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UK Pipeline Failure Frequencies

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Executive Summary

UKOPA collates pipeline fault and failure data in the UKOPA pipeline fault database, which has been developed and is managed for UKOPA by Advantica. The failure (leak and rupture data) is published by UKOPA bi-annually.

One of the key objectives of UKOPA is to provide comprehensive recommendations for pipeline failure frequencies for all the main pipeline damage mechanisms based on UK data. This report provides an overview of the UKOPA fault data (ie part-wall damage which has not resulted in product loss), demonstrates that the data is applicable to all UK Major Accident Hazard Pipelines (MAHPs), and provides recommendations for the derivation of pipeline specific failure frequencies. It includes a comparison with European natural gas (EGIG) and oil pipeline (CONCAWE) data in order to confirm that UKOPA data provides the best representation of UK MAHP performance.

Conclusions

Based on the overview of UKOPA data, the assessment of its application to all pipelines, assessment of pipeline fault data trends and comparison with EGIG and CONCAWE data, the following conclusions are drawn:-

i) The UKOPA fault and failure data is applicable to all UK MAHPs.

ii) Application of the failure frequency data for the derivation of failure frequencies for ethylene pipelines has been confirmed to be conservative for external corrosion, material and construction and external interference damage mechanisms.

iii) Application of the failure frequency data for the derivation of failure frequencies for spiked crude pipelines is conservative for material and construction and external interference damage mechanisms.

iv) The incident rate for external interference applies to all UK MAHPs.

v) In all cases, the failure frequency has reduced over the period 1970 – 2004.

vi) The relationship between material and construction and external corrosion failure rates and pipeline wall thickness has been derived, and is presented, as a reduction factor for specific pipeline data which may be applied to the average failure rate.

vii) The relationship between material and construction and external corrosion failure rates and pipeline age has been derived based on the number of reported faults, and is presented as a reduction factor for specific pipeline data which may be applied to the average failure rate.

viii) The failure frequency due to external interference is dependent upon the pipeline physical and operational parameters, so pipeline specific failure rates should be determined using predictive techniques.

ix) The approach used to derive failure frequencies for ground movement derived for National Grid for application to natural gas pipelines is applicable to all UK MAHPs, and the derived background failure rate should be applied to all UK MAHPs.

Recommendations

Based on the results of the assessment detailed and conclusions drawn in this report, it is recommended that:-

i) UKOPA data is used to derive failure frequencies for all damage mechanisms for UK pipelines.

ii) The failure frequency due to external interference is dependent upon the pipeline physical and operational parameters, so pipeline specific failure rates should be determined using predictive techniques based on fracture mechanics failure models and damage probability and incident rate derived from operational fault data.

iii) The background failure frequency due to ground movement for all UK pipelines be based on the rate predicted for the natural gas pipeline network.

Contents

1. INTRODUCTION

1.1 Background

The United Kingdom Onshore Pipeline Association (UKOPA) collates pipeline fault and failure data in the UKOPA pipeline fault database, which is developed and managed for UKOPA by Advantica. The failure data (leak and rupture) is published by UKOPA bi-annually [1].

One of the key objectives of UKOPA is to provide comprehensive recommendations for pipeline failure frequencies for all the main pipeline damage mechanisms, based on UK data. UKOPA published the first report presenting the first set of incident data for pipeline incidents resulting in the unintentional release of product up to the end of 1998, in November 2000, followed in 2002 by the second report covering product loss incidents up to the end of 2000, and a third report in 2004 covering product loss incidents up to the end of 2002. This report is an update of the previous data, covering product loss incidents up to the end of 2004

The data published by UKOPA can be readily compared with other recognised data sources, published by EGIG and CONCAWE. However, in all cases, the failure data is sparse as a result of the relatively good safety record for the onshore pipeline industry in Europe. This means that deriving realistic trends and robust failure rates is difficult, and derived rates relate to pipeline populations, not specific pipelines or pipeline cases. The UKOPA database includes fault data for each of the damage mechanisms. There is a considerably greater volume of fault data which enables detailed assessment of trends and therefore allows an in depth assessment of pipeline failure rates.

1.2 Scope of Work

This report provides an overview of the UKOPA fault data, demonstrates that the data is applicable to all UK MAHP's (Major Accident Hazard Pipelines), provides recommendations for the derivation of pipeline specific failure frequencies. It includes a comparison with European natural gas (EGIG) and oil pipeline (CONCAWE) data, in order to confirm that UKOPA data provides the best representation of UK MAHP performance.

1.3 Report Structure

The report is structured as follows:

Section 2	Overview of UKOPA Data
Section 3	Application of UKOPA Data to All Pipelines
Section 4	Assessment of Fault Trends
Section 5	Failure Frequencies for UK Pipelines
Section 6	Conclusions
Section 7	Recommendations
Appendix 1	Overview of the Chi^2 Test for Goodness of Fit
Appendix 2	Statistical Analysis of Fault Data
Appendix 3	UKOPA Fault and Failure Data

2. Overview of UKOPA Data

The UKOPA Pipeline Fault Database Report produced for UKOPA by Advantica [1] provides a wide range of data, as summarised below.

The lengths of pipeline in operation at the end of 2004, by transported product, are (in km):

Butane	19.5	LPG	9.6
CO*	0	Natural Gas (Dry)	20,001
Condensate	24.0	Natural Gas Liquid	225.8
Crude Oil (Spiked)	212.6	Propane	19.5
Ethane	38.1	Propylene	36.3
Ethylene	1,141	**TOTAL**	**21,727**

* Note that the database includes 36.3 km of decommissioned pipeline that used to transport CO.

A product loss incident is defined in the context of this report as:

'an unintentional loss of product from the pipeline within the public domain and outside the fences of installations excluding associated equipment (e.g. valves, compressors) or parts other than the pipeline itself'.

2.1 All Incidents

A total of 172 product loss incidents have been recorded in the period 1962 – 2004. These data provide generic failure rates.

9 out of 172 (5.2%) product loss incidents ignited.

The incident frequency over eight consecutive 5-year periods up to the end of 2004 is shown in Table 1. This shows that the incident frequency has reduced considerably over time.

Table 1 – Change in Incident Frequency in 5 Year Periods since 1965

Period	Number of Incidents	Total Exposure [km.yr]	Frequency [Incidents/1000 km.yr]
1965 - 1969	15	26.639	0.563
1970 - 1974	29	59.598	0.487
1975 - 1979	26	74.486	0.349
1980 - 1984	33	85.534	0.386
1985 - 1989	35	92.406	0.379
1990 - 1994	17	97.839	0.174
1995 - 1999	9	102.527	0.088
2000 - 2004	3	106.799	0.028

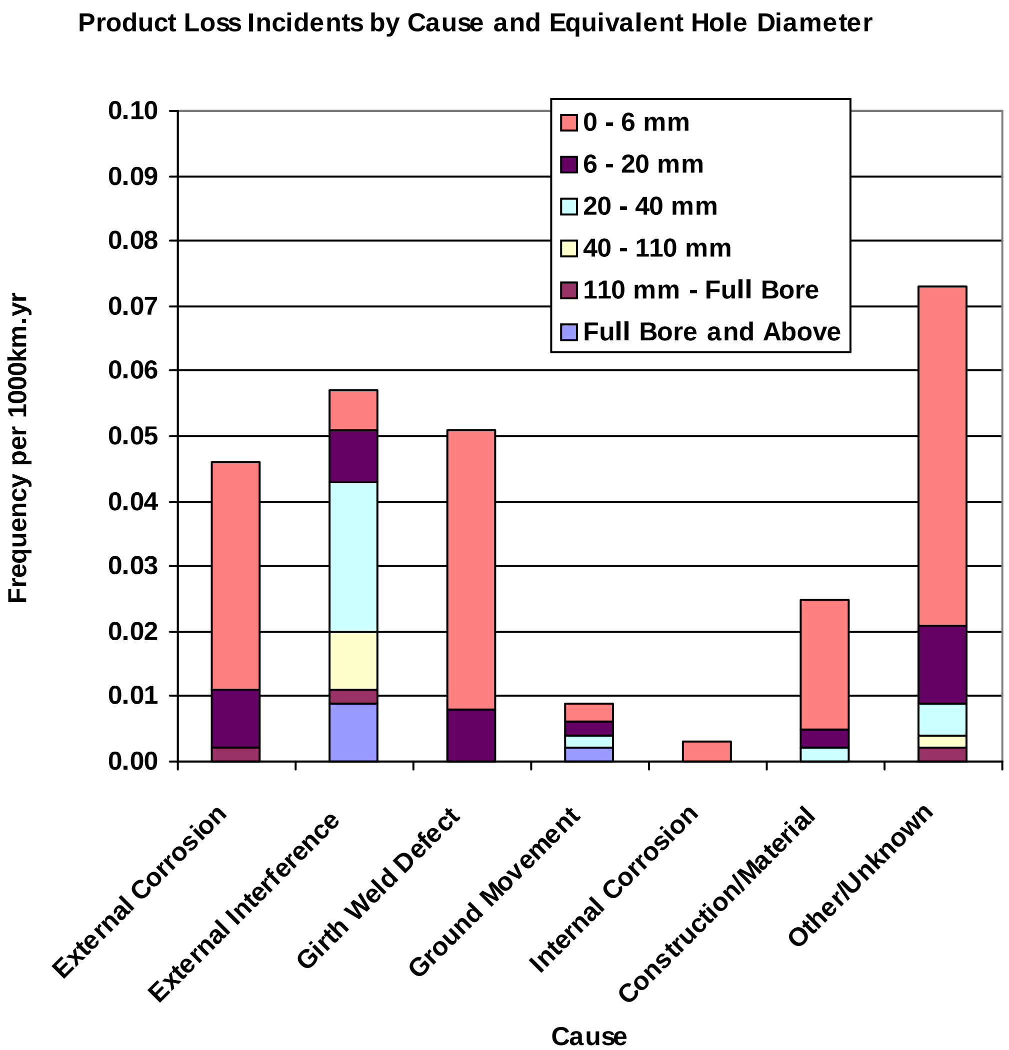
The overall incident frequency by hole size over the period 1962 - 2004 is shown in Table 2.

Table 2 – Overall Incident Frequency by Hole Size

Hole Size Class	Number of Incidents	Frequency [Incidents/1000 km.yr]
Full Bore* and Above	7	0.011
110mm – Full Bore*	3	0.005
40mm – 110mm	7	0.011
20mm – 40mm	20	0.031
6mm – 20mm	27	0.041
0 – 6mm	106	0.162

* Full Bore ≡ diameter of pipeline

Figure 1



Note the other/unknown product loss incidents in Figure 1 represent 48 out of 172 incidents. Of the 48, 40 are due to causes such as internal cracking due to wet town gas, leaking clamps, threaded joints, lightening strike etc, and 8 are of unknown cause. These data are not considered in the current assessment.

Figure 1 shows the main causes of failure are external corrosion, external interference, construction and material defects and ground movement.

Notes:-

1. *Construction/Material = Seam Weld Defect + Pipe Defect + Pipe Mill Defect + Damage During Original Construction*
2. *Other/unknowns requires specific pipeline/operator assessment*

2.2 External Interference

Figure 2

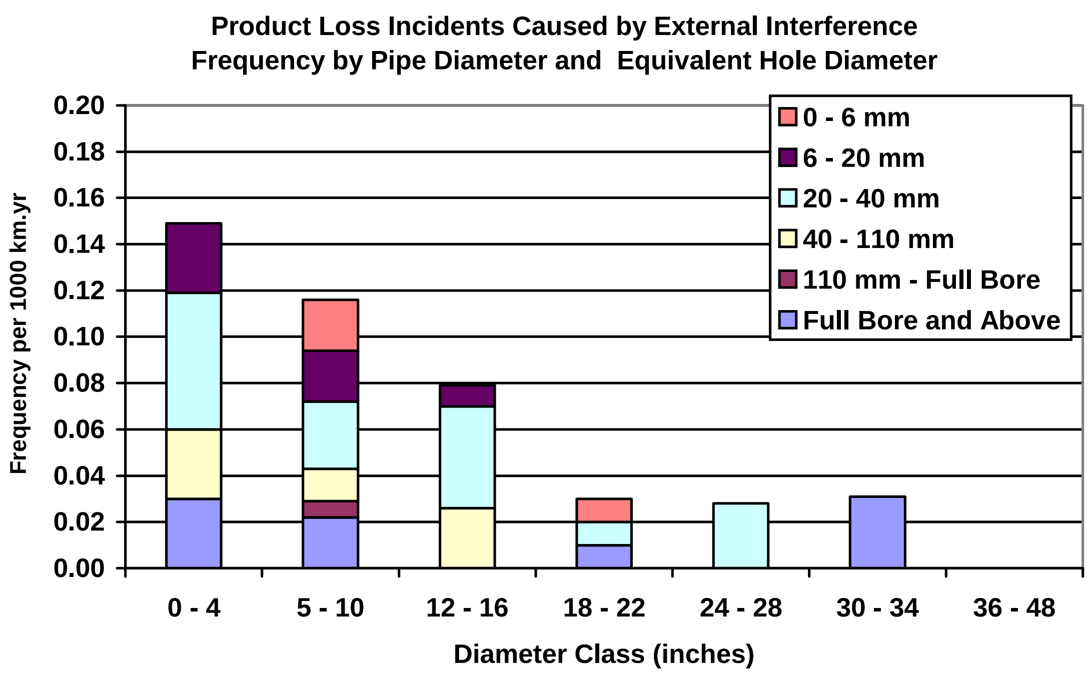


Table 3 – External Interference Failure Frequency vs. Diameter

Diameter Inches	Exposure km.yr	No. of Incidents	Frequency /1000 km.yr
0-4	33792	5	0.148
5-10	138216	16	0.116
12-16	113254	9	0.079
18-22	98969	3	0.030
24-28	106219	3	0.028
30-34	31960	1	0.031
36-48	132322	0	0.000
Total	**654732**	**37**	**0.057**

Table 4 – External Interference Failure Frequency vs. Wall Thickness

Wall Thickness mm	Exposure km.yr	No. of Incidents	Frequency /1000 km.yr
<5	49537	11	0.222
5-10	320504	22	0.069
10-15	242744	4	0.016
>15	41947	0	0.000
Total	**654732**	**37**	**0.057**

Note: Largest wall thickness for loss of product incident caused by external interference to date is 12.7mm.

