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AHP Approach for Assessing Effectiveness of Pipeline Risk Reduction Measures

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ABSTRACT

How one can account for the effectiveness of risk reduction measures, or conversely how risk is changed if certain maintenance activities are postponed or some of safety instruments (e.g. sensors) are partially circumvented or disabled. It is also desirable to know the impact of factors such as training, competency, complexity and manning level and postponing maintenance. All factors influencing a pipeline performance must therefore be identified and reduced to a level where their influence on the risk can be visualised and their impact assessed. Some of the factors that affect risk can only be assessed subjectively. The available knowledge determines the level of objectivity and if hard data does not exist then cognitive processes have to be used. Addressing such a problem requires synthesizing a variety of information including both quantifiable information and expert judgment.

This study uses Analytic Hierarchy Process (AHP) approach for structured thinking in pipeline risk reduction measures. Ina risk-based design AHP helps to select optimal solutions that best satisfies all of a decision maker's requirements. Often risk mitigation measures implemented for a pipeline cannot be easily quantified, but they can be ranked. Deciding on the effectiveness of risk reduction measures is a common problem that involves tradeoffs among multiple different and generally qualitative criteria. The proposed model of risk assessment is also useful for risk management during the planning and building stages of a new pipeline as well as for modification, or change of use, of an existing pipeline. Owing to its simplicity and ease of use, the AHP has found ready acceptance by decision-makers. It helps structure the decision-maker's thoughts and can help in organizing the problem in a manner that is simple to follow and analyse. Broad areas in which the AHP has been applied include option selection, resource allocation, forecasting, business process re-engineering, quality function deployment, balanced scorecard, benchmarking, public policy decisions, healthcare, pipeline route selection and many more.

INTRODUCTION

Quantitative Risk Assessment (QRA), which is mandatory in some countries, concentrates on the impact of installation (pipeline here) on its surroundings. Asset protection is not the primary goal but a by product of this process. The emphasis in safety is building safety into the design, not bolting it onto a completed design; however, such situation may present itself, e.g. recertification, upgrading or change of use. The degree, to which it is economically feasible to eliminate all hazards, rather than to control it, depends at which stage of development a hazard is identified. Continuous improvement is the stated aim of all operators, as the resources available for the safety is not unlimited. Thus, some measure would be discounted or deferred to be added on at a later date, if it is practical. In addition to improving hardware, many measures, mostly operational, can be implemented to mitigate the impact of hazards. This becomes more imperative for upgrading an existing pipeline or sour services. In principle there is no difference between a new and old pipeline when it comes to identifying ways and means of reducing risk, but implementation of mitigation measures is a different matter.

The way to improve a pipeline operation safety is to identify its vulnerabilities. Hazard Identification and subsequent QRA are effective means of enhancing the understanding of vulnerabilities, especially in complex situations involving several equipment and/or human failures. QRA is also a useful tool for optimizing efforts in implementing risk reduction measures. However, some aspects of pipeline safety are difficult to assess quantitatively. Examples include the influence of operation organization and safety culture, proactive and reactive maintenance, as well as aspects such as reliability of software, some types of human error, and external hazards.

The Analytical Hierarchy Process, developed by Saaty (1980), is able to transform qualitative input (mostly in natural language) into quantitative output. AHP method is useful where the analyst is choosing or ranking a finite number of options which are measured by two or more criteria. AHP is essentially the formalization of intuitive understanding of a complex problem using a hierarchical structure. The AHP offers a viable approach for decision making in situation involving multiple objectives. The method widely applied to decision problems in areas such as economics and planning, vendor selection, route selection etc. The AHP enables a decision maker to structure a Multi-Attribute Decision Making problem visually in the form of an attribute hierarchy. An attribute hierarchy has at least three levels. The focus or the overall goal of the problem is the top level, multiple criteria that define alternatives are the middle level, and competing alternatives are the bottom level.

RISK INFLUENCING FACTORS

There are a number Risk Influencing Factors (RIFs) which may influence a pipeline, and there is a certain probability that only a number of RIFs to affect a pipeline. For example, a pipeline in a shipping lane is subjected to certain risk by virtue of being there, or the geohazard would not affect all pipelines equally. Another example is sabotage, or being affected by fishing activity. Thus, not all pipelines will be subjected to the same hazard or with the same intensity. How strongly a RIF influences the risk is described by its weight relative to other RIFs in AHP, where the sum of all weights is one (Figure 1). If it is established that a number of RIFs have minimal or no influence on the risk, then they will be not carried forward in the analysis. In all cases the suggestion is not to use too many RIFs, since distinguishing between them becomes difficult; a reasonable degree of differentiation between them is necessary. The strength of each RIF in turn is decided by indentifying a set of sub-factors controlling its strength. These are termed attributes. The inclusion of variables is based on their importance and influence and is assigned to logical groupings of these variables.

