OPTIMIZING MAINTENANCE AND INSPECTION PRACTICES TO MINIMIZE 3RD PARTY DAMAGE PROBABILITY IN LIQUEFIED PETROLEUM GAS PIPELINE (LPG) IN INDIA

A thesis submitted to the
University of Petroleum And Energy Studies

For the Award of
Doctor of Philosophy
in
Chemical Engineering

BY
Saumitra Shankar Gupta

November 2019

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I dedicate this thesis to my family members and colleagues whose belief in me gave me courage to undertake this work

DECLARATION

I declare that the thesis entitled "*Optimising Maintenance and Inspection Practices to Minimize 3rd Party Damage Probability in Liquefied Petroleum Gas Pipeline (LPG) in India*" has been prepared by me under the guidance of Dr Adarsh Kumar Arya and Dr. P Vijay Professors of Department of Chemical Engineering, University of Petroleum and Energy Studies, Dehradun & Dr. Kannan Chandrasekharan, Pipeline & Corrosion Research Department, Indian Oil Corporation Limited, Faridabad. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

(Saumitra Shankar Gupta)
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Date: 20.6.2020

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis **"Optimizing Maintenance and Inspection Practices to Minimize 3rd Party Damage Probability in Liquefied Petroleum Gas Pipeline (LPG) in India"** by Saumitra Shankar Gupta in partial completion of the requirements for award of the degree of Doctor of Philosophy (Engineering) is an original work carried out by him under our joint supervision and guidance.

It is certified that this work has not been submitted anywhere else for the award of any other diploma or degree for this or any other university.

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It is certified that work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University

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ABSTRACT

Global growth in oil consumption from 2005 to 2015 was 1 %, while in India, oil consumption grew by 4.9%. During 2016 India's oil consumption was 21.8% of total global oil consumption, also India was the largest contributor to an increase in world oil consumption. India is the third largest Oil importer in 2016, behind USA and China (since 2017 USA is a net exporter of oil). In US$ terms 17.40% of total global import was accounted for by India. India's oil consumption in 2016 stood at 212.7 million tons, equivalent to an 8.3 percent increase over the previous year.

It is likely that in coming 4 to 5 years, India is going to be the strongest contributor to growth in oil demand. Projections show that the process may be further accelerated by the faster economic growth of India.

The growth in the hydrocarbon sector in India is driven largely by 8-22% increase in demand for petroleum coke, aviation turbine fuel (ATF) and liquefied petroleum gas (LPG). LPG is one of the developing sources of energy in India, primarily in the domestic sector. Production of LPG in India is significantly less than its demand, as such a significant quantity of LPG is imported. In 2016-17, India imported 11.00 million metric tons of LPG, resulting in India passing Japan as the world's second-largest importer of LPG after China. Year on year growth in imports of LPG stood in the range of 22-23% during 2016-17. India plans to increase its use of LPG by March’19 to cover 80% of its households, compared with 72.80% in 2017.

During the year 2016-17 consumption of LPG in India was 21.55 million tons, while that in 2017-18 was close to 24 million ton. PPAC has projected a growth of 11to 13% in the consumption of LPG in the coming years. LPG demand is projected to hit 35,0 million tons by 2031-32. Increased demand is primarily attributable to increased LPG connections in rural areas. Transportation of such large volume of LPG is possible only through cross country pipelines connecting between import terminal and the consumption centres. Pipelines are considered as the safest and energy-efficient transportation mode for bulk hydrocarbon over long distances. Pipeline industry in India is seeing phenomenal growth and more than 10,000km of the pipeline are in various stages of construction. In December 2017, the total length of the cross-country hydrocarbon pipeline in India was 42,644 km, of which approximately 2,690 km were LPG pipelines. Sources, including oil companies in the public sector, indicate that there are approximately 2500 km of LPG pipelines under different stages of construction. Upcoming 2700km long LPG pipeline between Kandla, Gujarat to Gorakhpur, Uttar Pradesh, when completed would be world’s longest LPG pipeline.

A properly built, closely monitored and maintained pipeline is the safest and most economical mode of long-distance transport of bulk hydrocarbon. Every alternative form of bulk LPG transport is not only expensive but also environmentally harmful and from a public safety point of view risky. LPG pipeline transport ensures public safety and minimizes the risk of damage to the environment and contributes to the supply chain quality. However, like all other engineering structures, leakage and rupture do take place in pipelines, prevention of such incidences is a major challenge for all pipeline operators.

One of the primary reasons of failures in pipeline in the developed nations like the USA, UK and Europe etc., is third-party damage, nearly 40-50% of all pipeline failures are caused because of third-party activities like excavations in the vicinity of the pipeline. In the USA, during 2015, 17.1% of all pipeline failures are caused due to third-party activity.

Pipelines, though the safest mode of transportation of bulk hydrocarbon, still there are significant number of pipeline failures even in developed nations like the USA, Canada and Europe. During the period between 1998 and 2017, there were as many as 306 fatalities due to pipeline-related accident in USA [PHMSA, Department of Transportation's Report]. Nearer to the home, during June 2015, gas pipeline rupture led to a huge fire that engulfed 29 lives and property worth millions of rupees were lost in the state of Andhra Pradesh.

Reasons for Pipeline failure

The major reasons for pipeline failures are Corrosion, Construction/ material defects, Third Party Damage, Ground movements like erosion, flood, landslide etc. and other unknown causes like lightning, maintenance error or design error, operational error etc.

Analysis of data for a period of 46 years (1970-2016) for European gas pipeline by EGIG for a length of gas pipeline ranging between 30,000 to 1,50,000km indicates that among the 5 major causes of pipeline failures, Third Party Damage remains the topmost cause. As per CONCAWE Report 2018, among liquid pipeline incidents 2016-17 nearly 38% of all failures were caused due to Third-Party interference. Unfortunately, no such data exist for India, but random data of pipeline failure available with Indian Oil Corporation Ltd. (IOCL) and other PSU oil companies indicate similar patterns of pipeline failures. The literature on pipeline failure (Jhang,2018) indicates that nearly 3/4th of all third-party damage cases are in the urban area, where the failure rates are around 0.66/ 1000km compared to 0.25/1000km in the rural segment. The reasons for a higher rate of failure (due to third party damage) in urban areas can be traced to a relatively higher degree of human activities.

The major volume release (from pipelines) is primarily in the Industrial areas, though the number of releases is more in the rural segment, this is in expected lines as pipeline failures in Industrial areas are dominated by 3rd party damage due to higher human activities, more cases of digging and use of excavators and higher number of pipeline crossing (by other utilities like other pipelines, cables, gas line and water lines etc.). The underlying reason for a higher volume of release in urban areas is that third-party damages usually cause a rupture in the pipeline, while other modes of failure e.g., corrosion, in the vast majority of cases result in leaks (rather than rupture).

The primary reasons for a pipeline failure can be categorized under the following 5 heads

1. Corrosion failure
2. Mechanical failures
3. Third-Party damages
4. Operational failure
5. Natural hazards

An analysis of reason specific pipeline failure data available in CONCAWE Report 6/18, (CONCAWE, 2016) for the period 1971-2016 reveals that third party damage is the topmost cause of pipeline failure even without considering theft/ pilferages. If theft/ pilferage incidents are included the third-party damage becomes close to half of all pipeline failure cause.

All major databases on pipeline failure like PHMSA, USA, European gas Pipeline Operators group (EGIG) also conclude that 3rd party activity is one of the key elements of pipeline risk. Such databases including CONCAWE, also concludes that spillage volume from pipeline failure is highest in case of the third party damaged related pipeline failures. Also, the data indicate that a higher volume of spillage are in the Industrial zone as the rate of failure due to third-party damage is higher in industrial zones where the degree of human activity is more intense.

As no such databases exist for India, pipeline failure rates in China, which in terms of population density and other human activities is nearest to India (than USA or Europe), also indicate that, the top pipeline failure cause in

China in the last 10 years has been Illegal Taps (unauthorized drilling into the pipeline to steal oil). In as much as 50% of pipeline damage in China is due to illegal taps. Illegal tapping from the pipeline is a special kind of third-party activity which is done with malicious intent. Very limited access to databases of Indian liquid pipeline companies also indicate illegal tap is the number one cause of pipeline failure. From the above study, it is clear that the main cause of pipeline failure in both developed and developing economies is harm from third parties.

Third-Party Damage to pipelines can be defined as accidental damage caused by excavation or construction in the vicinity of pipelines. This definition can be challenged by many considering that all third-party damages are not accidental, e.g. oil theft from the pipeline, sabotage and last but not the least damage caused due to negligence or casualness while digging in the vicinity to the pipeline. However, in the context of this work third-party damage is considered as the ones that are caused accidentally during an excavation in the vicinity of the pipeline or construction in the vicinity or across the pipeline. Third-Party damage to a pipeline is generally caused by organization/ individuals who are not aware of the presence of a pipeline at the spot or in close vicinity of their activities. The reasons for third-party damages are many, and occurrence random, therefore prevention is a challenge. But the primary reason is human activities which include various industrial activities and agricultural activities as well.

In India, there is a sharp increase in economic activities and large-scale urbanization, this has resulted into human population coming even closer to the pipeline, in fact, many pipelines are cutting across newly developed urban areas. It is quite likely that in line with pipeline failure trend in other developed nations, third party activities are likely to be the major cause of pipeline failure in India as well for a long time to come. LPG pipelines, in general, are touching urban areas due to the need for delivering bulk LPG to the bottling plants (for domestic use) that are in the vicinity of the cities. As more and more LPG pipelines are being built coupled with rapid urbanization and industrialization, the probability of third-party damage to these pipelines is also increasing. To counter this threat, owners and designers of pipeline need to incorporate measures that will reduce the possibility to minimum level, at the same time pipeline owner's maintenance effort should be such that focus remains on prevention of third-party damage and ensure that barriers created against third party damage at the design stage remain effective and functional at all times.

To keep the possibility of third-party damage to a minimum, owner of an LPG pipeline is required to consider certain measures at the design stage itself (as specified in the design standard for LPG pipeline viz. ASME B 31.4, OISD-214, PNGRB T4S etc.).

These measures include

1. Increased depth of burial (ground cover) for LPG pipeline
2. Using higher pipe wall thickness (to reduce the impact of any ignorant hit by excavator)
3. Avoiding populated areas along the pipeline route as far as possible.
4. Clearly marking the pipeline with signpost and boundary pillars.
5. Using intrusion detection systems

To ensure that the above measures functions in the desired manner the pipeline owner implements in its M&I scheme certain scheduled inspection surveys and activities at a fixed interval of time like daily, monthly, yearly etc. Surveys include

1. Ground Patrolling on foot, of the pipeline right of way,
2. Aerial Patrolling, Depth of cover survey,
3. Right of Way Inspection & Maintenance activities,
4. Inline Inspection through intelligent pigs and caliper pigs

5. Other special surveys like depth of cover measurement, pipeline coating surveys etc.

The M&I schemes implemented by Indian pipeline operators are common for the entire pipeline, that is quantum of threat perception is considered equal over the entire pipeline, this assumption results into development of M&I programme that is not fully aligned with the threats. The degree of such threats vary from pipeline stretch to stretch. As a results expenditure towards M&I activities remain unoptimized. Such type of M&I programme is also likely to remain poor in terms of effectiveness, besides, it remains at variance with regulatory standard OISD -214 which suggest that the M&I programme should be developed after segment-wise analysis of pipeline threats, rather than a common one applicable over the entire pipeline. In other words, the M&I schemes are not optimized to take care of the specific degree of threat that may arise at specific stretches of the pipeline, this may lead to enhanced possibility of pipeline damage due to third-party activity, occurrence of which is already random. For example, in a certain stretch of the pipeline, the possibility of a reduction in designed soil cover is higher than in certain other stretches, however, the frequency of depth of cover survey remains same for the entire pipeline, as a result, the possibility of pipeline damage from digging goes up. The requirement can be met by increasing the frequency of depth of cover survey in such stretches compared to other stretches.

> This research attempts to develop an M&I scheme for Indian LPG pipeline that would be optimized both in terms of cost of M&I and frequency of M&I survey so that possibility of pipeline failure from third-party damage especially in LPG pipelines are kept at the least.

Above objective is specified in the following manner.

Research Objectives

I. To develop a model that calculates the weight of factors contributing to failure of LPG pipeline in India from third-party interference.

II. To develop a Maintenance and Inspection plan for LPG pipelines in India in order to minimize the probability of failure from third party damage (as determined from the model developed in S.No.I above) and optimize M&I expenditure

Description of Research Methodology

1. An existing 135km long LPG pipelines of Indian Oil Corporation Ltd.(IOCL) is divided into multiple segments based upon the location of mainline sectionalizing valves.
2. Once the segments are made, 4 reputed and experienced experts are nominated out of a bunch of 23 personnel have wide-ranging skills and expertise from the different field of Pipeline Engineering viz. Pipeline Design, Pipeline Operation, Pipeline Maintenance and Pipeline Construction.

   The experts are evaluated on the following criteria

   i) Source of Knowledge (based on academic Qualification)
   ii) Source of Experience (based on length of service)
   iii) Source of Information (based on the type of service)
   iv) Source of Bias (based on their past and present occupation)

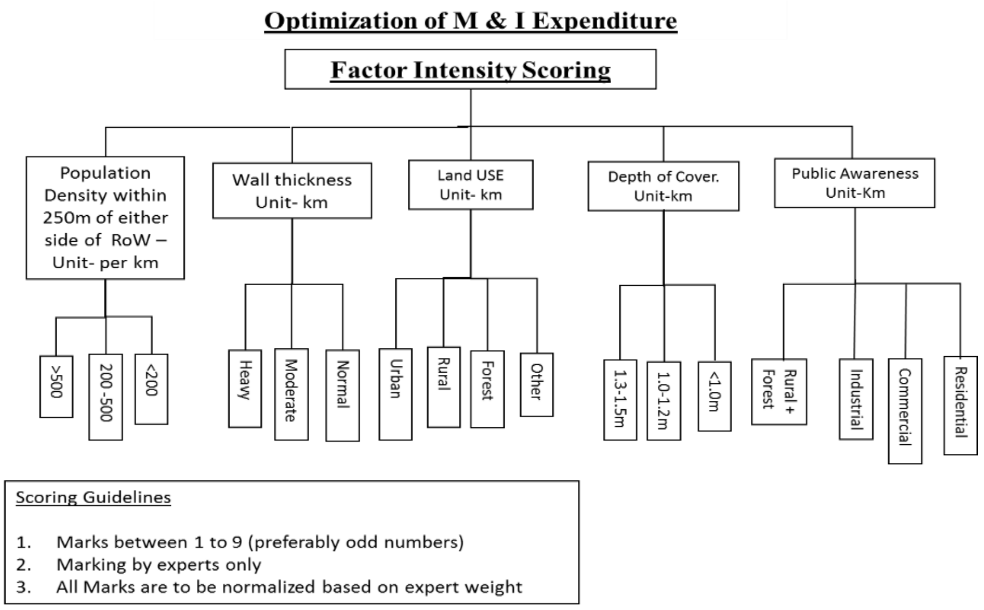
   On the above-listed criteria, all the candidate experts are evaluated and based on the scores on the above 4 criteria Relative Expert Weight (RET) is calculated. Following the above process out of the total 23 experts, 4 top experts are selected based on their RET.
3. These four experts are informed of the factors [i) to v) below] that play a key role in the possibility of damage to a pipeline by third parties. (data pertaining to the 135km long LPG pipeline under study is provided)

i) Population Density (PD)

ii) Depth of Cover (DC)
iii) Wall thickness (WT)
iv) Land use (LU)
v) Awareness Level (AL)

Each of these 5 factors mentioned above is further divided into sub-factors, and pipeline length under each sub-factor in a particular valve to valve section (hereinafter referred as segments) is provided (data arranged from IOCL). The sub-factors are formed in the manner indicated in the scheme overleaf.

All 4 experts are asked to provide a score between 0 to 9 (higher the possibility of third-party damage lower is the score) against each sub-factor for a particular segment, Marks given by the experts are normalized by multiplying with their respective normalized weight (Relative Expert Weight, RET). The stretches of pipeline in km, falling under each sub-factor category shall be multiplied by the score given by each expert.



Scoring Guidelines

1. Marks between 1 to 9 (preferably odd numbers)
2. Marking by experts only
3. All Marks are to be normalized based on expert weight

Scheme of Factors and Sub-factors

Segment-wise and expert wise scores are used to rank each of the 5 factors with DC being 1 and rest of the factors accordingly, as more than 1 or less than 1 based upon their expert score for a segment.Such numbers are used to compare the relative weight of each of the sub-factors for a specific segment of total 6 segments and for a specific expert ranking. For determination of relative weight Principles of Analytical Hierarchy Process (AHP) was used. Average weight (from pairwise comparison) of each factor for a particular segment are determined/ calculated to obtain combined relative weight, this exercise is repeated for all 6 segments.

4. Next step in the process is to compare the weight of each factor determined above, with the weight considered under current M&I scheme, which is uniform for all factors and can be assumed as 1/5 =0.20 (there are total 5 factors). This 0.2 is referred to as **nw** of a factor. The difference between calculated factor weight, referred as **cw** (of all 5 factors), for all segments are calculated and percentage variation worked out, the variation between **nw** and **cw** is considered as the extent of un-optimization referred as **Un,** [Un=nw-cw]. The per cent variation, that is %Un=(nw-cw/nw) x 100, indicate how much emphasis should be given to each of the factors in a particular segment vis-a-vis the emphasis given under existing M&I scheme in quantitative terms.

Variation (%Un) determined above is used to calculate the M&I expenditure incurred under the current M&I scheme vis-à-vis what should be incurred (optimized M&I expenditure). This calculation is done for all the segments and for all the factors to find out segment-wise M&I optimized expense for each of the 5 factors and summarized for the entire length of the pipeline to get overall optimized M&I expenditure.

The percentage variation (%Un) is also used to develop the M&I scheme by adjusting the number of days and frequency of inspection to be followed to generate optimized M&I scheme. Thus, both cost and M&I frequency shall be optimized.

Conclusion

Through above research, it could be established that it is possible to optimize M&I expenditure up to 8% to 10% (at present cost levels for a 135km long pipeline, likely to be higher for longer pipelines). It was also established that the existing M&I programme needs adjustment to align with the threats emerging from factors responsible for third party pipeline damage.

The current research is only to optimized M&I expenses and frequency to achieve/retain the possibility of third-party damage to the level envisaged at the design stage, however with changing scenario like increase in population, more areas coming under commercial and residential zones, increase in awareness levels and likely decrease in the pipe wall thickness due to corrosion and erosion, changes in provisions of standards and codes, govt. regulations etc. the outcome of the research may not remain valid for a long period (though the methodology remains valid as long as pipeline design and M&I practices remain valid). Therefore, fresh calculations shall have to be done as soon as basic data changes.

More work using the developed model can also be done for optimization of M&I practices for minimization of corrosion failure and other modes of failures in LPG and other pipelines.

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Saumitra Shankar Gupta
Noida, November, 2019

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LIST OF ABBREVIATIONS

AHP: Analytical Hierarchy Process

AHP-GP: Analytical Hierarchy Process & Goal Programming

AL: Awareness Level

ANFIS: Adaptive Neuro-Fuzzy Inference System

ANN: Artifical Neural Network

ANP: Artifical Neural Programming

ANSI: American National Standards Institute

AP:Aerial Patrolling

API: American Petroleum Institute

ASME: The American Society of Mechanical Engineers

ATF: Aviation Turbine Fuel

BBN: Bayseian Belief Network

BG: British gas

BLEVE: Boiling Liquid Expanding Vapor Explosion

BN: Bayseian Network

BP: British Petroleum

BPCL: Bharat Petroleum Corporation Limited

BS: Bristish Standard

CBA: Cost Benefit Analysis

CBM: Condition Based Maintenance

CEPA: Canadian Energy Pipeline Association

CGS: Centimetre–Gram–Second system of units

CI: Community Interaction

CM: Corrective Maintenance

CONCAWE: Conservation of Clean Air and Water in Europe

CR: Consistency Ratio

CW: Calclated Weight

DC: Depth of Cover

DCS: Depth of Cover Survey

DFBE: Double Fusion Bonded Epoxy

DOT: Department of Transportation, USA

EGIG: European Gas Pipeline Incident data Group

EM: Electro Magnetic

EN: European Standard

EPA: Enviornmental Protection Agency, USA

ERQ: Expert Response Questionnaire

ERW: Electric Resistance Welding

ET: Event Tree

GAIL: Gas Authority of India Limited

GIS: Geographic Information System

GOI: Government of India

GP: Ground Patrol

GPS: Global Positioning System

GS: Geometr y Survey

HPCL: Hindustan Petroleum Corporation Limited

HSE: Health Safety & Enviornment

HSLA: High Strength Low Alloy (Steel)

ID: Intrusion Detection

IGEM: Institiion of Gas Engineers & Managers

ILI: In-line Inspection

IOCL: Indian Oil Corporation Limited

LPG: Liquified Petroleum Gas

L-SAW Longitudinal Submerged Arc Welding

LU: Land Use

M&I: Maintenance and Inspection

MAOP: Maximum Allowable Operating Pressure

MCDM: Multi-criteria Decision Making

MC-DSS: Multi Criteria Decision Support System

MCPIPIN: Monte Carlo Pipeline Integrity

MCS: Monte Carlo Simulation

MOP: Maximum Operating Pressure

MOP&NG: Ministry of Petroleum & Natural Gas

MT: Metric Tonnes

NEB: National Energy Board

NTSB: National Transportation Safety Board

NW: Percieved Weight

OFC: Optical Fibre Cable

OI: Optimization Index

OISD: Oil Industry Safety Directorate

OMA: Operational Model Analysis

OPEC: Oil & Petroleum Exporting Countries

PD: Population Density

PESO: Petroleum and Explosive Safety Organization, India

PG: Post Graduate

PHA: Product Hazard Analysis

PHMSA: Pipeline and Hazardous Materials Safety Administration

PIPIN: Pipeline Integrity Software

PM: Preventive Maintenance

PMP: Petroleum & Mineral Pipeline Act, 1962 & amednments, India

PNGRB: Petroleum & Natural Gas Regulatory Board, India

POI: Probability of Ignition

PPAC: Petroleum Planning & Analysis Cell, India

PROMETHEE: Preference ranking organization method for enrichment evaluation

PSU: Public Sector Undertaking

PT: Personal tracker

QRA: Quantitative Risk Assessment

RA: Regression Analysis

RET: Relative Expert Weight

REW: Relative Expert Weight

RI: Random Index

ROW: Right of Way

RRS: Relative Risk Score

SAW: Submerged Arc Welding

SB: Source of Bias

SE: Source of Experience

SES: Synthesized Expert Score

SI : International System of Units

SI: Source of Information

SK: Source of Knowledge

SMYS: Specified Minimum Yield Strength

TPD: Third Party Damage

UK: United Kingdom

UKOPA: United Kingdom Onshore Pipeline Operators' Association

USA : United States of America

VCE: Vapour Cloud Explosion

WT: Wall Thickness

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CHAPTER 1: INTRODUCTION

1.1 RESEARCH MOTIVATION AND PROBLEM STATEMENT

The oil and gas industry is a wide domain that continues to grow, especially in developing nations such as India. Hydrocarbons will remain the key sources of energy and meet more than 90% of future energy demand. Global oil demand is expected to rise by around 1.6 percent annually. World Oil Outlook (2016) forecasts a rise of 6.20mb/d (million barrels per day) from 93.00 mb/d in 2015 to 99.20 mb/d in 2021 for medium-term oil demand.

BP World Energy Statistical Review (2016) indicates that India is the largest contributor to higher oil consumption in 2016, accounting for 21.80% of total consumption. India is also third largest importer of Oil after China and the United States in 2016. Assessment Report: Petroleum Planning & Analysis Cell (PPAC), 2016 indicates that India's import share amounts to 17.40 percent of total world imports in US$ terms.In 2016, India's oil consumption stood at 212.7 million tons, a growth of 8.3% over the previous year, Ready Reckoner, Indian Oil & Gas data (2016-17)

Global growth in oil consumption between 2005 and 2015 is 1%, against which India's oil consumption growth was 4.90%. It is likely that in the coming 4 to 5 years, India would be one of the most significant contributors of incremental oil demand growth; a robust economic growth may further accelerate the process, Assessment Report: Petroleum Planning & Analysis Cell (PPAC), 2016.

Growth in India's hydrocarbon sector is driven primarily by demand for liquefied petroleum gas (LPG), aviation turbine fuel (ATF), and petroleum coke, Assessment Report: Petroleum Planning & Analysis Cell (2016).

1.2 BACKGROUND

The safe and reliable transportation to the consumption centers of large volume of hydrocarbon fuel is a major challenge. Cross-country pipelines are India's fastest and most energy-efficient mode of bulk hydrocarbon transportation over long distances. The main commodities transported by pipelines in India are crude oil, petroleum products and natural gas. As of November 2017, India's total cross-country hydrocarbon pipeline was little over 42,644 km, with data from Ready Reckoner, Indian Oil & Gas (2016-17), about 2690 km of which are LPG pipelines. Statistics from various oil companies in the public sector suggest that approximately 13,800 km of gas pipeline, almost 6,800 km of liquid pipelines, and approximately 2,500 km of LPG pipelines are under different stages of development. The Petroleum and Natural Gas Regulatory Board (PNGRB) recently announced a 2700 km long LPG pipeline between Kandla and Gorakhpur.

If well-constructed, carefully monitored, and properly maintained, a pipeline can be the safest, most environmentally friendly, and most energy efficient mode for long-distance transport of hydrocarbons. Like other sectors though, pipelines can also be a source of significant health and environmental risks, if its content gets released due to leaks or ruptures.

1.3 LPG AND ITS ROLE IN ENERGY BASKET OF INDIA

Liquefied Petroleum Gas (LPG) is one of India's leading and emerging energy sources. India is not makin adequate LPG to meet its demand. A significant portion of LPG is therefore, imported, Fig.1 (livemint, 2017) . Indicates the growth rate of India's LPG import over the past four years. In 2016-17 India, as per Ready Reckoner, Indian Oil & Gas information (2016-17), imported 11 MMT of LPG,consequently, India surpassed Japan as the second largest importer of LPG in the world. India's imports of LPG, mostly used as a cooking fuel, soared by 23% in the financial year (2016-17). India aims to increase the use of LPG by March 2019 to cover 80% of its households, up from 72.8% as of April 1, 2017.

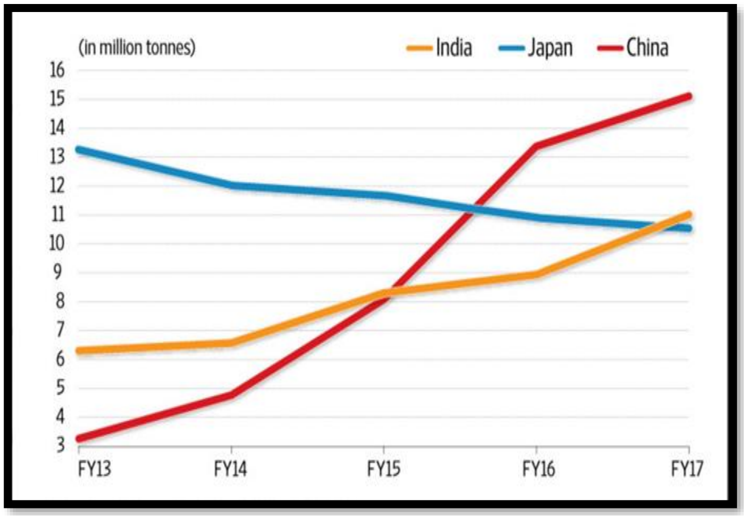


Fig 1-1: Growth of LPG import in India

In 2016-17 (up to March 31), India consumed 21.55 million tons of LPG. According to a PPAC estimate, India's LPG consumption is expected to increase by 9.7% in the financial year from 1 April 2017 to 23.7 million tons. LPG demand is likely to reach 35 million tons by 2031-32 due to increased penetration of cooking gas connections in rural areas. Most of this volume of LPG must be shipped by pipelines.

1.4 PIPELINE SYSTEM

A pipeline is a tubular structure that is used to transport hydrocarbon energy over short and long distances. Modern-day pipelines are built with high strength low alloy (HSLA) steel pipes. A pipeline is made by joining pipes through welding. Once made, it consists of a long uninterrupted chain of pipes from the starting point to the end. The length of a pipeline could be anything from 1km to 10, 000km, and more. The only limitation is after a certain distance, either a pumping station or a compressor station must be built to push liquid or gas up to the next pumping/ compressor station. The pressure generated by pumps or compressors should be such that an adequate quantity of oil or gas reaches the other end. In a long pipeline, there are several pump/ compressor stations.

As pipelines need to transport oil or gas at a pressure (to achieve desired flow), naturally, the pipes used should have the ability to withstand the pressure. The operating pressure of a pipeline could be much higher than 100kg/cm^2. At the design stage itself, the exact amount of pressure is calculated; pumping / compression equipment are therefore, stationed after a certain distance based on the nature of the terrain through which the pipeline passes. The main component of a pipeline is a steel tube, which is typically divided into two common types based on its manufacturing techniques, namely Electrical Resistance Welded and Submerged arc welded (SAW) type. SAW pipes are further categorized into two varieties, viz spiral seam submerged arc welded type (S-SAW) and longitudinal seam submerged arc welded (L-SAW).

High-pressure pipelines transporting liquid or gaseous hydrocarbons are hazardous, they need to be designed with the utmost care and as per the guidelines specified in relevant Technical Standards so that during their service life safety is not compromised. In India, the design engineers generally use ASME B31.4 / ASME B31.8 standards to design liquid/ gas pipelines. Oil Industry Safety Directorate (OISD) was established in 1986 to ensure the safety of pipelines and other oil installations in India. OISD came out with its design standard OISD-141 in April 1990, it is now mandatory in India to design a pipeline conforming to OISD-141 standard. Petroleum and Natural Gas Regualtory Board (PNGRB), a regulatory body constituted by an act of the parliament in 2006, has come out with a standard T4S, which now governs pipeline design, operation, and maintenance in India. Provisions of both OISD -141 and T4S are not far from those specified in ASME B 31.4 / ASME B31.8.

A pipe is generally specified in terms of its material grade, pipe wall thickness, diameter. For example, a pipe (used in making a pipeline) can be specified as API 5L Grade X-46, Wall thickness =0.25 inch and diameter = 12 inches. This means that the pipe has a specified minimum yield strength of 46,000 psi, 0.25-inch wall thickness and 12.75-inch diameter. As per Barlow's formulae, such a pipeline shall have a maximum allowable operating pressure of 92.33kg/cm^2, if we use a safety factor of 0.72 on the SMYS of 46,000 psi.

The formula for arriving at the operating pressure is

$$S = PDF/2t$$

Where S = Specified Minimum Yield Stress (SMYS)

P= Maximum Allowable Operating pressure (to be calculated)

D = Nominal diameter of the pipe and

F = Safety factor, generally taken as 0.72

t= Nominal pipe wall thickness

All input values are generally given in the CGS system (as a general practice in India, but not as a rule), and MAOP is determined in psi, which can be converted to a more popular SI unit of measurement to kg/cm^2 by diving the psi value with 14.22. (the subject is further discussed in chapter 3)

Pipelines are placed at a minimum depth of 1.2 m below the ground in normal terrain, OISD / T4S/ ASME standards also specify 1.2 m for normal terrain and higher depth of burial up to 1.5 m at specified locations like road crossing, rivers, canals, etc.

Underground pipelines generally face two types of threat i) time-dependent and (ii) time-independent. The time-dependent risk are those whose frequency increases with time, such as corrosion, errosion,fatigue etc., time-independent threat, on the other hand, those that do not depend on time, such as damage by third parties, operational failure, Acts of God etc.

It has been observed from pipeline failure data that primary reasons for failures are corrosion and third-party damage. These two reasons constitute more than 70% of all pipeline failures. Where corrosion failures have some scientific reasons, third-party damage has a significant human factor attached to it; third-party damage is random and, therefore, difficult to predict and prevent.

To prevent corrosion, specific measures such as external coating and cathodic protection are provided to the pipelines to keep under control, corrosion from the soil side. Corrosion from the pipe's inner side is triggered by the material passed through it, usually water/moisture present in oil / gas. To prevent inner side corrosion (generally called internal corrosion) measures like pigging and dosing of corrosion inhibitor is adopted by pipeline operators.

Various measures are also taken by the pipeline operators to prevent damage by third parties (as the term is used in this document, refers to any accidental damage done to the pipe as a result of activities of personnel not associated with the pipeline), such as patrolling the pipeline Right of Way (ROW) to prevent unauthorized diggings along the pipeline. The pipeline route, referred as Right of Way (ROW) is marked with appropriate signposts, and warning boards to alert the nearby community to prevent illegal activity in the ROW.

However, even with such measures pipelines do fail. A Pipeline failure can lead to the release of highly inflammable hydrocarbons content that can cause unimaginable destruction of life and property and severe damage to the environment.

1.4.1 PIPELINE TRANSPORTATION OF LPG

Compared to road of rail transportation, transportation of the LPG through pipelines increase public safety and reduces possibility of environmental harm as compared to other modes pipelines are safer. Any alternative method of transporting bulk LPG from the point of view of public safety is not only uneconomical but also environmentally harmful. Pipelines, however, are also susceptible to leakage and breakage, and therefore the preservation of the pipeline integrity is an essential task for organizations owning these pipelines.

In a pipeline, LPG is transported at a pressure much higher than the atmospheric pressure. Incidentally, the boiling point of LPG increases exponentially with pressure. For all practical purposes an LPG pipeline is modelled as a liquid pipeline as at a pressure beyond 8kg/cm^2 LPG turns into liquid and pipeline transportation of LPG is generally at a much higher pressure (in the range of 15 to 80 kg/cm^2 in Indian LPG pipelines). However, during an accidental release, at atmospheric pressure the liquid LPG is transformed into a gas having an expansion ration of 1:260.

Main constituents of LPG is Propane(C_3H_8) and Butane(C_4H_{10}) in the ratio of 40:60.The density of Propane & Butane is 1.899 and 2.544 kg / m3 (at 15 degrees C) respectively, whereas the air density at the same temperature is 1.225 kg / m3. Therefore, LPG remains on the earth's surface when it is released into the atmosphere (closer to the sources of ignition compared to natural gas), while natural gas (CH_4) being lighter than air escapes into the atmosphere. Therefore, an LPG pipeline failure is considered many time more risky than a failure of oil or natural gas pipeline.

1.5 RISKS IN PIPELINE OPERATION

Risk is the likelihood of an unwanted public or environmental impact due to some occurring event. As far as hydrocarbon pipelines are concerned, after an accidental release of the inventory, there is a chance of fire and explosion causing fatality or environmental damage or both.

The risk associated with pipelines depends on various factors, such as the type of commodity being transported, operating pressure of the pipeline, diameter of the pipeline, flow rate etc., Also ground profile of the pipeline right of way, population density along the pipeline, the concentration of flora and fauna, presence of watercourses, etc. contributes to the degree of risk.

Table No 1.1 is comparison of safety of different modes of bulk energy transportation wiht pipelines, **Hopkins (2005)**

Table 1.1: Comparision of Mode of Energy Transportation

Transportion mode	Factor - death	Factor - fire/explosion	Factor - injury
Road truck	87.30	34.70	2.30
Tanker ship	4.00	1.20	3.10
Rail	2.70	8.60	0.10
Pipeline	1.00	1.00	1.00
Barge	0.20	4.00	0.10

The risks associated with liquid hydrocarbon pipelines depends mainly on the commodity and the characteristics of the surrounding area. Upon the release from a pressurized pipeline, LPG can cause significant damage in the vicinity due to explosion and fire. Comapred to other liquid hydrocarbon intensity of damage caused by LPG explosion is much higher but in terms of long terms damage other liquid hydrocarbons are more severe for example crude oil leakage from pipeline can polluted ground water for a long time, which is not the case with LPG.

Additionally, in India, about 25% of the total 45,000km of the pipeline as per the published database of MOP&NG 2017, is more than 25 years old, this aging infrastructure needs extra care to prevent any release due to leakage or rupture of the pipeline.

Table 1.2: Pipeline Incidents in USA for 2015

S.No.	Cause of Failure	% of failure
1	Corrosion	18.2
2	3rd Party Damage	17.1
3	Operational Error	8.3
4	Material / construction failure	44.1
5	Natural causes	6.7

Source: PHSMA, all reported incident by cause 2015

Table 1.3: Canadian Pipeline Incident Data

Parameters	2018	2017	2013-2017 average
Number of occurrences	9	11	11
Number of occurrences with product release	6	7	7
Number of serious injuries	0	0	0
Number of fatalities	0	0	0

Source: NTSB, Canada

From the data listing in Table 1.3, it is quite apparent that pipelines though generally safe can cause severe damage to life and property if its content is released. Nearer to the home in Andhra Pradesh, India, on 27th June 2015, a gas pipeline rupture led to a massive fire, 29 lives were lost, and property worth millions of rupees [source: PNGRB, OISD report on GAIL Pipeline Failure] were destroyed.

Table 1.4: Serious Pipeline Incident, USA, 1998-2017

Year	Number	Fatalities	Injuries
1998	70	21	81
1999	66	22	108
2000	62	38	81
2001	40	7	61
2002	36	12	49
2003	61	12	71
2004	44	23	56
2005	38	16	46
2006	32	19	34
2007	42	15	46
2008	36	8	54
2009	46	13	62
2010	34	19	103
2011	31	11	50
2012	28	10	54
2013	24	8	42
2014	27	19	94
2015	26	9	48
2016	38	16	86
2017	25	8	33
Grand Total	**806**	**306**	**1,259**

Source: PHSMA, all reported incident by cause 2015

1.6 PIPELINE FAILURE

Corrosion, 3rd party damage, and construction / material flaws are the main cause of pipeline failure. Ground movements like erosion, flood, landslide, etc. and other unknown causes like lightning, maintenance error or design error, operational error, etc. EGIG, (2018), Concawe (2018), can also results into pipeline failure.

Analysis of data for 46 years (1970-12016) has been carried out for the European gas pipeline by EGIG for a length of gas pipeline ranging between 30,000 and 1,50,000km. The findings of the analysis by various agencies are presented in Table 1.5 and Table 1.6

Table 1.5: Cause -wise distribution of pipeline incident, Horalek (2004)

S. No.	Incident Cause	1970-2001 (%)
1	External Interferences	50
2	Construction Defect/ material failures	17
3	Corrosion	15
4	Earth Movement	7
5	Hot tap related errors	5
6	Others	6

Table 1.6: Primary failure frequencies per cause, CONCAWE, (2018)

Cause	Primary Failure Frequency per 1,000km-yr			
	1970-2016	1997-2016	2007-2016	2012-2016
External Interference	0.144	0.064	0.043	0.032
Corrosion	0.052	0.034	0.037	0.027
Construction defect/Material defect	0.051	0.022	0.027	0.021
Ground Movement	0.026	0.023	0.022	0.031
Hot tap made by error	0.014	0.006	0.006	0.003

Note: No such data exists for Indian Pipeline

From the table 1.6, it is apparent that over the last 46 years, at least in Europe, external interference (referred in Indian Pipeline Industry as third-party interference) has been the highest contributors to pipeline failures (it is presumed that damage due to third party interference, not leading to failure, would also be proportionately higher). Another interesting observation from Table 1.6 is that failure rates of the pipeline due to third party interference has been consistently going up every 5 years. The probable reason for this appears to be a higher human activity like industrial activities, digging, laying parallel pipelines or cables, reducing the depth of cover due to erosion, etc. near to pipeline ROW.

Conservation of Clean Air and Water in Europe (CONCAWE) has a data bank on the liquid pipeline for 46 years 1972-2016. The analysis of this database also reveals interesting facts about reasons for pipeline failure, location of pipeline failure, and their frequency.

1.6.1 PIPELINE FAILURE VERSUS INCIDENT LOCATION

As far as locations of incidents are concerned COCAWE report on liquid pipelines of Europe indicate the location wise distribution pattern of pipeline leaks, indicated in Table 1.7 (**CONCAWE, (2018)**

Table 1.7: Pipeline Failure Locations

S.NO	Area/Locality	Data from CONCAWE (%)
1	Rural	77
2	Industrial	17
3	Residential	5
4	Commercial	1

The segments 2, 3, and 4, namely Industrial, Residential, and Commercial areas, can be considered as Urban areas as per British Standard, BS 8010. It is also important to note that the majority of the accidents are in Rural areas because the significant percentage of the length of the pipeline is in the Rural areas. It was, however, could not be ascertained the percentage of the pipeline in Rural and Urban areas separately. Unfortunately, no such data exist for India, but random data of pipeline failure available with IOCL and other oil companies indicate a similar pattern of the failure as far as location is concerned.

Frequencies of pipeline failures and the localities/ area [refer Table 1.7] failure is indicated in the Table-1.8

Table 1.8: Failure Frequencies per 1000km per geographical areas, Hopkins (2005)

S. No	Locality	Frequency of failure/1000 km
1	Urban	0.66
2	Rural	0.25

The reasons for higher frequencies of failure in the Urban areas is naturally due to a higher degree of human activities. The failure causes given in Table 1.5 makes it further clear. CONCAWE data from 1971 till 2016, CONCAWE (2018) also indicate a similar trend of pipeline failures

Table 1.9: Location wise oil spill incident 1971 to 2016, CONCAWE, (2018)

Locality Type	Underground Pipeline		
	Number	Crude/ Product	%
Residential	17	3/14	4%
Rural	290	64/226	75%
Industrial	83	22/61	21%

Rural includes low-density residential, agricultural, forest hills, barren, and water body. Industrial include industrial and commercial areas.

Table 1.10: Volume of product release by location, Hopkins

S.No.	Release volume (KL)	% of Total Release		
		Residential	Industrial	Rural
1	➢ = 50	2	13	38
2	a) 100	-	8	26
3	b) 500	-	7	1
4	c) 1000	-	5	-

From the above table 1.10, it is apparent that major volume release is primarily in the Industrial areas, though the number of releases is more in the Rural segment. This data is in expected lines as pipeline failures in Industrial areas are dominated by third-party damage due to higher human activities and a higher degree of digging and use of excavators, higher number of pipeline crossing (by other utilizes like other pipelines, cables, gas line, and water lines, etc.).Generally, a release in case of third-party damage is in the form of rupture, which results more content to come out of the pipeline. Compared to this corrosion failrues are mostly in the form of leaks and quantum of release is genrallary much smaller than a rupture (this does not mean ruptures do not occur due to corrosion, they do occur but chances are much less when compared with third party damage as a cause of pipeline failure).