Figure 3

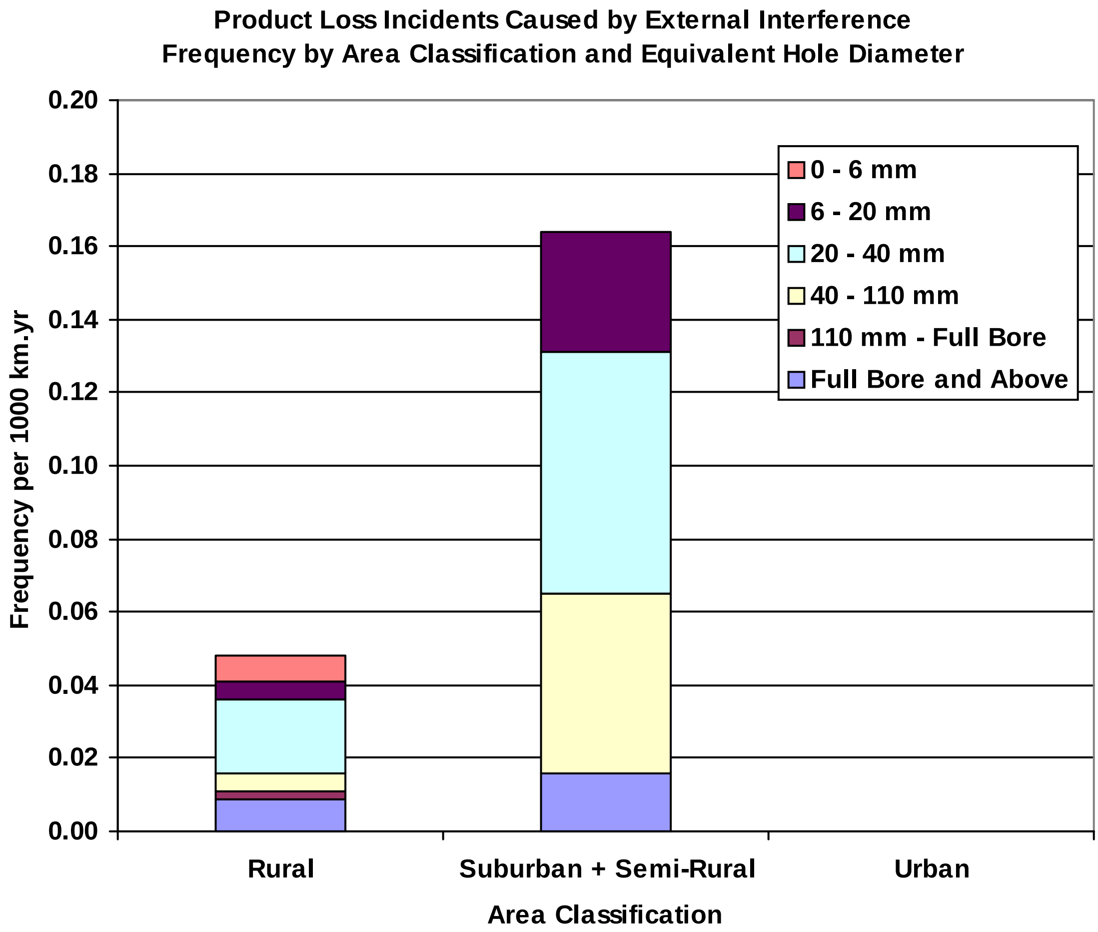


Table 5 – External Interference Failure Frequency vs. Area Classification

Area Classification	Exposure Km.yr	No. of Incidents	Frequency /1000 km.yr
Rural	558948	27	0.048
Suburban + Semi-Rural	60642	10	0.165
Urban	723	0	0.000
Total	**620313**	**37**	**0.060**

Notes:
1 *Rural = population density < 2.5 persons per hectare*
2 *Suburban and Semi-rural = population density > 2.5 persons per hectare and which may be extensively developed with residential properties*
3 *Urban = Central areas of towns or cities with a high population density*

Note - The above shows that the incidence rate for external interference is 3.44 times higher in suburban and semi-rural areas.

2.3 External Corrosion

Figure 4

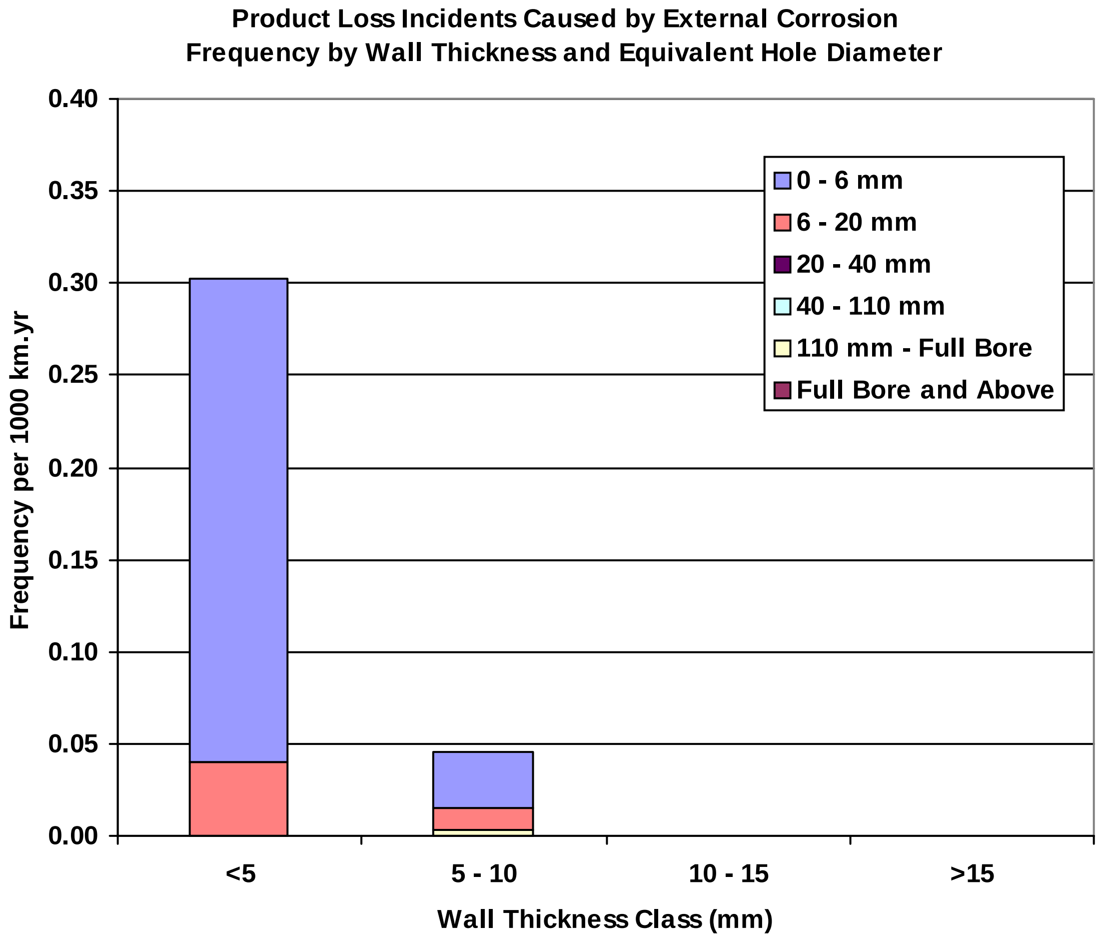


Table 6 - External Corrosion Failure Frequency vs. Wall Thickness

Wall Thickness mm	Exposure Km.yr	No. of Incidents	Frequency /1000 km.yr
<5	49537	15	0.303
5-10	320504	16	0.050
10-15	242744	0	0.000
>15	41947	0	0.000
Total	**654732**	**31**	**0.047**

The above data shows a strong relationship between the external corrosion failure rate and wall thickness, showing that the failure rate increases as wall thickness decreases. There are no recorded corrosion failures in wall thicknesses greater than 10mm. In addition, the data shows that corrosion failures predominantly occur as pin-holes and holes, not ruptures.

Figure 5

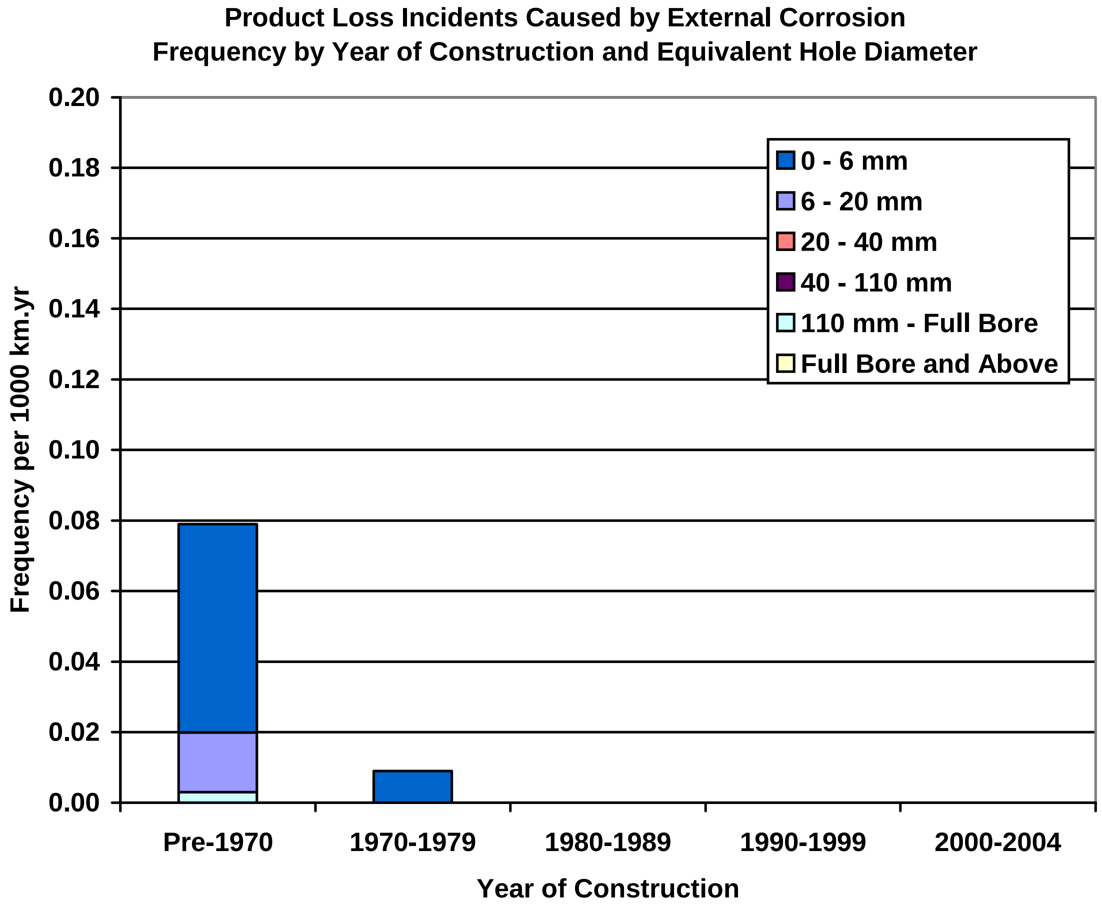


Table 7 – External Corrosion Failure Frequency vs. Year of Construction

Construction Year	Exposure Km.yr	No. of Incidents	Frequency /1000 km.yr
Pre-1970	353153	28	0.079
1970-1979	225176	3	0.013
1980-1989	52752	0	0.000
1990-1999	20932	0	0.000
2000-2004	2720	0	0.000
Total	**654732**	**31**	**0.047**

Figure 5 and Table 7 indicate a strong relationship between failure rate and year of commissioning, which indicates an age effect. In addition, the UKOPA report shows that the majority of corrosion incidents occur in pipelines with bitumen and coal tar coatings, and where the backfill is clay or heavy soil.

3. Application of UKOPA Data to all UK Pipelines

3.1 Background

The UKOPA Risk Assessment Working Group (RAWG) worked with the Health and Safety Executive (HSE) via the Working Group on Pipelines (WGP) Working Party (Risk Assessment) (WP(RA)) to agree the consistent use of UKOPA data to derive failure frequency data for all UK MAHPs. UKOPA data is dominated by that for natural gas pipelines, so the UKOPA RAWG worked with HSE to look at the applicability of the data to other MAHPs. A review and assessment of the pipeline fault and failure data was carried out, the results of which are reported in [2]. This report discussed issues which affect the data, but concluded that the data is relevant to all UK MAHPs. In their review of the report, HSE stated that the conclusions should be supported by a statistical analysis of the data.

Following restructuring and upgrading of the UKOPA pipeline fault and failure database in 2004, easier access to quantitative fault data has been possible, and a statistical assessment of the data has been carried out. The methodology applied and the results obtained are described below.

3.2 UKOPA Pipeline Fault Data

The UKOPA database contains records of pipeline faults. Fault data relates to part through wall damage which has not resulted in product loss. There is significantly more fault data compared to failure data, so this provides the opportunity to investigate potential differences in the data sets for different pipeline groups.

Figures 6 and 7 show the fault and failure rates for external corrosion and material and construction defects respectively. These figures show that while there are a large number of fault reports, the majority are detected and controlled or repaired, so the failure rate is low. In the current work, it is assumed that the rate of occurrence of part-wall damage for each damage mechanism is related to failure rate due to the damage mechanism. Hence, assuming that the fault rate data set for a given pipeline group is related to the failure rate data for the same pipeline group, the fault rates for different pipeline groups are compared to determine whether these are similar, and hence deduce whether the failure rates are likely to be similar.

Fault and failure rates for external corrosion and material and construction damage are shown in Figures 6 and 7 respectively. These figures confirm that the volume of fault data is significantly higher than the volume of failure data for each failure mechanism.

