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Risk Evaluation from Third Party Damage to LPG Pipelines in India and its Mitigation

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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 4,000 km 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. Worlds longest LPG pipelines is planned between Mundra port in Western India and Gorakhpur in Uttar Pradesh covering more than 200 km.

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

1. Introduction to LPG Pipelines

A. Liquefied Petroleum Gas (LPG) and it's Significance in India

The oil and gas business are big, and it is still growing especially in the developing countries like India. Fossil fuels will remain the primary sources of energy, meeting more than 90% of the increase in future energy demand; global oil demand will rise by about 1.6% per year. The medium-term oil demand outlook shows an increase of 6.2 mb/d from 93 mb/d in 2015 to 99.2 mb/d in 2021 [1].

India has surpassed China to become the largest contributor to incremental oil consumption in 2016, accounting for 21.8 per cent of it [2]. Also, India is 3rd Largest importer of Oil during 2016 after China and the USA, India's share of import accounted for 17.4% of total world import in terms of US $ value [3]. India's oil consumption grew 8.3% to 212.7 million tons in 2016 [4].
Between 2005 and 2015, India's oil consumption grew by 4.9% while global growth was 1%, at this rate, India could very well be the biggest contributor of incremental oil demand growth for the next few years, led by its strong economic growth [5].
In India, LPG is primarily used as fuels for household requirements**.** India does not produce enough LPG to meet its demand and a sizeable portion of LPG is imported. During the year 2017-18, 11.382 MT of LPG was imported by India [5]which is expected to reach by 13-14 MT in 2017-18: [as per Petroleum Planning & Analysis Cell, Ministry of Petroleum and Natural Gas]. India thus surpassed Japan as the world's second-largest importer of liquefied petroleum gas (LPG).

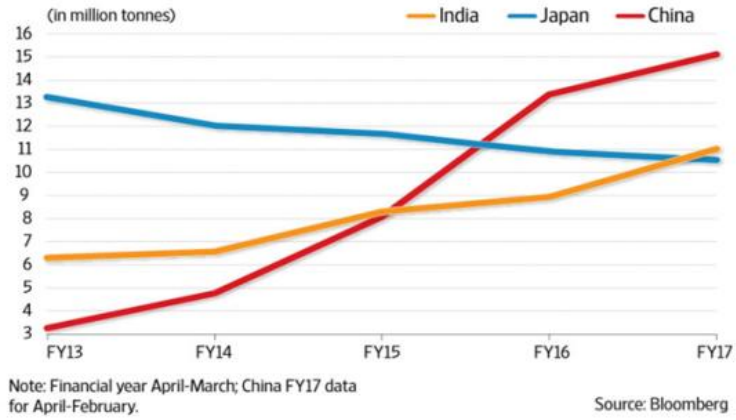

Figure 1: Growth of LPG import in India

B. LPG Pipelines in India

As of August 2018, the total length of cross-country hydro carbon pipelines in India is more than 43,669 km [5]. Out of which 2847 km are LPG pipelines. Further, various reports of Public Sector oil companies indicate that another nearly 13,800 km of gas pipeline, 6800 km of liquid pipelines, and approximately 4400 km of LPG pipelines are under various stages of construction/consideration.
Pipeline transportation of LPG ensures public safety and minimizes environmental damage. Any alternative mode of transportation of bulk LPG is not only uneconomical but also hazardous to environment and dangerous from public safety point of view. But pipelines too are prone to accident from leakage and rupture, therefore, maintenance of integrity of the pipelines is a major challenge to all oil and gas companies.

Table 1: LPG Pipelines in India [5]

Name of the Pipeline	Owner	Length (km)	Capacity (TMT)	Utilization
Mumbai-Uran Pipeline	BPCL	28	800	42.1%
Panipat-Jalandhar Pipeline	IOCL	274	700	85.6%
Mangalore-Mysore Pipeline	HPCL	356	1940	40.4%
Jamnagar-Loni Pipeline	GAIL	1414	2500	106.9%
Vizag-Secundrabad Pipeline	GAIL	618	1330	78.2%
Paradip-Haldia Durgapur pipeline	IOCL	157	503	9.3%

C. Pipeline Failures

The major causes of pipeline failures are common all around the developed and developing world, data for United States and Europe indicate Corrosion, 3rd party damage (external interference) are two major causes of pipeline failures, same is the trend in Asia and other regions, however, unlike USA and Europe availability of authentic data for these regions is limited, same is true for India as well. It is expected that with the emergence of a strong pipeline regulatory regime in India, availability of such data is likely to be better in future.

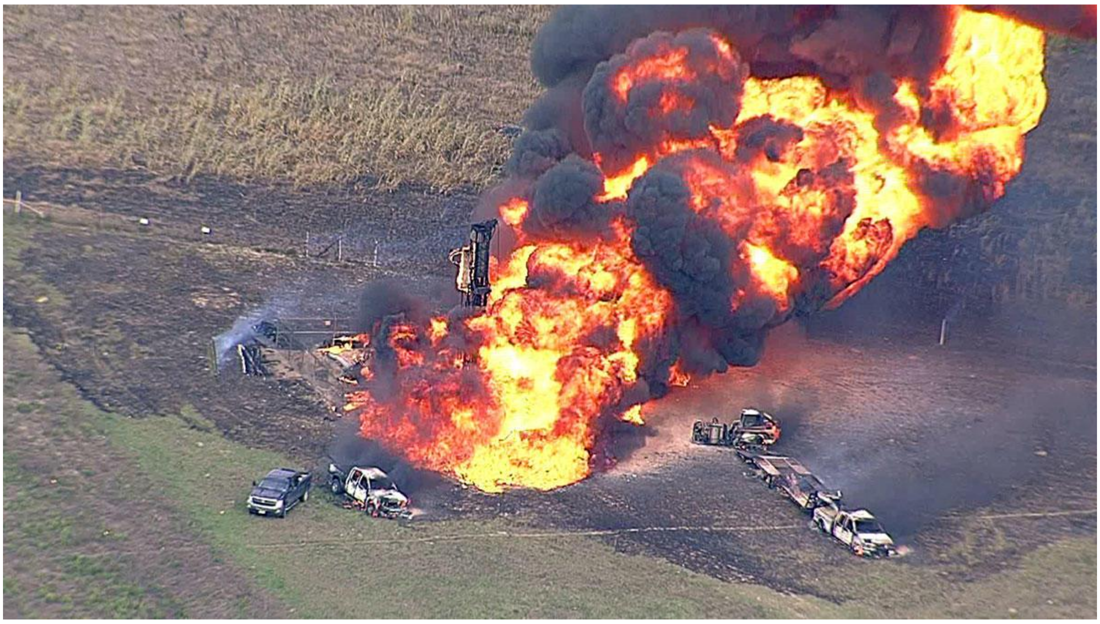

Figure 2: A Typical LPG Pipeline Failure [Source: National Transportation Safety Board (NTSB), USA]

D. Third Party Associated Pipeline risk in India

A look at the pipeline incidents data for US and Europe clearly indicate that 3rd party activity has emerged as a major cause of failure as far as pipeline safety is concerned.