1.7 REASONS FOR PIPELINE FAILURE

considered by CONCAWE (2018) is categorized under following 5 heads

1. Corrosion failure
2. Mechanical failures
3. Third-Party damages
4. Operational failures
5. Natural hazards

Reason specific analysis of failure data reported in CONCAWE (2018) report on the performance of European cross-country oil pipelines 1997-2016 data on pipeline failure, further sub-divides data on pipeline failure from third party damage into sub- categories as indicated in the Table 1.11 below:

Table 1.11: Reason Wise Pipeline Failure (1971-2016)

S.No.	Reasons for Failure		No. of Failure	% of Failure
1	Mechanical		135	18
2	Operational		35	5
3	Corrosion		141	19
4	Natural Hazards		15	2
5	Third Party	Excluding theft	168	23
		Theft	247	33
		Including theft	415	56
	Total		741	-

From Table 1.11 above, it is apparent that 3rd Party damage has been the leading cause of pipeline failure even when theft/ pilferages are not considered. If theft/ pilferage incidents are considered, the third-party damage becomes close to half of all pipeline failure cause.

Similar data as given in Table 1.12 for the period 1971-1996 also indicates the similar trend of pipeline failures, CONCAWE (2018)

Table 1.12: Reason Wise Pipeline Failures (1971-1996)

S.No.	Reasons for failure	% of Failure
1	Mechanical	14
2	Operational	2
3	Corrosion	16
4	Natural Hazard	4
5	Third-Party Activities	64

Thus, all the major databases on pipeline failure like PHMSA, USA, EGIG, CONCAWE conclude that third-party activity the most critical factor of pipeline risk. Such databases, including CONCAWE also concludes that spillage volume from third-party activities is the highest. Generally, incidents of higher spill volume are more in the Industrial zones' probably due to the more severe nature of failures.

Unfortunately, for India, no such database exists. The pipeline failure rates in China, which in terms of population density and other human activities is closer to India (then the USA or Europe), indicate that the top cause of pipeline failure (in China) in last 10 years has been Illegal tap, Li et.al (2016), which is close to 50% of all failures. Illegal tapping from a pipeline is a special kind of third-party activity that is done with malicious intent. A limited access to databases of Indian liquid pipeline companies also indicate a similar trend over the last 10 years.

As evident from CONCAWE data (refer Table 1.8), most of the significant liquid pipeline release cases are in the urban areas (industrial and residential), though the majority of the failures are in the rural areas. In India, a sharp increase in economic activities and large-scale urbanization has resulted in the human population residing even closer to the pipeline than ever before, in fact, many pipelines are cutting across newly developed urban areas. It is, therefore, quite likely that in line with the pipeline failure trend in other developed nations, third party activity is going to remain a significant cause of pipeline failure in India too for a long time to come. LPG pipelines, in general, are touching urban areas due to the need for delivering bulk LPG to the bottling plants that are in the vicinity of the cities. For example, the new 2700km long LPG pipeline announced by PNGRB in December 2018, has to feed as many as 22 LPG bottling plants. Among these, 5 are close to highly populated areas, therefore, the proposed pipeline shall have to pass through some of the highly populated areas of northern and western India.

1.8 NEED FOR RESEARCH

1.8.1 DEFINITION OF THIRD-PARTY DAMAGE

“Third-party damage (TPD) in the context of this study is defined as damage caused due to digging carried out by individuals or organizations, who are not related to the pipeline company, in the vicinity of buried pipelines without realizing that the pipeline is there or without considering the presence of the pipeline. The reason could be ignorance or negligence.”

In various countries, it is now recognized that third Party Damage (TPD) is the leading cause of pipeline failure and consequent loss to life and property. Pipeline failures due to third party damage generally have the potential to release more content from the pipeline than from a corrosion failure. The majority of corrosion failures are in the form of leaks, while the majority of third-party damages like hit by excavator are likely to cause pipeline rupture rather than leaks; consequently, pipeline failures from third-party damage has the potential to release more hydrocarbon. Besides, due to the very nature of the accident, the probability of human presence in close proximity to the site of the incident/accident in case of third-party damage is much higher. A third party damage is caused by instantaneous human action, for example, a hit by an excavator may result in fatality of the excavator operator. Consequently, a pipeline failure due to interference by third parties has the potential to cause very significant damage both in terms of property loss and life loss. The significance of third-party damage (TPD) can be assessed from the opinion of leading pipeline operators and regulators across the USA, Canada, etc.

a) According to Canadian Energy Pipeline Association (CEPA).

"Pipeline damage caused by third parties is the greatest risk to public safety because of the proximity of the person(s) to the pipeline when these incidents occur. Damage caused by third-party excavation around pipelines is one of the most common causes of leaks and explosions on transmission pipelines in Canada."

b) According to the DOT, USA, and PHMSA, the highest risk to the pipelines safety, especially in urban and sub-urban area, stems from individuals or businesses, referred to as third parties, excavation near a buried pipelines without knowing that there is a pipeline.

c) PHMSA, USA, recorded 1630 onshore Third-Party Damage (TPD) incidents between 1993 and 2012, resulting in 141 deaths, 440 injuries, and $369 million in property damage, DOT, USA, 2014.The real expenses involving the impacts of energy outages in the second-order are likely to be higher in order of magnitude.

d) Third party damage (TPD) is the primary cause of oil and gas pipeline failure. For nearly every sector (national and commercial) at least partially dependent on electricity from fossil fuel, TPD failure affects nearly every aspect of culture. Between 1985 to 1997, TPD, Kiefner et al. (2001) caused 28.1% of all pipeline accidents. For the period 2002 to 2013, this figure rose to 45.9%, Lam & Zhou (2016).

e) We have an urgent need to understand better the harm caused by third parties. Research on the failure of oil and gas pipelines has generally focused on more specific mechanisms of physical failure, particularly corrosion. Although the main cause of oil and gas pipeline failure was third-party damage, comparatively less attention was paid Jackson et.al. (2018).

The reasons for such a concern are genuine, as unlike other causes of pipeline failure, notably corrosion, TPD cannot be predicted or modelled easily. Prediction of corrosion and its control is a matter of science and studied widely; as a result, an ever-increasing number of corrosion models have been developed over the last one and half-decade. These models help to understand the science behind a corrosion failure, therefore, help in developing a preventive mechanism. Various pipeline failure databases indicate that there is a steady decrease in the number of pipeline failures due to corrosion. But TPD incidents are more a subject of understanding the human mind rather than laws of Physics and Chemistry, here the benefit of understanding scientific principle is not that important. Rather benefit could be more if one can examine (and understand) the process of decision making by the third party and takes preventive measures accordingly. This randomness in the occurrence of third-party damage is the biggest challenge in the prevention of such accidents. It is quite apparent that there is a significant need for a study of third-party damage to oil & gas pipelines.

1.9 PROBLEM STATEMENT

Liquified Petroleum Gas (LPG) is a highly inflammable hydrocarbon., which remains in gaseous form at natural temperature and pressure. In pipelines, LPG is pumped in liquid form at a pressure of more than 8 kg.sq.cm. LPG has a liquid -to-gas expansion ratio is 1:270. At atmospheric pressure, LPG in gaseous form is heavier than air. Therefore, LPG remains on the ground surface, thus possibly closer to the human population. All these characteristics make LPG one such hydrocarbon which, in the event of an accidental combustion, can cause maximum damage to life and property. Ufa Pipeline disaster on 4th June 1989 at Russia killed more than 500 persons and considered the worst pipeline disaster to date, involved leakage of LPG from a transmission pipeline that got ignited later. Unlike LPG, other conventional pipelines like crude oil or petroleum product or natural gas does not undergo phase change on release to the atmosphere from pipeline. LPG is pumped as a liquid through the pipeline at a pressure of more than 7 to 8 kg/cm^2, on release from pipeline to atmospheric pressure it turns into gas which is heavier than air.

Considering the rapid expansion of the LPG pipeline network in India and associated risk, it is essential that the probability of failure due to third party damage to LPG pipelines is studied and Maintenance and Inspection (M&I) practices optimized in a manner to reduce the possibility of failure.

M&I of LPG pipelines in India are governed by OISD Standard -214, Cross Country LPG Pipelines, 2013. Clause 16.4 of OISD-214 suggest the following:

Quote

" 16.1 A comprehensive manual containing program & practices shall be developed for existing pipeline / after the construction of the new pipeline to manage pipeline integrity taking into consideration consequence classification/category of the pipeline, and ***risk involved in each segment of the pipeline.***"

Unquote

The standard, however, does not suggest any methodology to achieve this objective of the segment-wise evaluation of the pipeline. In the absence of this Indian LPG, pipeline operators develop an M&I plan that is common for the entire pipeline treating the entire pipeline as one segment. As a result, the M&I plans are often unoptimized concerning the frequency of inspection and expenditure incurred and its effectiveness.

1.10 THE OBJECTIVE OF THE RESEARCH

The main objective of the present study is to develop an Optimized Maintenance & Inspection (M&I) Programme for Indian LPG pipeline operators with a view to reducing the possibility of third-party damage to the pipeline. The primary objective is further sub-divided into the following:

I) To develop a model that calculates the weight of factors contributing to the failure of the LPG pipelines in India from Third Party Interference.

II) To develop an optimized maintenance and inspection (M&I) programme for LPG pipeline in India

1.11 RESEARCH METHODOLOGY

While a comprehensive description of Research Methodology is dealt with in Chapter 3, the summary is presented below:

Step 1 Literature Review

A literature review has been done to identify works relevant to pipeline failures and causes in general and pipeline failure due to Third Party Interference in particular. Additionally, applicable international and national codes and standards and various reports on pipeline failure and failure trends have been reviewed. One of the objectives of the literature review apart from that stated above is to evaluate various techniques available for assessment of the impact of factors responsible for third party damage to pipelines.

Step 2 Selection of an operating cross country LPG pipeline

A currently operational LPG pipeline is identified after examining its technical details as well as current Maintenance & Inspection Practices to validate the developed model.

Step 3 Segmentation of the LPG pipeline (identified in step 2)

As the objective of this study is to develop a segment-wise optimized M&I programme for an LPG pipeline, in this step, the selected LPG pipeline shall be sub-divided into segments based on existing mainline block valves.

Step 4 Enlisting factors responsible for third party damage

A cross country pipeline is exposed to third-party interference along its route, the probability of failure to a pipeline due to third party activities depends on certain common factors. Such key factors are identified primarily through a review of relevant literature and internationally recognized databases on pipeline failure

Step 5 Selection of appropriate technique

A literature review indicates that several techniques or a combination of techniques are used to build a risk model for predicting possible pipeline failures and its consequences. Some of the techniques are Bayesian theory, Fuzzy theory, Bow-tie technique, Analytical Hierarchy Process (AHP), Fault Tree techniques, etc. For the present study, a combination of expert opinion and AHP technique has been used. The reason for the selection of AHP is primarily due to the inherent flexibility of the technique that permits ease of accommodating expert opinion and the ability to build models successfully, even where the availability of data is sparse.

Step 6 Selection of experts

Lack of availability of authentic data for Indian pipelines in general and LPG pipelines in particular, is a serious challenge to carry out any research. Whatever limited data are available is mostly with the public sector undertakings (PSU) of Government of India (GOI), who owns most of the pipelines in India. On the one hand, PSUs are reluctant to share their data; on the other, whatever little data is available in the public domain and with the regulators, are mostly not in any useful formats. It is, therefore, necessary to rely on expert opinion to overcome this limitation. For the present work opinion of experts have been collected in a semi-structured manner. 4 experts are selected after going through a process (elaborated in chapter 3), these experts were given the task to give marks against various factors and sub-factors upon whom the probability of third-party damage primarily depends.

Step 7 Building the model

A model is built through the application of AHP and synthesizing scores (of each factor) given by each of the 4 experts (elaborated in Chapter 3). The model thus built is utilized to quantify the extent of un-optimization in the current Maintenance & Inspection (M&I) programme both in terms of expenditure and frequency, for the selected pipeline.

Step 8 Development of Optimized M&I programme

In this step, an optimized (both in terms of cost and frequency of M&I) Maintenance & Inspection Programme is presented, which can be implemented by an LPG pipeline operator in India and with certain minor modification by other pipeline operators in India and abroad.

1.12 STRUCTURE OF THE THESIS

This thesis consists of 5 chapters. The summary of the chapters is given below:

Chapter 1: This chapter highlights the need for undertaking this work and research motivation, the objective of the study, and a brief on the methodology of the research work.

Chapter 2: This chapter reviews the previous works how similar problem has been handled by various researchers and authors, including the techniques available for undertaking such work. Also, literature reviews are organized, and the current gap on the subject under the Indian context is identified.

Chapter 3: In this chapter research methodology is elaborated in detail. The chapter also includes the basis of identification of key factors and sub-factors and significance of each of the factors, AHP techniques and its application under the present context, expert identification process, and expert weight determination, development of the model synthesizing quantified opinion of the expert and AHP technique

Chapter 4: In this chapter developed model is applied to an operating LPG pipeline, and the segment-wise quantum of un-optimization is determined with respect to the existing M&I programme in terms of cost and frequency.

Chapter 5: This chapter includes conclusion, possible contribution of this work, and recommendations for future works in this area.

CHAPTER 2: LITERATURE SURVEY

2.1 LITERATURE SURVEY AND OBSERVATIONS

One of the significant challenges while taking up any study on Indian pipeline failure is the poor availability of data on pipeline incidents. Generally, pipeline operating companies are reluctant to share such data on their own, OISD, a body established under the aegis of Ministry of Petroleum & Natural Gas, India, had in the past made some attempts to come out with a pipeline failure database, but in the absence of any mandatory requirement, the initiative was not successful. And after a couple of years, this data generation initiative seems to have died a natural death.

In recent year, PNGRB, a body established under an act of Indian Parliament, has been making an effort to organize such pipeline failure data. Hopefully, in future useful data would be available to the researchers, but as of date, the availability of pipeline failure data is insufficient, and no useful study can be based on the quantity of data available in India. In such a scenario, the only option left is to rely on databases maintained by International bodies like PHSMA,USA, UKOPA, EGIG, and CONCAWE.

Most of the papers published by various authors across the world in reputed journals have been reviewed, additionally, codes and applicable engineering standards are also reviewed. Pipeline failure reports published by EGIG (2018) on European gas pipelines and CONCAWE (2018) on European liquid pipelines that deal extensively on pipeline failures and their causes have been consulted. Besides, reports of the National Energy Board (NEB), Canada, and documents published by PHMSA and National Transportation Safety Board (NTSB), USA were also reviewed.

There are some research works that deal with pipeline risk, but these are primarily focused on the process of determination of the probability and consequence of failure rather than offering a workable solution to the pipeline operators in terms of focused Maintenance inspection practices. An exception to this would be the PhD dissertations work by Dawotola (2012), this research work was on the determination of risk from pipeline failure under the backdrop of the socio-economic scenario in Nigeria, this dissertation does deal with all possible causes of pipeline failure including failure from third party damage. Another significant research work on pipeline risk by Parvizsedghy (2015) deals extensively with impact factors of pipeline risk and methods to handle various risk parameters and their quantification. The work also proposes a maintenance model based on risk analysis. Research technique utilized by Parvizsedghy (2015) includes Bow-Tie analysis, Artificial Neural Network (ANN), Fuzzy Set theory, General theory of uncertainty, Monte-Carlo Simulation, and Neuro-Fuzzy technique. The author has done a thorough analysis by the application of the above techniques and established a model for comprehensive risk analysis. The author has presented extensive data and analyzed the reasons as well. The thesis, after determining risk arising out of various causes of pipeline failure, goes on to establish a model for the development of M&I programme, but workability of the proposed M&I programme in a real-life scenario was neither discussed nor presented in the thesis. The objective of the thesis seems primarily to predict the failure probability of pipelines and consequence with the ultimate objective to built a model. The thesis does not identify the gap between present M&I models with the proposed one; as a result, optimization of M&I expenditure is more or less left out.

Dey et.al. (1998) had done a couple of studies on pipeline risk analysis under the backdrop of the Indian pipeline scenario. In his work Dey (2001) evaluated the risk of failure of different segments of a cross-country pipeline and developed segment-wise strategies for the selection of the inspection techniques for such pipelines using the Analytic Hierarchy Process (AHP) technique. This model applied expert opinion to obtain the weight of variables that were identified to contribute to the failure of pipelines. Variables were categorized as risk factors that included external and internal corrosion, construction and material defects, as well as Acts of God. In another work by Dey (2003) proposed a risk-based maintenance model considering off-shore pipelines, the model had the provisions for considering the expert opinion to obtain the relative weight of various factors responsible for pipeline failure. However, the approach adopted to capture expert opinion was subjective in nature. The proposed model by Dey (2003) suggests inspection tools based on experience. Unfortunately, the relevance of such studies under Indian context has greatly diminished primarily due to the incumbency of the regulatory regime and enhanced public awareness with the development of Industrial scenario in India over the last one and half-decade.

The present literature survey indicate that generally Analytical Hierarchy Process (AHP), Fuzzy Set Theory, Bayesian network theory, and Event Tree methods are used for determination of risk arising out of pipeline failure, probability of pipeline failures, and factors contributing to pipeline failure. Barring a few, most of these studies are focused on the theoretical aspect of the analysis, while views of pipelines experts or pipeline operators are rarely reflected. Although some of the technique is quite straight forward and likes of AHP provide enough scope to incorporate the opinion of experienced pipeline experts. The approach in the majority of the studies is to formulate a model, but no serious attempt was made to establish the validity of such models in real-life scenario though some of the studies do provide directional assistance towards further studies in the field.

One interesting observation from the literature survey that very few pieces of research have tried to examine the significance of Third-Party Interference-related damage to cross country pipeline, one exception is the work done by Jun Li et al. (2016). This work does cover an approach to Third-Party Damage assessment probability in a pipeline, but the study is confined to the urban pipeline network only, rather than cross-country pipeline.

A significant work on third-party damage to the gas pipeline was done by Zeyang Qiu, et al. (2017), the authors emphasized on the development of a quantitative risk assessment model against third-party damage to gas pipelines by using Analytical Hierarchy Process (AHP) and fuzzy comprehensive evaluation technique. The objective of the authors was to quantify the weight of each of the factors responsible for third party damage and quantify their importance on the basis of number scored. The authors, however, did not attempt to validate the model on any gas pipeline or pipeline system. The work, however, provides valuable insight into the process of development of a model for assessing the probability of 3rd party damage to a pipeline.

Apart from the abovementioned works of significance, the author could not lay hand to any other work that is substantially related to the proposed study least so for the Indian pipeline scenario. Therefore, this work was taken up primarily considering public safety in mind, and the following points, i) growing network of LPG pipelines in India ; ii) rapid development of Indian economy leading to heightened human activity; iii) rapid urbanization leading to iv) growth of population in the areas close to pipelines; and v) till date no study was done on the probability of pipeline damage in India due to third-party interference/activities.

The work is expected to emphasize the need for optimizing current Maintenance & Inspection efforts to lower the probability of 3rd party Interference-related damage to LPG pipelines in India and directionally address the regulatory requirements specified for LPG pipelines in India.

Among the multi-criteria decision support techniques Analytical Hierarchy Process (AHP), Satty (2013) is the one that can, in a small extent, negate the implication of lack of availability of data. Also, by considering the opinion of experts in the respective fields, AHP provides a significant option to overcome the limitation of lack of data. Under the Indian context, expert opinion offers the advantage of being aware of many pipeline failures and their causes, which goes to make up to a certain degree the poor data availability. Besides, AHP has been a popular tool for analyzing pipeline risk and probability of failure for the past many years. Therefore, the author proposes to use AHP as a multi-criteria decision support tool for the present study. A brief on AHP technique and its possible application in the context of the present study is indicated under Research Methodology.

It is worthwhile to mention that though several pipeline failure incidents have taken place in India little details on these failures or study reports on these incidents could be found, whatever details available in public domain are rather sketchy and more in the format of a typical government report without any deliberation on the root cause of failure and underlying reasons for such incidents. One of the reasons for lack of availability of pipeline failure reports could be a lack of public awareness till the recent past. However, since the last major pipeline incident of 2015, when a gas pipeline failure caused 29 deaths, considerable awareness has been built around the area of pipeline operation and associated risk. Rapid urbanization and industrialization in India necessitated laying of more pipelines to meet the energy (read hydrocarbon) demand across the country. To ensure safe operation of these pipelines it is but essential that pipeline Maintenance & Inspection practices are made more efficient, the author expects that the present work is going to contribute in this area of oil & gas business in India. Under this backdrop of this emerging scenario in the pipeline industry in India, the present work has been undertaken by the author.

As mentioned previously, not many works are available on the topic of study, some works that deals with risk in general and pipeline risk, in particular, have been reviewed with a view to getting an idea about general approach to pipeline risk management and techniques used to quantify the probability of failure from various risk factors.

2.2 CRITICAL REVIEW OF THE LITERATURE

Kaplan and Garrick (1981) primarily dealt with the definition of Risk, Probability, and consequence, etc. The paper introduces a set of triplet concept in risk analysis. The paper also deals with the definition of the terms Risk, Probability, Consequence, and frequency. The authors suggest that the difference It suggests that Risk cannot be defined by a single point (or number), neither can it be defined by a curve, only a plane would be adequate to address the idea of risk. Further, it is argued that probability is, in fact, a measure of the state of knowledge.

Morrow et al., (1983) had proposed a model to evaluate the scenario that can develop in case of a break-in an LPG pipeline. The paper also proposes a mechanism to evaluate the flammability hazards associated with a pipeline rupture. LPG being heavier than air continues of flow over the surface in case of a release, the proposed model is capable of estimating the time-dependent flow rate of LPG from a pipeline rupture. For evaluation of the model, a typical case was considered to depict the effects of spacing of pipeline isolation valve, shutdown time, and flammable cloud boundaries that would result from a break in an LPG pipeline.

A large volume of experimental data was used by **Tam & Higgins (1990)** to compare and derive a simple mathematical model to determine the time-varying release rate of pressurized liquid petroleum gas (LPG) from a ruptured pipeline. For generating data in order to formulate the empirical model, a 100-meter-long pipeline of internal diameters of 50 mm and 150 mm, was chosen for performing experiments. The empirical model, thus developed was used to study the mass history of liquid propane inside the pipe.

For assessment of health of a pipeline containing various types of anomalies in large number need prioritization, in their report **Kiefner, J.F. et.al. (1990)** suggested to carry out risk rating as a means of prioritizing anomalies for repair, paper also evaluates various techniques of risk assessment, authors further suggest an algorithm to address various factors that contribute to risk. The paper also suggests that the algorithm or parts thereof can be used to rate pipeline segments in order of urgency for test or inspection. Such ranking permits an operator to use limited maintenance funds most effectively and efficiently.

Hopkins (1994) indicates that though the pipelines are the most reliable and safe mode of transportation, they do fail and sometimes with devastating consequences resulting in loss of life and property. Paper provides some guidelines on how the safe life of a pipeline can be extended. The author cites an example of erstwhile British Gas's pipeline system and how they were able to extend the safe life of their pipelines beyond 25 years through a selection of appropriate inspection techniques.

Stephens and Nessim (1995) discusses the limitation of present-day risk analysis and suggest a methodology for comprehensive and quantitative risk analysis. Paper introduces the concept of utility theory and consequence analysis for cost optimization. It covers the overall framework for all failure causes. The cost optimization concept assumes that life safety and environmental damage are to be treated as constraints or boundary limits. Under this approach, risk versus cost, curves are drawn for optimization of the maintenance budget. The advantages of this approach are a tradeoff between cost and life safety & environmental protection. The utility theory concept is introduced to develop a value function that results in optimization between different types of consequences viz. life safety, environmental, and economical. Under this theory, a utility function u=u(c,n,v) has been developed with a view to rank different combinations of c,n and v according to their perceived total impact. The paper concludes that with utility theory and value function, pipeline segments can be ranked as per the risk and accordingly maintenance budget allocated.

Ahammed and Melchers (1996) discuss the failure probability of a pipeline affected by corrosion. It considers various profiles of metal loss due to corrosion and their impact on the structural integrity of the pipeline. , however, the paper does not speak on risk arising out of corrosion of a pipeline.

Chareonsuk et al. (1997) discuss how, in a production system, the problem of determining optimal preventive-maintenance intervals for components can be arrived at. As a basis of their study, the maintenance planning of a factory is taken as a sample. The paper proposes a model that can handle multiple criteria, e.g., expected costs and reliability are considered two criteria. To arrive at the optimum maintenance interval MCDM method and the PROMETHEE techniques are used. To take care of the variations in the subjective weights assigned to the criteria sensitivity analysis was also carried out.

Dey (1998) proposes a maintenance model for cross country pipelines using the AHP technique. The model compares relative risk among various segments of a pipeline. The paper concludes that with a risk-based approach, both time and expenses can be optimized without sacrificing the safety and reliability of a pipeline. Authors use an AHP based model as a tool for determining the riskiness of various segments of the pipeline. The author also deals with the consequence of failure and the financial impact of a failure. The consequence analysis approach is adapted to determine the severity of the failure. The impact of failure due to various risk factors was established in terms of cost from consequence analysis. Both consequence and probability are merged to determine the overall impact of a failure.

Pandey (1998) proposed a framework for probabilistic analysis of in-line inspection data to estimate the pipeline integrity through impact assessment of inspection findings and repair of anomalies planned over the service life of a pipeline. The framework is then used to calculate optimal inspection intervals and the development of a repair policy to attain a reliability target level. Using Monte Carlo simulation, a practical approximation is also worked out and results validated in order to determine the pipeline failure probability after maintenance,

While discussing on pipeline route selection, **Dey et al. (1999), suggest that** the route selection of a pipeline needs to consider numerous factors. Therefore it qualifies as a multi-criteria decision support system. The authors identify various factors that are considered during pipeline route selection. Each of these factors was compared pairwise

in line with AHP guidelines and came up with a model that helps decide the most optimum pipeline route in terms of coast, maintainability, and ease of construction. The authors demonstrate through their model the usefulness of AHP as a technique while dealing with multiple criteria and limited availability of data.

In a study commissioned by the Health and Safety Executive (HSE) to ascertain the degree of risk posed by gasoline pipelines in the UK, **Atkins** (1999) concluded that the risk assessment for gasoline pipelines need to take full account of historical data available across the world if a realistic estimate of the levels of risk is to be determined.

Bottelberghs (2000), reviewed the basis of legislation in the Netherland that gives the full legal basis of risk tolerability criteria. The aim is to balance between risk control measures at the source through the licensing system, and spatial planning instruments to protect, e.g., residential areas against major hazards.

Paper by **Leonelli et.al**. (2000), introduces a risk analysis based new methodology to choose the most suitable route for the transport of a hazardous material. To optimize the methodology, a graphical network is considered with nodes and arcs.

Each of these arcs is assigned a cost per vehicle traveling on it and a vehicle capacity. The paper largely concentrates on risk and cost optimization-based transportation routes for hazardous material.

Konstantinos et.al. (2001) discuss the risk of transportation of hazardous material and the significance of determining the safest truck routes to reduce eventual impact/consequence in case of an accident. The paper also looks at the emergency response system along the selected route.

Dey (2001) proposes a model based on AHP that identifies various factors of degradation of the pipeline and identifies the stretches based on the nature of degradation in order to divert maintenance and inspection resources in a selective manner instead of one common solution for all entire pipeline. Analytic Hierarchy Process (AHP) is used to develop the risk-based model, which goes on to determine the factors that influence failure on specific zones of a pipeline and analyzes the effects of these factors by determining their probability. To determine the severity of failure, consequence analysis was done, with a technique that is not fully objective oriented; nevertheless, it is an improvement over the existing methods.

In a report on third-party damage probabilities to a high-pressure gas pipeline in UK and Europe **Mather et.al.** (2001) attempts to predict probability of third-party damage to pipelines using a computer programme PIPIN. This research used EGIG 1997 and UK's Transco incident database pipeline failure information to improve the third party operation model in the PIPIN computer program. The developed model for third party damage prediction considers the following 5 factors
Diameter of the pipeline ;
Pipeline wall thickness;
Location of the pipeline;
Depth of burial;
Measures for pipeline damage prevention

Droiyner and Veith (2002) discussed the general methodology of Risk-Based Inspection concerning the frequency and scope of inspection of static equipment. The paper emphasizes the need for prioritizing the inspection list, based on risk calculated for each of the equipment. The paper also presents the methodology to calculate risk for the above purpose.

In their paper, **Metropoloi et al**. (2002) attempts to analyze the risk associated with the gas pipeline from Bolivia to Brazil in two steps through preliminary hazard analysis (PHA) and finally through Event Tree (ET) Method. After risk assessment, the authors carry out a consequence and vulnerable analysis through simulation with CHEM-PLUS software. Likely consequences along the route of the pipeline under various scenarios were quantified.

Yuhuaa et al. (2002) propose a mathematical model by using computational fluid mechanics to predict the release of gas in a long transmission pipeline. The model is designed for a hole that is neither very small nor equal to complete breach in the pipeline. The model shows that beyond a certain pressure the total mass of gas released during the sonic flow is more than 90% with an average rate of release is 30% of the initial release rate.

Dey (2003) proposes a risk-based model using AHP to identify and quantify risk along an operating pipeline to assist the pipeline operators to manage risk in a methodical and systematic manner. The cost of failure is also assessed to help the operator to optimize risk maintenance and inspection efforts.

Brooker (2003) concludes that **d**amage, mainly puncture of pipelines by excavator, is a usual cause of pipeline failure across the globe. The author proposed a model that uses continuum damage mechanics theory and a material softening approach to simulate ductile failure. The model was validated by comparing actual events caused on pipes by excavator teeth hit for experimental purposes as well as those available in various published literature. A good correlation was observed between the theoretical model and actual events. A simulation was carried out through the FE technique to demonstrate the use of a shell-to-solid sub-modeling technique in conjunction with this material failure technique for establishing the effectiveness of the method.

Jo, et al. (2003), deals with the issue to pipeline route selection for a gas pipeline and how risk analysis helps in route planning based on the criteria of 32kW/m2 radiation level. The paper discusses the method to calculate based on a hypothetical scenario of gas pipeline leakage and fire and effective distance on either side of the pipeline that would receive a ration of more than 32kW/m2. The paper concludes that with a minimum proximity distance of 10-5 m for buildings and 10-6m distance for an individual risk, gas pipelines are safer than other risks like traffic and chemical industries.

In his book on risk management, **Muhlberger** (2004), handles the pipeline risk analysis in totality and offers a number of pipeline risk analysis techniques. Also, guidance is provided to select the most appropriate risk analysis techniques to take care of different types of pipelines related issues. The book primarily concentrates on qualitative, semi-quantitative, and quantitative methods on risk analysis. For the case where the availability of data is limited, the Indexing method of risk analysis is recommended.

Hopkins (2005), demonstrates how design factors can be adjusted considering the failure data findings to get built a pipeline with higher margins of safety. The paper deals with individual factors that lead to pipeline failure e.g., the thickness of the pipeline, depth of burial, diameter of pipes, and attempt to relate these factors with basic design considerations. The databases of various organizations in the UK and Europe were critically analyzed to obtain a relation between failures and the abovementioned factors to come out with a broad guideline for higher integrity pipeline design consideration.

Nataraj (2005), discusses how the Analytic Hierarchy Process (AHP) can be utilized in a multi-criteria decision support system, especially in pipeline route selection, pipeline maintenance, and construction, etc., in a cost-effective matter. For demonstration purpose author considers a hypothetical case of pipeline and demonstrates how AHP can be effectively applied to the various scenario of pipeline maintenance, construction, pipeline route selection, etc.

Al-Khalil, et.al. (2005) presents an analytical hierarchy process-based model to determine the probability of pipeline failure. To work out the cost of failure, the author uses the expected value approach. The approach adopted by the authors can help in developing a pipeline maintenance plan which is based upon i) cause of failure; ii) severity of the impact of failure.

The methodology proposed by **Dziubinski et al. (2006)** takes into account individual and societal risk arising out of a long-distance pipeline, the methodology suggested requires determination of the basic cause of pipeline failure and the likely consequence. The suggested methodology was verified through an application over a long-distance pipeline in Poland.

Sklavounos et al. (2006) proposes a method that uses the Event Tree Analysis approach to determine safety distances around pipelines transmitting liquefied petroleum gas and natural gas. For calculation of safety distances, a liquefied petroleum gas pipeline and a natural gas pipeline was considered. The failure mechanism examined consider jet fire and gas dispersion to the lower flammable limit modes. These modes correspond to immediate and delayed cloud ignition. The authors established that while calculating safety distances, the jet fire scenario should be considered as the limiter for both LPG and Natural gas pipelines.

The approach proposed by J**iang, Y., et al. (2006) for** new maintenance selection and scheduling process **is b**ased on the cumulative long-term risk caused by the failure of each equipment. This approach accounts for equipment failure probability and equipment damage, in addition to accounting for the consequence of outage in terms of overload and voltage security.

Alonso, (2006), in his paper deals on the method to address the uncertainty measurement issue in pair-wise comparison in AHP technique. The paper suggests a methodology to determine the Randomness Index (RI) in pairwise comparison under the AHP technique.

Department of Petroleum Resources, Nigeria. (2007), in their report, discusses the regulatory provision/guidelines prevailing in Nigeria. The provisions the Law of the Federation of Nigeria 1990, and the permissions that are required by a pipeline company (under this law)during construction and operation of a pipeline with the objective to reduce the possibility of accidents.

Teixeira, et.al. (2008) attempts to analyze the factors that make up the failure function and their influence on the likelihood of a rupture in a corroded or un-corroded pipes. The approach suggested was compared and verified w.r.t provisions of some of the modern-day codes and standards. For the purpose of the study, probabilistic models were proposed that considers material properties and geometrical parameters. The authors go on to prove that the target reliability index of 3.8 recommended in EN1990 (for a reference period of 50 years), can actually be obtained for a good pipe following the approach proposed by them.

Chang (2008), in his paper, proposes a model using a fuzzy and AHP concept to obtain a crisp priority vector from a triangular fuzzy comparison matrix. Authors in this paper, demonstrate by examples that the relative importance of decision criteria is not necessarily determined by the extent analysis of the priority vectors, and such an approach has the potential to lead to a wrong decision.

Quest Consultant Inc (2009), in their report, discusses the risk arising out of transporting gasoline, LPG, and anhydrous ammonia through road takers. It calculates risk against the release of each of the tree products through event tree analysis techniques. The report also takes into consideration the nature of release and their impact on the motorists and individuals, including the impact zone of a release and explosion. The report further concludes that transporting gasoline is the least risky, while LPG transportation is the riskiest. The author concludes that there is no relation between the frequency of failure with the nature of the fuel. Also, for fuel with the change in frequency of release, there is no relation with the impact zone.

Restrepo, C., et al., (2009), in their paper, examined the underlying causes and consequences of failure in hazardous liquid pipelines leading to the release of hazardous liquids. The paper analyses how the causes of accident and accident character affect the consequence. Stepwise statistical analysis of the failure incidents data is carried out to estimate the probability of an accident. In the second step,, the measure of consequence is evaluated as a function of accident characteristics. While calculating cost, therefore, the proposed model considers the value of product loss, property damage, and environmental cost, and based upon cost, the ranking of the importance of pipeline failure is made.

Ghosh et al., (2009) present a model for Preventive Maintenance (PM) using cost-benefit analysis (CBA). The authors conclude that while CBA does show that an optimum preventive maintenance schedule can be determined, the same is not possible through cost minimization approach where a processing unit has a constant failure rate.

Hopkins, et al. (2009), in a report, discusses the significance of quantitative risk assessment over qualitative one. It goes to state that using a quantitative risk management approach can address some of the limitations of qualitative risk management. ASME B31.8S and API 1160 are two documents that contain guidelines on quantitative risk management. The context of the discussion was the Application of Pipeline Risk Assessment for high-pressure gas pipelines of the UK considering provisions of IGEM/TD/2 and PD 8010:2004 and PD -8010 – 3:2009. The paper also gives an overview of the new approaches for consequence modeling and prediction of failure frequency, the usefulness of the risk criteria, and implementation of systems for risk mitigation.

To improve the safety of their pipeline network, generally, a pipeline operator adopts a quantitative approach, concludes **Jo, et al., (2010).** The authors propose a quantitative risk management approach that considers **fetal length** and **cumulative fatal length** as factors. The feral length is defined as the cumulative fatality along the pipeline where accidents are supposed to happen; cumulative fetal length is defined as that length of the pipeline where N or more fatalities take place due to an accident. Authors suggest that a similar approach for quantitative risk assessment to the one proposed by them would be more useful if considered at the planning and construction stages of a new pipeline or even during the modification of the existing pipelines.

In their guidelines (compiled in a book) **American Institute of Chemical Engineers, New York (2010) discusses** how to conduct a consequence analysis to fulfill your requirements and the EPA rules. These guidelines describe methodology for quantifying the size of a release, dissipation characteristics of vapour clouds (to an endpoint concentration), outcome of various types of explosions and fires, and how explosion and fires may affect people and structures.

Arunraj, et al., (2010) suggest an AHP and goal programming based approach for maintenance selection, to assess the risk of equipment failure and cost of maintenance. The AHP results indicate that for better risk reduction, condition-based maintenance (CBM) is probably a better approach than the one based on time. However, corrective maintenance (CM) is the preferred criteria for cost optimization. The AHP–GP results show for high -risk equipment CBM is preferred and CM for the low-risk ones if both risk and cost are considered as multiple criteria.

Chaczykowski (2010) proposes a model that helps to understand the effect of pipeline flow and pressure. The author indicates that to calculate the parameters of a natural gas pipeline through the assessment of gas character best approach is to work with a model (proposed by the authors) that can handle unsteady heat transfer with heat accumulation from sub-soil (for underground gas pipelines).

Jafari et al. (2011) proposed a model for quantitative risk assessment of a gas pipeline using GIS information, and other relevant information like risk factors were overlaid on the GIS layer. The model divides the pipeline into small sections of 500m, and risk was calculated for each 500m segments to get the overall risk profile of the entire pipeline. The approach suggested by the author is uncomplicated but requires detailed pipeline knowledge for its successful application.

Spoelstra et al., (2011) deals with the process of development of the risk model for underground pipelines at the Netherlands, transporting high-risk (to public and environment) substances like ethylene, chlorine, carbon dioxide using experience gathered from similar analysis for oil and gas pipelines. There are nearly 3000km of ethylene, carbon dioxide, and other such non-gas and oil pipelines in Netherland. Paper attempts to generate failure frequencies for such pipelines where only a few failure data are available. The ultimate objective is to establish the need for amendment of the existing regulation on pipelines in the Netherlands considering risk arising out of such pipelines.

Dawotola et al. (2011), demonstrates how the application of statistical methods to repairable (e.g., Pipelines) systems can help in modeling failure rates of three different cross-country crude and petroleum product pipelines. The study considers pipeline failure data for a period of 11 years and attempts to analyses the failure trend and establish an average time interval between failures. The paper studies the dynamics of corrosion incidents and concludes that the dynamics of corrosion incidents can be adequately addressed by the Homogenous Poisson Process. Further analysis indicates that corrosion failure rates for various pipelines follow a similar trend, and pipelines installed in a similar period may face corrosion failure within the same range of time. The results can be used as a basis for the creation of an inspection schedule based on the average failure and failure rate with the ultimate goal of formulating a suitable structure for the pipeline sustainability.

Rumnney and Goodfellow (2012) suggest an approach to address the issue of change in class location over the years due to a change in population and developmental pattern along the pipeline right of way over the original class location for a gas pipeline. Authors suggest that one way to overcome this problem could be a reduction in operating pressure or rerouting the pipeline, but these approaches involve sacrificing substantial benefits in terms of the high cost. This paper says that Quantitative risk assessment can be successfully employed to demonstrate that the change in location class due to a rise in population does not necessarily increase the threat from the pipeline to a specific population group, and the pipelines continue to remain within the regulatory guidelines. Through a case in Western Europe, the paper demonstrates that with the use of the Quantitate Risk Assessment method, the safe operation of a pipeline without any increase of risk can be justified.

Ali Jozi, et al., (2012) demonstrate how a combination of Indexing System Method (ISM) and Analytical Hierarchy Process can be applied to assess the environmental risks arising out of gas pipelines. Authors demonstrate that how AHP based method can quantify and classify numerous types of environmental risks. For depicting risk probability and risk severity in terms of Sum Index and Leak Impact Index, authors demonstrate the utilization of ISM. While cumulative environmental risk is calculated through the multiplication of total risk probability in risk severity, because differences existed in the total practical level of the factors, authors used AHP to determine the impact of each factor and evaluate their contribution in the overall risk. 24 inches, 42km long Aabpar – Zanjan gas pipeline is used as a platform to validate the application of the proposed approach for environmental risk assessment.

A data-driven approach is proposed by **Dawotola (2012)** for determiniation of an optimum inspection interval for a pipeline. The proposed methodology is designed for the determination of the probability of failure and resultant consequences. The probability of failure is calculated by using the pipeline's historical failure information in either a homogeneous Poisson process or a non-homogeneous Poisson process (power-law). The paper states that an analysis of historical data can reveal the Poisonous form that leads to an improved description of the failure process. Economic loss, damage to the environment, and loss of human life are evaluated to determine the consequences of failure. The overall loss to an operating pipeline is evaluated by considering the failure probability and consequences. The authors emphasize that to develop a successful risk-based integrity maintenance optimization program for a pipeline consideration should be given on minimizing the economic loss and assuming maintenance budget and human risk as constraints. The suggested structure has been validated effectively through its implementation for a cross-country petroleum pipeline maintenance planning. The authors further claim that any engineering system requiring inspection and maintenance planning can successfully apply the approach.

Hill (2012), states that consistency in performance and design is the primary requirement, but it can not be ensured through adherence to provisions of the standards and codes. The author further states that with the aging of the pipeline likelihood of accidents is increasing. While at the same time, the tolerance towards pollution and pipeline incidents is decreasing among the masses. Potential liabilities for a pipeline owner following a release of oil products is now a major concern confronting the pipeline industry. The author argues that from the pipeline operators, it is expected to demonstrate the safety and health condition of the pipelines to the general population.

