Decision support system for risk management: a case study

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Risk management,
Analytical hierarchy process,
Decision trees

Abstract
This study demonstrates a quantitative approach to construction risk management through analytic hierarchy process and decision tree analysis. All the risk factors are identified, their effects are quantified by determining probability and severity, and various alternative responses are generated with cost implication for mitigating the quantified risks. The expected monetary values are then derived for each alternative in a decision tree framework and subsequent probability analysis aids the decision process in managing risks. The entire methodology is explained through a case application of a cross-country petroleum pipeline project in India and its effectiveness in project management is demonstrated.

Introduction

The success parameters for any project are in time completion, within specific budget and with requisite performance (technical requirement). The main barriers for their achievement are the changes in the project environment. The problem multiplies with the size of the project as uncertainties in project outcome increase with size. Large-scale construction projects are exposed to 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 characterized 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 organization.

In these circumstances, a conventional approach (Figure 1) to project management (practiced by the organization under study) is not sufficient, as it does not enable the project management team to establish an adequate relationship among all phases of project, to forecast project achievement for building confidence of project team, to make decisions objectively with the help of available database, to provide adequate information for effective project management and to establish close co-operation among project team members.

The following incidents demonstrate the project management problems experienced by the pipeline operators while managing large pipeline construction projects.

In 1995, a 60 kilometre long pipeline (diameter 12 inches) was planned for replacing transportation mode of crude oil and petroleum products via vessels in the eastern part of India. The project duration was 18 months. The project consisted of laying pipe across river Ganges (river width two kilometres at the point of crossing) along with other work packages (laying main line pipes, station construction, cathodic protection, telecommunication, etc.). The river crossing work package was planned to be executed by a turnkey contractor to be selected through the global tendering method. As the owner had previous experience of laying pipe across river/canal (width maximum one kilometre) using horizontal direction drilling through turnkey contractors, no study was made either during feasibility analysis or during planning phase to check whether laying pipe across river of two kilometres is technically feasible or not through some experienced turnkey contractors. From previous experience, the bid document was prepared for engaging a turnkey contractor for laying pipe across the river and floated for receiving offers globally. However, no offer was received within the due dates and subsequent checking up with the prospective contractors revealed that

Management Decision
39/8 [2001] 634–649

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they did not have experience in laying pipe across river of width two kilometres. The case was referred to M/s Bechtel, Houston (global consultant) for identifying suitable contractor for the project. They reported that there were only two contractors having experience of laying pipe across river of 1.8 kilometre width. They recommended selecting one of them and checking up with them the applicability of using their technology for laying pipe across two kilometre wide river. However, they cautioned that the owner had to take the risk of failure. Alternatively, they suggested constructing a bridge across the river and laying pipe along the pier of the bridge. This option was not suitable to the owner, as constructing bridge across the river does not come under scope of their business. The owner decided to abandon the project in its current form and decided to look into the alternative designs. The project has been recently (1999) commissioned with the concept of laying branch pipeline from an existing pipeline by suitably augmenting the capacity of the existing pipeline. This has been done to get an alternative site for river crossing where the river width is within the limit of available experienced contractors for laying pipe across river.

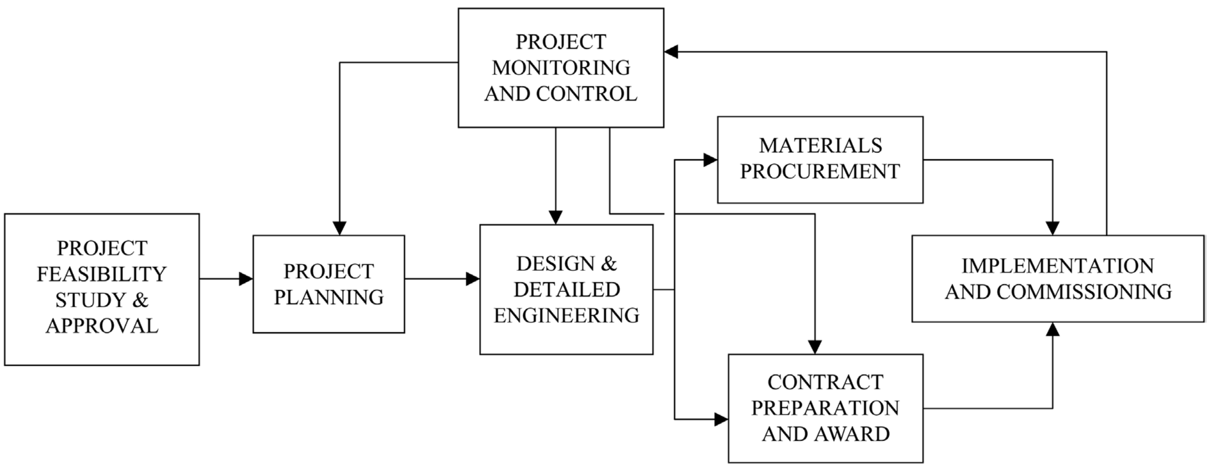
Another pipeline in northwest part of India had been commissioned in 1996 with huge cost escalation (more than 125 percent) from the original estimate due to devaluation of Indian currency during the project duration, changing contract type (unit contract to turnkey contract), distance management with main turnkey contractor (M/s SKODA Export), and many design alterations midway. Although the project was completed on schedule, the dispute between owner and the main contractor related to extra claims reached to such an extent that they went for arbitration. The hearings are reported to be still continuing.

