Project Risk Management: A Combined Analytic Hierarchy Process and Decision Tree Approach

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ABSTRACT: Time, cost and quality achievements on large-scale construction projects are uncertain because of technological constraints, involvement of many stakeholders, long durations, large capital requirements and improper scope definitions. Projects that are exposed to such an uncertain environment can effectively be managed with the application of risk management throughout the project life cycle. Risk is by nature subjective. However, managing risk subjectively poses the danger of non-achievement of project goals. Moreover, risk analysis of the overall project also poses the danger of developing inappropriate responses. This article demonstrates a quantitative approach to construction risk management through an analytic hierarchy process (AHP) and decision tree analysis. The entire project is classified to form a few work packages. With the involvement of project stakeholders, risky work packages are identified. As all the risk factors are identified, their effects are quantified by determining probability (using AHP) and severity (guess estimate). Various alternative responses are generated, listing the cost implications of mitigating the quantified risks. The expected monetary values are derived for each alternative in a decision tree framework and subsequent probability analysis helps to make the right decision in managing risks. In this article, the entire methodology is explained by using a case application of a cross-country petroleum pipeline project in India. The case study demonstrates the project management effectiveness of using AHP and DTA.

KEY WORDS: Risk management, work break down structure, analytic hierarchy process, decision tree analysis, cross-country petroleum pipeline, and time-cost control

The success parameters for any project are in time completion, within a specific budget and with requisite performance (technical requirement). The main barriers in achieving these are changes that occur in the project environment. The problem multiplies with the size of the project as uncertainties in project outcome increases with size. Large-scale construction projects are exposed to uncertain environments because of the following factors.

- 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;
- climactic 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, its location, and its degree of unfamiliarity.

A cross-country petroleum pipeline construction project is characterized by the complexity of its execution with respect to lack of experience in relation to certain design conditions being exceeded.

These conditions can include water depth, ground condition, pipeline size etc.

Other conditions include the influence of external factors that are beyond human control. External causes can limit resource availability, including the areas of techniques and technology. Various environment impacts, government laws and regulations, changes in the economic and political environment, cost and time overruns and the unsatisfactory quality of a project are the general sources of management disappointment with a pipeline organization.

A conventional approach to project management (as shown in figure 1) and as practiced by the organization studied in this article is not sufficient. It does not enable the project management team to accomplish the following.

- establish an adequate relationship among all phases of the project;
- forecast project achievement for building confidence of project team;
- make decisions objectively with the help of an available database;
- provide adequate information for effective project management; and
- establish close cooperation among the project team members.

The objective of this article is to model a decision support system (DSS) through risk analysis for making objective decisions on project planning, design, engineering, and resource deployment for completing a project on time, within budget, and in line with project objectives, organizational policy and the present business scenario.

Proposed Project Model

Figure 2 illustrates the proposed project model. Project planning, design, and detailed engineering should be taken up in sequence as soon as a project gets approval. Materials procurement and works contract preparation start concurrently with completion of design activities. The availability of funds, materials, drawings, specifications, contract document, and other utilities are initiated and implemented at the work site by contractors. Projects are controlled through effective monitoring of various performance parameters that are fixed during the planning phase. Just after project planning, risk management with respect to time achievement and covering all project phases is carried out. Risk management with respect to cost achievement should be carried out before implementing work.

The scope of this article is limited to establishing risk management after the project was approved.

Risk and Risk Management Process

C.B. Chapman and D.F. Cooper, [3] 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 into the following three stages.

- risk identification;
- risk analysis; and
- risk responses

Rao Tummala and Y.H. Leung, [17] developed a methodology for risk management that looks at risk identification, measurement, assessment, evaluation, risk control and monitoring. Their methodology was developed for managing the cost risk of an EHV transmission line project.

T.M. Williams [19] examined various project risk management research. He describes various risk identification and analysis tools being used by researchers and practitioners and the management structures and procedures needed to manage risk.

J.R. Turner [18] suggests using expert judgment, plan decomposition, assumption analysis, decision drives and brainstorming for effective identification of risk factors for a project. J.G. Perry and R.W. Hayes [15] present a checklist of risk that may occur throughout the life span of any project. The Delphi technique has been used by P.K. Dey [7] for identification of risk factors. Outside the field of engineering and construction, an approach for risk identification in product innovation has been reported by Jim Halman and J.A. Keizer [12].

Most of the analyses done so far are centered on analyzing the duration of the project. Management is interested in two aspects; the total