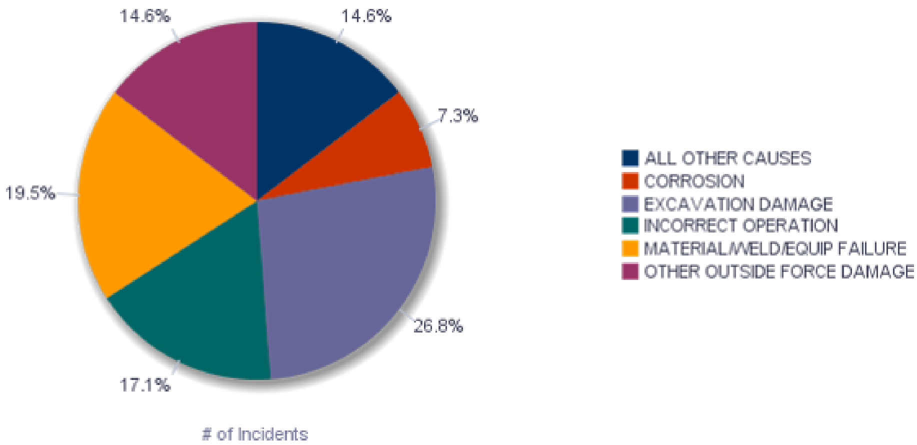

Figure 3: Reasons for Pipeline Failure in USA between 2002 and 2013 [Source: Pipeline and Hazardous Material Safety Administration, USA]

Data from PHMSA reportable incident indicate that from 1993 to 2012 there were 1632 incidents that are caused by third party excavation damage

An analysis of all pipeline incident data for US for the period 2002 to 2013 indicates third party contribute as much as 26.8% all pipeline incidents. Oil pipeline incident data for the period 1971 till 2006 for Europe [6], indicate 19% of failures is due to corrosion, 42% due to third party incidents (including digging/trenching, drilling/blasting, bulldozing and other), 28% due to mechanical issues like material failure, equipment failure, 8% due to operational errors and rest 3% due to other reasons. EGIG incident data base for European Gas pipeline network, for the period 1971 to 2007 indicate that 49.6% of all incidents in European Gas pipelines is due to third party activity (external interference - 7th EGIG report). 9th EGIG report (period between 2009-2013) indicate 28% incidents are due to External interference, though a significant drop from pervious figure of around 50% for the period 1971 to 2002 and 38% between 2004 and 2013.

Under the Indian context Third Party Damage can be considered as any damage to the pipeline caused by agencies working within the pipeline right of way with or without permission of the pipeline owner. Damaged caused to the pipeline with an intention to steal oil from pipeline is also considered under broad definition of Third-Party Damage (TPD) with malicious intention, other activities like sabotage can also be categorized under third party damage. Though there is no record available for TPD, however, unsubstantiated data indicate that in India too, a significant percentage of pipeline incidents are due to 3rd party activity and the trend in recent years shows sharp upswing.

2. Introduction to LPG Risk Assessment

A. Assessment of Probability of Failure in LPG pipeline in India

Indian demography and social structure are different as compared to most of the world. India has a population of 1.357 billion. About 66.87 % of the population is rural. With increased population density, pipeline failure may have significant impact on the population. LPG being highly inflammable, heavier than air and much higher liquid to gas expansion ratio, has the potential to cause devastating damage to surroundings in case of a pipeline leak or rupture. Therefore, 3^{rd} party activity (TPA) risk to an operating and LPG pipeline needs to be assessed and corrective measure accordingly, to be adopted to minimize the risk.

The General Risk Assessment Equation is

Risk = Probability X Consequence

The paper attempts to cover only a fraction of Risk that is arising out of 3rd party activity (TPA) under Indian context. Thus, more appropriate equation would be

Risk TPA = (Probability X Consequence) X TPA (India)

A general scheme followed for assessment of Risk arising out of 3rd party activity is depicted in a schematic form in Figure 4 below:

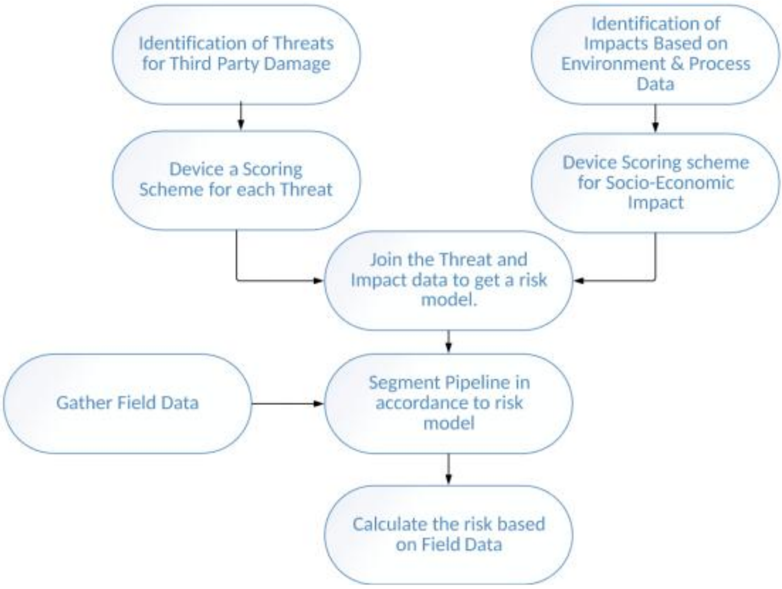

Figure 4: Third Party Risk modelling of the pipeline

B. Calculating Possibility of 3^{rd} Party Damage

To calculate possibility of 3^{rd} party damage to a pipeline, the primary requirement is to identify the factors that play a role in occurrence as well as deterrence to 3^{rd} party damage. While certain parameters play a dominant role, the others little less dominant but in order to quantify the over all probability of 3^{rd} party damage one has to take into consideration all the factors involved or may possibly get involved

