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PIPELINE RISK ASSESSMENT USING ANALYTIC HIERARCHY PROCESS (AHP)

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ABSTRACT
Deciding on the effectiveness of risk reduction measures is a common problem that involves tradeoffs among multiple different and generally qualitative criteria. Often risk mitigation measures implemented for pipeline risk reduction cannot be easily quantified, but it can be ranked. Hence, there is a need to identify which risk reduction measure is the most effective amongst the competing options. This paper uses Analytic Hierarchy Process (AHP) approach to select optimal solutions that best satisfies all of the decision maker's requirements. This paper presents the development of an AHP model and the derivation of a quality index. The model is used for a hypothetical case study of various remediation works to an existing pipeline. The advantages of using such a technique are also discussed. This proposed model of risk assessment is useful for risk management during the planning and building stages of a new pipeline, as well as for modification and changes of use for an existing pipeline.

INTRODUCTION
The risk a pipeline poses to its environment as well as risk to the asset is unique; due to the sheer number of Risk Influencing Factors (RIFs) which must be considered. Before assessing risk the assessor needs to consider a set of criteria (RIFs) and assess their relevance to the specific risk assessment to be undertaken. RIFs that may be important for one pipeline may be trivial for another. There are usually between four and eight main criteria and several sub-criteria that can affect the risk. The main criteria are: corrosion & cracking; design issues; materials; fabrication & construction; external interference; maintenance; operation & safety management programs; Geohazards & weather (route condition) and the lifecycle cost. In some situations the age of the pipeline and the burial depth may also require individual attention. Minor RIFs can be grouped together to facilitate the assessment.

Planning a new pipeline, or when upgrading or changing the use of an existing pipeline, requires considering the risk of the pipeline to surroundings and people as well as to the asset. Hence, there is a need to decide which risk reduction measure is the most effective amongst competing measures. Muhlbauer (1992) and Kiefner et al (1990) proposed a qualitative risk assessment by assigning scores to different RIFs that are thought to influence the probability and consequences of pipeline failures. These scores are combined using simple summation to give an index representing the relative level of risk.

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was originated by Saaty (1977 and 1994). The AHP is a decision support tool which is suitable for complex decision problems. It is based on a multi-level hierarchical structure of objectives, namely criteria, sub-criteria, and options. The first level is setting the objective; for the purpose of this paper, the objective is to determine the effectiveness of risk reduction measures. The second level is the identification of all RIFs. The assessor then undertakes a pairwise comparison of RIFs to assign a weight to one and the reciprocal of this is the weight of the other RIF. These comparisons are used to establish the relative importance of one RIF against another one. A consistency check can then be undertaken. If the comparisons are not perfectly consistent, then this check provides a mechanism for improving consistency.

AHP lacks a firm theoretical basis, but it formalises the intuitive approach to decision making by associating relative weights to all parameters which influence a decision. It also creates an auditable trail which can be used for risk communication and reaching a consensus by assessors.

NOMENCLATURE

Nomenclature	Description
AHP	Analytic Hierarchy Process
Alternatives/Options	These are feasible engineering solutions that can be chosen.
E	Excellent
G	Good
A	Acceptable
P	Poor
U	Unacceptable
RIF	Risk Influencing Factor

INTRODUCTION

AHP is based on these three steps:
Structuring the Hierarchy - structures the elements of the decision making problem into a top down hierarchy. The hierarchic structure is beneficial to a decision-maker by providing an overall view of the complex relationships inherent in the situation and in the judgment process. It also allows the decision-maker to assess whether he or she is comparing issues of the same order of magnitude and if they are important. A hierarchy is a tree-like structure that is used to breakdown a decision problem. It has a top-down flow, moving from general categories (criteria) to more specific ones (sub-criteria), and finally to the options or alternatives.

Comparative judgments - generates a matrix of pairwise comparisons of elements at the same level with respect to each related element in the level immediately above it, where the principal right eigenvector of the matrix provides ratio-scaled priority ratings for the set of elements compared. AHP uses a mathematical technique, eigenvector scaling, for translating pair wise rating into numerical scores representing the importance of each individual criterion (didn't understand). Based on the decision maker's perception, the priorities among the criterion items in the hierarchy are established, using pairwise comparisons. The judgments are entered using the fundamental scale for pairwise comparisons as given later in this paper.

Synthesis of priorities - generates the global or composite priority of the elements at the lowest level of the hierarchy, i.e., the alternatives. Local priority is the priority relative to its parent, or upper, level, while global priority, or final priority, is the priority with respect to the goal.