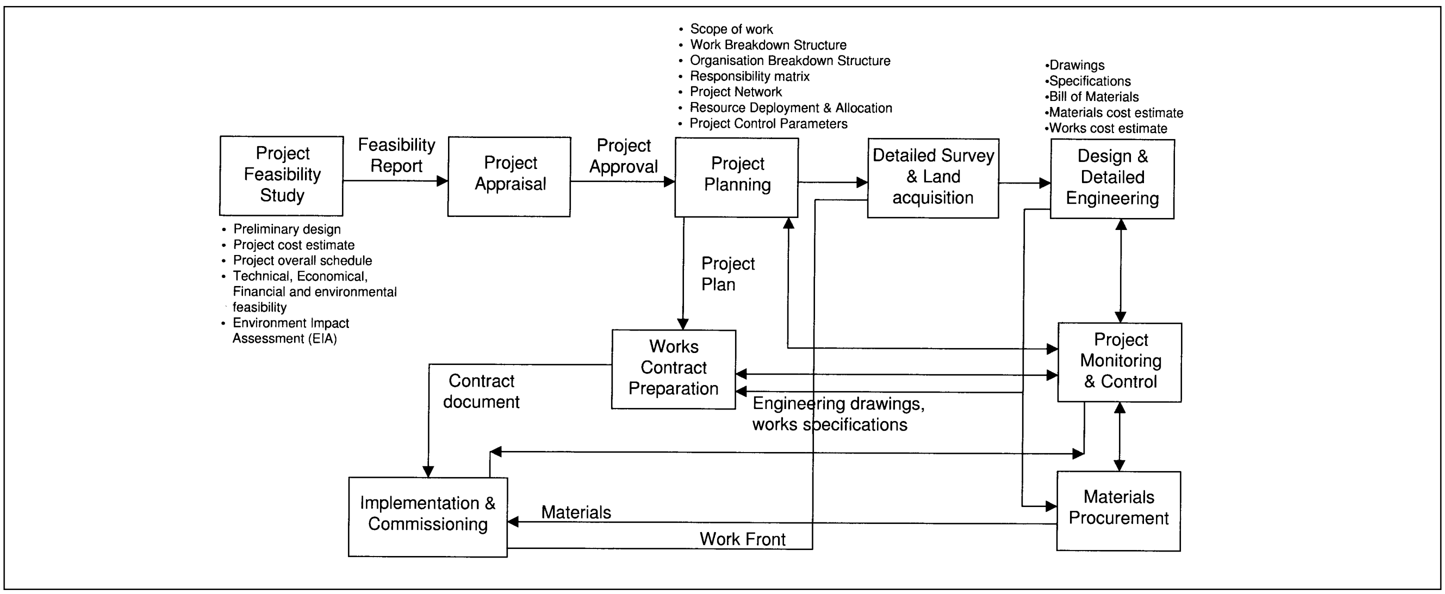

Figure 1—Conventional Project Management Model

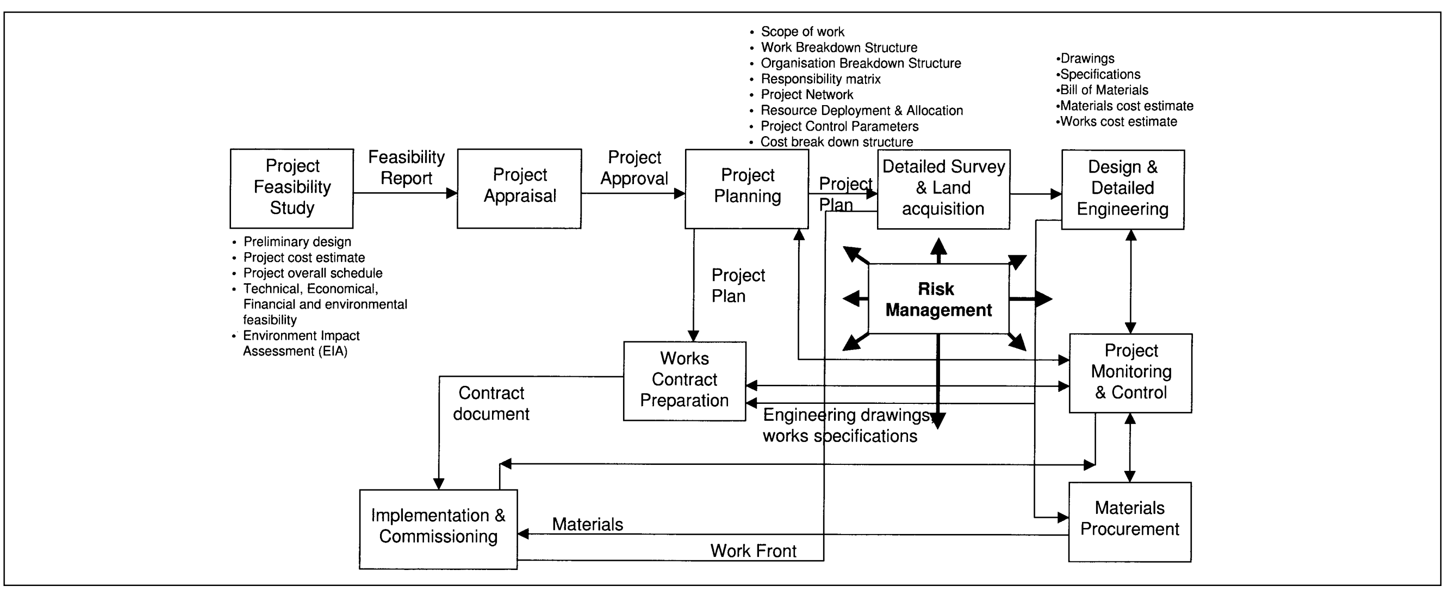

Figure 2—Proposed Project Management Model

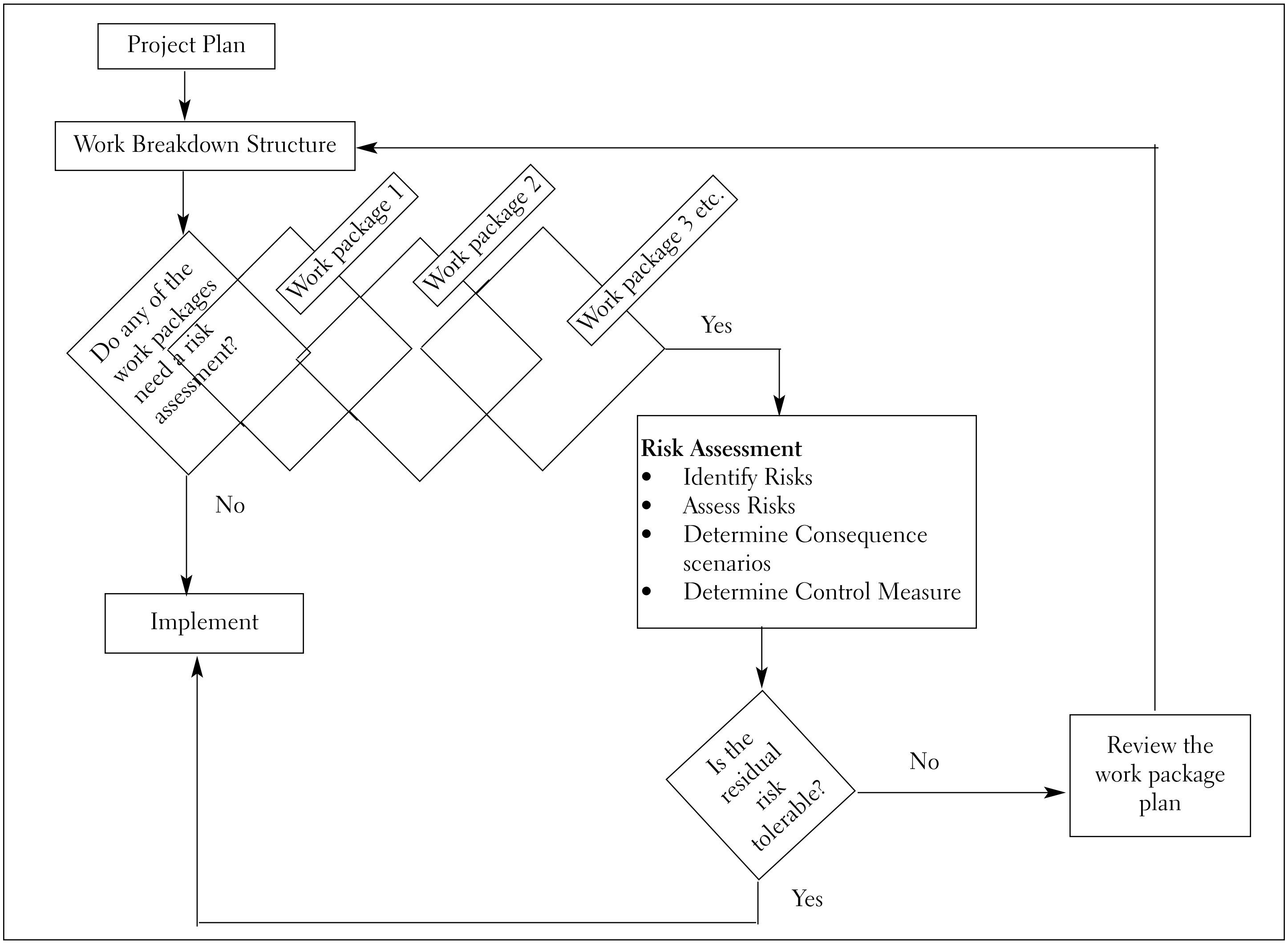

Figure 3—Risk Management Flow Chart

duration and which activities are critical in determining that duration. Many authors have presented the distribution of time duration of activities as classical Beta distribution [10]. J. Berny, [1] proposed his own distributions for practical simulations. P.K. Dey used Monte Carlo simulation for analyzing project risk of petroleum pipelines [8].

Recently, a number of systematic models have been proposed for use in the risk-evaluation phase of the risk-management process. R. Kangari and L.S. Riggs [13] 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, requiring subjective evaluations that classical models cannot handle.

There is a need for a subjective approach to project risk assessment, with objectivity in the methodology. The analytic hierarchy process (AHP) developed by T.L. Saaty [16] provides a flexible and easily understood way of analyzing project risks. It is a multi criteria decision-making methodology that allows subjective as well as objective factors to be considered in

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 favors one over another
5	Essential or strong importance	Strongly favors one over another
7	Demonstrated importance	Dominance of the demonstrated importance in practice
9	Extreme importance	Evidence favoring one over another of highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

*Source: T.L. Saaty, **The Analytic Hierarchy Process** [16].*

Table 2—Comparison Matrixes in Factor Level

Factors	Technical Risk	Financial & Economic Risk	Organizational Risk	Acts of God Risk	Clearance Risk	Likelihood
Technical Risk	1	3	4	5	5	0.479
Financial and Economic Risk	1/3	1	2	4	3	0.228
Organizational risk	1/4	1/2	1	2	3	0.146
Acts of God Risk	1/5	1/4	1/2	1	2	0.064
Clearance Risk	1/5	1/3	1/3	1/2	1	0.083
Consistency Ratio: 0.042. acceptable						

project risk analysis. The AHP allows the active participation of decision-makers in reaching agreement and it 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 or 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 prioritization 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 that is under consideration. The verbal scale used in an 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 are derived for the various elements. The relative weights of the elements of each level with respect to an element in the adjacent upper level are computed as the components of the normalized 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. This is accomplished by 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. The outcome of this aggregation is a normalized vector of the overall weights of the options. The mathematical basis for determining the weights has been established by T.L. Saaty [16].

Conventionally, risk analysis is performed at the overall project level. The risk analysis should show the effects of the risk factors on the project performance in terms of time, cost, and quality goals. 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.

D.F. Cooper [4] suggested that, in the risk-engineering approach, systematic risk evaluation could be performed by subdividing a project into its major elements, and analyzing 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. To risk analyze a project, the level of activity for which risks are to be analyzed has to first be determined.

M.A. Mustafa and J.F. Al-Bahar [14] applied the AHP in risk analysis for the assessment of risk in a construction project

Table 3—Likelihood of Risk in a Project

Factors	Likelihood	Sub-factors	Likelihood LP	Likelihood GP
