REDUCING FAILURE PROBABILITY OF CROSS COUNTRY PIPLINE FROM 3RD PARTY INTERFERENCE THROUGH OPTIMIZATION OF MAINTENANCE & INSPECTION PROGRAMME

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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

Pipelines are known to be the safest mode of transportation of bulk hydro carbon energy. A fast developing economy like India needs large volume of energy for its growth. Not only the requirement of the energy but its distribution across this vast nation is a major challenge. Added to this high population density in the major portion of the country poses additional constrain in safe operation of a cross country pipeline.

In India as on date there is around 45,000km of cross country oil and gas pipelines [3] more than 90% of these lines are owned and operated by public sector oil companies. Further, nearly 12,000km of new pipelines are being built across the country keeping in mind the projected growth.

Though failure rates of hydrocarbon pipelines are lowest among all other modes of bulk transportation (refer table 1), but failures do happen from time to time. Some of the failures unfortunately, led for major loss of life and property, a recent example is failure of a gas pipeline in Andhra Pradesh, India leading to a loss of 24 lives. The primary reasons for pipeline failures can be broadly categorised to the following:

1. 3rd party interference
2. Corrosion
3. Construction and material defects
4. Operational errors
5. Acts of God

The list however, varies from country to country and the way failure data are recorded by concerned agencies.

Table 1, Comparison on Modes of Energy Transportation and safety

Transport mode	Factor on death	Factor on fire/explosion	Factor on injury
Road truck	87.,3	34.7	2.3
Rail	2.7	8.6	0.1
Barge	0.2	4.0	0.1
Tanker ship	4.0	1.2	3.1
Pipeline	1	1	1

A look at the failure trends of US pipelines for the year 2015 indicate that major causes of failure are corrosion, outside interference (also referred here as 3rd Party Interference),operational error , construction and material failure, Natural causes (or acts of God). Elsewhere in Europe (mainly in Western Europe) also similar trend of pipeline failure can be noticed.

Table 2; Pipeline Incident 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

[PHMSA = The Pipeline and Hazardous Materials Safety Administration the federal agency of USA responsible for pipeline safety, keeps track of pipeline incidents throughout USA.]

Pipeline failure data recorded by EGIG for European Gas Pipeline for the period 1970 to 2016 indicate a significant majority of failures are due to 3rd Party Interference [Refer Table 3]

Table 3; Primary failure frequencies per cause [14]

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
Hot tap made by error	0.014	0.006	0.006	0.003
Ground Movement	0.026	0.023	0.022	0.031

Note: No such data exist for Indian pipelines

From these results it is apparent that 3rd Party Damage (also referred as External Interference/ outside force) is one of the predominant causes of pipeline failure.

Pipeline Failure versus Incident Location

Another interesting fact indicated by the failure data is that the majority of failures are in the rural areas rather than urban areas, one reason for this could be longer stretches of pipeline falls in the rural zone in any country, therefore, the probability of failure in rural areas would be higher.

COCAWE report on liquid pipelines of Europe indicates the location wise distribution pattern of pipeline leaks, indicated int Table No. The segments 2, 3 and 4, namely Industrial, Residential and Commercial areas can be considered as Urban areas [BS 8010]. It was, however, could not be ascertained the percentage of the pipeline in Rural and Urban areas separately

Table 4, Pipeline Failure Locations

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

CONCAWE- Oil Companies European Organization for Environment, Health and Safety

CONCAWE DATA from 1971 till 2016 also indicate similar trend of pipeline failures

Table 5, Location wise oil spill incident 1971 to 2016

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

[Source CONCAWE report on Pipeline Failure 1971-2016]

Analysis of failure frequencies in terms of length of pipeline, however present a different picture as can be seen from table 6 below:

Table 6, Failure Frequencies per 1000km per geographical areas

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

[Based on CONCAWE date 1971-1996]

Above figures confirms the fact the probability of failure in the urban areas is much higher than that in the rural areas though in terms of absolute number more failures happen in the rural areas.