Kirchhoff et al., (2012) discuss how risk assessment can be used to analyze the impact of natural gas pipelines on the environment and how risk assessment is linked with environmental impact assessment. Authors suggest that when risk assessment should be an essential tool for assessment of the suitability of a gas pipeline from the environmental impact point of view, including the selection of a route for such a pipeline. If done, the likely impact of a gas pipeline failure can be considerably reduced. Authors also conclude that present acceptance criteria followed in the Sao Paolo State of Brazil are not aligned to the requirement of environment protection criteria specified across the other parts of the world and thus need revision.

Pettit, (2012) suggests that it is necessary to consider design aspects and operational as well as maintenance-related factors while estimating/predicting failure rate of a pipeline, rather than relying on the failure databases of pipelines. The author also suggests that failure rates are likely to vary depending on the Right of Way (RoW) condition over various segments of a pipeline due to change in the population pattern as well as change in geological and geographical patterns. The paper also indicates how various preventive measures, especially against third-party activities, can positively affect the failure rate of a pipeline. It concludes that risk reduction measures adopted by a pipeline operator have a lasting impact on failure rate, as such preventive measures are necessary to be factored in a while estimating failure rates.

Kumar et.al., (2012), deals with the problem of maintenance policy selection for an industrial unit. Maintenance policies can be many e.g., Corrective Maintenance, preventive maintenance (subdivided into time-based maintained and condition-based maintenance). The selection of appropriate maintenance strategy involves consideration of factors like failure probability, consequence, cost etc., therefore, a multi-criteria decision support system (MC-DSS) is necessary to finalize the strategy. The author discussed the advantages and disadvantages of AHP as an MC-DSS and compares that with the Analytical Network Process (ANP) to suggest that ANP has better potential as an MC-DSS as far a selection of maintenance strategy is concerned.

Sahraoui, et al., (2013) propose a maintenance policy for pipelines subjected to corrosion. The author proposes to develop a procedure for maintenance planning by considering imperfection in inspection results. The approach consists of the formulation of a degradation model under corrosion defect, followed by the formulation of a maintenance model. Finally, the validation of the approach is attained through its application in a gas pipeline, with the objective to formulate an optimized inspection policy.

In their paper **Qiang BAI, et al., (2013)** attempt to carry out a risk assessment of the urban gas grid through a semi-quantitative risk assessment method. The indexing method of the semi-quantitative assessment technique was utilized to establish indexes of fault frequency and consequence for urban natural gas pipelines. The proposed model is utilized for initial risk assessment of the urban gas pipelines at the planning, construction, and service stage. The potential of the approach is emphasized in providing guidance for pipeline operation, reconstruction, and maintenance, etc.

Focke (2013) concludes that third-party interference is recognized as the major cause of pipeline damage. However, EGIG statistics show that in the last decade, probably due to a higher level of awareness and introduction of more effective/appropriate technologies has led to a significant reduction in failures of gas pipelines. Therefore, the introduction of appropriate technology may also be beneficial for the reduction of costs for rehabilitation and maintenance. Similarly, it may be possible to reduced overall risk that can substantially be reduced by the introduction of appropriate monitoring technologies.

In their paper **Jamshidi, et al., (2013**) demonstrates how a capable model can be developed using fuzzy logic for handling uncertainties involved in pipeline risk assessment. The model proposed by the authors is based on a combination of relative risk score (RRS) methodology and fuzzy logic. The paper, through a typical case study, attempts to compare between the classical risk assessment approach and the fuzzy logic-based model proposed by the authors and how a fuzzy logic-based model is capable of providing more accurate, precise, sure results.

El-Abbasy, et al., (2015) discusses the design of a model for pipelines condition assessment by using a combination of Analytical Network Process and Monte-Carlo simulation. The proposed model considers multiple pipeline degradation factors like corrosion and calculates the interdependency of the relations among degradation factors. The model was verified in an off-shore pipeline in Qatar and found to provide satisfactory results. The proposed model can be used to priorities the inspection and maintenance programme of a pipeline.

In a report**, Chaplin et al. (2015)** discuss pipeline failure rates due to various factors considering major failure databases of Europe like CONCAWE and EGIG for liquid and gas pipelines of Europe. The report uses 2 models viz., MCPIPIN (Monte Carlo Pipeline Integrity), to determine failure frequencies of major hazard pipelines taking into consideration 4 factors like mechanical failure, ground movement, and other events, corrosion, and third-party damage. The second predictive model considers pipeline failure due to third party interference only.

Pablo et.al., (2015) discuss how limitations of the Bayesian approach can be addressed by adopting a methodology which clearly avoids general arbitrariness in the selection of prior distribution and eliminates any difficulties in the proper use of expert information. Authors relaxed the presumption of a specific prior with the proposed approach, and we used the information gathered from the experts to construct prior classes consistent with their expertise.

It has also been shown (by the authors) that by selecting parameters for optimality, which provide unique values used in rating pipelines according to their need for replacement, a director can make a decision by looking at very simple plots representing a collection of non-dominated behavior.

Bhisham et al., (2015), examined the consequence of a failure of LPG vessel leading to BLEVE and generation of a fireball. Authors demonstrate that how impact assessment of thermal radiation hazards from the liquefied petroleum gas fireball can be assessed through semi-empirical equations and how safe distance from the impact zone can be determined.

Mironov et al. (2015), demonstrate the usefulness of Operational Modal Analysis (OMA) technique in monitoring the health of a pipeline. The writers try to validate the technical approach proposed using two laboratory-based experiments. The use of the OMA technique and the Finite Elements modeling demonstrate that the modal properties for monitoring the pipeline condition are adequate. Experimental data showed that the running pipeline modal parameters acquired from modal analysis techniques could characterize its dynamic characteristics so that modified these characteristics can be used as diagnostic indices for the pipeline model deficiencies.

In this thesis, Lam, (2015) analyses 480,000 km of onshore gas pipeline incident data between 2002 and 2013. The assessment shows that between 2002 and 2013, the average rupture rate was 3.1×10^{-5} /km/year, the major cause of internal corrosion being the rupture rates of 1.0×10^{-5} /km/year.
Drawing upon the above assessment author has created an on-shore gas pipeline logistic model to determine the probability of ignition (POI). The model is validated with an autonomous literature dataset.

In a research paper, **Parvizsedghy (2015),** suggests that while developing a model, all pipeline failure causes are to be considered to determine the risk arising out of a pipeline. Authors use various techniques like Bow-Tie analysis, Probability Theory, Artificial Neural Networks (ANN), Regression Analysis (RA), Neuro-Fuzzy technique, Monte Carlo Simulation (MCS) and Adaptive Neuro-Fuzzy Inference System (ANFIS) and to determine the weight of each factors contributing to a pipeline failure and its consequences. The author also proposes a model from which the maintenance programme of a pipeline can be developed.

Annual report **World Oil Outlook (2016),** published by Oil and Petroleum Exporting Countries (OPEC) contains almost all the data of the global Oil & gas sector for the year 2015-16 in addition to some information on the emerging scenario. Based on the data provided, conclusions can be drawn about the emerging scenario of Oil & Gas business and how pipeline safety and integrity would be a pressing need.

BP Statistical Review of World Energy (2016) contains global Oil & Gas and other energy-related data consisting of production and consumption of various kind of energy and their emerging trend. Analysis of the trend indicates that for the developing nations like India, the Oil & Gas consumption is likely to experience healthy growth throughout the twenties and thirties.

A risk-based maintenance scheme proposed by **Abbassia et al., (2016)** demonstrates how such a scheme can have an impact on direct and indirect economic consequences in terms of shutdowns and unavailability of systems. The model proposes to integrate predictive and preventive maintenance strategies to minimize maintenance interval without compromising operation availability and safety and integrity level of equipment with optimum utilization of resources. The methodology is applied in a power plant as a case study.

In his paper**, Xinhong Li, (2016)** demonstrates how, with the application of bow-tie modelling technique and Bayesian technique a relation can be established between pipeline leakage and likely accident scenario. The authors propose a model based on a Bayesian network to conduct quantitative risk analysis (QRA) for leakage failure of a submarine pipeline. Authors conclude that the Bayesian technique is a more appropriate tool for quantification of leakage risk assessment of a submarine pipeline compared to the Bow-tie technique.

Jun Li et al. (2016) evaluated the failure probability of an urban gas grid by utilizing the AHP and fuzzy network. By the combination of expert opinion and application of fuzzy mathematics on as many as 56 factors, the authors quantified the probability of failure due to each one of the factors. By using the fuzzy set theory, all the risk factors connected to third-party damage to urban gas pipelines were quantified to compute the fuzzy probabilities. The failure probability derived through this model was found to have a reasonable correlation with the data of a gas company

Cunha, (2016) indicated a general risk level of pipelines based on failure data analysis of the USA, Europe, and Brazil. The author calculated failure rates corresponding to corrosion, human action, and natural forces and how they compare with the expected failure rate for the above mechanisms of failure. The frequencies of ignition after a release of content from gas and liquid pipelines were studied, and risk levels evaluated. Consideration is given to i) a risk value that represents good engineering practice, ii) the risk described by the most relevant standard and rules on pipeline risk assessment iii) an analytically derived optimal risk level.

PPAC, MOPNG, Govt. of India, (2016), in their report, provide information on Indian LPG production, supply, and usage data for the year 2015-16. The data is provided by the Ministry of Petroleum & Natural Gas of Govt. of India. The report helps in understanding the growth pattern of LPG use in India

In a report by **PPAC, MOP&NG, Govt. of India, (2017),** annual Petroleum and Petroleum product and Natural Gas production, import, consumption, refining, pipeline transportation, and marketing and distribution data for the year 2016-17 corresponding to India's Oil & Gas sector is provided. Extrapolation of these data indicates the possibilities of significant growth in the oil and gas pipeline in India in the decade starting from 2020.

Trend in Oil & Gas sector and emerging global scenario of Oil & gas and other energy, patterns of consumption, etc. are reported by **CIA, USA (2017**). The data provided by them also indicate significant growth of the Oil & Gas Industry in India in the coming 5 to 10 years.

Dai et al. (2017), analyses and compares pipeline failure data for the USA, Europe, and China to identify primary reasons for failures of long-distance high-pressure cross-country pipeline. The author suggests that based on such analysis, corrective, and preventive measures can be adopted to make pipeline operation safer.

The article reviewed Vapour Cloud Explosions (VCEs) and presented them with the main conclusion that a powerful connection exists between weather conditions, source terms, and cloud growth.

The effects of a vapor cloud explosion could be higher when LP gas is discharged from the pipeline than methane.

The writers could conclude that tiny leaks for a longer time in low wind circumstances can lead to big clouds, which can result in a more high chance of ignition. The authors also comment on the analysis kiss of several incidents of LPG and fuel, which often lead to overpressure impacts leading to the creation of a severe vapor cloud and, therefore, to harm far beyond the spill area. The writers suggest that radiation effects may be one of the main components in many events to comprehend the mechanism of explosion.

Atkinson et al. (2017), concludes that how the availability of new data on vapour cloud explosions may affect risk assessment and emergency planning in the future.

In this paper, **Qiong et al. (2017),** suggests a safety barrier-based model as a supplement to Quantitative Risk Analysis as standard risk analysis techniques in many cases do not concentrate on the causation of the accident. A combination of QRA method and safety barrier-based method is likely to be better as far as overall management of safety in oil and gas plants like pipeline pumping stations

Qiu, et al. (2017), emphasizes the development of a quantitative risk assessment model against third-party damage to gas pipelines. A combination of AHP and Fuzzy Comprehensive evaluation is done to quantify the weight of each of the factors responsible for third party damage and calculate their importance. The authors, however, did not attempt to validate the model on any gas pipeline or pipeline system. Nevertheless, the work provides valuable insight into the process of development of a model for assessing the probability of third-party failure to a pipeline.

In the transportation of hazardous material, the risk is related to the occurrence of accidents, and consequential damage to life and property conclude **Rada et al., (2017)**. The paper also analyzes the potential scenario that may emerge due to such accident and suggest mitigation measures as well as a change in transportation guidelines.

Based on Bayesian Network (BN), a probabilistic analysis model for oil pipeline network was proposed by **Zhang, et al., (2018)**. The model considers nearly all the critical influencing factors of a pipeline accident, e.g., time and location, incident cause, key environment condition, etc. The paper further discusses the deployment rule of the model in consideration of various factors influencing pipeline accidents.

Dai, et al. (2018) compares global statistics on pipeline failure with that of China's. Comparison has been made in areas like several pipeline failures, types of failure, and reasons for failure. The authors conclude that as far as pipeline failure is concerned, China is not much behind the USA and Europe.

10th report of EGIG(2018) analyses failure rates in over 30,000km of European Gas Pipeline, Report considers 3rd party interference, corrosion, ground movement, and other mechanical causes as primary reasons for pipeline incident. The database considered, contains gas pipeline failure data from 1976 till 2016, and projects how various factors of pipeline failure is playing a role

CONCAWE Report 6/18 (2018) extensively analyses spillage data for European pipelines from 1971 to 2016. The report concludes that significant causes of failure of a pipeline has been External Interference. Accidental and incidental third-party events caused 34% of all spills, which is highest among all causes of pipeline failure

Jackson et al., (2018) think that developing a third-party damage prediction model is a complex task as it depends more on human actions than any science like corrosion. In this paper, a Bayesian Belief Network (BBN) based modeling approach is proposed; such a model can incorporate information from sources like failure databases. The approach also permits the incorporation of expert opinion, training, awareness, organization nature, and to make the model better than existing ones.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 OBJECTIVE OF THE RESEARCH

I. To develop a model that calculates the weight of factors contributing to failure of the LPG pipeline in India from third-party interference.

II. To develop an optimized maintenance and inspection programme for LPG pipelines specifically for India

3.2 PROCESS OF THE RESEARCH

To achieve the research objectives the work process followed is indicated below in Fig No.3.1

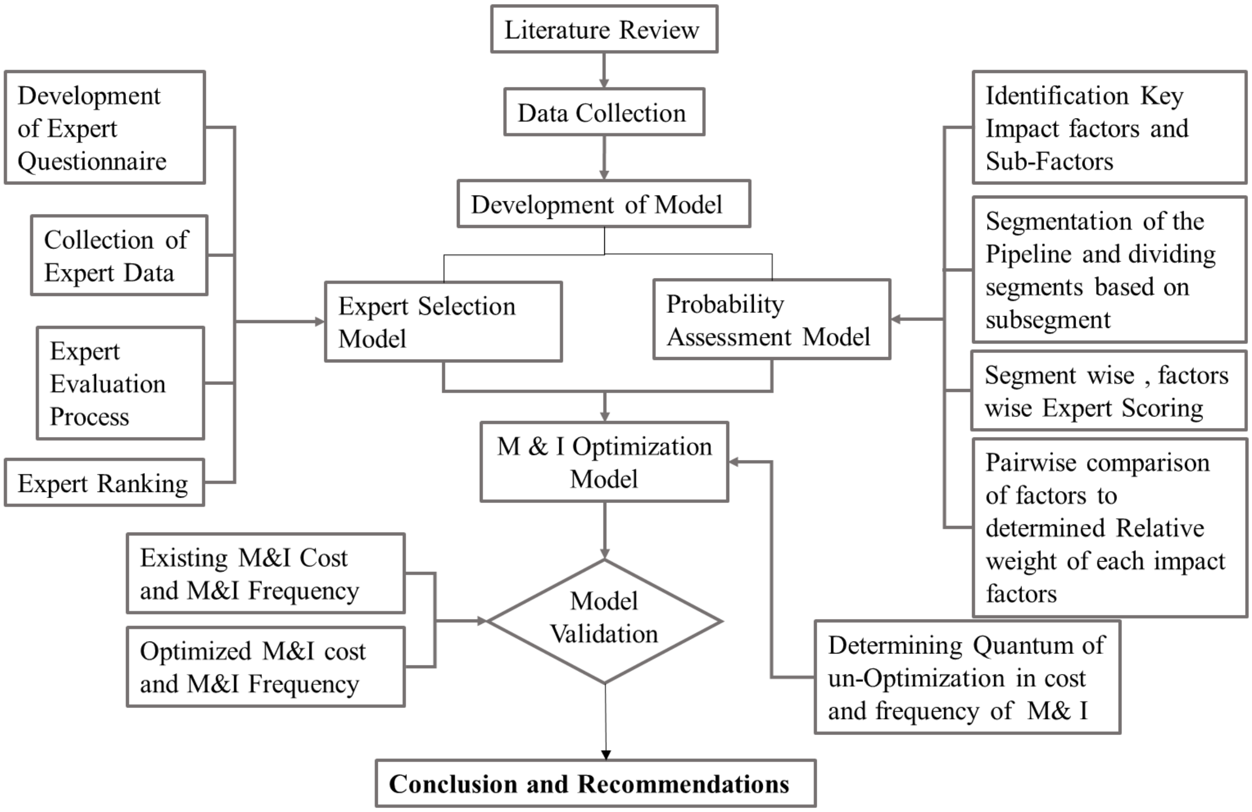


Fig 3-1: Overall Operations Process

To work on the above model, steps that are undertaken are indicated in fig 3.2. These steps shall be executed sequentially. In fig 3.2, steps are indicated along with the source of data/information and purpose of each of the steps. Sub-processes to the primary process for Expert Selection and Optimization are indicated in separate flow charts at fig.3.2 and fig.3.7

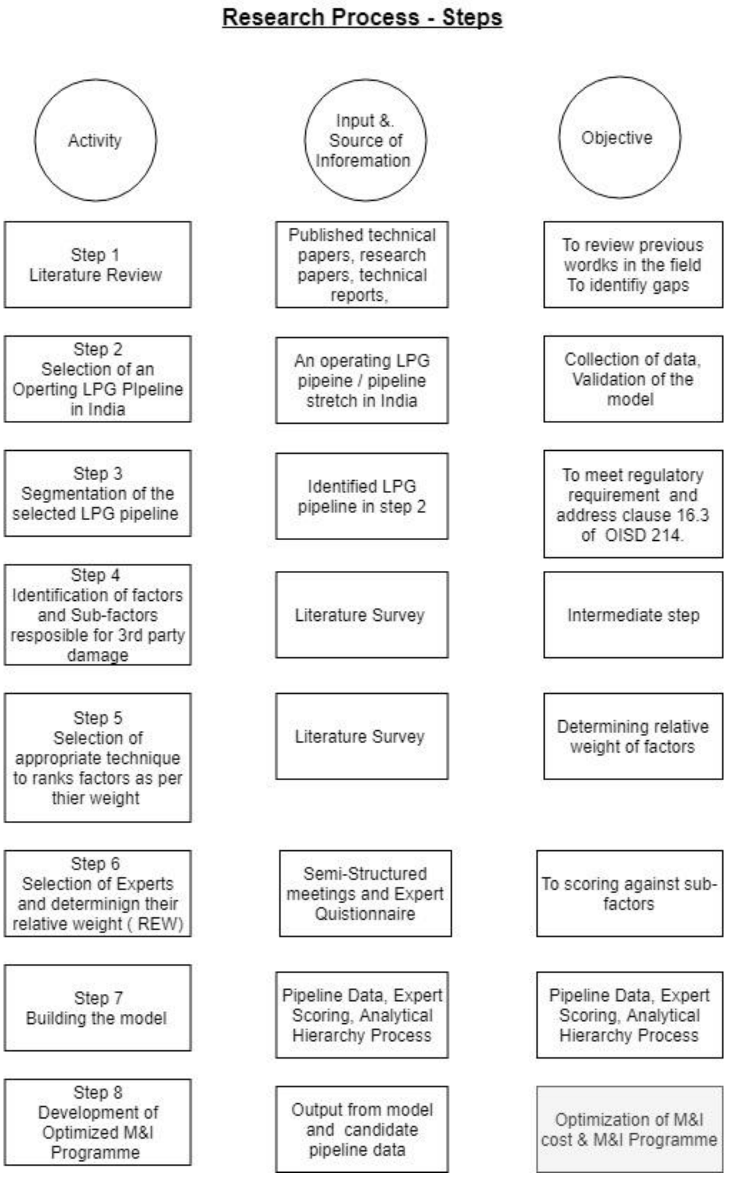


Fig 3-2: Break down of research process

3.3 DESCRIPTION OF RESEARCH METHODOLOGY

3.3.1 LITERATURE SURVEY & REVIEW

Literature review, primarily included 3 types of documents, technical articles, technical reports and codes and standards published by API, ASME, OISD, PNGRB, etc. Certain in-house documents of Indian Oil Corporation Ltd. (IOCL) were also referred in order to understand certain design concepts of the selected pipeline.

Primary purpose of the literature review was to get an idea about the prime causes of pipeline failure, factors responsible for third-party damage to a pipeline, current design practices adopted by pipeline operators, Maintenance & Inspection (M&I) practices and applicable regulations for the safe operation of LPG pipelines in India and their M & I requirement. as per regulatory guidelines applicable in India. A detailed literature review can be found in Chapter 2.

3.3.2 SELECTION OF THE PIPELINE

As of December 2018, the total length of cross-country hydrocarbon pipelines in India is little more than 43,600km, Ready Reckoner (2018), out of which 2847km are LPG pipelines. Furthermore, several reports from oil companies in the public sector state that another almost 13 800 kilometers is undergoing development or final phases of building and about 6800 kilometers of liquid pipelines and about 4400 kilometers of GLS pipeline.

Table 3.1: Major Operating LPG Pipelines in India

Name of the Pipeline	Owned and Operated By	Length (Km)	Capacity (1000 MT/Year)
Mumbai-Uran Pipeline	BPCL	28	800
Panipat- Nabha- Jalandhar Pipeline	IOCL	274	700
Mangalore-Mysore-Solur Pipeline	HPCL	356	1940
Jamnagar-Loni Pipeline	GAIL	1414	2500
Vizag-Secundrabad Pipeline	GAIL	618	1330
Paradip-Balasore Pipeline	IOCL	157	503
Source = Ready Reckoner, PPAC, India, June 2018			

For the present study Panipat – Nabha section of the LPG pipeline operated by IOCL is selected as a candidate pipeline for validating the proposed model. The pipeline under examination is 135km long 10inch diameter LPG pipeline, located in the populous northern region of India. There is no specific reason for selecting this section of the pipeline; however, ease of access to data is one of the primary considerations. For the study selected pipeline shall is divided into multiple segments based on the locations of mainline sectionalizing valves. This pipeline section is in operation since 2008 and constructed as per ASME B31.4, 2016 and OISD -214. The maintenance of the pipeline is done as per OISD -214, applicable standard in India for LPG pipelines. The pipeline is having a diameter of 10inch OD, and nominal wall thickness 0.219 inches (5.3mm) at normal terrain. At unique terrains like high consequential areas, the wall thickness varies between 0.375 inch and 0.438 inch depending on the design standard the corresponding permitted stress level for the LPG pipeline. The design stress level permitted at normal terrain is 72% of Specified Minimum Yield Stress (SMYS) whereas in such areas where reperceived risk level is higher, the design stress levels permitted are less than 72% SMYS, usually in the range of 40% of SMYS [class locations as per ASME B31.8, PNGRB T4S standard].

Designed operating pressure for a pipeline is determined using the equation given below.

$$Sf.S = \frac{PD}{2t}$$ [3.1] (refer. ASME B 31.4 / OISD -214 / PNGRB T4S]

For determining operating pressure, equation 3.1 can be modified as below

$$P = \frac{SF.S\ x\ 2t}{D} \qquad [3.2]$$

$Where,$

S =specified minimum yield strength(SMYS), a property of the material of pipe

Sf= Factors of safety on the SMYS, generally considered as 0.72 but shall be different for high consequence areas for example 0.40

P = Design Pressure

t= Nominal Pipe wall thickness

To get the same operating pressure at different stress levels t [pipe wall thickness] in equation 3.2 can be changed. As apparent from equation 3.2, design pressure *P* is directly proportional to nominal pipeline wall thickness.

A lower stress level is suggested considering the safety of life and property, and reduction in the probability of release of pipeline content (reduction in the probability of failure). The specification of the pipe used in the candidate pipeline section conforms to API 5 L standards for Line Pipe, designated as API 5LX46, electric resistance welded (ERW) type. The nominal wall thickness of the pipeline is 0.219inch; however, depending upon the class location, it varies up to 0.437inch. To prevent corrosion from the soil side, the pipeline is externally coated with double-layer fusion-bonded epoxy (DFBE). Over and above DFBE coating, the pipeline is provided with impressed current type cathodic protection as a second line of defense against external corrosion. The pipeline in normal terrain is buried at a depth of 1.2m below the ground. In more critical (from the point of view of 3rd party damage) locations the depth of cover could as high 1.5m or even more. The design pressure (or Maximum Allowable Operating Pressure-MAOP) of the pipeline is 99kg/ cm^2 while Maximum Operating Pressure (MOP) is in the range of 70kg/cm^2

3.3.3 SEGMENTATION OF PIPELINE

One of the practical ways to segment a pipeline for its failure probability study is to consider each stretch of pipeline falling between mainline isolating valve to valve sections as one segment. Generally, mainline sectionalizing valves are provided in any cross-country liquid pipeline at a maximum interval of 30 to 35km (there are significant exception to this rule, for example, mainline valves are placed on either side of major waterway crossing and in such other sensitive area), under special considerations like high consequence area, watercourses, variation in pipeline profile like sudden steep rise or fall locations of mainline sectionalizing valves can change. In some cases, these can be as close as 500metre (across waterways) also.

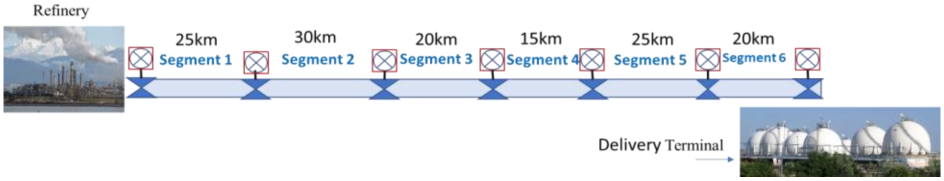


Fig 3-3: Pipeline Segmentation Scheme

LPG pipelines are designed and constructed as per ASME B 31.4, 2016 (also as per OISD 214, 2013), Pipeline Transportation System for Liquid and Slurry, clause 434.15.2 e) of suggests the following *"In order to facilitate operational control, limit the duration of an outage, and expedite repairs, mainline block valves shall be installed at 7.5 miles (12 km) maximum spacing on piping systems transporting LPG or liquid anhydrous ammonia in industrial, commercial, and residential areas*".

In the pipeline section under consideration for the present work, the mainline valves are randomly placed, reasons for this deviation could not be found out. (this design shortcoming is now being addressed through the installation of additional block valves in the pipeline]) Probably, valve spacing requirement specified under clause 434.15.2 e) of ASME B 31.4 has been incorporated in the 2016 version of the standard, prior to which there was no such requirement for LPG pipelines.

As on date, the LPG pipeline under discussion has mainline valves at random distance of 25km, 30km, 20km, 15km, 25km, and 20km, as shown in fig 3.3 above. For this research, the pipeline is divided into six (6) valve to valve segments, as indicated in figure 3.3 above.

3.4 FACTOR RESPONSIBLE FOR 3RD PARTY DAMAGE

To identify the key factors responsible for third party damage of a pipeline, reference has been made to major international databases on pipeline failure, e.g., CONCAWE(2018), EGIG(2018), and international standards like ASME B31.4, OISD-214 and PNGRB T4S, etc. Also, reference has been made to a large number of papers and articles (by pipeline experts) on pipeline failure analysis, pipeline maintenance, pipeline risk assessment, and modeling techniques have been reviewed. Some of the key references deals on pipeline failure data collected over a period of more than 40 years viz., Mather, Blackmore et.al (2001), Horalek (2006), Chaplin and Howard (2015), Hopkins (2005), Jackson et.al (2018), information provided in PHMSA, USA database, National Transportation Safety Board, USA, "Failure Investigation Report – Central Florida Pipeline 10-inch Jet Fuel Pipeline Failure", 2012 and National Energy Board (NEB) reports were also reviewed in detail.

Based on the above study it was concluded that following are the key factors upon which the possibility of third-party damage largely depends

1. Depth of Cover
2. Population Density
3. Land use pattern
4. Wall thickness of the pipe
5. Public Awareness Level

For the present work, each of these factors is further divided into sub-factors [fig 3.4] that are the controlling variables upon which the significance of primary factors largely depends. The factors and their corresponding sub-factors can be seen in figure 3.4

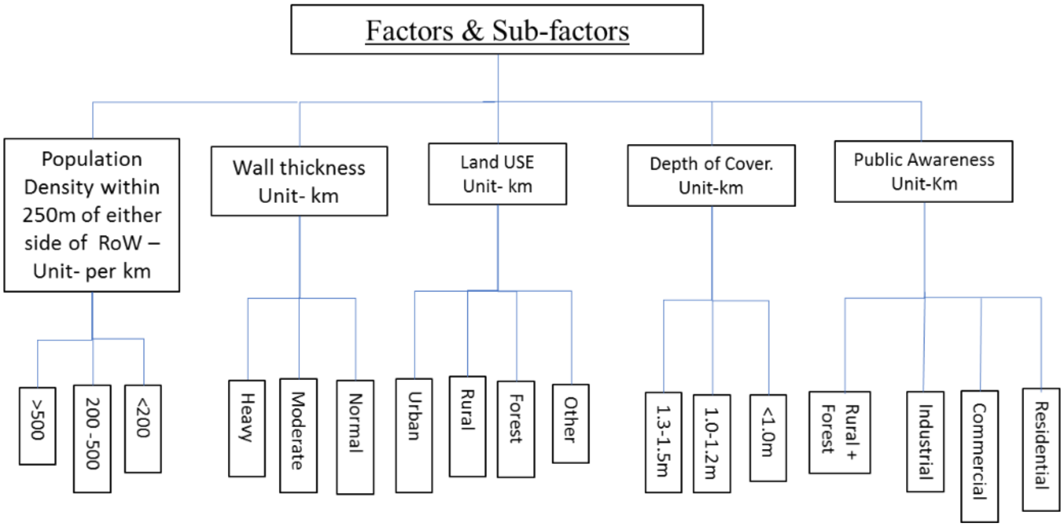


Fig 3-4: Factors and Sub-factors

There are 17 sub-factors in total; these sub-factors are connected to the parent factors, as indicated in fig 3.4. Sub-sector against each of the factors are the ones on whom the characteristic behaviour of the primary factors depend. The spread of the sub-factors is captured in terms of length in km. For the pipeline section selected for this study, table 3.2 indicates the segment-wise distribution of sub-factors.

Values shown in Table No.3.2, against each of the sub-factors (all values are in km.) means the pipeline stretch in km, where a particular sub-factor is present, for example within segment 6, factor population density, sub-factor >500 has a value of 8, this means over a length of 8km of the pipeline (in segment 6) has a population density of more than 500 persons/sq. Km A second example, for the factor Depth of Cover, sub-factor <1m, segment 1, the value indicated is 2, in table 3.2, this would mean over a length of 2km (may not be in a continuous stretch) of the pipeline the depth of cover is less than 1m.

Table 3.2: Value of the variable sub-factor in all the 6 pipeline segments

Factor	Sub-factors	Segment					
		1= 25km	**2= 30km**	**3= 20km**	**4=15km**	**5=25km**	**6=20km**
Population Density (PD)	>500	11	7	19	5	6	8
	200-500	6	20	7	8	14	9
	<200	8	3	3	1	1	3
Wall thickness	Heavy	3	6	4	0	5	0
	Moderate	2	6	0	0	6	0
	Normal	20	18	16	15	14	20
Land Use	Urban	19	6	5	1	10	3
	Rural	4	20	14	14	8	16
	Forest	2	4	0	0	2	0
	Others	0	0	1	0	5	1
Depth of Cover (DC)	1.3-1.5m	5	7	5	2	3	1
	1-1.2m	18	23	14.5	13	22	19
	<1m	2	0	0.5	0	0	0
Public Awareness	Rural+ Forest	6	24	5	10	5	16
	Industrial	3	0	4	0	5	0
	Commercial	2	1	2	1	5	2
	Residential	14	5	9	4	10	2

Note: all figures in km, Source of data = Design and O&M manual of the owner

3.4.1 ANALYSIS OF THE BEHAVIOUR OF PRIMARY FACTORS

Depth of cover

Increasing the depth of the burial of pipelines can reduce the possibility of external interference. Hopkins (2005) in a study indicated that if the depth of burial is increased from 1.2m to 2.2m the likelihood of third party damage gets reduced by more than 10 times.

Table 3.3: Frequency of third-party damage failure of pipeline per depth of cover, Hopkins (2005)

Depth of cover (m)	Failures (Number)	Frequency of failure (1000) km-yr)$^{-1}$
0-0.8	103	0.7430
0.8-1.0	248	0.2320
>1.0	120	0.1560

For the pipelines in India, the depth of cover considered at the design and construction stage is based on the guidelines given in table 3.4 below

Table 3.4: Minimum recommended earth cover over buried pipeline [OISD-214]

Locations	Min. Cover in (m)	Reference Note
Commercial, Industrial & Residential areas	1.20	2
Streams, Canals & minor water crossings	1.50	4
Drainage ditches at roadways & railways	1.20	2
Rocky area	1.00	2
Uncased / Cased Road crossing	1.20	3
Railway crossing	1.70	3
River crossing (below scour level)	2.50	2,5
Other areas	1.20	2

However, over a period of time, such depth of cover as conceived at the time of design and available on the first day of operation may undergo change (due to soil erosion, flood other natural reasons as well as due to human activities)

Land use pattern

As far as third-party damage to a buried pipeline is concerned, the land use pattern has a significant role to play. Report of CONCAWE (2018) summarised in Table 3.5, hereunder, indicates the kind of impact land use pattern has on pipeline failures due to third party activities.

Table 3.5: Location wise percentage of failures, CONCAWE(2018)

S.NO	Area/Locality	Data from CONCAWE (%)
1	Rural	77
2	Industrial	17
3	Residential	5
4	Commercial	1

From the table, 3.3 it is apparent that a significant percentage of pipeline incident due to third-party damage is in rural segment, but when seen together with the data in table 3.4, it is clear that rate of incident (in terms of per 1000km) is more than double in urban areas. The reason for this is high human activities in urban areas compared to rural segment. A similar trend is observed in the case of the number of oil spill incidents in various categories of land use, as indicated in Table 3.7. As such, land use pattern is one of the primary factors as far as third-party damage to the buried pipeline is concerned.

Table 3.6: Failure Frequencies per 1000km per geographical areas, Hopkins (2005)

S. No	Locality	Frequency of failure/1000 km
1	Urban	0.66
2	Rural	0.25

Table 3.7: Location wise oil spill incident 1971 to 2016, CONCAWE (2018)

Locality type	No. of Oil Spill Incident		
	Number	%	Remarks
Residential	17	4	Less number due to a lower overall length of pipeline present

Rural	290	75%	A higher number due to the longer length of pipeline cuts across rural areas
Industrial	83	21%	Less number due to a lower overall length of pipeline present

The above data confirm that the probability of failure in the urban areas is higher than that in the rural areas, though in terms of absolute numbers more failures happen in the rural areas. Thus, land use pattern plays an important role in third-party damage to a pipeline

Wall Thickness

Most of the pipeline failure due to third-party damage is due to digging by excavators or other similar machines. Probability of whether a pipeline shall develop a dent on being hit by an excavator or similar equipment or a crack within a dent would depend to a large extent on pipe wall thickness. Selected pipeline failure data from the UK, Hopkin(2005) indicate in the following Table 3.8.

Table 3.8: Pipeline Failures in UK and Pipe wall thickness

Pipe Thickness (mm)	Frequency/1000km-yr
0 to 10	0.20
>10	0.09

Data in table 3.8 indicate the significance of wall thickness in the reduction of the possibility of pipeline failures. The general relation that comes out from the above is higher the pipe wall thickness lowers the possibility of failure.

European Pipeline Research Group has also carried out considerable work on the role of higher pipe wall thickness in preventing third-party damage to the pipeline. They have come out with a formula based on their research findings, that shows benefits of increased pipe wall thickness vis-à-vis resistance of pipe puncture from a third-party hit, Hopkin (2005)

Quote

” Pipeline puncture resistance = $[1.17-0.0029(D/t). (1+w). (t. \sigma_u)]$

Where:

t = pipe wall thickness

D = pipe outside diameter
l = length, width of the digger tooth
σ_u = ultimate tensile strength”

Unquote

Table 3.9: Third Party activity: Failure Frequency against wall thickness, Hopkin(2005)

Wall thickness(mm)	Failure Classification(1000km-yr)$^{-1}$		Total (1000 km-year) $^{-1}$
	Leak	Rupture	
0 to 5	0.450	0.170	0.620
5 to 10	0.130	0.040	0.170
10 to 15	0.020	No data	0.020
15 to 20	No data	No data	No data

Similar conclusions can be made from the data given in table 3.9. Therefore, it can be established that an increase in pipe wall thickness reduces the possibility of pipeline failure from third-party damage.

Population density

Population density plays a significant role as far as third party damage is concerned; higher population density results in higher human activity thereby increasing chances of third-party damage. Considering this aspect applicable engineering standards like OISD -214, ASME B31.4, and ASME B 31.8, PNGRB regulations suggest various class locations based on population density along the pipeline route and consequently recommends specific design safety factors (refer equation 3.1) for specific class locations to reduce the possibility of pipeline failure. That population density is a critical parameter can also be seen from tables no 3.4, which indicates that more than half of all failures due to third party damage are in urban areas where population densities are higher compared to rural areas.

Public Awareness Level

One of the methods to enhance public awareness level on the susceptibility of a buried pipeline to failure from wanton public activities is widescale public advertising and organising community contact programmes. Historically, reductions in third-party damage cases are largely attributed to increase in interaction with utilities (power cables, water lines etc.) before the commencement of their activity Jackson et .al (2018).

Public awareness level plays an important role in ensuring the safety of such industrial activities that come into frequent contact with communities residing in the vicinity e.g. railways, motorways, and pipelines. While Railways and Motorways are visible, a pipeline is buried underground, as a result, need for enhanched public awareness is even more in case of a pipeline .

US Department of transportation guidelines in this regard is "Provide safe reliable service to the customer and ensure the safety of the people living in/or working near the pipelines. Every employee must be committed to fulfilling public awareness responsibilities". The standard is API RP 1162- Public Awareness Programme for Pipeline Operators. In India, Public safety against failures of a pipeline is covered under PMP Act 2012, and other regulations of PESO (Petroleum and Explosive Safety Organization).

3.5 MODEL DEVELOPMENT

In fig 3.5 the entire model of the study is depicted. Pipeline data is obtained from the owner's design and O&M manuals. The data sourced from the pipeline owner is indicated in table 3.2. This data corresponds to the subfactors that are under various prime factors (5 in number). Each segment (total 6 segments) is evaluated for the probability of third-party failure, against all the 5 factors and 17 sub-factors. The evaluation is done by 4 experts (expert selection process is described separately). Each expert would give marks against all the 17 sub-factors in a scale of 0 to 10 (as they deem fit) for 6 segments.

Total marks scored by a segment (given by 4 experts) are normalized per km by dividing with segment length. Among the 5 factors score of factor Depth of Cover is considered equal to 1 and other 4 factors are rationalized based on their respective per km score, with respect to per km score of Depth of Cover considering it equal to 1. The rationalized values of all the segments (for all the experts) are then considered for pairwise comparison through the Analytical Hierarchy Process (AHP).

AHP is selected as a tool for determining the relative weight of the factors because of its inherent design to accept expert opinion and overcome limitations of lack of availability of data. There are other techniques like Bayesian theory-based techniques, Fuzzy set theory-based techniques, Event Tree methods etc., these techniques have been used by various experts primarily in risk analysis field but for the current works literature survey indicate that AHP is the most popular technique among researchers in the field.

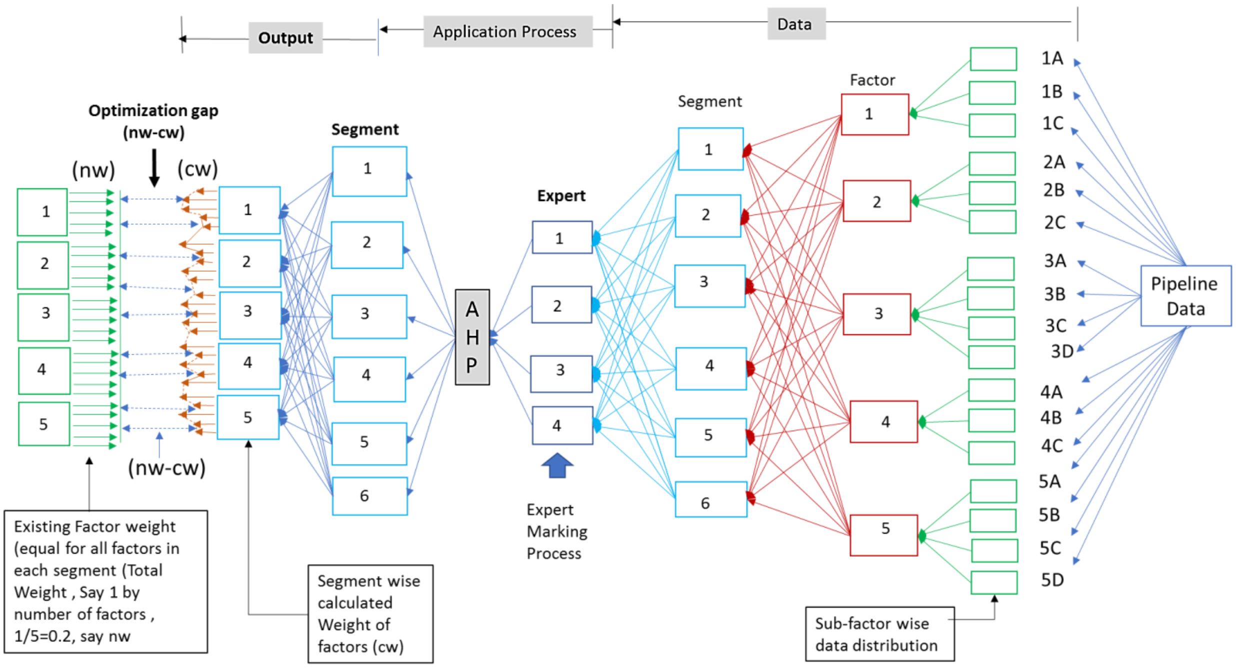


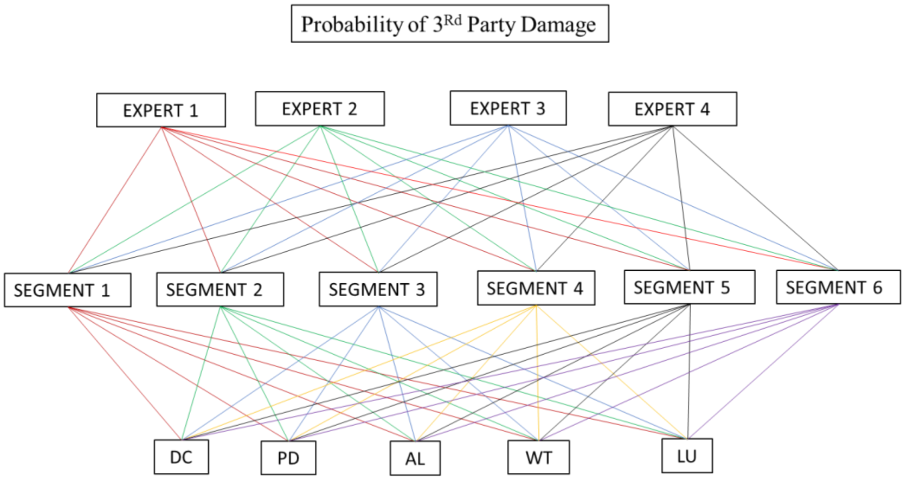
Fig 3-5: Model for Optimization of M&I

3.6 THE ANALYTICAL HIERARCHY PROCESS (AHP)

AHP is one of the common approaches for multi-criteria decision-making (MCDM) that involves qualitative data. It has been commonly implemented in making a choice in separate fields for over two decades. The technique utilizes a matrix of reciprocal choice acquired through pairwise comparisons in order to provide the data in a linguistic form.

