Development of a Risk Based Asset Management Tool for Gas Transmission Pipelines

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High-pressure natural gas transmission pipelines present potential major hazards (fires) in the unlikely event of accidental releases of gas, due to a range of threats including accidental interference damage by third parties. Under the Pipeline Safety Regulations, National Grid is required to manage the risks associated with these assets effectively and to be able to demonstrate that risks are As Low As Reasonably Practicable (ALARP).

This paper describes a project undertaken with Network Innovation Allowance (NIA) funding to assist National Grid in discharging its compliance obligations by building on risk methodologies developed previously for gas transmission pipelines, coupled with a powerful Pipeline Integrity Management System (PIMS). The combined tool was designed to provide a convenient means of accessing and displaying information on the variation in risk across the pipeline network, to support decision-making on pipeline safety and integrity issues, to promote greater efficiency in conducting risk assessments and to maintain a record of the audit trail for safety-related decisions.

National Grid Gas transmission utilises a PIMS (“Uptime”) to assist with the management and storage of detailed information on gas transmission pipelines. Uptime is a powerful tool, capable of a wide range of applications. National Grid identified a potential benefit in using the tool to streamline the process associated with affirmation of Maximum Operating Pressure surveys (in accordance with the IGEM/TD/1 pipeline standard) to facilitate site specific risk assessments of pipeline infringements, carried out using the PIPESAFE risk assessment package for onshore gas transmission pipelines, and to visualise risk profiles across the National Transmission System (NTS).

Development of the risk model in Uptime is complete. Expectation values are used to represent the variation in Societal Risk along the pipelines, calculated using a simplified version of the PIPESAFE methodology and an agreed rule set for estimating populations within the hazard range of the pipelines from Ordnance Survey mapping data. The results can be displayed as overlaid colour coding of the pipelines in Uptime based on the output risk values or tabulated according to user-defined requirements. As well as providing a risk overview of the NTS, the tool supplies hazard distances and emergency planning distances. It also includes tables of IGEM/TD/1 infringements, a facility to generate PIPESAFE site files automatically for site-specific risk assessments and links to the associated TD/1 risk assessment reports. The tool is also the repository for the NTS pipeline data, which can be used in subsequent TD/1 surveys and to provide the source data for input into industry databases. Key to the future success of the tool is the maintenance of the data. This is planned to be achieved on an ongoing basis through the 4-yearly cycle of TD/1 surveys.

The paper presents details of the methodology together with examples illustrating the use of the tool and the visualisation of the results.

Keywords: gas, transmission, pipeline, risk

Background

High-pressure natural gas transmission pipelines and installations present potential major hazards (i.e. fires) in the unlikely event of an accidental release of gas, due to a range of causes, but particularly accidental interference damage by third parties. Under the Pipeline Safety Regulations, National Grid is required to manage the risks associated with these assets effectively, and to be able to demonstrate to the HSE that the risk is managed to a level which is As Low As Reasonably Practicable (ALARP).

Objective

This initiative aimed to assist National Grid in discharging its compliance obligations by developing and applying techniques for quantifying the risk associated with pipelines, and investigating the effectiveness of means of reducing risk. The main objective of the project was to develop a risk based asset management tool incorporating novel visualisations of risk profiles across the National Transmission System (NTS).

Approach

This project involved linking DNV GL’s Uptime and PIPESAFE software packages. Details of both packages are provided below.

PIPESAFE is a knowledge-based software package, designed specifically to undertake risk assessments of buried natural gas transmission pipelines[1,2]. The tool is an integrated package, developed on behalf of an international Joint Industry Project (involving gas transmission pipelines companies from Europe, North America and Asia), and includes mathematical models for the consequences of pipeline failures validated by comparison with incidents and large and full scale experiments. The extensive validation that supports PIPESAFE includes the results from two full scale pipeline rupture experiments performed to ensure that the results of consequence calculations may be applied with confidence[3].

The package contains a suite of mathematical models, capable of predicting the various processes associated with a gas release, including transient outflow; dispersion and fires and their effects on people and buildings. There are also models for estimating frequencies of pipeline failure, as well as risk summation routines to calculate individual and societal risk levels. The models are linked together in a logical manner to allow fully quantified risk assessments to be undertaken. PIPESAFE has been produced to run as a Microsoft Windows application with a graphical user interface.

The approach adopted follows closely the PIPESAFE methodology, as reflected in the guidance given in IGEM/TD/2[4]. This sets out the recommended approach to evaluation of failure frequencies drawing on UK experience detailed in UKOPA/13/0047[5], ignition probability based on the correlation derived for PIPESAFE from historical incident statistics[6], consequence assessment and risk calculations.