If one corelates the reasons for failure with that of geographical locations of failure it becomes clear that higher frequency of failure in urban areas is due to more intense human activity in urban areas (urban areas also include industrial zones and commercial zones)

Analysis of various elements of pipeline design (refer design standards ASME B31.4 for liquid lines and ASME B31.8) indicate that the basic factors on which 3rd party damage (or external interference) depends can be listed as below:

Key factors responsible for 3d party Damage in a pipeline

Following (a-f) factors shall be considered for each segment of the pipeline for pairwise comparison using Analytical Hierarchy Process (AHP) to identify relative weight of all the factors, from the point of view of possibility of 3rd Party Interference (TPI). Key factors are identified primarily after a review of documents [**1)** *An assessment of measures in use for gas pipelines to mitigate against damage John Mather, Chris Blackmore, Andrew Petrie & Charlotte Treves, WS Atkins Consultants Ltd, UK, 2001,* ***2)*** *Safety Performance Determined the Acceptability of Gas Transmission System , EGIG Pipeline Incident Data Base, Vladimir Horalek, 2006,* ***3)*** *Update of pipeline failure rates for land use planning* *assessments, Zoe Chaplin and Kate Howard ,Health and Safety Laboratory, 2015.* ***4)*** *High Design Factor: Pipeline Integrity Issues (24) by Dr. Phil Hopkins]*

Besides, US Department of Transportation, PHMSA Pipeline and Hazardous Materials Safety Administration, Failure Investigation Report – Central Florida Pipeline 10-inch Jet Fuel Pipeline Failure,2012 and other PHMSA reports and data base was also consulted.

a) Depth of Cover (DC)
b) Population Density (PD)
c) Land use pattern (LU)
d) Wall thickness of pipe (WT)
e) Public Awareness Level (PA)

Wall Thickness: Selected pipeline failure data from UK [7] indicate the following

Table 7, Pipeline Failures in UK and Pipe wall thickness [7]

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

Above table indicate the significance of wall thickness in lowering possibility of pipeline failures. The general relation that comes out 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 3rd 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 3rd party hit [7]

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

Where:

t = pipe wall thickness

D = pipe outside diameter, l= length, width of the digger tooth

σ_u = ultimate tensile strength

Table 8, Third Party activity: Failure Frequency against wall thickness [7]

Wall thickness(mm)	Damage Classification$(1000\text{km-yr})^{-1}$		Total $(1000\text{ km-year})^{-1}$
	Leak	Rupture	
0-5	0.45	0.17	0.62
5-10	0.13	0.04	0.17
10-15	0.02	No data	0.02
15-20	No data	No data	No data

Therefore, it can be concluded that increase of wall thickness reduces the possibility of pipeline failure from 3rd party damage. This is mathematically confirmed through Equation 1 as well.

Depth of cover

Increase in depth of cover over al pipeline can reduce the likelihood of 3rd party damage. This fact can be established by studying damage data on pipeline system of UK. As can be seen from table below:

Table 9,. Frequency of 3rd Party damage failure of pipeline per depth of cover

Depth of cover (mm)	Number of failures	Total failure Frequency $(1000)\text{ km-yr})^{-1}$
0-800	103	0.743
800-1000	248	0.232
1000+	120	0.156

A summary of analysis given in Reference 37 indicate that likelihood of damage due to 3rd party interference is reduced by more than 10 times if the depth of cover is increased from 1.1m to 2.2m. In India, however in majority of pipeline locations a depth of cover of 1.2m is provides, in certain specific cases where population density is more the guidelines provided in design standard (indicated in table No.10) is followed.