The comparative method was first implemented in 1860 and later developed and almost established by 1930. Based on the comparative method, Professor T.L.Saaty suggested an approach to multi-criteria decision-making with the Analytical Hierarchy Process (AHP). It offers a logical way to sub-divide the overall issue into an array of more easily evaluated sub-problems.

A comparison of different criteria is described in pairs under AHP as described below in Alonso (2006). Criteria and alternative options are presented pairs of one or more judges (for example, specialists or decision-makers) in the parallel comparison technique. Alternatives to derive weights by each individual expert must be evaluated and the final rating of the alternatives must be established and the best determined. When you refer, for example, to A1 A2,..., An (the number of alternatives compared), their weights are as follows: X1,X2,...,Xn, and the matrix of all weights by



Population Density =PD, Land Use =LU ,Wall Thickness of the pipe = WT, Awareness Level =AL, Depth of Cover = DC

Fig 3-6: proposed hierarchical structure of AHP network for the present study

$$W = [Xi/Xj] = \begin{vmatrix} \mathbf{X_1/X_1, X_1/X_2 \ldots\ldots\ldots} & & \mathbf{X_1/X_n} \\ \mathbf{X_2/X_1,/X_2/X_2 \ldots\ldots\ldots} & & \mathbf{X_2/W_n} \\ - & - & - \\ - & - & - \\ - & - & - \\ \mathbf{X_n/X_1,\ Xn/X_2} \ldots\ldots\ldots & & \mathbf{X_n/X_n} \end{vmatrix}$$

The matrix of parallel comparisons (Ai vs Aj, for all I j=1,2,3... n) reflects the potential of expert choice between each pair. They are usually selected in a single scale (1/9, 1/8...., 8,9). Give n options{ A1, A2,......... An} to assess alternative pairs for all possible pairs and to generate a comparative matrix A where the element aij demonstrates Ai's preferences, acquired in relation to Aj, and Aj.

$$A = \left[a_{ij}\right] = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2j} & \cdots & a_{2n} \\ . & & & & & \\ 1/a_{1j} & 1/a_{2j} & \cdots & a_{ij} & \cdots & a_{in} \\ . & & & & & \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1/a_{in} & \cdots & 1 \end{pmatrix}$$

For this thesis, the steps involved in the preparation of a pairwise comparison matrix include:

1. Create the basic matrix as indicated in fig 3.6 above
2. Carry out normalization by adding each column of the matrix and dividing such element under the column by the sum of that column to get a normalized matrix
3. Add each row of the normalized matrix
4. Verify consistency of the base matrix say C

Procedure for checking the consistency

Determine a weight sum vector W_s

$$\{W_s\} = [\ C.\ W]$$

Find the Consistency Vector

- Dot product {consistency} = $\{W_s\}.\ \{1/W\}$
- Determine the average of elements of {consistency} = λ

- Determined consistency index = CI
- CI=(λ -n)/ (n-1), where n is the number of criteria
- Determine consistency ratio (CR)

$$CR= CI/RI,$$

Where RI is Random Index, its value varies with the number of factors compared, **n**. The random Index value for the various number of factors is available in many works of literature on AHP, Alonso (2006). If CR <0.10, ranking in the matrix C is considered consistent, else the comparison should be recalculated.

3.7 SELECTION AND RANKING OF EXPERTS

Once the segments are made and key factors identified, 4 reputed and experienced experts are identified from the different field of Pipeline Engineering viz. Pipeline Design, Pipeline Operation, Pipeline Maintenance and Pipeline Construction.

The Expert nomination process is a semi-structured process wherein responses of experts are collected in a format [fig.3.7]. Prior to the collection of expert details, 20 experts were called for a meeting to explain the objective of this work and the importance of expert opinion.

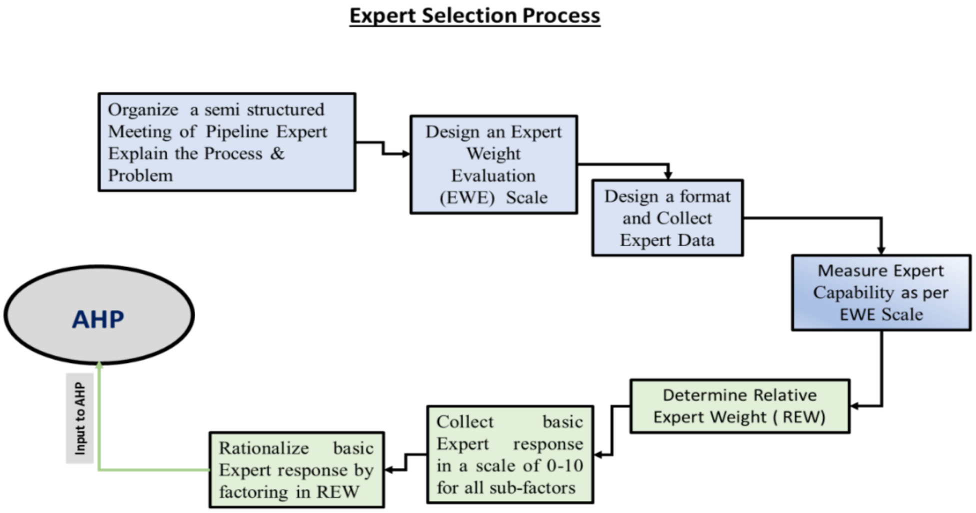


Fig 3-7: Process flow for selection of experts

Expert Response Questionnaire (ERQ) was circulated among 20 experts (Expert Data is given in Appendix 2). Based on the response (in the format), half of the initial batch of 20 experts i.e., 10 (selected based on their years of service) were evaluated against 4 criteria Subject Knowledge (SK), Subject Experience (SE), Source of Information (SI) and Sign of Bias (SB), Li et.al (2016). For each of these 4 parameters, marks are awarded in line with the marking criteria indicated in Table 3.10.

Table 3.10: Evaluation Criteria for Experts

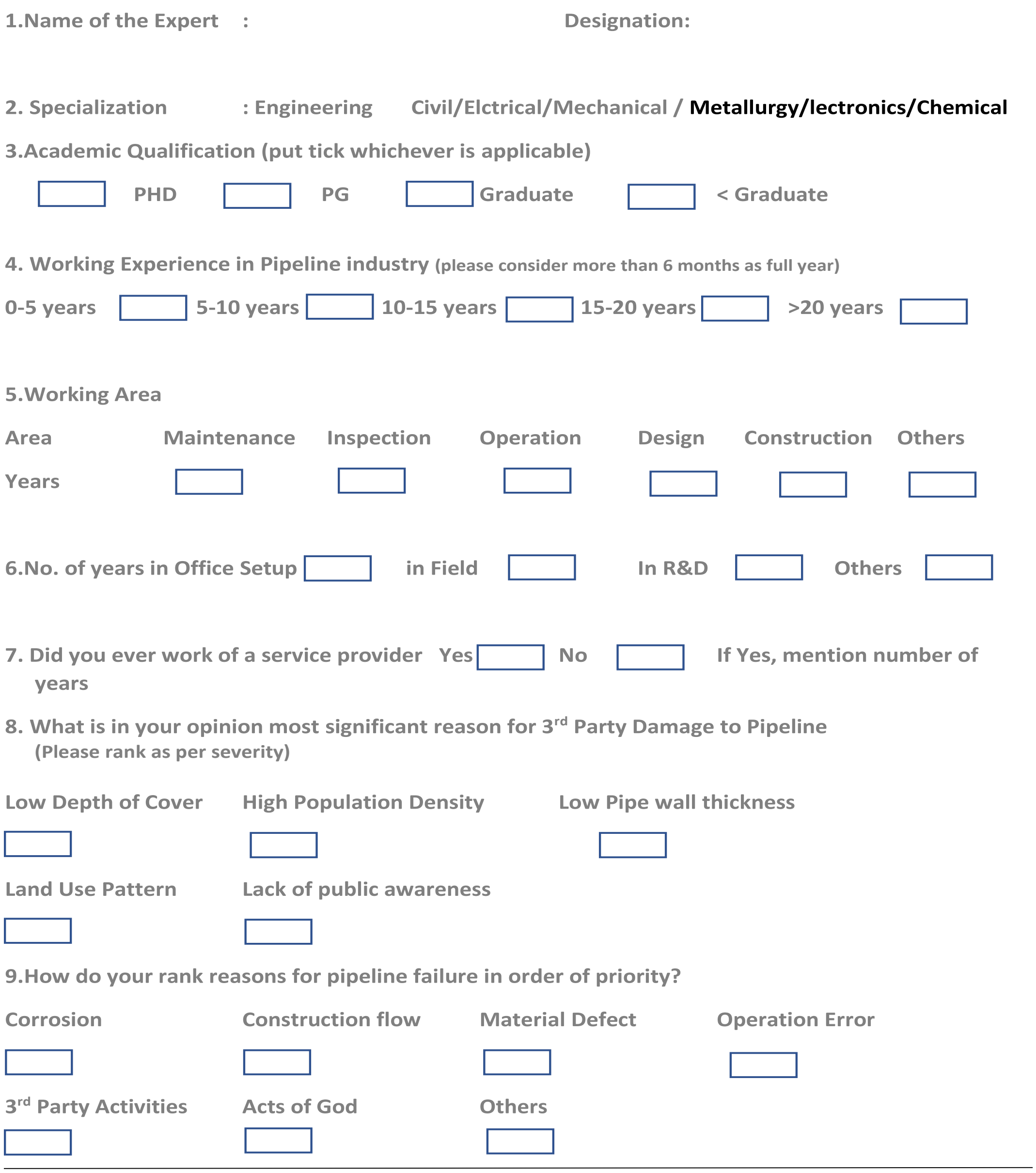
SK	Q	>PG	PG	G	<G	Q = Qualification, PG- Post Graduate, G=Graduate, M=Marks SK= Source of Knowledge
	Marks	7	5	3	1	
SE	Years	>20	15-20	10-15	<10	Years of experience SE= Source of Experience
	Marks	7	5	3	1	
SI	Source	F+T	F	T	UN	F=Field, T=Theoretical, UN= Not Known SI=Source of Information
	Marks	7	5	3	1	
SB	Severity	VL	L	M	H	VL=Very Low, L=Low, M=Medium, H=High SB= Source of Bias
	Marks	7	5	3	1	

4 highest scoring experts were selected to for giving value (in a scale of 0 to 10) against each of the 17 sub-factors for 6 segments. The values are to be given on a scale of 0 to 10 as the experts deem fit. For rationalization purpose expert with the highest score is considered to have a Relative Expert Weight (REW) =1, REW of rest of the 3 experts are determined considering their score with respect to the highest scoring expert. The relative weight of the 4 experts are given in table 3.11

The purpose of determining REW is to rationalize values given by each expert (considering that all the 4 experts are not having an equal degree of expertise) against a subfactor. For example, for segment 1 subfactor population density, if Expert 1 award a value (from 0 to 10) 7 then the same value shall be retained and considered as normalized value, however, if the value 7 is given by expert 2 the same shall be multiplied by his (Expert 2’s) REW factor which is 0.92 (table 3.9) so the final value would be 7 x 0.92= 6.44 (if the fraction is greater than 0.5 it shall be considered as 1) thus 6.44 shall be considered to have a value 6.

On the presented data, expert scoring scale indicated in Table 3.8 was employed and the final expert score is determined. The scores are then rationalized to determined REW considering the highest scoring expert having a REW=1, REW of the rest 3 experts are determined as given in Table 3.9

$$REW = \frac{\% Max\ (n,n+1\ldots\ldots N+3)}{\% Max\ n} \qquad \textbf{[Equation 3.1]}$$



1.Name of the Expert : Designation:

2. Specialization : Engineering Civil/Elctrical/Mechanical / **Metallurgy/lectronics/Chemical**

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☐ Graduate ☐ < Graduate

4. Working Experience in Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 10-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☐	☐	☐	☐	☐	☐

6.No. of years in Office Setup ☐ in Field ☐ In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☐ If Yes, mention number of years

8. What is in your opinion most significant reason for 3rd Party Damage to Pipeline (Please rank as per severity)

Low Depth of Cover ☐

High Population Density ☐

Low Pipe wall thickness ☐

Land Use Pattern ☐

Lack of public awareness ☐

9.How do your rank reasons for pipeline failure in order of priority?

Corrosion ☐

Construction flow ☐

Material Defect ☐

Operation Error ☐

3rd Party Activities ☐

Acts of God ☐

Others ☐

Fig 3-8: Expert Data Collection Format

Table 3.11: Details of expert for data collection

Expert Selection			SK				SE					SI				SB	
S.No.	Personal Profile		Qualification				Service Length					Work Profile				Service Type	
	Name	Stream	PHD	PG	G	<G	0-5	5-10	10-15	15-20	>20	Offce	Field	R&D	Others	Owner	Service
1	Dr. C.Kannan	Metallurgy	yes	-	-	-	-	-	-	-	31	0	0	31	0	YES	NO
2	Mr. S C Thakur	Electrical	-	-	Yes	-	-	-	-	-	32	14	18	0	0	YES	NO
3	Mr. R.D Sabherwal	Metallurgy	-	-	Yes	-	-	-	-	-	31	10	18	0	0	YES	NO
4	Mr. Atul Parmer	Electrical	-	-	Yes	-	-	-	-	19	-	2	18	0	0	YES	NO
5	Mr. Rajeev Sharma	Electrical	-	-	Yes	-	-	-	15	-	-	1	14	0	0	YES	NO
6	Mr. Amit Kumar	Mechanical	-	-	Yes	-	-	-	-	16	-	2	14	0	0	YES	NO
7	Mr.Ayon Roy	Metallurgy	-	yes	-	-	-	-	-	18	-	1	17	0	0	YES	NO
8	Mr. S.P.Yadav	Metallurgy	-	yes	-	-	-	-	13	-	-	10	3	0	0	YES	NO
9	Mr. Deepak Kr. Agarwal	Electrical	-	yes	Yes	-	-	9	-	-	-	2	7	0	0	YES	NO
10	Mr.Dipak Agarwal	Metallurgy	-	-	Yes	-	-	-	11	-	-	5	6	0	0	YES	NO
11	Mr.Santosh Kumar	Metallurgy	-	-	Yes	-	-	-	11	-	-	9	2	0	0	YES	NO
12	Mr.Rakesh Mahato	Electrical	-	-	Yes	-	-	10	-	-	-	6	4	0	0	YES	NO
13	Mr.Niraj Kumar	Metallurgy	-	-	Yes	-	-	8	-	-	-	1	7	0	0	YES	NO
14	Mr.Sayan Roy	Electrical	-	-	Yes	-	-	7	-	-	-	1	6	0	0	YES	NO
15	Mr.M.K. Meena	Electrical	-	-	Yes	-	-	7	-	-	-	0	7	0	0	YES	NO
16	Mr.Mohit Garg	Mechanical	-	-	Yes	-	-	7	-	-	-	3	4	0	0	YES	NO
17	Ms.Mamta Chiniya	Electronics	-	-	Yes	-	5	-	-	-	-	1	4	0	0	YES	NO
18	Mr.Ankit Kumar	Mechanical	-	-	Yes	-	5	-	-	-	-	2	3	0	0	YES	NO
19	Mr.Pushp Raj Patel	Electrical	-	-	Yes	-	-	6	-	-	-	2	4	0	0	YES	NO
20	Mr.Vivek Kumar	Mechanical	-	-	Yes	-	4	-	-	-	-	0	4	0	0	YES	NO

Table 3.12: Expert ranking

Parameters	Expert 1	Expert 2	Expert 3	Expert 4
Max	28	28	28	28
Score	26	24	22	20
% of Max.	0.93	0.86	0.79	0.72
REW	1	0.92	0.85	0.77

3.8 OPTIMIZATION

The above-developed model was applied in an actual pipeline (described under clause 3.3.2) considering two aspects

1. Surveys/ actions currently adopted by the owner to prevent third-party damage to the pipeline and expenditure incurred thereof.
2. Frequency of the surveys/ actions taken by the owner to prevent third-party damage to the pipeline

Under the current system, the owner considers all the 5 factors on which the possibility of third-party damage depends, to have equal weight in all 6 segments. To elaborate the matter, under the existing system for a segment 1 is considered the total weight of the 5 factors responsible for third party damage in the segment, in such an event it can be assumed that each factor is having a weight equivalent to 1/5 =0.20. Under the proposed model, the weight of each of 5 factors is determined separately. The variation in the weight of individual factors determined through the proposed model and the average weight of 0.2 is considered the optimization gap or degree of un-optimization. Therefore, a mathematical equation can be developed to measure the extent of un-optimization. If $\boldsymbol{n_w}$ is termed as average weight (0.20 in the present context), and if calculated factor weight is termed as $\boldsymbol{c_w}$ the equation can be written as

$$\boldsymbol{U_n = \frac{n_\omega - c_\omega}{n_\omega}} \qquad \text{[Equation 3.2]}$$

Where $\boldsymbol{U_n}$ *is* the degree of un-optimization. Thus, the measure of un-optimization (U_n) can be used to work out optimized M&I expenses towards control of third-party damage as well as optimizing the frequency of M&I activities. Prior to this, however, the present practice of M&I activities followed in the pipeline under examination has been reviewed.

CHAPTER 4: MODEL DEVELOPMENT & APPLICATION

4.1 PROCESS OF VERIFICATION OF MODEL

For verification of the developed model, the approach indicated in fig 4.1 is adopted. As can be seen from the process map, the first step is to identify the expenditure incurred by the pipeline owner under the head of Maintenance & Inspection (M&I). Before, this the M&I Practices adopted by the owner are to be identified and reviewed.

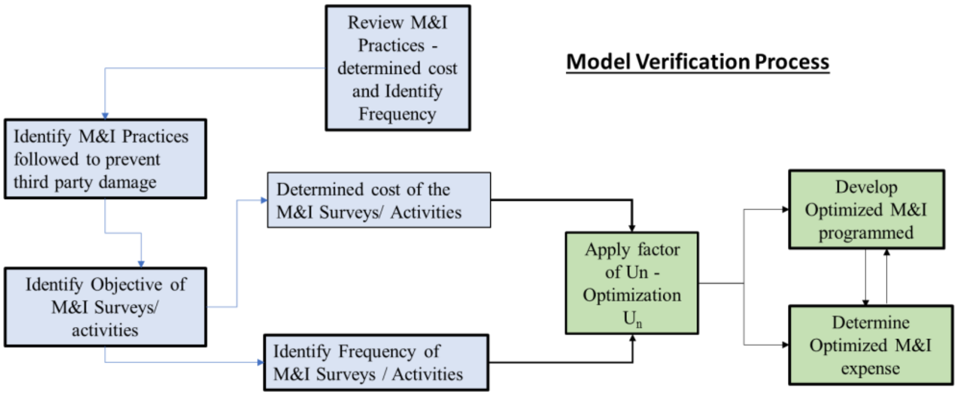


Fig 4-1: Model Verification Process

4.2 MAINTENANCE & INSPECTION PRACTICES

The primary factors responsible for third party damage are

1. Depth of Cover,
2. Population Density,
3. Awareness Level,
4. Wall Thickness,
5. Land Use pattern

To manage these 5 factors, the pipeline owner (nearly all pipeline owners use similar practices for this purpose) carry out various maintenance surveys/actions with the same intensity over the entire pipeline. No efforts are generally made to rationalize the M&I activities, and all 5 factors are considered to have an equal impact over the entire pipeline/ pipeline segments. Under this scenario, the pipeline owner is not able to estimate whether the expenditure caused towards undertaking M&I activities is adequate or more/less than necessary; secondly, pipeline owner is also in the dark about the appropriateness of his scheduled M&I programme. As a result, the effectiveness of the resources deployed by the pipeline owner remains unknown; consequently, the probability of failure of the pipeline due to third party interference also remains mostly unknown. M&I activities carried out to manage above 5 factors are discussed hereunder:

4.2.1 GROUND PATROLLING (GP)

Ground patrolling is undertaken over the entire pipeline through trained security personnel. Every day the Patrolman must cover a fixed distance (8km in the pipeline under discussion) on foot over the pipeline right of way; wherever approachability to the ROW is poor, the patrolling is to be done as close to ROW as feasible. Each of the security personals carries a hand-held GPS device (generally referred to as Personnel Tracker or PT) so that his movement can be tracked from the nearest pipeline control room. The entire pipeline right of way (RoW) is geo-fenced, and if a patrolman goes out of the pipeline RoW, an alarm is generated at the control room immediately, control room personnel, in turn, alerts the Patrolman about his position error, it is done to ensure that Patrolman does not play truant. Besides, at random frequency, foot patrolling is also undertaken by the engineering staff of the owner. There is no fixed frequency for such officials and neither any fixed timing or period of patrolling. Apart from foot patrolling, during the night, small teams of armed patrolmen also travel on the road as far as possible parallel to the pipeline. This night patrolling teams also inspect the vulnerable locations thoroughly. GP is carried out to take care of situations that may cause damage to the pipeline viz. pilferage or theft attempts through illegal taps, sabotage, working by other agencies (without permission of the pipeline owner), encroachment in RoW, digging by the agriculturalist, digging by other utility service agencies like power lines, telephone cables, water line laying agencies etc. The average expenditure towards GP for the last 3 years is found to be Rs.600 lakh per annum for 365 days of GP.

4.2.2 AERIAL PATROLLING (AP)

In addition to ground patrolling, the owner has started deployment of drones for aerial surveillance of the entire pipeline once in 15 days. Drones are low flying aerial devices that do videography of the entire pipeline RoW in real-time and transmits the same to the nearest control room for review by the responsible personnel of the owner. Besides, all the previous videos are compared off-line to identify any important development in the RoW. For the last one year since Drones are deployed, the expenditure incurred is Rs. 400lakh for inspection of the entire 135km of the pipeline every fortnight.

4.2.3 DEPTH OF COVER SURVEY (DCS)

One of the critical factors that determine the possibility of 3rd party damage to a pipeline is the lack of earth cover. In India, whenever an LPG pipeline is designed (and constructed), a minimum depth of cover of 1.2m is provided, i.e., the pipeline is buried in a manner that pipe top is 1.2m below the ground the surface to meet the minimum specified regulatory requirement. The regulation is covered by Oil Industry Safety Directorate (OISD) standard OISD -214, Cross-Country LPG Pipeline -2006. LPG pipelines in India are to be designed, constructed, operated and maintained as per OISD -214, the standard also specifies depth of cover as indicated in table 4.1

In order to ensure that specified earth cover is maintained all along the pipeline the owner carries out Depth of Cover surveys once every 6 months over the entire pipeline through special techniques which first determine exact location of the pipeline in the RoW and then through induced (into the pipeline) electromagnetic signals (and its analysis) determine the depth of pipe from the EM signal that is being received (there could be multiple other techniques to determine the depth of burial of a pipeline).

Table 4.1: Specified Minimum Earth Cover

Location	Min Cover in meters
Industrial, Commercial & Residential areas	1.2
Streams, Canals & minor water crossings	1.5
Drainage ditches at roadways & railways	1.2
Rocky areas	1.0
Uncased / Cased Road crossings	1.2
Railway crossings	1.7
River crossings (below scour level)	2.5
Other areas	1.2

In case the device indicates a low depth of cover at specific locations, the pipeline is exposed at such locations, and measurements are made manually. All low depth of cover zones is addressed by building enough depth of cover through earth filling. In case such remedial actions are not possible immediately, the spot is marked for more frequent ground patrolling till such time remedial actions are completed. Owner's annual M&I expenditure sheet indicated that annually Rs.100lakh is spent on DCS.

4.2.4 IN-LINE INSPECTION AND GEOMETRY SURVEY (ILI/GS)

In-Line Inspection (ILI) is a technique in which an electronic device is passed through the pipeline (propelled by the pipeline flow itself) from one end of the pipeline to another. This device is commonly referred to as Intelligent Pig. The device can record the entire pipe wall thickness profile of the pipeline and can report locations where deviations in thickness of the pipeline are observed with pinpoint accuracy. As mentioned earlier, in India LPG pipelines are designed as per Oil Industry Safety Directorate (OISD) Standard OISD-214 (ASME B31.4 is also followed for designing of LPG and other liquid pipelines), which among other things, suggest following design considerations

Quote

> ”*DESIGN*
>
> *5.0 PIPELINE SYSTEM*
>
> *Design of the LPG pipeline system shall be in accordance with ANSI / ASME B 31.4 and API 2510 or equivalent. While designing the pipeline system, the design engineer shall provide reasonable protection to prevent damage to the pipeline from unusual external conditions. Some of the protective measures which the design engineer may provide are encasing with steel pipe of larger diameter, adding concrete protective coating, increasing the wall thickness of the pipe, lowering the pipeline to a greater depth or indicating the presence of the pipeline with additional markers”*

Unquote

While the owner of the pipeline has generally followed design guidelines lines in OISD-214, 2006 and ASME B 31.4, 2004, in certain areas owner has gone beyond the requirements specified in above-mentioned engineering standards, two such significant areas that can have a bearing on the possibility of 3rd party damage viz.,

1. Design stress levels
2. Inter distance between remotely operated mainline segmentation valves shall be 12km. In the case of this LPG pipeline, the inter-distance between remotely operated segmentation valves is beyond 12km (in all cases), maximum being 30km, reasons for this could not be identified. However, it seems that ASME B31.4 had included such a requirement at a later date. The owner has now taken up a scheme to provide additional segmentation valves at every 12th Km to address the later day requirement of the applicable design standard for LPG pipeline in India, OISD-214.

In case of 1) above the owner of the LPG pipeline has gone beyond the design requirement of applicable engineering standard, instead followed gas pipeline design standard [ASME B 31.8, Gas Transmission and Distribution Piping System] that is generally considered more stringent, ASME B 31.8 specify limits for pipeline design factors [that controls stress levels in a pipeline] based on class location as indicated below.

Pipeline design based on the following formula

$$Sxfx\ w = \frac{PD}{2t} (Equation\ 1)\ * \qquad [Equation\ 4.1]$$

**as specified in ASME B31.4 and OISD -214*

Where S = Specified Minimum Yield Stress, D=Nominal Diameter of the pipeline, P = Design Pressure and t=nominal pipe wall thickness, f= design factor, w=weld joint factor, considered 1 for all modern pipeline

From equation 4.1, it is apparent that to maintain the same Design Pressure P, at a reduced stress level S, one must increase pipe wall thickness **t**. In the present case owner choose to keep operating stress levels at various class locations (decided based on population density along the pipeline ROW) in line with the requirement specified in ASME B31.8 (applicable for natural gas transmission pipeline) by increasing the pipe wall thickness as a measure of extra precaution against 3rd Party damage and corrosion damage.

Table 4.2: Basic Design Factor, F for Class Location

Location Class	Design Factor, F	Definition
Location Class 1, Division 1	0.80	A one-mile-long section of pipeline having 10 or fewer dwellings for human occupancy or any section that has been hydro tested at 1.25 times of (MAOP) corresponding to design stress level of less than or equal to 80% but higher than 72% of SMYS
Location Class 1, Division 2	0.72	Pipeline section having a design factor of the pipe is not higher than 72% of SMYS and hydro tested to 1.1 times of maximum operating pressure(MOP).
Location Class 2	0.60	A one-mile-long section of the pipeline has more than 10 but less than 46dwellings for human occupancy
Location Class 3	0.50	A one-mile-long section of pipeline has more than 46 dwellings for human occupancy
Location Class 4	0.40	Urban areas like city centers where traffic is high and multistoried buildings are present

[ref. ASME B31.8, Gas Transmission and Distribution Piping System, 2003, page 30]

As pipe wall thickness is a key controlling factor as far as 3rd party damage is concerned, ILI survey is carried out by the owner to ensure that design pipe wall thickness is maintained (in case of reported loss of thickness due to corrosion/erosion, remedial measures are taken at the earliest).

Generally, it has been observed that a pipeline damaged by digging equipment (e.g., earthmovers) undergoes geometric deformity, which may result in immediate failure or delayed failure. It is crucial to identify those deformities that are present but not known to the owner so that appropriate measures can be taken to prevent failure of the pipeline. To ensure that the pipeline has not undergone any geometric deformity, the owner carries out the pipeline Geometry Survey (GS). Like Intelligent Pigging, Geometry Survey (GS) is done by sending a device through the pipeline from one end to the other propelled by the pipeline flow itself. This device is commonly referred to as Caliper Pig and reports any mechanical damage like dents, ovality, buckles with size, and their location. Mechanical damage like dent (other than rock penetration) on the top half of a pipeline is almost a sure sign of 3rd party damage, a deformity at the lower half of pipe could be due to pipeline resting on a rock or similar hard surface.

As per the prevailing regulation in India, an LPG pipeline operator must get ILI/GS done at a maximum interval of 5 years. The owner of this pipeline has been adhering to this schedule of ILI/GS. ILI/GS being an expensive survey, prorate annual cost works out to Rs.100lakh for the entire pipeline.

4.2.5 ROW MANAGEMENT (ROW M)

Generally, the pipeline right of way (ROW) has one or more than one pipeline passing through it. In India, ROW is generally 30m wide in case (there are 18m wide ROW as well). The owner, as a part of management of RoW must ensure that it is free from any encroachment, the ROW is sufficiently identifiable with adequate no of markers at fixed intervals, there are warning signs and contact information, all turning points and crossing are indicated clearly, the RoW should have clear visibility and free from all wild growth and as far as possible approachable though vehicle or on foot. Management of RoW is vital for prevention of unintended release due to third-party damage.

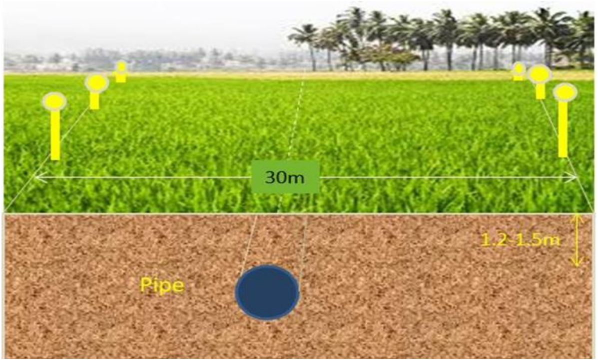


Fig 4-2: Typical Pipeline Right of Way

To ensure the above requirements for the LPG pipeline owner spend Rs.500 lakh per annum. ROW management is an activity that involves all 365 days a year.

4.2.6 PIPELINE INTRUSION DETECTION (ID) SYSTEM

The owner of this LPG pipeline has also introduced the optical fiber cable (OFC) based intrusion detection system to pick up any signal from digging directly from the dig spot to the control room. ID system involves laying of OFC cables at the same depth as that of the pipeline. The system has the capability to pick up a sound signal from activities like digging and transmit it to the nearest control room with a location accuracy of +/- 10m. The owner has spent Rs. 1000 lakh as a onetime investment considering a life of 10 years. Prorating the expenditure, the cost works out to Rs.100lakh per annum.

4.2.7 COMMUNITY INTERACTION (CI)

To reduce the probability of third party damage, the owner has a programme of community interaction, wherein one community meeting is held every month in each of the pipeline segments. The idea is to inculcate awareness among the communities living near the pipeline about the consequences of a pipeline failure and how to avoid such a failure. Under these programmes, Talks and Video shows are organized. The owner spends Rs.50lakh per annum for this activity. The table below shows a summary of expenditure per segment of the pipeline under the existing M&I programme to avoid 3rd party damage to the pipeline.

Table 4.3: M&I Expenditure towards 3rd party Damage Prevention *

M&I Actions	Annual Total Expense (Rs. Lakh)
1. Ground Patrol (GP)	600
2. Aerial Patrol (AP)	400
3. Depth of Cover Survey (DCS)	100
4. Inline Inspection / Geometry Survey (ILI/GS)	100
5. Right of Way Management (RoW M)	500
6. Intrusion Detection System (ID)	100
7. Community Interaction (CI)	50
Total Expense (Rs.Lakh)	1850

*all survey expenditure and other expenditure is as per the average Repair – Maintenance expenditure of Indian Oil Corporation Ltd (IOCL), owner for last 3years

4.3 OPTIMIZATION OF M&I EXPENDITURE

Each of the seven (7) M&I activities that are carried out to keep the possibility of 3rd party Damage to the LPG pipeline to a minimum, costs the owner Rs.1850lakh per annum [source: Pipeline Owners O&M Budget]. This expenditure is done over the entire pipeline length of 135km. For optimization purpose pipeline is divided into 6 segments, each of the M&I surveys/actions contributes to restricting possibilities of 3rd Party damage arising out of the above mentioned 5 factors as indicated in table 4.4. From the table, it is seen that one survey/action can reduce the possibility of pipeline damage caused by one or more than one factors

Table 4.4: M&I Activity vs. Factors covered

S.No	M&I Actions	Factors covered				
		DC	PD	AL	WT	LU
1	Ground Patrol (GP)	No	Yes	Yes	No	Yes
2	Aerial Patrol (AP)	No	Yes	Yes	No	Yes
3	Depth of Cover Survey (DCS)	Yes	No	No	No	No
4	Inline Inspection / Geometry Survey (ILI/GS)	No	No	No	Yes	No
5	Right of Way Management (RoW M)	No	Yes	Yes	No	Yes
6	Intrusion Detection System (ID)	Yes	No	No	No	Yes
7	Community Interaction (CI)	No	Yes	Yes	No	Yes

Yes=Cover, No=does not cover

For each segment (total 6 segments) the percentage variations has been compared and added for those factors that are covered by a particular type of M&I survey/activity, if more than one factors are covered by one particular M&I activity then variation in the impact of all those factors are added to get overall variation. Overall variation is then multiplied to the expenditure incurred for that activity under a non-optimized M&I programme to determine variation in expenditure. If the percentage variation for the M&I activity is negative, then less money is spent under the current M&I programme by that much percentage, and if positive more money is spent than what is required.

4.4 DETERMINATION OF DEGREE OF UN-OPTIMIZATION, U_n

The first step in the process of determination of U_n is to determine cw. Equation No. 3.2 in Chapter 3, establishes a relation between **nw** (normal weight of any one of the 5 factors, considering 1 as the combined weight of all 5 factors and **nw**=1/5= 0.20 equal for all 5 factors overall 6 segments), and **cw** (calculated weight). Calculation of **cw** is a lengthy process and involves multiple considerations (refer steps given under figure 3.5, Chapter - 3). The detailed calculation for **cw** of all the 6 segments and for all 4 experts is kept in **Appendix 2,** the summary tables of the calculations are reproduced here.

Calculation of **cw** for all segments and for the 5 factors needs a certain process to be followed, the steps involved are indicated below:

4.4.1 STEPS TO ARRIVE AT SEGMENTWISE EXPERT RELATIVE WEIGHT OF FACTORS

Step 1 Basic Mark by Experts

Step 2 Rationalized Basic Marks by multiplying with REW of the expert

Step 3 Multiply Step 2 marks with the length under the sub-factor

Step 4 Sum marks of each sub-factor under a factor for a segment

Step 5 Transfer the score (from step 1) to Summary table

Step 6 Divide score of a factor by length of the segment for which the marks are valid

Step 7 Rationalize the marks (considering score against DC =1)

Step 8 Transfer the rationalized score from step 7 for pairwise comparison as per AHP

Step 9 To get a normalized value table, divide each element of the primary table by addition of the particular column (e.g all elements of column 1 should be divided by sum of column 1).

Step 10 Take averages of values in the Normalized table to get the relative weight of each factor for a particular segment as per the scoring is done by Expert.