This paper considers the case in which one wishes to improve a design with the intention of reducing risk to the asset as well to mitigate the pipeline's failure impact on its surroundings. There are a number of failure modes and also there are various different configurations to choose from. The different configuration is the alternatives or options. A decision should also consider all risk influencing factors which are pertinent for the problem in hand. For instance, seismic activity or landslides may not be very much of concern for certain pipeline. The intention is to determine the relative safety of all options under consideration, or to indentify the best option.

The AHP and its use of pairwise comparisons have inspired the creation of many other decision-making methods. Besides its wide acceptance, it also attracted considerable criticism; both for theoretical and for practical reasons. There are some problems with the way pairwise comparisons are used and the way the AHP evaluates alternatives. The AHP may reverse the ranking of the options when another alternative is introduced which is identical to one of the already existing alternatives. The fact that rank reversal occurs in the AHP when near copies are considered, has also been studied by Dyer (1990). Saaty (1983a and 1987) provided some guidelines on how close a near copy can be to an original option without causing a rank reversal. He suggested that the decision maker has to eliminate options from consideration that score within 10 percent of another option.

PAIR-WISE COMPARISON MATRIX

Very often qualitative data cannot be known in terms of absolute values. Therefore, many decision-making methods attempt to determine the **relative** importance, or weight, of the alternatives in terms of each criterion involved in a given decision-making problem.

Saaty's (1980) proposed a pairwise comparison for determining the relative importance of each alternative in terms of each criterion. In this approach the decision-maker has to express his/her opinion about the value of one single pairwise comparison at a time. Usually, the decision-maker has to choose his answer from 10-17 discrete choices. Each choice is a linguistic phrase. Some examples of such linguistic phrases are: *"A is more important than B"*, or *"A is of the same importance as* "*B"*, or *"A" is a little more important than B"*, and so on (see also Table 1). The main problem with the pairwise comparisons is **how to quantify** the linguistic choices selected by the decision maker during the evaluation. All methods which use the pairwise comparisons approach eventually express the qualitative answers of a decision maker into some numbers which are ratios of integers. The success of the method depends on correct quantification of pairwise comparisons.

Table 1: Scale of Relative Importance (Saaty (1980))

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	

If there are n criteria there must be n (n-1)/2 the pair-wise comparison. Let *C1*, *C2*, …, *Cn* denote the criteria, while a_{ij} represents a quantified judgment on a pair of elements *Ci*, *Cj*. The relative importance of two elements is rated using a scale with the values 1, 3, 5, 7, and 9, where 1 refers to "equally important", 3 denotes "slightly more important", 5 equals "strongly more important", 7 represents "demonstrably more important" and 9 denotes "absolutely more important". This yields an n-by-n matrix *A* as follows:

$$A = [a_{ij}] = \begin{array}{c|c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_n \end{array} & \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & w_1/a_{2n} & \dots & 1 \end{bmatrix} \end{array} \qquad (1)$$

Where $a_{ij} = 1$ and $a_{ji} = 1/a_{ij}$ where $i, j = 1,2,, \dots, n$. In matrix *A*, the problem becomes one of assigning to the n elements *C1*, *C2*, …, *Cn* a set of numerical weights *W1*, *W2*, …, *Wn* that reflects the recorded judgments. If *A* is a consistency matrix, the relations between weights *Wi* and judgments a_{ij} are simply given by $W_i/W_j = a_{ij}$ (for *i*, *j* =1, 2, ..., *n*.) and matrix *A* as follows:

$$A = \begin{array}{c|c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_n \end{array} & \begin{bmatrix} w_1/w_1 & w_1/w_1 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \end{array} \qquad (2)$$

Matrix *A* multiply the elements weight vector (*x*) equal to *nx* , that is (*A* - *nI*) *x* =0, the *x* is the Eigenvalue (*n*) of Eigenvector. Due to *ij a* be makers' subjective judgment give comparison and appraisal, with the truly value (W_i/W_j) have the same level degree difference, so that $Ax = nx$ can not to be set up. Saaty (1990) suggested that the largest eigenvalue λ_{max} be:

$$\lambda_{max} = \sum_{j=1}^{n} a_{ij} \frac{w_j}{w_i}, \qquad (3)$$

If *A* is a consistency matrix, eigenvector *X* can be calculated by

$$(A - \lambda I)X = 0 \qquad (4)$$

Saaty developed the consistency index (*CI*) to measure the deviation from a consistent matrix:

$$Max\ CI = (\lambda - n)/(n - 1) \qquad (5)$$

The consistency ratio (*CR*) is introduced to aid the decision on revising the matrix or not. It is defined as the ratio of the *CI* to the so-called random index (*RI*) which is a *CI* of randomly generated matrices:

$$CR = CI/RI \qquad (6)$$

For $n = 3$ the required consistency ratio (*CR Goal*) should be less than 0.05, for $n = 4$ it should be less than 0.08 and for $n \geq 5$ it should be less than 0.10 to get a sufficient consistent matrix. Otherwise the matrix should be revised (Saaty, 1994).

PIPELINES RELATIVE RISK ASSESSMENT

There are a range of databases available for comparing pipeline failure frequencies (see references). The information stored within these databases varies widely depending on the reporting criteria.

Through extensive literature review and consultation with the industry experts it was found that the areas (referred here as RIFs) that have the biggest direct effect on risk are corrosion and cracking, design issues, external interference, operation & information, geohazard & weather condition (route influence), maintenance & safety culture, and material & construction. Generally there are a number of RIFs, but not all would affect a pipeline or their influence may be equal for alternatives considered; hence they can be left out.

The first step is identifying risk influencing factors (primary decision criteria) and sub-criteria for each of RIF as a hierarchical system as shown in Figure 1. AHP determines the weight of all attributes, and then the assessor scores each attribute from unacceptable to excellent. As the performance index approaches maximum then the pipeline safety is optimal and it will be reasonable to say that the failure probability decreases.

Each of these factors has attributes A1, A2,………., G3 and these are given in Table 1 (in the Appendix) and are shown in Figure 1. Attributes will be rated on a constructed scale with unacceptable on the lower quality and excellent as the highest rating. While carrying out an assessment it is possible to see which of seven areas are rated as lacking or having inadequate protection.

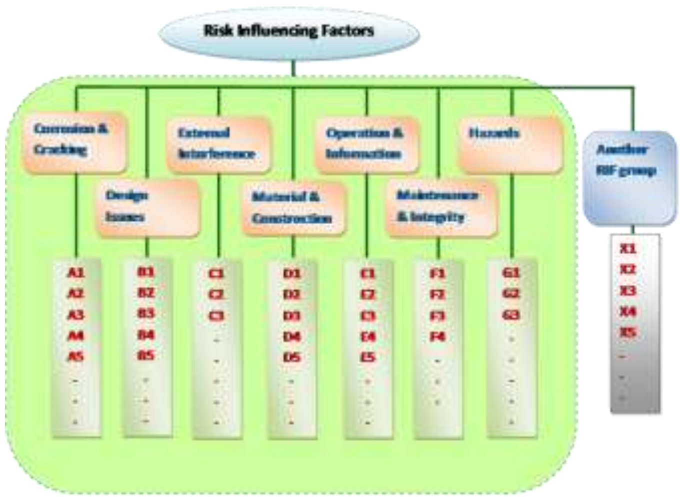

Figure 1: Hierarchical decomposition of RIFs

There are more RIFs reported in technical literature, but some can be left out due to their lack of importance for the case study in hand. Moreover, some analysts might feel that some attributes have been placed under a wrong RIF or have been named differently to their particular case. A different structuring of this AHP may be necessary to fit the occasion.

WEIGHTS OF CRITERIA AND SUB-CRITERIA

In consultation with the industry experts the following pairwise comparison matrices were developed to determine the criteria and sub-criteria weights. The weights for all the pairwise comparison matrices were computed using a spreadsheet.

	CC	DI	EI	MFI	OP	MI	HAZ	Weight
CC	1	3	2	4	4	6	6	0.36
DI	1/3	1	1	2	2	4	4	0.18
EI	1/2	1	1	1	1	1	1	0.11
MFI	1/4	1/2	1	1	3	3	4	0.15
OP	1/4	1/2	1	1/3	1	1	2	0.08
MI	1/6	1/4	1	1/3	1	1	2	0.07
HAZ	1/6	1/4	1	1/4	1/2	1/2	1	0.05
Sum	2.667	6.500	8.000	8.917	12.500	16.500	20.000	1.00

Figure 2: First level pairwise comparison matrix: Criteria versus Goals

Some of these threats are time dependent (for instance, corrosion; a small area of corrosion could grow over time to cause a failure) while some are time independent (for example, Third Party Damage; if a pipeline survives its installation then it may never be exposed to that category of risk.

