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Construction Risk Management: A Quantitative Approach

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Conventional project management techniques are not always sufficient for ensuring time, cost and quality achievement of large-scale construction projects due to complexity in planning and implementation processes. The main reasons for project non-achievement are changes in scope and design, changes in Government policies and regulations, unforeseen inflation, under-estimation and improper estimation. Projects that are exposed to such an uncertain environment can be effectively managed with the application of risk management throughout project life cycle. However, the effectiveness of risk management depends on the technique in which the effects of risk factors are analysed and/or quantified. This study proposes Analytic Hierarchy Process (AHP), a multiple attribute decision-making technique as a tool for risk analysis because it can handle subjective as well as objective factors in decision model that are conflicting in nature. This provides a decision support system (DSS) to project management for making the right decision at the right time for ensuring project success in line with organisation policy, project objectives and competitive business environment. The whole methodology is explained through a case study of a cross-country petroleum pipeline project in India and its effectiveness in project management is demonstrated.

1. Introduction

The success parameters for any project are on-time completion, within specific budget and with requisite performance (technical requirement). The main barriers to their achievement are the changes in the project environment. The problems multiply with the size of the project as uncertainties in project outcome increase with size. Large-scale construction projects are exposed to an uncertain environment because of such factors as planning and design complexity, presence of various interest groups (project owner, owner's project group, consultants, contractors, vendors, etc.), resources (materials, equipment, funds, etc.) availability, climatic environment, the economic and political environment and statutory regulations.

Although risk and uncertainty affect all projects, size can be a major cause of risk. Other risk factors include the complexity of the project, the speed of its construction, the location of the project, and its degree of unfamiliarity.

A cross-country petroleum pipeline construction project is characterised by the complexity of its execution with respect to lack of experience in relation to certain design conditions being exceeded (water depth, ground condition, pipeline size, etc.), the influence of external factors that are beyond human control, external causes which limit resource availability (of techniques and technology), various environment impacts, government laws and regulations, and changes in the economic and political environment. Cost and time overruns and the unsatisfactory quality of a project are the general sources of disappointment to the management of a pipeline organisation.

In these circumstances, a conventional approach (**Figure 1**) to project management (practiced by the

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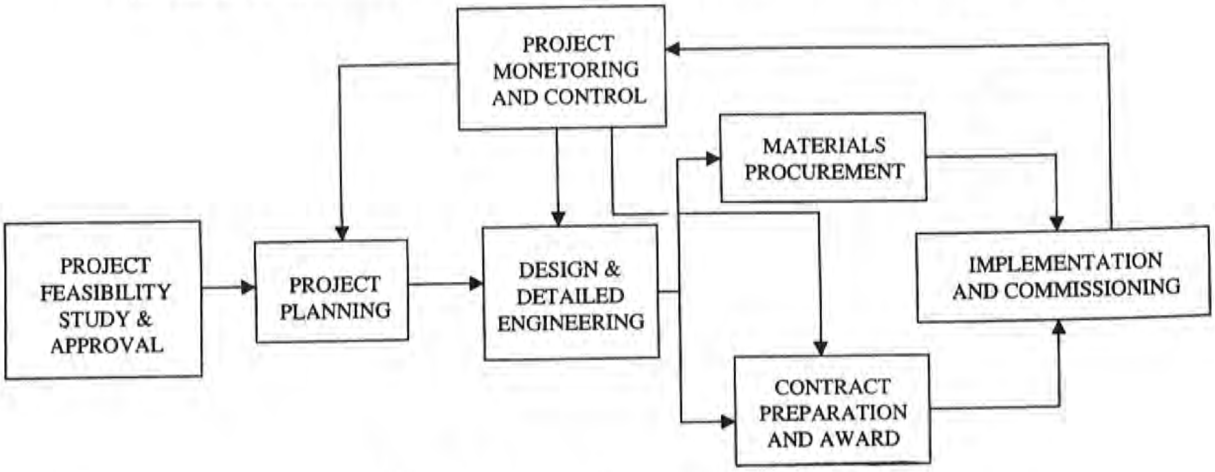

FIGURE 1: *Conventional Project Management Model*

organisation under study) is not sufficient, as it does not enable the project management team to establish an adequate relationship between the different phases of the project, to forecast project achievement for building the confidence of the project team, to make decisions objectively with the help of available databases, to provide adequate information for effective project management or to establish close cooperation among project team members.

The objective of the study is to model a Decision Support System (DSS) through risk analysis for making objective decisions on project design, engineering, and resource deployment for completing a project in time, within budget and with required specification in line with project objectives, the organisation's policy and the present business scenario.

2. Proposed Project Model

Figure 2 illustrates the proposed project model. Project planning and design and detailed engineering are taken up in sequence as soon as the project gets approved. Materials procurement and works contract preparation can start concurrently with completion of design activities. Availability of funds, materials, work front, drawings, specifications, contract document, and other utilities initiate implementation works at site through contractors. Project gets controlled through effective monitoring of various performance parameters that are fixed during the planning phase. Risk management is proposed to be carried out covering all project phases, once just after project planning with respect to time achievement and next before starting implementation works with respect to cost achievement.