Table 10 [13]: Minimum recommended earth cover over buried pipeline

Location	Minimum Cover in meters	Reference Note
Industrial, Commercial & Residential areas	1.2	2
Streams, Canals & minor water crossings	1.5	4
Drainage ditches at roadways & railways	1.2	2
Rocky areas	1.0	2
Uncased / Cased Road crossings	1.2	3
Railway crossings	1.7	3
River crossings (below scour level)	2.5	2,5
Other areas	1.2	2

Note:

1)The above-mentioned minimum cover requirements shall be valid for all class locations
2) Minimum depth of cover shall be measured from the top of pipe coating to the top of undisturbed surface of the soil, or top of graded working strip, whichever is lower. Fill material in working strip shall not be considered to add to the depth of cover.
3) Cover shall be measured from the top of road or top of rail, as the case may be.
4) In case of rivers/water bodies, which are prone to scour and erosion, adequate safe cover (minimum 1.5 metre) shall be provided below the predicted scour profile expected during the life time of the pipeline
5) Soft soil / sand padding of minimum 150 mm thickness to be provided around the pipe in rocky areas
6) For river /water bodies which are prone to scour and erosion, adequate safe cover shall be provided below the predicted scour profile expected during the life time of the pipeline.

Land use pattern plays a significant role in 3rd party damage is evident from the fact that failure frequency is more in case of urban areas compared to rural as can be seen from table No. Similar observations can be made for population density as well, that is higher the population density along the pipeline right of way more is the probability of 3rd party damage due to higher human activity. One of the important factors that plays a role in prevention of 3rd party damage is awareness levels of the community residing near a pipeline. Pipelines operators regularly carries out interaction with the such communities in the form of educational fare, community meeting etc., with the objective of improvement of awareness level so that pipelines remain incident free.

How the possibility of 3rd Party damage to a pipeline is managed

A pipeline operator generally develops a Maintenance & Inspection (M&I) plan that consists of surveys and activities that are designed to reduced likelihood of pipeline damage from 3rd party interference.

Considering a case of 135km long pipeline in northern India, to prevent the incidents of 3rd party damage the operator's M&I plan consists of following surveys. Under this M&I plan surveys mentioned below are carried out in a prefixed frequency.

a) **Ground Patrolling (GP)**: Ground patrolling is undertaken over the entire pipeline through trained security personnel. Every day the Patrolman must cover at least 8km of distance on foot. Each of the security personal carries a hand-held GPS device (generally referred as Personnel Tracker or PT) so that his movement can be tracked from the nearest pipeline control room. Entire pipeline right of way (RoW) is geo-fenced, as such any patrolman going out of the pipeline RoW immediately gets an alarm which is also replicated in the control room, who informs the patrolman about his position. This is done to ensure that Patrolman does not play truant. In addition to the Patrolman, on foot patrolling is also undertaken by engineering staff of the owner at random frequency. There is no fixed frequency for such officials and neither any fixed timing or period of patrolling. Apart from on foot patrolling, during the night small teams of armed patrolman also travel on road as far as possible parallel to the pipeline. This night patrolling teams also inspects 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 though 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 cables, telephone cables, water line laying agencies etc. The average expenditure towards GP for last 3 years is found to be Rs.600 lakh per annum for 365 days of GP.

b) **Aerial Patrolling (AP):** In addition to ground patrolling, owner has started deployment of drones for aerial surveillance of the entire pipeline once in 15 days. Drones are a low flying aerial device 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 pervious videos are compared off-line to identify any unusual development in the RoW. For the last one year since Drones are deployed the expenditure incurred is Rs. 400lakh for inspection of entire 135km of the pipeline every fortnight.