Uptime is an Asset Integrity Management software system hosted by DNV GL for National Grid. It stores pipeline data, related assets and integrity survey data in a geographical format. It also allows other datasets to be included, viewed and placed in context with the pipeline network. This includes roads, railways, rivers, building data, geological data, and any other mapping data that may be of relevance.

An example Uptime screenshot, showing a pipeline schematic, is provided in Figure 1.

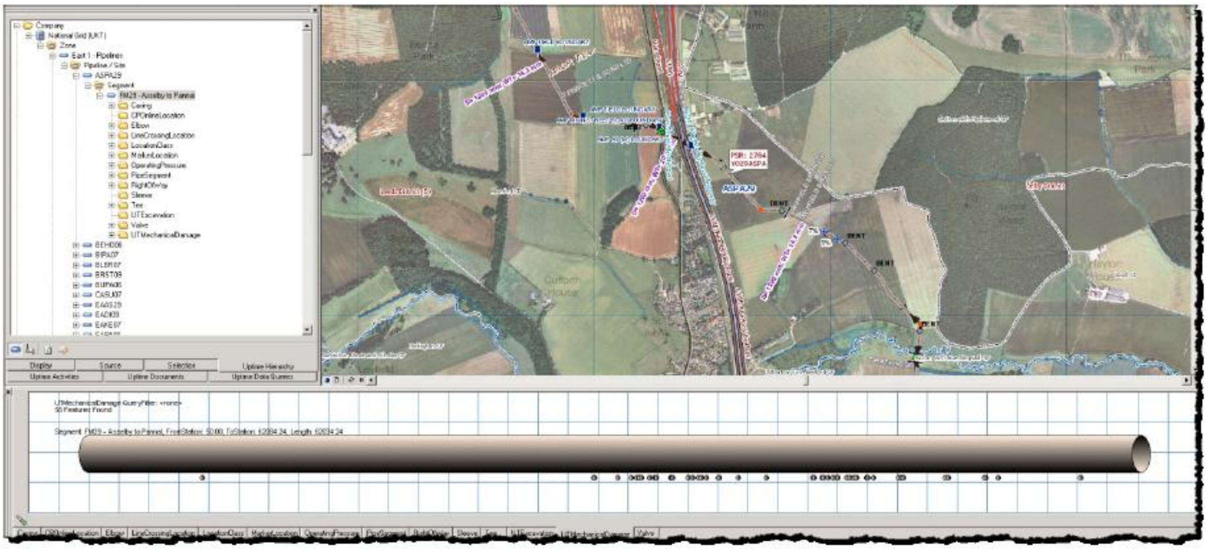

Figure 1: Uptime Screenshot Showing Pipeline Schematic

As part of a structured approach to the implementation, DNV GL produced documentation to clearly record the design of the following items:

- High level societal risk calculation model: The model dynamically segments the pipeline based on a defined set of uniform properties as well as crossings, any protective measures installed on the pipeline, population density and the surrounding area classification (Rural or Suburban). For each segment the model calculates the average casualties per rupture incident for the population density. Look-up tables of hazard distances have been developed

[1] Acton, M. R., Baldwin, P. J., Baldwin, T. R., and Jager, E. E. R. ‘The Development of the PIPESAFE Risk Assessment Package for Gas Transmission Pipelines’, Proceedings of the International Pipeline Conference, ASME International, Calgary, Canada, 1998

[2] Acton, M.R., Baldwin, T.R. and Jager, E.E.R., ‘Recent Developments in the Design and Application of the PIPESAFE Risk Assessment Package for Gas Transmission Pipelines’, Proceedings of the International Pipeline Conference, ASME International, Calgary, Canada, 2002

[3] Acton M. R., Hankinson G., Ashworth B. P., Sanai M., and Colton J. D., ‘A Full Scale Experimental Study of Fires following the Rupture of Natural Gas Transmission Pipelines’, Proceedings of the International Pipeline Conference, ASME International, Calgary, Canada, 2000

[4] IGEM/TD/2 Edition 2 - Assessing the risks from high pressure Natural Gas pipelines, Communication number 1764, The Institution of Gas Engineers and Managers

[5] UKOPA Pipeline Product Loss Incidents and Faults Report (1962 – 2012), UKOPA/13/0047

[6] Acton, M.R. and Baldwin, P.J., ‘Ignition Probability for High Pressure Gas Transmission Pipelines’, Proceedings of the 7th International Pipeline Conference 2008 (Calgary), ASME International

using an accepted methodology previously established with National Grid (obtained by a series of generic PIPESAFE assessments) and these are incorporated in the model. The event frequency is determined based on calculation of ignition probabilities, ground movement zones and failure frequencies (derived in part from the FFREQ model[7], which is called from Uptime as an "add-in" external library). These are combined to determine high level expectation values per year and per kilometre year for a segment. The model supports aggregation for the pipeline and groups of pipelines. Methods for handling missing data were also described including the use of default values or alternatives (e.g. where building occupancy is unknown on an identified structure, lookup values based on structure type support population density calculations).