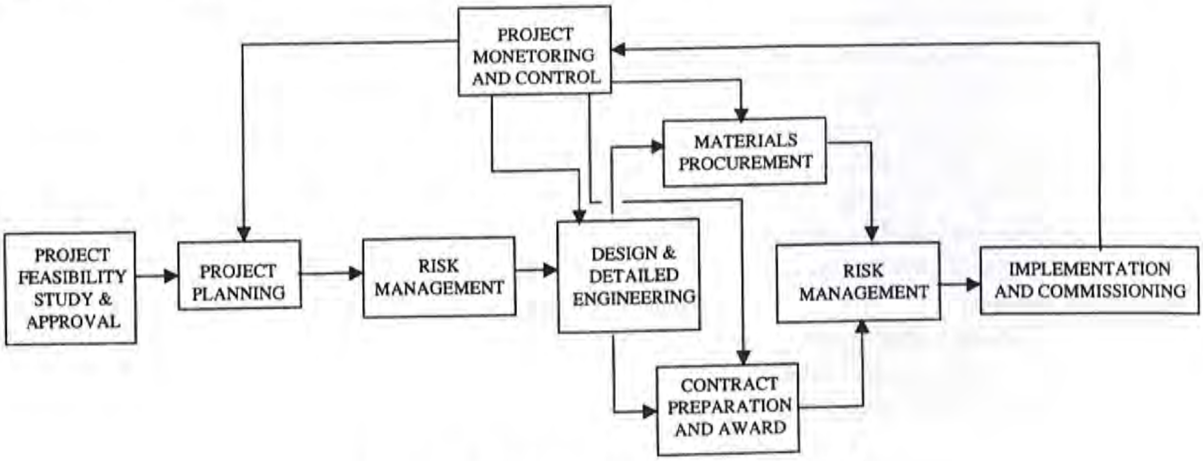

FIGURE 2: *Proposed Project Management Model*

The scope of this study is limited to establishing risk management after the project gets approved. This study demonstrates risk management at the early phase of project.

3. Risk and Risk Management Process

Chapman & Cooper (1983) define risk as "*exposure to the possibility of economic or financial loss or gains, physical damage or injury or delay as a consequence of the uncertainty associated with pursuing a course of action*". The task of risk management can be approached systematically by breaking it down to the following three stages:

1) Risk identification
2) Risk analysis
3) Risk responses

Figure 3 demonstrates the root of the risk management technique.

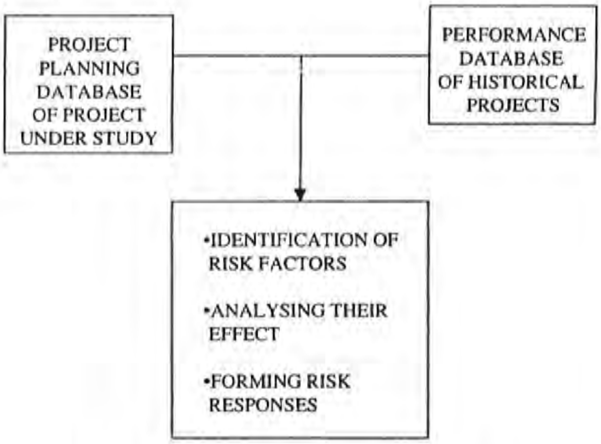

FIGURE 3: *Risk Management Process*

Tummala & Leung (1999) developed a methodology for risk management governing risk identification, measurement, assessment, evaluation and risk control and monitoring. They have applied for managing cost risk for an EHV transmission line project.

Williams (1995) demonstrated the various researches in Project risk management. He has described various risk identification and analysis tools being used by researchers and practitioners. Finally, the management structures and procedures needed to manage risk are discussed.

Turner (1999) suggested expert judgment, plan decomposition, assumption analysis, decision drives and brainstorming for effective identification of risk factors in a project. **Perry & Hayes (1985)** have suggested a checklist of risk that may occur throughout the life span of any project. Delphi technique has been used by **Dey (1999)** for identification of risk factors. Outside the field of engineering and construction, an approach for risk identification in product innovation has been reported by **Halman & Keizer (1998)**.

Most of the analyses done so far focus on the duration of the project. Management is interested in two aspects; the total duration and which activities are critical in determining that duration. Many authors have presented the distribution of time duration of activities as a classical Beta distribution (e.g., **Farnum *et al* (1987)**. Some authors have proposed their own distributions (e.g., **Berny (1989)** for practical simulations, in particular the Triangular distribution.

Recently, a number of systematic models have been proposed for use in the risk-evaluation phase of the risk-management process. **Kangari & Riggs (1989)** classified these methods into two categories: classical models (i.e., probability analysis and Monte Carlo simulation), and conceptual models (i.e., fuzzy-set analysis). They noted that probability models suffer from two major limitations. Some models require detailed quantitative information, which is not normally available at the time of planning and the applicability of such models to real project risk analysis is limited, because agencies participating in the project have a problem with making precise decisions. The problems are ill-defined and vague, and they thus require subjective evaluations, which classical models cannot handle.

There is, therefore, a need for a subjective approach to project risk assessment, with there being the necessary objectivity in the methodology. The Analytic Hierarchy Process (AHP) developed by **Saaty (1980)** provides a flexible and easily understood way of analysing project risks. It is a multi criteria decision-making methodology that allows subjective as well as objective factors to be considered in project risk analysis. The AHP allows the active participation of decision-makers in reaching agreement, and gives managers a rational basis on which to make decisions.

Formulating the decision problem in the form of a hierarchical structure is the first step. In a typical hierarchy, the top level reflects the overall objective (focus) of the decision problem. The elements affecting the decision are represented in intermediate levels.