Another pipeline project, recently completed in southern part of India was badly affected due to delayed delivery of a few vertical turbine pumps by a supplier in public sector of India. The bid for supplying the pumping units was awarded to them on competitive basis with the consideration of past performance including delivery schedule. Although the financial performance of the company has deteriorated over the past few years, this was ignored while evaluating their offer. During the manufacturing of the referred order, the management of the supplier decided to reduce the production capacity so as to minimize the loss. This caused disruption of delivery schedule of all of their orders including the vertical turbine pumps under consideration. However, the project owner could not anticipate the delayed delivery until the due date reached, as they did not establish many follow-ups with the supplier. Later they improved the follow-up with the supplier and got the delivery of the pumping units after five months of scheduled delivery. These resulted in an overall delay in completing the project by more than a year.

All of the cases show clear evidence of not using any formal risk management method for managing project and experienced time and cost overrun respectively. Other than these, there are many examples of non-achieving time, cost and quality of projects due to absence of risk management technique in project management.

The objective of the study is to model a decision support system (DSS) through risk

Figure 1
Conventional project management model



Management Decision
39/8 [2001] 634–649

analysis for making objective decisions on project planning, design, engineering, and resource deployment for completing project in time, within budget and with requisite specification in line with project objectives, organization's policy and present business scenario.

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 project got 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 got controlled through effective monitoring of various performance parameters that are fixed during 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.

The scope of this study is limited to establishing risk management after the project got approved.

Risk and risk management process

Chapman and 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; and
3 risk responses.

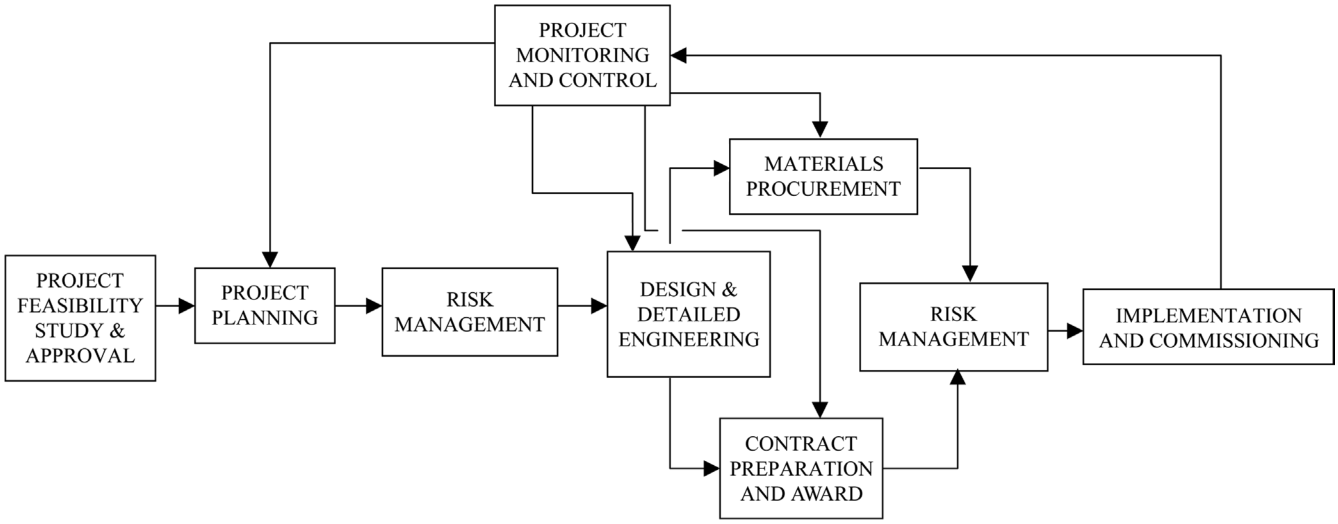
Tummala and Leung (1999) developed a methodology for risk management governing risk identification, measurement, assessment, evaluation and risk control and monitoring. They have applied for managing cost risk for an EHV transmission line project.