- Site specific PIPESAFE assessment data extract model: This model accepts as input the pipeline extent under assessment, interrogates the Uptime database for all required data, including property and residency data, and outputs the data plus any calculated data in the format required for PIPESAFE. This significantly reduces the data entry overhead in running PIPESAFE assessments and makes the process much more consistent and transparent.
- Pipeline data extraction and migration procedures: the data items required by the above models which were not already held or fully populated in Uptime (such as pipe segment wall thickness changes, material grade, internal and external coating type) were identified together with potential sources that hold construction and commissioning information and data from site excavations. For each source, the process for examining these systems and extracting the data into pre-populated Excel worksheets was described together with any conversion calculations using Excel formula and macros. If there were discrepancies between any of the data, then strip maps were consulted.

High Level Model Methodology

The methodology assumes that the population density (PopD) around the section of pipeline being assessed is uniform and known. This is calculated from the building and population data in Uptime. It is noted that the casualty calculations in PIPESAFE assume an exclusion zone equal to one Building Proximity Distance (BPD) around the pipeline.

Pipeline Segmentation and Model Formulas

The pipeline under consideration need to be divided into segments of uniform properties as well as population density, and the surrounding area classification (Rural or Suburban). The Uptime Risk Manager automatically segments each input pipeline, and it uses the following factors for its segmentation:

- Diameter
- Wall Thickness
- MAOP
- Grade
- Depth of Cover
- Seam Type
- Location Class
- Maximum Landslip Zone
- Sleeve Diameter (if applicable)
- Sleeve WT (if applicable)

So if any of these parameters change along a pipeline, a new risk segment is created for input into the model calculations.

For each risk segment the following calculation steps are needed:

Step 1: The total rupture failure frequency FF is calculated as:

$$\boldsymbol{FF = FF_{EI} + FF_{GM}}\ (\boldsymbol{per\ million\ km\ yr}) \quad (1)$$

Where the rupture rates due to external interference FF_{EI} and ground movement FF_{GM} should be calculated as described below.

Failure Frequency due to External Interference (FF_{EI})

The failure frequencies due to external interference are obtained by running FFREQ. The data required are listed in Table 1.

The Uptime risk model runs FFREQ for each pipe segment and retrieves the appropriate value for FF_{EI}.

[7] FFREQ is the structural reliability mode for predicting failure frequencies due to external interference damage, incorporated in PIPESAFE.

Parameter	Symbol	Type	Units
Diameter	D	Number	Mm
Thickness	WT	Number	Mm
MOP	P	Number	Barg
Material grade	-	Number	-
Yield/Tensile	Y/T	Number	-
Charpy Energy	CE	Number	J
Depth of cover	DOC	Number	M
Sleeve diameter	-	Number	Mm
Sleeve thickness	-	Number	Mm
Seam type	-	String	-
Sleeve present?	-	String	-

Table 1 - Input Data for FFREQ

Failure Frequency due to Ground Movement (FF_{GM})

FF_{GM} is calculated by finding the maximum Landslip Zone class that intersects the segment (derived from the British Geological Survey [BGS] data in Uptime) and assigning an appropriate failure frequency as per IGEM/TD/2[8].

FF_{GM}= Landslide Incident Rate (LIR) * Survival Value (SV) (2)

Where *LIR* = 0.005 per km year for BGS classes A or B

= 0.05 per km year for BGS class C

= 0.5 per km year for BGS classes D or E

And *SV* = $0.15e^{-0.18*wt}$ for pipes with poor quality welds (3)

= $0.15e^{-0.30*wt}$ for pipes with good quality welds (4)

If the pipe segment contains any Inline Inspection (ILI) "Girthweld Anomalies" then it is considered to have poor quality welds.

This factor is determined by querying the Uptime database for any previously loaded ILI survey data where the *Feature Code* of that feature is *GirthWeldAnomaly*, and applying that to each pipeline risk segment (see below).