Figure 2 shows the pairwise comparison of the second level criteria against the goal. Figures 3 to 9 are the pairwise comparison matrices for the sub-criteria against each RIF.

	A1	A2	A3	A4	A5	Weight
A1	1	2	1	1	2	0.242
A2	1	1	2	3	6	0.352
A3	1	1/2	1	1	2	0.167
A4	1	1/3	1	1	2	0.159
A5	0.5	1/6	1/2	0.5	1	0.080
Sum	4 1/2	4	5 1/2	6 1/2	13	1.000
CR=0.037						

Figure 3: Second level of praise for attributes of corrosion and cracking RIF

	B1	B2	B3	B4	B5	Weight
B1	1	1	5	1	3	0.295
B2	1	1	2	1	1	0.207
B3	1/5	1/2	1	1/3	1/4	0.071
B4	1	1	3	1	3	0.268
B5	1/3	1	4	1/3	1	0.159
Sum	3 1/2	4 1/2	15	3 2/3	8 1/4	1
CR=0.08						

Figure 4: Second level of praise for attributes of corrosion and cracking RIF

	C1	C2	C3	Weight
C1	1	1	3	0.436
C2	1	1	2 1/2	0.410
C3	1/3	2/5	1	0.154
Sum	2 1/3	2 2/5	6 1/2	1
CR=0.06				

Figure 5: Second level of praise for attributes of corrosion and cracking RIF

	E1	E2	E3	E4	E5	Weight
E1	1	7/8	1 1/4	4/5	4/5	0.183
E2	1 1/7	1	5/6	1 1/4	1 1/4	0.212
E3	4/5	1 2/9	1	1	1	0.196
E4	1 1/4	4/5	1	1	1	0.196
E5	1 1/4	1 1/4	1	1	1	0.213
Sum	5 4/9	5 1/7	5	5	5	1.000
CR=0.03						

Figure 6: Second level of praise for attributes of corrosion and cracking RIF

	F1	*F2*	*F3*	*F4*	Weight
F1	1	2	1/2	1	0.23
F2	1/2	1	1/3	1/2	0.12
F3	2	2	1	1/2	0.28
F4	1	3	2	1	0.36
Sum	4 1/2	8	3 5/6	3	1.00
CR=0.05					

Figure 7: Second level of praise for attributes of corrosion and cracking RIF

	G1	G2	G3	Weight
G1	1	2	2	0.490
G2	1/2	1	1/2	0.198
G3	1/2	2	1	0.312
Sum	2	5	3 1/2	1
CR=0.06				

Figure 8: Second level of praise for attributes of corrosion and cracking RIF

Intensity Scale of Arrtibutes						
	E	*G*	*A*	*P*	*U*	Weight
E	1	3	5	7	9	0.503
G	1/3	1	3	5	7	0.260
A	1/5	1/3	1	3	5	0.134
P	1/7	1/5	1/3	1	3	0.068
U	1/9	1/7	1/5	1/3	1	0.035
	1 4/5	4 2/3	9 1/2	16 1/3	25	1.000
CR=0.08						

Figure 9: Five-level scale for rating attributes

The attributes of the pipeline segment being assessed are rated using a five-level Likert scale. Likert scale is often used in questionnaires and surveys. These rates are the performance measures of the pipeline segment. The pairwise comparison matrix for the performance namely, Excellent (E), Good (G), Acceptable (A), Poor (P), and Unacceptable (U) is the following:

Five judges were asked to score an existing design by deciding unacceptable, poor, acceptable and excellent. These rates are multiplied by the global weights of each attribute before finally adding the weighted scores to obtain the global index. If a segment attained a maximum score in all areas then the index assumes 0.503. Any other score is a fraction of this maximum value.

Table2: Overall range of index

Sum of weighted Score	Linguistic description
>0.3	Excellent
0.299-0.190	Good
0.189-0.101	Acceptable
0.100-0.068	Poor
<0.068	Unacceptable

The pipeline is divided into segments of similar risk characteristics. Data related to RIFs were gathered, along the pipeline length. Segmenting criteria included variables such as pipe specifications (diameter, wall thickness, etc.), coating type, age, and population density. Each segment is therefore unique in terms of its exposure to risk. Segment length is entirely dependent on how often RIFs change. The smallest segments are only a few meters in length where one or more variables are changing rapidly; the longest segments are several hundred meters long, where variables are fairly constant.