4.5 SCHEMA FOR DETERMINING SEGMENT WISE, EXPERT WISE RELATIVE WEIGHT OF THE FACTORS

A detailed analysis of each expert was carried for the determination of expert score. The schematic for each expert is detailed herein and also summarised in Appendix-D

4.5.1 SCORING SCHEMA FOR EXPERT -1

Basic Mark	**Expert 1**	7	5	1	3	4	7	8	3	1	3	1	3	7	3	7	7	5
Normalised I	Expert 1	7.00	5.00	3.00	1.00	3.00	7.00	7.00	3.00	1.00	3.00	3.00	7.00	9.00	3.00	5.00	5.00	7.00
Pipeline	Length	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+forest	Industrial	Commercial	Residential
1	**25**	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	**77.00**	**30.00**	**24.00**	**3.00**	**6.00**	**140.00**	**133.00**	**12.00**	**2.00**	**0.00**	**15.00**	**126.00**	**18.00**	**18.00**	**15.00**	**10.00**	**98.00**
2	**30**	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	**49.00**	**100.00**	**9.00**	**6.00**	**18.00**	**126.00**	**42.00**	**60.00**	**4.00**	**0.00**	**21.00**	**161.00**	**0**	**72.00**	**0.00**	**5.00**	**35.00**
3	**20**	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	**70.00**	**35.00**	**9.00**	**4.00**	**0.00**	**112.00**	**35.00**	**42.00**	**0.00**	**3.00**	**15.00**	**101.50**	**0**	**15.00**	**20.00**	**10.00**	**63.00**
4	**15**	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
	Score	**35.00**	**40.00**	**3.00**	**0.00**	**0.00**	**105.00**	**7.00**	**42.00**	**0.00**	**0.00**	**6.00**	**91.00**	**0.00**	**30.00**	**0.00**	**5.00**	**28.00**
5	**25**	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	**42.00**	**90.00**	**3.00**	**5.00**	**18.00**	**98.00**	**70.00**	**24.00**	**2.00**	**15.00**	**9.00**	**154.00**	**0.00**	**15.00**	**25.00**	**25.00**	**70.00**
6	**20**	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	**56.00**	**45.00**	**9.00**	0	0	**140.00**	**21.00**	**48.00**	0	**3.00**	**3.00**	**133.00**	**0.00**	**48.00**	0	**10.00**	**14.00**

PD= Population Density, DC= Depth of Cover, Lu=Land Use, WT = Wall thickness, AL = Awareness level

Segment wise Summary of Marks Scored by Factors

Factors	**Segment**						**Total**	**Average**
	1	**2**	**3**	**4**	**5**	**6**	**Score**	**Score**
PD	131.00	158.00	114.00	78.00	135.00	110.00	726.00	121.00
LU	147.00	106.00	80.00	49.00	111.00	72.00	565.00	94.17
WT	149.00	150.00	116.00	105.00	121.00	140.00	781.00	130.17
AL	141.00	112.00	108.00	63.00	135.00	72.00	631.00	105.17
DC	159.00	182.00	116.50	97.00	163.00	136.00	853.50	142.25
Total	727.00	708.00	534.50	392.00	665.00	530.00	3556.50	26.34
Segment Length, Km	25	30	20	15	25	20	135	22.50
Score/km	29.08	23.60	26.73	26.13	26.60	26.50	26.34	26.43

Expert	**1**	**Segment**	**1**
Length (km)	**25**		

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	159.00	6.36	1
Population Density	131.00	5.24	0.82
Awareness Level	141.00	5.64	0.89
Wall Thickness	149.00	5.96	0.94
Land Use	147.00	5.88	0.92

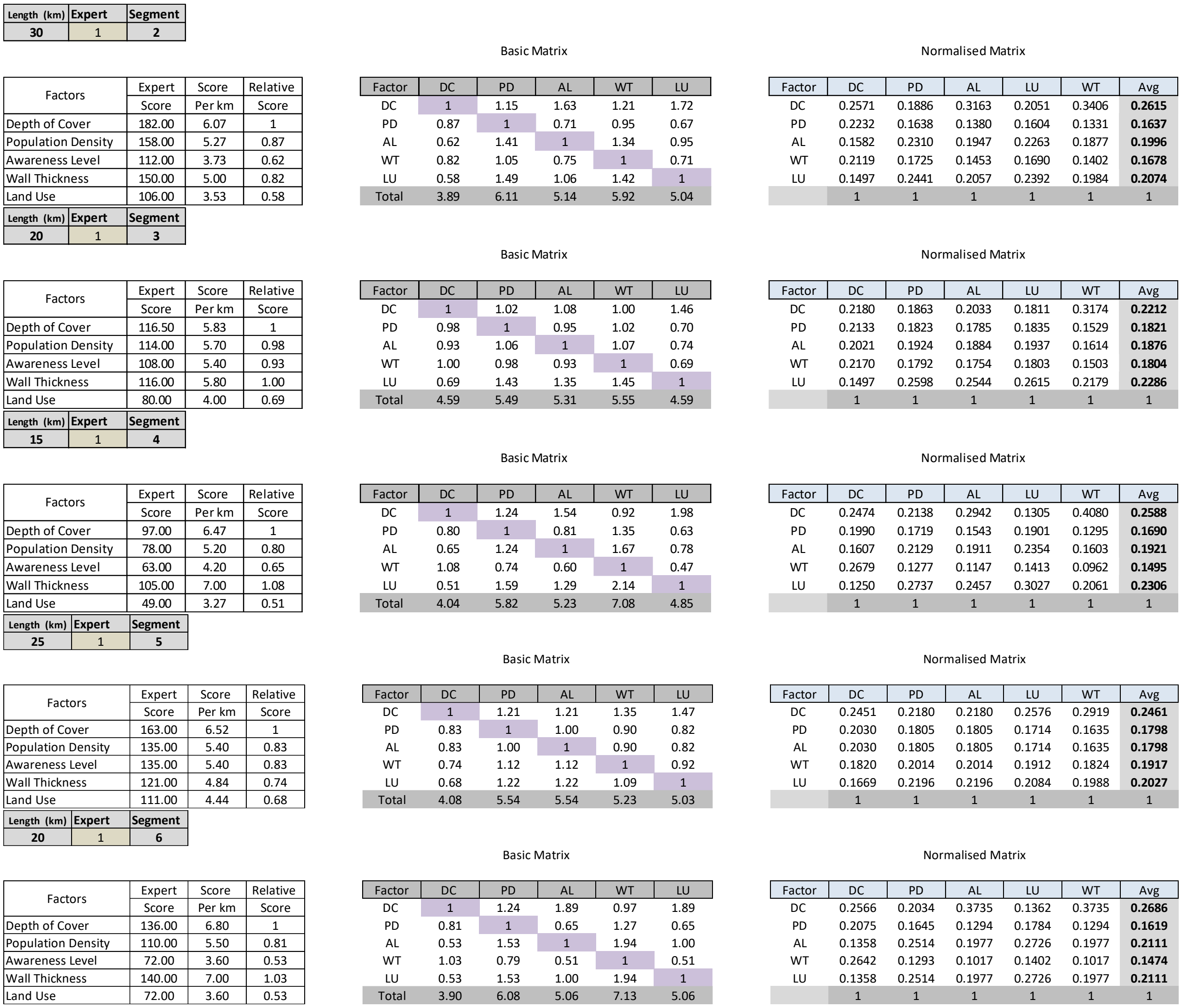
Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.21	1.13	1.07	1.08
PD	0.82	1	1.08	1.14	1.12
AL	0.89	0.93	1	1.06	1.04
WT	0.94	0.88	0.95	1	0.99
LU	0.92	0.89	0.96	1.01	1
Total	4.57	4.91	5.11	5.27	5.23

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2187	0.2470	0.2207	0.2023	0.2067	**0.2191**
PD	0.1802	0.2035	0.2107	0.2156	0.2144	**0.2049**
AL	0.1939	0.1891	0.1957	0.2003	0.1992	**0.1957**
WT	0.2050	0.1789	0.1852	0.1896	0.1885	**0.1894**
LU	0.2022	0.1814	0.1877	0.1922	0.1911	**0.1909**
	1	1	1	1	1	1

1) To get values in normalised matrix, divide each element in the basic matrix with sum of that column. 2) Average column shows weight of respective factors for a segment



Length (km)	Expert	Segment
30	1	2

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	182.00	6.07	1
Population Density	158.00	5.27	0.87
Awareness Level	112.00	3.73	0.62
Wall Thickness	150.00	5.00	0.82
Land Use	106.00	3.53	0.58

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.15	1.63	1.21	1.72
PD	0.87	1	0.71	0.95	0.67
AL	0.62	1.41	1	1.34	0.95
WT	0.82	1.05	0.75	1	0.71
LU	0.58	1.49	1.06	1.42	1
Total	3.89	6.11	5.14	5.92	5.04

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2571	0.1886	0.3163	0.2051	0.3406	**0.2615**
PD	0.2232	0.1638	0.1380	0.1604	0.1331	**0.1637**
AL	0.1582	0.2310	0.1947	0.2263	0.1877	**0.1996**
WT	0.2119	0.1725	0.1453	0.1690	0.1402	**0.1678**
LU	0.1497	0.2441	0.2057	0.2392	0.1984	**0.2074**
	1	1	1	1	1	1

Length (km)	Expert	Segment
20	1	3

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	116.50	5.83	1
Population Density	114.00	5.70	0.98
Awareness Level	108.00	5.40	0.93
Wall Thickness	116.00	5.80	1.00
Land Use	80.00	4.00	0.69

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.02	1.08	1.00	1.46
PD	0.98	1	0.95	1.02	0.70
AL	0.93	1.06	1	1.07	0.74
WT	1.00	0.98	0.93	1	0.69
LU	0.69	1.43	1.35	1.45	1
Total	4.59	5.49	5.31	5.55	4.59

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2180	0.1863	0.2033	0.1811	0.3174	**0.2212**
PD	0.2133	0.1823	0.1785	0.1835	0.1529	**0.1821**
AL	0.2021	0.1924	0.1884	0.1937	0.1614	**0.1876**
WT	0.2170	0.1792	0.1754	0.1803	0.1503	**0.1804**
LU	0.1497	0.2598	0.2544	0.2615	0.2179	**0.2286**
	1	1	1	1	1	1

Length (km)	Expert	Segment
15	1	4

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	97.00	6.47	1
Population Density	78.00	5.20	0.80
Awareness Level	63.00	4.20	0.65
Wall Thickness	105.00	7.00	1.08
Land Use	49.00	3.27	0.51

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.24	1.54	0.92	1.98
PD	0.80	1	0.81	1.35	0.63
AL	0.65	1.24	1	1.67	0.78
WT	1.08	0.74	0.60	1	0.47
LU	0.51	1.59	1.29	2.14	1
Total	4.04	5.82	5.23	7.08	4.85

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2474	0.2138	0.2942	0.1305	0.4080	**0.2588**
PD	0.1990	0.1719	0.1543	0.1901	0.1295	**0.1690**
AL	0.1607	0.2129	0.1911	0.2354	0.1603	**0.1921**
WT	0.2679	0.1277	0.1147	0.1413	0.0962	**0.1495**
LU	0.1250	0.2737	0.2457	0.3027	0.2061	**0.2306**
	1	1	1	1	1	1

Length (km)	Expert	Segment
25	1	5

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	163.00	6.52	1
Population Density	135.00	5.40	0.83
Awareness Level	135.00	5.40	0.83
Wall Thickness	121.00	4.84	0.74
Land Use	111.00	4.44	0.68

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.21	1.21	1.35	1.47
PD	0.83	1	1.00	0.90	0.82
AL	0.83	1.00	1	0.90	0.82
WT	0.74	1.12	1.12	1	0.92
LU	0.68	1.22	1.22	1.09	1
Total	4.08	5.54	5.54	5.23	5.03

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2451	0.2180	0.2180	0.2576	0.2919	**0.2461**
PD	0.2030	0.1805	0.1805	0.1714	0.1635	**0.1798**
AL	0.2030	0.1805	0.1805	0.1714	0.1635	**0.1798**
WT	0.1820	0.2014	0.2014	0.1912	0.1824	**0.1917**
LU	0.1669	0.2196	0.2196	0.2084	0.1988	**0.2027**
	1	1	1	1	1	1

Length (km)	Expert	Segment
20	1	6

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	136.00	6.80	1
Population Density	110.00	5.50	0.81
Awareness Level	72.00	3.60	0.53
Wall Thickness	140.00	7.00	1.03
Land Use	72.00	3.60	0.53

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.24	1.89	0.97	1.89
PD	0.81	1	0.65	1.27	0.65
AL	0.53	1.53	1	1.94	1.00
WT	1.03	0.79	0.51	1	0.51
LU	0.53	1.53	1.00	1.94	1
Total	3.90	6.08	5.06	7.13	5.06

Normalised Matrix

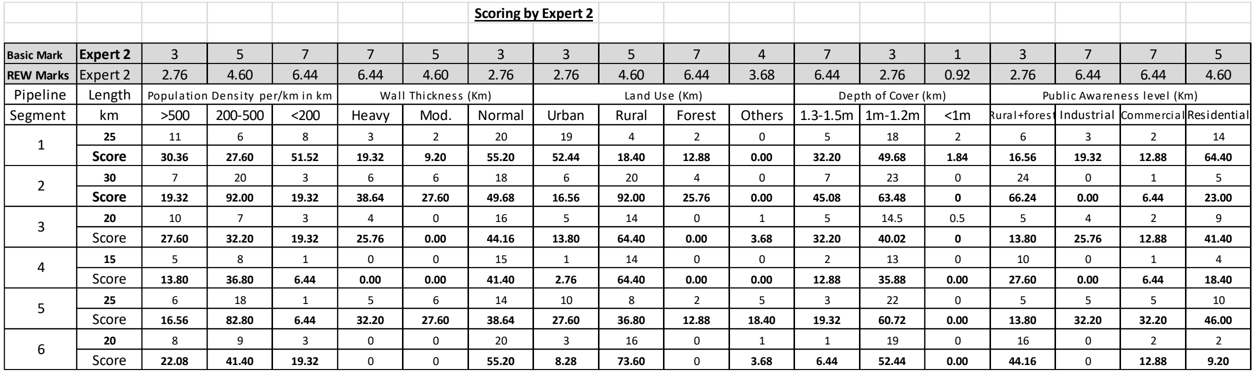
Factor	DC	PD	AL	LU	WT	Avg
DC	0.2566	0.2034	0.3735	0.1362	0.3735	**0.2686**
PD	0.2075	0.1645	0.1294	0.1784	0.1294	**0.1619**
AL	0.1358	0.2514	0.1977	0.2726	0.1977	**0.2111**
WT	0.2642	0.1293	0.1017	0.1402	0.1017	**0.1474**
LU	0.1358	0.2514	0.1977	0.2726	0.1977	**0.2111**
	1	1	1	1	1	1

Fig 4-3: Scoring Schema for expert-1

Table 4.5: Segment wise Summary - Relative Weight of Factors: Expert 1

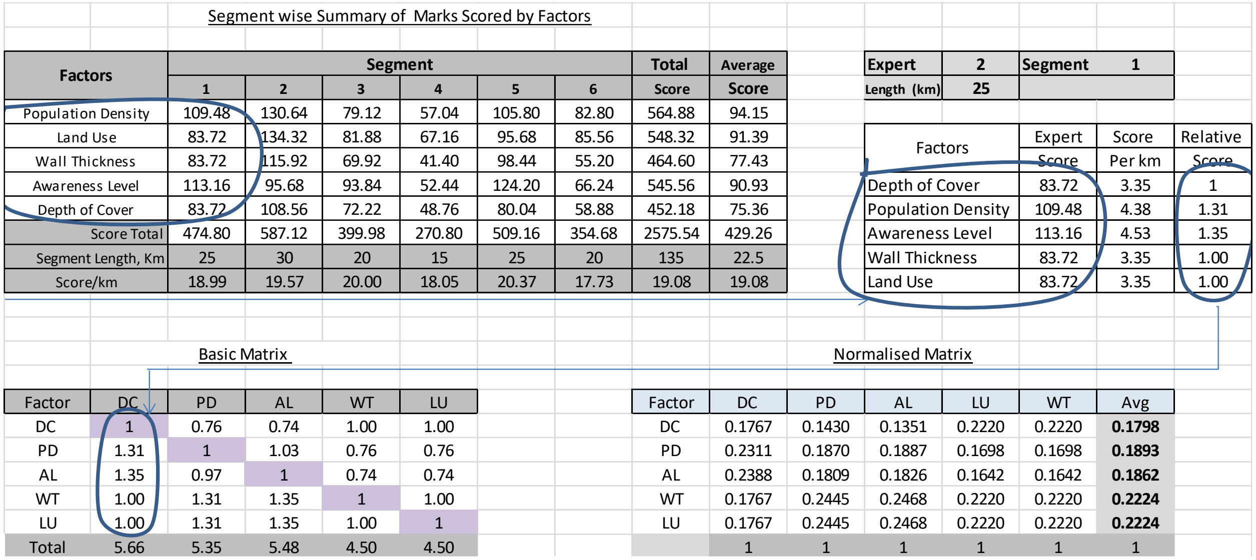
Factors	Segment						Average
	1	2	3	4	5	6	Expert 1
DC	0.219	0.262	0.221	0.259	0.246	0.269	**0.246**
PD	0.205	0.164	0.182	0.169	0.180	0.162	**0.177**
AL	0.196	0.200	0.188	0.192	0.180	0.211	**0.194**
WT	0.189	0.168	0.180	0.150	0.192	0.147	**0.171**
LU	0.191	0.207	0.229	0.231	0.203	0.211	**0.212**

4.5.2 SCORING SCHEMA FOR EXPERT -2



Scoring by Expert 2

Basic Mark	**Expert 2**	3	5	7	7	5	3	3	5	7	4	7	3	1	3	7	7	5
REW Marks	Expert 2	2.76	4.60	6.44	6.44	4.60	2.76	2.76	4.60	6.44	3.68	6.44	2.76	0.92	2.76	6.44	6.44	4.60
Pipeline	Length	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+forest	Industrial	Commercial	Residential
1	**25**	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	**30.36**	**27.60**	**51.52**	**19.32**	**9.20**	**55.20**	**52.44**	**18.40**	**12.88**	**0.00**	**32.20**	**49.68**	**1.84**	**16.56**	**19.32**	**12.88**	**64.40**
2	**30**	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	**19.32**	**92.00**	**19.32**	**38.64**	**27.60**	**49.68**	**16.56**	**92.00**	**25.76**	**0.00**	**45.08**	**63.48**	**0**	**66.24**	**0.00**	**6.44**	**23.00**
3	**20**	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	**27.60**	**32.20**	**19.32**	**25.76**	**0.00**	**44.16**	**13.80**	**64.40**	**0.00**	**3.68**	**32.20**	**40.02**	**0**	**13.80**	**25.76**	**12.88**	**41.40**
4	**15**	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
	Score	**13.80**	**36.80**	**6.44**	**0.00**	**0.00**	**41.40**	**2.76**	**64.40**	**0.00**	**0.00**	**12.88**	**35.88**	**0.00**	**27.60**	**0.00**	**6.44**	**18.40**
5	**25**	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	**16.56**	**82.80**	**6.44**	**32.20**	**27.60**	**38.64**	**27.60**	**36.80**	**12.88**	**18.40**	**19.32**	**60.72**	**0.00**	**13.80**	**32.20**	**32.20**	**46.00**
6	**20**	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	**22.08**	**41.40**	**19.32**	0	0	**55.20**	**8.28**	**73.60**	0	**3.68**	**6.44**	**52.44**	**0.00**	**44.16**	0	**12.88**	**9.20**



Segment wise Summary of Marks Scored by Factors

Factors	**Segment**						**Total**	**Average**
	1	**2**	**3**	**4**	**5**	**6**	**Score**	**Score**
Population Density	109.48	130.64	79.12	57.04	105.80	82.80	564.88	94.15
Land Use	83.72	134.32	81.88	67.16	95.68	85.56	548.32	91.39
Wall Thickness	83.72	115.92	69.92	41.40	98.44	55.20	464.60	77.43
Awareness Level	113.16	95.68	93.84	52.44	124.20	66.24	545.56	90.93
Depth of Cover	83.72	108.56	72.22	48.76	80.04	58.88	452.18	75.36
Score Total	474.80	587.12	399.98	270.80	509.16	354.68	2575.54	429.26
Segment Length, Km	25	30	20	15	25	20	135	22.5
Score/km	18.99	19.57	20.00	18.05	20.37	17.73	19.08	19.08

Expert	**2**	**Segment**	**1**
Length (km)	**25**		

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	83.72	3.35	1
Population Density	109.48	4.38	1.31
Awareness Level	113.16	4.53	1.35
Wall Thickness	83.72	3.35	1.00
Land Use	83.72	3.35	1.00

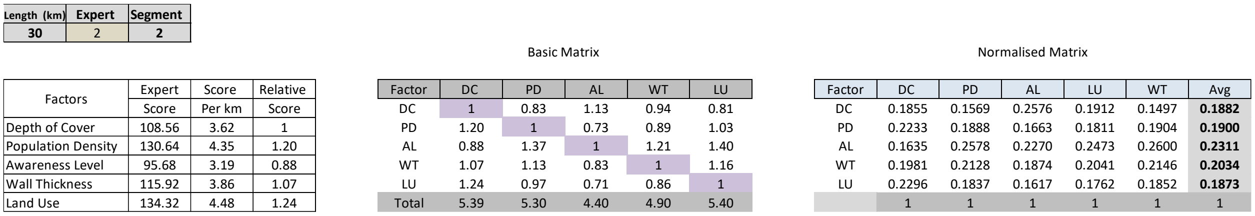
Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.76	0.74	1.00	1.00
PD	1.31	1	1.03	0.76	0.76
AL	1.35	0.97	1	0.74	0.74
WT	1.00	1.31	1.35	1	1.00
LU	1.00	1.31	1.35	1.00	1
Total	5.66	5.35	5.48	4.50	4.50

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1767	0.1430	0.1351	0.2220	0.2220	**0.1798**
PD	0.2311	0.1870	0.1887	0.1698	0.1698	**0.1893**
AL	0.2388	0.1809	0.1826	0.1642	0.1642	**0.1862**
WT	0.1767	0.2445	0.2468	0.2220	0.2220	**0.2224**
LU	0.1767	0.2445	0.2468	0.2220	0.2220	**0.2224**
	1	1	1	1	1	1

1) To get values in normalised matrix, divide each element in the basic matrix with sum of that column. 2) Average column shows weight of respective factors for a segment



Length (km)	**Expert**	**Segment**
30	2	**2**

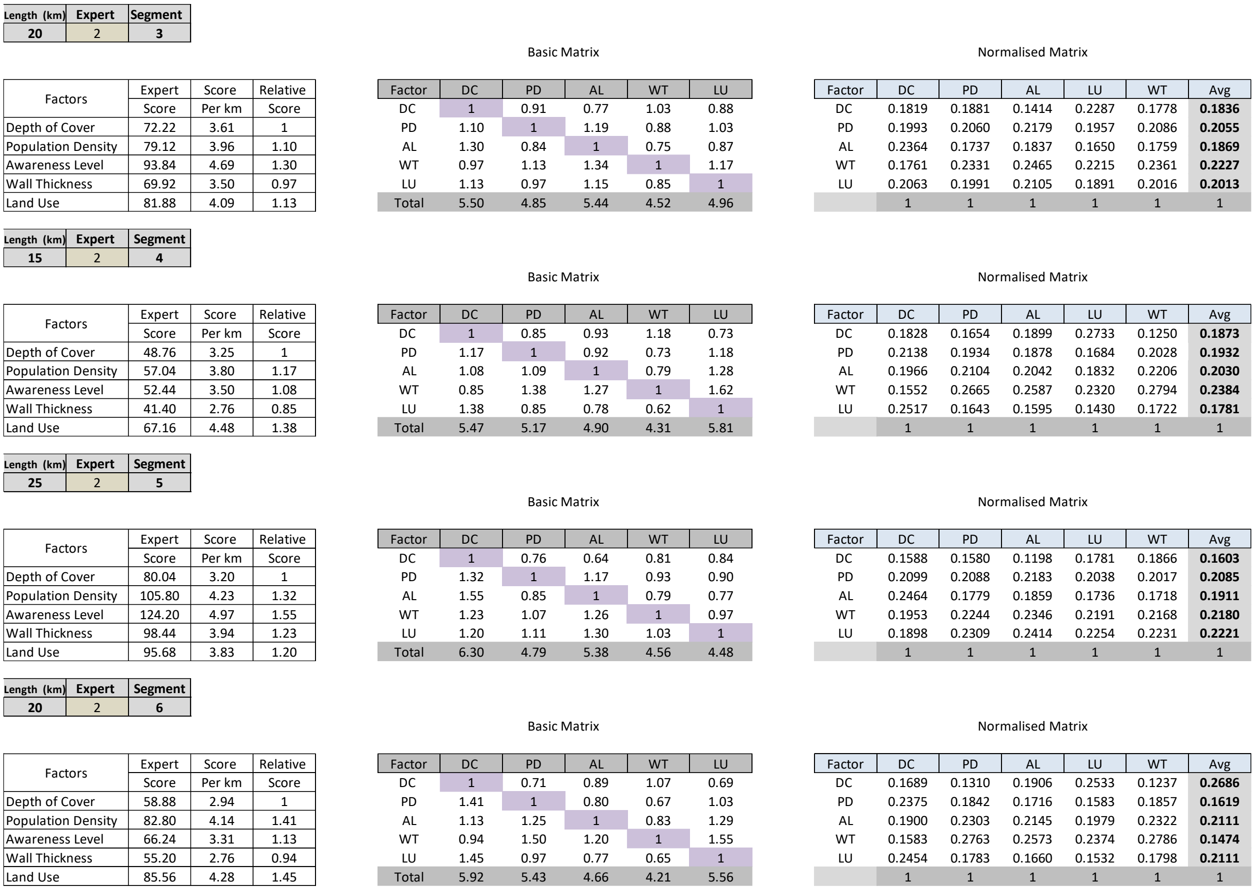
Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	108.56	3.62	1
Population Density	130.64	4.35	1.20
Awareness Level	95.68	3.19	0.88
Wall Thickness	115.92	3.86	1.07
Land Use	134.32	4.48	1.24

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.83	1.13	0.94	0.81
PD	1.20	1	0.73	0.89	1.03
AL	0.88	1.37	1	1.21	1.40
WT	1.07	1.13	0.83	1	1.16
LU	1.24	0.97	0.71	0.86	1
Total	5.39	5.30	4.40	4.90	5.40

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1855	0.1569	0.2576	0.1912	0.1497	**0.1882**
PD	0.2233	0.1888	0.1663	0.1811	0.1904	**0.1900**
AL	0.1635	0.2578	0.2270	0.2473	0.2600	**0.2311**
WT	0.1981	0.2128	0.1874	0.2041	0.2146	**0.2034**
LU	0.2296	0.1837	0.1617	0.1762	0.1852	**0.1873**
	1	1	1	1	1	1



Length (km)	Expert	Segment
20	2	**3**

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	72.22	3.61	1
Population Density	79.12	3.96	1.10
Awareness Level	93.84	4.69	1.30
Wall Thickness	69.92	3.50	0.97
Land Use	81.88	4.09	1.13

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.91	0.77	1.03	0.88
PD	1.10	1	1.19	0.88	1.03
AL	1.30	0.84	1	0.75	0.87
WT	0.97	1.13	1.34	1	1.17
LU	1.13	0.97	1.15	0.85	1
Total	5.50	4.85	5.44	4.52	4.96

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1819	0.1881	0.1414	0.2287	0.1778	**0.1836**
PD	0.1993	0.2060	0.2179	0.1957	0.2086	**0.2055**
AL	0.2364	0.1737	0.1837	0.1650	0.1759	**0.1869**
WT	0.1761	0.2331	0.2465	0.2215	0.2361	**0.2227**
LU	0.2063	0.1991	0.2105	0.1891	0.2016	**0.2013**
	1	1	1	1	1	1

Length (km)	Expert	Segment
15	2	**4**

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	48.76	3.25	1
Population Density	57.04	3.80	1.17
Awareness Level	52.44	3.50	1.08
Wall Thickness	41.40	2.76	0.85
Land Use	67.16	4.48	1.38

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.85	0.93	1.18	0.73
PD	1.17	1	0.92	0.73	1.18
AL	1.08	1.09	1	0.79	1.28
WT	0.85	1.38	1.27	1	1.62
LU	1.38	0.85	0.78	0.62	1
Total	5.47	5.17	4.90	4.31	5.81

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1828	0.1654	0.1899	0.2733	0.1250	**0.1873**
PD	0.2138	0.1934	0.1878	0.1684	0.2028	**0.1932**
AL	0.1966	0.2104	0.2042	0.1832	0.2206	**0.2030**
WT	0.1552	0.2665	0.2587	0.2320	0.2794	**0.2384**
LU	0.2517	0.1643	0.1595	0.1430	0.1722	**0.1781**
	1	1	1	1	1	1

Length (km)	Expert	Segment
25	2	**5**

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	80.04	3.20	1
Population Density	105.80	4.23	1.32
Awareness Level	124.20	4.97	1.55
Wall Thickness	98.44	3.94	1.23
Land Use	95.68	3.83	1.20

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.76	0.64	0.81	0.84
PD	1.32	1	1.17	0.93	0.90
AL	1.55	0.85	1	0.79	0.77
WT	1.23	1.07	1.26	1	0.97
LU	1.20	1.11	1.30	1.03	1
Total	6.30	4.79	5.38	4.56	4.48

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1588	0.1580	0.1198	0.1781	0.1866	**0.1603**
PD	0.2099	0.2088	0.2183	0.2038	0.2017	**0.2085**
AL	0.2464	0.1779	0.1859	0.1736	0.1718	**0.1911**
WT	0.1953	0.2244	0.2346	0.2191	0.2168	**0.2180**
LU	0.1898	0.2309	0.2414	0.2254	0.2231	**0.2221**
	1	1	1	1	1	1

Length (km)	Expert	Segment
20	2	**6**

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	58.88	2.94	1
Population Density	82.80	4.14	1.41
Awareness Level	66.24	3.31	1.13
Wall Thickness	55.20	2.76	0.94
Land Use	85.56	4.28	1.45

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.71	0.89	1.07	0.69
PD	1.41	1	0.80	0.67	1.03
AL	1.13	1.25	1	0.83	1.29
WT	0.94	1.50	1.20	1	1.55
LU	1.45	0.97	0.77	0.65	1
Total	5.92	5.43	4.66	4.21	5.56

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1689	0.1310	0.1906	0.2533	0.1237	**0.2686**
PD	0.2375	0.1842	0.1716	0.1583	0.1857	**0.1619**
AL	0.1900	0.2303	0.2145	0.1979	0.2322	**0.2111**
WT	0.1583	0.2763	0.2573	0.2374	0.2786	**0.1474**
LU	0.2454	0.1783	0.1660	0.1532	0.1798	**0.2111**
	1	1	1	1	1	1

Fig 4-4: Scoring Schema for expert-2

Table 4.6: Segment-wise Summary - Relative Weight of Factors: Expert 2

Factors	Segment						**Average**
	1	2	3	4	5	6	**Expert 2**
DC	0.180	0.188	0.184	0.187	0.160	0.173	**0.179**
PD	0.189	0.190	0.206	0.193	0.191	0.187	**0.193**
AL	0.186	0.231	0.187	0.203	0.218	0.213	**0.206**
WT	0.222	0.203	0.223	0.238	0.222	0.242	**0.225**
LU	0.222	0.187	0.201	0.178	0.208	0.185	**0.197**

4.5.3 SCORING SCHEMA FOR EXPERT -3

Basic Mark	Expert 3	3	5	7	7	4	3	3	5	7	5	6	4	1	3	7	7	5
REW Marks	Expert 3	2.55	4.25	5.95	5.95	3.40	2.55	2.55	4.25	5.95	4.25	5.10	3.40	0.85	2.55	5.95	5.95	4.25
Pipeline	Length	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+forest	Industrial	Commercial	Residential
1	**25**	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	**28.05**	**25.50**	**47.60**	**17.85**	**6.80**	**51.00**	**48.45**	**17.00**	**11.90**	**0.00**	**25.50**	**61.20**	**1.70**	**15.30**	**17.85**	**11.90**	**59.50**
2	**30**	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	**17.85**	**85.00**	**17.85**	**35.70**	**20.40**	**45.90**	**15.30**	**85.00**	**23.80**	**0.00**	**35.70**	**78.20**	**0**	**61.20**	**0.00**	**5.95**	**21.25**
3	**20**	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	**25.50**	**29.75**	**17.85**	**23.80**	**0.00**	**40.80**	**12.75**	**59.50**	**0.00**	**4.25**	**25.50**	**49.30**	**0**	**12.75**	**23.80**	**11.90**	**38.25**
4	**15**	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
		12.75	**34.00**	**5.95**	**0.00**	**0.00**	**38.25**	**2.55**	**59.50**	**0.00**	**0.00**	**10.20**	**44.20**	**0.00**	**25.50**	**0.00**	**5.95**	**17.00**
5	**25**	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	**15.30**	**76.50**	**5.95**	**29.75**	**20.40**	**35.70**	**25.50**	**34.00**	**11.90**	**21.25**	**15.30**	**74.80**	**0.00**	**12.75**	**29.75**	**29.75**	**42.50**
6	**20**	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	**20.40**	**38.25**	**17.85**	0	0	**51.00**	**7.65**	**68.00**	0	**4.25**	**5.10**	**64.60**	**0.00**	**40.80**	0	**11.90**	**8.50**

Segment wise Summary of Marks Scored by Factors

Factors	**Segment**						**Total**	**Average**
	1	**2**	**3**	**4**	**5**	**6**	**Score**	**Score**
Population Density	101.15	120.70	73.10	52.70	97.75	76.50	521.90	86.98
Land Use	77.35	124.10	76.50	62.05	92.65	79.90	512.55	85.43
Wall Thickness	75.65	102.00	64.60	38.25	85.85	51.00	417.35	69.56
Awareness Level	104.55	88.40	86.70	48.45	114.75	61.20	504.05	84.01
Depth of Cover	88.40	113.90	74.80	54.40	90.10	69.70	491.30	81.88
Score Total	448.10	551.10	378.70	259.85	486.10	344.30	2447.15	407.86
Segment Length, Km	25	30	20	15	25	20	135	22.50
Score/km	18.99	19.57	20.00	18.05	20.37	17.73	19.08	19.08

Expert	**3**	**Segment 1**
Length (km)	**25**	

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	88.40	3.54	1
Population Density	101.15	4.05	1.14
Awareness Level	104.55	4.18	1.18
Wall Thickness	75.65	3.03	0.86
Land Use	77.35	3.09	0.88

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.87	0.85	1.17	1.14
PD	1.14	1	1.03	0.75	0.76
AL	1.18	0.97	1	0.72	0.74
WT	0.86	1.34	1.38	1	1.02
LU	0.88	1.31	1.35	0.98	1
Total	5.06	5.49	5.61	4.62	4.67

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1977	0.1593	0.1506	0.2530	0.2447	**0.2011**
PD	0.2262	0.1823	0.1842	0.1620	0.1638	**0.1837**
AL	0.2338	0.1763	0.1782	0.1567	0.1584	**0.1807**
WT	0.1692	0.2437	0.2462	0.2165	0.2190	**0.2189**
LU	0.1730	0.2384	0.2408	0.2118	0.2141	**0.2156**
	1	1	1	1	1	1

1) To get values in normalised matrix, divide each element in the basic matrix with sum of that column. 2) Average column shows weight of respective factors for a segment

Length (km)	Expert	Segment
30	3	**2**

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	113.90	3.80	1
Population Density	120.70	4.02	1.06
Awareness Level	88.40	2.95	0.78
Wall Thickness	102.00	3.40	0.90
Land Use	124.10	4.14	1.09

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.94	1.29	1.12	0.92
PD	1.06	1	0.73	0.85	1.03
AL	0.78	1.37	1	1.15	1.40
WT	0.90	1.18	0.87	1	1.22
LU	1.09	0.97	0.71	0.82	1
Total	4.82	5.46	4.60	4.94	5.57

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2074	0.1727	0.2801	0.2262	0.1649	**0.2103**
PD	0.2198	0.1830	0.1592	0.1712	0.1847	**0.1836**
AL	0.1610	0.2498	0.2174	0.2337	0.2522	**0.2228**
WT	0.1858	0.2165	0.1884	0.2025	0.2186	**0.2024**
LU	0.2260	0.1780	0.1549	0.1665	0.1796	**0.1810**
	1	1	1	1	1	1

Length (km)	Expert	Segment
20	3	**3**

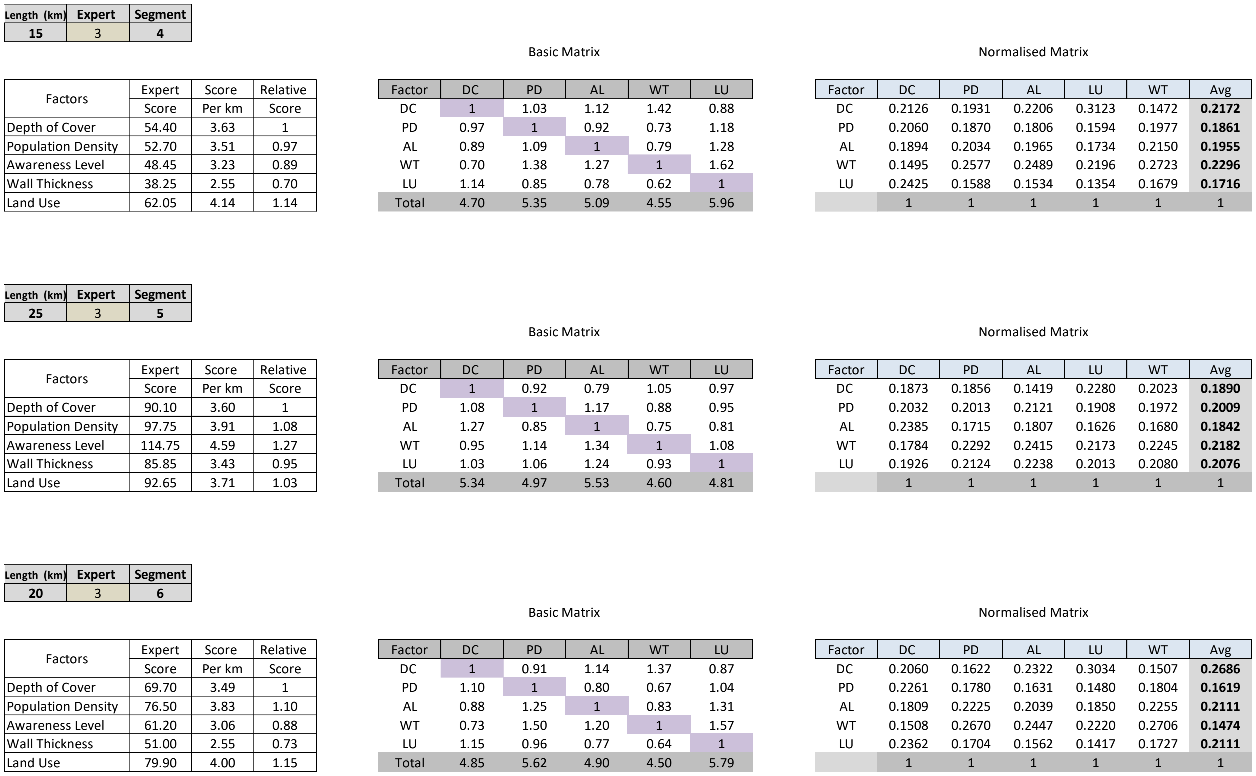
Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	74.80	3.74	1
Population Density	73.10	3.66	0.98
Awareness Level	86.70	4.34	1.16
Wall Thickness	64.60	3.23	0.86
Land Use	76.50	3.83	1.02

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.02	0.86	1.16	0.98
PD	0.98	1	1.19	0.88	1.05
AL	1.16	0.84	1	0.75	0.88
WT	0.86	1.13	1.34	1	1.18
LU	1.02	0.96	1.13	0.84	1
Total	5.02	4.95	5.52	4.63	5.09

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1991	0.2066	0.1562	0.2500	0.1921	**0.2008**
PD	0.1946	0.2019	0.2147	0.1908	0.2056	**0.2015**
AL	0.2308	0.1702	0.1810	0.1609	0.1733	**0.1832**
WT	0.1719	0.2284	0.2429	0.2159	0.2326	**0.2184**
LU	0.2036	0.1929	0.2052	0.1823	0.1964	**0.1961**
	1	1	1	1	1	1



Length (km)	Expert	Segment
15	3	4

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	54.40	3.63	1
Population Density	52.70	3.51	0.97
Awareness Level	48.45	3.23	0.89
Wall Thickness	38.25	2.55	0.70
Land Use	62.05	4.14	1.14

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.03	1.12	1.42	0.88
PD	0.97	1	0.92	0.73	1.18
AL	0.89	1.09	1	0.79	1.28
WT	0.70	1.38	1.27	1	1.62
LU	1.14	0.85	0.78	0.62	1
Total	4.70	5.35	5.09	4.55	5.96

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2126	0.1931	0.2206	0.3123	0.1472	**0.2172**
PD	0.2060	0.1870	0.1806	0.1594	0.1977	**0.1861**
AL	0.1894	0.2034	0.1965	0.1734	0.2150	**0.1955**
WT	0.1495	0.2577	0.2489	0.2196	0.2723	**0.2296**
LU	0.2425	0.1588	0.1534	0.1354	0.1679	**0.1716**
	1	1	1	1	1	1

Length (km)	Expert	Segment
25	3	5

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	90.10	3.60	1
Population Density	97.75	3.91	1.08
Awareness Level	114.75	4.59	1.27
Wall Thickness	85.85	3.43	0.95
Land Use	92.65	3.71	1.03

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.92	0.79	1.05	0.97
PD	1.08	1	1.17	0.88	0.95
AL	1.27	0.85	1	0.75	0.81
WT	0.95	1.14	1.34	1	1.08
LU	1.03	1.06	1.24	0.93	1
Total	5.34	4.97	5.53	4.60	4.81

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.1873	0.1856	0.1419	0.2280	0.2023	**0.1890**
PD	0.2032	0.2013	0.2121	0.1908	0.1972	**0.2009**
AL	0.2385	0.1715	0.1807	0.1626	0.1680	**0.1842**
WT	0.1784	0.2292	0.2415	0.2173	0.2245	**0.2182**
LU	0.1926	0.2124	0.2238	0.2013	0.2080	**0.2076**
	1	1	1	1	1	1

Length (km)	Expert	Segment
20	3	6

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	69.70	3.49	1
Population Density	76.50	3.83	1.10
Awareness Level	61.20	3.06	0.88
Wall Thickness	51.00	2.55	0.73
Land Use	79.90	4.00	1.15

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	0.91	1.14	1.37	0.87
PD	1.10	1	0.80	0.67	1.04
AL	0.88	1.25	1	0.83	1.31
WT	0.73	1.50	1.20	1	1.57
LU	1.15	0.96	0.77	0.64	1
Total	4.85	5.62	4.90	4.50	5.79

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2060	0.1622	0.2322	0.3034	0.1507	**0.2686**
PD	0.2261	0.1780	0.1631	0.1480	0.1804	**0.1619**
AL	0.1809	0.2225	0.2039	0.1850	0.2255	**0.2111**
WT	0.1508	0.2670	0.2447	0.2220	0.2706	**0.1474**
LU	0.2362	0.1704	0.1562	0.1417	0.1727	**0.2111**
	1	1	1	1	1	1

Fig 4-5: Scoring Schema for expert-3

Table 4.7: Segment-wise Summary - Relative Weight of Factors: Expert 3

Factors	Segment						**Average**
	1	2	3	4	5	6	**Expert 3**
DC	0.201	0.210	0.201	0.217	0.189	0.211	**0.205**
PD	0.184	0.184	0.202	0.186	0.184	0.179	**0.186**
AL	0.181	0.223	0.183	0.196	0.218	0.204	**0.201**
WT	0.219	0.202	0.218	0.230	0.208	0.231	**0.218**
LU	0.216	0.181	0.196	0.172	0.201	0.175	**0.190**

4.5.4 SCORING SCHEMA FOR EXPERT -4

Basic Mark	Expert 4	3	5	6	8	5	3	3	5	7	3	8	5	2	3	7	6	5
REW Marks	Expert 4	2.31	3.85	4.62	6.17	3.85	2.31	2.31	3.85	5.40	2.31	6.17	3.85	1.54	2.31	5.40	4.62	3.85
Pipeline	Length	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+forest	Industrial	Commercial	Residential
1	**25**	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	**25.43**	**23.12**	**36.99**	**18.50**	**7.71**	**46.24**	**43.93**	**15.41**	**10.79**	**0.00**	**30.83**	**69.37**	**3.08**	**13.87**	**16.19**	**9.25**	**53.95**
2	**30**	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	**16.19**	**77.07**	**13.87**	**36.99**	**23.12**	**41.62**	**13.87**	**77.07**	**21.58**	**0.00**	**43.16**	**88.63**	**0**	**55.49**	**0.00**	**4.62**	**19.27**
3	**20**	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	**23.12**	**26.98**	**13.87**	**24.66**	**0.00**	**36.99**	**11.56**	**53.95**	**0.00**	**2.31**	**30.83**	**55.88**	**0**	**11.56**	**21.58**	**9.25**	**34.68**
4	**15**	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
	Score	**11.56**	**30.83**	**4.62**	**0.00**	**0.00**	**34.68**	**2.31**	**53.95**	**0.00**	**0.00**	**12.33**	**50.10**	**0.00**	**23.12**	**0.00**	**4.62**	**15.41**
5	**25**	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	**13.87**	**69.37**	**4.62**	**30.83**	**23.12**	**32.37**	**23.12**	**30.83**	**10.79**	**11.56**	**18.50**	**84.78**	**0.00**	**11.56**	**26.98**	**23.12**	**38.54**
6	**20**	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	**18.50**	**34.68**	**13.87**	0	0	**46.24**	**6.94**	**61.66**	0	**2.31**	**6.17**	**73.22**	**0.00**	**36.99**	0	**9.25**	**7.71**

Segment wise Summary of Marks Scored by Factors

Factors	**Segment**						**Total**	**Average**
	1	**2**	**3**	**4**	**5**	**6**	**Score**	**Score**
Population Density	85.55	107.13	63.97	47.01	87.86	67.05	458.58	76.43
Land Use	70.14	112.53	67.82	56.26	76.30	70.91	453.96	75.66
Wall Thickness	72.45	101.74	61.66	34.68	86.32	46.24	403.09	67.18
Awareness Level	93.26	79.38	77.07	43.16	100.19	53.95	447.02	74.50
Depth of Cover	103.28	131.79	86.71	62.43	103.28	79.38	566.87	94.48
Score Total	425.67	534.57	360.23	247.55	458.96	323.54	2329.51	388.25
Segment Length, Km	25	30	20	15	25	20	135	22.50
Score/km	17.03	17.82	18.01	16.50	18.36	16.18	17.26	19.08

Expert	**4**	**Segment**	**1**
Length (km)	**25**		

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	103.28	4.13	1
Population Density	85.55	3.42	0.83
Awareness Level	93.26	3.73	0.90
Wall Thickness	72.45	2.90	0.70
Land Use	70.14	3.09	0.75