The lowest level comprises the decision options. Once the hierarchy has been constructed, the decision-maker begins the prioritisation procedure to determine the relative importance of the elements in each level of the hierarchy. The elements in each level are compared pair-wise with respect to their importance in making the decision under consideration. The verbal scale used in AHP enables the decision-maker to incorporate subjectivity, experience and knowledge in an intuitive and natural way. After the comparison, matrices have been created, the process moves on to the phase in which relative weights and derived for the various elements. The relative weights of the elements of each level with respect to an element in the adjacent upper lvel are computed as the components of the normalised eigenvector associated with the largest eigenvalue of their comparison matrix. The composite weights of the decision alternatives are then determined by aggregating the weights through the hierarchy. Following a path from the top of the hierarchy to each alternative at the lowest level, and multiplying the weights along each segment of the path do this. The outcome of this aggregation is a normalised vector of the overall weights of the options. The mathematical basis for determining the weights has been established by **Saaty (1980)**.

Conventionally, risk analysis is performed at the overall project level. Hence, the risk analysis should show the effects of the risk factors on the project performance (in terms of time, cost and quality goals). Therefore, although risk analysis at the project level may be sufficient for a small project from the investment-decision and feasibility-study point of view, the technique has its limitations for large projects.

Cooper *et al* (1985) suggested that, in the 'risk-engineering' approach, systematic risk evaluation could be performed by subdividing a project into its major elements, and analysing the risk and uncertainty associated with each in detail. Moreover, the severity of risk pertaining to a project varies from activity to activity. Some activities are more responsive to a specific risk than others. Therefore, to risk analyse the project, the level of activity for which risks are to be analysed is first determined.

Mustafa & Al-Bahar (1991) have applied the AHP in risk analysis for the assessment of risk in a construction project from the evaluation perspective and **Dey *et al* (1994)** for cost risk analysis of construction project. No other prior work has to the knowledge of the author been conducted on the use of AHP for the risk analysis with respect to time achievement.

4. Methodology

The methodology adopted in this study is explained through the following steps:

1) Identification of risk factors and sub-factors.
2) Identification of work packages for risk analysis.
3) Formation of risk structure in line with AHP requirement.
4) Comparing pair-wise at different levels (factors and sub-factors) for determining likelihood of occurrence of failure due to various factors.
5) Comparing pair-wise the alternative work packages with respect to each sub-factor to determine relative failure chance of specific work package.
6) Determining severity of each risk sub-factor by estimating consequences (time overrun) on each work package.
7) Mapping risk with respect to probability and severity.
8) Determining overall impact (time and cost overrun) on project by Monte Carlo Simulation and probability analysis.
9) Making decision on preventive and corrective actions through change in design and engineering, resources deployment, etc. (risk responses) for effective project management.

5. Application

The above steps have been explained through a case study of a cross-country petroleum pipeline project in India having length 1300 km in the western part of India. The pipeline size is 22" in diameter for a length of 1112 km, 18" for a length of 218 km, and 10.75" for a length of 123 km (branch line). The pipeline is designed for 5 million metric tons per annum (MMTPA) throughput. The project also consists of the construction of three pump stations, one pumping-cum-delivery station, two scraper stations, four delivery stations, and two terminal stations. The project cost was estimated as US$600 Million. The detailed description of the project is available elsewhere (**Dey (1997)**).

A risk management group was formed to do risk analysis for the project under study. The group consisted of one member each from Mechanical, Electrical, Civil, Telecommunication and Instrumentation, Finance, and Materials. They were entrusted with collecting data, analysing, interpreting and preparing recommendations, with active interactions with the project groups.

5.1 Identification of Risk Factors

The risk factors and sub-factors were identified with the involvement of executives working in projects with more than 15 years of experience through brainstorming sessions. The following are the risk factors and sub-factors of the project under study.

(1) Technical Risk
- a. Scope change
- b. Technology selection
- c. Implementation methodology selection
- d. Equipment risk
- e. Materials risk
- f. Engineering and design change

(2) Natural Hazards
- a. Natural calamities normal
- b. Natural calamities abnormal

(3) Financial, Economical and Political Risk
- a. Inflation risk
- b. Fund risk
- c. Changes of local law
- d. Changes in Government policy
- e. Improper estimation

(4) Organisational risk
- a. Capability risk of owner's project group
- b. Contractor's failure
- c. Vendor's failure
- d. Consultant's failure

(5) Statutory clearance risk
- a. Environmental clearance
- b. Land acquisition
- c. Clearance from Chief Controller of Explosive (CCE)
- d. Other clearance from Goverment authorities

5.2 Identification of Work Packages

The total project scope was decomposed and classified to form work breakdown structure (WBS). **Figure 4** shows the WBS of the project under study. According to the importance in achieving time and cost target, the following work packages were considered for risk management.

- River-crossing
- Pipeline-laying
- Stations construction
- Other packages (Telecommunication and Cathodic protection)

5.3 Formation of Risk Structure

This study focuses on two dimensions (probability and severity) of project risk. The risk perception as shown by **Turner (1999)** has not been considered due to the nature of construction risk. **Figure 5** shows the AHP model for risk analysis. Level 1 is the goal, i.e., "*determining riskiness of project*". Levels 2 and 3 are for factors and sub-factors respectively. Level 4 contains the alternatives, i.e., work packages.