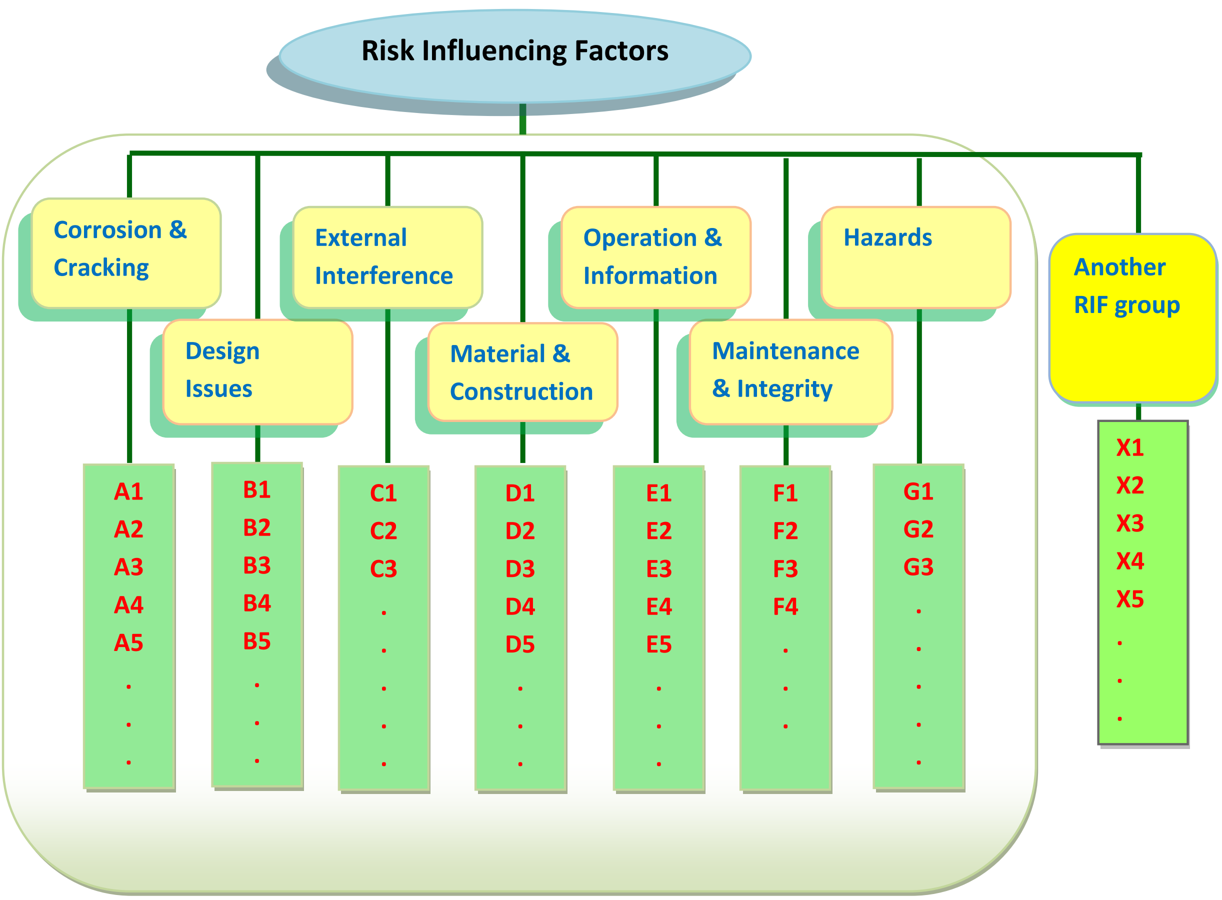

Figure 1- Hierarchical structure of Risk Influencing factors and their attributes

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 & cracking, design issues, external interference, operation & information, geohazard & weather condition (route influence), maintenance & safety culture, and material & construction. Generally there are a more RIFs, but not all would affect a pipeline or their influence may be equal for alternatives considered. Thus, for each case one must decided on relevant RIFs.

An efficient way of evaluating risk is to divide a pipeline into segments; these are areas whose risks are evidently different from its neighbours and defined by well defined boundaries. Thus each segment has a well defined boundary and all elements with direct effects are within this boundary. For the relative risk assessment one need to gather data on current conditions of each segment. The procedure starts with identifying all hazard or Risk Influencing Factors (RIFs) and means of mitigating them. Implementing risk reduction measures generally requires cost-benefit analysis to gain some insight into the economics of improvement. An absolute calculation of risk cannot be attempted, but a relive risk measure is possible by scoring factors that influences risk.