Technical Risk	0.479	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	0.228	Inflation risk	0.152	0.035
		Fund risk	0.383	0.087
		Changes in local law	0.105	0.024
		Changes in Govt. policy	0.105	0.024
		Improper estimate	0.255	0.058
Organizational Risk	0.146	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	0.064	Calamity Normal	0.44	0.028
		Calamity abnormal	0.56	0.036
Clearance risk	0.083	Environmental clearance	0.026	0.022
		Land acquisition	0.461	0.038
		Explosive clearance	0.133	0.011
		Other clearances	0.142	0.012

LP—Local percentage
GP—Global percentage

Table 3—Likelihood of Risk in a Project (continued)

Sub-factors	River 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
eng.. 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 Contractors capability	0.37	0.015	0.33	0.014	0.22	0.009	0.08	0.003
Vendors 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
Explosive 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

from the evaluation perspective. P.K. Dey, [5] applied AHP for cost risk analysis of a construction project

This article adopts AHP for analyzing risk in the project and uses decision tree analysis (DTA) for selecting specific risk responses for specific work packages from various alternatives.

Decision trees use calculations of expected monetary value (EMV) to measure the attractiveness of alternatives. They also use graphical models to display several relevant aspects of a decision situation. These graphical models consist of treelike structures (hence the name) with branches to represent the possible action-event combinations. The conditional payoff is written at the end of each branch. A tree gives much the same information as a matrix, but, in addition, it can be used to depict multiple-stage decisions. These are a series of decisions over time[9].

A decision tree approach does the following.

- It logically structures risk management philosophy by identifying alternative responses in mitigating risk.
- It provides a basis for quantitative risk management.
- It incorporates management perceptions.

Methodology

The methodology adopted for risk management in this article is explained in the following steps.

- Identifying the work packages for risk analysis.
- Identifying the factors that affect the time, cost, and quality achievement of a specific work package.
- Analyzing the effect by deriving the likelihood of the occurrences in an AHP framework.
- Determining severity of failure by guess estimation.
- Driving various alternative responses for mitigating the effect of risk factors.
- Estimating cost for each alternative.
- Determining the probability and severity of failure of a specific work package after a specific response.
- Forming a decision tree.
- Deriving expected monetary value EMV or the cost of risk response in this case.

Table 4—Risk Mapping in Project Level

Severity	Probability: Low	Probability: Medium	Probability: High
High	• Calamity normal	• Land acquisition • Technology selection • Engineering and Design change • Contractor's capability • Vendors 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 clearance • Other clearances		

- Selecting the best option through statistical analysis.

Application

The above steps will be explained through the case of a cross-country petroleum pipeline project in the western part of India. The pipeline has a length of 1300 km. Its diameter is 22 inches for a length of 1112 km, 18-inches for a length of 218 km, and 10.75 inches for a length of 123-km (a 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 600 million in US dollars. A detailed description of the project is available in Dey's Planning for Project Control Through Risk Analysis, A Case of a Petroleum Pipeline Laying Project [5].