5.4 Pair-wise Comparison

The above model was made in the Expert Choice software package developed by **Forman & Saaty (1983)**. Pair-wise comparisons were made using the information in **Table 1** through executives working on projects in a group decision-making process. A questionnaire was made and distributed among the executives separately so as not to influence by other. Risk management group analysed the responses. **Table 2a** and **2b** show a comparison matrix in factor level. The outcome of matrix operation results likelihood of these risks while the project is being executed.

The pair-wise comparison in other levels also results likelihood of occurrence of risk sub-factors. Synthesising all likelihood of risk factors and sub-factors across hierarchy results overall likelihood of failure of work packages. **Table 3** shows the detailed analysis of AHP model.

5.5 Results and Findings from Risk Analysis Study

Based on the above analysis, the following observations were made by the project executives:

i) Technical risk is the major factor for time and cost overrun of project. Among the technical risk, scope change, engineering and design change, technology and

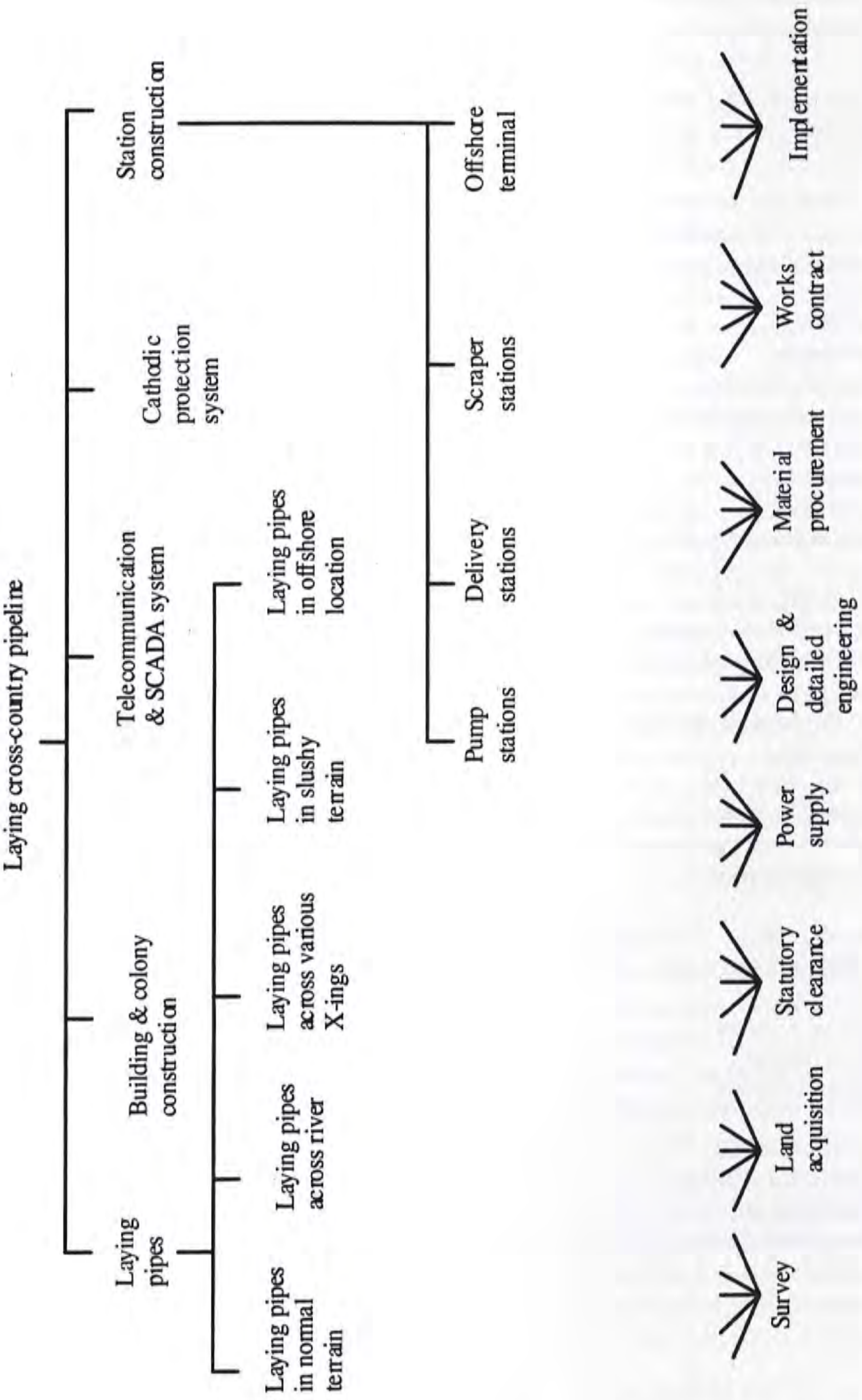

FIGURE 4: *Work Breakdown Structure*

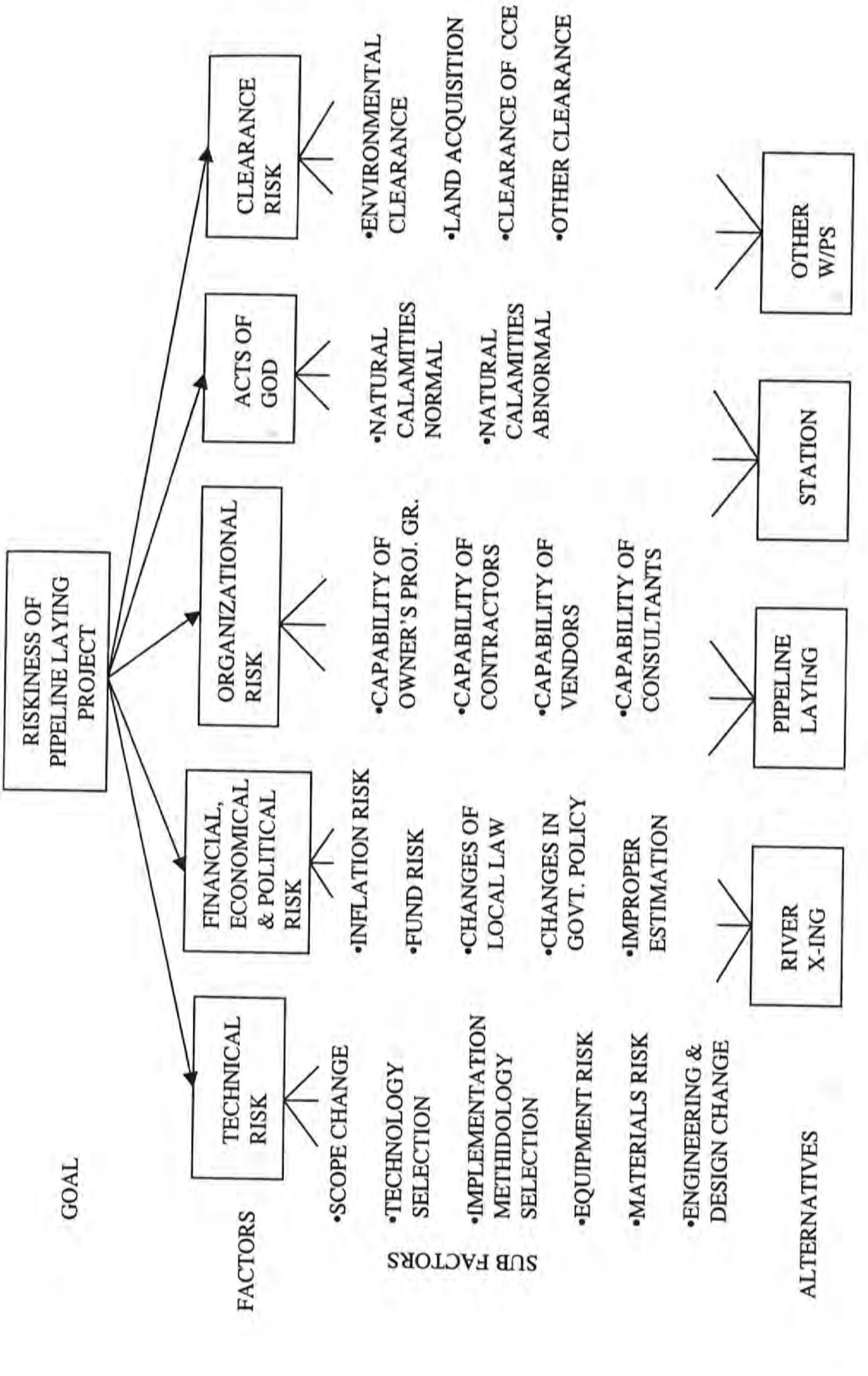

