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Quantitative Risk Assessment for Crude Oil Pipelines

Huseyin Murat Cekirge

Department of Mechanical Engineering, Prince Mohamed Bin Fahd University, Al Khobar, KSA

Email address:
hmcekirge@usa.net

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Abstract: Risk Assessment is an extremely useful tool in providing a framework in which to identify the possible hazards and evaluate the risks associated with all crude oil pipelines. By using index method and multivariable analysis, a methodology of the threat and risk of crude oil pipelines to environment are presented. General concepts are introduced and explained in detail. Principles of the methodology, the specific equations, and data required to prepare a risk analysis for environmental risk and failure analysis are discussed and explained, and an example is presented to illustrate the method.

Keywords: Crude Oil Pipelines, Risk Analysis, Risk Assessment, Index Method

1. Introduction

Risk Management in its broadest sense represents the successful control of all threats of harm and loss to a crude oil pipeline. The assessment and analysis produces numerical value of the risk involved and evaluates the results against specified risk criteria. The purpose of the Risk Analysis stage is to obtain an idea of the size or the scale of the risk, [1].

Simply, a risk assessment is finding out what could cause harm to people, environment, task or equipment. The results presents if it is being done enough, or need to do more to protect the installation. If risk is expressed in terms of High, Medium or Low, that qualitative. Attempt to express risk in numerical terms will be based on calculation using data for failure rates of equipment, human error, etc., that is Low(2 or less), Medium(3 – 6) and High(6 or more).

These principles presented are specifically for crude oil pipelines in the context of this paper. A fundamental aim of this paper is to present an assessment method that is providing reasonable risk estimates for policy decisions. Certain assumptions used are part of the paper. The methodologies presented in the paper cover pipelines carrying crude oil.

The data required for a risk analysis includes pipeline data and site data. Some information that would aid in a risk analysis is proprietary to the pipeline operator. In general, the required data include:

- The location of the proposed pipeline site, including roads and major terrain feature boundaries;
- The location of the pipeline with respect to the proposed site, and specifically the segment lying within the site;
- Land use and terrain characteristics adjacent to and within the site;

A phase of environmental assessment study will sometimes have identified hazardous material pipelines near the site and several key characteristics of a pipeline such as:

- Location;
- The product transported;
- Diameter;
- Operating pressure;
- Materials of construction; and
- Date of construction.

The fundamental approach in the paper is the former, as described in detail in the remainder of this section. The paper also describes the latter, which can be done through the basic process by iterating on distance as described briefly later in this section.

2. Risk Assessment System Features

This document contains the results of the risk analysis technological pipeline transport system for which a methodology has been applied to meet new requirements and risk management infrastructure. It has been estimated as a basis for risk valorization and as a tool for the determination of the most dangerous areas in the event of a leak or spill which has not been declared a threatening even to foil spills to take appropriate action. Through the methodology used, is to also have a basis for risk management, represented a risk value for each section of the pipeline, and defined from the threat related variables, the constructive aspects of the system and the events that may originate from third parties or natural phenomenon. The study explains step by step the aspects of the methodology it is necessary that the operating group responsible for maintaining the Contingency Planning formation make necessary modifications to update the risk analysis, and also use these results in decisions for annual investment programs, conditioning it to risk management in the system.

This study initially present general aspect of risk, to facilitate understanding of the procedures and results of the methodologies employed in selection estimation causes and risk. Such methodologies are described later and are carried thereon to application pipeline transport system. The valuation methodology is based on the universal concept of risk, in which the parameters are determined amending it so semi quantitative leveraging estimation consequences (quantitative values) and qualitative assessments that define some parameters or aspects of risk.