Step 2: The ignition probability is calculated in terms of the pipeline diameter D and pressure P:

$$P_{(ign)} = \begin{cases} 0.0555 + 0.0137PD^2;\ if\ 0 \le PD^2 \le 57 \\ 0.81;\ if\ PD^2 > 57 \end{cases} \quad (5)$$

Step 3: The number of average casualties $N_{(1/ha)}$ for population density 1/ha is obtained from a lookup table (for rural or suburban areas) for the given P and D.

Step 4: The event frequency (per year) F is calculated as

$$F = FF \times 10^{-6} \times L \times P_{(ign)} \quad (6)$$

where L is the pipe segment length in km.

Step 5: The average casualties per incident N are

$$N = PopD \times N_{(\frac{1}{ha})} \quad ()$$

where *PopD* is the population density (per ha).

8 IGEM/TD/2 Edition 2 - Assessing the risks from high pressure Natural Gas pipelines, Communication number 1764, The Institution of Gas Engineers and Managers

Calculation of Population Density

The Uptime model queries the data in the database using a spatial query by looking out from each segment to find building polygons and then querying the related *OccupantCount* attribute and summing up for all buildings in that segment's encroachment buffer (see Figure 2).

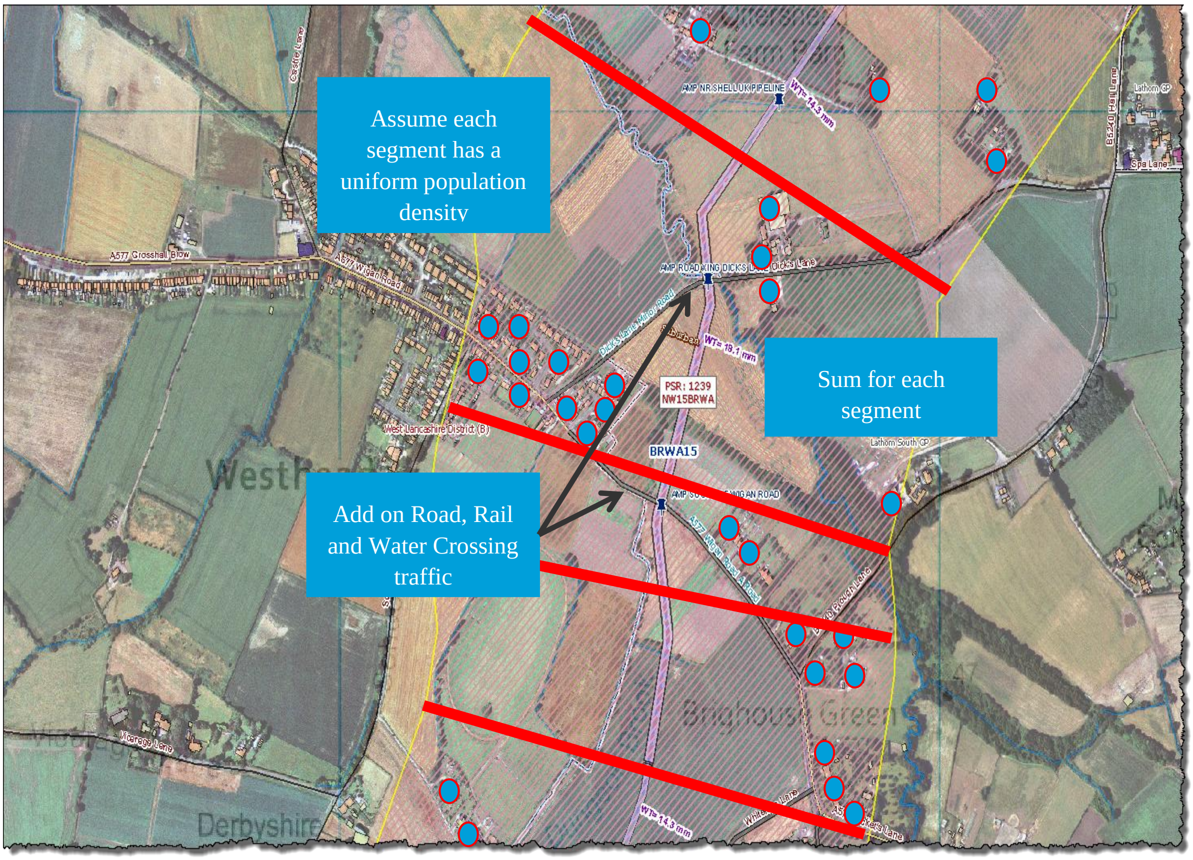

Figure 2 - Graphical representation of Population Density calculation

$$\textbf{\textit{Population Density}} = \frac{\textbf{\textit{Population}}}{\textbf{\textit{Encroachment Area}}\ (\textbf{\textit{ha}})} \quad (7)$$