FIGURE 5: *AHP Model for Determining Riskiness of Project*

TABLE 1: *Scale of Relative Importance for Pair-wise Comparison*

Intensity	Definition	Explanation
1	Equal importance	Two activities contribute equally to the object
3	Moderate importance	Slightly favours one over another
5	Essential or strong importance	Strongly favours one over another
7	Demonstrated importance	Dominance of the demonstrated in practice
9	Extreme importance	Evidence favouring one over another of highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

(Source: Saaty, 1980)

TABLE 2a: *Pair-wise Comparison in Factor Level*

Factors	Technical Risk	Financial & Economical Risk	Organisational Risk	Acts of God Risk	Clearance Risk
Technical Risk	1	3	1	1	1
Financial & Economical Risk	1/3	1	1/3	1/3	1/3
Organisational Risk	1/4	1/2	1/4	1/4	1/4
Acts of God Risk	1/5	1/4	1/5	1/5	1/5
Clearance Risk	1/5	1/3	1/5	1/5	1/5

TABLE 2b: *Normalised Matrix*

Factors	Technical Risk	Financial & Economical Risk	Organisational Risk	Acts of God Risk	Clearance Risk	Likelihood
Technical Risk	0.50	0.59	0.51	0.36	0.40	0.472
Financial & Economical Risk	0.17	0.20	0.26	0.29	0.24	0.229
Organisational Risk	0.13	0.10	0.13	0.14	0.24	0.147
Acts of God Risk	0.10	0.05	0.06	0.07	0.04	0.065
Clearance Risk	0.10	0.07	0.04	0.14	0.08	0.086