Figure 3 shows a flow chart for risk management. A risk management group was formed to do a risk analysis study for the project in this article. The group consisted of one member each from mechanical, electrical, civil, tele-communication, instrumentation, finance, and materials of project function. They were entrusted with collecting data, analyzing, interpreting and preparing recommendations with active interactions with the project groups.

Table 5—Probability and Severity of Risk Factors

Risk Factors	Probability	Severity	
		Time over-run (in months) US $)	Cost Over-run (in Millions)
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
Contractors capability	0.041	6	30
Vendors 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

Identification of Work Packages

The total project scope was decomposed and classified to form a work break down structure (see figure 4). The first level is project, the second and third levels are work packages, and the forth level is activities of each work package. Based on the importance of achieving time targets, the following work packages were considered for risk management.

- river crossing;

Table 6—The Cost Data (Million US $) for Each Package Against Various Responses

Responses	Pipeline laying	River crossing	Station Construction	Telecommun-ication & CP	Building & colony construction
Carrying out detailed survey with the objective of minimum scope and design change	12	6	6	3	3
Selecting technology and implementation methodology on the basis of owner's / consultant's expertise, availability of contractors and vendors and lifecycle costing	3	6	4	1.5	1.5
Executing design and detailed engineering on the basis of selected technology and implementation methodology and detailed survey	1	1	1	1	1
Selecting superior contractors, consultants and vendors on the basis past performance	22	16	10	2	2
Scheduling project by accommodating seasonal calamities	6	-	4	-	-
Planning contingencies and acquiring insurance	11	2	6	1	1
Ensuring the availability of all statutory clearance before design and detailed engineering	1	1	1	1	1
Total	56	32	32	10	10
Grand total	140				

- pipeline laying;
- stations construction; and
- telecommunication and SCADA system

Identification of Risk Factors

The risk factors and sub-factors were identified with the involvement of executives working through brainstorming sessions. These executives had more than 15 years of project work experience. In the brainstorming session, they were given a checklist of risk that was initially used to identify risk factors and sub-factors. The executives next used group consensus to develop a risk structure.

The following are the risk factors and sub-factors of the project used in this article.

Technical Risk

- scope change;
- technology selection;
- implementation methodology selection;
- equipment risk;
- materials risk; and
- engineering and design change

Acts of God

- normal natural calamities; and
- abnormal natural calamities

Financial, Economical and Political Risk

- inflation risk;
- fund risk;
- changes of local law;
- changes in government policy; and
- improper estimation

Organizational Risk

- capability risk of owner's project group;
- contractor's failure;
- vendor's failure; and
- consultant's failure

Statutory Clearance Risk

- environmental clearance;
- land acquisition;
- clearance from chief controller of explosives (CCE); and
- other clearance from government authorities

Formation of Risk Structure

This article focuses on two dimensions of risk; its probability and severity. The risk perception, as shown by J.R. Turner [18], has not been considered because of the nature of construction risk. Figure 5 shows the AHP model for risk analysis. Level 1 is the goal of determining the riskiness of the project. Levels 2 and 3 are for factors and sub-factors respectively. Level 4 contains the alternatives or work packages.

Pair Wise Comparison

The AHP model was made in an Expert Choice software package developed by E.H. Forman and T.L. Saaty [11]. Pair wise comparisons were made through executives working on projects in a group decision-making process, using the information from Table 1. A questionnaire was made and distributed individually to the executives so they would not be influenced by each other. A risk management group analyzed the responses. Table 2 shows a comparison matrix of the factor level. The outcome of matrix operation shows the likelihood of these risks occurring while the project is being executed.

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

Results and Findings From Risk Analysis Study

Technical risk is the major factor for time and cost overrun of a project. Within the technical risk category—scope change, engineering and design change, technology, and implementation methodology selection are the major causes of project failure. The pipeline laying and station construction work packages are vulnerable from scope changes. Technology selection is vital for the river crossing and telecommunication packages. Engineering and design changes are quite likely for the river crossing and the pipeline laying work packages. A prior selection of implementation methodology is crucial for the river cross-

Table 7—The EMV for "Pipeline Laying Project"

Decision Alternatives	Cost (million US$)	Probability of failure **	Effect		Expected Value		EMV* (million US$)
			Time (months)	Cost (million US$)	Time (months)	Cost (million US$)	
Do nothing	0	0.317	12	22	3.8	6.97	35.5
Carrying out detailed survey	12	0.158	2	4	0.32	0.64	15
Using superior technology	3	0.158	12	22	1.9	3.5	21
Engaging expert project team	22	0.317	2	4	0.64	1.3	28
Taking all responses as indicated in table	56	0.05	2	2	0.1	0.1	56.9

**EMV = 0 + 3.8 X 7.5 + 6.97 = 35.5*

(Return on investment is 7.5 million US $ per month i.e. 15% of 600 million US $ per annum)

** Basis for probability figures

Decision Alternatives	Basis for Probability figures
Do nothing	From Table 3
Carrying out detailed survey	50 percent of "do nothing"
Using superior technology	50 percent of "do nothing"
Engaging expert project team	Same as "do nothing"
Taking all responses as indicated in table	Assumption: probability of failure is five percent

Table 8—The EMV for "Pipeline Laying Across River"

Decision Alternatives	Cost	Probability of failure	Effect		Expected Value		EMV* (million US$)
			Time (months)	Cost (million US$)	Time (months)	Cost (million US$)	
Do nothing	0	0.286	15	40	4.3	11.44	43.7
Carrying out detailed survey and using superior technology	12	0.143	15	40	2.15	5.72	33.85
Engaging expert project team	16	0.286	8	20	2.3	5.72	39
Taking all responses as indicated in table	32	0.05	2	8	0.1	0.4	33.15

Table 9—The EMV for "Station Construction"

Decision Alternatives	Cost	Probability of failure	Effect Time (months)	Cost (million US$)	Expected Value Time (months)	Cost (million US$)	EMV* (million US$)
Do nothing	0	0.229	12	24	2.75	5.5	26.2
Carrying out detailed survey and using superior technology	9	0.115	0.6	12	0.7	1.32	15.06
Engaging expert project team	10	0.229	2	0.4	0.46	0.92	14.5
Taking all responses as indicated in table	32	0.05	2	4	0.1	0.2	33

Table 10—The EMV for "Telecommunication and SCADA System"

Decision Alternatives	Cost	Probability of failure	Effect Time (months)	Cost (million US$)	Expected Value Time (months)	Cost (million US$)	EMV* (million US$)
Do nothing	0	0.169	2	2	0.34	0.34	3
Carrying out detailed survey and using superior technology	4.5	0.085	2	2	0.17	0.17	5
Engaging expert project team	3	0.169	0.5	1	0.085	0.17	3.8
Taking all responses as indicated in table	10	0.05	0.5	1	0.025	0.05	10.25

ing packages, as improper selection could cause major time and cost overruns. The unavailability of pipe materials and delayed delivery of pumping unit sometimes results in a considerable time overrun.