1. Parameters for Third party related failures:
2. Depth of Cover /Under water crossing/ above ground crossings
3. Construction activities
4. Pipeline awareness programs

5. Pipeline surveillance
6. Previous cases of pilferage/vandalism
7. Common ROW
8. Calliper Survey/Inline inspection
9. Third party intrusion detection system
10. Coating survey results
11. Line location
12. ROW conditions
13. Population density

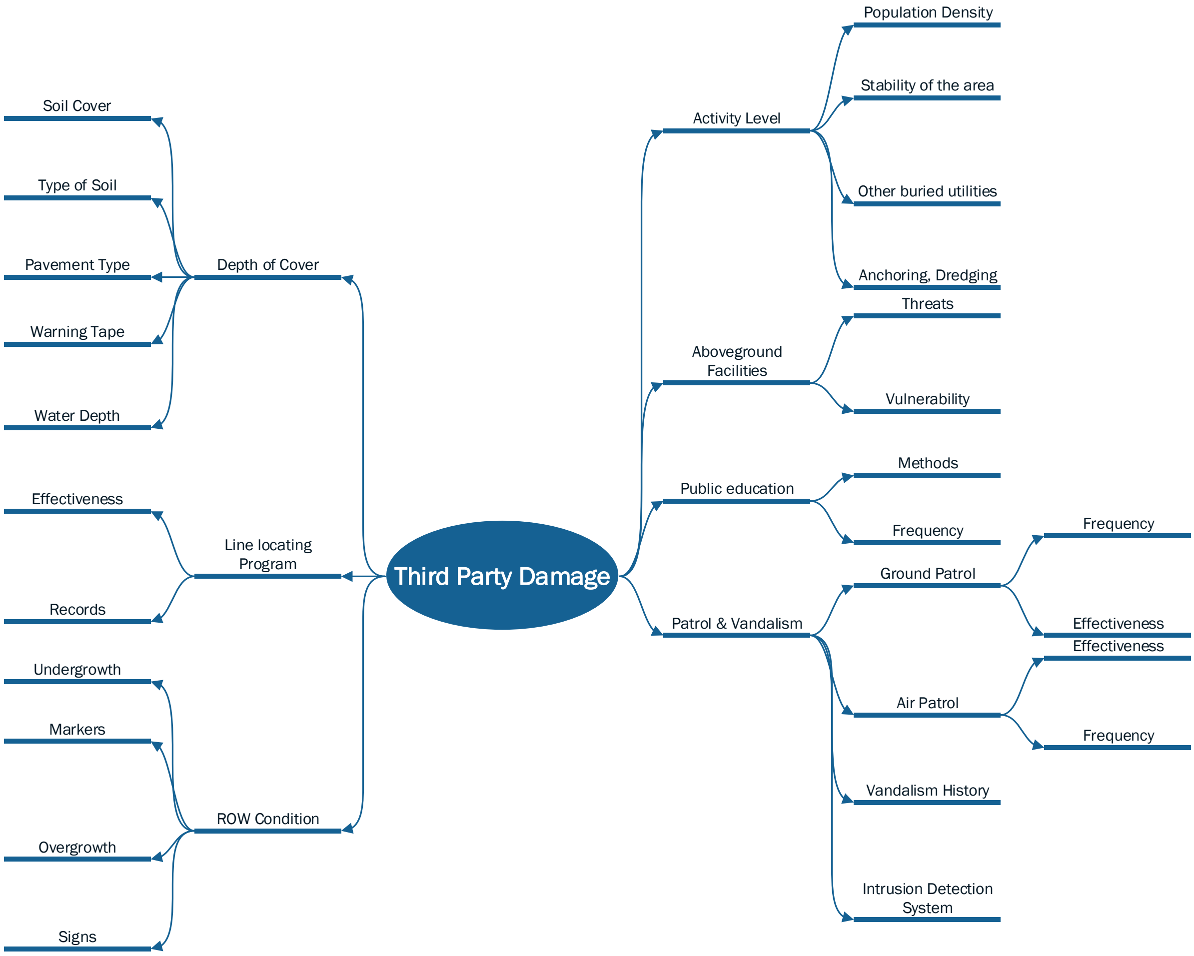

Figure 5: Factors that play a role in 3rd party Damage to Pipelines

Each of the above factors is weighed through a scoring scheme and finally all the scores are evaluated to find out over all probability of 3rd party damage. For the purpose of development of a maintenance scheme with a view to reduce the risk arising out of 3rd party activity the most logical approach is to sectionalize a pipeline into smaller segments, this is because entire pipeline does not face same amount of threat from 3rd party damage for example a pipeline segment falling in country side is less vulnerable to digging damage rather than the one close to urban centre. The segmentation scheme and its basis considered for this paper is as discussed below.

C. Segmentation scheme

Pipeline is dynamically segmented based on Population density, Depth of Cover and Pipeline Right of Way (ROW) Conditions. A sample pipeline (48km long) is used to develop and evaluate the risk model. The indicating score are designed keeping Indian scenario in the backdrop.

Table 2: Dynamic Segmentation of a 48.6 km sample pipeline

Section	Row Condition	Population Class	Depth of Cover
0-2	Excellent	1	>1.5 mtr
2-3.5	Excellent	2	>1.5 mtr
3.5-5	Good	2	>1.5 mtr
5-12	Good	2	1-1.5 mtr
12-16.2	Excellent	2	1-1.5 mtr
16.2-18	Average	2	1-1.5 mtr
18-19	Average	2	<1 mtr
19-22	Good	2	<1 mtr
22-28	Good	3	<1 mtr
28-29	Average	3	<1 mtr
29-29.7	Average	2	<1 mtr
29.7-33	Average	2	1-1.5 mtr
33-36	Average	3	<1 mtr
36-37	Good	3	<1 mtr
37-42.5	Good	3	1-1.5 mtr
42.5-44	Excellent	3	1-1.5 mtr
44-48.6	Excellent	1	>1.5 mtr

3. Assessment of Failure Probability

A. Depth of Cover: Total score of 20 (on absolute scale of 100)

Score for depth of cover is divided into two parts:

i. Pipeline buried underground
ii. Pipeline at a crossing

1.5m depth of soil cover is ideal and used during construction. Hence, 1.5m qualifies for the full score of 20, minimum score of 0 (zero) for pipeline above ground/exposed to the surface. A negative score of -2 is assigned if the line is not exposed to the ground but is at a depth much less than what is desired e.g., 200 to 300mm, because a pipeline section inadequately lowered (covered underground) has higher probability of digging damage than one that is over ground a or buried at adequate depth. The depth of cover (X metre) is evaluated as below:

Following formula is used in the model for scoring of depth of cover.

$$Score = \begin{cases} 0, & x < 0 \\ -2, & 0.3 > x \geq 0 \\ \max(22 * \frac{x-0.3}{1.2} * m - 2, 20), & 1.5 > x \geq 0.3 \\ 20, & x \geq 1.5\ forall m \end{cases}$$

Score can be higher if additional protections are provided; a scheme is devised for selecting additional values to be added in x to assess the score based on type of cover:

Concrete Coating on the pipe : 0.2
Hard Pavement over the pipeline : 0.6
Warning Tape over the pipe (to avoid excavation damage) : 0.15

Excess wall thickness: 0.10, each for every higher schedule thickness as per API 5L [7]

Table 3: Soil type score: Factor *m*

Soil Classification	Example & Attributes	Cover [*m*]
Stable Rock	Stable rocks	1.1
Type A	clay, silty clay, sandy clay and clay loam. Compressive strength >1.5 tonnes per sq feet	1
Type B	crushed rock; silt; silt loam; sandy loam; Compressive strength 0.5 to 1.5 tsf	0.9
Type C	gravel, sand and loamy sand; submerged soil	0.8

Certainty Parameter: A quality indicator is added to the score for practical assessment of the depth of cover score (based on data quality indicator shown in the table 4). These marks are given to take care of uncertainty that may creep in to the process.

Table 4: Data uncertainty calibration table

Activity	Value	Score
Construction Data Available [a]	Yes	1
	No	0
Construction years [b]	<2	1
	2 to 5	0.8
	5 to 10	0.5
	>10	0
Last Depth of Cover measurement (time) [c]	<5	1
	5 to 7	0.8
	7 to 10	0.6
	>10	0.4
	None	0
Last Depth of Cover measurement (efficiency) [d]	<10 mtr	1
	10 to 100 mtr	0.9
	100 to 500 mtr	0.8
	>500	0.7
Activity Type [e]	Pipeline exposed	0.5
	In ROW	0.7
	In 50 mtr	0.9
	>50 mtr	1
Measurement after Activity [f]	Yes	1
	No	0.8

$$Uncertainity factor = \min(a * b, c * d) * e * f$$

Final Score for Depth of cover = Uncertainty Factor X Score

Figure 6: A view of the damage caused due to failure of a Gas pipeline. The Failure was caused due to 3rd Party activity [Source: NTSB, USA]

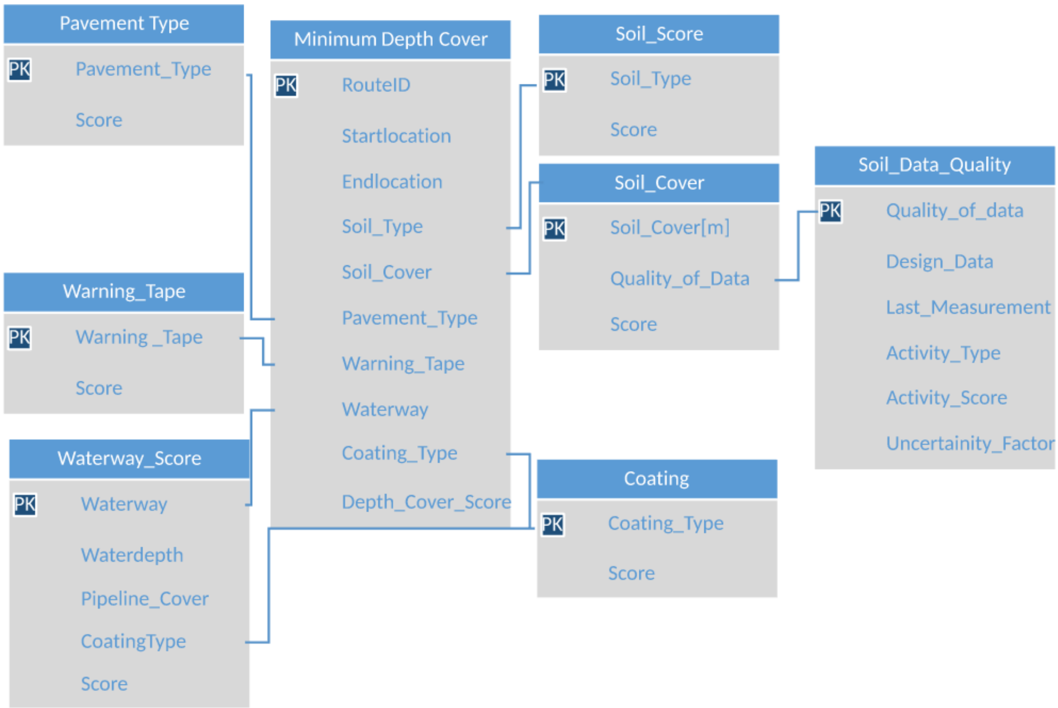

Figure 7: Entity Relationship Diagram for Depth of Cover Measurement

B. Depth of cover scores for Pipeline crossings (crossing a railway line, road, rivers etc.)

Scoring scheme for the waterways: Depth of cover score scheme utilised as per Table 5 below:

Table 5: Scoring Scheme for water ways

Parameter	**Value**	**Score**
Depth below water surface	<1.5 [m]	0
	1.5 [m] to max anchor depth	5
	Max anchor depth	7
Depth below bottom of water way	<0.6[m]	0
	0.6 to 0.9 [m]	3
	0.9-1.5[m]	5
	1.5-2[m]	7
	>2[m]	10
Coating Type	Concrete	5
	3LPE	3
	Another	0

Uncertainty factor: Table 4 in conjunction with table 6 is used for assessment of uncertainty factor.

Table 6: Modified uncertainty factor [e],[f]

Parameter	**Condition**	**Score**
Activity Type [e]	Pipeline exposed	0.2
	Change in waterway coarse	0.5
	Rain more than average	0.7
	Rain equal to or less than average	1
Measurement after Activity [f]	Yes	1
	No	0.8

C. Activity level: Total score of 20 (on absolute scale of 100):

Following matrix may be used for getting the activity score. Final score can be derived by using an interaction function.

Table 7: Activity based classification of pipeline right of way and corresponding scores

Activity/Score	0	0.4	0.7	1
Population	Class_4	Class_3	Class_2	Class_1
Construction (200 m)	Frequent	No routine	<10 peryear	Rare
Construction dist [m]	Line exposed	In ROW	In 20mtr	>20mtr
Rail/Road Traffic	High	Low	-	Rare
nearby utilities	Many	Few	None	Rare
wildlife damage	Frequent	Occasional	None	Rare
Dredging	Frequent	Low	-	Rare
Anchoring	Normal	Low	-	Rare
Agricultural			Yes	Rare

$$Activity\ score = 20 * (\sum (2^{Score} - 1) - (2^{\prod Score} - 1)$$

Formulation is derived considering, for any activity falling under high will have a zero score and 20 if all activities fall under rare.