ANALYTICAL HIERARCHY PROCESS

The AHP structures the decision making problem into a hierarchy of three levels or more. The top level is the goal of decision making, which is the pipeline risk assessment here. The second level consists of all decision making criteria; for the purpose this paper are factors which influences the risk (RIFs). In order to decide on the importance of each RIF, attributes or parameters that define each RIF are indentified. The last level is the alternatives, or options, which must be ranked and one to be selected.

Generally, AHP has the following seven steps:

1. Define the problem and determine its goal.
2. Structure the hierarchy from the top (the goal) through intermediate levels (criteria on which subsequent levels depend) to the lowest level, which typically contains a list of alternatives.
3. Employ a pair-wise comparison approach. Saaty (2001) developed the fundamental scale for pair-wise comparisons. The elements in the second level are arranged into a matrix and judgments about the relative importance of the elements with respect to the overall goal are selected.

Table 1- The Fundamental Scale

Scale	Definition	Explanation
1	Equal important	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favour and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocal- if activity i has one of the above numbers assigned to it when compared with RIF j, then j has the reciprocal value when compared with i.		

When the elements being compared are closer together than indicated by the scale, one can use the scale 1.1, 1.2, ..., 1.9. If still finer, one can use the appropriate percentage refinement [Saaty, 1989].

The pair-wise comparison matrix A, in which the element a_{ij} of the matrix is the relative importance of the i^{th} factor with respect to the j^{th} factor, could be calculated as

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

4. There are $n(n-1)/2$ judgments required developing the set of matrices in step 3. Reciprocals are automatically assigned to each pair-wise comparison, where n is the matrix size.

6. A reciprocal value is assigned to the inverse comparison; that is, $a_{ij} = 1/a_{ji}$ where $a_{ij}(a_{ji})$ represents the importance weight of the ith(jth) element. Once the pairwise comparisons are completed, the local priority vector $w$is computed as the unique solution to $A \times w = \lambda_{max}\ w$ where A is the matrix of pairwise comparison, w is the eigenvector and λ_{max} is the largest eigenvalue of A.

In addition to eigenvalue method, there are several other algorithms available for approximating the vector w (Saaty, 1988). We use a two-stage algorithm for averaging normalised columns and approximating the vector w.

$$w_i = \left(\sum_{j=1}^{n}\left(a_{ij}/\sum_{i=1}^{n} a_{ij}\right)\right)/n \quad \text{for } i = 1, \dots, n. \quad (2)$$

7. Consistency test. Each pair-wise comparison contains numerous decision elements for the consistency index (CI), which measures the entire consistency judgment for each comparison matrix and the hierarchy structure. Saaty (1990) utilized the CI and consistency ration (CR) to assess the consistency of the comparison matrix. The CI and CR are defined as

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{CI}=\frac{\lambda \max - n}{n-1} \quad (3)$$

where n is the matrix size.

$$CR=\frac{CI}{RI} \quad (4)$$

The consistency can be checked by taking the CR of CI with the appropriate value (Table 1). The *CR* is acceptable if it does not exceed 0.10. The CR is > 0.10, the judgment matrix is inconsistent. To acquire a consistent matrix, judgments should be reviewed and improved.

Table 2- Average random consistency (RI).

Size of Matrix, n	1	2	3	4	5	6	7	8	9	10
Random Consistency Index, RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The AHP allows inconsistency, but provides a measure of the inconsistency in each set of judgments. This measure is an important by-product of the process of deriving priorities based on pair-wise comparisons. It is natural for people to want to be consistent, as being consistent is often thought of as a prerequisite to clear thinking. However the real world is hardly ever perfectly consistent and we can learn new things only by allowing for some inconsistency with what we already know. Some causes for inconsistency are listed below:

• ***Lack of information***. If the decision maker has little or no information about the factors being compared, then the judgments will appear to be random and a high consistency ratio will result. It is useful to find out that a lack of information exists, although sometimes decision maker might be willing to proceed without immediately spending time and money gathering additional information in order to ascertain if the additional information is likely to have a significant impact on the decision.

• ***Lack of concentration***. Lack of concentration during the judgment process can happen if the decision makers become fatigued or are not really interested in the decision. It is the decision analyst job to prevent this from happening.

• ***Real world is not always consistent***. The real world is rarely perfectly consistent and is sometimes fairly inconsistent. Football is a good example: It is not uncommon for team A to defeat team B, after which team B defeats team C, after which team C defeats team A. Inconsistencies such as this may be explained as being due to random fluctuations, or to underlying causes (such as match-ups of personnel), or to a combination. Regardless of the reasons, real world inconsistencies do exist and thus will appear in our judgments.