Five industry experts were instructed to use AHP to conduct appraisal of segments of existing design. These experts assessed the segments against each attribute and ranked them as unacceptable, poor, acceptable, good and excellent. Table 4 (in Appendix) shows their scoring, the numerical values and average score of all five experts. The sums of scores are given at the foot of each column and the average score of the five is also noted. Table 5 gives the scores by the same five assessors.

These numerical scores can also be converted into a linguistic description using the system performance entries in Table 2. For example, the remediated design can be described as very good according to the current industry achievement.

LEAK FREQUENCY

It is interesting to associate these scores with the leak frequencies for the purpose of performing a quantitative analysis of impact of pipeline leaks on its surroundings. This approach gives only three data points, namely two extremes and the assessed case. Their data are the minimum number of points that can represent a curve. Thus, strong correlation cannot be established between these score and the leak frequency. However, exponential curves can be determined using these points, consistent with intuitive beliefs about risk. The initial part of exponential curve is very steep suggesting even minimal improvements of an extremely poorly rated system yield large reductions in the probability of failure. An argument can be made for gradual reduction, i.e. failure probability may be reduced only gradually until some threshold of risk-reduction is reached, perhaps because multiple failure modes are possible and significant gains aren't achieved until mitigation measures address a sufficient number of them. However, the portions of the curves of practical interest are the central parts, which are not sensitive to the arguments stated above. This curve also suggests that as more improvements are made, it becomes more difficult to achieve improvements—a point of diminishing returns is reached (ALARP).

Table 3- Relationship with Score Sum and leak frequency

Score	Assumed Leak Frequency	Equation
0.035	1.5E-2 (Assumed)	1.54E-2
0.134	1.8E-3 (industry's maximum)	1.79E-3
0.180	6.5E-4 (industry's Average)	6.35E-4
0.210	3.5E-4 (industry's Median)	3.28E-4
0.277	7.5E-5 (industry's minimum)	7.52E-5
0.4	5.0E-6 (assumed)	5.02E-6

Figure 10 compares assumed leak frequencies of table 3 with Equation 7.

The highest score in this analysis is 0.503 which should have a very low frequency of leak, and the lowest score is 0.035 that must have the highest frequency leak. In Table 3 scores are approximately associated to leak frequencies, which also induce data for the existing pipelines performance. An approximate relationship between the risk and the Score based on exponential equation can be derived as:

$$Leak\ Frequency = \frac{1}{30} EXP(-20 \times Score\ Sum) \qquad (7)$$

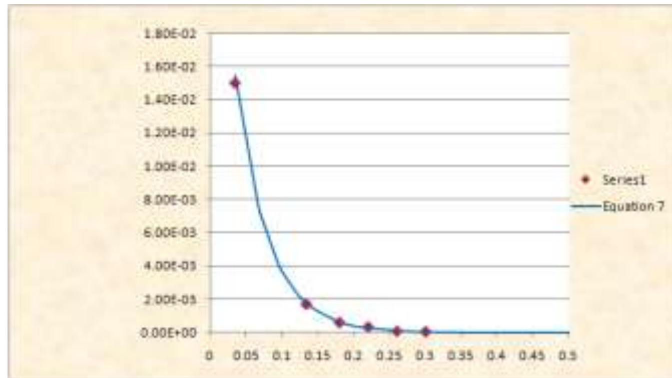

Figure 10: Plot of Equation 7 and assumed leak frequencies

CONCLUSIONS

Measuring effectiveness of remediation is essential in organizational effort for continuous improvement, and it can used for other purposes such as upgrading an existing pipeline for life extension, change of use, reducing corporate risk exposure or measuring cost effectiveness of expenditures. A simple and effective appraisal system that emphasizes continuous improvement enhances an operator's overall performance. Over time, every system deteriorates and it should be monitored. AHP provides a measuring tool for monitoring essentially unquantifiable changes to an asset.

The AHP is a versatile decision aid which can handle problems involving both multiple objectives and uncertainty. It is popular with many decision makers who find the questions it poses easy to answer. The method has also attracted much controversy from people who have questioned its underlying axioms and the extent to which the questions which it poses can lead to meaningful responses from decision makers. It has been argued that the apparent simplicity of the questions belies a lack of clarity in their definition and may lead to superficial and erroneous judgments or even abuse.

It should, however, not be forgotten that the purpose of any decision aid is to provide insights and understanding, rather than to prescribe a "correct" solution. Often the process of attempting to structure the problem is more useful in achieving these aims than the numeric output of the model.