3. Risk Assessment Methodology

The methodology used is a adaptation Indexing method developed in Pipeline Risk Management Manual, [2], [3], [4], and [5] using influence distances reported for the estimation of consequences and characteristics of operation pipeline transport system, to modify the risk variables, balance from the point of view of individual risk covered by Guidelines for Chemical Process Quantitative Risk Analysis that includes advances in Chemical Process Quantitative Risk Analysis (CPQRA), [6], [7]. [8] and [9].The methodology incorporates risk valorization specific data input and output to be updated constantly by staff in each infrastructure. It is the input characteristics that modify the risk, which are related to infrastructure, operation, maintenance, environment, prevention activities, and the characteristics of the load. These characteristics influence the frequency of a novice event, the probability of occurrence of a threatening event, the probability of producing damage in the area in which the event occurred given the same conditions and environmental vulnerability. These characteristics will be valued for the conditions of the pipeline transport system by sector, so that each will produce a separate segmentation along the pipeline. The combination of the values of these characteristics affected by factors defined for each weight results as a result a risk factor for the sector, which will be represented along a graphical pipeline to facilitate analysis. The methodology allows the calculation of a risk value of all infrastructures per unit length, besides being able to view the areas of greatest risk in the pipeline.

The risk is defined as the combination of four factors, one of which is a frequency (occurrences per unit time) and others are likely to occurrence (dimensionless values) of events that are chained in a threatening event, resulting in a risk value in terms of the occurrence of a particular damage per unit time. To facilitate risk management defines a set of characteristics that infer in the same and related infrastructure, ancillary systems, the operation, safety programs and environmental characteristics. To perform valorization should identify partitions that each feature occurs along the pipe and so to assign the respective values of each sector using sectorization maxima occur in the system. Each feature referred to faith will be given a relative value, which is a number between 0 and 10 following the guidelines presented in Table 1 and considering each risk characteristic independently.

3.1. Characteristics of Risk Factors

Threatening events considered are oil spills. If given an escape, not have any of these events, it is said that the event is a consequent pollution oil scattering or dispersion of the spill and oil. The environmental risk factors Ci‘s are listed in the following table:

Table 1. *Environmental risk elements.*

Variable	Definition	Explanation
C1	Surface Water Sensitivity	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=1
C2	Ground Water Sensitivity	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=1
C3	Terrestrial Ecological Resource	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=0.75
C4	Land Use	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=0.75
C5	Archaeology	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=0.25

As base of four, the risks are classified as Not Sensitive = 0, Low = 2, Medium = 2, High = 3 and Very High =4.

To perform valorization should identify partitions that each feature occurs along the pipe and so to assign the respective values of each sector. The pipeline is beginning segmented for by one kilometer segmented. In the tables KP (Kilometer Point) represents segments, and KP 5 presents segment starts at 4th kilometer and ends at 5th kilometer from staring point of the pipeline. The length of the segment may be chosen more and less than one kilometer.

Each feature referred to faith will be given a relative value, which is a number between 0 and 10 following the guidelines presented in Table 1 and considering each risk characteristic independently.

Table 2. *Qualitative values of environmental risk for the segments.*

KP (km)	Surface Water Sensitivity	Ground Water Sensitivity	Terrestrial Ecological Resource	Land Use	Archaeology
0					
1	Not Sensitive	Not Sensitive	Very High	Not Sensitive	Not Sensitive
2	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
3	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
4	Low	Not Sensitive	Very High	Medium	Not Sensitive
5	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
6	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
7	Not Sensitive	Not Sensitive	Very High	Not Sensitive	Not Sensitive
8	Not Sensitive	Not Sensitive	Very High	Not Sensitive	Not Sensitive

Table 3. *Quantitative values of environmental risk for the segments.*

KP (km)	Surface Water Sensitivity	Ground Water Sensitivity	Terrestrial Ecological Resource	Land Use	Archaeology
0					
1	1	1	10	1	1
2	1	1	10	5	1
3	1	1	10	5	1
4	3	1	10	5	1
5	1	1	10	5	1
6	1	1	10	5	1
7	1	1	10	1	1
8	1	1	10	1	1