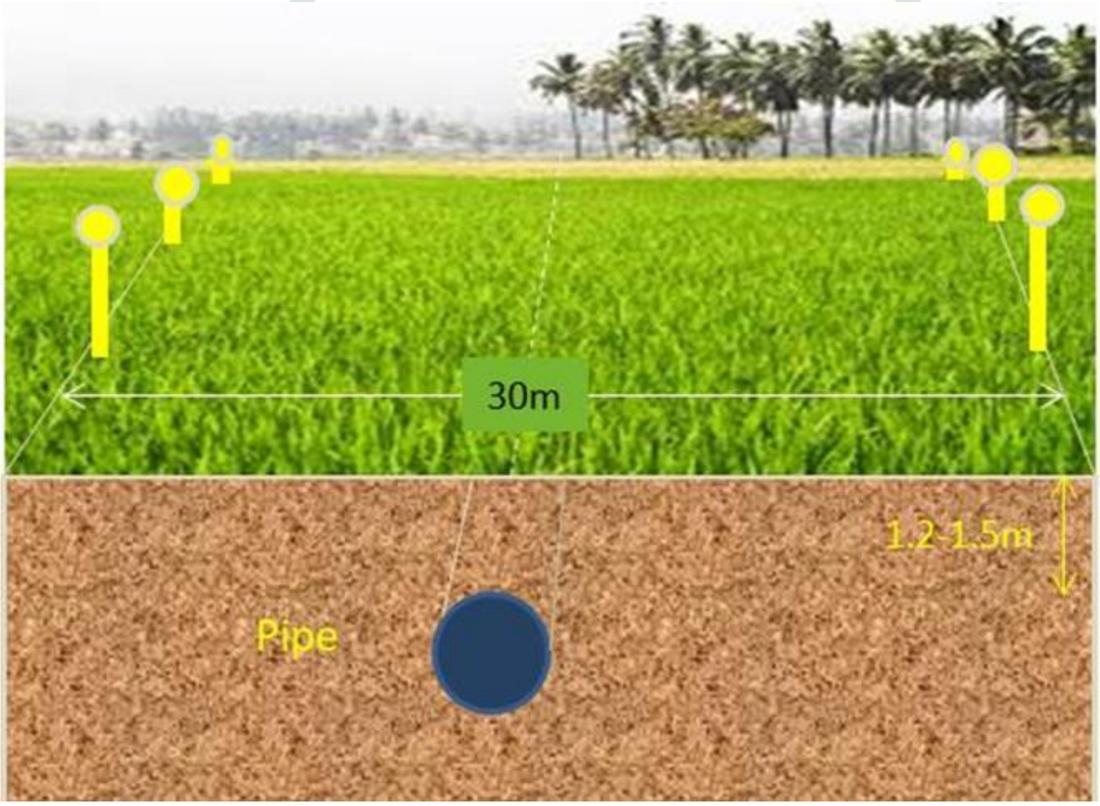


Fig.1, A typical pipeline Right of Way (ROW)

c) **Depth of Cover Survey (DCS)**: One of the key factors that determined possibility of 3rd party damage to a pipeline is lack of earth cover. In India whenever a 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.

d) **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 as Intelligent Pig. This device can record entire pipe wall thickness profile of the pipeline and reporting exact locations where deviations in thickness of the pipeline is observed with pin point accuracy. In India pipelines are designed as per Oil Industry Safety Directorate (OISD) standard OISD -141, OISD-214 and ASME B 31.4 and ASME

B31.8 standards. OISD standards suggest certain frequency for Inline inspection (once in 8 to 10 years for crude oil and petroleum product pipelines, gas pipelines and 5 years for LPG pipelines and off-shore pipelines)

Apart from the above surveys the operators have an elaborate plan to maintain the pipeline Right of Way (ROW), the plan includes removal of wild growth from the ROW for clear visibility, providing markers and boundary pillar for identification of the pipeline route and danger signs with phone number of the nearest control room for handling of emergency. Additionally, OFC based pipeline intrusion detection system is also deployed in the above-mentioned 135km long pipeline.

However, the pipeline operators existing M&I plan is common for the entire pipeline, the M&I programme does not distinguish between various stretches of the pipeline from the point of view of threat perception, so to say one-size-fit-all type of approach is taken. As a result, the M&I programme is not optimized, leading to unnecessary expenditure and lower effectiveness from the point of view of third party interreference to the pipeline.