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ANNEX A

Table 3: Hierarchy structure of solid waste treatment technologies

Risk Influencing Factors (RIFs)	Atributtes
Corrosion (CC)	A1:Internal
This includes all forms of internal and external corrosions; Defect growth possibility; Stress level problems. Cracking can be in the form of Stress Corrosion Cracking (SCC), Hydrogen-assisted cracking, mechanical damage delayed cracking, corrosion and fatigue cracking. Product characteristics; Type and quality of external coatings; conveyed product and protection against it; pipeline environment; possibility of internal erosion	A2:External
	A3:Content & External envroment
	A4:Corrosion Management Plan
	A5: Loss of Protection
Design Issues (DI)	B1: Hazard indenfication
Adequate margins in the design of systems and plant components for normal and abnormal loadings, including robustness and resistance to accident conditions. Adequate reserve strength for unforeseen conditions, particularly aimed at reducing the demand on higher levels of protection (barriers). surge & other overloads, hurricane, seismic induced.bThe clear definition of abnormal loading based on their frequency of occurrence and capability of the design to withstand them and the level of expected damage.	B2: Reliability of Equipment
	B3: Abnormal loading (Geohazard)
	B4: Design Safety margin (e.g corrosion allowance)
	B5: Cathodic protection/coating
External interference (EI)	C1: Activity along the pipeline
External interference (IO) sometimes referred to as contact damage includes anchor drag and snagging; fishing activity (trawl impact; explosive fishing); dropped objects/anchor drop; for onshore pipeline includes third party damage. Adequate cover would alleviate these hazards.	C2: Buried or above seabed
	C3: Line locating
Material/Fabrication/Installation (MFI)	D1: Material Selection & Management
Manufacturing Defects; Construction Defects; Equipment Failure; Defect growth rates; Weld defects; suitability of material for product, environment and hazards; quality control and assurance; aging; change of use; requalification for higher pressure; effect of repairs	D2: Lesson Learned (feedback)
	D3: Compliance
	D4: Integrity of welds & material Defects
	D5: Installtion error
Operation & Information (OP)	E1:Operations Management
SCADA ; flow rate; improper operation such as over pressuring that could have been caused by inappropriate procedures, training or operator error; oversight for sound engineering design and construction practices, regular inspection and a vigilant approach for the operation safety, safety culture and management system; auditing and enforcement. Pipe wall Physical support	E2: Operating Instructions - Procedures & Documentation
	E3: Communication
	E4: Reliable automated safety systems
	E5: Enforcment (safety culture)-Compliance tracking
Maintenance & Integrity (MI)	F1: Budgeted and actual manatice budge
Leak history, CP history, Age of pipe; Leak detection In-line inspection; proactice and bcklog for reactive maintenace;The product throughput for possible potential release rates	F2: Incident reports and investigations
	F3: Facility and mechanical integrity project status
	F4: Tracking and enforcemnet
Hazards (Haz)	G2 Acute
Geotechnical and Weather related refer to various types of ground movement, hydrogeotechnical and weather-related hazards such as settlement, frost	G2: Latent
	G3: Chronic