Table 4. *Normalization of environmental risk for the segments.*

KP (km)	Surface Water Sensitivity	Ground Water Sensitivity	Terrestrial Ecological Resource	Land Use	Archaeology
Weight	1	1	0.75	0.25	0.25
0					
1	0.1	0.1	0.75	0.025	0.025
2	0.1	0.1	0.75	0.125	0.025
3	0.1	0.1	0.75	0.125	0.025
4	0.3	0.1	0.75	0.125	0.025
5	0.1	0.1	0.75	0.125	0.025
6	0.1	0.1	0.75	0.125	0.025
7	0.1	0.1	0.75	0.025	0.025
8	0.1	0.1	0.75	0.025	0.025

Table 5. *Probability of environmental risk for the segments.*

To (km)	Surface Water Sensitivity	Ground Water Sensitivity	Terrestrial Ecological Resource	Land Use	Archaeology	Max Probability	Normalized Probability	Total Index
0								
1	0.4	0.4	3	0.1	0.1	0.75	3	1
2	0.4	0.4	3	0.5	0.1	0.75	3	1.1
3	0.4	0.4	3	0.5	0.1	0.75	3	1.1
4	1.2	0.4	3	0.5	0.1	0.75	3	1.3
5	0.4	0.4	3	0.5	0.1	0.75	3	1.1
6	0.4	0.4	3	0.5	0.1	0.75	3	1.1
7	0.4	0.4	3	0.1	0.1	0.75	3	1
8	0.4	0.4	3	0.1	0.1	0.75	3	1

3.2. Base Frequencies and Modification Factors

The frequency of an event is the expected number of times per length of pipe that an event will occur in a year. As an illustration, the excavation damage frequency for a given segment might be1.4×10-6 based on historical incident data. That frequency represents the number of times that excavation is expected to cause a leak in that segment of the pipe in a year. For each segment of the pipeline, the frequency of events (and thus possible leaks) was determined by first assessing the frequency of each spill case individually, distributed among the three hole sizes. These were summed to give the total leak frequency, considering additivity, i= i^{th} frequency,

$$f = \sum_{i=1}^{n} f_i$$

fi = leak event of i,

n= number of leaks or

$$f = f_{mo} + f_{co} + f_{ih} + f_{ai} + f_{nh} , \tag{4.1}$$

where:

f_{mo} = leak frequency from material mechanical and operational faults,

f_{co}= leak frequency from corrosion,

f_{ih}= leak frequency from intentional hostile action,

f_{ai}= leak frequency from accidental / incidental action,

f_{nh}= leak frequency from natural hazards.

The individual frequencies were determined by applying modification factors to a base leak frequency for each spill cause. The specific modification factors and hole size distributions are discussed for each of the relevant causes in the following subsections. The sizes are, Table 6:

Table 6. *Hole sizes.*

LEAK	HOLE	RUPTURE
Leak Area (cm²)	Leak Area (cm²)	Leak Area (cm²)
0.2	20.0	full bore

The frequencies are presented by Tables 7, 8, 9, 10 and 11.

Table 7. *Frequency values of various events, [10], [11], [12], [13], [14], [15], [16] and [17].*

RAW FREQUENCY DATA				SPLIT FRACTIONS			FREQ FOR APPLICATION		
CATEGORY	CAUSE	APPLICATION	RAW FREQ [/y km]	LEAK	HOLE	RUPTURE	LEAK	HOLE	RUPTURE
MECH& OP FAULTS	Mechanical (Line Pipe Fault)	General	8.44E-05	0.7	0.24	0.06	5.91E-05	2.03E-05	5.06E-06
	Op Faults	General	4.78E-05	0.75	0.25	0	3.59E-05	1.20E-05	0.00E+00
CORROSION	Internal	General	4.22E-05	0.9	0.09	0.01	3.80E-05	3.80E-06	4.22E-07
	External	General	5.35E-05	0.9	0.09	0.01	4.82E-05	4.82E-06	5.35E-07
INTENTIONAL HOSTILE ACTION	Sabotage/ War/Hostilities	General	1.41E-05	0.25	0.25	0.5	3.53E-06	3.53E-06	7.05E-06
ACCIDENTAL / INCIDENTAL ACTION	Impact due to Farming / Excavation / Pilfering	General	1.55E-04	0.5	0.5	0	7.75E-05	7.75E-05	0.00E+00
NATURAL HAZARDS		General	1.41E-05	0.1	0.2	0.7	1.41E-06	2.82E-06	9.87E-06
TOTAL							2.63E-04	1.25E-04	2.29E-05