TABLE 3: *Likelihood of Risk in Project*

Factors	Likelihood*	Sub-Factors	Likelihood	
			LP**	GP***
Technical Risk	0.472	Scope change	0.36	0.172
		Technology selection	0.124	0.059
		Implementation methodology	0.13	0.062
		Equipment risk	0.073	0.035
		Materials risk	0.08	0.038
		Engineering and design change	0.233	0.112
Financial & Economical Risk	0.229	Inflation risk	0.152	0.035
		Fund risk	0.383	0.087
		Changes in local law	0.105	0.024
		Changes in Government policy	0.105	0.024
		Improper estimate	0.255	0.058
Organisational Risk	0.147	Capability of owner's project group	0.106	0.015
		Contractor's capability	0.283	0.041
		Vendor's capability	0.448	0.065
		Consultant's capability	0.163	0.024
Acts of God Risk	0.065	Calamity normal	0.44	0.028
		Calamity abnormal	0.56	0.036
Clearance Risk	0.086	Environmental clearance	0.026	0.022
		Land acquisition	0.461	0.038
		CCE clearance	0.133	0.011
		Other clearances	0.142	0.012

LP - Local percentage
GP - Global percentage

(Continuation of Table 3 on next page)

* The figures are from **Table 2b** (Likelihood).
** The figures are generated through matrix operation in sub-factors level through pair wise comparison using scale in **Table 1**.
*** The Figures are determined by multiplying likelihood of factor with likelihood of individual sub-factors

implementation methodology selection are the major causes of project failure. The "pipe-line-laying" and "station construction" work packages are vulnerable from scope change. Technology selection is vital for river-crossing and telecommunication packages. Engineering and design change are quite likely for the "river-crossing" and "the pipe-line laying" work packages. Prior selection of implementation methodology is crucial for the "river-crossing" packages, as improper selection cause major time and cost overrun. Unavailability of pipe materials and delayed delivery of pumping unit sometimes result in considerable time overrun.

ii) Other major risks in project achievement are financial, economical and political risk (F&ER) and organisational risk. Among F&ER, fund flow problem and improper estimate are the major causes of concerns. All the packages are equally vulnerable from fund flow problem. However, the "river-crossing" and "pipeline-laying" packages are prone to improper estimate due to more uncertainties in design and implementation methodology selection. Although the organisational risk is less vulnerable for the project under study, consultant and contractor's capabilities are a bit of concern to the management of project. The "river-crossing" work package is the most susceptible from consultant and contractor's performance. The capability of owner's project group is required for achievement of all the work packages.

TABLE 3: *Likelihood of Risk in Project (Continued)*

Sub-Factors	Rive X-ing		Pipeline Laying		Station Construction		Other Work Packages	
	LP	GP	LP	GP	LP	GP	LP	GP
Scope change	0.17	0.029	0.39	0.067	0.31	0.053	0.13	0.022
Technology selection	0.29	0.017	0.23	0.014	0.11	0.007	0.37	0.022
Implementation methodology	0.47	0.029	0.26	0.016	0.17	0.011	0.1	0.006
Equipment risk	0.33	0.012	0.21	0.007	0.28	0.010	0.18	0.006
Materials	0.17	0.007	0.35	0.013	0.26	0.010	0.22	0.008
Engineering and design change	0.37	0.041	0.33	0.037	0.13	0.015	0.17	0.019
Inflation	0.25	0.009	0.25	0.009	0.25	0.009	0.25	0.009
Fund	0.25	0.022	0.25	0.022	0.25	0.022	0.25	0.022
Local law	0.18	0.004	0.18	0.004	0.19	0.005	0.25	0.006
Policy	0.25	0.006	0.25	0.006	0.25	0.006	0.25	0.006
Estimate	0.43	0.025	0.43	0.025	0.17	0.010	0.08	0.005
Capability of owner's project	0.33	0.005	0.3	0.005	0.27	0.004	0.1	0.002
Group contractor's capability	0.37	0.015	0.33	0.014	0.22	0.009	0.08	0.003
Vendor's capability	0.21	0.014	0.29	0.019	0.4	0.026	0.1	0.007
Consultant capability	0.49	0.012	0.13	0.003	0.15	0.004	0.23	0.005
Calamity normal	0.41	0.012	0.35	0.010	0.14	0.004	0.1	0.003
Calamity abnormal	0.32	0.011	0.47	0.017	0.09	0.003	0.12	0.004
Environmental	0.25	0.005	0.25	0.005	0.25	0.005	0.25	0.005
Land Acquisition	0.13	0.005	0.51	0.020	0.3	0.011	0.06	0.002
CCE clearance	0.25	0.003	0.28	0.003	0.36	0.004	0.11	0.001
Other clearance	0.25	0.003	0.25	0.003	0.15	0.002	0.35	0.004
Overall Likelihood of failure		**0.286**		**0.317**		**0.229**		**0.169**
Rank		**2**		**1**		**3**		**4**

LP - Local percentage
GP - Global percentage

The LPs are generated by pair wise comparison in alternative level using the scale of comparison in **Table 1** with respect to each sub-factor.
The GPs are determined by multiplying likelihood of sub-factor with LP of individual alternative. The overall likelihood of failure of each package is determined by summing up the figures in each GP column.

iii) Although the project under study is not that much vulnerable from statutory clearance risk, but care should be taken for getting environmental clearance and explosive clearance on time for trouble-free implementation.

iv) Normal and abnormal calamities are the part and parcel of any pipeline project. Hence, they are not perceived well by the project executives and rated unimportant and not likely for the project under study. However, these factors are vulnerable for all work packages and appropriate contingency plans are strongly recommended for each package.

v) The "pipeline-laying" work package is the most risky package with a probability of failure of 0.317. The major factors for possible failure are changes in scope, change in engineering and design, fund availability, vendor's capability, abnormal natural calamity and land acquisition. The "river-crossing" work package with probability of failure 0.286 comes next. The main contributing factors are scope change, implementation methodology selection, engineering and design change, and improper estimate thereon. The "station construction" work package is vulnerable from scope change and has 23% probability of failure.