Table 4: The weight of Attributes of each RIF in the hierarchy

RIF	Weight	Attribute	Local weight	Global weight
Corrosion (CC)	0.36	**A1:Internal**	0.25	0.09
Corrosion includes all forms of pipeline corrosion (internal, external); Defect growth Stress level; **Cracking** can be in the form of Stress Corrosion Cracking (SCC), Hydrogen-assisted cracking, mechanical damage delayed cracking, corrosion and fatigue cracking; Product characteristics; Type and quality of coating		**A2:External**	0.38	0.14
		A3:Content & External envrom	0.17	0.06
		A4:Corrosion Management Plar	0.14	0.05
		A5: Loss of Protection	0.06	0.02
Design Issues (DI)	0.18	**B1: Hazard indenfication**	0.31	0.05
Adequate margins in the design of systems and plant components for normal and abnormal loadings, including robustness and resistance to accident conditions. Adequate reserve strength for unforeseen conditions, particularly aimed at reducing the demand on higher levels of protection (barriers). surge & other overloads, hurricane, seismic induced.bThe clear definition of abnormal loading based on their frequency of occurrence and capability of the design to withstand them and the level of expected damage.		**B2: Reliability of Equipment**	0.21	0.04
		B3: Abnormal loading (Geohazard)	0.10	0.02
		B4: Design Safety margin (e.g corrosion allowance)	0.23	0.04
		B5: Cathodic protection/coating	0.14	0.02
External interference (EI)	0.11	**C1: Activity along the pipeline**	0.44	0.05
External interference (IO) Sometimes referred to as contact damage Anchor drag and snag; Fishing activity (trawl impact ; explosive fishing); Anchor drag and snag; Dropped objects/anchor drop		**C2: Buried or above seabed**	0.39	0.04
		C3: Line locating	0.16	0.02
Material/Fabrication/Installation (MFI)	0.15	**D1: Material Selection & Management**	0.28	0.04
The product throughput is used in estimating potential release rates Manufacturing Defects Construction Defects Equipment Failure Defect growth rates		**D2: Lesson Learned (feedback)**	0.27	0.04
		D3: Compliance	0.16	0.02
		D4: Integrity of welds & material Defects	0.14	0.02
		D5: Installtion error	0.15	0.02
Operation & Information (OP)	0.08	**E1:Operations Management**	0.19	0.02
) SCADA ; flowrate improper operation such as over pressuring that could have been caused by inappropriate procedures, training or operator error Sound engineering design and construction practices, regular inspection and a vigilant right of way patrol program will minimize, but cannot completely eliminate the effect of these hazards. Pipe wall Physical support		**E2: Operating Instructions - Procedures & Documentation**	0.21	0.02
		E3: Communication	0.19	0.02
		E4: Reliable automated safety systems	0.19	0.02
		E5: Enforcment (safety culture)-Compliance tracking	0.22	0.02
Maintenance & Integrity (MI)	0.07	**F1: Budgeted and actual manatice budge**	0.22	0.02
Leak history, CP history, Age of pipe; Leak detection In-line inspection; proactice and bcklog		**F2: Incident reports and investigations**	0.17	0.01
		F3: Facility and mechanical integrity project status	0.29	0.02
		F4: Tracking and enforcemnet	0.34	0.02
Hazards (Haz)	0.05	**G2 Acute**	0.51	0.03
Geotechnical and Weather related refer to various types of ground movement, hydrogeotechnical and weather-related hazards such as settlement, frost heave (freezing and thawing), landslides/slope movement, earthquake, wash outs erosion and lightning Soil corrosivity Rugged train		**G2: Latent**	0.19	0.01
		G3: Chronic	0.30	0.02

- 0.36x0.25=0.09

Table 5: **Third level pairwise comparison matrix: Alternative Versus Subcriteria**

Base Design										
	Assessor1	Assessor2	Assessor 3	Assessor4	Assessor 5	Assessor 1	Assessor 2	Assessor 3	Assessor4	Assessor 5
A1	G	G	A	G	G	0.0238	0.0238	0.0123	0.0062	0.0238
A2	A	S	S	S	A	0.0182	0.0092	0.0092	0.0092	0.0182
A3	G	E	G	G	S	0.0159	0.0308	0.0159	0.0159	0.0021
A4	A	G	S	A	A	0.0068	0.0131	0.0034	0.0068	0.0068
A5	A	A	S	S	S	0.0029	0.0029	0.0015	0.0015	0.0015
B1	G	A	G	S	S	0.0142	0.0073	0.0142	0.0037	0.0037
B2	G	S	G	A	A	0.0098	0.0025	0.0098	0.0051	0.0051
B3	S	A	S	S	S	0.0012	0.0025	0.0012	0.0012	0.0012
B4	G	E	G	G	A	0.0055	0.0207	0.0107	0.0107	0.0055
B5	S	G	A	A	A	0.0016	0.0062	0.0032	0.0032	0.0032
C1	G	A	S	A	S	0.0127	0.0066	0.0033	0.0066	0.0033
C2	G	A	S	S	S	0.0112	0.0058	0.0029	0.0029	0.0029
C3	S	A	A	A	A	0.0012	0.0006	0.0024	0.0024	0.0024
D1	A	S	A	S	S	0.0056	0.0056	0.0056	0.0028	0.0028
D2	G	G	G	A	A	0.0103	0.0103	0.0103	0.0053	0.0053
D3	P	P	P	P	P	0.0008	0.0008	0.0008	0.0008	0.0008
D4	A	S	A	S	S	0.0027	0.0014	0.0027	0.0014	0.0014
D5	A	S	S	A	S	0.0029	0.0015	0.0015	0.0029	0.0015
E1	S	A	G	G	A	0.0011	0.0021	0.0041	0.0041	0.0021
E2	G	E	G	G	G	0.0045	0.0087	0.0045	0.0045	0.0045
E3	S	A	A	A	S	0.0011	0.0021	0.0021	0.0021	0.0011
E4	G	G	G	S	S	0.0041	0.0041	0.0041	0.0011	0.0011
E5	G	A	S	A	S	0.0046	0.0024	0.0012	0.0024	0.0012
F1	G	A	G	A	A	0.0042	0.0021	0.0042	0.0021	0.0021
F2	G	G	G	A	A	0.0032	0.0032	0.0032	0.0004	0.0017
F3	G	E	A	S	S	0.0054	0.0105	0.0028	0.0014	0.0014
F4	G	G	G	A	A	0.0063	0.0063	0.0063	0.0032	0.0032
G1	A	G	A	S	A	0.0037	0.0071	0.0037	0.0018	0.0037
G2	A	G	G	A	S	0.0014	0.0027	0.0027	0.0014	0.0007
G3	A	A	A	S	A	0.0021	0.0021	0.0021	0.0011	0.0021
						0.1890	0.2049	0.1518	0.1142	0.1164
									Average	**0.1553**