Table 8. *Frequency values for segments, basic data and landslide.*

FEATURE	KP (km)	FREQ FROM BASIC DATA			FREQ FROM LANDSLIDE DATA		
		LEAK	HOLE	RUPTURE	LEAK	HOLE	RUPTURE
					0.1	0.2	0.7
Land	0						
Land	1	2.63E-04	1.25E-04	2.29E-05	1.48E-06	2.96E-06	1.04E-05
Land	2	2.63E-04	1.25E-04	2.29E-05	8.49E-06	1.70E-05	5.94E-05
Land	3	2.63E-04	1.25E-04	2.29E-05	4.71E-08	9.43E-08	3.30E-07
Land	4	2.63E-04	1.25E-04	2.29E-05	1.03E-06	2.07E-06	7.24E-06
Land	5	2.63E-04	1.25E-04	2.29E-05	2.42E-06	4.84E-06	1.69E-05
Land	6	2.63E-04	1.25E-04	2.29E-05	1.59E-06	3.18E-06	1.11E-05
Land	7	2.63E-04	1.25E-04	2.29E-05	1.91E-06	3.81E-06	1.33E-05
Land	8	2.63E-04	1.25E-04	2.29E-05	1.67E-09	3.33E-09	1.17E-08

Table 9. *Frequency values for segments, seismic data and river hazards.*

FEATURE	KP (km)	FREQ FROM SEISMIC DATA			RIVER HAZARDS		
		LEAK	HOLE	RUPTURE	LEAK	HOLE	RUPTURE
		0.1	0.2	0.7	0.1	0.2	0.7
Land	0						
Land	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 10. *Frequency values for segments, gas line hazards and block valve stations.*

FEATURE	KP (km)	CROSSING GAS LINE HAZARDS			BV STATIONS		
		LEAK	HOLE	RUPTURE	LEAK	HOLE	RUPTURE
		0.1	0.2	0.7	0.1	0.2	0.7
Land	0						
Land	1	0.00E+00	0.00E+00	0.00E+00			
Land	2	0.00E+00	0.00E+00	0.00E+00			
Land	3	0.00E+00	0.00E+00	0.00E+00			
Land	4	0.00E+00	0.00E+00	0.00E+00			
Land	5	0.00E+00	0.00E+00	0.00E+00			
Land	6	0.00E+00	0.00E+00	0.00E+00			
Land	7	0.00E+00	0.00E+00	0.00E+00			
Land	8	0.00E+00	0.00E+00	0.00E+00			

Table 11. *Frequency values for segments, total leak frequencies and block adjacent pipeline impact.*

FEATURE	KP (km)	TOTAL LEAK FREQUENCIES			ADJACENT PIPELINE IMPACT		
		LEAK	HOLE	RUPTURE	LEAK	HOLE	RUPTURE
Land	0						
Land	1	2.65E-04	1.28E-04	3.33E-05	0.00E+00	0.00E+00	0.00E+00
Land	2	2.72E-04	1.42E-04	8.23E-05	0.00E+00	0.00E+00	0.00E+00
Land	3	2.64E-04	1.25E-04	2.33E-05	0.00E+00	0.00E+00	0.00E+00
Land	4	2.65E-04	1.27E-04	3.02E-05	0.00E+00	0.00E+00	0.00E+00
Land	5	2.66E-04	1.30E-04	3.99E-05	0.00E+00	0.00E+00	0.00E+00
Land	6	2.65E-04	1.28E-04	3.41E-05	0.00E+00	0.00E+00	0.00E+00
Land	7	2.65E-04	1.28E-04	3.63E-05	0.00E+00	0.00E+00	0.00E+00
Land	8	2.63E-04	1.25E-04	2.30E-05	0.00E+00	0.00E+00	0.00E+00