Other major risk categories for project achievement are financial, economic, and political risk (F&ER) and organizational risk. Among F&ER, fund flow problems and improper estimates are the major causes of concerns. All the packages are equally vulnerable from fund flow problems. However, the river crossing and pipeline laying packages are prone to problems from improper estimates because there are more uncertainties in the design and implementation methodology selection. Although the organizational risk is less vulnerable for the project under study, consultant and contractor's capabilities are of concern to the management of the project. The river crossing work package is the most susceptible to problems from the performance of consultants and contractors. The capability of the owner's project group is required for achievement of all the work packages.

Table 11—The Decisions Emerge From the Decision Tree Approach of Risk Management for Each Work Package

Work package	Risk response
pipeline laying	Carrying out detailed survey
pipeline laying across river station construction	Taking all responses as indicated in table Engaging expert project team
telecommunication and SCADA system	Do nothing
Total cost for risk responses is 65.65 million US$ which is much lower than 140 million US$.	

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

Normal and abnormal calamities are the part and parcel of any pipeline project. Many times project executives rate these as unimportant and not likely to occur.

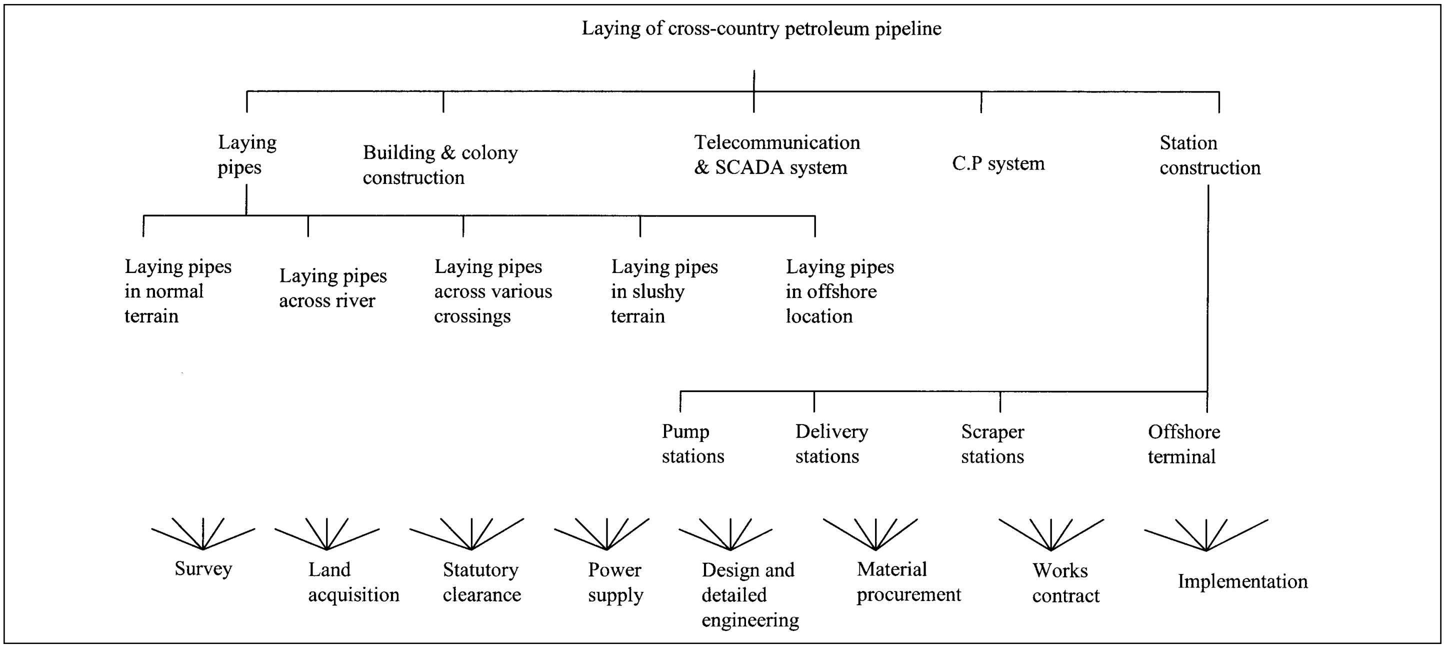

Figure 4—Work Breakdown Structure of "Cross-country Petroleum Pipeline" project

However, these factors are vulnerable for all work packages and appropriate contingency plans are strongly recommended for each package.

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, changes in engineering and design, fund availability, vendors capability, abnormal natural calamity and land acquisition. The river crossing work package with a probability of failure of 0.286 comes next. The main contributing factors are scope changes, implementation methodology selection, engineering and design change, and improper estimates. The station construction work package is vulnerable from scope changes and has a 23 percent probability of failure.

Risk Mapping

All the factors were organized 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 a 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 consid-