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 identification of risk factors effectively in a project. Perry and 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 and Keizer (1998).

Most of the analyses done so far are centered on analyzing the duration of the

Figure 2
Proposed project management model



Management Decision
39/8 [2001] 634–649

project. The 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 classical Beta distribution (e.g. Farnum and Stanton, 1987). Berny (1989) proposed his own distributions for practical simulations.

Recently, a number of systematic models have been proposed for use in the risk-evaluation phase of the risk-management process. Kangari and 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 analytical hierarchy process (AHP) developed by Saaty (1980) 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 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 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 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 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. 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 normalized 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 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. Therefore, to risk analyze the project, the level of activity for which risks are to be analyzed is first determined.

Mustafa and 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.

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

Decision trees use calculations of expected monetary value (EMV) to measure the attractiveness of alternatives. Decision trees, however, use graphical models as well 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 – a series of

Management Decision
39/8 [2001] 634–649

decisions over time (Dilworth, 2000). The decision tree approach:

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

Methodology

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

1 identifying the work packages for risk analysis;
2 identifying the factors that affect the time, cost and quality achievement of specific work package;
3 analyzing their effect by deriving the likelihood of their occurrences in AHP framework;
4 determining severity of failure by guestimation;
5 driving various alternative responses for mitigating the effect of risk factors;
6 estimating cost for each alternative;
7 determining the probability and severity of failure of specific work package after specific response;
8 forming decision tree;
9 deriving expected monetary value (EMV) (cost of risk response in this case); and
10 selecting the best option through statistical analysis.

Application

The above steps have been explained through a case of cross-country petroleum pipeline project in India having length 1,300 kilometres in the western part of India. The pipeline size is 22 inches diameter for a length of 1,112 kilometres, 18 inches for a length of 218 kilometres, and 10.75 inches for a length of 123 kilometres (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)

Figure 3 shows the flow chart for risk management.

A risk management group was formed to do risk analysis study for the project under study. The group consisted of one member each from mechanical, electrical, civil, telecommunication and 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.

Identification of work packages

The total project scope was decomposed and classified to form work break down structure. According to the importance in achieving time target, the following work packages were considered for risk management.

- river crossing;
- pipeline laying;
- stations construction; and
- other packages (telecommunication and cathodic protection).

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

2 *Acts of God*:
   - natural calamities normal; and
   - natural calamities abnormal.

3 *Financial, economical and political risk*:
   - inflation risk;
   - fund risk;
   - changes of local law;
   - changes in government policy; and
   - improper estimation.

4 *Organizational risk*:
   - capability risk of owner's project group;
   - contractor's failure;
   - vendor's failure; and
   - consultant's failure.

5 *Statutory clearance risk*:
   - environmental clearance;
   - land acquisition;
   - clearance from chief controller of explosive (CCE); and
   - other clearance from government authorities.

Formation of risk structure

This study focuses on two dimensionality (probability and severity) of project risk. The

Management Decision
39/8 [2001] 634–649

risk perception as shown by Turner (1999) has not been considered due to the nature of construction risk. Figure 4 shows the AHP model for risk analysis. Level 1 is the goal i.e. "determining riskiness of project". Level 2 and 3 are for factors and sub-factors respectively. Level 4 contains the alternatives i.e. work packages.

Pair wise comparison

The above model was made in Expert Choice software package developed by Forman and Saaty (1983). Pair wise comparisons were made through executives working in projects in a group decision-making process. Questionnaire was made and distributed among the executives separately so as not to influence each other. Risk management group analyzed the responses. Table I shows a comparison matrix in factor level. The outcome of matrix operation results in the likelihood of these risks while the project is being executed.