Figure 6

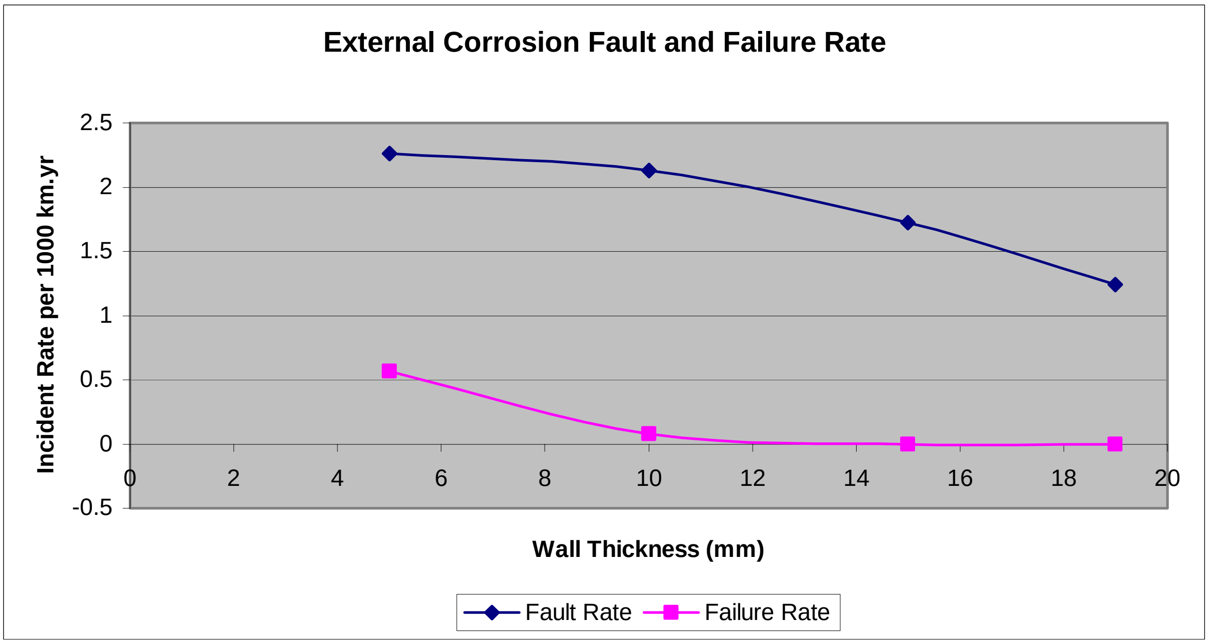
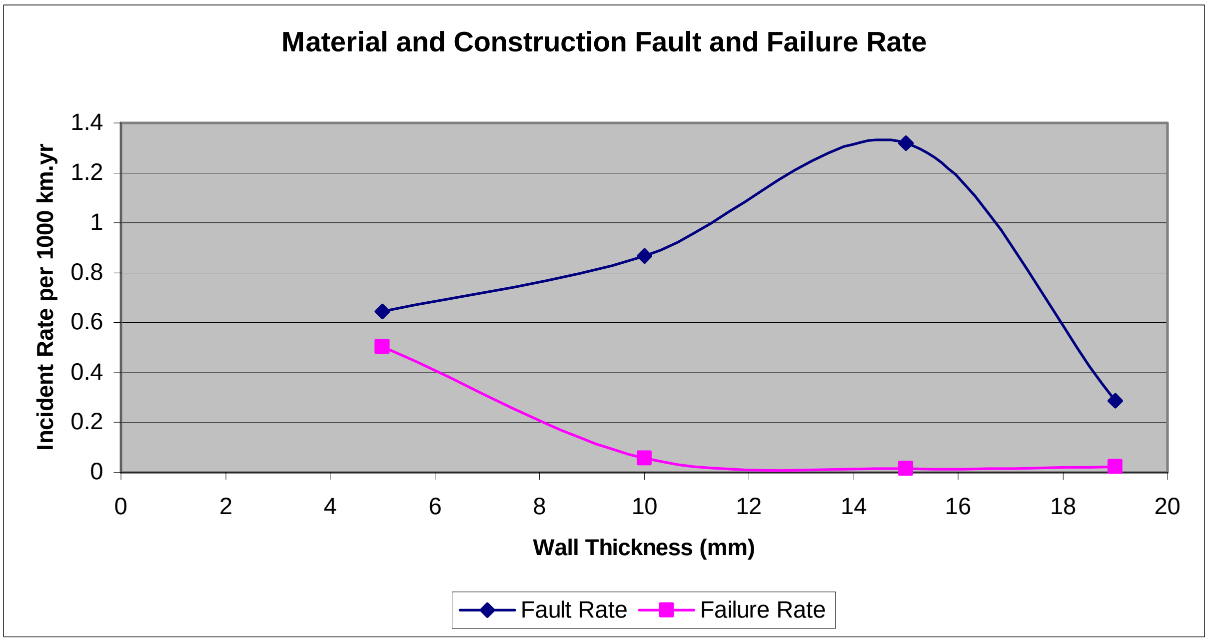


Figure 7



3.3 Methodology and Statistical Assessment

The methodology involved detailed comparison of selected datasets of natural gas pipelines with equivalent datasets for other MAHPs. The assessment and comparison of the fault rates recorded in each dataset was then carried out. The pipeline failure (leak and rupture) data for all damage mechanisms is sparse. There is a significantly greater volume of fault data, so in order to confirm the failure rate trends apply to all MAHPs, a statistical assessment of the fault data for the different groups of MAHPs for each damage mechanism was carried out. The scope of the work is shown in Table 8.

Table 8 – Statistical Assessment of Fault Data

<table>
<tr><th>MAHP Group</th><th>Pipeline Dataset</th><th>Equivalent Natural Gas Pipeline Dataset</th><th>Fault Data Assessed</th></tr>
<tr><td>Ethylene</td><td>Diameters - 219mm, 273mm, 324mm diameter</td><td>Diameter range 102 - 406mm</td><td rowspan="2">• External corrosion faults
• Material and Construction faults
• External interference incidents
• Ground movement incidents</td></tr>
<tr><td>Spiked Crude + NGL</td><td>Diameters 610, 914mm</td><td>Diameter range 914 – 1220mm</td></tr>
</table>

A statistical assessment was performed on the proportions of external corrosion, material and construction damage, 3rd party interference and ground movement faults recorded in the UKOPA database for natural gas pipelines compared with other groups of MAHPs. The Chi Squared (χ^2) test was applied to data for each specific fault type in each of the above pipeline groups, to test the probability that the data for the specific MAHP group of pipelines is similar to the equivalent natural gas data set. A summary of the Chi^2 test is given in Appendix 1.

3.4 Results

In assessing the fault data, it was considered appropriate to assess the groups of MAHPs separately to take account of the relevant diameter and wall thickness ranges. Also, as the fault data is different in type and the parameters recorded for each type vary, each set of damage data was assessed separately. The results of the statistical assessment of the goodness of fit of the fault data for i) ethylene and ii) spiked crude pipelines with equivalent dataset for natural gas pipelines are summarised in Table 9 below. Full results are given in Appendix 2.

Table 9 – Summary of Results of Statistical Assessment of Pipeline Fault Data

MAHP Group	Damage Mechanism	Statistical Assessment	Goodness of fit at 95% confidence level	Assessment[1]
Ethylene	Material and construction faults	Chi^2 = 0.6079	No statistical evidence that data sets are different	Observed number of faults =21 vs. 26 assumed
	Ext Corrosion	Chi^2 = 0.4703.		Observed number of faults =48 vs. 42 assumed
	Ext Interference	Chi^2 = 17.259	The observed number of faults is significantly lower than the assumed number, thus using approximation of gas gives a conservative estimate	Observed number of faults =20 vs. 54 assumed
	Ground Movement	Exact Test P = 0.3947	No statistical evidence that data sets are different	Observed number of faults =2 vs. 1 assumed
Spiked Crude	Material and construction faults	Exact Test P = 0.3808	No statistical evidence that data sets are different	Observed number of faults =2 vs. 5 assumed
	Ext Interference	Exact Test P=0.5143		Observed number of faults = 1 vs. 5 assumed
	External Corrosion			Data under review
	Ground Movement	Data set too small to draw conclusions from		

Based on the Chi^2 test results for ethylene, it is concluded that the data sets are equivalent for material and construction, external corrosion faults and ground movement while, for external interference, the number of faults on ethylene pipelines is lower or equivalent to the number of faults on gas pipelines. Similar results are obtained for material and construction and external interference faults on the spiked crude pipeline. Note that for all pipelines, ground movement data is very sparse and in this case, a qualitative assessment is recommended.

The above summary shows that with the exception of external corrosion in the spiked crude pipeline group, the number of observed faults is lower than the expected value. This indicates that it is conservative to apply the UKOPA data trends to all damage mechanisms for ethylene pipelines, and to all mechanisms except external corrosion for the spiked crude pipeline group.

[1] *Note, the assumed number of incidents is calculated based on the hypothesis that the populations are equivalent and the number of incidents is spread according to the operational exposure.*

4. Assessment of Fault Trends

Fault data recorded in the UKOPA database relates to part through wall damage which has not resulted in product loss. There is significantly more fault data compared to failure data, so this provides the opportunity to investigate trends. The following observations are made in relation to the fault trends with respect to time.

4.1 External Corrosion

There are a large number of corrosion damage reports, however the majority are detected, repaired/controlled and the failure rate is low.

The external corrosion fault data shows that the fault rate increases as the pipeline age increases. This is shown as the 5 year fault incident rate and the cumulative fault incident rate/1000 km.yrs in Figure 8.

Figure 8

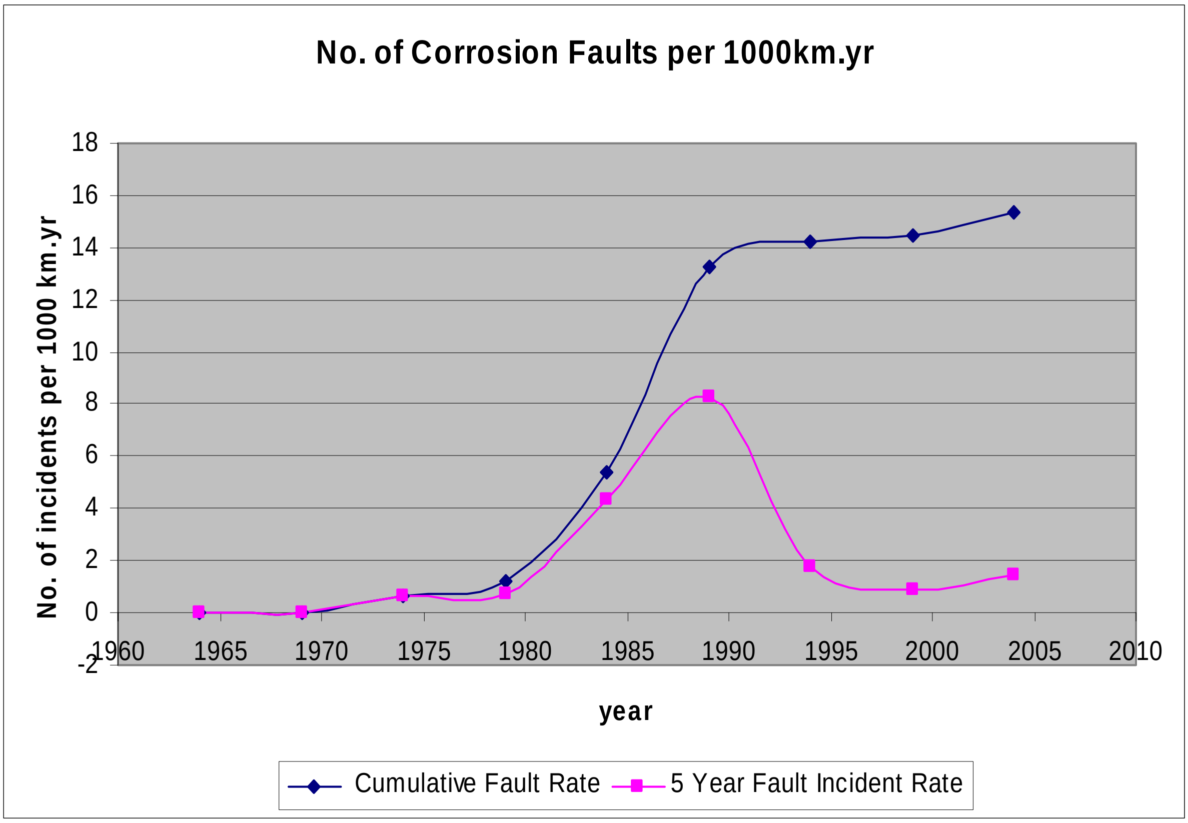


Figure 8 shows clearly that the cumulative faults rate increases significantly from 1980, levelling off around 1990, after which it remains relatively constant, indicating a slight increase around 2000. The five year corrosion fault incident rate confirms that the increased rate commences around 1980, peaks around 1990 and then falls to a much lower rate. These trends are discussed in Section 4.4.

4.2 Material and Construction Faults

There is a high rate of material and construction damage faults, but the product loss incident rate is low.

The material and construction fault data shows that the fault rate increases for older pipelines. This is shown as the 5 year fault incident rate and the cumulative fault incident rate per 1000 km.yrs in Figure 9.

Figure 9

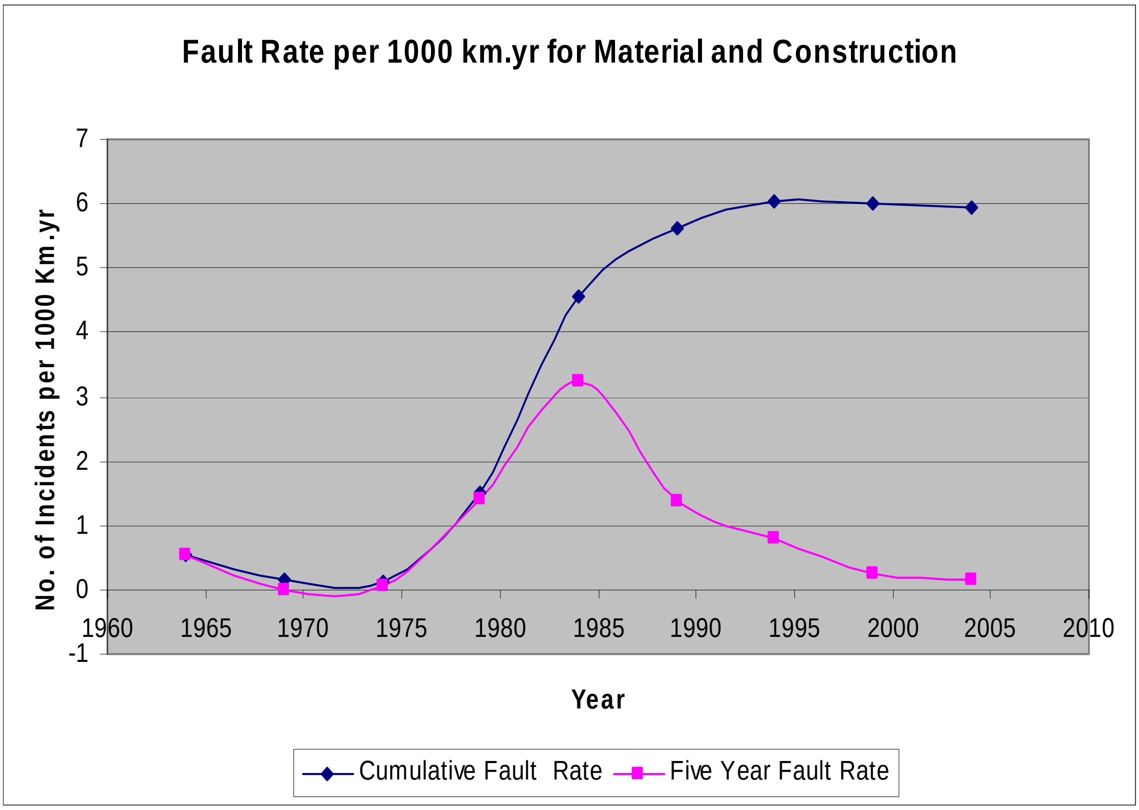


Figure 9 shows clearly that the cumulative fault rate increases significantly from around 1975, levelling off around 1995, after which it remains relatively constant. The five year material and construction fault incident rate confirms that the increased rate commences around 1975, peaks around 1985 and then falls consistently to a much lower rate. These trends are discussed in Section 4.4.