Table 12. *Spill values from each leak, calculated pipe considering pipe's geometry and location of block valves location.*

KP (km)	LEAK	HOLE	RUPTURE
	Leak Area (cm²)	Leak Area (cm²)	Leak Area (cm²)
	0.2	20.0	full bore
	Spill Time (h)	Spill Time (h)	Spill Time (h)
	72	25.3	24
0			
1	451.83	3533.80	5245.31
2	432.61	2721.47	4465.33
3	418.88	2751.77	4518.32
4	421.10	2697.42	4460.66
5	394.51	2062.35	3874.67
6	336.57	1143.66	3026.92
7	326.57	1033.34	2922.79
8	338.48	4634.67	6535.46

The volume of the oil in each segment is presented by Table 12.Tables 13, 14 and 15 are presenting risk values of leak, hole and rupture with environmental risk, respectively and Table 16 total environmental risk. The methodology of calculating risk is in the following: Fifty percent of oil is being recovered and cost of recovering oil for m3 oil is, if;

0 ≤ Environmental Max Probability < 0.1	Cost = $ 1 000
0.1≤ Environmental Max Probability < 0.4	Cost = $ 2 000
0.4≤ Environmental Max Probability < 0.6	Cost = $ 5 000
0.6 ≤ Environmental Max Probability< 0.8	Cost = $ 7 500
0.8≤ Environmental Max Probability	Cost = $ 10 000.

These dollar values can be always adjusted depending on area and land conditions. Environmental risk as dollar value becomes,

Risk as Dollar Value = Frequency * Volume of the Oil * Percentage of recoverable Oil * Cost.

Total cleaning cost, which is the risk at a segment, can found for leak, hole and rupture. The sum of these costs becomes risk at every segment.

Table 13. *Risk measure as dollar at every segment for leaks.*

feature	kp (km)	leak frequency	volume of oil spilt / leaked with pumps off & BVs shut	level of success of clean-up (any size spillage)	environmental sensitivity to oil pollution	cost of pollution of environment [$/cu m]	risk of environmental pollution / impact [$/y]
basic dummy		2.00e-04	100	0.5	0.50	5000	50.0
land	0.0	0.00e+00	0	0.5	0.000	1000	0.0
land	1.0	2.65e-04	452	0.5	0.750	7500	449.0
land	2.0	2.72e-04	433	0.5	0.750	7500	441.2
land	3.0	2.64e-04	419	0.5	0.750	7500	414.0
land	4.0	2.65e-04	421	0.5	0.750	7500	417.7
land	5.0	2.66e-04	395	0.5	0.750	7500	393.4
land	6.0	2.65e-04	337	0.5	0.750	7500	334.6
land	7.0	2.65e-04	327	0.5	0.750	7500	325.0
land	8	2.63e-04	338	0.5	0.75	7500	334.5

Table 14.*Risk measure as dollar at every segment for holes.*

feature	kp (km)	leak frequency	volume of oil spilt / leaked with pumps off & BVs shut	level of success of clean-up (any size spillage)	environmental sensitivity to oil pollution	cost of pollution of environment [$/cu m]	risk of environmental pollution / impact [$/y]
Land	0	0.00E+00	0	0.5	0.00	1000	0.0
Land	1	1.28E-04	3534	0.5	0.000	1000	225.5
Land	2	1.42E-04	2721	0.5	0.000	1000	192.7
Land	3	1.25E-04	2752	0.5	0.000	1000	171.7
Land	4	1.27E-04	2697	0.5	0.100	1000	170.9
Land	5	1.30E-04	2062	0.5	0.100	1000	133.5
Land	6	1.28E-04	1144	0.5	0.100	1000	73.1
Land	7	1.28E-04	1033	0.5	0.100	1000	66.4
Land	8	1.25E-04	4635	0.5	0.100	1000	288.9