• ***Inadequate model structure***. A final cause of inconsistency is “inadequate” model structure. Ideally one would structure a complex decision in a hierarchical fashion such that factors at any level are comparable, within an order of magnitude or so, of other factors at that level. Practical considerations might preclude such a structuring and it is still possible to get meaningful results. Suppose for example, several items that differed by as much as two orders of magnitude were compared. One might erroneous conclude that the AHP scale is incapable of capturing the differences since the scale ranges from 1 to 9. However, because the resulting priorities are based on second, third and higher order dominances, AHP can produce priorities far beyond any order of magnitude. A higher than usual inconsistency ratio will result because of the extreme judgments necessary.

It is important that a low consistency ratio does not become the goal of the decision making process. A low consistency ratio is necessary but not sufficient for a good decision. It is possible to be perfectly consistent but consistently wrong. It is more important to be accurate than consistent.

PIPELINES RELATIVE RISK ASSESSMENT

A measure of the relative risk can be obtained by performing an assessment of important RIFs related to all known failure modes as influenced by hazards. All variables governing failures are grouped into four to eight categories (Figure 2). Each failure initiator combines specific system variables that contribute to the probability of failure. All nominated members of each group is considered to be the most critical contributors to risk and each RIF is weighted based upon their respective contribution to the risk by experts and combined using AHP. The model captures the contribution of all variables to the probability of failure in index scores, which are summed into an overall "Index Sum" score. The variables are assessed for each individual area. Figure 2 shows the seven failure initiator groups and variables within them.

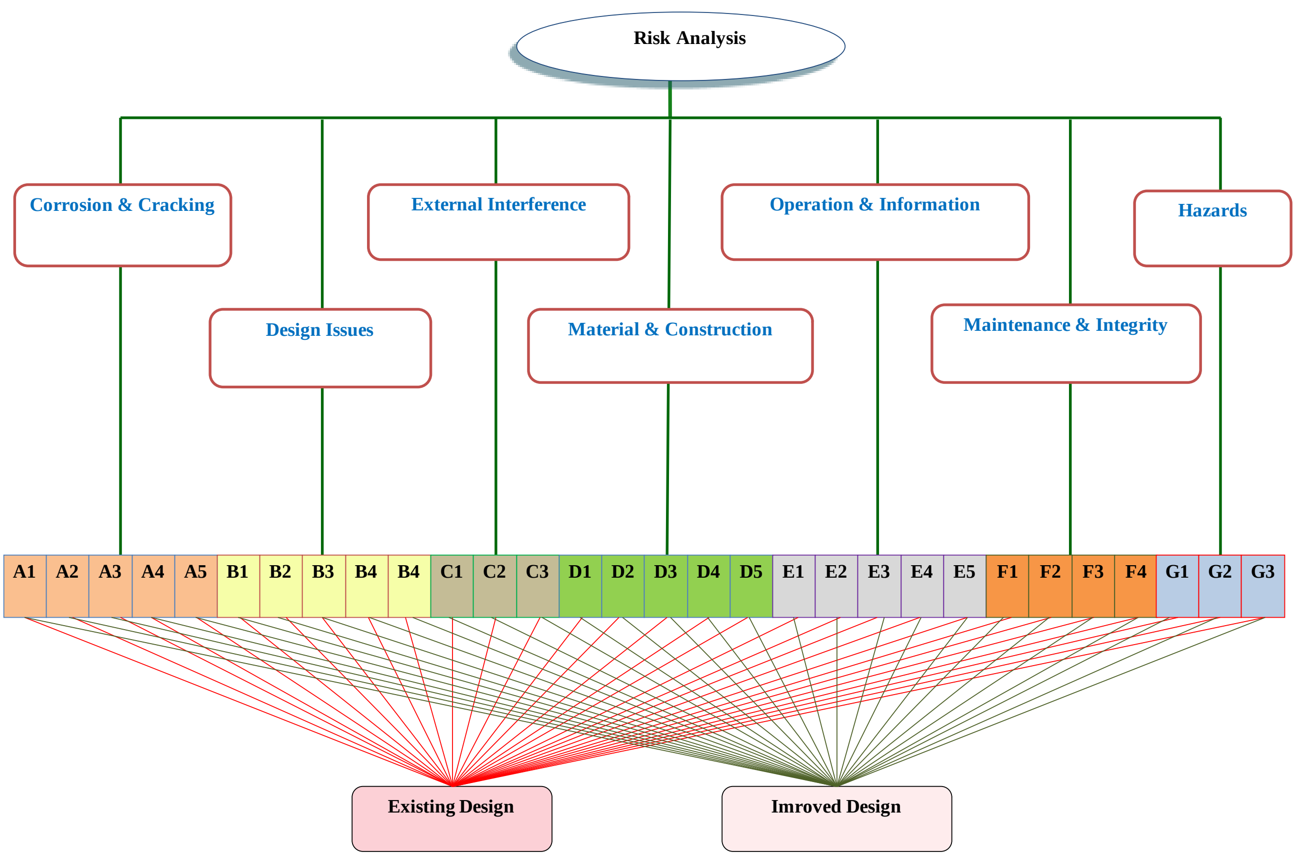

Figure 2- Hierarchy for supplier selection

Each of these RIFs has attributes A1, A2,.., G3 and these are given in Figure 3. 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.