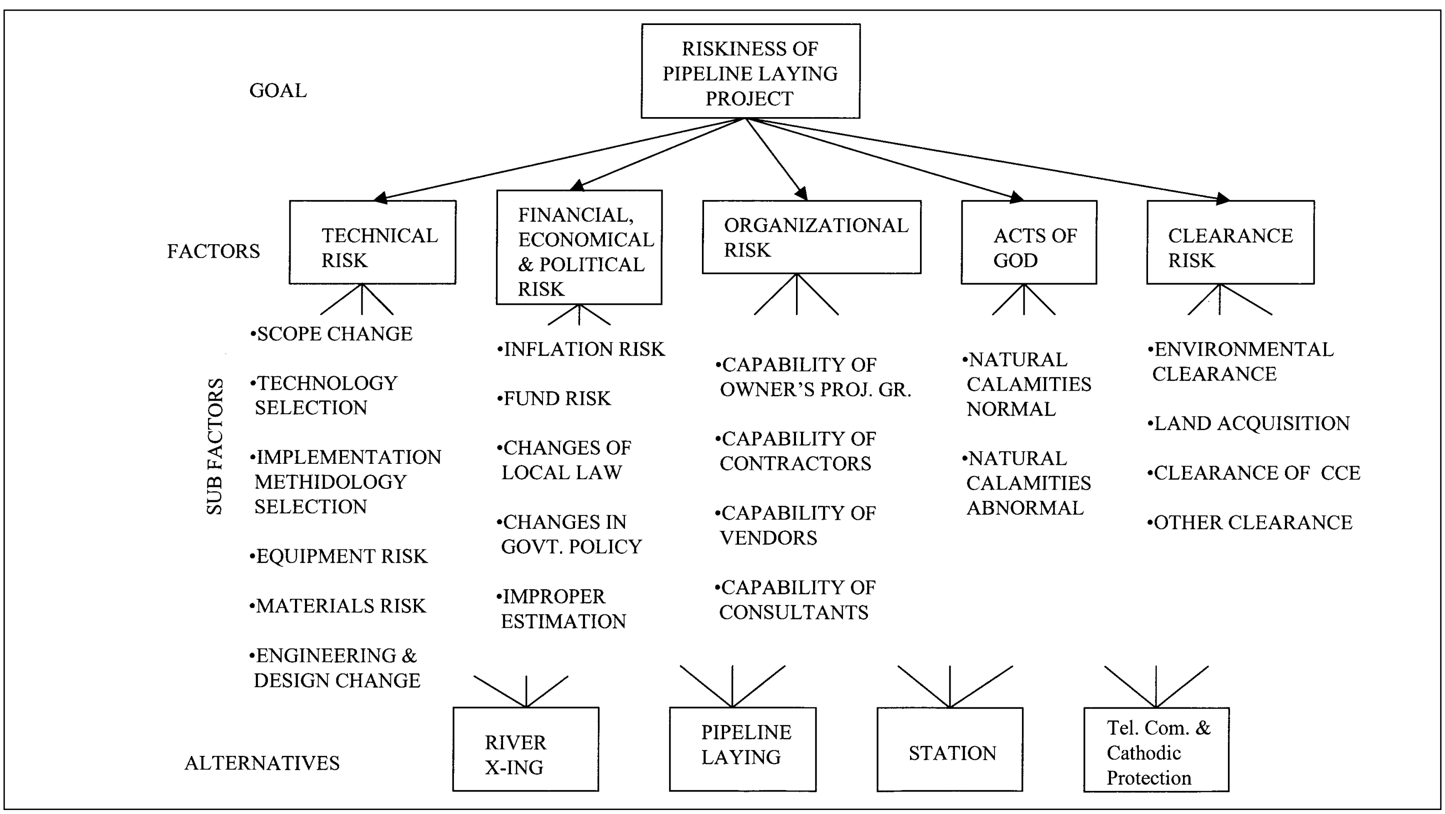

Figure 5—AHP model for determining riskiness of project

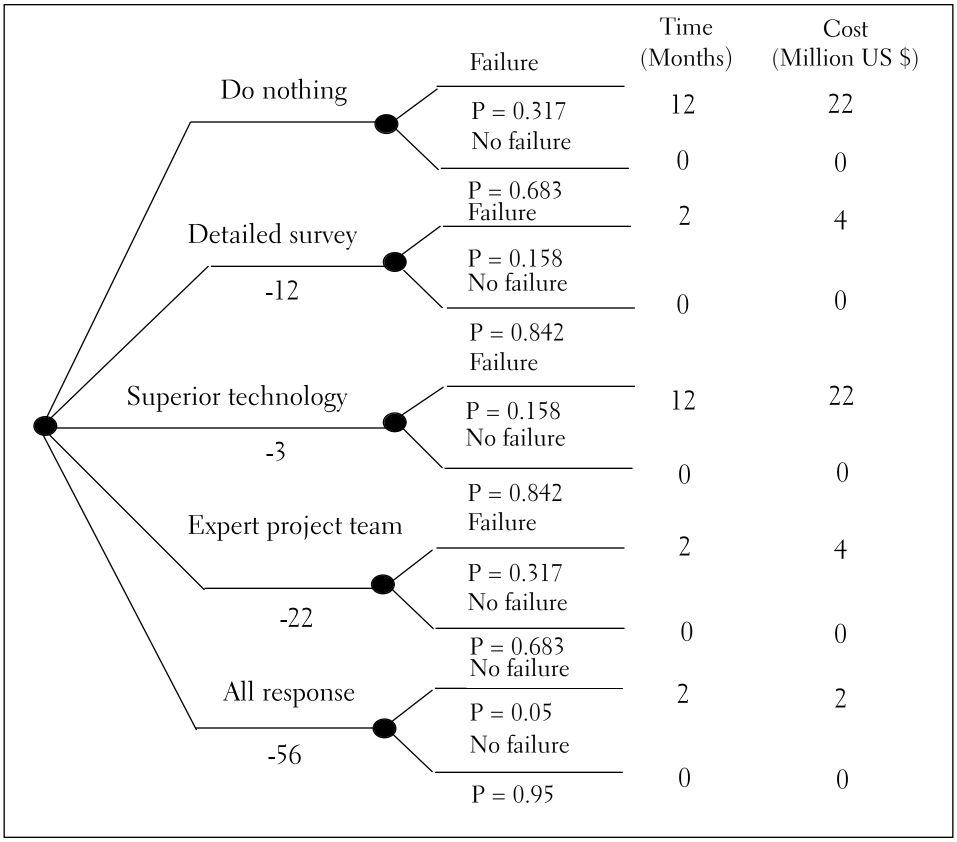

Figure 6—Decision Tree for Pipeline Laying Work Package

erable implications on design, planning, and implementation of the program. These will cause considerable time and cost overruns in the project. Factors like land acquisition, technology selection, engineering and design changes, contractor's capability, vendors capability, and abnormal calamity are rated as having medium probability, as adequate planning for the project under study prompts the executives to perceive these factors as less vulnerable. However, the project will end up experiencing a major time and cost overrun, if any of the above factors occur during the project implementation. Implementation methodology, fund risk, improper estimate, and materials risk are rated as having medium probability of 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.

Overall Impact on Project

The factors that are in the zones having medium to high probability and severity were considered for further study. The severity of the risk factors was calculated with independent consideration to their effect on each work package and on each phase (planning, design, materials, contract preparation and implementation). Project executives were actively involved in these calculations. Table 5 shows the probability and severity of all risk factors.

The above results were used to derive the expected time and cost overrun along with the respective standard deviations using the following formula [2].