4.3 External Interference Incidents

The external interference incident rate trend also indicates that the number of external interference incidents again shows a steady reduction since 1982 for all diameters and wall thicknesses.

This trend is shown as the 5 year fault incident rate and the cumulative fault incident rate/1000 km.yrs in Figure 10.

Figure 10

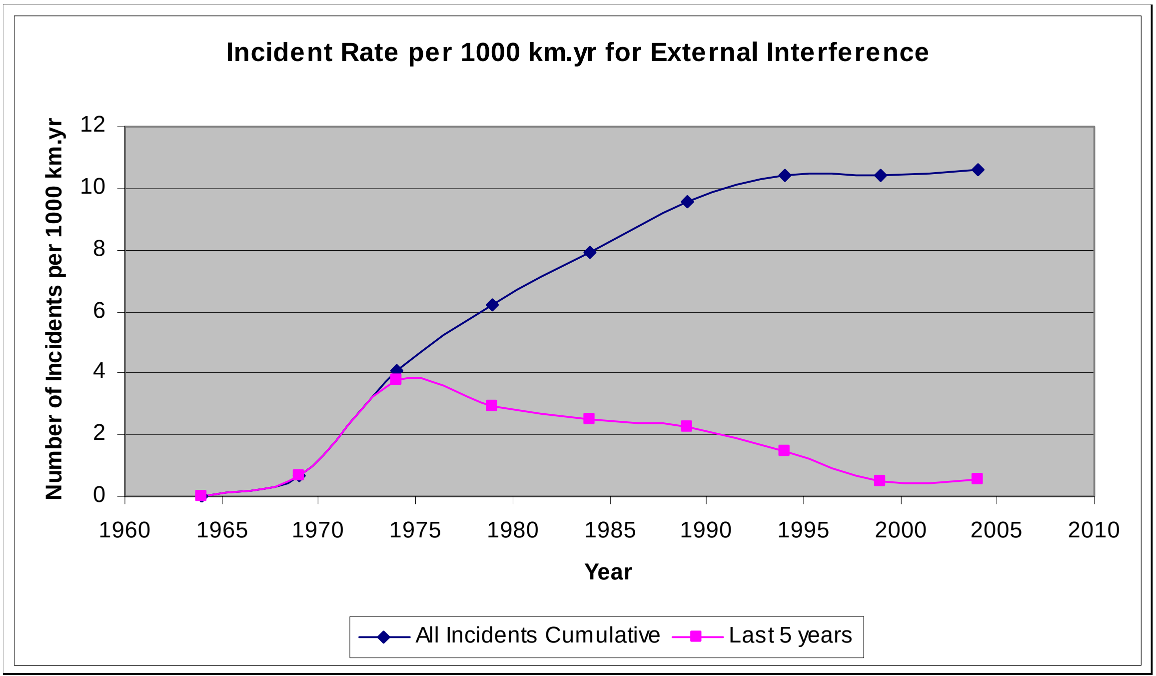


Figure 10 shows clearly that the cumulative incident fault rate increases significantly from around 1970, levelling off around 1990, after which it remains relatively constant. The five year external interference incident fault rate confirms that the increased rate commences in the late 1960s and peaks around 1974 after which it gradually reduces to a lower rate in 2000, and appears to be remaining constant at this rate. These trends are discussed in Section 4.4.

4.4 Discussion

The fault data for external corrosion, material and construction damage and external interference incidents presented in Sections 4.1 to 4.3 respectively shows that there is sufficient fault data to investigate the trends with respect to pipe diameter and wall thickness. The number of faults of all categories presented by diameter and wall thickness indicates a decrease with time. Taking into account the fact that operational exposure increases with time, this means that use of fault and failure incident rates calculated using all data in the database is conservative.

The cumulative and 5 year incident fault rate trends for each fault type in the whole pipeline population are of significant interest. For all fault types, these trends show a significant increase from the late 1960s – early 1970s, followed by a peak and then levelling off at different times between the mid-1970s and 1990. These trends demonstrate the effects of the introduction of new policies (fault reporting), new technology (intelligent pigging) and targeted operational practices (surveillance and landowner liaison) in the pipeline industry.

The incident fault rate for both external corrosion and external interference shows an increase from 1969, when the policy for fault recording was introduced, the fault database was created and the requirement to provide pipeline fault reports became mandatory within the gas industry. In the case of material and construction faults, an increase in incident fault rate starts later, around 1974.

The cumulative and 5 year incident fault rates for external corrosion show a slight increase from 1969, and then a much more significant increase from 1980 which peaks at around 1990. These trends are due to the introduction of intelligent pigging in the gas industry in the late 1970s. Pigging tools were developed and introduced by diameter in stages, commencing with the 610mm (24") diameter. The increase and peak in the incident fault rate is due to the reporting of both historic and current corrosion faults on the existing pipeline population, and the levelling off and reduction in incident fault rate is due to the repair and control of corrosion faults and improvements in corrosion management.

The incident fault rate for material and construction faults increases from 1974 and peaks in 1984. This is likely to be due to the fact that the detection of material and construction faults is associated with new build programmes, the introduction of improved material specifications during the 1970s and the improvements in the analysis of intelligent pigging data, in particular the ability to characterise laminations and mill features.

The cumulative and 5 year incident fault rates for external interference show a significant increase from 1969 which peaks at around 1974. These trends are due to the introduction of the requirement to report faults. In this case the peak in 1974 is likely to be associated with a government initiative to provide improvement grants to farmers for drainage work, which caused a significant and recognised increase in 3rd party interference incidents. A reduction in external interference incident fault rate is shown, but this is much less significant than for external corrosion or material and construction faults. This is due to the fact that the incidence of external interference is due to 3rd party activity and is less affected by the reporting of historical damage. The stabilisation of the incident fault rate is considered to be due to the introduction of operational practices for effective response to surveillance reports, and programmes for landowner/occupier awareness and liaison.

Finally, it is noted that the ability to detect metal loss and material features drove the need to develop and apply robust defect assessment methods to be applied when features were investigated. The application of recognised defect assessment methods then allowed more specific definitions of reporting criteria to be used to ensure that reports produced following in-line inspection identified and drew attention to the most significant features.

5. Damage Mechanism Relationships

The data presented and discussed in Section 4 demonstrates the relationships between failure rate and pipeline age (based on assessment of fault data vs year of commissioning) for specific damage causes. These relationships are considered further in this section. Fault and failure data for different damage causes recorded in the UKOPA fault database provided by Advantica for this study is given in Appendix 3.

5.1 External Corrosion

Product loss incident rate data for external corrosion by wall thickness and year of construction provided by Advantica for this study are given in Appendix 3.

The failure frequency due to material and construction defects vs. wall thickness is given in Table 10 and shown in Figure 11, and the failure frequency due to material and construction defects vs. year of construction is shown in Figure 12.

Table 10 – Failure Frequency due to External Corrosion

Wall Thickness (mm)	Frequency per 1000 km years			
	Pin Hole	Hole	Rupture	Total
< 5	0.262	0.04	0	0.302
5 - 10	0.031	0.015	0	0.046
>10 - 15	0	0	0	0
>15	0	0	0	0

Where:-

Pin hole = leak size equivalent to hole diameter ≤ 6mm
Hole = Leak size equivalent to hole diameter > 6mm≤ pipe diameter
Rupture = Full Bore, hole size equivalent to diameter ≥ pipe diameter

Figure 11

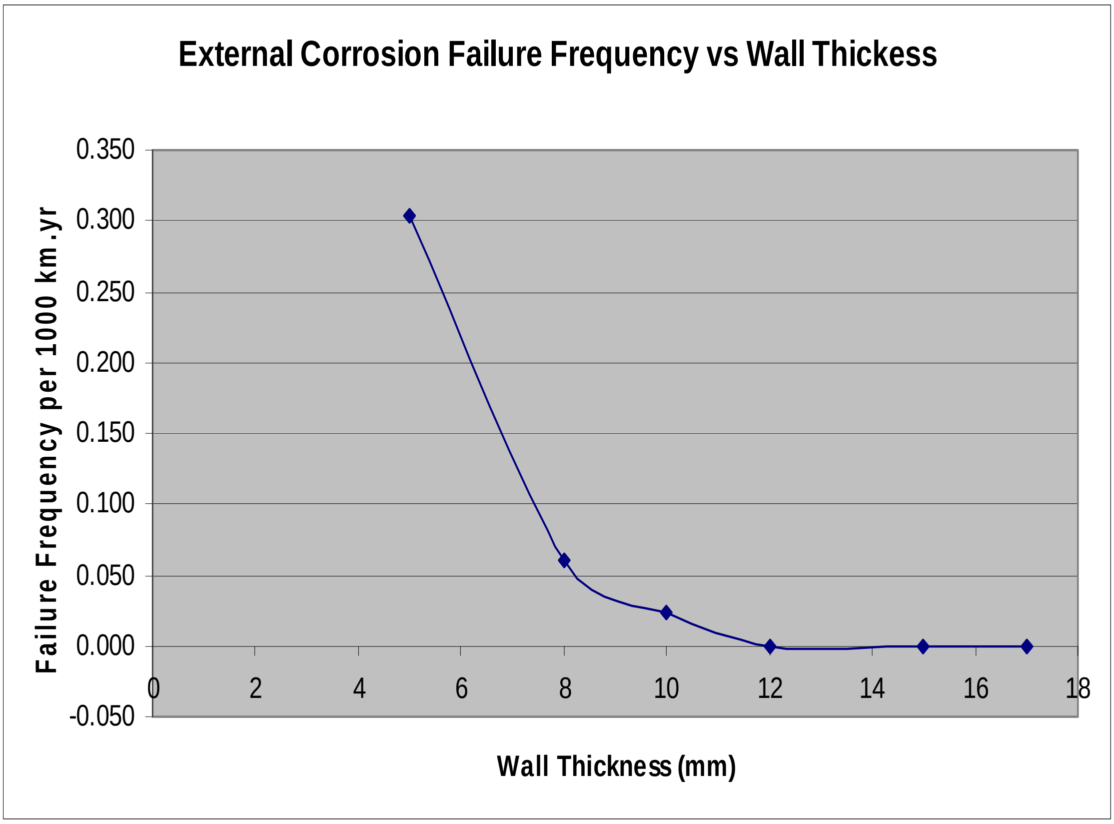
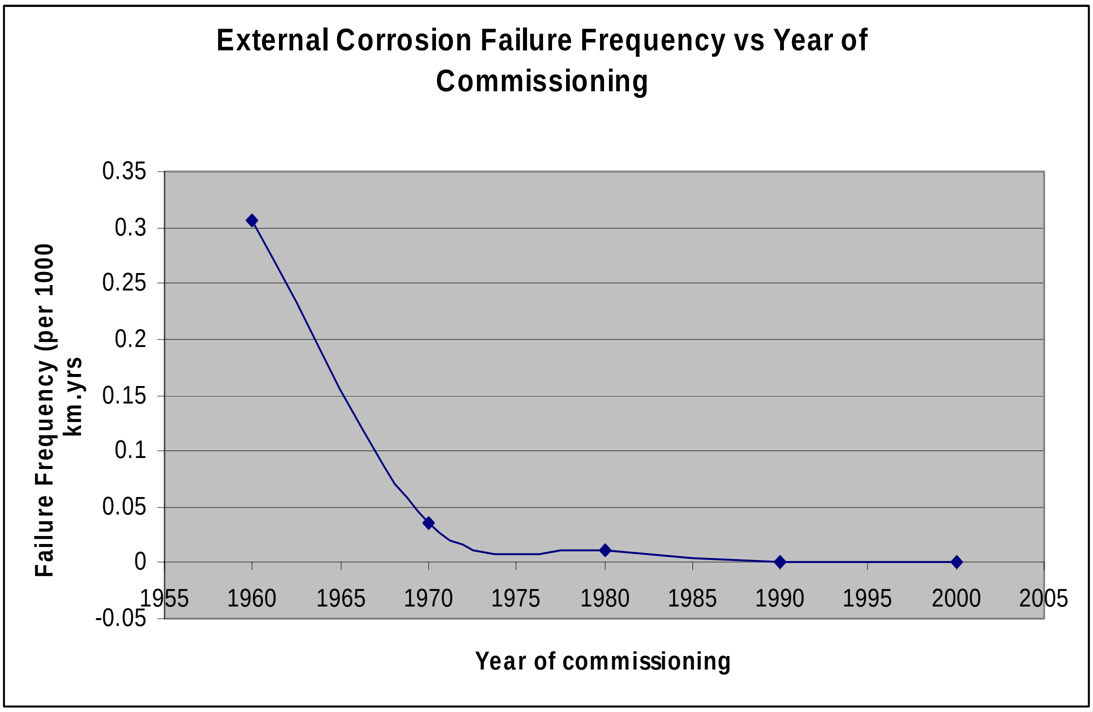


Figure 12



5.2 Material and Construction

Product loss incident rate data for material and construction defects by wall thickness and year of construction provided by Advantica for this study are given in Appendix 3.