There are more RIFs reported in technical literature, but some are 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.

Corrosion (C & C) 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	**A1:Internal** **A2:External** **A3:Content & External envroment** **A4:Corrosion Management Plan** **A5: Loss of Protection**
Design Issues (DI) 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. The 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.	**B1: Hazard indenfication** **B2: Reliability of Equipment** **B3: Abnormal loading (Geohazard)** **B4: Design Safety margin (e.g corrosion allowance)** **B5: Cathodic protection/coating**
External interference (EI) 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	**C1: Activity along the pipeline** **C2: Buried or above seabed** **C3: Line locating**
Material/Fabrication/Installation (MFI) The product throughput is used in estimating potential release rates Manufacturing Defects Construction Defects Equipment Failure Defect growth rates	**D1: Material Selection & Management** **D2: Lesson Learned (feedback)** **D3: Compliance** **D4: Integrity of welds & material Defects** **D5: Installtion error**
Operation & Information (OP) 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	**E1:Operations Management** **E2: Operating Instructions -Procedures & Documentation** **E3: Communication** **E4: Reliable automated safety systems** **E5: Enforcment (safety culture)-Compliance tracking**
Maintenance (MA) Leak history, CP history, Age of pipe; Leak detection In-line inspection; proactive and backlog for reactive maintenance	**F1: Budgeted and actual manatice budge** **F2: Incident reports and investigations** **F3: Facility and mechanical integrity project status** **F4: Tracking and enforcemnet**
Hazard (Haz) Geotechnical and Weather related refer to various types of ground movement, hydro geotechnical and weather-related hazards such as settlement, frost heave (freezing and thawing), landslides/slope movement, earthquake, wash outs erosion and lightning Soil corrosivity Rugged terrain	**G2 Acute** **G2: Latent** **G3: Chronic**

Figure 3- Description of RIFs and their attributes

Figure 4 shows the author ranking of the RIFs as an example. Each column is summed up first, and then each element is divided by the sum of its column. The weight is then average of each row, as shown Figure 4b.

	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
MA	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 4a: First level pairwise comparison matrix: Criteria versus Goals

	CC	DI	EI	MFI	OP	MI	HAZ	Weight
CC	0.375	0.462	0.250	0.449	0.320	0.364	0.300	0.36
DI	0.125	0.154	0.125	0.224	0.160	0.242	0.200	0.18
EI	0.188	0.154	0.125	0.112	0.080	0.061	0.050	0.11
MFI	0.094	0.077	0.125	0.112	0.240	0.182	0.200	0.15
OP	0.094	0.077	0.125	0.037	0.080	0.061	0.100	0.08
MI	0.063	0.038	0.125	0.037	0.080	0.061	0.100	0.07
HAZ	0.063	0.038	0.125	0.028	0.040	0.030	0.050	0.05
Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 4b: First level pairwise comparison matrix: Criteria versus Goals

Five industry experts were asked to rate the factors in level I (main criteria) and attributes in level II (sub-criteria) according to the perceived importance towards risk. This exercise was repeated for all the factors and attributes as weighted by the experts. Matrices of pair-wise comparison are developed for the factors and their respective attributes. These factors/attributes are compared against each other to determine the relative importance (see Figure 5). A total of 8 matrices were produced for each judge. One matrix corresponding to level I of the hierarchy and 7 matrices for level II. The matrices were found to be relatively consistent with the consistency ratio ranging from 0 to 0.06. The relative weights for each factor and attribute obtained from the matrices of pair-wise comparison were averaged to obtain the mean relative weights. These are illustrated in Figure 6 illustrates the results obtained for the factors/attributes that need to be considered while assessing the risk for a pipeline. The weights are important aid to decision making on where more effort or resources should be directed. Global weight is obtained by combining the relative weights down a branch of the hierarchy. These are illustrated graphically in Figure 7.