Optimization of M&I

For optimization of M&I programme the first step is to divide the entire 135 km length of the pipeline into multiple smaller sections. The segmentation scheme is based upon sectionalizing valve to valve section as indicated in figure 2.

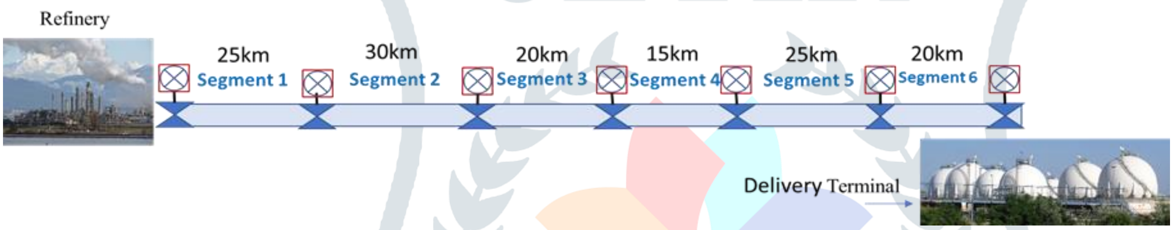


Fig 2 Location of sectionalizing valves along the pipeline

Next step is to calculate the weight of 5 primary factors on which the possibility of 3rd party damage largely depends viz., Depth of cover, Population Density, Land Use Patten, wall thickness and Awareness level. To determine the relative weight of each of these 5 factors in each of the 6 pipeline segments as marking scheme is developed. The marking scheme involved sub-diving 5 key factors in subfactors as indicated in figure 3.