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.21	1.11	1.43	1.47
PD	0.83	1	1.09	0.85	0.82
AL	0.90	0.92	1	0.78	0.75
WT	0.70	1.18	1.29	1	0.97
LU	0.68	1.22	1.33	1.03	1
Total	4.11	5.53	5.81	5.08	5.01

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2432	0.2185	0.1905	0.2805	0.2938	**0.2453**
PD	0.2015	0.1810	0.1875	0.1666	0.1636	**0.1800**
AL	0.2196	0.1660	0.1720	0.1529	0.1500	**0.1721**
WT	0.1706	0.2137	0.2214	0.1968	0.1931	**0.1991**
LU	0.1652	0.2208	0.2287	0.2033	0.1995	**0.2035**
	1	1	1	1	1	1

1) To get values in normalised matrix, divide each element in the basic matrix with sum of that column. 2) Average column shows weight of respective factors for a segment

Length (km)	**Expert**	**Segment**
30	4	**2**

Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	131.79	4.39	1
Population Density	107.13	3.57	0.81
Awareness Level	79.38	2.65	0.60
Wall Thickness	101.74	3.39	0.77
Land Use	112.53	3.75	0.85

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.23	1.66	1.30	1.17
PD	0.81	1	0.74	0.95	1.05
AL	0.60	1.35	1	1.28	1.42
WT	0.77	1.05	0.78	1	1.11
LU	0.85	0.95	0.71	0.90	1
Total	4.04	5.58	4.89	5.43	5.75

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2475	0.2203	0.3397	0.2385	0.2039	**0.2500**
PD	0.2012	0.1791	0.1516	0.1749	0.1828	**0.1779**
AL	0.1491	0.2416	0.2046	0.2360	0.2467	**0.2156**
WT	0.1910	0.1886	0.1597	0.1841	0.1925	**0.1832**
LU	0.2113	0.1705	0.1444	0.1665	0.1741	**0.1733**
	1	1	1	1	1	1

Length (km)	**Expert**	**Segment**
20	4	**3**

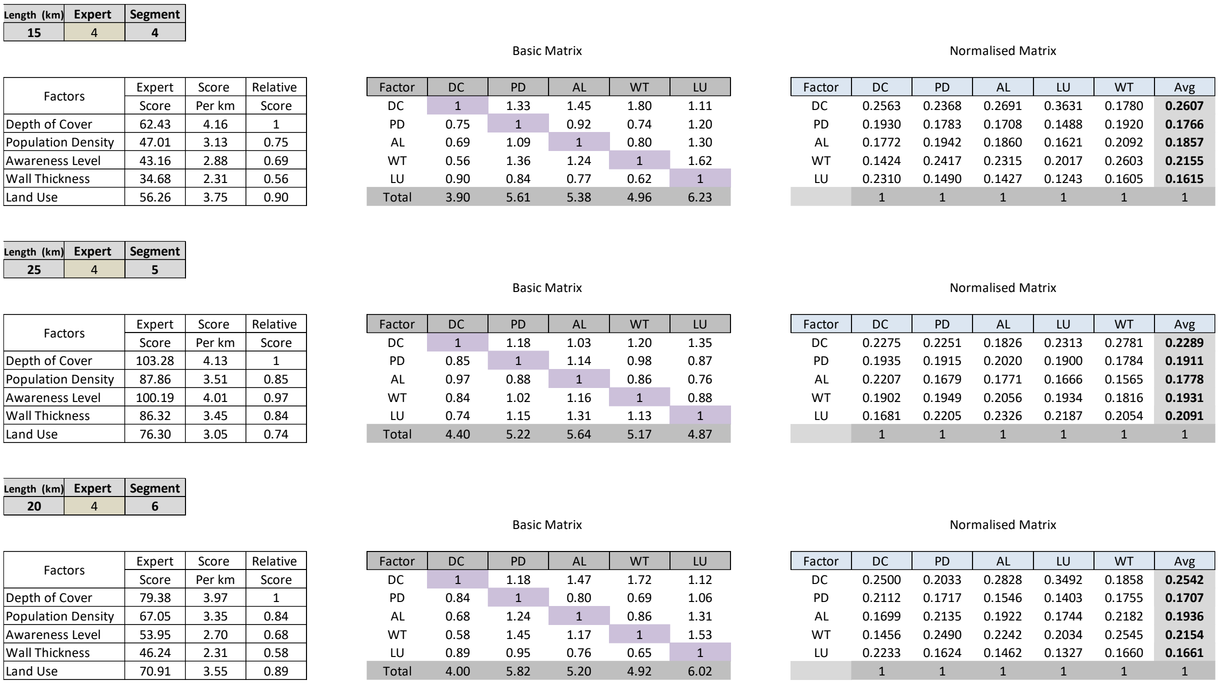
Factors	Expert	Score	Relative
	Score	Per km	Score
Depth of Cover	86.71	4.34	1
Population Density	63.97	3.20	0.74
Awareness Level	77.07	3.85	0.89
Wall Thickness	61.66	3.08	0.71
Land Use	67.82	3.39	0.78

Basic Matrix

Factor	DC	PD	AL	WT	LU
DC	1	1.36	1.13	1.41	1.28
PD	0.74	1	1.20	0.96	1.06
AL	0.89	0.83	1	0.80	0.88
WT	0.71	1.04	1.25	1	1.10
LU	0.78	0.94	1.14	0.91	1
Total	4.12	5.17	5.72	5.08	5.32

Normalised Matrix

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2427	0.2624	0.1968	0.2769	0.2404	**0.2438**
PD	0.1791	0.1936	0.2108	0.1898	0.1993	**0.1945**
AL	0.2157	0.1607	0.1749	0.1575	0.1655	**0.1749**
WT	0.1726	0.2008	0.2187	0.1969	0.2068	**0.1992**
LU	0.1899	0.1826	0.1988	0.1790	0.1880	**0.1876**
	1	1	1	1	1	1



Length (km)	Expert	Segment
15	4	4

Basic Matrix

Normalised Matrix

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	62.43	4.16	1
Population Density	47.01	3.13	0.75
Awareness Level	43.16	2.88	0.69
Wall Thickness	34.68	2.31	0.56
Land Use	56.26	3.75	0.90

Factor	DC	PD	AL	WT	LU
DC	1	1.33	1.45	1.80	1.11
PD	0.75	1	0.92	0.74	1.20
AL	0.69	1.09	1	0.80	1.30
WT	0.56	1.36	1.24	1	1.62
LU	0.90	0.84	0.77	0.62	1
Total	3.90	5.61	5.38	4.96	6.23

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2563	0.2368	0.2691	0.3631	0.1780	**0.2607**
PD	0.1930	0.1783	0.1708	0.1488	0.1920	**0.1766**
AL	0.1772	0.1942	0.1860	0.1621	0.2092	**0.1857**
WT	0.1424	0.2417	0.2315	0.2017	0.2603	**0.2155**
LU	0.2310	0.1490	0.1427	0.1243	0.1605	**0.1615**
	1	1	1	1	1	1

Length (km)	Expert	Segment
25	4	5

Basic Matrix

Normalised Matrix

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	103.28	4.13	1
Population Density	87.86	3.51	0.85
Awareness Level	100.19	4.01	0.97
Wall Thickness	86.32	3.45	0.84
Land Use	76.30	3.05	0.74

Factor	DC	PD	AL	WT	LU
DC	1	1.18	1.03	1.20	1.35
PD	0.85	1	1.14	0.98	0.87
AL	0.97	0.88	1	0.86	0.76
WT	0.84	1.02	1.16	1	0.88
LU	0.74	1.15	1.31	1.13	1
Total	4.40	5.22	5.64	5.17	4.87

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2275	0.2251	0.1826	0.2313	0.2781	**0.2289**
PD	0.1935	0.1915	0.2020	0.1900	0.1784	**0.1911**
AL	0.2207	0.1679	0.1771	0.1666	0.1565	**0.1778**
WT	0.1902	0.1949	0.2056	0.1934	0.1816	**0.1931**
LU	0.1681	0.2205	0.2326	0.2187	0.2054	**0.2091**
	1	1	1	1	1	1

Length (km)	Expert	Segment
20	4	6

Basic Matrix

Normalised Matrix

Factors	Expert Score	Score Per km	Relative Score
Depth of Cover	79.38	3.97	1
Population Density	67.05	3.35	0.84
Awareness Level	53.95	2.70	0.68
Wall Thickness	46.24	2.31	0.58
Land Use	70.91	3.55	0.89

Factor	DC	PD	AL	WT	LU
DC	1	1.18	1.47	1.72	1.12
PD	0.84	1	0.80	0.69	1.06
AL	0.68	1.24	1	0.86	1.31
WT	0.58	1.45	1.17	1	1.53
LU	0.89	0.95	0.76	0.65	1
Total	4.00	5.82	5.20	4.92	6.02

Factor	DC	PD	AL	LU	WT	Avg
DC	0.2500	0.2033	0.2828	0.3492	0.1858	**0.2542**
PD	0.2112	0.1717	0.1546	0.1403	0.1755	**0.1707**
AL	0.1699	0.2135	0.1922	0.1744	0.2182	**0.1936**
WT	0.1456	0.2490	0.2242	0.2034	0.2545	**0.2154**
LU	0.2233	0.1624	0.1462	0.1327	0.1660	**0.1661**
	1	1	1	1	1	1

Fig 4-6: Scoring Schema for expert-4

Table 4.8: Segment-wise Summary - Relative Weight of Factors: Expert 4

Factors	Segment						**Average**
	1	2	3	4	5	6	**Expert 4**
DC	0.245	0.250	0.244	0.261	0.229	0.254	**0.247**
PD	0.180	0.178	0.195	0.177	0.178	0.171	**0.180**
AL	0.172	0.216	0.175	0.186	0.193	0.194	**0.189**
WT	0.199	0.183	0.199	0.216	0.209	0.215	**0.204**
LU	0.203	0.173	0.188	0.162	0.191	0.166	**0.181**

Table 4.9: Synthesized Expert Score (SES)

Factors	**Expert**				**cw,** Calculated Weight
	1	**2**	**3**	**4**	
DC	0.246	0.179	0.205	0.247	0.219
PD	0.177	0.193	0.186	0.180	0.184
AL	0.194	0.206	0.201	0.189	0.198
WT	0.171	0.225	0.218	0.204	0.204
LU	0.212	0.197	0.190	0.181	0.195

(cw= average of all 4 expert value for each factor)

In clause 4.5 it was indicated that to determine **Un** from the equation 3.2, it is necessary to determined **cw,** in table 4.9, cw values for all 5 factors are calculated, as **nw** is already known as 0.20 and equal for all 5 factors, Un can be easily calculated from equation 3.2, that is **Un= (nw-cw).** Table 4.7 indicates the value of **Un** for various factors

Table 4.10: Calculated factor weight (cw) vs. Normal factor weight (nw)

Factors	DC	PD	AL	WT	LU
cw	0.219	0.184	0.198	0.204	0.195
nw	0.20	0.20	0.20	0.20	0.20
Un = (nw-cw)	**-0.019**	**0.016**	**0.002**	**-0.004**	**0.005**
% Un	**-9.5%**	**8.0%**	**1.0%**	**-2.0%**	**2.5%**

Un= Measure of Un-optimization

Table 4.10 quantifies the extent of variation in perceived weight (nw) and actual calculated weight (cw) of a factor responsible for third-party damage. As current M&I programme is based on the perceived weight of the factors, a **Un** in negative means actual M&I expenditure and inspection programmes fall short of the requirement, for example in case of monitoring/ maintenance of depth of cover (DC) and marginally in case of Wall thickness measurement/ monitoring. A positive Un value means more than required efforts are given to manage those factors for example in case of PD as much as 8% more efforts/ resources are deployed and optimization would lead to saving of M&I expenditure as well as effort in M&I activities as far as factor Population Density (PD) Management.

4.6 PROCESS OF OPTIMIZATION M&I EXPENDITURE

Optimization of M&I expenditure is done in the following steps:

1. Get the existing M&I Expenditure done by the owner [table 4.3]. Existing M&I expenditure is based on equal importance to all the surveys/ M&I activities for all sections. As already indicated, if total importance is considered equal to 1 combined for all 5 factors, then for individual factors, it becomes 1/5 =0.2, which is defined as **nw**.
2. Determine prorate expenditure for each section based on the section length.
3. Determine the difference between cw calculated section-wise for each of the 5 factors.
4. Determine percentage variation (Un) between nw and cw from equation 3.2 in chapter 3.
5. Identify surveys/ M&I actions that take care of one or more factors and corresponding expenditure for such surveys/ M&I actions
6. Multiply expenditure identified in step 5 with corresponding Un (factor of un-optimization). In case more than one M&I survey/ actions necessary to take care of a particular factor [refer table 4.4], multiple expenses of each such M&I surveys/ actions expenses with corresponding Un and add the values to get overall variation in expenses. The Un can be positive or negative, while positive means more expenditure is incurred than what is necessary and negative means more expenditure is to be made to manage that factor
7. Compare the pro-rata expense for a segment against various M&I surveys/ action with optimized expenses for such M&I survey/ actions to get variation in terms of money. This exercise, if done segment-wise, then optimized M&I expenditure for that segment can be determined.

Table 4.11: Segment-wise, cw

Factor	Segment					
	1	2	3	4	5	6
DC	0.212	0.228	0.213	0.216	0.218	0.224
PD	0.189	0.183	0.188	0.181	0.180	0.179
AL	0.184	0.217	0.183	0.203	0.203	0.205
WT	0.207	0.189	0.205	0.208	0.208	0.209
LU	0.208	0.187	0.203	0.185	0.201	0.184
Length (km)	25	30	20	15	25	20
% of total length	19%	22%	15%	11%	19%	15%

Table 4.12: Difference in Factor weight, Calculated (cw) Vs. Average (nw) – Segment 1

Factors	Segment 1		Difference	%Un
	CW	NW	NW-CW	(nw-cw)/nw
DC	0.212	0.200	-0.012	-6.24%
PD	0.189	0.200	0.011	5.53%
AL	0.184	0.200	0.016	8.17%
WT	0.207	0.200	-0.007	-3.74%
LU	0.208	0.200	-0.008	-4.05%

Table 4.12 above indicates the difference in calculated weight (cw) and the average weight (nw) for all 5 factors, and the difference in weight with percentage variation, Table 4.13 below, represents the difference in M&I expenses between optimized and unoptimized condition for segment1. The difference between the optimum expense column and prorate expense column is the optimization gap (Rs.342.59 lakh – Rs.318.64 lakh) =Rs. 23.96 lakh. [Prorate expense = [total expense/ total length of pipeline (135km)] x segment length (25km)]. Where Sum Un is negative, means more expenses are required for that activity and visa vera.

Table 4.13: Optimized Expense for Segment 1

M&I Actions	Total Expense	Prorate Expense	Factors Covered			Sum Un	Optimum Expense
GP	600	111.11	PD	AL	LU	9.65%	100.39
AP	400	74.07	PD	AL	LU	9.65%	66.92
DCS	100	18.52	DC	-	-	-6.24%	19.67

ILI/GS	100	18.52	WT	-	-	-3.74%	19.21
RoW M	500	92.59	PD	AL	LU	9.65%	83.65
ID	100	18.52	LU	DC		-10.29%	20.42
CI	50	9.26	PD	AL	LU	9.65%	8.37
Rs. (Lakh)/yr	1850	342.59					318.64

Table 4.14: Difference in Factor weight, Calculated (cw) vs. Average (nw) – Segment 2

Factors	Segment 2		Difference	Un
	cw	nw	nw-cw	(nw-cw)/nw
DC	0.228	0.200	-0.028	-13.89%
PD	0.183	0.200	0.017	8.53%
AL	0.217	0.200	-0.017	-8.65%
WT	0.189	0.200	0.011	5.41%
LU	0.187	0.200	0.013	6.38%

Table 4.15: Optimized Expense for Segment 2

M&I Actions	Total Expense	Prorate Expense	Factors Covered			Sum Un	Optimum Expense
GP	600	133.33	PD	AL	LU	6.26%	124.99
AP	400	88.89	PD	AL	LU	6.26%	83.33
DCS	100	22.22	DC	-	-	-13.89%	25.31
ILI/GS	100	22.22	WT	-	-	5.41%	21.02
RoW M	500	111.11	PD	AL	LU	6.26%	104.16
ID	100	22.22	LU	DC		6.38%	20.81
CI	50	11.11	PD	AL	LU	6.26%	10.42
Rs.(Lakh)/yr	1850	411.11					390.02

Table 4.16: Difference in Factor weight, Calculated (cw) vs. Average (nw) – Segment 3

Factors	Segment 3		Difference	Un
	cw	nw	nw-cw	(nw-cw)/nw
DC	0.213	0.200	-0.013	-6.36%
PD	0.188	0.200	0.012	6.06%
AL	0.183	0.200	0.017	8.42%
WT	0.205	0.200	-0.005	-2.58%
LU	0.203	0.200	-0.003	-1.71%

Table 4.17: Optimized Expense for Segment 3

M&I Actions	Total Expense	Prorate Expense	Factors Covered			Sum Un	Optimum Expense
GP	600	88.89	PD	AL	LU	12.77%	77.54
AP	400	59.26	PD	AL	LU	12.77%	51.69
DCS	100	14.81	DC	-	-	-6.36%	15.76
ILI/GS	100	14.81	WT	-	-	-2.58%	15.20
RoW M	500	74.07	PD	AL	LU	12.77%	64.62
ID	100	14.81	LU	DC		-1.71%	15.07
CI	50	7.41	PD	AL	LU	12.77%	6.46
Rs. (Lakh)/yr	1850	274.07					246.33

Table 4.18: Difference in Factor weight, Calculated (cw) vs. Average (nw) – Segment 4

Factors	Segment 4		Difference	Un
	cw	nw	nw-cw	(nw-cw)/nw
DC	0.216	0.200	-0.016	-8.00%
PD	0.181	0.200	0.019	9.47%
AL	0.203	0.200	-0.003	-1.46%
WT	0.208	0.200	-0.008	-4.13%
LU	0.185	0.200	0.015	7.27%

Table 4.19: Optimized Expense for Segment 4

M&I Actions	Total Expense	Prorate Expense	Factors Covered			Sum Un	Optimum Expense
GP	600	66.67	PD	AL	LU	15.27%	56.48
AP	400	44.44	PD	AL	LU	15.27%	37.66
DCS	100	11.11	DC	-	-	-8.00%	12.00
ILI/GS	100	11.11	WT	-	-	-4.13%	11.57
RoW M	500	55.56	PD	AL	LU	15.27%	47.07
ID	100	11.11	LU	DC		7.27%	10.30
CI	50	5.56	PD	AL	LU	15.27%	4.71
Rs.(Lakh)/yr	1850	205.56					179.79

Table 4.20: Difference in Factor weight, Calculated (cw) vs. Average (nw) – Segment 5

Factors	Segment 5		Difference	Un
	cw	nw	nw-cw	(nw-cw)/nw
DC	0.218	0.200	-0.018	-8.94%
PD	0.180	0.200	0.020	9.91%
AL	0.203	0.200	-0.003	-1.65%
WT	0.208	0.200	-0.008	-3.81%
LU	0.201	0.200	-0.001	-0.40%

Table 4.21: Optimized Expense for Segment 5

M&I Actions	Total Expense	Prorate Expense	Factors Covered			Sum Un	Optimum Expense
GP	600	111.11	PD	AL	LU	7.87%	102.37
AP	400	74.07	PD	AL	LU	7.87%	68.25
DCS	100	18.52	DC	-	-	-8.94%	20.17
ILI/GS	100	18.52	WT	-	-	-3.81%	19.22
RoW M	500	92.59	PD	AL	LU	7.87%	85.31
ID	100	18.52	LU	DC		-0.40%	18.59
CI	50	9.26	PD	AL	LU	7.87%	8.53
Rs.(Lakh)/yr	1850	342.59					322.45

Table 4.22: Difference in Factor weight, Calculated (cw) vs. Average (nw) – Segment 6

Factors	Segment 6		Difference	Un
	cw	nw	nw-cw	(nw-cw)/nw
DC	0.224	0.200	-0.024	-11.77%
PD	0.179	0.200	0.021	10.59%
AL	0.205	0.200	-0.005	-2.64%
WT	0.209	0.200	-0.009	-4.42%
LU	0.184	0.200	0.016	7.86%

Table 4.23: Optimized Expense for Segment 6

M&I Actions	Total Expense	Prorate Expense	Factors Covered	Sum Un	Optimum Expense

GP	600	88.89	PD	AL	LU	15.81%	74.84
AP	400	59.26	PD	AL	LU	15.81%	49.89
DCS	100	14.81	DC	-	-	-11.77%	16.56
ILI/GS	100	14.81	WT	-	-	-4.42%	15.47
RoW M	500	74.07	PD	AL	LU	15.81%	62.37
ID	100	14.81	LU	DC		7.86%	13.65
CI	50	7.41	PD	AL	LU	15.81%	6.24
Rs.(Lakh)/yr	1850	274.07					239.01

Table 4.24: Segment-wise optimized Expense of M&I

M&I Actions	Total Expense	Optimized Expense	Segment-wise Optimized Expense					
			1	2	3	4	5	6
GP	600	536.61	100.39	124.99	77.54	56.48	102.37	74.84
AP	400	357.74	66.92	83.33	51.69	37.66	68.25	49.89
DCS	100	109.47	19.67	25.31	15.76	12.00	20.17	16.56
ILI/GS	100	101.69	19.21	21.02	15.20	11.57	19.22	15.47
RoW M	500	447.17	83.65	104.16	64.62	47.07	85.31	62.37
ID	100	98.84	20.42	20.81	15.07	10.30	18.59	13.65
CI	50	44.72	8.37	10.42	6.46	4.71	8.53	6.24
Rs.(Lakh)/yr	1850	1696.24	318.64	390.02	246.33	179.79	322.45	239.01

All amounts are in Rs. in lakhs. 10 lakhs = 1 million

Table 4.24 indicates the segment-wise optimized M&I expense and the total optimized M&I expense for the entire 135km long pipeline. The difference between un-optimized (present) M&I expense and optimized M&I expense is Rs. 1850.00 – Rs.1696.24 = Rs 153.76lakh, which is equal to 8.31% of the present M&I expense incurred for controlling third party damage. Thus with optimization, over the entire pipeline, an annual amount of Rs. 153.76 lakhs can be saved; besides, data from table 4.18 indicate how the amount shall be spent among 6 segments taking into consideration the calculated weight (cw) of the 5 factors responsible for third party damage

Table 4.25: Segment-wise- Factor wise difference in terms of percentage between Un-Optimized and optimized M&I Expenditure

	Segment					
Factor	1	2	3	4	5	6
DC	-6%	-3%	-7%	-8%	-9%	-12%
PD	6%	9%	6%	10%	10%	**11%**
AL	8%	-9%	9%	-2%	-2%	**-3%**
WT	-4%	**6%**	-3%	-4%	-4%	-5%
LU	-4%	7%	-2%	8%	-1%	8%

Negative values in table 4.25 indicate that expenditure incurred at present is less than what is necessary (corresponding to the calculated weight **cw** for that factor over various segments) to take care of the factor depth of cover (DC). Similarly, positive values indicate that M&I expenditure carried out against a particular factor in a particular segment is higher than what should actually be required.

Therefore, both segment-wise and for the complete pipeline of 135km, the optimization for M&I expenditure could be carried out by the application for the model developed under clause 3.5 of chapter 3.

4.7 OPTIMIZATION OF M&I PROGRAMME

The measures taken under the overall M&I programme with the specific purpose of reduction in the probability of 3rd Party damage to the pipeline include M&I surveys/ actions.

The characteristics of these M&I surveys/actions and how these measures are supposed to take care of various factors are indicated under clause 4.2. Currently followed M&I programme is indicated in table 4.26.

Table 4.26: Existing M&I Frequency for third-party Damage Prevention

M&I Actions	Frequency	No of times/year	Factors taken care
1. Ground Patrol (GP)	Daily	365	PD+AL+LU
2. Aerial Patrol (AP)	Fortnightly (15 days)	24	PD+AL+LU
3. Depth of Cover Survey (DCS)	6 monthly	2	DC
4. In line Inspection / Geometry Survey	5 yearly	0.20	WT
5. Right of Way Management (RoW M)	Weekly	52	PD+AL+LU
6. Intrusion Detection System (ID)	Daily	365	DC+LU
7. Community Interaction (CI)	6 monthly	2	PD+AL+LU

For optimizing the M&I program indicated in table 4.20, the frequencies of the M&I surveys/actions are aligned with the calculated factor weight (cw) in the following manner.

Segment-wise difference between nw and cw is calculated [Table 4.21], the data in this table indicate the factor wise -segment-wise difference between average factor weight (nw=0.2) and calculated factor weight (cw).

Optimization Index (OI) is determined for all 5 factors in line with the considerations given herein, for factors where all values (nw-cw) are in one direction (negative or positive), such values are summed up for all 6 segments to get a final value of shortage/excess. For example, for factor DC (shortage) and PD (excess), the trend in all 6 segments is in M&I effort shortage (negative nw-cw) side and excess (positive nw-cw) side, respectively. For those factors where there is absence of clear directional trend in the (nw-cw) values [refer table 4.21] for example AL, WT and LU the highest negative value out of all 6 segments values are considered as critical value for determining the extent of shortage of M&I effort corresponding to calculated weight (cw) of that factor. The highest negative values are considered with the assumption that an M&I programme should address the maximum possible deficiency in the system.

Based on the guidelines stated above, the OI for all the factors [refer table 4.27 last column] in percentages terms are determined.

Table 4.27: Segment-wise difference between nw and cw

Factor	Segment-wise (nw-cw)						Optimization Index	Remarks
	1	2	3	4	5	6		
DC	-0.012	**-2.8%**	-0.013	-0.016	-0.018	-0.024	-11.04%	Sum of 1 to 6
PD	0.011	0.017	0.012	0.019	0.020	**0.021**	10.02%	Sum of 1 to 6
AL	0.016	**-0.017**	0.017	-0.003	-0.003	-0.005	-1.73%	Max. -ve
WT	-0.007	0.011	-0.005	-0.008	-0.008	-0.009	-0.88%	Max.-ve
LU	**-0.008**	0.013	-0.003	0.015	-0.001	0.016	-0.81%	Max.-ve

Existing M&I frequency of a survey as shown in table 4.20, if multiplied by highest OI value corresponding to the factor (s) taken care of by that survey, the value thus obtained is the optimized inspection frequency. There shall be no change in frequency where the regulatory requirement is the bindings or in such cases where hardware is provided to monitor third-party activity on a continuous basis for example in the above case ILI / Geometry inspection is mandatory to be done once in 5 years with a maximum gap of 3 years. Similarly, Intrusion Detection (ID) system is installed permanently for continuous monitoring of digging/ excavation within the right of way of the pipeline; therefore, there is no need to change the frequency of ID. With the above considerations Optimized M&I Survey frequency has been worked out as given in table 4.28.

Table 4.28: Optimized M&I Frequency for 3rd party Damage Prevention

S.No.	M&I Actions	Frequency/ No. of times			Factors taken care
		Unoptimized		Optimized	
		A	B	C= B x OI	
8.	Ground Patrol (GP)	Daily	**365**	**328**	PD+AL+LU
1.	Aerial Patrol (AP)	Fortnightly (15 days)	**24**	**22**	PD+AL+LU
2.	Depth of Cover Survey (DCS)	Bi- Annually	**2**	**3**	DC
3.	In line Inspection / Geometry Survey (ILI/GS)	Once within 5 years with a minimum gap	No change due to regulatory requirement		WT

		of 3 years			
4.	Right of Way Management (RoW M)	Weekly	**52**	**47**	PD+AL+LU
5.	Intrusion Detection System (ID)	Daily/ continuous	Continuous	Continuous	DC+LU
6.	Community Interaction (CI)	Bi-Annually	**2**	**1**	PD+AL+LU

4.8 CONCLUSION

Thus, both the objectives of this study, as given below, could be met.

1. Development of a model to the determined weight of factors responsible for third-party damage and
2. Optimization of M&I programme to minimize the probability of third-party damage to LPG pipeline in India

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

Due to surging demand for LPG consumption and distribution in India, more and more LPG pipelines are rapidly built across the country. International data on pipeline failure indicate that though the pipelines are the one of the safest mode of transporting bulk hydrocarbon, there are many cases pipeline failure across the globe, even in USA, Canada, UK, etc., where the awareness levels are higher, instances of pipeline failure due to the activity of a third agency is quite numerous. In fact, the databases maintained in the USA (by DOT), UK, and Europe indicate that as much as 50% of all pipeline failures are due to third party damage. Even in India, cases of third party damage far outnumber that of other causes of pipeline failure. Majority of the cases of third party damage in India is in the form of pilferage attempts from petroleum product and crude oil pipelines. Cases of third party damage with non-malicious intention is also on the rise, though no authenticated database for Indian pipelines are still available. India being a highly populous nation with fast-growing industrial facilities, in the coming days, the cases of pipeline failure due to third party damage may show a jump.

Apart from third party damage activities, a pipeline can fail due to many reasons like corrosion, operational error, material failure, poor construction quality, etc. While all the other reasons of pipeline failure can be attributed to the limitation in understanding the underlying scientific process, third party damage is one reason that hardly has anything scientific about it, human greed (e.g., pilferage attempts) and ignorance are the primary causes of third party damage.

As such it becomes a more complex task to prevent third party damage, for example, there are many cases where in-spite of deployment of prominent signposts and warning marks on either side of the pipeline right of way, accidents happened due to inadvertent digging, In one such incident a cable laying contractor while crossing a trunk pipeline through horizontal directional drilling process, could not control his pilot drill, ultimately the drill bid hit the pipeline and caused a puncture. There could be a higher number of similar incidents that points towards a lack of seriousness to protect other structure (read pipeline), adopting incorrect digging practice, lack of communication between working agencies, etc.

In India, pipeline operators have always been laying more stress on prevention of corrosion of pipelines, failures due to third party damage has so far received relatively less attention, however, with sudden surge in building pipelines especially LPG pipelines, awareness level of general population about the dangers associated with pipelines has also gone up manifold. As a result, the regulatory bodies like Petroleum and Natural Gas Regulatory Board (PNGRB), Oil Industry Safety Directorate (OISD), Petroleum and Explosive Safety Organization (PESO) having jurisdiction over pipeline safety, have come out with more stringent regulations and auditing of pipelines facilities both existing and upcoming (under construction) ones.

While petroleum pipelines are operational since last more than 5 decades, LPG pipelines are relatively recent development in India. Due to a sudden surge in demand of LPG, Public Sector Units (PSU), who control the majority of LPG import and sales, have started laying cross country LPG pipelines in higher numbers.

The consequence of failure in LPG pipeline could be significantly different from that of liquid or natural gas pipeline primarily because of different physical and chemical properties of this product. Natural gas is lighter than air and on release (from pipelines) escapes into atmosphere, on the other hand liquid petroleum (crude oil or refined product) remains on the earth surface or on the surface of the water bodies thus offering a chance to contain within a small or big area on land or on water bodies. A leaky gas or oil pipeline can be repaired after depressurizing and daylighting the pipeline at the point of leak. Unfortunately, a leak scenario in LPG pipeline could be quite different from that in liquid or gas pipeline one significant difference is LPG remains liquid while under pressure and turns into gas upon release to atmosphere, the expansion ratio is 1:270. Therefore, any release of LPG from a pressurized pipeline can quickly engulf a large area, besides LPG being heavier than air, continues to remain on the surface of the ground. Thus the probability of LPG coming in contact with sources of ignition is much higher compared to other petroleum liquid or natural gas. During release of LPG from pipeline due to high expansion ratio the temperature in the vicinity of the leak drops drastically, and in many cases freezing the surrounding soil, therefore, only option to attend an LPG pipeline leak is to wait till all the LPG from the pipeline section is vented out safely (possible in case of controlled venting not in case of leak). Unfortunately, majority of Third-Party damage cases cause pipeline rupture (not leak), which results into sudden gushing out of liquid/ gas under pressure and in most of the causes human presence is in the vicinity of Third-Party damage spot (as damage is caused by human activity like digging, pilfering etc.) results into fatalities.

LPG pipelines are a relatively recent phenomenon in India but are being built at a fast pace. Very soon, India will have the world's longest Mundra- Gorakhpur LPG pipeline, more than 2700km long. External interference is globally acknowledged as the topmost cause of pipeline failures. With high population density and significant industrial growth, the potential for third party damage related failure is significantly high in India. The present work is done under the backdrop of the above emerging scenario.

Several studies have been done globally to model a pipeline failure, the studies are primarily focused on building a model using one or other techniques like AHP, Bayesian network, or its variants, Fuzzy set theory (or some variant of this) and some others. The majority of these studies are, however, confined in the realm of theory. On rare occasions, an exercise is done with a view to solving real-life problems of pipeline operators. Such studies mostly remain a theoretical exercise. As far as India is concerned, studies are even more rare for cross-country pipelines and more so concerning third-party interference and related pipeline damage. This work attempt to overcome such constrains and proposes a model that is simple, easy to understand and primarily built on the foundation of opinion of pipeline experts, as prevention of 3rd party damage is more of a work of experience rather than scientific knowledge for reasons already discussed above.

The model proposed here is capable of determining the relative weight of factors responsible for third party damage to the LPG pipeline. The calculated relative weight (cw) is compared with the existing factor weight, nw, which is the average of total weight i.e., 1 divided by 5 (number of factors). The relative weight of factors is determined segment-wise and compared with nw. The difference of (cw-nw) in terms of percentage of nw) is consider degree of un-optimization (Un). Once the degree of optimization is determined, the actual cost of M&I, as well as frequency of M&I activities like various types of surveys, were optimized by adjusting the factor of un-optimization. Therefore, the objective of the research that is the development of a model to quantify the weight of each of the factors responsible for third-party damage and optimization of M&I programme, are fully met.

Table 5.1: Relative Weight of Factors - Synthesized Expert Score

Factors	**Expert**				**All Expert Average**
	1	**2**	**3**	**4**	
DC	0.246	0.179	0.205	0.247	0.219
PD	0.177	0.193	0.186	0.180	0.184
AL	0.194	0.206	0.201	0.189	0.198
WT	0.171	0.225	0.218	0.204	0.204
LU	0.212	0.197	0.190	0.181	0.195

Table 5.2: Degree of Un-Optimization (%Un)

Factors	DC	PD	AL	WT	LU
cw	0.219	0.184	0.198	0.204	0.195
nw	0.20	0.20	0.20	0.20	0.20
Un =nw-cw	-0.019	0.016	0.002	-0.004	0.005
% Un	-9.5%	8.0%	1.0%	-2.0%	2.5%

Table 5.3: Segment wise Optimized M&I Expense (same as table 4.18)

M&I	Existing	Optimized	Segment wise Optimized Expense					
Actions	Expense	Expense	1	2	3	4	5	6
GP	600	536.61	74.84	102.37	56.48	77.54	124.99	100.39
AP	400	357.74	49.89	68.25	37.66	51.69	83.33	66.92
DCS	100	109.47	16.56	20.17	12.00	15.76	25.31	19.67
ILI/GS	100	101.69	15.47	19.22	11.57	15.20	21.02	19.21
RoW M	500	447.17	62.37	85.31	47.07	64.62	104.16	83.65
ID	100	98.84	13.65	18.59	10.30	15.07	20.81	20.42
CI	50	44.72	6.24	8.53	4.71	6.46	10.42	8.37
Rs.(Lakh)/yr	1850	1696.24	239.01	322.45	179.79	246.33	390.02	318.64

The developed model can quantify the likely impact of a cause for third party damage like Depth of Cover or Public Awareness Level (AL) or other such vital factors will have. The model is also dynamic in the sense that with a change in land use patterns or other developmental activities, the expert marking can be modified easily to suit a new scenario. Another important feature of the model is that it can be adopted for any pipeline within or outside India subject to selection of an appropriate set of experts for scoring and collecting data with respect to the candidate pipeline where deployment of the model is planned.

The results of the data analysis indicate that out of 5 key factors responsible for third party damage depth of cover is likely to have the most significant role followed by pipe wall thickness, land use pattern, Awareness level, and population density. These results can be used by pipeline owners to develop effective M&I plan, use as an input at the design stage of new pipeline for selection of wall thickness of the pipe and deciding about depth of cover during construction and forecast probability of failure vis – a – vis pipeline segment, and develop emergency plans accordingly, assistance in the form of decision support system for appropriate levels of deployment of M&I efforts.

Prevention of pipeline failure from third party damage needs to start from the design stage itself, EGIG, Gas pipeline incidents, 10th report literature (2018) on probability of pipeline failure from 3rd party damage indicate the more the depth of cover, thicker the pipe wall and larger the diameter of the pipeline, lower is the probability of third-party damage. The parameters for a pipeline is required to be addressed at the design stage itself. ASME B 31.4 and OISD-141 are the two design standards followed for LPG pipelines in India, the provision of both these standards are more or less similar, these standards specify only the minimum requirements, for example the standard does not specify the minimum thickness of the pipe that is to be used for LPG transportation, but global experience shows higher the wall thickness lesser is the probability of failure from third party damage. Thus it is for the pipeline owner and designers to choose appropriate wall thickness keeping an eye on the public safety, a higher wall thickness pipe would definitely increase the cost of project, but would significantly lower the probability of failure, a choice, therefore, has to be made by the pipeline owner between profit and safety, in such situation risk analysis studies may help in taking correct decision. The uniqueness of an LPG pipeline lies in the fact that LPG is pumped in the liquid form when the pressure is more than 7kg/cm^2, while at a lesser pressure, say at atmospheric pressure, LPG turns into gas with a liquid to gas expansion ration close to 1:270. Being heavier than air LPG also travels along the surface of the earth and accumulates into depressions, drains, etc., being closer to earth's surface probability of catching fire is higher than say, natural gas which on release goes higher up into the atmosphere. A more challenging task is to control the leakage of LPG from a pipeline, due to its high expansion ratio, leaking LPG can freeze the earth surface making it nearly impossible to dig out and expose the leak point in the pipeline, besides it is extremely dangerous for the repair crew to approach the leak spot. Therefore, the only option is to isolate the leaky section between two mainline valves and wait for the LPG to vent out. It would also be necessary to evacuate the population at least from 250m on either side of the pipeline. In a country like India, where population density is very high, it is quite a herculean task to evacuate a large number of persons, and this might take a couple of hours at least. Therefore, extremely high-risk scenario could build up in case of a leakage or rupture of an LPG pipeline, as such best way is to prevent with inbuilt safety parameters in the design and an alert team of maintenance personnel for prevention of any undesired activity taking place in the vicinity of the pipeline.

For quite some time to come LPG would remain a popular choice for domestic fuel and consumption of LPG is going to go up significantly, correspondingly demand to build more LPG pipelines shall always be there, under this scenario , regulators and pipeline operators shall have to join hands to ensure that LPG pipelines are built with adequate safety provisions and margins and maintenance of LPG pipelines are done in a manner that possibility of an untoward incident happening remains nil .

5.2 RESEARCH CONTRIBUTIONS

The main contributions of this research include the following:

- A framework to develop a model for different infrastructure types using expert opinion and the current set of data rather than historical data.
- Application of Analytical Hierarchy Process (AHP) to calculate relative weight of each of the key factors responsible for causing failures
- Optimization of M&I expenditure Segment wise and the overall system.
- Optimizing frequency of inspection surveys and other M&I actions based on relative factor weight
- A simple approach for the selection of experts.

5.3 RESEARCH METHODOLOGY AND DEVELOPMENT OF MODEL

To achieve the objective of optimization of M&I cost and M&I frequency, the adopted research methodology led to the development of a model which is designed in manner that it can incorporate views of experienced pipeline experts on one hand and on the other hand give importance to the fact that third party damage has a significant human factor built-in into it. Therefore, a large degree of randomness is always associated with it any prediction of third-party damage. As such, there is no (there cannot be any) straight forward formula to work out the probability of failure from third party damage. Considering expert opinion seems to be the only appropriate approach to determine the weight of critical factors on which probability of third-party damage largely rests. Another challenge faced while preparing the model was the absence of structured and authenticated data on the failure of the Indian pipeline; this shortcoming could be circumvented only through the opinion of experienced experts.

Due to limited availability of research work in the chosen area in the international arena and more so in India, unique and innovative approaches had to be adopted to capture expert views and draw a meaningful conclusion from it. To make the proposed model useful to the actual operators of the pipeline attempt has been made to keep the model as simple as feasible without losing sight on the primary objective. To achieve this objective Analytical Hierarchy Process (AHP) proved to a useful tool because of two primary reasons, i) AHP is relatively a simple technique compared to techniques like fuzzy set theory, Bayesian theory, etc. ii) AHP can accept the opinion of experts to provide meaningful output.

Another area where an innovative approach was necessary is in establishing logical and rational relation between relative weight of 5 key factors of third-party damage and the M&I cost and M&I frequency. This necessitated developing a factor (Un) which is a measure of un-optimization in existing M&I cost and M&I frequency, the factor Un is proposed in order to quantify in numerical terms, the difference between existing resource deployment in M&I of the LPG pipeline and the proposed optimized resource deployment in terms of expenditure and frequency of

M&I surveys/ actions. Finally, the methodology proved to be the most appropriate approach in optimizing M&I programme and cost of M&I. The developed model was able to demonstrate that for the pipeline under consideration, it is possible to reduce M&I expenditure by at least 8% without sacrificing the objective of M&I programme through optimization.

5.4 RESEARCH LIMITATIONS

The research has some limitations summarized as follows:

1. Failure model does not consider the interdependency of factors
2. The expert selection process considers only 4 criteria for evaluating prospective experts; there could be more such criteria to improve the fineness of the process.
3. The model provides the relative weight of critical factors rather than absolute weight
4. The model does not address the impact of failure. Moreover, the likely probability of failure can be assessed from the relative weight of critical factors.
5. The Optimized M&I expenditure and frequency for M&I surveys are based on the relative weightage of the factors rather than the actual weight.

5.5 FUTURE WORK AND RECOMMENDATIONS

The proposed objective of the research could be achieved through the development of the model, but there are areas that require improvement/ enhancement.

5.5.1 AREAS OF IMPROVEMENT

- The model can be amended in a manner to include historical data apart from expert opinion to improve the accuracy of the output.