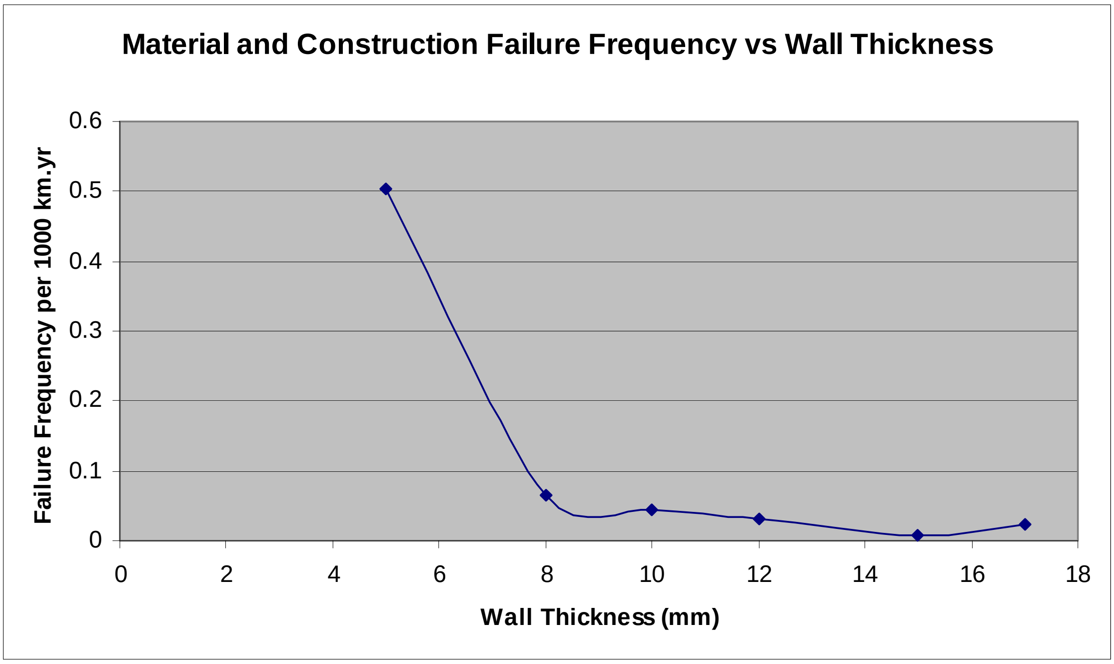
The failure frequency due to material and construction defects vs. wall thickness is given in Table 11 and shown in Figure 13.

Table 11 – Material and Construction Failure Frequency vs. Wall Thickness

Wall Thickness Range (mm)	Wall Thickness Value Assigned to Range (mm)	Failure Frequency (/1000 km years)
<5	5	0.505
5 - 8	8	0.064
>8 - 10	10	0.046
>10 -12	12	0.031
>12 - 15	15	0.007
>15	17	0.024

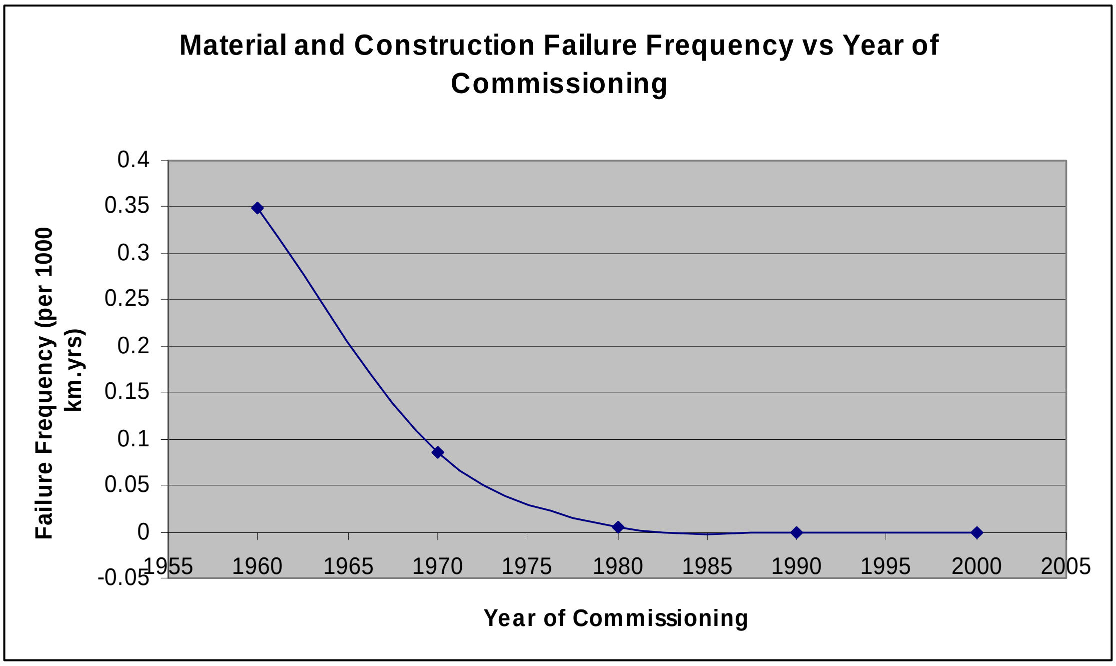
Assessment of the data indicates that 80% of material and construction failures occur as small (pin hole) leaks, 20% as larger leaks, no ruptures are recorded.

Figure 13



The failure frequency due to material and construction defects vs. year of construction is shown in Figure 14.

Figure 14



5.3 External Interference

Failure frequency data vs. diameter and wall thickness are given in Tables 12 and 13 respectively and shown in Figures 15 and 16 respectively.

Table 12 – Failure Frequency due to External Interference vs. Diameter

Diameter (mm)	Frequency per 1000 km years			
	Pin	Hole	Rupture	Total
100	0	0.119	0.03	0.149
250	0.022	0.072	0.022	0.116
400	0	0.079	0	0.079
560	0.01	0.01	0.01	0.03
700	0	0.028	0	0.028
860	0	0	0.031	0.031
1200	0	0	0	0

Table 13 – Failure Frequency due to External Interference vs. Wall Thickness

Wall Thickness (mm)	Frequency per 1000 km years			
	Pin	Hole	Rupture	Total
< 5	0	0.162	0.061	0.223
5 - 10	0.012	0.049	0.006	0.067
>10 - 15	0	0.012	0.004	0.016
>15	0	0	0	0

Figure 15

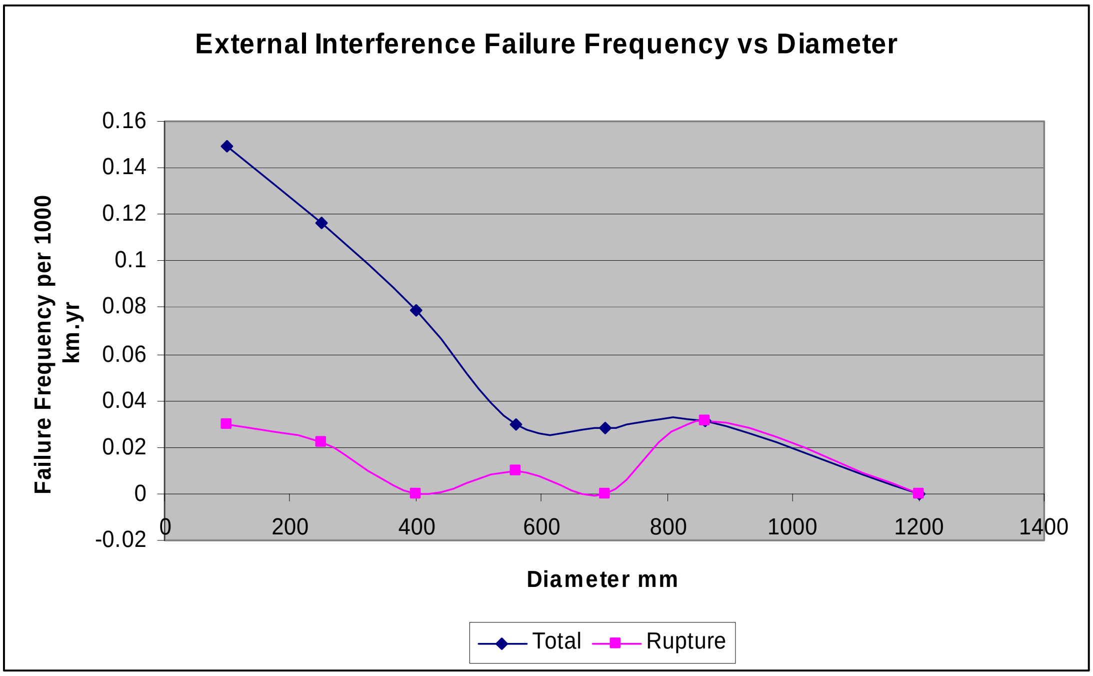
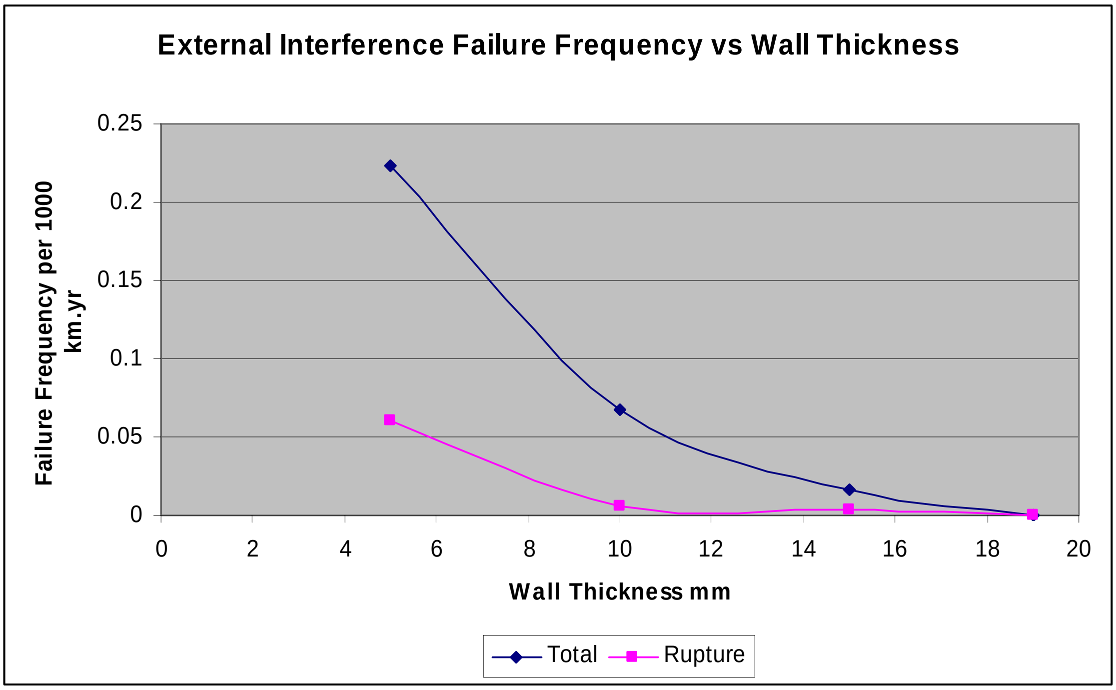


Figure 16



The relationship between failure frequency due to external interference and pipeline parameters has been investigated in previous work reported in [3] . The failure frequency is dependant upon i) the rate of occurrence (i.e. the hit rate) and ii) the pipeline diameter/radius to thickness ratio. These relationships are presented and discussed in [4].

The occurrence of external interference is random. Assessment of the data indicates that with regard to age, shown in Figure 10, there has been a reduction in the incident rate, and that this has now stabilised. There is a possibility that damage caused by external interference can fail at a later stage, but this is not indicated in the UK data.

It is recommended that prediction of failure frequency due to external interference is carried out using a recognised fracture mechanics (dent/gouge) failure model. In applying the prediction methodology, use of the complete UKOPA data set for occurrences of external interference is conservative, as this includes historical incidents of damage which, following the introduction of revised codes and practices, are unlikely to occur under current practice.

5.4 Ground Movement

There is insufficient data to establish a relationship between ground movement failure data and pipeline parameters. In order to assess accurately the background rate which applies to the gas network, National Grid actioned analysis work which calculated the background failure rate due to rupture based upon a conservative assessment of the land sliding incident rate and the structural response of the pipeline network.

Based on an assessment of this work, UKOPA considers that the gas pipeline network represents UK MAHP pipeline routes, geometries and operating parameters. It is therefore concluded that the analysis carried out for National Grid is applicable to all UK MAHPs, and the predicted background rupture failure rate of 2.1×10^{-4} / 1000 km years calculated for the natural gas pipeline network can be applied to all UK MAHPs.

6. Failure Frequencies for UK Pipelines

6.1 Derivation of Recommended Failure Frequencies

Overall failure frequencies for UK MAHP pipelines, based on all data recorded in the UKOPA database calculated using the 2004 operational exposure of 654,700 km years, are given in Table 14.

Table 14 - Averaged Failure Frequencies for UK MAHPs (/1000 km years)

Damage Mechanism	Frequency per 1000 km years			
	Pin	Hole	Rupture	Total
External Interference	0.006	0.04	0.011	0.057
External Corrosion	0.035	0.011	0	0.046
Internal Corrosion	0.003	0	0	0.003
Material & Construction	0.063	0.013	0	0.076
Ground Movement	0.003	0.004	0.002	0.009
Other	0.052	0.019	0.002	0.073
Total				**0.264**

Note the data given in Table 14 represents the overall averaged set of failure frequencies applied to the whole pipeline population included in the database. It is presented to enable general comparison of the datasets only, and should not be applied to specific pipelines. The above data clearly shows that the failure data comprises predominantly small (pin-hole) leaks. The average breakdown gives 61% small leaks, 32% large leaks and 7% ruptures. As ruptures and large leaks dominate the results of risk analysis, in assigning failure frequencies to specific pipelines, the proportion of failures due to ruptures and large leaks for each specific damage mechanism must be considered. The UKOPA data indicates this increases to a maximum of 70% for large leaks and 19% for ruptures for external interference, reducing to 24% and 17% for large leaks, no ruptures, for external corrosion and material and construction respectively.

Based on the assessments in Sections 4 and 5, the following specific recommendations are made for failure frequency for UK MAHPs:-

External Corrosion:-

External corrosion failure data relates in all cases to leaks, no ruptures are recorded. In terms of leaks, a conservative interpretation of the recorded data indicates that 50% are small (pin-hole) leaks and 50% are larger leaks. External corrosion data varies with thickness and age. Based on the assessment in Section 5, it is recommended that the reduction factors given in Section 6.2 are used as appropriate when interpreting the UKOPA data for application to specific pipelines.

Material and Construction:-

Material and construction failure data relates in all cases to leaks, no ruptures are recorded. In terms of leaks, the recorded data indicates that 80% are small (pin hole) leaks, 20% are larger leaks. Material and construction data varies with thickness and age. Based on the assessment in Section 5, it is recommended that the reduction factors given in Section 6.2 are used as appropriate when interpreting the UKOPA data for application to specific pipelines.

External Interference:-

The failure due to external interference is a random event and the probability of failure is dependent upon the pipeline physical and operational parameters, so pipeline specific failure rates should be determined using predictive techniques.

In predicting the failure frequency due to external interference, comparisons should be made with the trends in total and rupture failure rates for UK pipelines given in Section 5.

Ground Movement:-

There is insufficient data to establish a relationship between ground movement failure data and pipeline parameters. In order to assess accurately the background rate which applies to the gas network, National Grid actioned analysis work which calculated the background failure rate due to rupture based upon a conservative assessment of the land sliding incident rate and the structural response of the pipeline network.