Where:

$$\textbf{\textit{Population}} = \textbf{\textit{Occupancy}} + (6 \times f\_A\_Road\_CrossingsCount) + (10 \times f\_Motorway\_CrossingsCount) + (3 \times f\_B\_Road\_CrossingsCount) + (2 \times f\_PRoadCrossingsCount) + (f\_MRoadCrossingsCount) + (f\_LRoadCrossingsCount) + (12 \times f\_MRail\_CrossingsCount) + (5 \times f\_SRail\_CrossingsCount) + (3 \times f\_River\_CrossingsCount) \quad (8)$$

Where:

$$\textbf{\textit{Encroachment Area}}\ (\textbf{\textit{ha}}) = \textbf{\textit{EncDistance}} \times \textbf{\textit{RiskSegmentLength}} \times 0.0001 \quad (9)$$

And *EncDistance* is obtained from that pipeline's 4 BPD length and *RiskSegmentLength* from the newly created risk segments.

Where:

$$\textbf{\textit{Occupancy}} = \begin{cases} \textbf{\textit{DefaultOccupancy}}; \textbf{\textit{ if KnownOccupancy}} = 0 \\ \textbf{\textit{KnownOccupancy}}; \textbf{\textit{otherwise}} \end{cases} \quad (10)$$

And *DefaultOccupancy* is the sum of all *OccupantCount* values for polygons that meet the spatial criteria, where the building type is used to lookup the default occupant count.

KnownOccupancy is the sum of all *OccupantCount* values stored against the polygons themselves, rather than looking up the default value. This is to override the default values with known data, edited into Uptime as part of future TD/1 surveys, or PIPESAFE site specific assessments.

The "…*CrossingsCount"* factors count up all of the road, rail and river crossings stored in Uptime for that pipe segment. They are then multiplied by the numbered factors shown to account for the average populations assumed to be at those types of crossings at any given time.

Step 6: The expectation value EV (per year) for a pipeline section (or sections) consisting of M segments of uniform properties is

$$EV = \sum_{J=1}^{M} F_J \cdot N_J \quad (11)$$

where F_J and N_J are the event frequency and average casualties for the J^{th} pipeline segment, as calculated from equations (6) and (7), respectively.

Step 7: The average number of casualties (per km.year) for the same pipeline section is

$$\textbf{Average casualties per unit length} = \boldsymbol{EV / \sum_{J=1}^{M} L_J} \quad (12)$$

where L_J is the length of the J^{th} segment.

Outcome

A risk based asset management tool has been developed using the methodology outlined above, which provides a risk overview of the NTS based on expectation values (EV and EV/L), hazard distances (see Figure 3) and emergency planning distances across the NTS, tables of IGEM/TD/1 infringements and links to the associated TD/1 reports. The tool also generates input files for site specific assessment Quantitative Risk Assessments (QRAs) with PIPESAFE. Previously pipeline risk assessment was limited to infringement locations and involved significant levels of effort to gather and validate the data required. This tool streamlines existing business processes and delivers efficiencies. The resulting network risk profiles will provide input into investment and planning decisions.