- The M&I cost considered is from one source (other sources were reluctant to part with such information); such data from multiple sources would contribute in terms of accuracy of the output, which is M&I Expenditure.
- The issue of the interdependence of factors responsible for third party failure needs to be dealt with and contribution quantified and incorporated into the model to make its output more accuracy
- This model may be improved to include other causes of pipeline failure like corrosion, material defects etc., so that the entire spectrum of pipeline failure type is covered.

5.5.2 EXTENSION AREAS

- Incorporation of data related to Indian pipeline failures is necessary to make the model more relevant. Although such data is not available currently, regulatory agencies may have to play a more proactive role in this regard. In the absence of the Indian pipeline failure data, some adjustment factors may have to be determined to make the model more attractive to the pipeline owners.
- The model is to be validated for the determination of optimum M&I expenditure, considering reasons other than third party damage.

5.6 RECOMMENDATION

Looking at the rate of growth of petroleum product consumption, the rapid growth of the pipeline industry in India is a reality; therefore, pipeline owners would do well to encourage more research work in the area of pipeline failure. The author suggests that the model developed can be turned into a computer program thereby permitting further study of the probability of pipeline failure its prevention from causes like corrosion etc.

REFERENCES

Abbassia, Rouzbeh, Bhandaria, Jyoti, Khana,Faisal b, Garaniyaa, Vikram, Shuhong, Chai. (2016), Developing a Quantitative Risk-based Methodology for Maintenance Scheduling Using Bayesian Network, Chemical Engineering Transactions, VOL. 48,

Ahammed, M. and Melchers, R. E., (1996), Probabilistic method for the assessment of the suitability of corroded pipelines under pressure loading.

Al-Khalil, M., Assaf, S. and Al-Anazi, F. (2005), Risk-Based Maintenance Planning of Cross-Country Pipelines, Journal of Performance of Constructed Facilities. Vol. 19, Issue 2 pp. 124-131.

Alonso, Jose Antonio. (2006), Consistency in analytical hierarchy process: A new approach, International Journal of Uncertainty, Vol. 14, No. 4 445−459

Arias-Nicolá, José Pablo, Martín, Jacinto, Ruggeri,Fabrizio and Alfonso, Suárez-Llorens. (2015), A Robust Bayesian Approach to an Optimal Replacement Policy for Gas Pipelines, Entropy 17, 3656-3678

Arunraj, N.S and Maiti. A. (2010), Risk-based maintenance policy selection using AHP and goal programming, Safety Science 48(2):238-247

Atkins WS, Health and Safety Executive, HSE. (1999), Assessing the risk from gasoline pipelines in the United Kingdom based on a review of historical experience, Contract Research Report, 210/1999, prepared by WS Atkins Safety & Reliability

Atkinson, Graham, Cowpe, Edmund, Halliday, Julie, Paintera, David. (2017), A review of very large vapour cloud explosion: cloud formation and explosion severity, Journal of Loss Prevention in the Process Industries, Volume 48, pp 367-375

BAI, Yong Qiang, Liang, Hai LV and Tong, WANG. (2013), The Application of the Semi-quantitative Risk Assessment Method to Urban Natural Gas Pipelines Journal of Engineering Science and Technology Review 6 (2) pp. 74-77

Bhisham K. Kumar, Ravi, Dhiman, Amit. (2015), Impact Assessment of Thermal Radiation Hazard from LPG Fireball, Procedia Earth and Planetary Science, Volume 11, Pages 499-506

Bottelberghs, P.H, (2000), Risk analysis and safety policy developments in the Netherlands, Journal of Hazardous Material, Pages 59-84

BP Statistical Review of World Energy. (2016), World Oil & gas data, pp.11, BP

Brooker, D.C. (2003), Numerical modelling of pipeline puncture under excavator loading. International Journal of Pressure Vessels and Piping p.p 715–725

C Zhang, T X Qin, B Jiang and C Huang. (2018), A comprehensive probabilistic analysis model of oil pipelines network based on Bayesian network, IOP Conf. Series: Earth and Environmental Science,

Central Intelligence Agency. (2017), The World Fact book, Field Listing: Imports – Commodities, Oil & Gas data analysis, USA

Centre for Chemical Process Safety. (2010), Guidelines for Consequence Analysis of Chemical Releases, American Institute of Chemical Engineers, New York.

Chaczykowski Maciej. (2010), Transient flow in natural gas pipeline – The effect of pipeline thermal model, Applied Mathematical Modelling 34 1051–1067

Chang, D.Y. (2008), On the extent analysis method for fuzzy AHP and its applications, European Journal of Operational Research 186 735–747

Chaplin, Zoe and Howard, Kate. (2015), Update of pipeline failure rates for land use planning assessments, Health Safety Laboratory, PR1035 Research Report, UK, Chareonsuk, C., Nagarur, N. and Tabucanon, M.T. (1997) ,A Multicriteria Approach to the Selection of Preventive Maintenance Intervals, International Journal of Production Economics, Vol. 49, Issue 1, pp. 55-64.

CONCAWE. (2018), Report 6/18, Performance of European cross-country oil pipelines, Statistical summary of reported spillages in 2016 and since 1971,

Dawotola Alex W., Gelder P.H.A.J.M. van, Charima J J, Vrijling J.K. (2011), Estimation of failure rates of crude product pipelines, Applications of Statistics and Probability in Civil Engineering – Faber, Köhler & Nishijima (eds), Taylor & Francis Group, London, ISBN 978-0-415-66986-3

Dawotola Alex. (2012), Risk Based Maintenance of Petroleum Pipelines, Delft University of Technology, The Netherlands. Doctoral Thesis,

Dawotola, A.W., Trafalis, T.B., Mustaffa, Z., Van Gelder, P.H.A.J.M. and Vrijling, J. K. (2012), Risk Based Maintenance of a Cross Country Petroleum Pipeline System, Journal of Pipeline Systems Engineering and Practice,

Department of Petroleum Resources. DPR (2007), Guidelines and Procedures for the Design, Construction, Operation and Maintenance of Oil and Gas pipelines Systems in Nigeria, Department of Petroleum Resources, Nigeria.

Department of Transport (DOT). (2014), A Study on the Impact of Excavation Damage on Pipeline Safety, Washington, D.C,

Dey, P. K., Ogunlana S.O., Gupta S.S. & Tabucanon M.T, (1998), A risk-based maintenance model for cross country pipelines, Journal of cost engineering, Vol.40. No.4, pp24-31.

Dey, P.K. (2001), A Risk-Based Model for Inspection and Maintenance of Cross-country Petroleum Pipeline, Journal of Quality in Maintenance Engineering, Vol. 7 No. 1, pp. 25-41,

Dey, P.K. (2003), Analytical Hierarchy Process Analyses risk of operating cross-country petroleum pipelines in India, Hazards Review, Vol. 4, Issue 4, pp 213-222,

Dey, Prasanta Kumar, Gupta S.S., (1999), Decision Support System for Pipeline Route Selection. International Journal of Project Management 41(10), pp.29-35.

Dziubinski, M. Fratczak, M. and Markowski, A.S. (2006), Aspects of risk analysis associated with major failures of fuel pipelines. Journal of Loss Prevention in the Process Industries, Vol. 19, pp. 399–408.

EGIG. (2018), Gas pipeline incidents, 10th report of the European Gas Pipeline Incident Data Group (Period 1970 – 2016),

El-Abbasy, Mohammed. S. (2015), A condition assessment model for oil and gas pipelines using integrated simulation and analytic network process, Structure and Infrastructure Engineering, 2015 Volume 11, Issue 3,

Focke, Jens. (2013), Localization and identification of external interference on pipelines and methods for prevention, 13th Pipeline Technology Conference

Ghosh, D. and Roy, S. (2009), Maintenance Optimization Using Probabilistic Cost-Benefit Analysis, Journal of Loss Prevention in the Process Industries, Vol. 22, Issue 4, pp. 403-407.Git, C.W

Hill Roger T. (2012), Risk Analysis for safety of European community from operating pipelines, Chem E Symposium Series No. 130, pp.657-670

Hopkins, P. (1994), ensuring the safe operation of older pipelines, International Pipelines and offshore Contractors Association, 28th Convention, Acapulco, Mexico

Hopkins, Phil. (2005), High design factor pipelines: Integrity issues -Key consideration to decided appropriate pipeline design factor to achieve higher levels of integrity, Journal of Integrity, Penspen

Hopkins,Phil Goodfellow Graham, Ellis Roger, Hassel Jane. (2009), Pipeline Risk Assessment: New Guidelines, WTIA/APIA WELDED PIPELINE SYMPOSIUM, Sydney, Australia.

Horalek Vladimir. (2004), Safety Performance Determined the Acceptability of Gas Transmission System EGIG Pipeline Incident Data Base,

Jackson,Christopher, Ali, Mosleh. (2018) Oil and Gas Pipeline Third Party Damage (TPD) - A New Way to Model External Hazard Failure B. John Garrick Institute for the Risk Sciences, University of California, Los Angeles, United States

Jafari Hamid Reza, Karimi Saeed, Bidhendi Gholamreza Nabi, Jabari Mousa, Ghahi Nasim Kheirkhah. (2011), Applying Indexing Method to Gas Pipeline Risk Assessment by Using GIS: A Case Study in Savadkooh, North of Iran, Journal of Environmental Protection Vol.2, No.7, pp.957-970

Jamshidi Ali, Abdolreza Yazdani-Chamzini, Siamak, Haji Yakhchali Sohrab Khaleghi. (2013), Developing a new fuzzy inference system for pipeline risk assessment, Journal of Loss Prevention in the Process Industries 26 197e208

Jiang, Y, Zhang, Z, Mc Calley, J.D. and Van Voorhis, T. (2006), Risk-Based Maintenance Optimization for Transmission Equipment, IEEE Trans Power System, Vol. 21, Issue 3, pp. 1191–1200.

Jo Y.D., Park K.S., Kim H.S., Kim J.J., Kim J.Y. & Ko J. W. (2010), A quantitative risk analysis method for the natural gas pipeline network, WIT Transactions on Information and Communication Technologies, Vol 43, WIT Press

Jo,Y.D., Park, K.S, J. Ko W. and Ahn, B. J. (2004), Risk analysis of natural gas pipeline, Risk Analysis IV, C. A. Brebbia

Jozi,Seyed Ali, Rezaian,Sahar, Shahi Edris. (2012), Environmental Risk Assessment of Gas Pipelines by using indexing system methods, CCCP, Kuala Lumpur, Malaysia, 2012, pp.231 – 234

Jun Li, Hong Zhang, Yinshan Han, Baodong Wang. (2016), Study on Failure of Third-Party Damage for Urban Gas Pipeline Based on Fuzzy Comprehensive Evaluation, (online), https://doi.org/10.1371/journal.pone.0166472

Kaplan, S. and Garrick, B. J. (1981) On the Quantitative Definition of Risk, Risk Analysis, Vol. 1, Issue 1, pp. 11–27

Kiefner, J. F, Mesloh,R. E. and Kiefner,B. A. (2001), Analysis of DOT Reportable incidents for gas transmission and gathering system pipelines, 1985 through 1997, Pipeline Res. Counc. Int. Inc Cat., no. L51830e,

Kiefner, J.F. Veith, P.H., Orban, J.E. and Feder, P.I. (1990) Methods for prioritizing pipeline maintenance and rehabilitation, Pipeline Research Council, Houston.

Kirchhoff Denis & Doberstein Brent. (2012), Pipeline risk Assessment and risk acceptance criteria in the state of Sao Paulo, Brazil, pp. 221-234 (online), https://doi.org/10.3152/147154606781765156

Kumar, Goldy, Maiti,J.(2012), Modeling risk based maintenance using fuzzy analytic network process, Expert Systems with Applications, Volume 39, Issue 11, Pages 9946-9954

Lam, C. and Zhou, W. (2016), Statistical analyses of incidents on onshore gas transmission pipelines based on PHMSA database, Int. J. Press. Vessels Pip., vol. 145, pp. 29–40,

Lam, Chico. (2015), Statistical Analyses of Historical Pipeline Incident Data with Application to the Risk Assessment of Onshore Natural Gas Transmission Pipelines, PG Thesis, University of Western Ontario,

Leonelli P., Bonvicini S., Spadoni G. (2000), Hazardous materials transportation: a risk-analysis-based routing methodology, Journal of Hazardous Materials, Volume 71, Issues 1–3, , Pages 283-300

Li Qiong Chen, Xia Li, Tao Cui, Jianlin Ma, Hong Liu and Zhijian Zhang. (2017), Combining accident modeling and quantitative risk assessment in safety management, Advances in Mechanical Engineering Vol. 9(10) 1–10

Lianshuang, Dai, Dongpo, Wang,Ting, Wang,Qingshan, Feng, and Xinqi,Yang. (2017) ,Analysis and Comparison of Long-Distance Pipeline Failures, Journal of Petroleum Engineering, Volume Article ID 3174636, (online) https://doi.org/10.1155/2017/3174636

Livemint 2017, Dhwani Pandya, Debjit Chakraborty, New Delhi https://www.livemint.com/Industry/q23PMeBZJ33qJecgln9XSO/Modis-push-to-make-kitchens-safer-makes-India-no-2-LPG-imp.html

Mather John, Blackmore, Chris, Petrie, Andrew & Treves, Charlotte, (2001), An assessment of measures in use for gas pipelines to mitigate against damage caused by third party activity, WS Atkins Consultants Ltd. CONTRACT RESEARCH REPORT 372/2001

Metropoloi, P.L., Brown, A.E.P. (2002), Natural gas pipeline accident consequence analysis, ‘Unidade de Pat.his, Paulinia/SP, Brazil, ~EscolaPolitecnica, USP, Rua Jacatirlo, 240, S. Paulo/SP, Brazil,

Mironov Aleksey, Doronkin Pavel, Priklonsky Aleksander, Kabashkin Igor. (2015), Condition Monitoring of Operating Pipelines with Operational Model Analysis application, Transport and Telecommunication, volume16, no. 4, 305–319

Muhlbauer W.K. (2004), Pipeline Risk Management Manual – Ideas, Techniques and Resources, 3rd Edition,

Nataraj Sam. (2005), Analytical Hierarchy Process as a decision support system in the petroleum pipeline industry, Issues in Information System, Vol.No.2, page 16-21

Oil Industry Safety Directorate (OISD). (2015), Guidelines on Pipeline Integrity Management System Pipeline Integrity Guideline, India,

Pandey, M. D. (1998), Probabilistic Models for Condition Assessment of Oil and Gas Pipelines, NDT&E International, Vol 31, No 5, pp. 349-358.

Parvizsedghy, Laya. (2015), Risk-Based Maintenance Planning Model for Oil and Gas Pipelines, A Thesis in the Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada,

Petroleum Planning & Analysis Cell, Ministry of Petroleum & Natural Gas, Govt. of India. (2016). Assessment report: Primary survey on household cooking fuel usage and willingness to convert to LPG,

Petroleum Planning & Analysis Cell. (2018), Ready Reckoner, Indian Oil & Gas data, 2016-17, Ministry of Petroleum & Natural Gas, GOI

Pettit Glenn. (2012), Key factors for the estimation of cross-country pipelines failure rate, Environmental Resources Management, UK, SYMPOSIUM SERIES NO. 158 Hazards XXIII, IChemE,

Prof. Konstantinos G. Zografos, and Dr. Konstantinos N. Androutsopoulos, (2001), A decision support system for hazardous material transportation and emergency response -, Athens University of Economics and Business, Department of Management Science and Technology

Przemysáaw, Droiyner, Veith, Eric (2002), Risk bases inspection methodology overview,

Quest Consultant Inc(a). (2009), Comparative Quantitative Risk analysis of Motor Gasoline, LPG and Anhydrous Ammonia as an automotive fuel. IOWA University,

Rada, Elena Cristina, Ferronato,Navarro and Vincenzo, Torretta. V. (2017), Individual risk evaluation and interventions for mitigation in the transportation of hazardous goods: a case study, MA TEC web conferences 121,

Restrepo, C., Simonoff, C.J. and Zimmerman, R. (2009), Causes, Cost Consequences, and Risk Implications of Accidents in U.S. Hazardous Liquid Pipeline Infrastructure, International Journal of Critical Infrastructure Protection, Vol. 2, pp. 38-50.

Rumnney Paul, Goodfellow Graham. (2012), Using quantitative risk assessment to justify location class changes: Case Study, Proceedings of 9th International Pipeline Conference,

Sahraoui Yacine, Khelif Rabia and Chateauneuf Alaa, (2013), Maintenance planning under imperfect inspections of corroded pipelines, International Journal of Pressure Vessels and Piping,

Satty, T. L. (2013), Fundamentals of decision-making process and priority theory with the analytical hierarchy process, Vol-VI, e-book second edition,

Sérgio Barros da Cunha. (2016), A review of quantitative risk assessment of onshore pipelines, Journal of Loss Prevention in the Process Industries

Sklavounos, S. and Rigas, F. (2006), Estimation of safety distances in the vicinity of fuel gas pipelines, Journal of Loss Prevention in the Process Industries, Vol. 19, pp. 24–31, 2006

Spoelstra M.B. & Laheij G.M.H. (2011), Towards a method to calculate risks of underground pipelines transporting hazardous substances, Bilthoven, Netherlands National Institute for Public Health and the Environment Symposium Series No. 156 Hazards XXII, @ Chem, pp 254-260

Stephens, M. J. and Nessim, M. A. (1995) Risk-Based Optimization of Pipeline Integrity Maintenance, Proceedings, Proceedings of the 14th International conference on offshore mechanics and arctic engineering (OMAE), Copenhagen

T. B. Morrow, R. L. Bass and J. A. Lock et al, (1983), An LPG Pipeline Break Flow Model, Journal of Energy Resources Technology, Volume 105, Issue 3, Research Paper, , pp.379-387

Teixeira, A.P., Soares, C.G., Netto, T.A., and Estefen, S.F. (2008), Reliability of Pipelines with Corrosion Defects, International Journal of Pressure Vessels and Piping,Vol. 85, Issue 4, pp. 228-237.

V.H.Y. Tam and R.B. Higgins, (1990), Simple Transient Release Rate Models for Release of Pressurized Liquid Petroleum Gas from Pipelines Journal of Hazardous Materials, Volume 25, Issues 1–2, pp. 193-203

World Oil Outlook. (2016), OPEC, World Oil & gas data, pp 38, OPEC

Xinhong, Li, Guoming, Chen Hongwei Zhu. (2016), Quantitative risk analysis on leakage failure of submarine oil and gas pipelines using Bayesian network, Process Safety and Environmental Protection, Volume 103, Part A, Pages 163-173

Yuhuaa, Dong, Huilinb, Gao Jing’ena, Zhou, Yaorong, Feng, (2002), Evaluation of gas release rate through holes in pipelines, Journal of Loss Prevention in the Process Industries 15 423– 428

Zeyang Qiu, Wei Liang, Xue Wang,Yang Lin and Meng Zhang, (2017) Study on quantitative risk assessment model of the third party damage for natural gas pipelines based on fuzzy comprehensive assessment, 12th International Conference on Damage Assessment of Structures IOP Publishing

APPENDICES

APPENDIX A : EXPERT QUESTIONNAIRE & RESPONSE

UPES
UNIVERSITY WITH A PURPOSE

1.Name of the Expert : **Designation:**

2. Specialization : Engineering Civil/Elctrical/Mechanical / Metallurgy/lectronics/Chemical

3.Academic Qualification (put tick whichever is applicable)

☐ **PHD** ☐ **PG** ☐ **Graduate** ☐ **< Graduate**

4. Working Experience in Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ **5-10 years** ☐ **10-15 years** ☐ **15-20 years** ☐ ☐ **0 years**

5.Working Area

Area Maintenance Inspection Operation Design Construction Others

Years ☐ ☐ ☐ ☐ ☐ ☐

6.No. of years in Office Setup ☐ **in Field** ☐ **In R&D** ☐ ☐ **Others**

7. Did you ever work of a service provider Yes ☐ **No** ☐ **If Yes, mention number of years**

8. What is in your opinion most significant reason for 3rd Party Damage to Pipeline (Please rank as per severity)

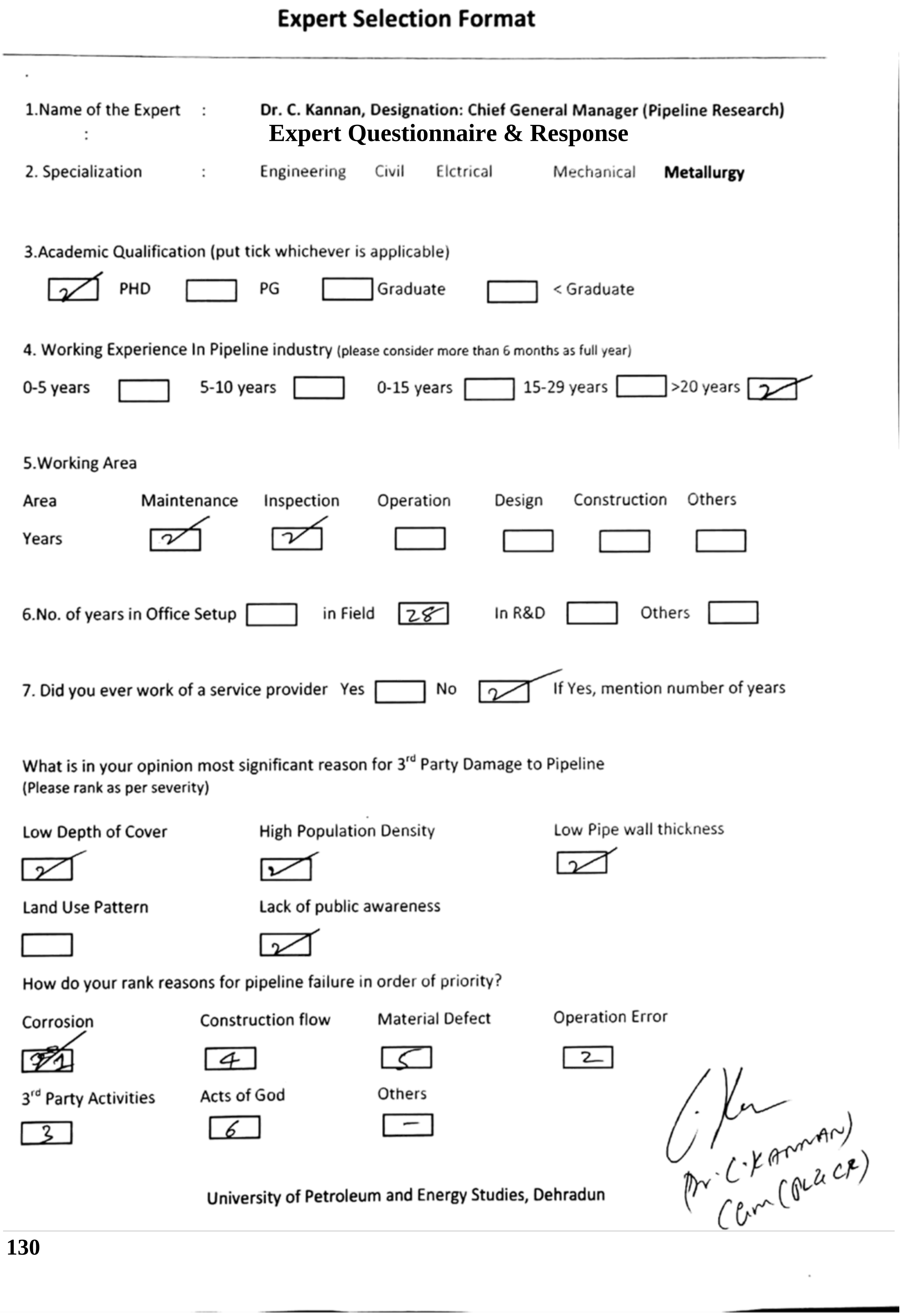
Low Depth of Cover ☐ **High Population Density** ☐ **Low Pipe wall thickness** ☐

Land Use Pattern ☐ **Lack of public awareness** ☐

9.How do your rank reasons for pipeline failure in order of priority?

Corrosion ☐ **Construction flow** ☐ **Material Defect** ☐ **Operation Error** ☐

3rd Party Activities ☐ **Acts of God** ☐ **Others** ☐



Expert Selection Format

1.Name of the Expert : **Dr. C. Kannan, Designation: Chief General Manager (Pipeline Research)**

:

Expert Questionnaire & Response

2. Specialization : Engineering Civil Elctrical Mechanical **Metallurgy**

3.Academic Qualification (put tick whichever is applicable)

☑ PHD ☐ PG ☐ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 0-15 years ☐ 15-29 years ☐ >20 years ☑

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☑	☑	☐	☐	☐	☐

6.No. of years in Office Setup ☐ in Field 28 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover ☑

High Population Density ☑

Low Pipe wall thickness ☑

Land Use Pattern ☐

Lack of public awareness ☑

How do your rank reasons for pipeline failure in order of priority?

Corrosion ~~3~~1

Construction flow 4

Material Defect 5

Operation Error 2

3rd Party Activities 3

Acts of God 6

Others –

Dr. C. KANNAN)
CGM (PL&CR)

University of Petroleum and Energy Studies, Dehradun

Expert Selection Format

1.Name of the Expert : R D Sabharwal

2. Specialization : Engineering Civil/Elctrical/Mechanical/[✓ Metallurgy]/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 0-15 years ☐ 15-20 years ☐ >20 years ☑

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☐	☑	☐	☐	☑	☑

6. No. of years in Office Setup 15 in Field 18 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover 1

High Population Density 3

Low Pipe wall thickness 2

Land Use Pattern 4

Lack of public awareness 5

How do your rank reasons for pipeline failure in order of priority?

Corrosion 2

Construction flow 3

Material Defect 4

Operation Error 5

3rd Party Activities 1

Acts of God 6

Others 7

(R D Sabharwal)

Expert Selection Format

1.Name of the Expert : : Atul Parmar

2. Specialization : Engineering Civil/[✓ Elctrical]/Mechanical/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 0-15 years ☐ 15-20 years ☑ >20 years ☐

5.Working Area

Area	[✓ Maintenance]	Inspection	[✓ Operation]	Design	[✓ Construction]	[✓ Others]
Years	08		04		05	02

6. No. of years in Office Setup 1.5 in Field 17.5 In R&D — Others —

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

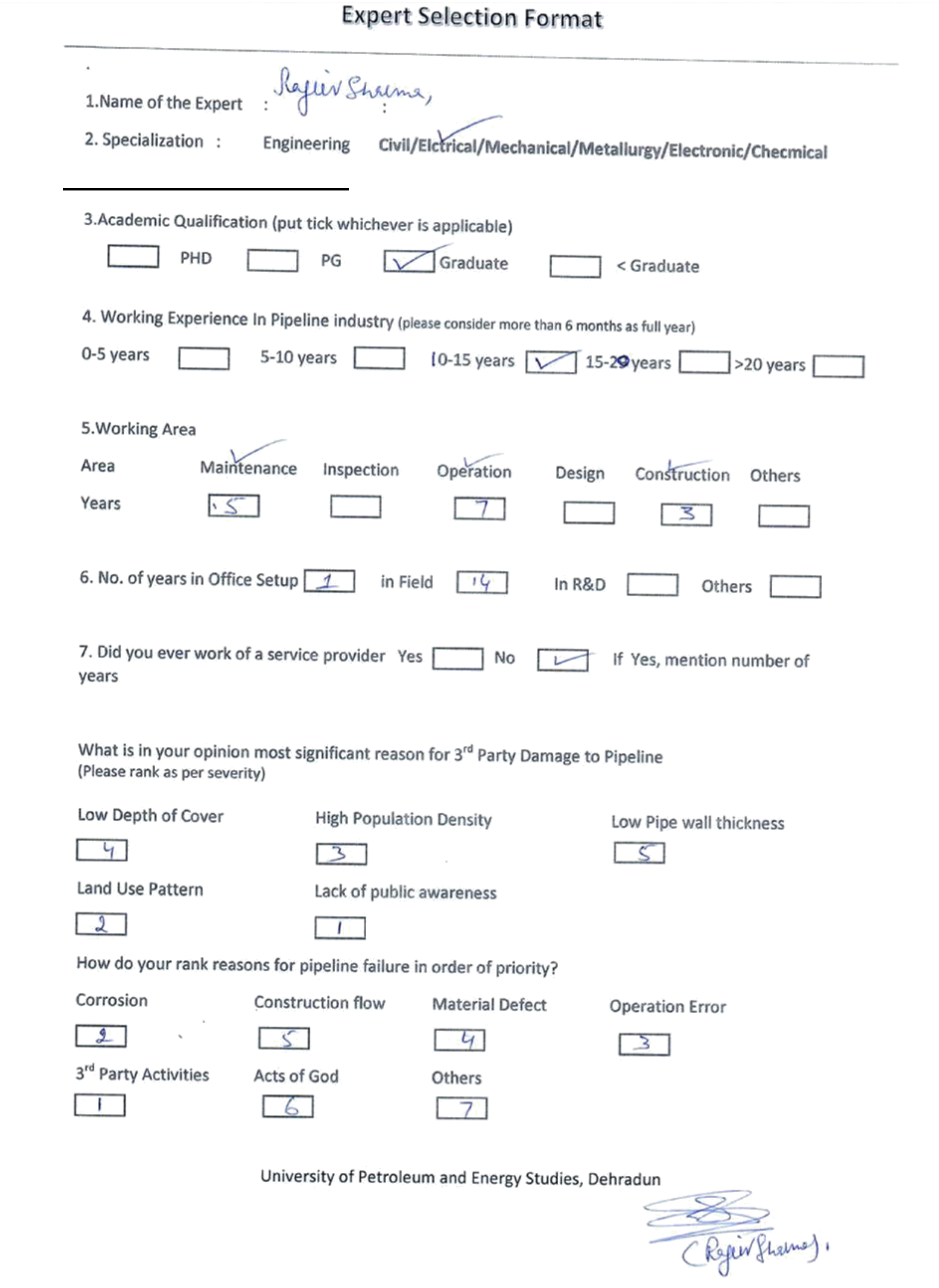
Low Depth of Cover 1
High Population Density 4
Low Pipe wall thickness 5
Land Use Pattern 3
Lack of public awareness 2

How do your rank reasons for pipeline failure in order of priority?

Corrosion 1
Construction flow 4
Material Defect 2
Operation Error 7
3rd Party Activities 5
Acts of God 3
Others 6

University of Petroleum and Energy Studies, Dehradun

Parmar
(Atul Parmar)
CM(Mainline)



Expert Selection Format

1.Name of the Expert : Rajiv Sharma,

2. Specialization : Engineering Civil/[✓ Elctrical]/Mechanical/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 10-15 years ☑ 15-20 years ☐ >20 years ☐

5.Working Area

Area	[✓ Maintenance]	Inspection	[✓ Operation]	Design	[✓ Construction]	Others
Years	.5		7		3	

6. No. of years in Office Setup 1 in Field 14 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

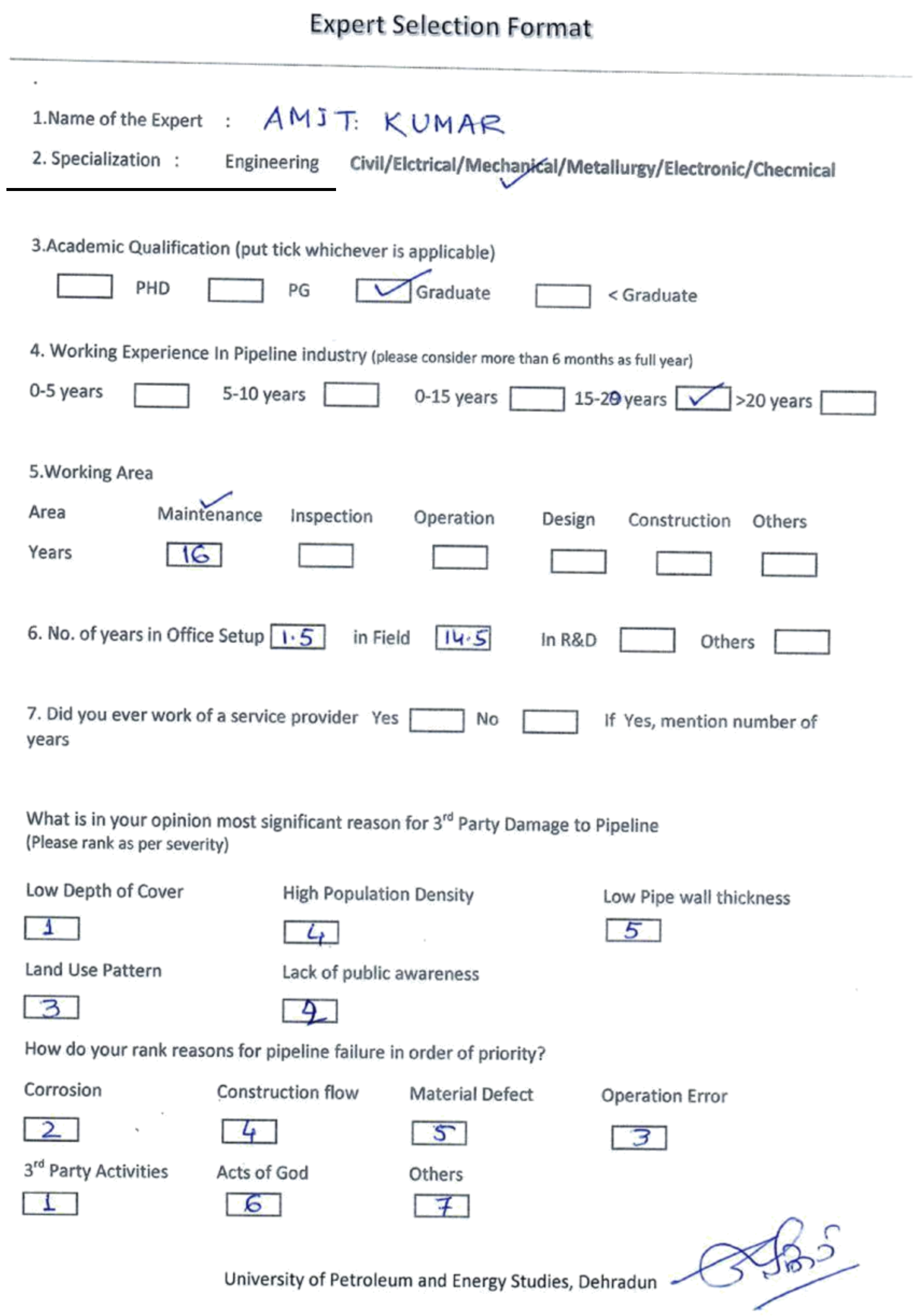
Low Depth of Cover	High Population Density	Low Pipe wall thickness
4	3	5
Land Use Pattern	Lack of public awareness	
2	1	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	5	4	3
3rd Party Activities	Acts of God	Others	
1	6	7	

University of Petroleum and Energy Studies, Dehradun

(Rajiv Sharma).



Expert Selection Format

1.Name of the Expert : AMIT KUMAR

2. Specialization : Engineering Civil/Elctrical/[✓ Mechanical]/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 0-15 years ☐ 15-20 years ☑ >20 years ☐

5.Working Area

Area	[✓ Maintenance]	Inspection	Operation	Design	Construction	Others
Years	16					

6. No. of years in Office Setup 1.5 in Field 14.5 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☐ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
1	4	5
Land Use Pattern	Lack of public awareness	
3	2	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	4	5	3
3rd Party Activities	Acts of God	Others	
1	6	7	

University of Petroleum and Energy Studies, Dehradun

Expert Selection Format

1.Name of the Expert : : SATYA PRAKASH YADAV

2. Specialization : Engineering Civil/Elctrical/Mechanical/[✓ Metallurgy]/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☑ PG ☐ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 0-15 years ☑ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☑ ~~4~~5	0	0	0	☑ ~~7~~3	☑ ~~2~~5

6. No. of years in Office Setup 10 in Field 3 In R&D ☐ Others [illegible]

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover 4

High Population Density 2

Low Pipe wall thickness 3

Land Use Pattern 1

Lack of public awareness 5

How do your rank reasons for pipeline failure in order of priority?

Corrosion 3

Construction flow 5

Material Defect 2

Operation Error 4

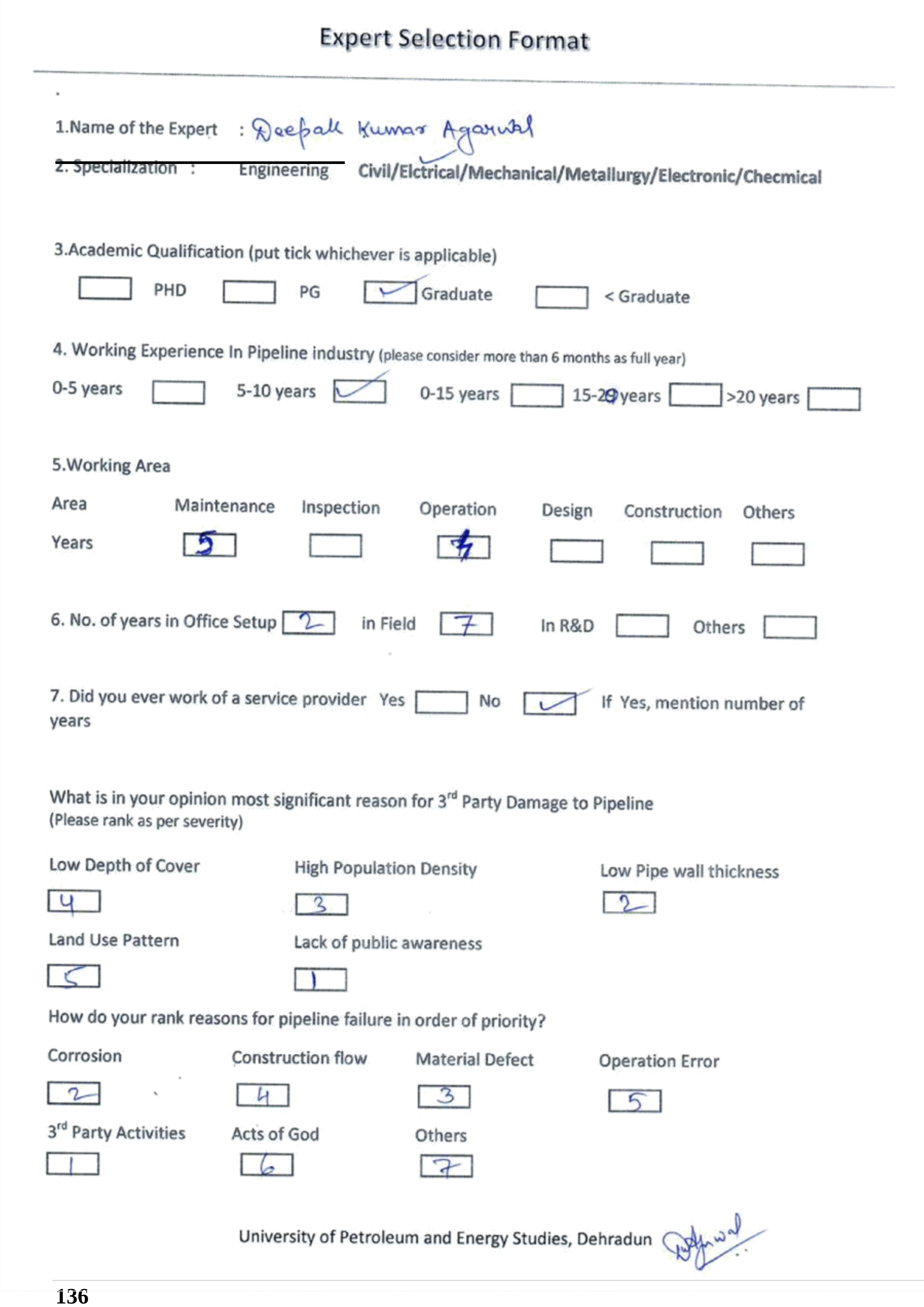
3rd Party Activities 1

Acts of God 7

Others 6

University of Petroleum and Energy Studies, Dehradun

(SATYA PRAKASH YADAV)
SMNM (OFF SHORE)



Expert Selection Format

1.Name of the Expert : Deepak Kumar Agarwal

2. Specialization : Engineering Civil/[✓ Elctrical]/Mechanical/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☑ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	5		4			

6. No. of years in Office Setup 2 in Field 7 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover 4
High Population Density 3
Low Pipe wall thickness 2
Land Use Pattern 5
Lack of public awareness 1

How do your rank reasons for pipeline failure in order of priority?

Corrosion 2
Construction flow 4
Material Defect 3
Operation Error 5
3rd Party Activities 1
Acts of God 6
Others 7

University of Petroleum and Energy Studies, Dehradun

Expert Selection Format

1.Name of the Expert : : Deepak Agarwal

2. Specialization : Engineering Civil/Elctrical/Mechanical/[✓ Metallurgy]/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 10-15 years ☑ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years		3	5			3

6. No. of years in Office Setup 5 in Field 6 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
1	3	2
Land Use Pattern	Lack of public awareness	
4	5	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	3	4	6
3rd Party Activities	Acts of God	Others	
1	5	7	

University of Petroleum and Energy Studies, Dehradun

Deepak

Expert Selection Format

1.Name of the Expert : : SANTOSH KUMAR

2. Specialization : Engineering Civil/Elctrical/Mechanical/[✓ Metallurgy]/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☐ 10-15 years ☑ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☐	☑	☑	☐	☑	☐

6. No. of years in Office Setup 8.5 in Field 2 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
3	4	5
Land Use Pattern	Lack of public awareness	
1	2	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flaw	Material Defect	Operation Error
1	5	2	4
3rd Party Activities	Acts of God	Others	
3	6	7	

University of Petroleum and Energy Studies, Dehradun

Kumar
(Santosh Kumar)

Expert Selection Format

1.Name of the Expert : : Rakesh Mahato

2. Specialization : Engineering Civil/[✓ Elctrical]/Mechanical/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☑ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	4 ✓	☐	☐	☐	☐	6 ✓

6. No. of years in Office Setup 6 in Field 4 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
1	3	2
Land Use Pattern	Lack of public awareness	
4	5	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	3	1	6
3rd Party Activities	Acts of God	Others	
4	5	7	

University of Petroleum and Energy Studies, Dehradun

(Rakesh Mahato)

Expert Selection Format

1.Name of the Expert : : NIRAJ KUMAR

2. Specialization : Engineering Civil/Elctrical/Mechanical/[✓ Metallurgy]/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☑ 10-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☑	☑	☐	☐	☐	☐

6. No. of years in Office Setup 01 in Field 07 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
1	2	5
Land Use Pattern	Lack of public awareness	
4	3	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	5	4	3
3rd Party Activities	Acts of God	Others	
1	6	7	

Niraj Kumar
(NIRAJ KUMAR)
AM (Insp.)