Let X be a random variable. The rth moment of X about zero is defined by

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

if X is discrete, (equation 1)

or

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

if X is continuous (equation 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 rth central moment of X or the rth 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, (equation 3)

or

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

if X is continuous (equation 4)

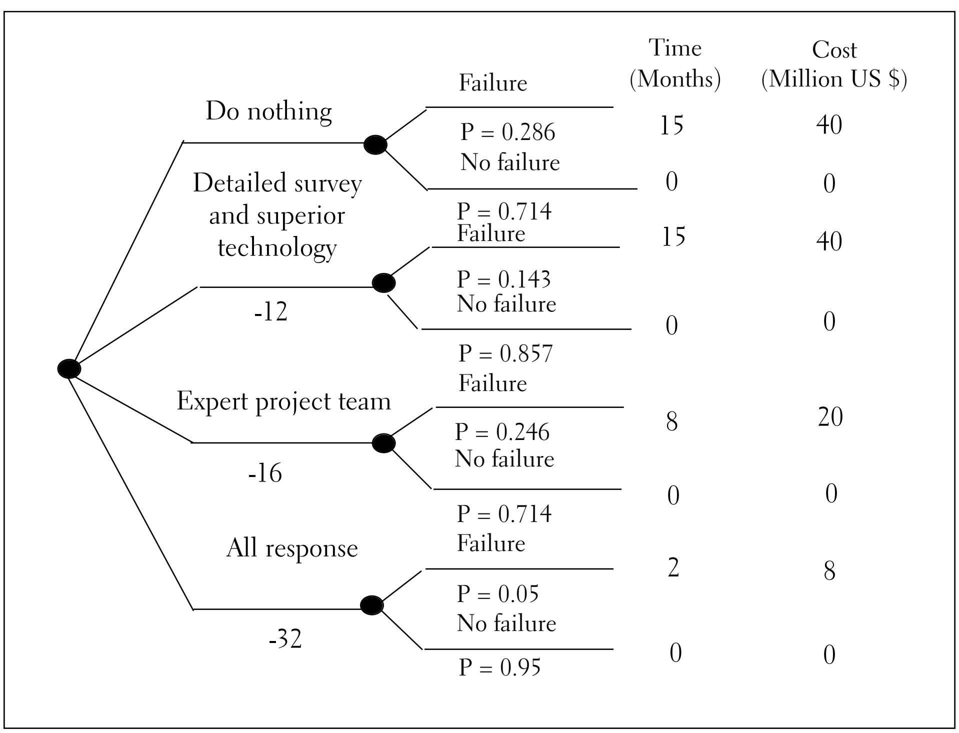

Figure 7—Decision Tree for River Crossing Work Package

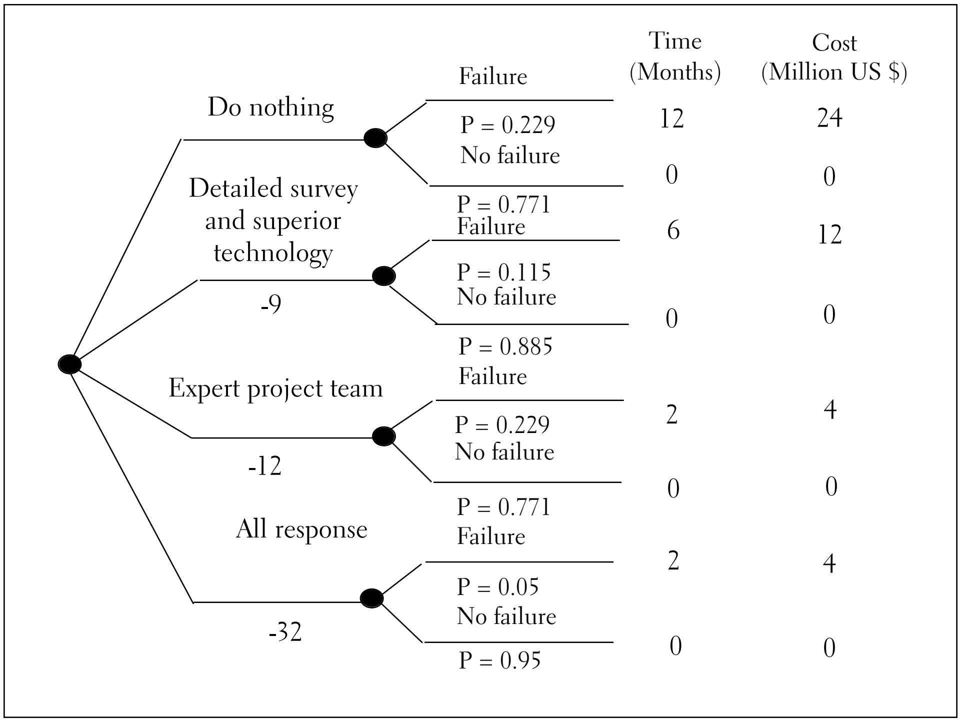

Figure 8—Decision Tree for Station Construction Work Package

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 4 and equation 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.

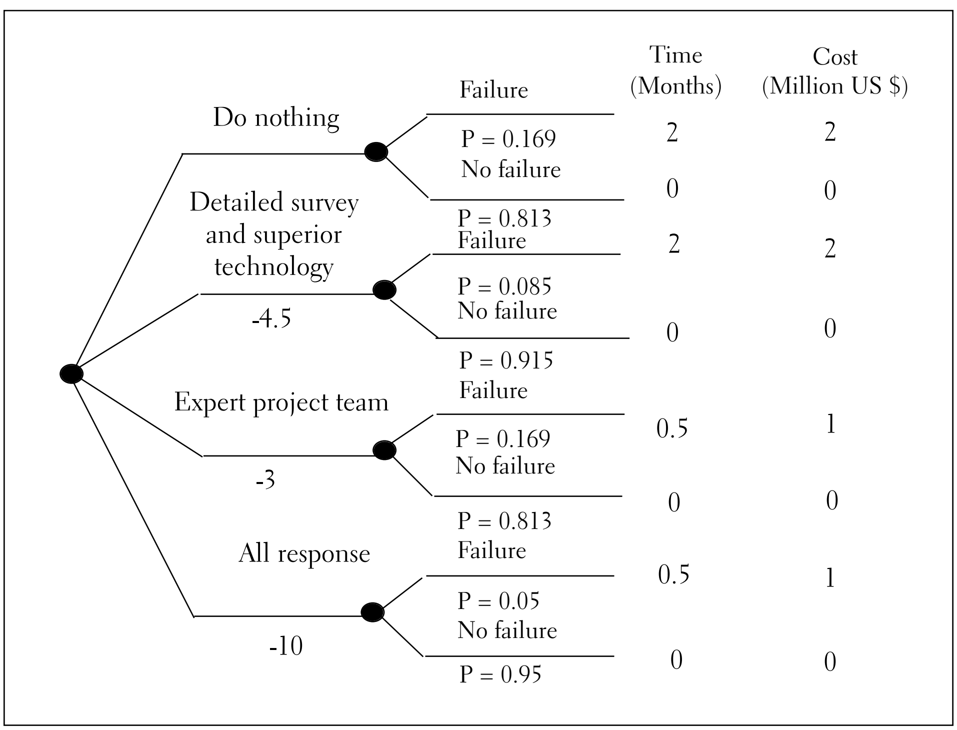

Figure 9—Decision Tree for Telecommunication and Cathodic Protection Work Package

The expected cost overrun = 26.44 million in US dollars,
The standard deviation = 34.72 million in US dollars.
The approved cost was 600 million in US dollars.