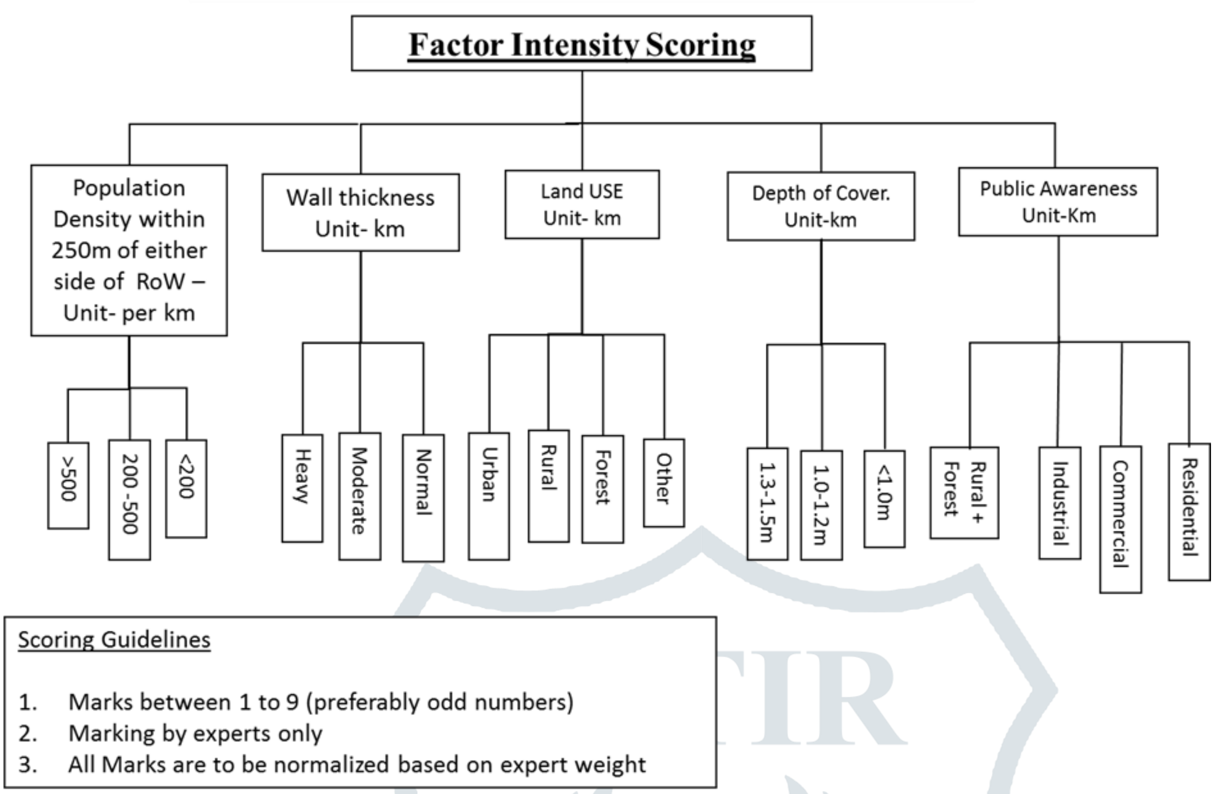
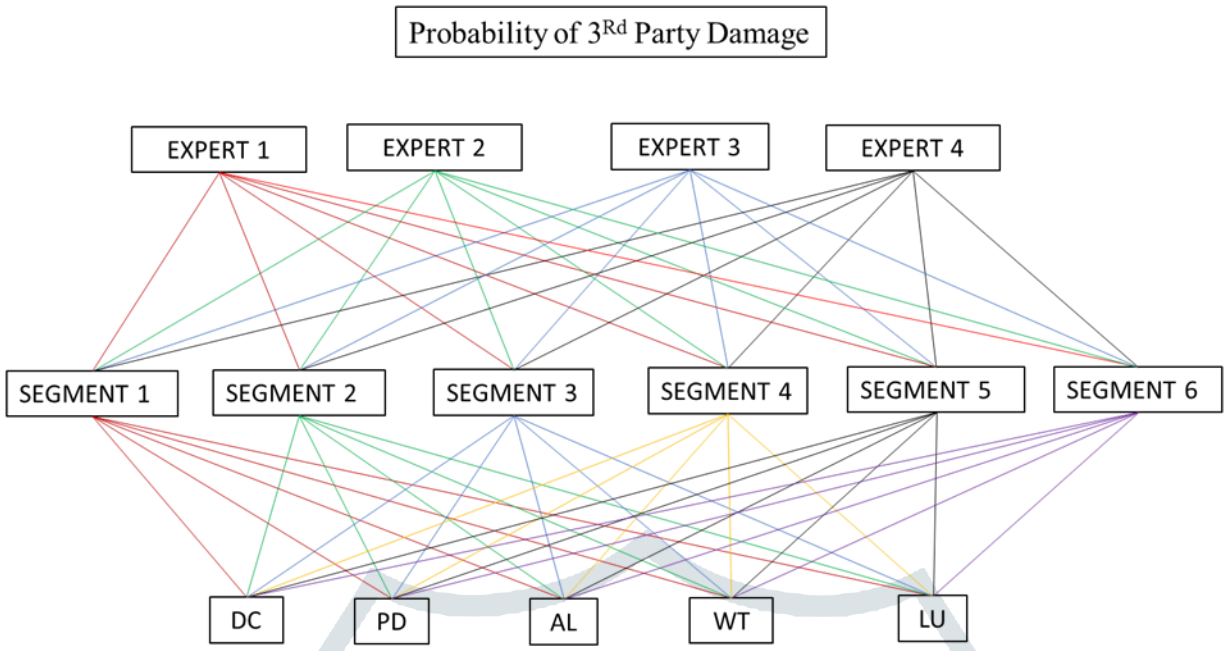


Fig 3, Optimization of M&I – Factors and sub-factors

Against each of the subfactors certain marks (between 0 to 9) is awarded by 4 experts (identified through a separate expert identification module and relative weight of each expert is also determined based on academic qualification, years of experience, areas of work e.g. field location or design office etc). The marks awarded against each of the sub-factors are multiplied by the length of pipeline in a segment (out of 6 segments) to get an overall score against each factor per segment per expert.