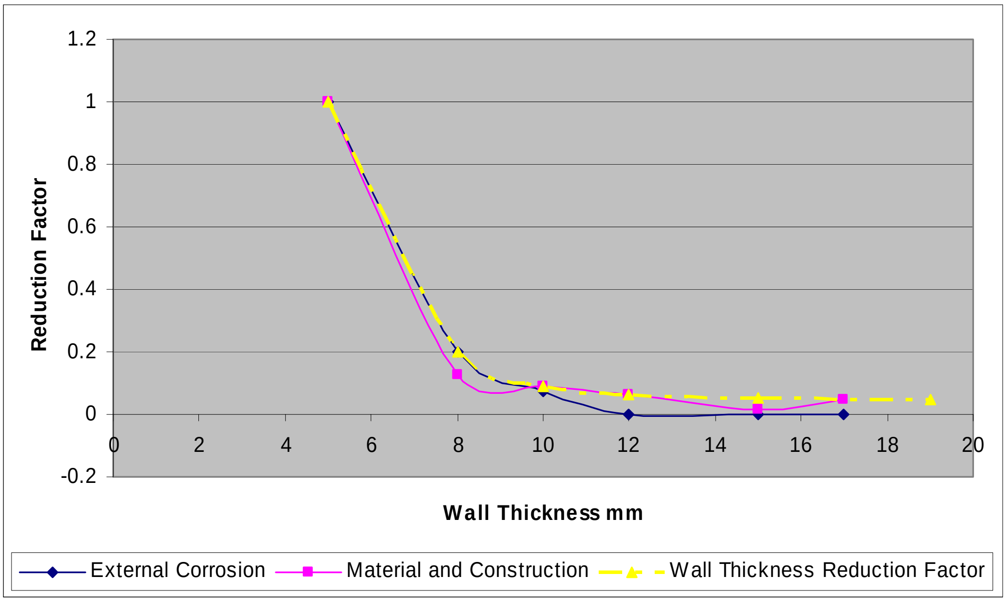
Based on an assessment of this work, UKOPA considers that the gas pipeline network represents UK MAHP pipeline routes, geometries and operating parameters. It is therefore concluded that the analysis carried out for National Grid is applicable to all UK MAHPs, and the predicted background rupture failure rate of 2.1×10^{-4} per 1000 km years calculated for the natural gas pipeline network can be applied to all UK MAHPs.

6.2 Failure Frequency Reduction Factors for Material and Construction and Corrosion Data

Data presented in Section 5.1 for external corrosion and 5.2 for material and construction show a relationship with wall thickness and year of construction (i.e. pipeline age).

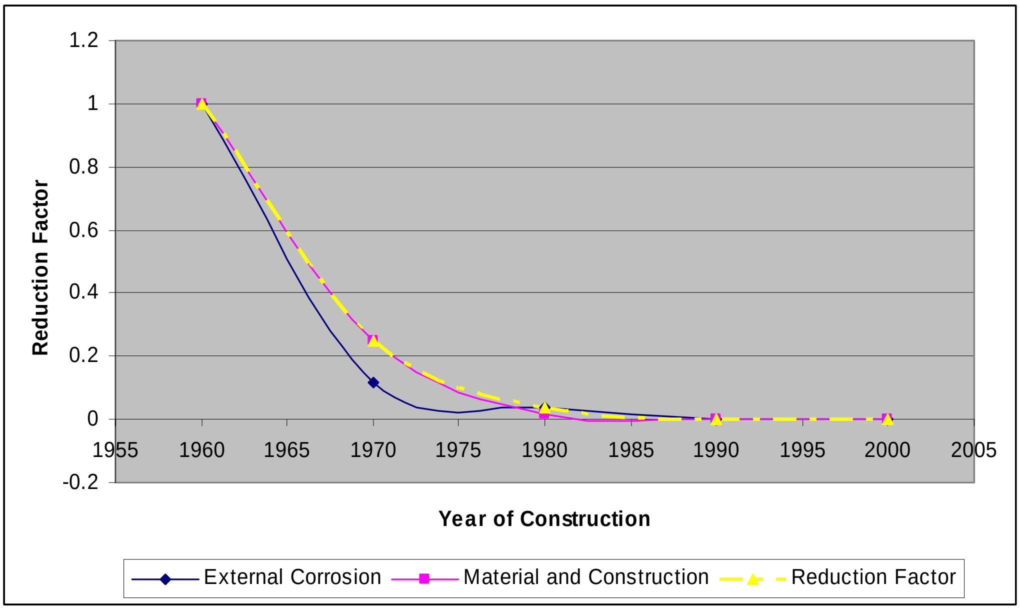
Figure 17 shows the variation in failure frequency with wall thickness for both material and construction (see Figure 11) and external corrosion (see Figure 12) presented as reduction factors, which represent the data normalised by its maximum value. The reductions factors for both external corrosion and material and construction are similar, and a common reduction factor representing the upper bound case is therefore proposed.

Figure 17 – Wall Thickness Reduction Factor for Failure Frequencies due to Material and Construction and External Corrosion



Similarly, Figure 18 shows the variation in failure frequency with year of construction for external corrosion (refer to Figure 13) and material and construction (refer to Figure 14) presented as reduction factors. Again, the reduction factors are similar and a common reduction factor representing the upper bound case is therefore proposed.

Figure 18 – Age Reduction Factor for Failure Frequencies due to Material and Construction and External Corrosion



6.3 Comparison of UKOPA Data with EGIG and CONCAWE Data

The European Gas Pipeline Incident Data Group (EGIG) records failure data for gas pipelines in 12 European countries[2]. Failure frequencies for European gas pipelines based on all data recorded in the EGIG data base [5] calculated using the 2004 operational exposure of 2770 1000 km.yrs are given in Table 15.

Table 15 - Failure Frequencies for European Natural Gas Pipelines, EGIG (per 1000 km years)

Damage Mechanism	Frequency per 1000 km years			
	Pin	**Hole**	**Rupture**	**Total**
External Interference	0.054	0.113	0.038	0.205
External Corrosion	0.048	0.003	0	0.051
Internal Corrosion	0.001	0	0	0.001
Material & Construction	0.044	0.018	0.005	0.067
Ground Movement	0.006	0.012	0.012	0.03
Other	0.035	0.011		0.046
Total				0.4

The Conservation of Clean Air and Water in Western Europe (CONCAWE) Oil Pipelines Management Group records data on the performance of oil pipelines in Europe since 1971 [6]. The data relates to oil spillages, and is categorised by cause and size of spill. A detailed assessment of the CONCAWE data for clean product oils [7] calculated based on the operational exposure of 685,500 km years is given in Table 16.

Table 16 - Failure Frequencies for European Oil Pipelines, CONCAWE (per 1000 km years)

Damage Mechanism	Frequency per 1000 km years			
	Pin	**Hole**	**Rupture**	**Total**
External Interference	0.051	0.108	0.045	0.204
Corrosion	0.012	0.049	0.002	0.063
Material & Construction	0.025	0.022	0.012	0.059
Ground Movement	0.002	0.008	0.004	0.014
Other				
Total				0.34

The total (leak + rupture) failure rates for each damage mechanism obtained from EGIG and CONCAWE are compared with those obtained from UKOPA in Table 17.

[2] Denmark, Spain, Belgium, Finland, The Netherlands, France, Germany, Italy, Switzerland, UK, Czech Republic, Portugal

Table 17 - Comparison of UKOPA Failure Frequency Data with EGIG and CONCAWE Data (/1000 km.yrs)

Exposure (1000 km years)	UKOPA	EGIG	EGIG/ UKOPA	CONCAWE	CONCAWE/ UKOPA
	6.55E+02	2.77E+03		6.86E+02	
Damage Mechanism					
External Interference	0.057	0.201	3.526	0.204	3.579
External Corrosion	0.047	0.051	1.085	0.063	1.340
Internal Corrosion	0.003	0.01	3.333		0.000
Material & Construction	0.075	0.068	0.907	0.059	0.787
Ground Movement	0.008	0.029	3.625	0.014	1.750
Other	0.074	0.046	0.622		0.000
Total	**0.263**	**0.405**	**1.540**	**0.341**	**1.297**

The comparison in Table 17 shows that the major differences between UKOPA and EGIG and CONCAWE data are for external interference and ground movement data.

The external interference rate indicated in the EGIG and CONCAWE data is more than 3.5 times the incident rate in the UKOPA data. One possible reason for this is the difference in routing requirements in the UK compared to Europe. Area or location classes defined according to population density and/or infrastructure are not applied consistently throughout Europe, and the proportion of high pressure gas transmission pipelines routed in suburban or Class 2 areas (where 3rd party incident rates are higher due to increased activity levels) is higher than in the UK. Another reason may be differences in pipeline route surveillance and response to sightings.

The ground movement failure rate in EGIG is 3.6 times the UKOPA rate, and that in CONCAWE is 1.75 times the UKOPA rate. The land area in which the pipelines in the EGIG and CONCAWE databases are routed is considerably larger and much more varied than that in which the UKOPA pipelines are routed. The European land area contains a number of locations with greater land instability than in the UK (eg Italy, Spain). It is therefore reasonable to expect the failure rate due to ground movement to be lower in the UK.

Table 17 indicates similar overall total averaged failure rates for external corrosion and material and construction for UKOPA, EGIG and CONCAWE. However these data include and are dominated by historical data which are not representative of current codes and practice. Changes in standards, material specifications, quality assurance and inspection mean that certain incidents due to poor material quality and welding would not now be expected to occur. In addition, improvements in corrosion protection application and monitoring, pipeline route surveillance, and use of in-line inspection have reduced the failure frequency due to material and construction, external interference and corrosion. In order to assess the relevance of the data to current pipeline operations, the failure frequency trends must be considered. The failure frequency trends for the UKOPA, EGIG and CONCAWE are given in Figure 19 ([1], Figure 3), Figure 20 ([5], Figure 12) and Figure 21 ([6], Figure 8).

Figure 19 - UKOPA Failure Frequency Trend ([1], Figure 3)

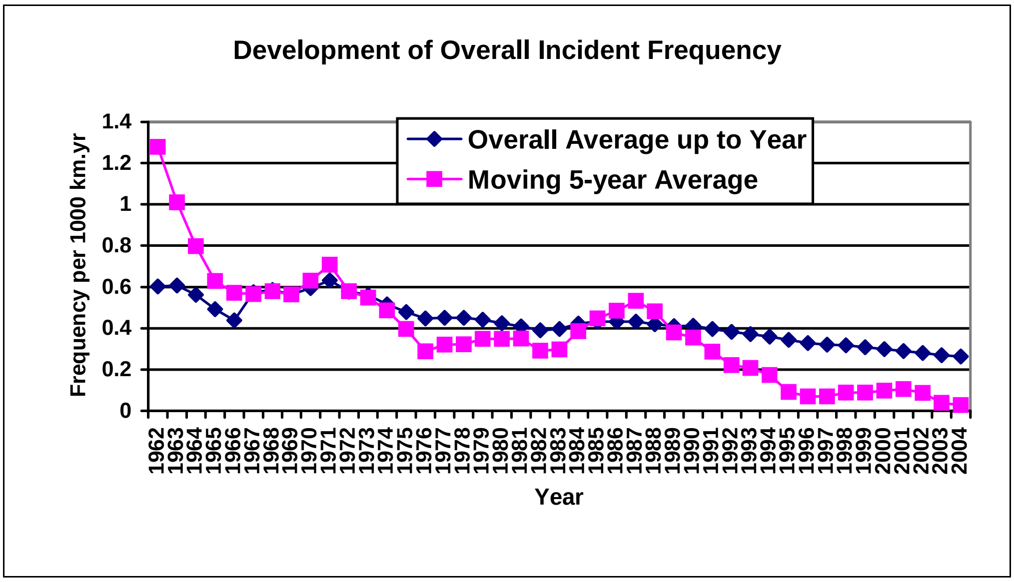


Figure 20 - EGIG Failure Frequency Trend ([5], Figure 12)

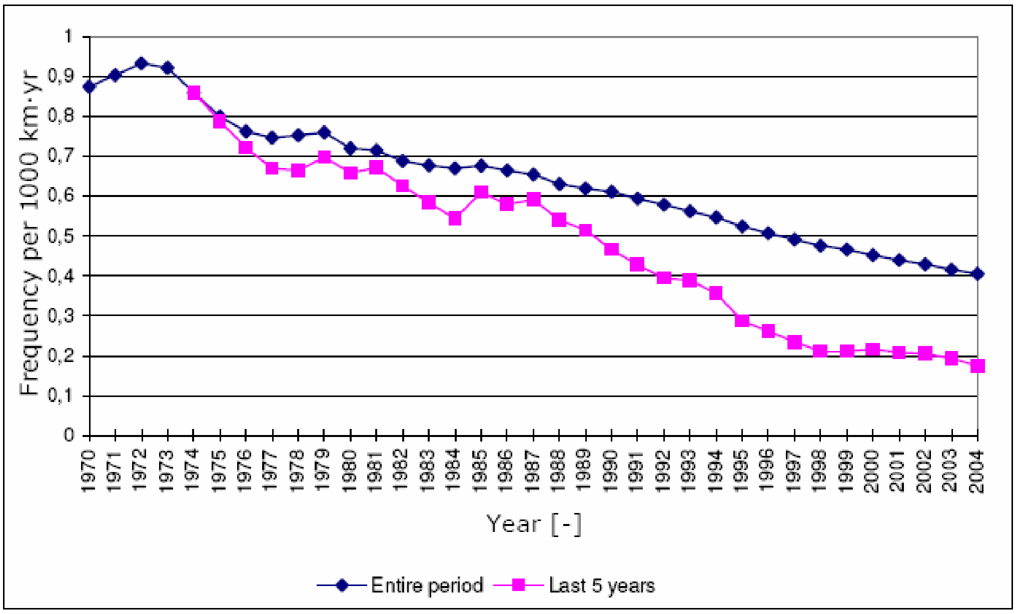
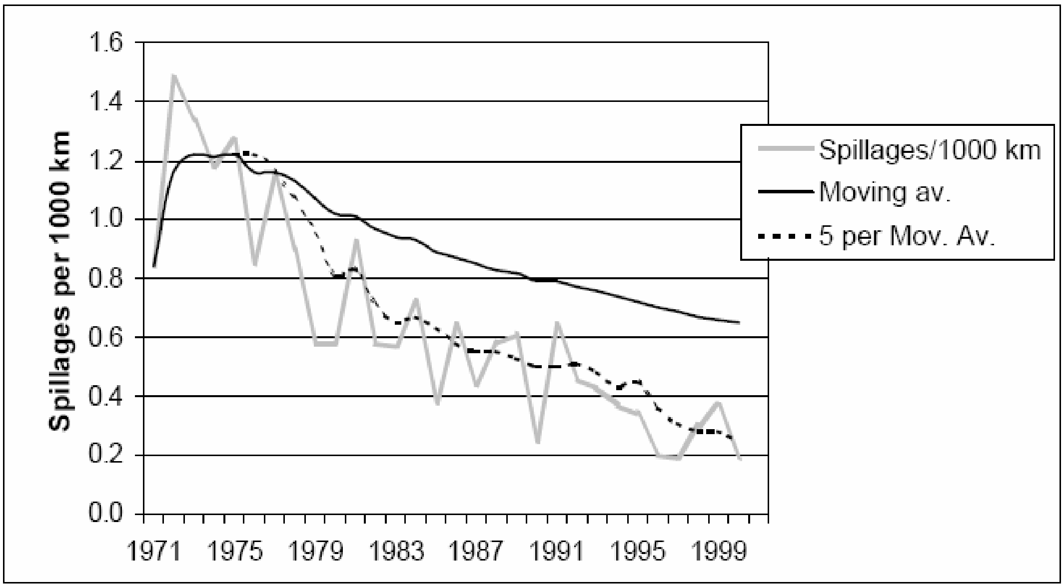


Figure 21 - CONCAWE Failure Frequency Trend ([6], Figure 8)



The above trends indicate that in the 30 year period 1970 – 2000, the overall failure frequency has reduced. The EGIG and CONCAWE data indicate that the moving average failure frequency over 5 years has decreased by a factor of approximately 5 over this period, the UKOPA data indicates a higher factor decrease of approximately 25. The UKOPA and EGIG failure frequency trends for different failure mechanisms are shown in Figures 22 and 23 respectively. These figures confirm that there is a reduction in failure rate for all damage mechanisms. The UKOPA data shows the more significant reductions in failure rate occur for external interference, material and construction (and other/unknown) damage mechanisms, while the EGIG data is dominated by the external interference failure trend.