Table 15. *Risk measure as dollar at every segment for ruptures.*

feature	kp (km)	leak frequency	volume of oil spilt / leaked with pumps off & BVs shut	level of success of clean-up (any size spillage)	environmental sensitivity to oil pollution	cost of pollution of environment [$/cu m]	risk of environmental pollution / impact [$/y]
BASIC DUMMY		2.00E-04	100	0.5	0.50	5000	50.0
Land	0	0.00E+00	0	0.5	0.000	1000	0.0
Land	1	3.33E-05	5245	0.5	0.750	7500	655.1
Land	2	8.23E-05	4465	0.5	0.750	7500	1,378.8
Land	3	2.33E-05	4518	0.5	0.750	7500	394.3
Land	4	3.02E-05	4461	0.5	0.750	7500	504.8
Land	5	3.99E-05	3875	0.5	0.750	7500	579.6
Land	6	3.41E-05	3027	0.5	0.750	7500	386.7
Land	7	3.63E-05	2923	0.5	0.750	7500	397.6
Land	8	2.30E-05	6535	0.5	0.75	7500	562.52

Table 16. *Total risk measure as dollar at every segment for leak, holes and ruptures.*

Environmental risk [$/y]					
FEATURE	KP (km)	Pipeline Leak	Pipeline Hole	Pipeline Rupture	Total Risk
Land	0	0.00	0.00	0.00	0.00
Land	1	449.0	1691.2	655.1	2,795.28
Land	2	441.2	1445.5	1378.8	3,265.49
Land	3	414.0	1287.4	394.3	2,095.66
Land	4	417.7	1281.9	504.8	2,204.51
Land	5	393.4	1001.6	579.6	1,974.56
Land	6	334.6	548.3	386.7	1,269.57
Land	7	325.0	497.8	397.6	1,220.46
Land	8	334.5	2166.7	562.5	3,063.70

These values can be used for various statistical interpretations and graphical presentation. The following risks can be included more detailed risk analysis, [18],

- Risk to Company Operations [$/Year].
- Probability Staff Exposed to Fatal Consequences of Explosion,
- Probability Public Exposed to Fatal Consequences of Fire at Leak Site,
- Probability Public Exposed to Fatal
- Consequences of Fire at Remote Ignition Site,
- Probability Public Exposed to Fatal
- Consequences of Explosion,
- Total Number of Staff Exposed to Fire,
- Total Number of Staff Exposed to Explosion,
- Total Number of Public Exposed to Fire,
- Total Number of Public Exposed to Explosion,
- Sensitivity of Environment to Effects of Fire / Explosion,
- Individual Risk to Staff [Fatality/Year],
- Individual Risk to General Public [Fatality/Year],
- Societal Risk to Staff [Fatalities/Year],
- Societal Risk to Public [Fatalities/Year],
- Total Societal Risk [Fatalities/Year],
- Cost of Life of Member of Staff [$],
- Cost of Life of Member of Public [$],
- Cost of Equipment Lost In Accident and Its Replacement [$],
- Loss of Revenue Resulting From
- Accident [$],
- Penalties to Company - Fines, Profit Loss, Adverse Publicity [$]
- Risk to Company Operations [$/Year].

4. Conclusion

The methodology presented is a detailed analysis of quantifying risk of crude oil pipelines. The methodology can be easily be used for any crude oil pipeline with local frequency values. These values may be improved through new statistical data. In considering risk valorization characteristics of pipeline transport system and operation, it has been defined as the process valorization risk. The values acceptable and tolerable can be defined.

This study of risk of pipeline transport system activity definition presented the individual risk and total risk estimation infrastructures based on the characteristics of the infrastructure. These evaluations are based on results of estimation threatening consequences of events identified. The flow of tables presents computational details. The procedures and methodology can be used without difficulty.

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