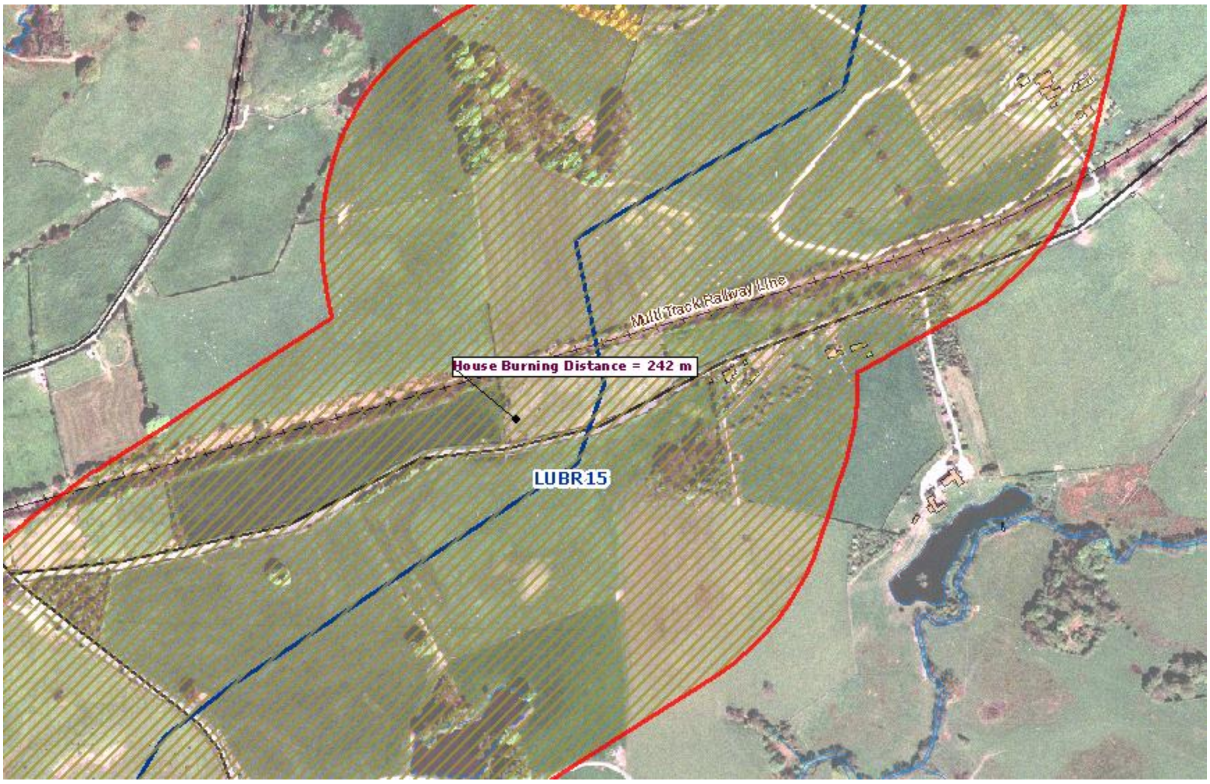

Figure 3: Example of Hazard Distances: House Burning Distances

The Uptime system is being established as the repository for up-to-date pipeline data and associated mapping and population information (e.g. to facilitate TD/1 surveys) and the primary source of National Grid pipeline data for input into industry databases. Key to the future success of the tool is the maintenance of the data. This is planned to be achieved on an ongoing basis through the 4-yearly cycle of TD/1 surveys.

Examples of the output from the tool are provided in Figures 4 and 5, in which sections of pipeline are colour coded according to the expected number of casualties. Figure 6 shows an example page from the reports which detail the expectation value changes along each pipeline for both quantities EV and EV/L.