Figure 22 – UKOPA Failure Frequency Trend for Different Damage Mechanisms ([1], Figure 4)

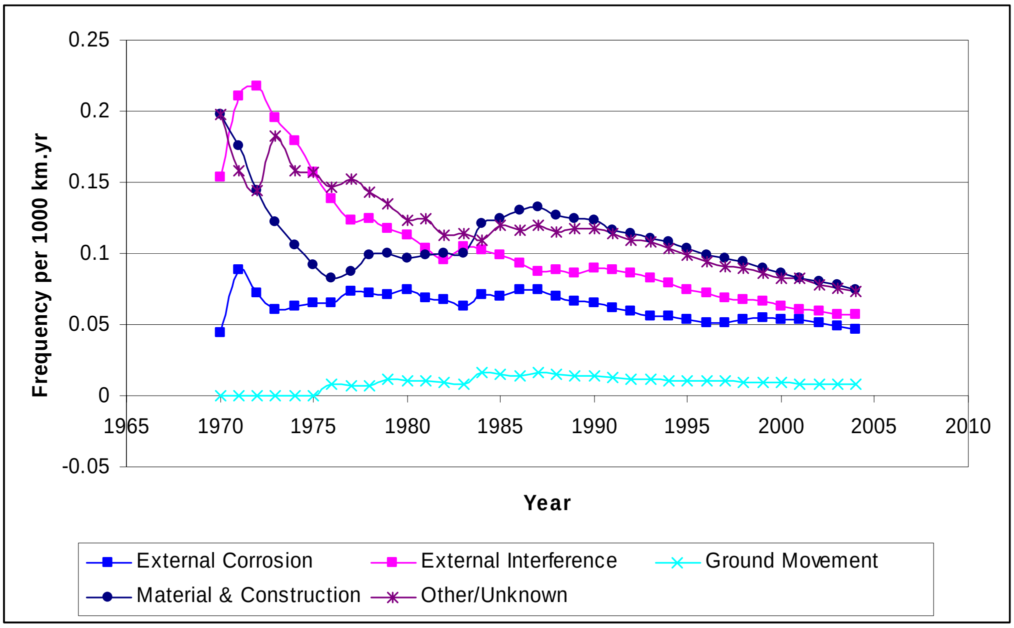
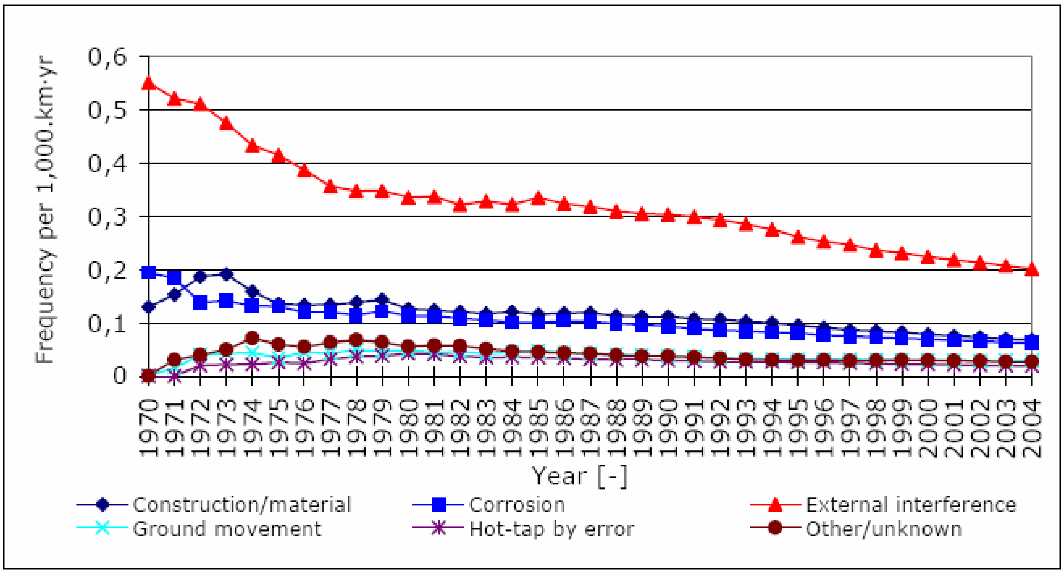


Figure 23 – EGIG Failure Frequency Trend for Different Damage Mechanisms ([5], Figure 15)



Only the UKOPA data is sufficiently detailed to allow fault trends for these damage mechanisms to be derived, and assessment of these trends has confirmed the reduction in fault rate with more recent commissioning dates. It is concluded that failure rates based on the UKOPA data provide the best representation of the performance of pipelines in the UK.

7. Conclusions

Based on the overview of UKOPA Data, the assessment of its application to all pipelines, assessment of pipeline fault data trends and comparison with EGIG and CONCAWE data, the following conclusions are drawn:-

7.1 The UKOPA fault and failure data is applicable to all UK MAHPs.

7.2 Application of the failure frequency data for the derivation of failure frequencies for ethylene pipelines has been confirmed to be conservative for external corrosion, material and construction and external interference damage mechanisms.

7.3 Application of the failure frequency data for the derivation of failure frequencies for spiked crude pipelines is conservative for material and construction and external interference damage mechanisms.

7.4 The incident rate for external interference applies to all UK MAHPs.

7.5 In all cases, the failure frequency has reduced over the period 1970 – 2004.

7.6 The relationship between material and construction and external corrosion failure rates and pipeline wall thickness has been derived, and is presented, as a reduction factor for specific pipeline data which may be applied to the average failure rate.

7.7 The relationship between material and construction and external corrosion failure rates and pipeline age has been derived based on the numbers of reported faults, and is presented as a reduction factor for specific pipeline data which may be applied to the average failure rate.

7.8 The failure frequency due to external interference is dependent upon the pipeline physical and operational parameters, so pipeline specific failure rates should be determined using predictive techniques.

7.9 The approach used to derive failure frequencies for ground movement derived for National Grid for application to natural gas pipelines is applicable to all UK MAHPs, and the derived background failure rate should be applied to all UK MAHPs.

8. Recommendations

Based on the results of the assessment detailed and conclusions drawn in this report, it is recommended that UKOPA data is used to derive failure frequencies for all damage mechanisms for UK pipelines.

9. References

1 Pipeline Product Loss Incidents (1962 - 2004) 4th Report of the UKOPA **F**ault **D**atabase **M**anagement **G**roup. Advantica Report R8099 April 2005.

2 UKOPA Pipeline Fault Database – Application to All Pipelines. PIE/03/R034. May 2003.

3 Failure Frequency Prediction for Pipelines Due to 3rd Party Interference. PIE/06/R121. C Lyons. July 2006.

4 The Influence of Pipe Design Factor and Geometry on the Failure of Pipelines Subject to 3rd Party Damage. PIE/05/R104. C Lyons and J Haswell. October 2005.

5 6th EGIG Report 1970 – 2004. Gas Pipeline Incidents. 6th Report of the European Gas Pipeline incident Data Group. EGIG.05.R.0002. December 2005.

6 Western European Cross–Country Oil Pipelines 30-year performance Statistics Prepared on behalf of the CONCAWE Oil Pipelines Management Group (OPMG) by D Lyons. Report 1/02. February 2002

7 Review of CONCAWE Data for Product Pipelines Part 2 – Calculation of Failure Rates to end of 2003. Report prepared for the UKOPA Working Group on Pipelines by R McConnell. April 2005.

Appendix 1 Summary of the Chi^2 Test for Goodness of Fit

Degrees of Freedom	Chi^2 Result - Confidence Level Criteria				
	0.1% Level	1% Level	5% Level	10% Level	25% Level
1	10.83	6.64	3.84	2.706	1.323
2	13.82	9.21	5.99	4.605	2.772
3	16.27	11.35	7.82	6.251	4.108
4	18.47	13.28	9.49	7.779	5.385
5	20.52	15.09	11.07	9.236	6.626
6	22.46	16.81	12.59	10.645	7.841
7	24.32	18.48	14.07	12.017	9.037
8	26.13	20.09	15.51	13.362	10.219

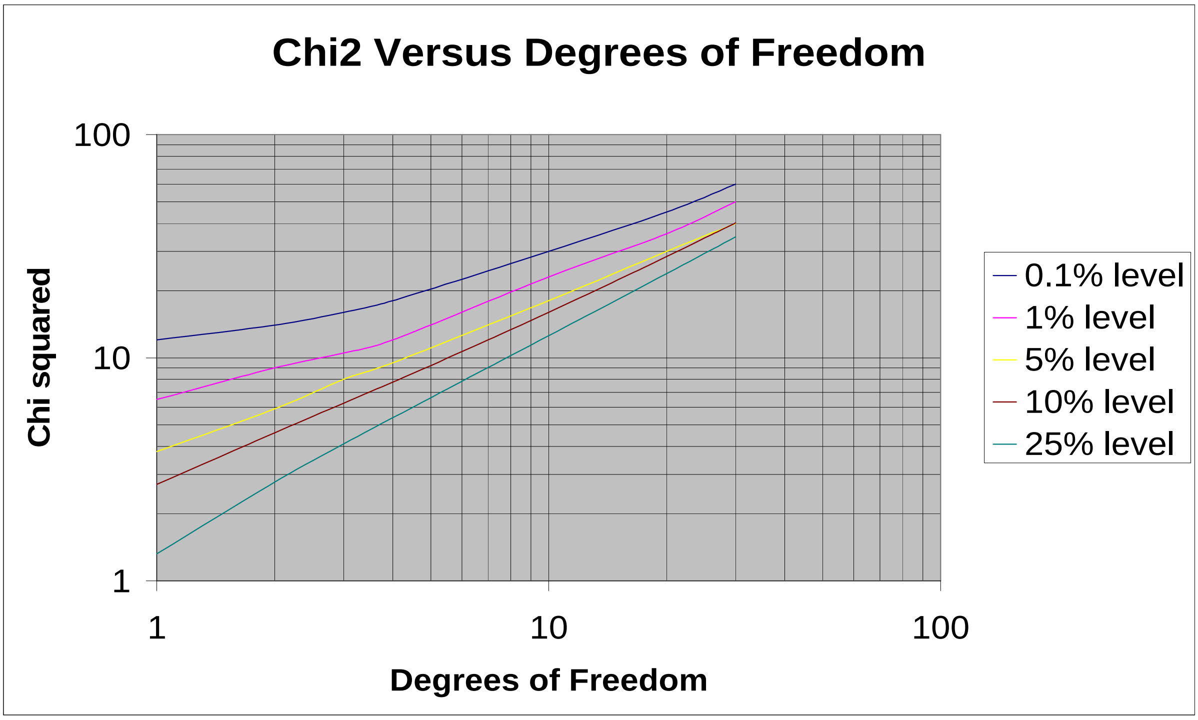
0.1%, 1% and 5% indicate a significant difference between two samples with levels of certainty increasing as % gets smaller

Chi^2 levels above 25% indicate no significant difference between two samples

Values between these two figures must be carefully interpreted.

Chi-squared = sum of [{(observed number - expected number)^2}/expected number]

Degrees of Freedom indicates number of independent variables included in the analysis (less 1 for more than 1)


Chi2 Versus Degrees of Freedom
100
10
1
1
10
100
Chi squared
Degrees of Freedom
0.1% level
1% level
5% level
10% level
25% level

Appendix 2 Statistical Analysis of Fault Data

A2.1 Comparison of Data for Ethylene Pipelines with Equivalent Data for Natural Gas Pipelines

Fault reports are available for ethylene pipelines with diameters 168mm, 219mm 273mm and 324mm. The data for the 168mm diameter pipeline was not considered, as this pipeline is now decommissioned.

External Corrosion Fault Data

The corrosion fault data for ethylene pipelines comprising diameters 219mm, 273mm and 324mm was compared to the equivalent data for the natural gas pipeline population using the Chi^2 test. The application of Chi^2 Test involved the construction of a 2x2 table to enable comparison of proportions. The results are summarised below.

	Gas	Ethylene	Total	
Population size	141334	22736	164070	Given in km.yrs
Observed	253	48	301	Observed number of corrosion incidents
Assumed	259	42	301	Assumed number of corrosion incidents

Note – The assumed number of incidents is calculated assuming the populations are equivalent. Assuming that the gas and ethylene populations have an equivalent level of failures allows the number of corrosion incidents to be estimated by allocating an equivalent number of tests proportionally between the groups weighted by the population.

observed numbers

	gas	ethylene	Total
actual	253	48	301
assumed from population	259	42	301
total	512	90	602

expected numbers

	gas	ethylene	Total
actual	256	45	301
assumed from population	256	45	301
total	512	90	602

	0.03516	0.2
	0.03516	0.2
chi-sq =	0.47031	
df =	1	
probability	>0.25	

The results of the above assessment show that the Chi^2 value is equivalent to a probability greater than 0.25. This shows that there is no statistical evidence of a difference between the populations for external corrosion incidents in natural gas and ethylene.