TABLE 4: *Risk Mapping in Project Level*

Severity	Low probability	Medium probability	High probability
High	• Calamity normal	• Land acquisition • Technology selection • Engineering & Design change • Contractor's capability • Vendor's capability • Calamity abnormal	• Scope change
Medium	• Change in policy • Capability of owner's project group • Consultant's capability	• Implementation methodology • Fund risk • Improper estimate • Materials risk	
Low	• Inflation risk • Environmental clearance • CCE clearnace • Other clearances		

5.6 Risk-Mapping

All the factors were organised as per their probability and severity (effect on time and cost) characteristics as indicated in **Table 4**. The factor scope change has been identified as the most vulnerable for the project under study as it has high probability of occurrence as well as high severity. If there is a change in scope of any of the work packages, there will be considerable implications on design, planning and implementation programme. These will cause considerable time and cost overrun in project. The factors like, land acquisition, technology selection, engineering and design change, contractor's capability, vendors capability and abnormal calamity are rated as medium probability, as adequate planning for the project under study prompts the executives to perceive these factors as less vulnerable. However, project will experience major time and cost overrun, if any of the above factors occur during project implementation. Implementation methodology, fund risk, improper estimate and materials risk are rated as medium with respect to probability of their occurrence as well as severity. The other factors are perceived as either low probability or low severity. The factors which have low probability and high severity should be handled carefully with the development of contingency plans.

5.7 Overall Impact on Project

The factors that are in the zones having medium-to-high probability and severity were considered for further study. Severity of the risk factors was calculated with the consideration of their effect on each work package and on each phase (planning, design, materials, contract preparation and implementation) independently with the active involvement of project executives. **Table 5** shows the probability and severity of all risk factors. The probability figures are taken from **Table 3** and the severity figures are estimated by the executives through group consensus.

As for example, the effects of "scope change" on project achievements are explained below.

The followings are the possible changes in the total scope of project with respect to present level of planning, design and detailed engineering:

- Increase in length of pipe-laying due to change in terrain condition as envisaged in detailed survey.
- Effect of design and technology change of "river-crossing" and "offshore pipeline" work packages.

TABLE 5: *Probability and Severity of Risk Factors*

Risk Factors	Probability	Severity	
		Time over-run (in months)	Cost over-run (in US$M)
Scope change	0.172	8	90
Engineering and Design change	0.112	5	30
Technology selection	0.059	6	20
Land acquisition	0.038	4	0
Contractor's capability	0.041	6	30
Vendor's capability	0.065	8	30
Calamity abnormal	0.036	12	90
Implementation methodology	0.062	3	0
Fund availability	0.087	2	0
Improper estimate	0.058	2	0
Materials risk	0.038	3	0

- Increase in capacity of prime movers due to increase in pipe length and change in hydraulic gradient.
- The changes in pipeline route and length will affect the requirement of statutory clearance, power supply, change in design, additional and changes in materials procurement, contract administration as well as implementation.

The impact of the above factors was studied and analysed by the concerned project executives to derive and guess-estimate the time and cost overrun of the project as eight months and US$90 Million respectively. Similarly, the effect of other risk factors on project outcomes were studied and tabulated in **Table 5**.

The above results were used to derive the expected time and cost overrun along with the respective standard deviations using the following formula **(Canavos, G.C. (1984))**.

Let X be a random variable. The *r* th moment of X about zero is defined by:

$$\mu'_r = E(X^r) = \sum_X x^r p(x)$$

If X is discrete, or ....(1)

$$\mu'_r = E(X^r) = \int_{-\infty}^{\infty} x^r f(x)dx$$

If X is continuous ....(2)

The first moment about zero is the mean or expected value of the random variable and is denoted by μ; thus $\mu'_1 = \mu = E(X)$.

Again, the *r* th central moment of X or the *r* th moment about the mean of X is defined by:

$$\mu_r = E(X-\mu)^r = \sum_x (x-\mu)^r p(x)$$

If X is discrete, or ....(3)

$$\mu_r = E(X-\mu)^r = \int_{-\infty}^{\infty} (x-\mu)^r f(x)dx$$

If X is continuous ....(4)

The second central moment,

$$\mu_2 = E(X-\mu)^2$$

is known as the variance of the random variable. Therefore, using the data from **Table 5** and Equations 1 and 3, the following statistical parameters were derived:

The expected increase in project duration
= 4.88 months

The standard deviation
= 2.686 months

The approved schedule of the project was 36 months.

The expected cost overrun
= US$26.44 Million
The standard deviation
= US$34.72 Million

The approved cost was US$600 Million

No management can be satisfied with a 50% chance of achievement. Hence, more realistic time target was derived with the application statistical model as shown by **Yeo (1990)**. Accordingly, increase in duration of project with respect to initial planning was determined with the application of following mathematical relationship:

$$[X_t - \mu] / \sigma = Z \qquad ....(5)$$

X_t = Increase in duration of time of project/ work package
μ = Expected increase in project duration, 4.88 months
σ = Standard deviation of duration distribution, 2.686
Z = Corresponding value from normal distribution chart against probability value (90% confidence level in this case), 1.29

Therefore, the project will be completed with 8.3 months time overrun with 90% likelihood.

Similarly, the project will experience cost overrun of US$71.23 Million with 90% likelihood.