Final score thus obtained for a segment for each of the 5 factors (not sub-factor) is normalised considering relative weight of depth of cover as 1, relative weight of other 4 factors are determined w.r.t. the relative weight of depth of cover based upon their expert scoring. Based upon their relative weight determined from expert scoring all 5 factors are compared utilising Analytical Hierarchy Process (AHP) which permits pair wise comparison of factors (based on their weight) to determined normalised weight of each factors.

The hierarchy formed in this case for pairwise comparison of factors for a particular segment is represented in figure 4. After normalized relative weight for each of the 5 factors are determined through AHP process for a segment for expert rating, exercise is repeated for 3 other experts and finally a surmised (synthesized for all 4 experts) weight of 5 factors for a segment is determined, this weight could be termed as calculated weight (cw). Similar exercise is done for all 6 segments.



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

Fig 4: The hierarchical structure of AHP network for the present study

As mentioned earlier under the existing M&I scheme all factors in all segment (in fact no segmentation is made in existing M&I programme design) is considered to have equal weight. In consideration to the above approach if 1 is the total weight of 5 factors, then for each of these 5 factors shall have 1/5=0.20 as their weight, this weight is termed as normal weight (nw). The difference between nw and cw is the deviation from optimized M&I programme. In terms of percentage variation of the difference [(nw-cw)/nw]. If percentage difference is (-) minus this would mean under the existing M&I scheme more effort and money is being spent to control that particular factor in a particular segment, to achieve optimum level of M&I effort in terms of money and activities the percentage variation determined shall have to be narrowed down to as close as possible to 0(zero) in other word in a optimized M&I scheme ***nw*** should be as close to ***cw*** as possible.

Table 11, Segment Wise Marks allocation by Expert 1 and Calculation of Score

Expert 1		Basic Mark	**7**	**5**	**1**	**3**	**4**	**7**	**8**	**3**	**1**	**3**	**1**	**3**	**7**	**3**	**7**	**7**	**5**
		Norm. Mark	**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		**Factors**	Population Density per/km in km			Wall Thickness (Km)			Land Use (Km)				Depth of Cover (km)			Public Awareness level (Km)			
Segment	**Length (km)**	**Criteria**	>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	Length(km)	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	Length(km)	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	0.00	72.00	0.00	5.00	35.00
3	20	Length(km)	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	0.00	15.00	20.00	10.00	63.00
4	15	Length(km)	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	Length(km)	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	Length(km)	8	9	3	0	0	20	3	16	0	1	1	19	0	16	0	2	2
		Score	**56.00**	**45.00**	**9.00**	**0.00**	**0.00**	**140.00**	**21.00**	**48.00**	**0.00**	**3.00**	**3.00**	**133.00**	**0.00**	**48.00**	**0.00**	**10.00**	**14.00**

Table 11A, Summary of Table 11

Factors	Segment						Total **Score**	Average **Score/Segment**
	1	**2**	**3**	**4**	**5**	**6**		
Population Density	131.00	158.00	114.00	78.00	135.00	110.00	726.00	121.00
Land Use	147.00	106.00	80.00	49.00	111.00	72.00	565.00	94.17
Wall Thickness	149.00	150.00	116.00	105.00	121.00	140.00	781.00	130.17
Awareness Level	141.00	112.00	108.00	63.00	135.00	72.00	631.00	105.17
Depth of Cover	159.00	182.00	116.50	97.00	163.00	136.00	853.50	142.25
Score Total	727.00	708.00	534.50	392.00	665.00	530.00	3556.50	592.75
Segment Length, Km	25	30	20	15	25	20	135	22.5
Score/km	29.08	23.60	26.73	26.13	26.60	26.50	26.34	26.34