University of Petroleum and Energy Studies, Dehradun

Expert Selection Format

1.Name of the Expert : : SAYAN ROY

2. Specialization : Engineering Civil/Elctrical/Mechanical/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☑ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	7	–	–	–	–	–

6. No. of years in Office Setup 0.5 in Field 7 In R&D – Others –

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover 1

High Population Density 3

Low Pipe wall thickness 5

Land Use Pattern 2

Lack of public awareness 4

How do your rank reasons for pipeline failure in order of priority?

Corrosion 2

Construction flow 3

Material Defect 4

Operation Error 5

3rd Party Activities 1

Acts of God 6

Others 7

(Sayan Roy)

University of Petroleum and Energy Studies, Dehradun

Expert Selection Format

1.Name of the Expert : MAHENDRA KUMAR MEENA.

2. Specialization : Engineering Civil/[✓ Eletrical]/Mechanical/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☑ 10-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☑	☐	☑	☐	☐	☐

6. No. of years in Office Setup ☐ in Field 07 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
1	2	4
Land Use Pattern	Lack of public awareness	
3	5	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	3	1	6
3rd Party Activities	Acts of God	Others	
4	5	7	

University of Petroleum and Energy Studies, Dehradun

(M.K. Meena)

Expert Selection Format

1.Name of the Expert : MOHIT GARG

2. Specialization : Engineering Civil/Elctrical/[✓ Mechanical]/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☑ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☐	☐	☑	☐	☐	☐

6. No. of years in Office Setup 3 in Field 4 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover 3

High Population Density 4

Low Pipe wall thickness 5

Land Use Pattern 1

Lack of public awareness 2

How do your rank reasons for pipeline failure in order of priority?

Corrosion 4

Construction flow 3

Material Defect 2

Operation Error 5

3rd Party Activities 1

Acts of God 6

Others ☐

University of Petroleum and Energy Studies, Dehradun

1/11/18

Expert Selection Format

1.Name of the Expert : Mamta Chiniya

2. Specialization : Engineering Civil/Elctrical/Mechanical/Metallurgy/[✓ Electronic]/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☑ 5-10 years ☐ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☑	☐	☐	☐	☐	☐

6. No. of years in Office Setup 0.5 in Field 4 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
1	3	4
Land Use Pattern	Lack of public awareness	
2	5	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	3	1	6
3rd Party Activities	Acts of God	Others	
4	5	7	

University of Petroleum and Energy Studies, Dehradun

Mamta

Mamta Chiniya

Expert Selection Format

1.Name of the Expert : ANKIT KUMAR

2. Specialization : Engineering Civil/Elctrical/[✓ Mechanical]/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☑ 5-10 years ☐ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance ✓	Inspection	Operation ✓	Design	Construction	Others
Years	3		1.5			

6. No. of years in Office Setup 1.5 in Field 3 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

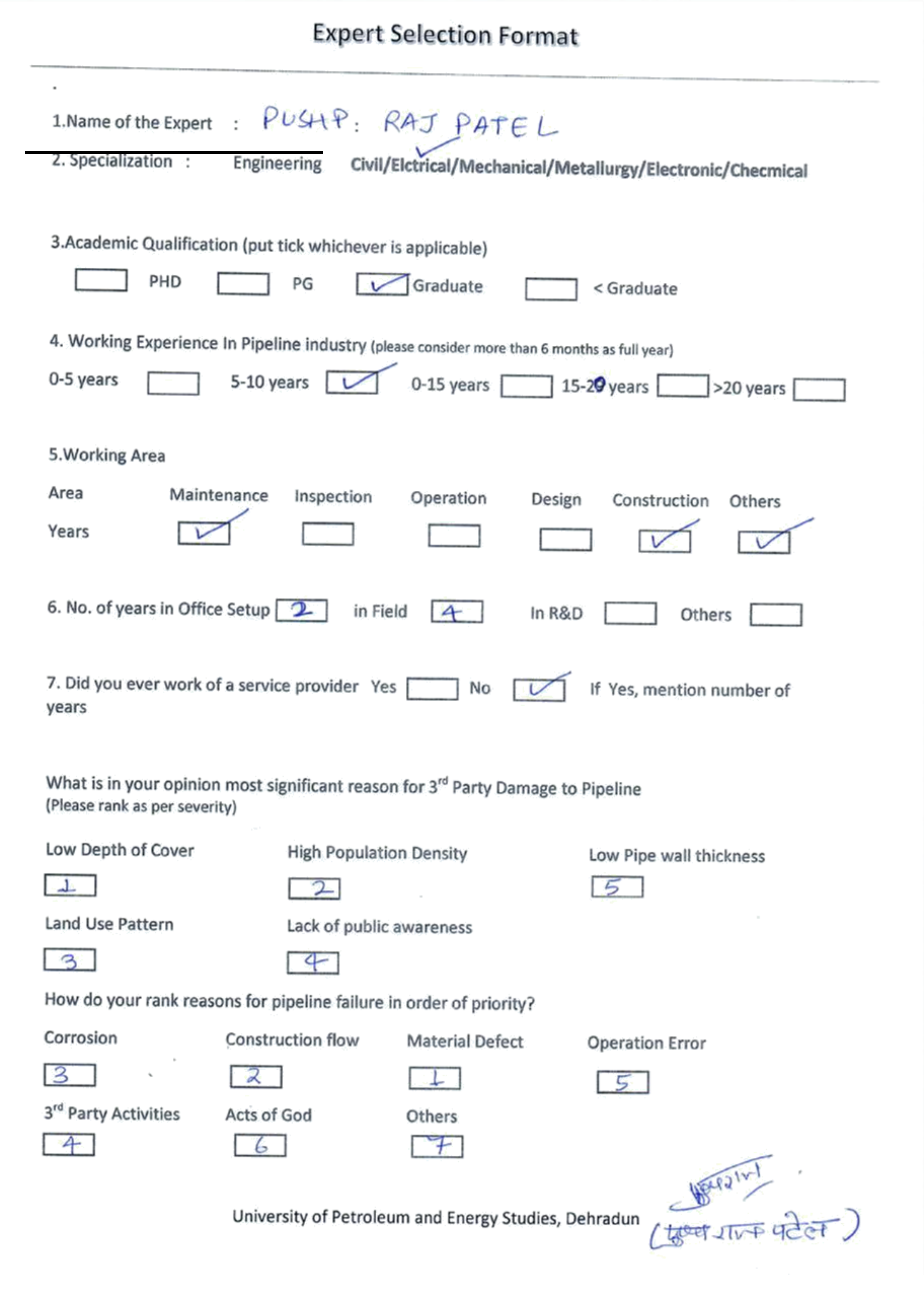
Low Depth of Cover	High Population Density	Low Pipe wall thickness
2	1	3
Land Use Pattern	Lack of public awareness	
5	4	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
2	4	3	5
3rd Party Activities	Acts of God	Others	
1	6	7	

University of Petroleum and Energy Studies, Dehradun

(Ankit Kumar)



Expert Selection Format

1.Name of the Expert : PUSHP: RAJ PATEL

2. Specialization : Engineering Civil/[✓ Elctrical]/Mechanical/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☐ 5-10 years ☑ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☑	☐	☐	☐	☑	☑

6. No. of years in Office Setup 2 in Field 4 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover 1

High Population Density 2

Low Pipe wall thickness 5

Land Use Pattern 3

Lack of public awareness 4

How do your rank reasons for pipeline failure in order of priority?

Corrosion 3

Construction flow 2

Material Defect 1

Operation Error 5

3rd Party Activities 4

Acts of God 6

Others 7

University of Petroleum and Energy Studies, Dehradun (पुष्प राज पटेल)

Expert Selection Format

1.Name of the Expert : VIVEK K:

~~2. Specialization : Engineering~~ Civil/Elctrical/[✓ Mechanical]/Metallurgy/Electronic/Checmical

3.Academic Qualification (put tick whichever is applicable)

☐ PHD ☐ PG ☑ Graduate ☐ < Graduate

4. Working Experience In Pipeline industry (please consider more than 6 months as full year)

0-5 years ☑ 5-10 years ☐ 0-15 years ☐ 15-20 years ☐ >20 years ☐

5.Working Area

Area	Maintenance	Inspection	Operation	Design	Construction	Others
Years	☐	☑	☐	☐	☐	☐

6. No. of years in Office Setup [illegible] in Field 04 In R&D ☐ Others ☐

7. Did you ever work of a service provider Yes ☐ No ☑ If Yes, mention number of years

What is in your opinion most significant reason for 3rd Party Damage to Pipeline
(Please rank as per severity)

Low Depth of Cover	High Population Density	Low Pipe wall thickness
1	2	5
Land Use Pattern	Lack of public awareness	
3	4	

How do your rank reasons for pipeline failure in order of priority?

Corrosion	Construction flow	Material Defect	Operation Error
1	6	5	4
3rd Party Activities	Acts of God	Others	
3	2	7	

University of Petroleum and Energy Studies, Dehradun

(VIVEK K)

APPENDIX B : LIST OF PUBLICATIONS AND PRESENTATIONS

1. Pipeline Technology Conference 2018, Berlin, Germany

Reduction in Risk from Third Party damage to LPG Pipelines in India

S S Gupta, Deepak Agarwal

Abstract

India is one of the largest consumers of Liquified Petroleum Gas (LPG). For distribution of LPG, there are approximately 2600km of cross-country LPG pipelines in India. Another approximately 4,000km, is under construction by 2022 total length of LPG pipelines is likely to touch 10,000km. During pipeline transportation LPG behaves like any other liquid, but on release (due to leaks and ruptures) turns into gas expanding 270 times, besides, LPG being heavier than air travels on the surface of the earth unlike natural gas that goes up. Also, upon release of LPG from pipeline, atmosphere surround the leak spot turns into a very low temperature zone (due to rapid expansion) and the ground becomes frozen. Under such condition repair of pipeline leak involving soil excavation is nearly impossible till the soil thaws back. Therefore, the best approach is preventing leaks in LPG pipeline.

3rd party interference is one of the primary causes of pipeline failure across the globe. In a country like India where population density is generally high, human activities like cable laying, water line laying etc., across the pipeline Right of Way (ROW) has increased many fold in the recent years, consequently probability of third party damage to a pipeline has also increased. A LPG pipeline operator, therefore, needs an M&I programme that is primarily focused on 3rd party interference prevention. This paper proposes one such M&I programme for LPG pipelines in India with special emphasis on 3rd Party activity monitoring. The proposed M&I programme is developed based on Risk Assessment of an operating LPG pipeline, paper quantifies the amount of risk that can be eliminated by adopting the proposed M&I programme over the present one.

2. Designing a Model for Optimization of Maintenance and Inspection efforts against Third Party Damage to cross country Pipelines in India

International Journal of Innovative Technology and Exploring Engineering October 2019 Published in Vol. 8, Issue 12.
SCOPUS Index Journal: Scopus Link: https://www.scopus.com/sourceid/21100889409

S. S. Gupta, Dr.A K Arya, Dr. P.Vijay

Abstract

Keeping pace with the growth of Indian economy, the energy demand of the country is increasing rapidly. One of the major modes of transportation of oil and gas is the cross-country pipelines networks. In India there are nearly 45000km of cross- country pipelines in operation, safe operation and reliability of this network of pipelines play a major role in the energy security of the country. Like any other industrial structures pipelines are also prone to failure, one of the major causes of failure is corrosion but in a populous country like India third party damage has emerged as a new threat to pipelines, as on date nearly 40% of all pipeline failures are due to third party damage only. Therefore, it is necessary that causes of third- party damage are analyzed and factors responsible for third party damages are carefully evaluated so that actions in terms of maintenance and inspection of pipelines can be more focused. This paper proposes a model that helps in evaluation of third party damages and quantifies the factors in a manner so that maintenance and inspection efforts can be optimized to get best results out of resources deployed.

Keyword: Third party Damage, Pipelines, Hydrocarbon, M&I,

3. IJRAR October 2018, Volume 5, Issue 4, International Journal of Research and Analytical Reviews, DOI : http://doi.one/10.1729/journal.19074

Risk of third-party damage to LPG pipeline in india and its mitigation

S S Gupta, Deepak Agarwal

“**Abstract:** India is rapidly expanding its network of cross-country pipelines; a significant portion of this network consists of LPG pipeline. India is operating around 2600km of LPG transmission pipelines and another 4,000km are under construction. Given the demand, it is perceived that India shall reach a total of 10,000km of LPG pipeline by 2022. LPG pipelines in India are primarily laid

between either between refineries or ports and LPG bottling plants near to consumption centers. Given the size of the country naturally majority of existing and upcoming LPG lines are long distance ones. World’s longest LPG pipelines is planned between Mundra port in Western India and Gorakhpur in Uttar Pradesh covering more than 200km.

While pipelines are considered one of the safest modes of transporting bulk hydrocarbon over long distances, but occasional failure of pipelines have been encountered both in India and abroad. Due to the typical characteristics of LPG, pipelines engaged in transporting LPG has a very different risk scenario compared to oil and gas pipelines. LPG during pipeline transportation behaves like any other liquid media, but upon its release (caused either due to leaks or ruptures) to atmosphere LPG turns into gas expanding 270 times in volume. Further, LPG is heavier than air as a result it travels on the surface of the earth and tend to accumulate in the lower elevation spots. Upon release of LPG from pipeline, atmosphere surrounding the release spot turns into a very low temperature zone (due to adiabatic expansion & latent heat of vaporization of LPG) and the ground becomes frozen. Under such condition repair of pipeline leak involving soil excavation is nearly impossible till the soil thaws back. Therefore, the best approach is to prevent leaks or ruptures in LPG pipeline.

One of the predominating causes of pipeline failures across the world is 3rd party damage (excavation damage, theft, sabotage etc), especially in developed and industrial nations. India with high population density and increased human activities like cable laying, water line laying etc., across the pipeline Right of Way (ROW) in the recent years, the probability of third-party damage to a pipeline has increased multiple times. An LPG pipeline operator, therefore, must have a Maintenance & Inspection (M&I) programme that is primarily focused on 3rd party damage prevention. This paper proposes one such M&I programme for LPG pipelines in India with special emphasis on 3rd Party activity monitoring. The proposed M&I programme is developed based on Risk Assessment of an operating LPG pipeline, paper quantifies the amount of risk that can be eliminated by adopting the proposed M&I programme over the present one.”

Keywords: Third Party Damage, LPG Pipelines, Risk Assessment,

4. Reducing failure probability of cross country pipline from 3rd party interference through optimization of maintenance & inspection programme

S S Gupta, Dr. A K Arya, Dr.P.Vijay

Journal of Emerging Technology and Innovative Research October 2018, Volume 5, Issue 10 www.jetir.org (ISSN-2349-5162), http://doi.one/10.1729/Journal.19130

Abstract

Pipelines are an important mode of transportation of bulk hydrocarbon energy across a vast country like India. With projected growth of Indian economy more and more new pipelines are being built across the country. Safe operation of these pipelines is crucial from the point of view of protection of life and property of the citizens. While pipelines are the safest mode of transportation, accident does occur in the pipelines. A major cause of pipeline accident is damage by external forces both with ignorance and sometimes with malicious intention. A pipeline operator manages the integrity of the pipeline by deployment of a structured Maintenance & Inspection (M&I) plan. However, the effectiveness of the M&I plan depends upon threat perception. This paper suggests an approach that leads to optimization of the M&I programme of a pipeline operator from the point of view of reduction in possibility of damage to the pipeline from external forces. Optimized M&I programme also results in cost saving and proper distribution of M&I activities based on threat perception.

Key words; Pipeline, external interference, M&I, Optimization

5. Implementation of Pipeline Integrity Management in a Large Pipelines Network in India

S S Gupta, Dr. A K Arya, Dr.P.Vijay

‘International Journal of Recent Technology and Engineering (IJRTE)’ Volume-8 Issue-4, November 2019, SCOPUS Indexed Journal

Abstract

Hydrocarbon pipelines are one of the key elements of the energy security system of a country, especially in a large country like India hydrocarbon pipelines are the backbone of the energy distribution system. While the operational reliability of such a system is important to ensure a sustained supply of hydrocarbon energy across the country, the continued structural integrity of the network is vital for public safety. Generally, pipelines are the safest mode of transportation of bulk hydrocarbon energy, but pipeline failure is not uncommon. Recent global databases on pipeline failure indicate that third party damage and corrosion are two major causes of pipeline failure though there are other reasons like poor construction quality; an incorrect operation etc., may also lead to pipeline failure. The extent of damage that a pipeline failure can cause depends on the extent of the release, for example, a small leak may not cause much damage if detected with a short period, while a rupture of the pipeline can release a significant amount of pipeline content and may cause significant damage to property and life. With a higher degree of public awareness and stricter regulatory regime, pipeline operators are having a relook into their integrity management system to prevent any untoward incident. Majority of the pipeline operator now realize that holistic approach taking together as much factor as possible could be a better approach to manage the integrity of the pipeline network especially a large network of pipeline spread across a vast country like India. This realization has led many pipeline operators to implement computer-based pipeline integrity management system. While this is a welcome change but implementation of PIMS across a vast network of pipeline built over a long period, with various technologies and having diverse engineering requirements have come of the challenges that the pipeline operator must overcome. This paper discusses one such case of implementation of the Pipeline Integrity Management System (PIMS) in a large and diverse network pipeline in India and the challenges faced in the course of implementation. Authors feel that the case could be a good learning ground for those operators who are contemplating implementation of PIMS in their respective pipeline network.

Key word: Pipeline, Integrity Management; corrosion; third-party damage; Cathodic Protection; GIS; risk

APPENDIX C: PHOTOGRAPH OF LPG PIPELINE INSTALLATION PIPELINE SYSTEM

Fig A-1: Typical LPG Storage Facility

Fig A-2: Arrangements in a Sectionalizing Valve Station in LPG Pipeline

Fig A-3: Sectionalizing valve station

Fig A-4: Mainline Block Valves and Sectionalising Valves

Fig A-5: LPG Station Valves

Fig A-6: A Typical LPG Flaring System in a Pumping Station

Fig A-7: A Typical LPG Pipe Station Control Room

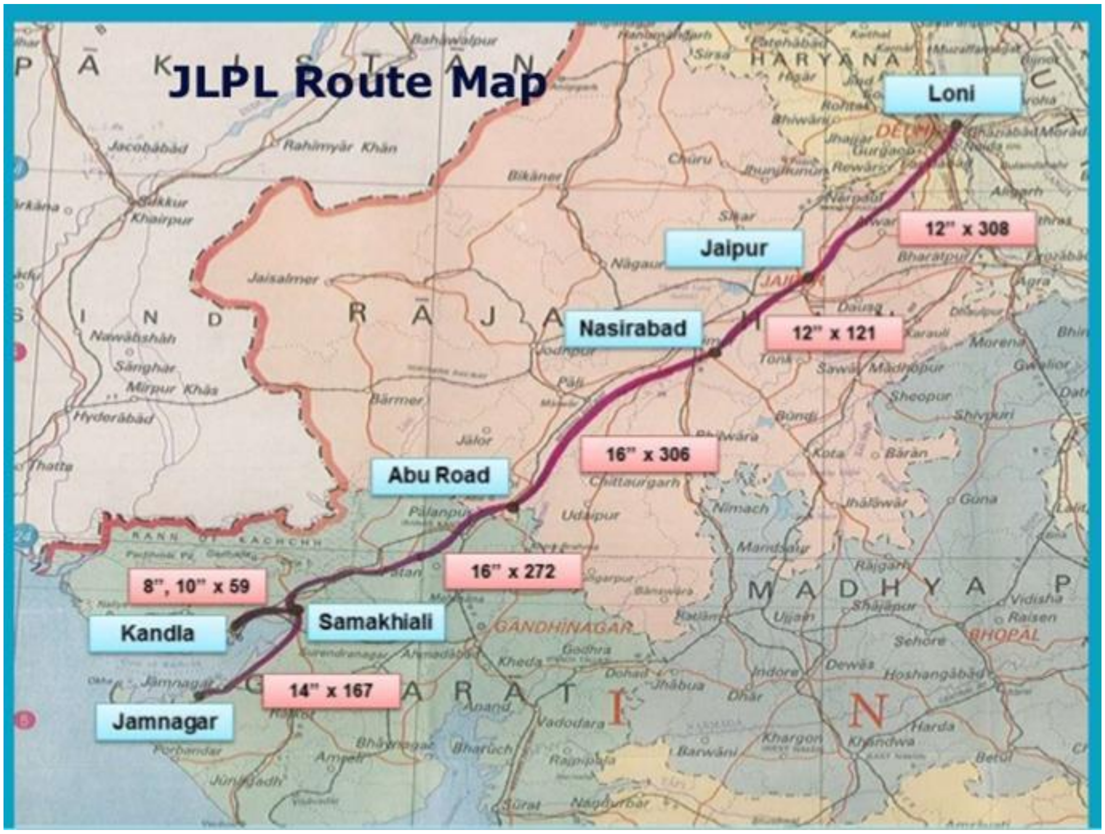
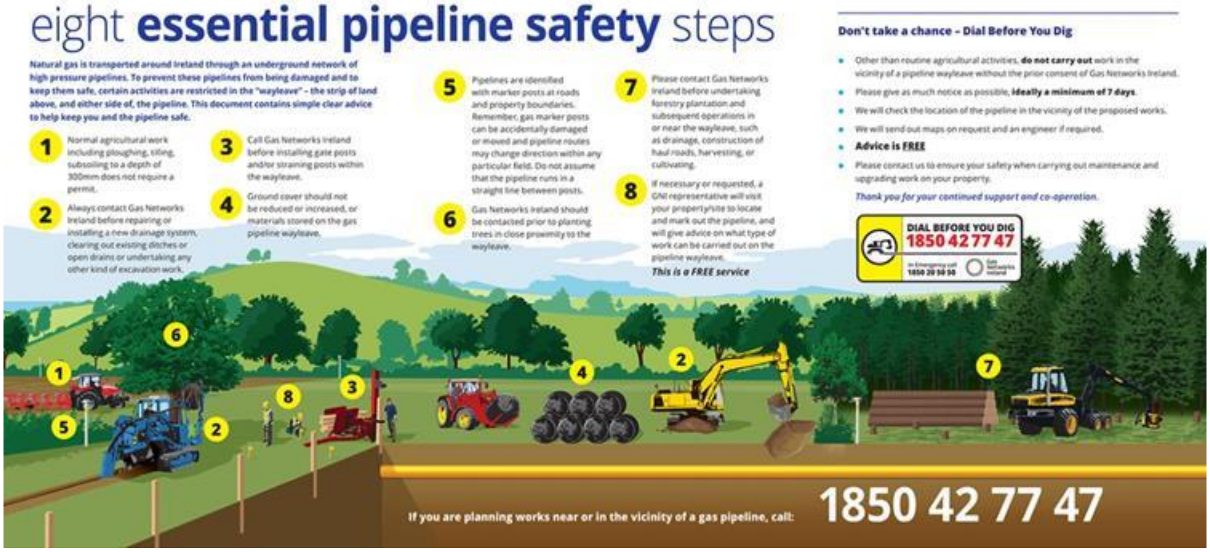


Fig A-8: Jamnagar Luni (Delhi) LPG Pipeline is currently longest Operating LPG Pipeline in India

Fig A-9: A Typical Pipeline Damage Due to third Party Activity



eight **essential pipeline safety** steps

Natural gas is transported around Ireland through an underground network of high pressure pipelines. To prevent these pipelines from being damaged and to keep them safe, certain activities are restricted in the "wayleave" – the strip of land above, and either side of, the pipeline. This document contains simple clear advice to help keep you and the pipeline safe.

1. Normal agricultural work including ploughing, tilling, subsoiling to a depth of 300mm does not require a permit.
2. Always contact Gas Networks Ireland before repairing or installing a new drainage system, clearing out existing ditches or open drains or undertaking any other kind of excavation work.
3. Call Gas Networks Ireland before installing gate posts and/or straining posts within the wayleave.
4. Ground cover should not be reduced or increased, or materials stored on the gas pipeline wayleave.
5. Pipelines are identified with marker posts at roads and property boundaries. Remember, gas marker posts can be accidentally damaged or moved and pipeline routes may change direction within any particular field. Do not assume that the pipeline runs in a straight line between posts.
6. Gas Networks Ireland should be contacted prior to planting trees in close proximity to the wayleave.
7. Please contact Gas Networks Ireland before undertaking forestry plantation and subsequent operations in or near the wayleave, such as drainage, construction of haul roads, harvesting, or cultivating.
8. If necessary or requested, a GNI representative will visit your property/site to locate and mark out the pipeline, and will give advice on what type of work can be carried out on the pipeline wayleave.

This is a FREE service

Don't take a chance – Dial Before You Dig

- Other than routine agricultural activities, **do not carry out** work in the vicinity of a pipeline wayleave without the prior consent of Gas Networks Ireland.
- Please give as much notice as possible, **ideally a minimum of 7 days**.
- We will check the location of the pipeline in the vicinity of the proposed works.
- We will send out maps on request and an engineer if required.
- **Advice is FREE**
- Please contact us to ensure your safety when carrying out maintenance and upgrading work on your property.

Thank you for your continued support and co-operation.

If you are planning works near or in the vicinity of a gas pipeline, call: 1850 42 77 47

Fig A-10: A Typical warning display in the ROW

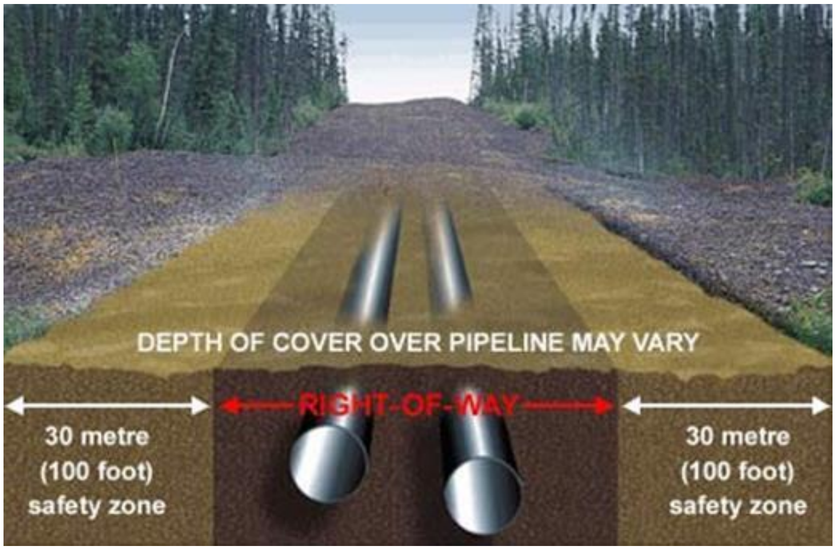


Fig A-11: A typical Awareness Notice in Pipeline ROW for Sensitizing people,

Fig A-12: A typical Pipeline construction activity

Fig A-13: A typical Pipeline construction activity

Fig A-14: Fire in a LPG pipeline

Fig A-15: A gas pipeline Failure in Andhra Pradesh, June 2015

APPENDIX D : CRITICAL TABLES

Table A.1: Details of scoring by expert 1

Basic Mark	**Expert 1**	7	5	3	3	4	7	7	3	1	3	3	3	9	3	5	5	7
Norm. Mark	Expert 1	7.00	5.00	3.00	3.00	4.00	7.00	7.00	3.00	1.00	3.00	3.00	7.00	9.00	3.00	5.00	5.00	7.00
Pipeline	Length	Population Density per/km (in km)			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+ forest	Industrial	Commercial	Residential
1	**25**	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	**77.00**	**30.00**	**24.00**	**3.00**	**6.00**	**140.00**	**133.00**	**12.00**	**2.00**	**0.00**	**15.00**	**126.00**	**18.00**	**18.00**	**15.00**	**10.00**	**98.00**
2	**30**	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	**49.00**	**100.00**	**9.00**	**6.00**	**18.00**	**126.00**	**42.00**	**60.00**	**4.00**	**0.00**	**21.00**	**161.00**	**0**	**72.00**	**0.00**	**5.00**	**35.00**
3	**20**	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	**70.00**	**35.00**	**9.00**	**4.00**	**0.00**	**112.00**	**35.00**	**42.00**	**0.00**	**3.00**	**15.00**	**101.50**	**0**	**15.00**	**20.00**	**10.00**	**63.00**
4	**15**	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
	Score	**35.00**	**40.00**	**3.00**	**0.00**	**0.00**	**105.00**	**7.00**	**42.00**	**0.00**	**0.00**	**6.00**	**91.00**	**0.00**	**30.00**	**0.00**	**5.00**	**28.00**
5	**25**	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	**42.00**	**90.00**	**3.00**	**5.00**	**18.00**	**98.00**	**70.00**	**24.00**	**2.00**	**15.00**	**9.00**	**154.00**	**0.00**	**15.00**	**25.00**	**25.00**	**70.00**
6	**20**	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	**56.00**	**45.00**	**9.00**	0	0	**140.00**	**21.00**	**48.00**	0	**3.00**	**3.00**	**133.00**	**0.00**	**48.00**	0	**10.00**	**14.00**

Table A.2: Details of scoring by expert 2

Basic Mark	**Expert 2**	3	5	7	7	5	3	3	5	7	4	7	3	1	3	7	7	5
REW Marks	Expert 2	2.76	4.60	6.44	6.44	4.60	2.76	2.76	4.60	6.44	3.68	6.44	2.76	0.92	2.76	6.44	6.44	4.60
Pipeline	Length	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+ forest	Industrial	Commercial	Residential
1	**25**	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	**30.36**	**27.60**	**51.52**	**19.32**	**9.20**	**55.20**	**52.44**	**18.40**	**12.88**	**0.00**	**32.20**	**49.68**	**1.84**	**16.56**	**19.32**	**12.88**	**64.40**
2	**30**	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	**19.32**	**92.00**	**19.32**	**38.64**	**27.60**	**49.68**	**16.56**	**92.00**	**25.76**	**0.00**	**45.08**	**63.48**	**0**	**66.24**	**0.00**	**6.44**	**23.00**
3	**20**	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	**27.60**	**32.20**	**19.32**	**25.76**	**0.00**	**44.16**	**13.80**	**64.40**	**0.00**	**3.68**	**32.20**	**40.02**	**0**	**13.80**	**25.76**	**12.88**	**41.40**
4	**15**	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
	Score	**13.80**	**36.80**	**6.44**	**0.00**	**0.00**	**41.40**	**2.76**	**64.40**	**0.00**	**0.00**	**12.88**	**35.88**	**0.00**	**27.60**	**0.00**	**6.44**	**18.40**
5	**25**	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	**16.56**	**82.80**	**6.44**	**32.20**	**27.60**	**38.64**	**27.60**	**36.80**	**12.88**	**18.40**	**19.32**	**60.72**	**0.00**	**13.80**	**32.20**	**32.20**	**46.00**
6	**20**	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	**22.08**	**41.40**	**19.32**	0	0	**55.20**	**8.28**	**73.60**	0	**3.68**	**6.44**	**52.44**	**0.00**	**44.16**	0	**12.88**	**9.20**

Table A.3: Details of scoring by expert 3

Basic Mark	**Expert 3**	3	5	7	7	4	3	3	5	7	5	6	4	1	3	7	7	5
REW Marks	Expert 3	2.55	4.25	5.95	5.95	3.40	2.55	2.55	4.25	5.95	4.25	5.10	3.40	0.85	2.55	5.95	5.95	4.25
Pipeline	Length	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+ forest	Industrial	Commercial	Residential
1	**25**	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	**28.05**	**25.50**	**47.60**	**17.85**	**6.80**	**51.00**	**48.45**	**17.00**	**11.90**	**0.00**	**25.50**	**61.20**	**1.70**	**15.30**	**17.85**	**11.90**	**59.50**
2	**30**	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	**17.85**	**85.00**	**17.85**	**35.70**	**20.40**	**45.90**	**15.30**	**85.00**	**23.80**	**0.00**	**35.70**	**78.20**	**0**	**61.20**	**0.00**	**5.95**	**21.25**
3	**20**	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	**25.50**	**29.75**	**17.85**	**23.80**	**0.00**	**40.80**	**12.75**	**59.50**	**0.00**	**4.25**	**25.50**	**49.30**	**0**	**12.75**	**23.80**	**11.90**	**38.25**
4	**15**	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
	Score	**12.75**	**34.00**	**5.95**	**0.00**	**0.00**	**38.25**	**2.55**	**59.50**	**0.00**	**0.00**	**10.20**	**44.20**	**0.00**	**25.50**	**0.00**	**5.95**	**17.00**
5	**25**	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	**15.30**	**76.50**	**5.95**	**29.75**	**20.40**	**35.70**	**25.50**	**34.00**	**11.90**	**21.25**	**15.30**	**74.80**	**0.00**	**12.75**	**29.75**	**29.75**	**42.50**
6	**20**	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	**20.40**	**38.25**	**17.85**	0	0	**51.00**	**7.65**	**68.00**	0	**4.25**	**5.10**	**64.60**	**0.00**	**40.80**	0	**11.90**	**8.50**

Table A.4: Details of scoring of expert 4

Basic Mark	Expert 4	3	5	6	8	5	3	3	5	7	3	8	5	2	3	7	6	5
REW Marks	Expert 4	2.31	3.85	4.62	6.17	3.85	2.31	2.31	3.85	5.40	2.31	6.17	3.85	1.54	2.31	5.40	4.62	3.85
Pipeline	Length	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	km	>500	200-500	<200	Heavy	Mod.	Normal	Urban	Rural	Forest	Others	1.3-1.5m	1m-1.2m	<1m	Rural+ forest	Industrial	Commercial	Residential
1	25	11	6	8	3	2	20	19	4	2	0	5	18	2	6	3	2	14
	Score	25.43	23.12	36.99	18.50	7.71	46.24	43.93	15.41	10.79	0.00	30.83	69.37	3.08	13.87	16.19	9.25	53.95
2	30	7	20	3	6	6	18	6	20	4	0	7	23	0	24	0	1	5
	Score	16.19	77.07	13.87	36.99	23.12	41.62	13.87	77.07	21.58	0.00	43.16	88.63	0	55.49	0.00	4.62	19.27
3	20	10	7	3	4	0	16	5	14	0	1	5	14.5	0.5	5	4	2	9
	Score	23.12	26.98	13.87	24.66	0.00	36.99	11.56	53.95	0.00	2.31	30.83	55.88	0	11.56	21.58	9.25	34.68
4	15	5	8	1	0	0	15	1	14	0	0	2	13	0	10	0	1	4
	Score	11.56	30.83	4.62	0.00	0.00	34.68	2.31	53.95	0.00	0.00	12.33	50.10	0.00	23.12	0.00	4.62	15.41
5	25	6	18	1	5	6	14	10	8	2	5	3	22	0	5	5	5	10
	Score	13.87	69.37	4.62	30.83	23.12	32.37	23.12	30.83	10.79	11.56	18.50	84.78	0.00	11.56	26.98	23.12	38.54
6	20	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
	Score	18.50	34.68	13.87	0	0	46.24	6.94	61.66	0	2.31	6.17	73.22	0.00	36.99	0	9.25	7.71

Table A.5: Segment wise Summary - Relative Weight of Factors - Expert 1

Factors	Segment						Average
	1	2	3	4	5	6	Expert 1
DC	0.219	0.262	0.221	0.259	0.246	0.269	**0.246**
PD	0.205	0.164	0.182	0.169	0.180	0.162	**0.177**
AL	0.196	0.200	0.188	0.192	0.180	0.211	**0.194**
WT	0.189	0.168	0.180	0.150	0.192	0.147	**0.171**
LU	0.191	0.207	0.229	0.231	0.203	0.211	**0.212**

Table A.6: Segment wise Summary - Relative Weight of Factors - Expert 2

Factors	Segment						**Average**
	1	2	3	4	5	6	**Expert 2**
DC	0.180	0.188	0.184	0.187	0.160	0.173	**0.179**
PD	0.189	0.190	0.206	0.193	0.191	0.187	**0.193**
AL	0.186	0.231	0.187	0.203	0.218	0.213	**0.206**
WT	0.222	0.203	0.223	0.238	0.222	0.242	**0.225**
LU	0.222	0.187	0.201	0.178	0.208	0.185	**0.197**

Table A.7: Segment wise Summary - Relative Weight of Factors - Expert 3

Factors	Segment						**Average**
	1	2	3	4	5	6	**Expert 3**
DC	0.201	0.210	0.201	0.217	0.189	0.211	**0.205**
PD	0.184	0.184	0.202	0.186	0.184	0.179	**0.186**
AL	0.181	0.223	0.183	0.196	0.218	0.204	**0.201**
WT	0.219	0.202	0.218	0.230	0.208	0.231	**0.218**
LU	0.216	0.181	0.196	0.172	0.201	0.175	**0.190**

Table A.8: Segment wise Summary - Relative Weight of Factors - Expert 4

Factors	Segment						**Average**
	1	2	3	4	5	6	**Expert 4**
DC	0.245	0.250	0.244	0.261	0.229	0.254	**0.247**
PD	0.180	0.178	0.195	0.177	0.178	0.171	**0.180**
AL	0.172	0.216	0.175	0.186	0.193	0.194	**0.189**
WT	0.199	0.183	0.199	0.216	0.209	0.215	**0.204**
LU	0.203	0.173	0.188	0.162	0.191	0.166	**0.181**

Table A.9: Relative Weight of Factors - Synthesized Expert Score

Factors	**Expert**				**All Expert Average**
	1	**2**	**3**	**4**	
DC	0.246	0.179	0.205	0.247	0.219
PD	0.177	0.193	0.186	0.180	0.184
AL	0.194	0.206	0.201	0.189	0.198
WT	0.171	0.225	0.218	0.204	0.204
LU	0.212	0.197	0.190	0.181	0.195

Table A.10: Degree of Un-Optimization (%Un)

Factors	DC	PD	AL	WT	LU
cw	0.219	0.184	0.198	0.204	0.195
nw	0.20	0.20	0.20	0.20	0.20
Un =nw-cw	-0.019	0.016	0.002	-0.004	0.005
% Un	-9.5%	8.0%	1.0%	-2.0%	2.5%

Table A.11: Segment Wise, Expert Wise Weight - Depth of Cover (DC)

Segment	E1	E2	E3	E4	Avg
1	0.219	0.180	0.201	0.250	0.212
2	0.262	0.188	0.201	0.261	0.228
3	0.221	0.184	0.217	0.229	0.213
4	0.259	0.187	0.189	0.229	0.216
5	0.246	0.160	0.211	0.254	0.218
6	0.269	0.173	0.205	0.247	0.224

Table A.12: Segment Wise, Expert Wise Weight- Population Density (PD)

Segment	E1	E2	E3	E4	Avg
1	0.205	0.189	0.184	0.178	0.189
2	0.164	0.190	0.202	0.177	0.183
3	0.182	0.206	0.186	0.178	0.188
4	0.169	0.193	0.184	0.178	0.181
5	0.180	0.191	0.179	0.171	0.180
6	0.162	0.187	0.186	0.180	0.179

Table A.13: Segment Wise, Expert Wise Weight- Awareness Level (AL)

Segment	E1	E2	E3	E4	Avg
1	0.196	0.186	0.181	0.172	0.184
2	0.200	0.231	0.223	0.216	0.217
3	0.188	0.187	0.183	0.175	0.183
4	0.192	0.238	0.196	0.186	0.203
5	0.180	0.222	0.218	0.193	0.203
6	0.211	0.213	0.204	0.194	0.205

Table A.14: Segment Wise, Expert Wise Weight- Wall Thickness (WT)

Segment	E1	E2	E3	E4	Avg
1	0.189	0.222	0.219	0.199	0.207
2	0.168	0.203	0.202	0.183	0.189
3	0.180	0.223	0.218	0.199	0.205
4	0.150	0.238	0.230	0.216	0.208
5	0.192	0.222	0.208	0.209	0.208
6	0.147	0.242	0.231	0.215	0.209

Table A.15: Segment Wise, Expert Wise Weight- Land Use (LU)

Segment	E1	E2	E3	E4	Avg
1	0.191	0.222	0.216	0.203	0.208
2	0.207	0.187	0.181	0.173	0.187
3	0.229	0.201	0.196	0.188	0.203
4	0.231	0.178	0.172	0.162	0.185
5	0.203	0.208	0.201	0.191	0.201
6	0.211	0.185	0.175	0.166	0.184

Table A.16: Segment wise un-optimization

Factor	Segment wise (nw-cw)						Optimization Index
	1	2	3	4	5	6	(Sum 1 to 6)
DC	-0.012	**-0.028**	-0.013	-0.016	-0.018	-0.024	-11.04%
PD	0.011	0.017	0.012	0.019	0.020	**0.021**	10.02%
AL	0.016	**-0.017**	0.017	-0.003	-0.003	-0.005	-1.73%
WT	-0.007	**0.011**	-0.005	-0.008	-0.008	-0.009	-0.88%
LU	**-0.008**	0.013	-0.003	0.015	-0.001	0.016	-0.81%

Table A.17: Segment wise Optimized M&I Expenditure

M&I	Existing	Optimized	Segment wise Optimized Expense					
Actions	Expense	Expense	1	2	3	4	5	6
GP	600	536.61	74.84	102.37	56.48	77.54	124.99	100.39
AP	400	357.74	49.89	68.25	37.66	51.69	83.33	66.92
DCS	100	109.47	16.56	20.17	12.00	15.76	25.31	19.67
ILI/GS	100	101.69	15.47	19.22	11.57	15.20	21.02	19.21
RoW M	500	447.17	62.37	85.31	47.07	64.62	104.16	83.65
ID	100	98.84	13.65	18.59	10.30	15.07	20.81	20.42
CI	50	44.72	6.24	8.53	4.71	6.46	10.42	8.37
Rs.(Lakh)/yr	1850	1696.24	239.01	322.45	179.79	246.33	390.02	318.64

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