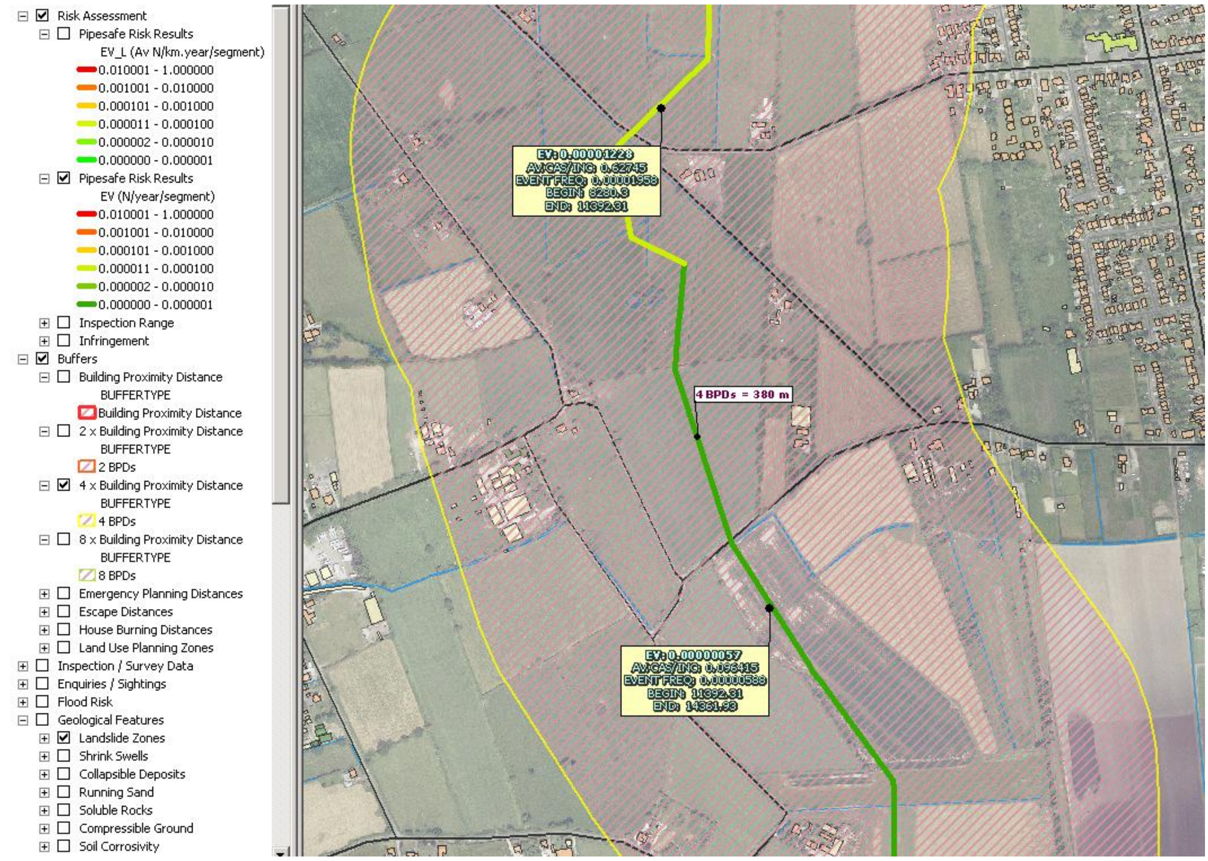

Figure 4: Example Output from Risk Based Asset Management Tool

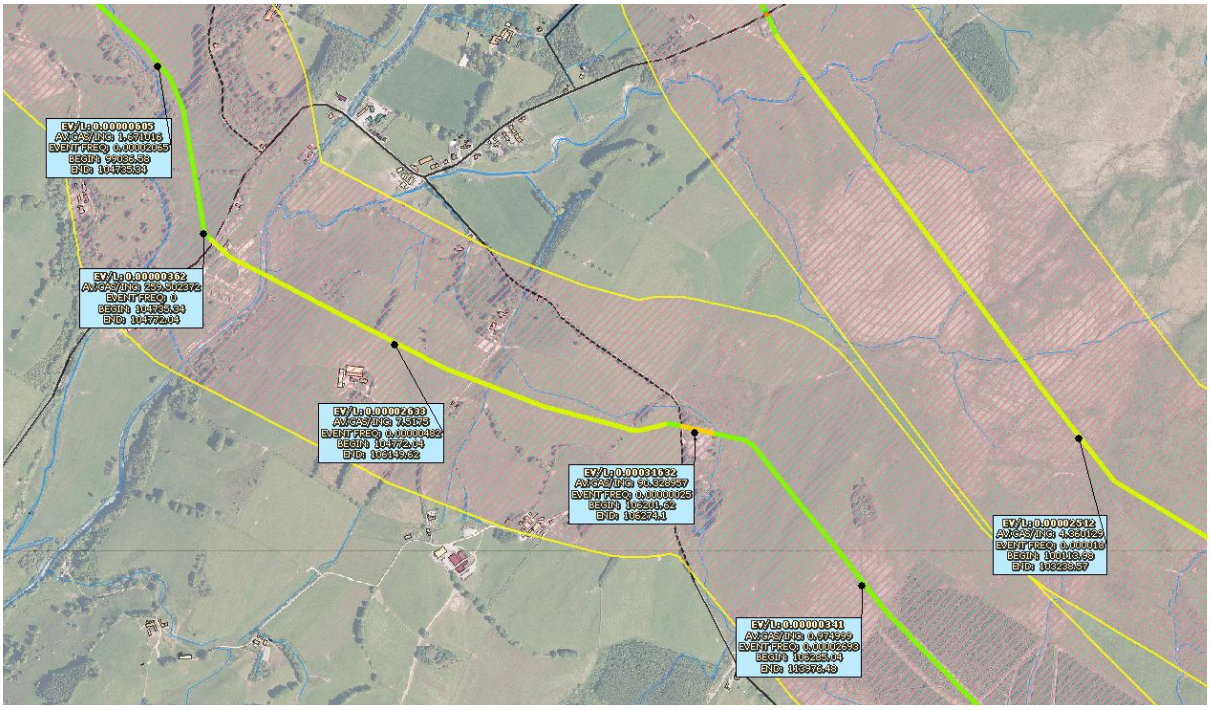

Figure 5: Example Output from Risk Based Asset Management Tool

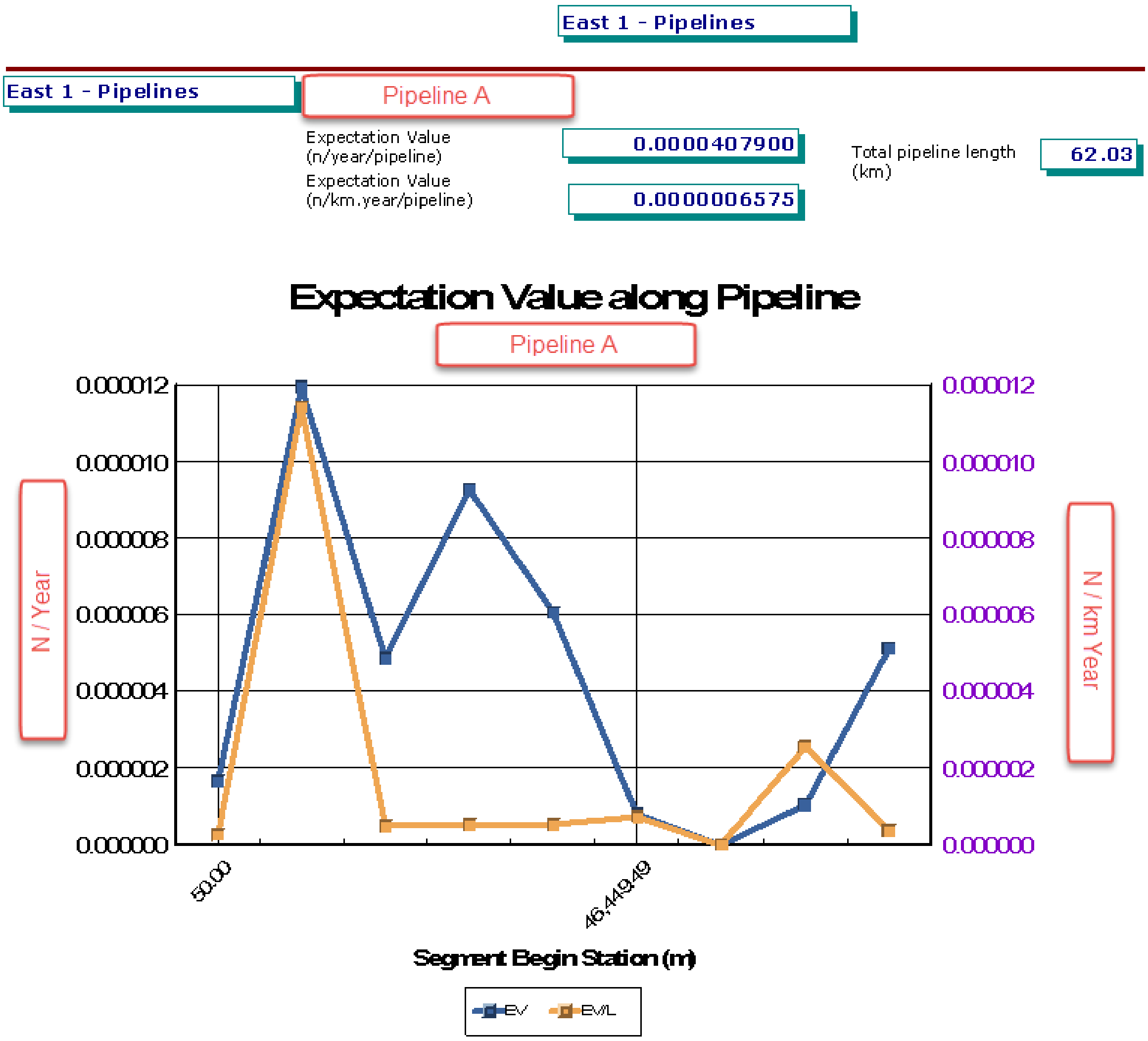

Figure 6: Example Output from Risk Based Asset Management Tool reports

Benefits

A risk based asset management tool that incorporates novel visualisations of risk profiles across the NTS has been developed. The tool provides a risk overview of the NTS, and includes hazard distances and emergency planning distances across the NTS. The tool also includes tables of IGEM/TD/1 infringements and links to the associated TD/1 reports.

The tool streamlines the post TD/1 survey process by facilitating site specific risk assessments of TD/1 infringements. The tool is the repository for National Grid Transmission pipeline data. This data can be used in subsequent TD/1 surveys and as source data for input into industry databases.

The combined tool allows National Grid to collectively manage the risks across all sections of the Network, and an automatically updated risk-profile can be obtained. This risk data can assist National Grid with, for example, investment decisions. Novel ways of displaying the output data from risk assessments are incorporated. This provides up-to-date and readily accessible information for the user. The tool provides a new feature in that risk assessments can be undertaken along the pipe, pipe networks, or the whole system; not just at infringement points as previously.