999	DOMESTIC	SERVICE	63	BAND_A	DI	85	5	59.39739369	LOW_PRESSURE	4	1
10119615	DOMESTIC	SERVICE	63	BAND_A	SI	391	23	35.09133921	LOW_PRESSURE	17	6
10382181	DOMESTIC	SERVICE	63	BAND_A	PE	119	7	86.14124451	LOW_PRESSURE	5	2
16360737	DOMESTIC	SERVICE	63	BAND_A	PE	17	1	12.91399818	LOW_PRESSURE	1	0
17249545	DOMESTIC	SERVICE	63	BAND_A	PE	102	6	130.4045015	LOW_PRESSURE	5	1
10408277	DOMESTIC	SERVICE	63	BAND_A	PE	85	5	66.98041121	LOW_PRESSURE	4	1
16340524	DOMESTIC	SERVICE	63	BAND_A	PE	51	3	138.6015259	LOW_PRESSURE	2	1
10366544	DOMESTIC	SERVICE	63	BAND_A	DI	153	9	403.2930034	LOW_PRESSURE	7	2
10342516	DOMESTIC	SERVICE	63	BAND_A	CI	17	1	15.42295186	LOW_PRESSURE	1	0
10383490	DOMESTIC	SERVICE	63	BAND_A	PE	34	2	18.66020163	LOW_PRESSURE	2	0
10305968	DOMESTIC	SERVICE	63	BAND_A	PE	442	26	84.57510302	LOW_PRESSURE	19	7
10361933	DOMESTIC	SERVICE	63	BAND_A	DI	374	22	257.0978672	LOW_PRESSURE	14	8
10139923	DOMESTIC	SERVICE	63	BAND_A	PE	221	13	186.0828871	LOW_PRESSURE	9	4
16621089	DOMESTIC	SERVICE	63	BAND_A	PE	68	4	30.09519441	LOW_PRESSURE	3	1
10354556	DOMESTIC	SERVICE	63	BAND_A	PE	136	8	57.63555605	LOW_PRESSURE	6	2
10424142	DOMESTIC	SERVICE	63	BAND_A	PE	68	4	58.78451486	LOW_PRESSURE	3	1
10102900	DOMESTIC	SERVICE	63	BAND_A	PE	51	3	53.22733623	LOW_PRESSURE	2	1
10064041	DOMESTIC	SERVICE	63	BAND_A	PE	425	25	92.83385596	LOW_PRESSURE	17	8
10378363	DOMESTIC	SERVICE	63	BAND_A	DI	170	10	106.4109058	LOW_PRESSURE	7	3
16672278	DOMESTIC	SERVICE	63	BAND_A	PE	102	6	64.71169508	LOW_PRESSURE	4	2
10012750	DOMESTIC	SERVICE	63	BAND_A	SI	170	10	124.9133162	LOW_PRESSURE	8	2
10153372	DOMESTIC	SERVICE	63	BAND_A	DI	136	8	173.8207235	LOW_PRESSURE	6	2
10019589	DOMESTIC	SERVICE	63	BAND_A	PE	51	3	20.01122251	LOW_PRESSURE	2	1

Table 23. Example of data format for Domestic services model showing pipe level information and the numbers of connected services (split by PE and non-PE)

The material is split on each mains pipe length between metallic and PE using a global proportion. All planned investments designed to replace metallic services only with PE can defined within intervention rules.

Likewise, 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)

B3.2. Services Probability of Failure Assessment

There are many ways that initial 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 specific data holdings.

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

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

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

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 3.1.3) that <63mm diameter Services are not individually represented in the base data, but are allocated to Mains pipe sections (which may hold a mixture of PE and non-PE Services). The PoF for the grouped Services on a <63mm diameter pipe section will be weighted average of the PE and non-PE PoF values for that Network ID. Where Services are less than 63mm in diameter they will have their own individual pipe sections and will have a PoF value directly related to their Material and Network ID.

In terms of the PoF calculation:

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

B3.3. Services Deterioration Assessment

There are many ways that asset deterioration can be statistically derived. An example that has been applied for NGN distribution mains modelling is described below, but this methodology could be GDN specific given specific 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
- 0.05% 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 B5. For simplicity each Consequence of Failure for mains 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 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 Section B5.). The sum of all consequences is the monetised risk for the Corrosion Failure Mode.

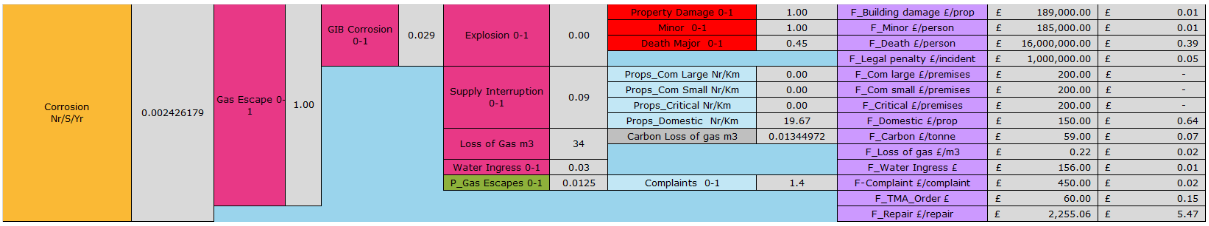


Fig 43. Modelled consequences and values for Services Corrosion failure

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 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.