D. Aboveground facility: Total score of 10 (on absolute scale of 100)

Following Scoring Used for evaluating cross-country above ground facilities such as valves, CP stations, repeaters etc., CP (Cathodic Protection) Test Lead Points (TLPs) are kept out of scope of any of these facilities.

Table 8: Scoring scheme for above ground facilities

Activity	Score
No aboveground facility	10
Above Ground Facility	0
facility>30 mtrs from road	5
Area with chain fence	2
Protective railing	3
Concrete wall (without security)	7
Concrete wall (with security Manned/CCTV)	10
Trees	4
Ditch	3
Warning signs	2

E. Line locating program: Total score of 10 (on absolute scale of 100)

Line location program is central for safe construction activities nearby/ sharing same trench. Accurate pipeline location provides the accurate information which can be shared for crossings. India is going through a phase of high growth in building infrastructure; several new projects like dedicated railway freight corridor, Bharatmala road project, other road projects, irrigation canals, new pipelines and other underground facilities are coming up at a fast pace. In order to access the risk arising out of such activities, it is important that a health pipeline locating programme is in place.

Table 9below provides a marking system based on history of activities undertaken in the pipeline right of way and its current state of management.

Table 9: RoW management scores

Activity	Parameter	Score
Effectiveness	Previous history	2
Proven record of efficiency	Previous history	1
Widely advertising	% of public reached in last one year	2*[% of public reached]
Reaction to call	>4 hour	0
	2 to 4hour	2
	<2 hour	3
Maps & Records	Records available	2
GPS Coordinates	Available	2
Onsite inspection during excavation	Yes	1
Proven record for permission of excavation of utility crossing	Yes	1

Sum of the applicable scores are considered for line location and other ROW management.

F. Public Awareness Program: Total score of 15 (on absolute scale of 100)

Public education plays a vital role for minimising the damage associated to the pipeline failure as well as the probability of the pipeline failure.

Table 10: Score on public awareness

Activity	Parameter	Score
Meeting with Public Officials	Minimum twice a year	3
	Once a year	2
	Infrequent/rare	Nil
Meeting with local contractors	Minimum twice a year	3
	Once a year	2
	Infrequent/rare	Nil
Education program Frequency	Minimum one in two year	3
	Minimum one in five year	2
	Infrequent/rare	Nil
Education program Effective	% of persons in nearby villages`	3 *[% of public contacted]
Door to door contact	% of persons in consequence area`	4*[% of public contacted]
Advertisement in local publications	Once a year	2
Community awareness programs	Once in 3 years	2

G. Right of way condition: Total score of 5 (on absolute scale of 100)

A well-marked and clear Right of Way (ROW) reduces the susceptibility for third party intrusion and aids in leak detection

Table 11: Right of Way management Score

Activity	Parameter	Score
Marker & signs (availability)	>95% km marker in position	1.5
	95 to 80% km markers in position	0.75
	Less than 80 % km markers	Nil
Marker & signs (effectiveness)	>90% km marker visible from any point in ROW	1.5
	95 to 80% km markers in position	0.75
	Less than 80 % km markers	Nil
ROW navigable	Yes	2
	No	0
Vegetation	Yes	-2
	No	0
Third party encroachment	Yes	-2
	No	0

H. Patrolling (of RoW) and Vandalism: Total score of 5 (on absolute scale of 100)

Line patrol reduces the chances of failure due the third-party activities & vandalism.

Table 12: Score on Patrolling

Activity	Parameter	Score
Ground Patrol Efficiency[a]	Area Covered >95%	2
	Area covered >80-95%	1
	Area covered <80%	0
Ground Patrol Frequency [b]	Daily	4
	In two days	2
	In four days	1
Surprise Higher official visits [c]	Yes	1
	No	0
Pilferage& Vandalism [d]		
Another utility in ROW	Yes	0
	No	3
Third party intrusion detection system	Yes	0
	No	-3
Previous history	Refer matrix	

Previous history matrix: (applicable minimum is used)

Table 12a: Score on Incident history

Activity/Frequency (Last 10 years)	None	Once	Twice	> Twice
Incident on pipelines in same ROW anywhere	7	6	5	3
Segment (between compressor/pump stations) of pipelines in same ROW	7	5	3	0
Incidence within district	7	5	3	0
Incidence within state	7	6	5	3
Vandalism in 50 km radius	7	5	3	0
Vandalism in 100 km radius	7	6	5	3

$$Partol\ score = [a * (b + c)] + d$$

I. Third Party Damage Assessment: Adjustments (Scoring of -10)

Table 13: 3rd Party Damage Assessment Scoring Scheme

Activity/Frequency	None	In 10 years	In 5 years	After major construction in ROW	
				Yes	No
Electronic Gauge Pigging	-2.5	-2	0	0	-2.5
Depth of cover	-2.5	-2	0	0	-2.5
CIPS	-2.5	-1	0	0	-2.5
DCVG	-2.5	-2	0	0	-2.5

Gouging and crack detection surveys are not considered for scoring adjustments and CIPS& DCVG surveys identify the coating defects attributing to corrosion. In case a recent Intelligent Pigging Survey (IPS) is carried out, the same may be used for replacement of CIPS/DCVG survey. However, the IPS beyond 5 years may not be considered as substitute for CIPS/DCVG survey.

J. Failure Probability Calculations

A sample pipeline as described above was assessment of the associated threats pertaining to third party damage. The schematic score for the pipeline works out as detailed in the table 14. It can easily be seen that one score can be masked by the others as in km 28-29 the pipeline overall score is 80 which is better as compared to others. However, it has a low depth of cover. To overcome the issue, a separate algorithm is created to avoid such parametrical masking in conventional methods.

A functional survival is calculated as following:

$$Survival = \prod \frac{ActivityScore}{MaxActivityScore}$$

If we plot the Survival & Score (Summation), we can see that survival/failure are better representative than the summation of individual Score.