No management can be satisfied with a 50 percent chance of achievement. A more realistic time target was derived with the application of a statistical model as shown by K.T. Yeo [20]. Accordingly, an increase in duration of the project with respect to initial planning was determined with the application of following mathematical relationships:

$$[X_t - \mu] / \sigma = Z$$

(equation 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, 2.616
Z = Corresponding value from normal distribution chart against probability value (90 percent confidence level in this case), 1.29.

Therefore, the project will be completed with a 90 percent likelihood of an 8.3 months time over-run. Similarly, the project will experience a 90 percent likelihood of a cost overrun of 71.23 million in US dollars.

Risk Responses

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

- to avoid;
- to reduce;
- to transfer; and
- to absorb.

The risk management group derived the following responses for the project under study:

- Carry out a detailed survey with the objective of minimum scope and design change.
- Select technology and implementation methodology on the basis of

owner's/consultant's expertise, availability of contractors and vendors and lifecycle costing.
- Execute design and detailed engineering on the basis of selected technology and implementation methodology and a detailed survey.
- Select superior contractors, consultants and vendors on the basis of past performance.
- Schedule project by accommodating seasonal calamities.
- Plan contingencies and acquire insurance.
- Ensure the availability of all statutory clearances before doing design and detailed engineering work.

Table 6 shows the estimated cost of the above risk responses for each work package. Sources for the cost data are the detailed feasibility report and cost estimate for the project along with looking at other recently completed projects and quotations from vendors and contractors.

The next step is to form a decision tree for each work package considering the probability and severity of failure and various possible responses.

The group arrived at the following decision alternatives.

- do nothing;
- carrying out detailed survey (or additional survey work);
- using superior technology;
- engaging an expert project team; and
- taking all responses as indicated in the tables included with this article.

Figures 6, 7, 8, and 9 show the decision trees for the work packages (pipeline laying, pipe laying across river, station construction, and telecommunication and cathodic protection) of the project under study. The probability and severity (time and cost) for each decision alternative are derived from the risk analysis study of each package and the expert opinions gained through brainstorming.

The expected money values (EMV) are then calculated for each alternative decision for all the packages. Tables 7-10 show the calculations of decision tree approach of risk management. Table 11 shows the decisions emerge from the decision tree approach of risk management.

This study suggests a project management model with the application of risk management principles. A decision support system (DSS) has been developed in an analytic hierarchy process (AHP) and decision tree analysis (DTA) framework. This helps the management of projects and helps in making objective decisions. The DSS identifies risk factors that are inherent in the project, analyzes their effect on various activities, and derives responses in line with project objectives, the organization's policy, and business opportunities.

Risk is by nature subjective. However, AHP allows one to objectively analyze the effect of risk on a project by determining the probability of its occurrences. The probability and severity of each risk factor are determined through the active involvement of field experienced persons in an interactive environment. The information is collected in a very structured format in line with AHP requirements and processed using available computer programs. Additionally, sensitivity utility of AHP provides an opportunity to the risk management group to observe the nature of model outcomes in different alternative decision situations. DTA helps in selecting from among various decision alternatives. Risk management using a combined AHP and DTA approach provides the following benefits.

- Although most of the risk analysis methodologies quantify risk by determining probability and severity of risk factors, they do not identify responses objectively. However, the combined AHP and DTA approach not only determines probability and severity of risk factors, but also identifies risk responses for each work package using an expected monetary value concept. This approach is especially required for large-scale projects because there are many outcome uncertainties.
- It provides an objective basis to management for additional investment in planning or for engaging superior consultants, contractors, and suppliers for specific work packages or items.
- It defines the roles of project stakeholders in responding to specific risk factors and it provides a basis of control to the owner or management.
- It develops an algorithm to model a computerized decision support system using an integrated risk management approach. It combines identification of risk factors, analyzes their effects, allows responses through desired actions and controls these responses in an interactive way by involving all project stakeholders. Using sensitivity analysis at each step provides management with an ongoing bases for decisions.

General benefits can be achieved from the application of risk management in any type of project, including the following benefits.

- The issue/problems are clarified and allowed for from the start of the project.
- Decisions are supported by thorough analysis of available data.
- The structure and definition of the project are continually and objectively monitored.
- Contingency planning allows prompt, controlled, and pre-evaluated responses to risk issues that materialize.
- There are clearer definitions of the specific risk associated with a project.
- It builds-up of a statistical profile of the historical risk and this allows better modeling for future projects.
- It encourages problem solving and provides innovative solutions to the risk problems within a project.
- It provides a basis for project organizational structure and appropriate responsibility matrix.

Specific benefits, achieved by applying risk management techniques in managing the study project, include the following.

- Problems encountered while executing a project were identified during the planning phase. This helped in making suitable responses for effective project management. Responses included alternative design and engineering, engaging superior consultants, contractors and vendors.
- Critical activities were identified and appropriate responsibilities were prepared for managing these critical activities.
- Use of a risk management methodology helped complete the project without any time or cost overruns.

- It helped in forecasting the project achievement quantitatively and allowed management to make decisions objectively.
- It provided a control basis for effective implementation of the project.
- Changes in scope were accommodated through proper study of the implications on the overall objectives of the projects.
- Risk is by nature subjective. AHP provides a flexible and easily understood way to analyze each risk factor with respect to project achievement.
- The risk analysis model, even for a large complex project, can easily be computerized through an Expert Choice software package or Microsoft Excel package.
- AHP calls for active involvement of the project stakeholders in risk analysis and provides a rational basis for determining the probability of project failure.
- Risk management using AHP integrates all project stakeholders. This not only involves them in making group decisions but also improves the team spirit and motivation.
- Although using a decision tree approach (DTA) in deciding a specific course of action is not a new method, the logical structure of risk management philosophy is identified by the alternative responses in mitigating risk and incorporating management perceptions.

Risk management using a combined AHP and DTA provides an effective means for managing a complex project efficiently, and for fighting against time, cost, and quality non-achievement.

Though this article makes an effort to quantify risk by modeling its probability and severity in line with the perceptions of experienced project executives, subjectivity could not be reduced to zero because the findings and recommendations vary with the types of projects, risk perceptions of management, the organization's objectives and policies, and the business environment.

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