	1	2	3	4	5	Mean	St. Dev.
Corrosion (C & C)	0.39	0.39	0.37	0.25	0.42	0.36	0.11
Design Issues (DI)	0.19	0.19	0.16	0.11	0.23	0.18	0.06
External interference (EI)	0.08	0.09	0.16	0.05	0.11	0.10	0.07
Material/Fabrication/Installation (MFI)	0.19	0.18	0.07	0.25	0.05	0.15	0.07
Operation & Information (OP)	0.04	0.03	0.12	0.15	0.11	0.09	0.05
Maintenance (MA)	0.06	0.05	0.05	0.15	0.05	0.07	0.03
Hazard (HAZ)	0.05	0.07	0.07	0.03	0.04	0.05	0.02
A1:Internal	0.27	0.25	0.17	0.31	0.27	0.25	0.10
A2:External	0.28	0.48	0.48	0.33	0.31	0.38	0.13
A3:Content & External envroment	0.24	0.11	0.13	0.14	0.23	0.17	0.05
A4:Corrosion Management Plan	0.12	0.11	0.16	0.16	0.15	0.14	0.05
A5: Loss of Protection	0.09	0.05	0.06	0.06	0.04	0.06	0.16
B1: Hazard indenfication	0.36	0.28	0.46	0.36	0.09	0.31	0.11
B2: Reliability of Equipment	0.21	0.28	0.2	0.23	0.15	0.21	0.07
B3: Abnormal loading (Geohazard)	0.09	0.09	0.1	0.12	0.12	0.10	0.08
B4: Design Safety margin (e.g corrosion allowance)	0.2	0.25	0.14	0.24	0.34	0.23	0.10
B5: Cathodic protection/coating	0.14	0.1	0.09	0.05	0.3	0.14	0.18
C1: Activity along the pipeline	0.43	0.45	0.51	0.42	0.41	0.44	0.05
C2: Buried or above seabed	0.43	0.41	0.42	0.37	0.33	0.39	0.13
C3: Line locating	0.14	0.14	0.07	0.21	0.26	0.16	0.09
D1: Material Selection & Management	0.25	0.33	0.2	0.36	0.28	0.28	0.09
D2: Lesson Learned (feedback)	0.25	0.17	0.46	0.26	0.2	0.27	0.10
D3: Compliance	0.18	0.17	0.2	0.06	0.2	0.16	0.06
D4: Integrity of welds & material Defects	0.17	0.22	0.07	0.11	0.12	0.14	0.06
D5: Installtion error	0.15	0.11	0.07	0.21	0.2	0.15	0.09
E1:Operations Management	0.38	0.07	0.17	0.21	0.12	0.19	0.10
E2: Operating Instructions -Procedures & Documentation	0.14	0.35	0.2	0.23	0.14	0.21	0.06
E3: Communication	0.18	0.19	0.2	0.23	0.16	0.19	0.04
E4: Reliable automated safety systems	0.16	0.1	0.23	0.25	0.21	0.19	0.09
E5: Enforcment (safety culture)-	0.14	0.29	0.2	0.08	0.37	0.22	0.09
F1: Budgeted and actual manatice budge	0.17	0.17	0.31	0.16	0.3	0.22	0.06
F2: Incident reports and investigations	0.17	0.17	0.1	0.22	0.2	0.17	0.10
F3: Facility and mechanical integrity project status	0.39	0.38	0.13	0.3	0.25	0.29	0.09
F4: Tracking and enforcemnet	0.37	0.28	0.46	0.32	0.25	0.34	0.13
G2 Acute	0.6	0.53	0.34	0.63	0.46	0.51	0.19
G2: Latent	0.2	0.21	0.24	0.11	0.2	0.19	0.09
G3: Chronic	0.2	0.26	0.42	0.26	0.34	0.30	0.09

Figure 5: Results for the Industry experts' weighting of the RIFs attributes

Corrosion (C & C)	0.36	A1:Internal	A1	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	A2	0.38	0.14
		A3:Content & External envroment	A3	0.17	0.06
		A4:Corrosion Management Plan	A4	0.14	0.05
		A5: Loss of Protection	A5	0.06	0.02
Design Issues (DI)	0.18	B1: Hazard indenfication	B1	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	B2	0.21	0.04
		B3: Abnormal loading (Geohazard)	B3	0.10	0.02
		B4: Design Safety margin (e.g corrosion allowance)	B4	0.23	0.04
		B5: Cathodic protection/coating	B5	0.14	0.02
External interference (EI)	0.10	C1: Activity along the pipeline	C1	0.44	0.04
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	C2	0.39	0.04
		C3: Line locating	C3	0.16	0.02
Material/Fabrication/Installation (MFI)	0.15	D1: Material Selection & Management	D1	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)	D2	0.27	0.04
		D3: Compliance	D3	0.16	0.02
		D4: Integrity of welds & material Defects	D4	0.14	0.02
		D5: Installtion error	D5	0.15	0.02
Operation & Information (OP)	0.09	E1:Operations Management	E1	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	E2	0.21	0.02
		E3: Communication	E3	0.19	0.02
		E4: Reliable automated safety systems	E4	0.19	0.02
		E5: Enforcment (safety culture)-Compliance tracking	E5	0.22	0.02
Maintenance (MA)	0.07	F1: Budgeted and actual manatice budge	F1	0.22	0.02
Leak history, CP history, Age of pipe; Leak detection In-line inspection; proactice and bcklog for reactive maintenace		F2: Incident reports and investigations	F2	0.17	0.01
		F3: Facility and mechanical integrity project status	F3	0.29	0.02
		F4: Tracking and enforcemnet	F4	0.34	0.02
Hazard (HAZ)	0.05	G2 Acute	G1	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 trrain		G2: Latent	G2	0.19	0.01
		G3: Chronic	G3	0.30	0.02
Check	1.00				1.001