It is therefore concluded that the external corrosion fault data for ethylene pipelines is equivalent to that for natural gas. It is therefore concluded that the failure rate determined for UK ethylene pipelines can be based on UKOPA fault data.

Material and Construction Fault Data

The material and construction fault data for ethylene pipelines comprising diameters 219mm, 273mm and 324mm was compared to the equivalent data for the natural gas pipeline population using the Chi^2 test. The application of Chi^2 Test involved the construction of a 2x2 table to enable comparison of proportions. The results are summarised below.

	Gas	**Ethylene**	**Total**	
Population size	141334	22736	164070	Given in km.yrs
Observed	167	21	188	Observed number of corrosion incidents
Assumed	162	26	188	Assumed number of corrosion incidents based on populations being equivalent

observed numbers

	gas	ethylene	Total
actual	167	21	188
assumed from population	162	26	188
total	329	47	376

expected numbers

	gas	ethylene	Total
actual	164.5	23.5	188
assumed from population	164.5	23.5	188
total	329	47	376
	0.03799	0.26596	
	0.03799	0.26596	
chi-sq =	0.6079		
df =	1		
probability	>0.25		

The results of the above assessment show that the Chi^2 value is equivalent to a probability greater than 0.25. This shows that there is no statistical evidence of a difference between the populations.

It is therefore concluded that the material and construction fault data for ethylene pipelines is equivalent to that for natural gas. It is therefore concluded that the failure rate determined for UK ethylene pipelines should be based on UKOPA fault data.

External Interference

The external fault data for ethylene pipelines comprising diameters 219mm, 273mm and 324mm was compared to the equivalent data for the natural gas pipeline population using the Chi^2 test. The application of Chi^2 Test involved the construction of a 2x2 table to enable comparison of proportions.

	Gas	Ethylene	Total	
Population size	141334	22736	164070	Given in km.yrs
Observed	370	20	390	Observed number of material and construction incidents
Assumed	336	54	390	Assumed number of material and construction incidents based on populations being equivalent

observed numbers

	gas	ethylene	Total
actual	370	20	390
assumed from population	336	54	390
total	706	74	780

expected numbers

	gas	ethylene	Total
actual	353	37	390
assumed from population	353	37	390
total	706	74	780
	0.81869	7.81081	
	0.81869	7.81081	
chi-sq =	17.2590		
df =	1		
probability	<0.001		

The Chi^2 results indicate the ethylene data is not equivalent to the gas data, however the observed number of ethylene faults is much lower than the assumed number. It is therefore concluded that the failure rate determined for UK ethylene pipelines can be based on UKOPA data, as this is conservative.

Ground Movement Fault Data

The ground movement fault data for ethylene pipelines comprising diameters 219mm, 273mm and 324mm was compared to the equivalent data for the natural gas pipeline population using the Chi^2 test. The application of Chi^2 Test involved the construction of a 2x2 table to enable comparison of proportions.

	Gas	Ethylene	Total	
Population size	141334	22736	164070	Given in km.yrs
Observed	8	2	10	Observed number of ground movement incidents
Assumed	9	1	10	Assumed number of ground movement incidents based on populations being equivalent

In this case, as 50% of the expected numbers have values less than 5, the Chi^2 test is not valid. As an alternative, Fisher's Exact Test is applied.

Fisher's Exact Test, calculation of exact probability of occurrence of assumed proportions:-

observed numbers

	gas	ethylene	Total
actual	8	2	10
assumed from population	9	1	10
total	17	3	20

expected numbers

	gas	ethylene	Total
actual	8.5	1.5	10
assumed from population	8.5	1.5	10
total	17	3	20

Fishers Exact Test Calculation:-

p of table:- 0.394737

The significance level is equal to the sum of the probability of the observed table and of less probable tables. There are three other tables giving the same row and column totals. One has an identical probability to the observed table resulting from the fact that it is the same but with the numbers reversed with respect to the row they are in. The other two are variations of the table shown below and have the same probability.

Probability of extreme table:-

	gas	**ethylene**	**total**
actual	10	0	10
assumed from population	7	3	10
total	17	3	20

Fishers Exact Test Calculation:-

p of table:- 0.105263

The overall significance level is therefore equal to 0.394737+0.394737+0.015263+0.105263=1

This value, 1, is above 0.05 and therefore indicates that the occurrence of the observed table was by chance rather than any real effect.

The exact test results indicate the ethylene data is not significantly different to the gas data. It is therefore considered reasonable that the failure rate due to ground movement determined for UK ethylene pipelines is based on that determined for gas pipelines.

A2.2 Comparison of Data for Spiked Crude Pipelines with Equivalent Data for Natural Gas Pipelines

Fault reports are available for the 914mm diameter spiked crude pipeline.

External Corrosion Fault Data

The corrosion fault data for the 914 mm diameter spiked crude pipeline was compared to the data for 610 – 914 mm diameter natural gas pipelines

Data under review.

Material and Construction Fault Data

The material and construction fault data for spiked crude pipelines comprising diameters 914mm was compared to the equivalent data for the natural gas pipeline population using the Chi^2 test. The application of Chi^2 Test involved the construction of a 2x2 table to enable comparison of proportions. In this case, as 50% of the expected numbers have values less than 5, the Chi^2 test is not valid. As an alternative, Fisher's Exact Test is applied.

	Gas	**Spiked crude**	**Total**	
Population size	97555.18	6679.22	104234	Given in km.yrs
Observed	32	1	33	Observed number of material and construction incidents
Assumed	31	2	33	Assumed number of material and construction incidents

Probability of assumed distribution:-

observed numbers

	gas	Crude	total
actual	32	1	33
assumed from population	31	2	33
total	63	3	66

expected numbers

	gas	ethylene	total
actual	31.5	1.5	33
assumed from population	31.5	1.5	33
total	63	3	66

Fishers Exact Test Calculation:-
p of table:- 0.380769

Probability of extreme table:-

	gas	Crude	total
actual	33	0	33
assumed from population	30	3	33
total	63	3	66

Fishers Exact Test Calculation:-
p of table:- 0.119231

The significance level is equal to the sum of the probability of the observed table and the probabilities of less probable tables. There are three other tables giving the same row and column totals as the observed table. One has an identical probability to the observed table resulting from the fact that it is the same but with the numbers reversed with respect to the row they are in. The other two are variations of the extreme table shown above and have the same probability.

The overall significance level is therefore equal to:-
0.380769+0.380769+0.119231+0.119231=1

This value, 1, is above 0.05 and therefore indicates that the occurrence of the observed table was by chance rather than any real effect.

The exact test results indicate the spiked crude pipeline data is not significantly different to the gas pipeline data. It is therefore concluded that the failure rate due to material and construction faults determined for UK spiked crude pipelines can be determined using UKOPA data.

External Interference

The external interference fault data for spiked crude pipelines comprising diameters 914mm was compared to the equivalent data for the natural gas pipeline population using the Chi^2 test. The application of Chi^2 Test involved the construction of a 2x2 table to enable comparison of proportions. In this case, as 50% of the expected numbers have values less than 5, the Chi^2 test is not valid. As an alternative, Fisher's Exact Test is applied.

	Gas	**Spiked Crude**	**Total**	
Population size	97555.18	6679.22	104234	Given in km.yrs
Observed	17	1	18	Observed number of External Interference incidents
Assumed	17	1	18	Assumed number of External Interference incidents

Probability of assumed distribution:-

observed numbers			
	gas	Crude	total
actual	17	1	18
assumed from population	17	1	18
total	34	2	36
expected numbers			
	Gas	ethylene	total
actual	17	1	18
assumed from population	17	1	18
total	34	2	36

Fishers Exact Test Calculation

p of table:- 0.51428

Probability of extreme table:-

observed numbers

	gas	Crude	total
actual	18	0	18
assumed from population	16	2	18
total	34	2	36

Fishers Exact Test Calculation

p of table:- 0.24285

The significance level is equal to the sum of the probability of the observed table and the probabilities of less probable tables. There are two other tables giving the same row and column totals as the observed table. They are variations of the extreme table shown above and have the same probability.

The overall significance level is therefore equal to 0.51428+0.24285+0.24285=1

This value, 1, is above 0.05 and therefore indicates that the occurrence of the observed table was by chance rather than any real effect.

The exact test results indicate the spiked crude pipeline data is not significantly different to the gas pipeline data. It is therefore concluded that the failure rate due to external interference determined for UK spiked crude pipelines can be determined using UKOPA data.

Ground Movement Fault Data

The ground movement fault data for spiked crude pipelines comprising diameters 914mm was compared to the equivalent data for the natural gas pipeline population below:-

	Gas	**Spiked Crude**	**Total**	
Population size	97555.18	6679.22	104234	Given in km.yrs
Observed	2	0	2	Observed number of External Interference incidents

As shown above, the sample sizes are small, and it is not considered relevant to carry out any statistical analysis on this dataset.

Appendix 3 UKOPA Fault and Failure Data

A3.1 Fault Data

Year	Number of Faults		
	External Interference	Materials and Construction	External Corrosion
1962	0	2	0
1963	0	1	0
1964	0	1	0
1965	0	0	0
1966	0	0	0
1967	2	0	0
1968	6	0	0
1969	10	0	0
1970	36	4	6
1971	69	0	14
1972	53	0	5
1973	57	0	4
1974	13	0	9
1975	33	0	5
1976	40	0	4
1977	46	5	17
1978	49	85	18
1979	51	16	12
1980	39	12	96
1981	40	37	22
1982	32	82	48
1983	38	53	102
1984	68	95	103
1985	49	34	107
1986	41	17	71
1987	28	34	49
1988	44	18	446
1989	45	26	96
1990	58	17	37
1991	24	24	17
1992	33	12	47
1993	21	12	20
1994	11	13	57
1995	21	2	27
1996	4	10	33
1997	12	7	16
1998	11	5	7
1999	2	2	10
2000	6	3	59
2001	25	3	27
2002	5	8	49
2003	9	0	16
2004	16	2	8

A3.2 UKOPA Failure Data - External Corrosion and Material and Construction Data by Year of Commissioning

Year of Commissioning	Exposure (km.Year)	Number of External Corrosion Failures	Number of Material & Construction Failures	External Corrosion Failure Frequency	Material & Construction Failure Frequency
1952	44.7	0	0	0.000	0.000
1955	156.69	0	0	0.000	0.000
1956	8172.33	4	5	0.489	0.612
1957	11515.46	8	11	0.695	0.955
1958	11379.27	1	0	0.088	0.000
1959	7579.2	0	0	0.000	0.000
1960	9997.82	2	1	0.200	0.100
1961	5370.7	0	0	0.000	0.000
1962	5287.58	0	5	0.000	0.946
1963	21055.06	1	5	0.047	0.237
1964	46029.97	6	4	0.130	0.087
1965	22194.48	2	3	0.090	0.135
1966	33085.91	0	5	0.000	0.151
1967	44054.34	0	2	0.000	0.045
1968	59613.72	2	5	0.034	0.084
1969	67615.43	1	1	0.015	0.015
1970	55796.42	1	1	0.018	0.018
1971	47270.42	1	1	0.021	0.021
1972	10950.27	0	0	0.000	0.000
1973	14462.52	1	0	0.069	0.000
1974	7272.11	0	0	0.000	0.000
1975	16442.39	0	0	0.000	0.000
1976	24885.13	0	0	0.000	0.000
1977	15578.44	0	0	0.000	0.000
1978	24514.89	0	0	0.000	0.000
1979	8003.06	0	0	0.000	0.000

Year of Commissioning	Exposure (km.Year)	Number of External Corrosion Failures	Number of Material & Construction Failures	External Corrosion Failure Frequency	Material & Construction Failure Frequency
1980	8721.36	0	0	0.000	0.000
1981	8053.77	0	0	0.000	0.000
1982	4812.97	0	0	0.000	0.000
1983	3959.84	0	0	0.000	0.000
1984	12075.38	0	0	0.000	0.000
1985	4902.93	0	0	0.000	0.000
1986	2554.79	0	0	0.000	0.000
1987	2715.71	0	0	0.000	0.000
1988	2552.05	0	0	0.000	0.000
1989	2403.11	0	0	0.000	0.000
1990	1752.16	0	0	0.000	0.000
1991	2451.97	0	0	0.000	0.000
1992	8475.45	0	0	0.000	0.000
1993	2823.17	0	0	0.000	0.000
1994	2018.37	0	0	0.000	0.000
1995	264.07	0	0	0.000	0.000
1996	454.80	0	0	0.000	0.000
1997	680.55	0	0	0.000	0.000
1998	1237.74	0	0	0.000	0.000
1999	773.91	0	0	0.000	0.000
2000	753.13	0	0	0.000	0.000
2001	1183.19	0	0	0.000	0.000
2002	495.17	0	0	0.000	0.000
2003	279.57	0	0	0.000	0.000
2004	8.62	0	0	0.000	0.000
TOTAL	**654732.09**	**30**	**49**	**0.046**	**0.075**

A3.3 UKOPA Failure Data - External Corrosion and Material and Construction Data by Wall Thickness

Wall Thickness	Exposure (km.year)	Number of External Corrosion Failures	External Corrosion Failure Frequency	Number of Material & Construction Failures	Material & Construction Failure Frequency
< 5	49536.54	15	0.303	25	0.505
5 - 10	320338.01	16	0.050	19	0.059
10 - 15	242910.22	0	0.000	4	0.016
>= 15	41947.33	0	0.000	1	0.024

Wall Thickness	Exposure (km.year)	Number of External Corrosion Failures	External Corrosion Failure Frequency	Number of Material & Construction Failures	Material & Construction Failure Frequency
< 5	49536.54	15	0.303	25	0.505
5 - 6	21873.51	4	0.183	1	0.046
6 - 7	103341.65	8	0.077	9	0.087
7 - 8	107502.58	2	0.019	5	0.047
8 - 9	10224.96	0	0.000	0	0.000
9 - 10	77395.31	2	0.026	4	0.052
10 - 11	25185.56	0	0.000	2	0.079
11 - 12	71891.93	0	0.000	1	0.014
12 - 13	118095.70	0	0.000	1	0.008
13 - 14	22.51	0	0.000	0	0.000
14 - 15	27714.51	0	0.000	0	0.000
15 - 16	40718.40	0	0.000	1	0.025
>= 16	1228.93	0	0.000	0	0.000
TOTAL	**654732.10**	**31**	**0.047**	**49**	**0.075**