Table 6: **Third level pairwise comparison matrix: Alternative Versus Sub-criteria**

Improved Design										
	Assessor1	Assessor2	Assessor 3	Assessor4	Assessor 5	Assessor1	Assessor2	Assessor3	Assessor4	Assessor 5
A1	G	G	A	G	G	0.0238	0.0238	0.0123	0.0062	0.0238
A2	G	A	A	A	G	0.0352	0.0182	0.0182	0.0182	0.0182
A3	G	E	G	G	S	0.0159	0.0308	0.0159	0.0159	0.0041
A4	G	E	A	A	G	0.0131	0.0253	0.0068	0.0068	0.0131
A5	A	A	S	S	S	0.0029	0.0029	0.0015	0.0015	0.0015
B1	E	G	E	E	G	0.0274	0.0142	0.0274	0.0274	0.0142
B2	E	G	E	G	A	0.0189	0.0098	0.0189	0.0098	0.0051
B3	G	G	S	A	S	0.0048	0.0048	0.0012	0.0025	0.0012
B4	E	E	E	E	A	0.0207	0.0207	0.0207	0.0207	0.0055
B5	G	G	G	G	G	0.0062	0.0062	0.0062	0.0062	0.0062
C1	E	G	A	A	G	0.0245	0.0127	0.0066	0.0066	0.0127
C2	E	G	G	A	A	0.0217	0.0112	0.0112	0.0058	0.0058
C3	G	G	G	G	G	0.0047	0.0047	0.0047	0.0047	0.0047
D1	E	G	G	E	G	0.0210	0.0109	0.0109	0.0210	0.0109
D2	E	E	E	E	G	0.0198	0.0198	0.0198	0.0103	0.0103
D3	G	G	A	G	A	0.0062	0.0062	0.0032	0.0062	0.0032
D4	E	E	G	G	G	0.0102	0.0102	0.0053	0.0053	0.0053
D5	E	G	G	E	G	0.0109	0.0057	0.0057	0.0109	0.0057
E1	E	E	E	G	G	0.0078	0.0078	0.0078	0.0041	0.0041
E2	G	E	G	G	E	0.0045	0.0087	0.0087	0.0045	0.0087
E3	G	G	G	G	A	0.0041	0.0041	0.0041	0.0041	0.0021
E4	E	E	E	A	A	0.0078	0.0078	0.0078	0.0021	0.0021
E5	G	G	A	G	A	0.0046	0.0046	0.0024	0.0046	0.0024
F1	E	G	G	G	G	0.0080	0.0042	0.0042	0.0042	0.0080
F2	E	G	G	G	A	0.0062	0.0032	0.0032	0.0032	0.0017
F3	E	E	A	A	G	0.0105	0.0105	0.0105	0.0028	0.0054
F4	E	G	G	G	A	0.0122	0.0063	0.0000	0.0122	0.0032
G1	E	E	G	G	E	0.0137	0.0137	0.0071	0.0071	0.0137
G2	E	E	E	G	G	0.0052	0.0052	0.0052	0.0027	0.0027
G3	E	G	E	G	G	0.0080	0.0041	0.0041	0.0080	0.0041
						0.3806	0.3182	0.2615	0.2453	0.2096
									Average	0.2831