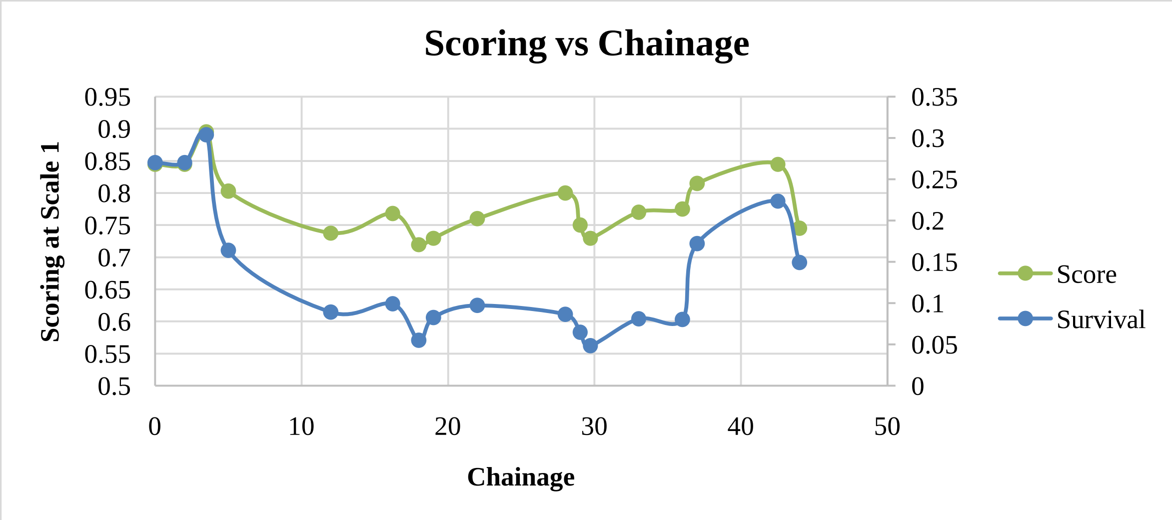

Figure 8: Scoring on summation & Survival with chainage

This Survival score can be normalised to obtain a survival/failure probability with historical third-party related failure data. The analysed pipeline section for scoring is as detailed in table 14:

Table 14: Scores against each threat

Section	Surf Cond[n]	Activity level	Above ground	Line locat[n]	Pub Ed program	ROW Condn	Security	Insp Plan	Score
0-2	20	8	10	9	15	5	20	-2.5	84.5
2-3.5	20	8	10	9	15	5	20	-2.5	84.5
3.5-5	20	15	10	9	15	3	20	-2.5	89.5
5-12	10.8	15	10	9	15	3	20	-2.5	80.3
12-16.2	10.8	15	6	9	15	3	17	-2	73.8
16.2-18	10.8	15	10	9	15	2	17	-2	76.8
18-19	6	15	10	9	15	2	17	-2	72
19-22	6	15	10	9	15	3	17	-2	73
22-28	6	15	10	9	15	3	20	-2	76
28-29	6	20	10	9	15	2	20	-2	80
29-29.7	6	15	10	9	15	2	20	-2	75
29.7-33	6	15	10	9	15	2	20	-4	73
33-36	10	15	10	9	15	2	20	-4	77
36-37	10	20	7	9	15	2	17	-2.5	77.5
37-42.5	10	20	10	9	15	3	17	-2.5	81.5
42.5-44	13	20	10	9	15	3	17	-2.5	84.5
44-48.7	13	8	10	9	15	5	17	-2.5	74.5

4. Assessment of failure consequences

Following parameters are considered for evaluation of the consequences:

1. Product Hazard (PH)
2. Spill size (SS)
3. Spread (Spr.)
4. Receptors (Rec.)

Total score = PH*Size*Spread*Receptors

A. Product Hazard: Score out of 12

Risk model is derived for specific purpose of LPG pipeline. LPG consists of C3 & C4.Both of the products are flammable but less reactive &hazardous. For acute hazards, both propane & butane has similar hazards as enlisted below:

Table 15: Hazards Scores scheme [8]

Product	Nh	Nf	Nr	RQ Points	Score
Propane	1	4	0	2	7
Butane	1	4	0	2	7
Benzene	2	3	0	8	
Crude	1	3	0	6	

Abbreviations: Nh: Hazard Score, Nf: Flammability Score, Nr: Reactivity Score, RQ: Receptors Score (Reportable spill quantity) RQ points states chances of the chronic hazards. Crude imposes chronic threats than the acute threats; however, LPG has a higher acute threat than chronic threat.

B. Spill Size: Score out of 5

Spill size is calculated using API 581 [9]. Following leak reduction factors were used to arrive at the spill size. Loss of containment is calculated using the pressure, expected hole size, pipeline pressure, pipeline liquid.

Table 16: Spill Detection and Isolation Score

Detection	Isolation		
	A: (Automatic Remote operated)	B: (Remote operated)	C: (Manual operated)
A: (Flow based Detection in instrumentation)	0.25	0.2	0.1
B: (Acoustic/OFC based detection)	0.15	0.15	0.1
C: (Visual Detection)	0	0	0

C. Spread Score: Score out of 6

For assessment of consequence and award of score a model 10” LP Gas pipeline operating at operating at 90 kg/cm^2 pressure is considered.

When a container of liquefied gas (that has been liquefied by pressure) is ruptured or has a broken valve, it results in a sudden loss of pressure. This causes the liquid in the container to boil violently (flash boil) and the contents to foam up, filling the container with a mixture of gas and fine liquid droplets (called aerosol).

When the liquid and gas phases of a LPG escape together from a ruptured container, the release is called a two-phase flow. When a two-phase mixture escapes from storage, the release rate can be significantly higher than release rates for pure gases or unpressurized liquids.

ALOHA is used for dispersion and effective area spread calculation for LPG pipelines. LPG is stored/ pumped in liquid phase and while coming out LPG transforms into gas.

Ambient temperature considered is 350 °C which is generally valid given the Indian conditions. However, for complete assessment of threat, 150 °C is also considered for evaluation. A wind speed of 2 miles/hr (above 3mtr of ground level) is considered, ground roughness as open terrain & Relative humidity as 50%.

Source is modelled as 10” diameter &1 km long tank where the fluid is stored as liquid. As per statutory requirements, sectionalising valves are to be provided at every 10 km. Upon initial blast 10% of the liquid comes out of the pipe section as gas that cause the first blast.

Full bore rupture is considered for evaluation of the consequence area. Two types of scenarios have been considered for evaluation of high consequence area. Two fire scenarios, Jet fire & BLEVE (Boiling liquid expanding vapour explosion) have been considered for evaluation of affected area.