Fig 44. Modelled consequences and values for Services General Emissions failure

B3.5. Service Intervention Definitions

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

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

Some potential interventions to be modelled for Services are listed below.

With Intervention activities	Without Intervention activities
• Service relays (part of mains replacement) • Bulk service replacements • Alteration • Decommission	• ECV replacement • Service valve replacement

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).

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)

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

*Assumes an average service pipe length of 17 metres

B3.5.2 Example Services Interventions

Based on the logic discussed in Section B2, all Non-domestic service interventions must be planned using the main upon which the service is connected. This is because the main acts as the "placeholder" to account for the fact that actual Non-domestic service locations and characteristics are unknown. To plan a service intervention both the Domestic/Non-domestic attribute and the pipe material on which the service is assumed to be connected must be stated. **Please note that as Non-domestic services are recorded directly in the GIS (and therefore have their own individual record in the base data) the Non-domestic service material (and diameter) is of the actual service, not of the supplying main**.

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 connected to DI mains

	Year0	Year1	Year2	Year3	Year4	Year5	Year6	Year7	Year8
Cohort Name	Initial Number of Services	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention
AS / DOMESTIC / NO	115								
CI / DOMESTIC / NO	54381								
CI / DOMESTIC / YK	54183								
CI / NON DOMESTIC / NO	191								
CI / NON DOMESTIC / YK	124								
DI / DOMESTIC / NO	82145	500	500	500	500	500	500	500	500
DI / DOMESTIC / YK	116952	500	500	500	500	500	500	500	500
DI / NON DOMESTIC / NO	274								
DI / NON DOMESTIC / YK	170								
PE / DOMESTIC / NO	775586								
PE / DOMESTIC / YK	902262								
PE / NON DOMESTIC / NO	12487								
PE / NON DOMESTIC / YK	19146								
SI / DOMESTIC / NO	123181								
SI / DOMESTIC / YK	108062								
SI / NON DOMESTIC / NO	238								
SI / NON DOMESTIC / YK	85								
ST / DOMESTIC / NO	30787								
ST / DOMESTIC / YK	59633								
ST / NON DOMESTIC / NO	1073								
ST / NON DOMESTIC / YK	3871								
UNKN / DOMESTIC / YK	10								
UNKN / NON DOMESTIC / NO	1								
UNKN / NON DOMESTIC / YK	2								

Table 24. Intervention definition in monetised risk trading tool. DI/DOMESTIC/NO corresponds to Domestic non-PE Services attached to DI mains in North-East. DI/DOMESTIC/YO corresponds to Domestic non-PE Services attached to DI mains in Yorkshire.

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

Fig 45. Example pre and post intervention rules for the above services replacement intervention (non-PE Services with PE)

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

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

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

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 25 - Discounted costs and benefits of 1000 service per annum Domestic service replacement programme

Example 2 – 50 replacements per annum of non-PE Non-domestic services connected to DI mains

			Year0	Year1	Year2	Year3	Year4	Year5	Year6	Year7	Year8
Cohort Number	Cohort Name	Intervention Plan	Initial Number of Services	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention	Proposed Intervention
1	AS / DOMESTIC / NO		115								
2	CI / DOMESTIC / NO		54381								
3	CI / DOMESTIC / YK		54183								
4	CI / NON DOMESTIC / NO		191								
5	CI / NON DOMESTIC / YK		124								
6	DI / DOMESTIC / NO		82145								
7	DI / DOMESTIC / YK		116952								
8	DI / NON DOMESTIC / NO	Intervention 1	274	30	30	30	30	30	30	30	30
9	DI / NON DOMESTIC / YK	Intervention 1	170	20	20	20	20	20	20	20	20
10	PE / DOMESTIC / NO		775586								
11	PE / DOMESTIC / YK		902262								
12	PE / NON DOMESTIC / NO		12487								
13	PE / NON DOMESTIC / YK		19146								
14	SI / DOMESTIC / NO		123181								
15	SI / DOMESTIC / YK		108062								
16	SI / NON DOMESTIC / NO		238								
17	SI / NON DOMESTIC / YK		85								
18	ST / DOMESTIC / NO		30787								
19	ST / DOMESTIC / YK		59633								
20	ST / NON DOMESTIC / NO		1073								
21	ST / NON DOMESTIC / YK		3871								
22	UNKN / DOMESTIC / YK		10								
23	UNKN / NON DOMESTIC / NO		1								
24	UNKN / NON DOMESTIC / YK		2								

Table 26. Intervention definition in monetised risk trading tool. DI/NON-DOMESTIC/NO corresponds to Non-domestic non-PE Services attached to DI mains in North-East. DI/NON-DOMESTIC/YO corresponds to Non-domestic non-PE Services attached to DI mains in North-East.

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

Fig 46. Example pre and post intervention rules for the Non-domestic replacement intervention (non-PE Services with PE).

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

Appling these rules and modelling the costs and benefits over a 45 year period delivers the following risk reduction profile. A cumulative monetised risk reduction of £51,189 has been delivered over 8 years. By 45 years this cumulative risk reduction benefit has risen to £594,893 for an initial £390,483 (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

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 27. Discounted costs and benefits of 50 service per annum Non-domestic service replacement programme