Table 11B, Segment-1, Basic Score, Expert 1

A	B	C	D
Factor	Exposure	Exp/km	Relative Score
Depth of Cover (DC)	159.00	6.36	1
Population Density (PD)	131.00	5.24	0.82
Awareness Level (AL)	141.00	5.64	0.89
Wall Thickness (WT)	149.00	5.96	0.94
Land Use (LU)	147.00	5.88	0.92

Table 11C, Segment 1- Pairwise Comparison- Normalized Matrix- Expert -1

Factor	**DC**	**PD**	**AL**	**LU**	**WT**	**Average**
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**

Table 12, Ranking of Factors in terms of Impact Severity of Possibility of 3rd Party Damage- Based on synthesis of all 4 experts rating

Factors	Segment						Average score	Impact Rank
	1	2	3	4	5	6		
DC	0.215	0.217	0.203	0.237	0.222	0.211	0.218	**2**
PD	0.190	0.175	0.152	0.158	0.178	0.182	0.174	**5**
AL	0.191	0.184	0.143	0.169	0.169	0.203	0.193	**3**
WT	0.211	0.262	0.252	0.267	0.244	0.210	0.222	**1**
LU	0.194	0.162	0.249	0.169	0.187	0.195	0.192	**4**

Note =Values against factors is the ***cw*** corresponding to that segment of the pipeline.

Table 13 Determination of variation between nw and cw

Factors	Segment 1		Difference	Variation
	CW	NW	NW-CW	(nw-cw)/nw
DC	0.26	0.20	-0.06	-30%
PD	0.18	0.20	0.02	10%

AL	0.20	0.20	0.00	-1%
WT	0.21	0.20	-0.01	-6%
LU	0.15	0.20	0.05	27%

Table 14, M&I Activity vs. Factors managed

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	In line 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

Table 15, Optimized M&I Expenditure
(Pipeline Segment 1, Length=25km)

M&I Actions	Total Expense	Expense Segment 1	Factors Covered			Total Variation	Optimum Expense
GP	600	111.11	PD	AL	LU	36%	71.06
AP	400	74.07	PD	AL	LU	36%	47.37
DCS	100	18.52	DC	-	-	-30%	24.13
ILI/GS	100	18.52	WT	-	-	-6%	19.58
RoW M	500	92.59	PD	AL	LU	36%	59.22
ID	100	18.52	LU	DC		-3%	19.13
CI	50	9.26	PD	AL	LU	36%	5.92
Rs. (Lakh)/yr	1850	342.59	-	-	-	-	246.42

Table 16, Summary of Segment-wise Optimized Vs. Non-Optimization M&I Expenditure

S. No.	**Segment**	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
1	Segment Length(km)	25	30	20	15	25	20	135
2	Percent Segment Length	19%	22%	15%	11%	19%	15%	100%
3	**Existing M&I Expense***	**342.59**	**411.11**	**274.07**	**205.56**	**342.59**	**274.07**	**1850.00**
4	**Optimized M&I Expense***	**246.42**	**325.14**	**218.06**	**122.10**	**254.56**	**252.92**	**1419.20**
5	Variation [(3-4/)3]	**28%**	**21%**	**20%**	**41%**	**26%**	**8%**	**23%**

(Expenses in S.No.3 & 4 are M&I Expenditure in Rupee Lakh/Year)

Conclusion:

3rd party interference is the most significant cause of pipeline failure all more so in the developed and developing nations. Current M&I scheme to prevent possibilities of 3rd party interference/ damage is not optimized both in terms of expenditure and efforts. A more focused, cost effective and efficient M&I programme can be developed through optimization exercise to reduce threat from 3rd party damage to pipelines.

A finer optimization is possible by handing more data and considering opinion of a bigger and more varied team of experts, however, this may not be possible through manual exercise, a computer software with capacity to handle multiple input points and larger amount to data can be developed utilizing the approach used in this paper.

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