The results of various case scenarios for 60 seconds are enlisted as below:

Table 17A: For Jetfire, nature of effect on individual vs. distance from source

Liquid Type	Ambient Temp (°C)	Lethal	2nd Degree burn	Pain
		Distance in Metre		
Propane	35	164	243	387
Butane	35	120	187	305
Propane	15	177	259	410

Table 17B: For BLEVE, nature of effect on individual vs. distance from source

Liquid Type	Temperature (°C)	Lethal	2nd Degree burn	Pain
	Distance in Metre			
Propane	35	366	517	805
Butane	35	351	495	772
Propane	15	388	548	855

The inferred radius has been considered as 548m(x). LPG disperse in the atmosphere with time, hence cleaning & contamination is not major contributing factor for scoring.

$$SpreadScore = \begin{cases} x * 6/1000, & x < 1000\,mtr \\ 6, & x \geq 1000 \end{cases}$$

Figure 9: Affect area representation in ALOHA

D. Receptor Score (Max Score 45)

Main hazard related in LPG pipeline is related to population. Considering that LPG is not soluble in water and doesn't require extensive cleaning as compared to liquid. In view of this argument following scheme is used for receptor score.

Table 18: Consequence Scoring Scheme for High Consequence Area

Population	Score (x)	Special	Score(y)	High Value Area	Score (z)
Extraordinary	10	Apartments	10	None	0
Multi-story	9	Hospital	10	School	5
Commercial	8	School	9	Church	3.5
Residential urban	7	Park	8	Hospital	5
Residential sub-urb	6	Roadways	5	Historic site	2
Industrial	5	Nil	4	Cemetery	2
Semi Rural	4	Residential	8	Busy harbour	4
Rural	2			airport (major)	5
Isolated	1			airport (minor)	3
				University	5
				Industrialcenter	3.5
				Highway	3
				Parks	2
				special agriculture	1
				water treatment	1
				Multiple	5
				Other	2

Receptor Score = max(x,y) + z + Sum(Environment*Damage level * 5)

R, Population growth of around 2% has been considered which can be aligned appropriately again with the fresh population density survey.

Table 19: Consequence Scoring Scheme vis. Receptor

Environment/ Damage level	Neutral	High	Extreme
Public land (Forest)	-	-	1
Wetlands	-	0.6	-
Water Intakes	0	-	-
Water	0	-	-
Navigable Waterways	-	-	0.7

E. Scoring of the Leak Impact Factor:

Leak impact factor is score based on the above scenarios with a relative scale as represented in the graph

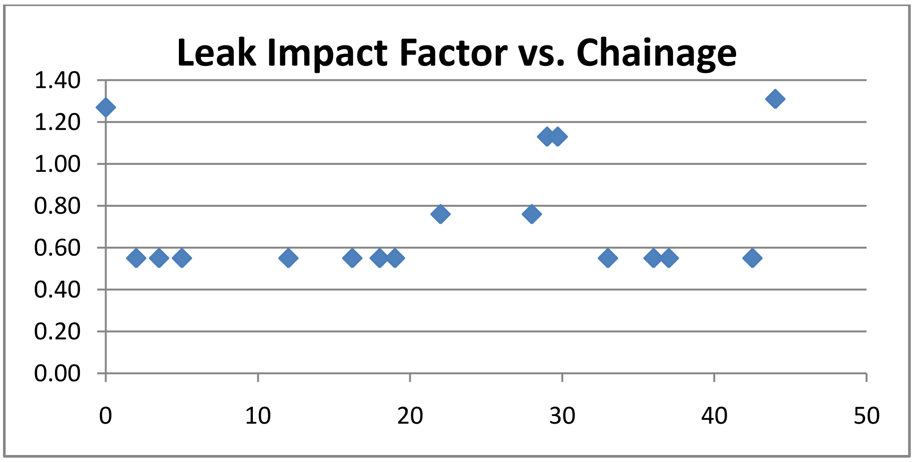

Figure 10: Relative leak impact factor vs. Chainage

5. Assessment of failure consequences

A. Risk assessment of a sample Pipeline:

Risk Matrix is created. Based on the risk model, a 48.6 km section 10 LPG pipeline is analysed. The risk of the risk scores are displayed as below:

Probability Rating						
	0.2 - Very High	0	1	0	0	0
	0.4 - High	0	5	0	2	1
	0.6 - Moderate	0	2	0	0	0
	0.8- Low	0	2	0	0	1
	1- Very Low	0	1	0	0	0
		0.1	0.5	0.8	1.1	1.3
		Very Low	Low	Moderate	High	Very High
		Consequence				

Figure 11: Risk Matrix with pipeline segmentation in 2018

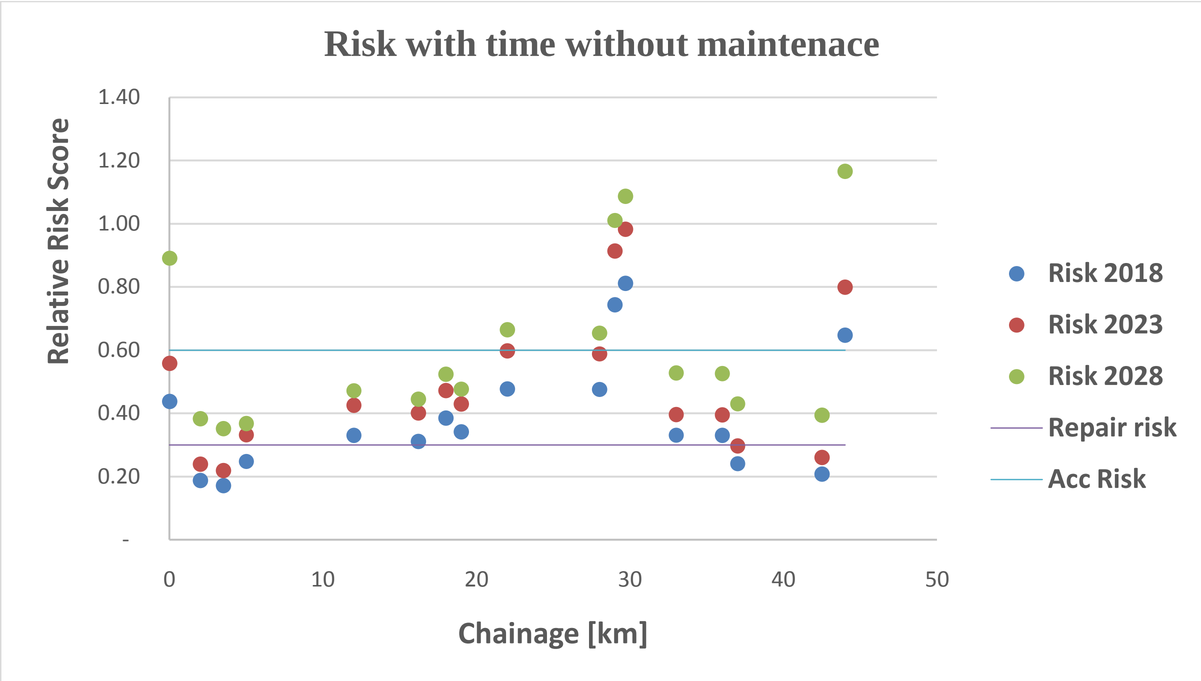

Figure 12: Relative risk with time without maintenance

- Acc. Risk is acceptable risk level.
- Repair level is risk for repairs shall be initiated.