5.8 Risk Responses

Risk analysis results lead to the need to derive a few effective risk responses in line with the following principles:

- To avoid;
- To reduce;
- To transfer;
- To absorb

The risk analysis of the project under study derived the following responses for effective project management.

"Telecommunication and Cathodic protection system" work packages:

Factors for which risk responses were made are 'scope change', 'technology selection' and 'engineering and design change'. Suitable consultant was engaged to help in selecting technology for Telecommunication package. Provisions were made in contract document for accommodating changes in scope, engineering and design.

"Station construction" work package:

- Scope changes were accommodated through contract provisions with contractors
- Vendors were selected from pre-qualified pool of vendors with proper examination of their present commitments.

"River-crossing" work package:

- Turnkey contract was designed for coping up with engineering and design changes.
- A contractor was selected from a pre-qualified pool of contractors with proper examining of their present commitments.
- The scope of work was appropriately defined through a detailed survey.
- Implementation methodology was decided at an early stage of design in consultation with the pool of probable turnkey contractors.
- Cost estimate was made from budgetary offers of turnkey contractors.

"Pipeline-laying" work package:

- Suitable contract provisions were made for accommodating change in scope, and engineering and design change.
- A qualified consultant was engaged for selection of technology and project implementation methodology for

complicated and uncommon terrain during project planning stage. A group of project people also was engaged with them to transform their recommendations to actual planning documents.

- Vendors and contractors were selected from the pre-qualified pool with proper examination of their present commitments.
- Authority and responsibility were fixed for handling issues related to "Land acquisition". The compensation package to the landowners was made through concensus decisions in the presence of the representatives of project ownerS and landowners.
- Suitable insurance coverage was made for safeguarding facilities from abnormal calamities during construction. Additionally, a few contingency plans through resource mobilisation were made to handle such situations.

5.9 Cost-benefit Analysis

The cost of implementing the risk management technique in project management for the project under study is enumerated in **Table 6**.

The benefit of risk management accrued by the project under study has been explained in **Table 7** by elaborating the cost expected to incur in absence of risk management study.

The result shows quantum benefit of project risk management.

5.10 Summary and Conclusions

This study suggests a project management model with the application of risk management principles. A decision support system (DSS) has been developed in the Analytic Hierarchy Process (AHP) framework that helps the management of projects in making objective decisions. This DSS identifies risk factors that are inherent in the project under study, analyses their effect on various activities and derives responses in line with project objectives, organisation's policy and business opportunities.

Risk is by nature subjective. However, AHP allows to analyse the effect of risk on project objectively by determining the probability of their occurrences through active involvement of project executive in-group decision-making framework. The severity of each risk factor is estimated through active involvement of the experienced persons from the field in an interactive environment. The information is collected in a very structured format in line with AHP requirement and processed through computer (Expert Choice). Additionally, sensitivity analysis with AHP provides an opportunity to the risk management group to observe the nature of model outcome in different alternative decision situations.

TABLE 6: *The Cost of Implementing Risk Management*

Items	Cost (in US$M)	Basis/Reasons
Increase in cost of project management	0.6	Additional man-hours, cost of hardware and software for project risk management
Increase in materials cost	2.6	This is due to the selection of superior vendors for supplying a few critical items
Increase in implementation cost	1.8	Supeerior contractors were selected for a few work packages
Additional cost for engaging consultants	2.0	For technology and implementation methodology selection
Total	**7.0**	

TABLE 7: *Expected Cost for Time Over-Run of Project under Study*

Items	Cost (in US$M)	Basis/Reasons
Loss of revenue due to delay in project completion	49.8	Estimated revenue from the project: US$M6 per month. Expected delay without risk response 8.3 months
Cost escalation due to project delay	4.5	10% of implementation cost per year (implementation cost : US$M60
Total	**54.3***	

* Inventory carrying cost, interests on capital and opportunity costs are not considered.

The followings are the general benefits that can be achieved from the application of risk management in any type of projects:

1) The issue/problems of the project are clarified, understood and allowed for right from the start.

2) Decisions are supported by thorough analysis of available data.

3) The structure and definition of the project are continually and objectively monitored.

4) Contingency planning allows prompt, controlled and pre-evaluated response to risks that materialise.

5) Clearer definition of the specific risk associated with a project.

6) It builds up a statistical profile of historical risk to allow better modelling for future projects.

7) It encourages problem-solving and providing innovate solutions to the risk problems within a project.

8) It provides a basis for project organisation structure and appropriate responsibility matrix.

Specific benefits that were achieved by applying risk management techniques in managing the project under study can be enumerated as follows:

i) Problems that were likely to be encountered while executing a project were identified during planning phase. These helped in making suitable responses for effective project management by alternative design and engineering, engaging superior consultants, contractors and vendors.

ii) Critical activities were identified and appropriate responsibilities were prepared for managing the critical activities.

iii) Risk management methodology helped in completing the project without any time and cost overrun.

iv) It helped in forecasting the project achievement quantitatively allowing management to make decisions objectively.

v) It provided a control basis for effective implementation of the project.

vi) It accommodated changes in scope through proper study on implication of overall objectives of projects.

Though this study makes an effort to quantify risk by modelling the probability, and severity of risk in line with the perception of the experienced project executives, subjectivity could not be reduced to zero. The findings and recommendations would vary with the type of project, risk perception of its management, organisation's objectives and policies and business environment.

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