Figure 6: Relative and Global Weights of RIFs and their Attributes

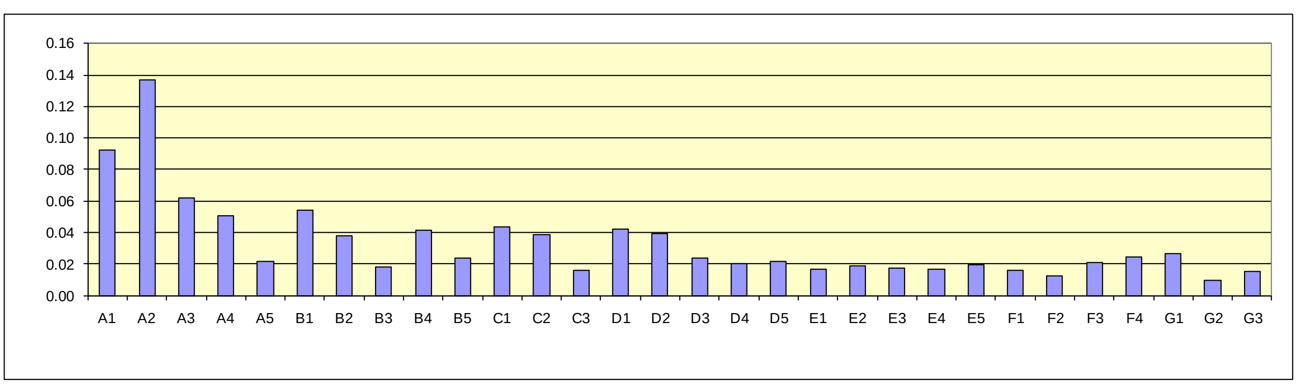

Figure 7: Resulting RIF Weights (A1, A2….., G3 are defined in Figure 6)

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:

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 8: Five-level scale for rating attributes

These numerical scores can also be converted into a linguistic description using the system performance entries in Table 3. For example, the remediated design can be described as very good according to the current industry achievement.

Table3: Overall range of risk 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. Figure 9 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.

Figure 10 gives the scores by the same five assessors after some risk reduction measures were implemented. The average score is up now. The original design with a score of 0.1556 was just acceptable according to Table3. The average score of 0.28 put this pipeline at the upper end of Good.

	Expert1	Expert2	Expert 3	Expert4	Expert 5	Expert 1	Expert 2	Expert 3	Expert4	Expert 5
A1	G	G	A	G	G	0.0241	0.0241	0.0124	0.0063	0.0241
A2	A	S	S	S	A	0.0184	0.0093	0.0093	0.0093	0.0184
A3	G	E	G	G	S	0.0161	0.0311	0.0161	0.0161	0.0022
A4	A	G	S	A	A	0.0068	0.0133	0.0035	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	0.0026	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	0.0113	0.0058	0.0029	0.0058	0.0029
C2	G	A	S	S	S	0.0100	0.0052	0.0026	0.0026	0.0026
C3	S	A	A	A	A	0.0011	0.0006	0.0022	0.0022	0.0022
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	0.0012	0.0023	0.0044	0.0044	0.0023
E2	G	E	G	G	G	0.0050	0.0096	0.0050	0.0050	0.0050
E3	S	A	A	A	S	0.0012	0.0023	0.0023	0.0023	0.0012
E4	G	G	G	S	S	0.0044	0.0044	0.0044	0.0012	0.0012
E5	G	A	S	A	S	0.0051	0.0026	0.0013	0.0026	0.0013
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	0.0033	0.0033
G1	A	G	A	S	A	0.0036	0.0069	0.0036	0.0018	0.0036
G2	A	G	G	A	S	0.0013	0.0026	0.0026	0.0013	0.0007
G3	A	A	A	S	A	0.0021	0.0021	0.0021	0.0011	0.0021
						0.1885	0.2062	0.1529	0.1148	0.1170
								Average		**0.1559**