As can be seen that few sections are more time dependent than others due to factors, that they have either high leak impact factor or higher threats for third party damage.

6. Maintenance & Inspection Plan

A. Inspection &Maintenance Plans:

Base line risk assessment can be used at the time of risk assessment with the relative risk scoring. As the risk model is time dependent, where various inspection and ongoing construction data can be linked with the risk model. With the advent of the time, the risk related to data uncertainty increases, & the risk increases. This can be used to identify an appropriate inspection & maintenance plans. As the receptor risk are driven either by socio-economic factor or to be consider in the design stage, the major choices are left with the reducing the probability of failure.

Primary concept of the risk model is the depth of cover which can be taken care during inspection and maintenance phase. With the help of the risk model, proposed maintenance plans are proposed as under:

1. Immediate Maintenance Plan 2018:

Immediate maintenance plan lists the following activities:

- Carry out EGP survey and repair unacceptable defects
- Carry out CIP survey of chainage 5km to 33km and repair unacceptable defects
- Carry out DCVG survey of chainage 29.7km to 33km and repair unacceptable defects
- Increase patrolling of chainage 12 to 28 km
- Revamp ROW from chainage 28 to 36 km.

2. Long term maintenance plan till 2023:

- Increment of depth of cover in chainage 18 to 29.7 km &chainage 33-44 km.
- Inspection in chainage from 44 to 48.6 km after completion of construction.

Probability Rating	0.2 - Very High	0	0	0	0	0
	0.4 - High	0	0	0	0	0
	0.6 - Moderate	0	0	1	0	0
	0.8- Low	0	0	2	0	0
	1- Very Low	0	0	8	2	4
		0.1	0.5	0.8	1.1	1.3
		Very Low	Low	Moderate	High	Very High
		Consequence				

Figure 13: Risk Matrix with pipeline segmentation in 2023 with maintenance plan

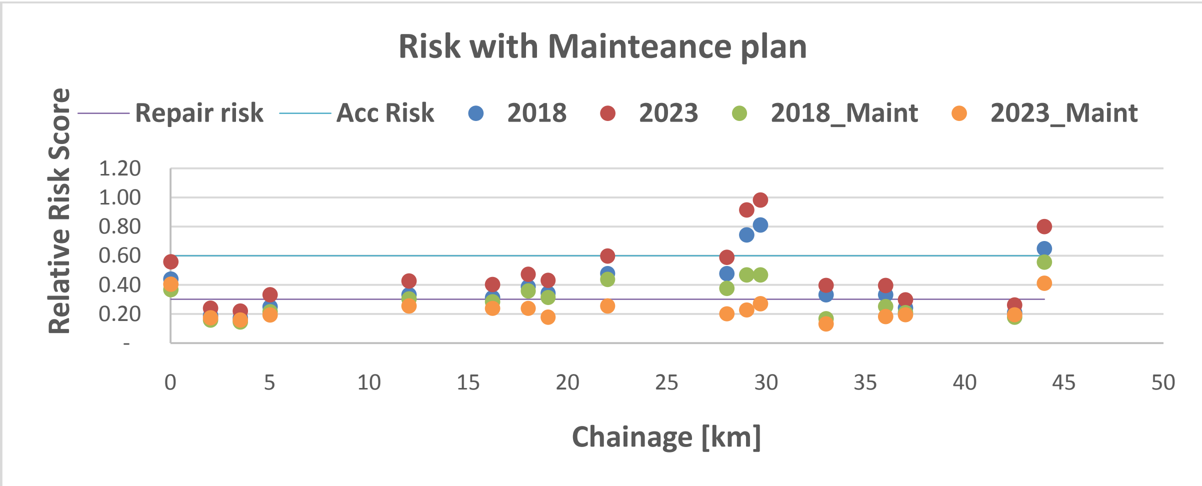

Figure 14: Relative risk in time vs chainage& maintenance scheme

3. Change in maintenance & construction plan:

- Increase the EGP frequency to 5 years
- Change ECDA(external corrosion direct assessment) frequency techniques such as CIPS/CAT/DCVG to 5 years
- Carry out EGP & ECDA of a section after major construction.
- Leak impact factor from chainage 0 to 2 km & 44 to 48.6 km is major risk contributing factor. This case may be taken as reference and additional design safety can be provided by increasing the wall thickness.

7. Results & Discussions

The developed risk evaluation scheme is a time dependent and real time based one, so to say, .the risk value increases with the real time fed on real times conditions. Model automatically takes an educated guess whether the data is old or stale. Similarly, the risk evaluation technique as briefed also adjusts the inspection intervals reckonedto be fit in to local Indian conditions which is based on engineering judgements of Indian experts and various Indian Codes. However, the risk model mostly provides a relative risk scoring to identify the section prone to the maximum threat. These sections can be prioritised for inspection and maintenance to bring down the risk at an acceptable level.

LPG pipelines are associated with high socio-environmental risk which further effects the viable risk as well, in a populated area. Hence, separate commercial impact was not studied. However, a commercial module can be added to this model to assess the commercial risk associated with the third-party related damage.

Definition

i. LPG= Liquified Petroleum Gas, a refinery product and generally a mixture of Ethane >90%, Propane and Butane
ii. CP= Cathodic Protection: to preserve pipeline against external corrosion
iii. ILI= In Line Inspection to measure metal loss and geometry profile of the pipeline, commonly referred as Intelligent pig survey (IPS), calliper survey etc.
iv. Gas Pipeline = Natural Gas Pipeline
v. Depth of Cover = Depth beneath the ground at which pipeline is buried, Generally 1 to 1.2m below the surface. of the earth.
vi. Crossings = Areas where a pipeline crossed below a road or a rail track or a linear facility, water ways etc. In case areas special measures are to be taken to ensure safety of the pipeline as well as structure or assets above it.

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