Figure 9: Industry experts' weighting of the RIFs attributes

	Expert1	Expert2	Expert 3	Expert4	Expert 5	Expert1	Expert2	Expert3	Expert4	Expert 5
A1	G	G	A	G	G	0.0241	0.0241	0.0124	0.0063	0.0241
A2	G	A	A	A	G	0.0356	0.0184	0.0184	0.0184	0.0184
A3	G	E	G	G	S	0.0161	0.0311	0.0161	0.0161	0.0042
A4	G	E	A	A	G	0.0133	0.0256	0.0068	0.0068	0.0133
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	0.0219	0.0113	0.0058	0.0058	0.0113
C2	E	G	G	A	A	0.0193	0.0100	0.0100	0.0052	0.0052
C3	G	G	G	G	G	0.0042	0.0042	0.0042	0.0042	0.0042
D1	E	G	G	E	G	0.0211	0.0109	0.0109	0.0211	0.0109
D2	E	E	E	E	G	0.0199	0.0199	0.0199	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	0.0103	0.0103	0.0053	0.0053	0.0053
D5	E	G	G	E	G	0.0110	0.0057	0.0057	0.0110	0.0057
E1	E	E	E	G	G	0.0086	0.0086	0.0086	0.0044	0.0044
E2	G	E	G	G	E	0.0050	0.0096	0.0096	0.0050	0.0096
E3	G	G	G	G	A	0.0045	0.0045	0.0045	0.0045	0.0023
E4	E	E	E	A	A	0.0086	0.0086	0.0086	0.0023	0.0023
E5	G	G	A	G	A	0.0051	0.0051	0.0026	0.0051	0.0026
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	0.0033
G1	E	E	G	G	E	0.0133	0.0133	0.0069	0.0069	0.0133
G2	E	E	E	G	G	0.0050	0.0050	0.0050	0.0026	0.0026
G3	E	G	E	G	G	0.0078	0.0040	0.0040	0.0078	0.0040
						0.3788	0.3193	0.2627	0.2458	0.2094
								Average		**0.2832**

Figure 10: Industry experts' weighting of the RIF's attributes for the improved design

RELATIVE STRENGTHS OF AHP

The AHP method is fundamentally different to other assessment methods in many respects. The following are some of its strength and the criticisms which have been made of the technique.

Strength

- ***Formal structuring of the problem-*** The AHP provides a formal structure to problems. This allows complex problems to be decomposed into sets of simpler judgments and provides documented rationale for the choice of a particular option.
- ***Simplicity of Pair-wise comparisons***. The use of pair-wise comparisons means that the decision maker can focus, in turn, on each small part of the problem. Only two attributes or options have to be considered at any one time so that the decision maker's judgmental task is simplified. Verbal comparisons are also likely to be preferred by decision makers who have difficulty in expressing their judgments numerically. *Redundancy allows consistency to be checked.* The AHP requires more judgments to be made by the decision maker than is needed to establish a set of weights. For example, if a decision maker indicates that attribute A is twice as important as B, and B, in turn, is three times as important as C, then it can be inferred that A is six times more important than C. However, by also asking the decision maker to compare A with C it is possible to check the consistency of the judgments. It is considered to be good practice in decision analysis to obtain an input for a decision model by asking for it in several ways and then asking the decision maker to reflect on any inconsistencies in the judgments put forward. In the AHP this is carried out automatically.
- ***Versatility***. The wide range of applications of the AHP is evidence of its versatility. In addition to judgments about importance and preference, the AHP also allows judgments about the relative likelihood of events to be made. This has allowed it to be applied to problems involving uncertainty and also to be used in forecasting. AHP models have also been used to construct scenarios by taking into account the likely behaviour and relative importance of key actors and their interaction with political, technological, environmental, economic and social factors.

Criticism

- ***Conversion from verbal to numeric scale***. Decision makers using the verbal method of comparison will have their judgments automatically converted to the numerical scale, but the correspondence between the two scales is based on untested assumptions.
- ***Inconsistencies imposed by 1 to 9 scale -*** In some problems the restriction of pair-wise comparisons to a 1 to 9 scale is bound to force inconsistencies on the decision maker. For example if A is considered to be 5 times more important than B, and B is 5 times more important than C, then to be consistent A should be judged to be 25 times more important than C, however this is not possible.
- ***Meaningfulness of responses to questions***. Weights are elicited in the AHP without reference to the scales on which attributes are measured.
- ***New alternatives can reverse the rank of existing alternatives***.
- ***Number of comparisons required may be large***. While the redundancy build into the AHP is an advantage, it may also require a large number of judgments from the decision maker. Consider, for example, an office location problem which involves 8 alternatives and 8 attributes, this would involve 224 pair-wise comparisons of importance or preference.

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.

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 and the Expert Choice software user friendly. Its applications have moreover led to a huge number of published papers (Vaidya & Kumar, 2006). Nevertheless, 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. Indeed, 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. Critics have also questioned the extent to which an AHP model can faithfully represent a decision maker's preferences given the numerical representations of these judgments and the mathematical processes which are applied to them.

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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