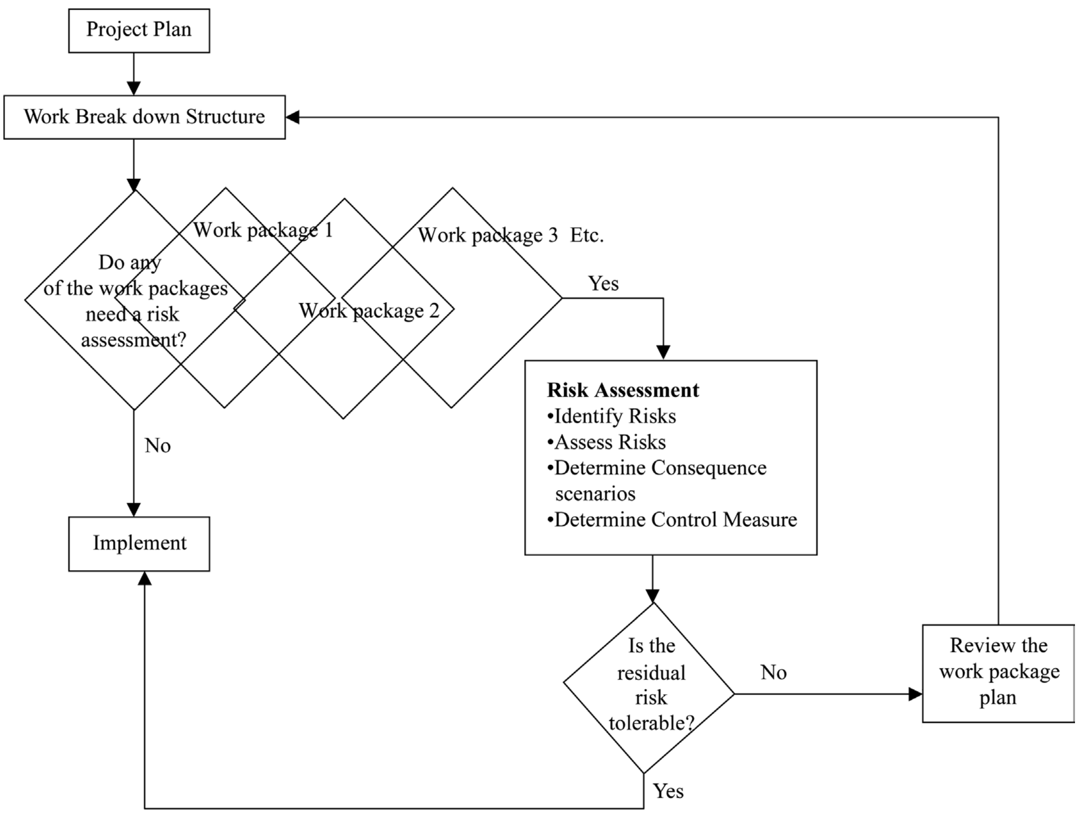
The pair wise comparison in other levels also results in the likelihood of occurrence of risk sub factors. Synthesizing all likelihood of risk factors and sub-factors across hierarchy forms overall likelihood of failure of work packages. Table II shows the detailed analysis of AHP model.

Results and findings from risk analysis study

Results and findings from the risk analysis study included:

- Technical risk is the major factor for time and cost overrun of project. Among the technical risks, 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 change. Technology selection is vital for river crossing and telecommunication packages. Engineering and design change is quite likely for the "river crossing" and "the pipeline laying" work packages. Prior selection of implementation methodology is crucial for the "river crossing" packages, as improper selection causes major time and cost overrun. Unavailability of pipe materials and delayed delivery of pumping unit sometimes result in considerable time overrun.

Figure 3
Risk management flow chart



Management Decision
39/8 [2001] 634–649

- Other major risks in project achievement are financial, economical and political risk (F&ER) and organizational 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 organizational risk is less vulnerable for the project under study, consultant and contractor's capabilities are os some 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.
- Although the project under study is not particularly vulnerable from statutory clearance risk, care should be taken for getting environmental clearance and explosive clearance on time for trouble free implementation.
- 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.
- 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 there on. The "station construction" work package is vulnerable from scope change and has 23 percent probability of failure.

Risk mapping

All the factors were organized as per their probability and severity (effect on time and

Figure 4
AHP model for determining riskiness of project

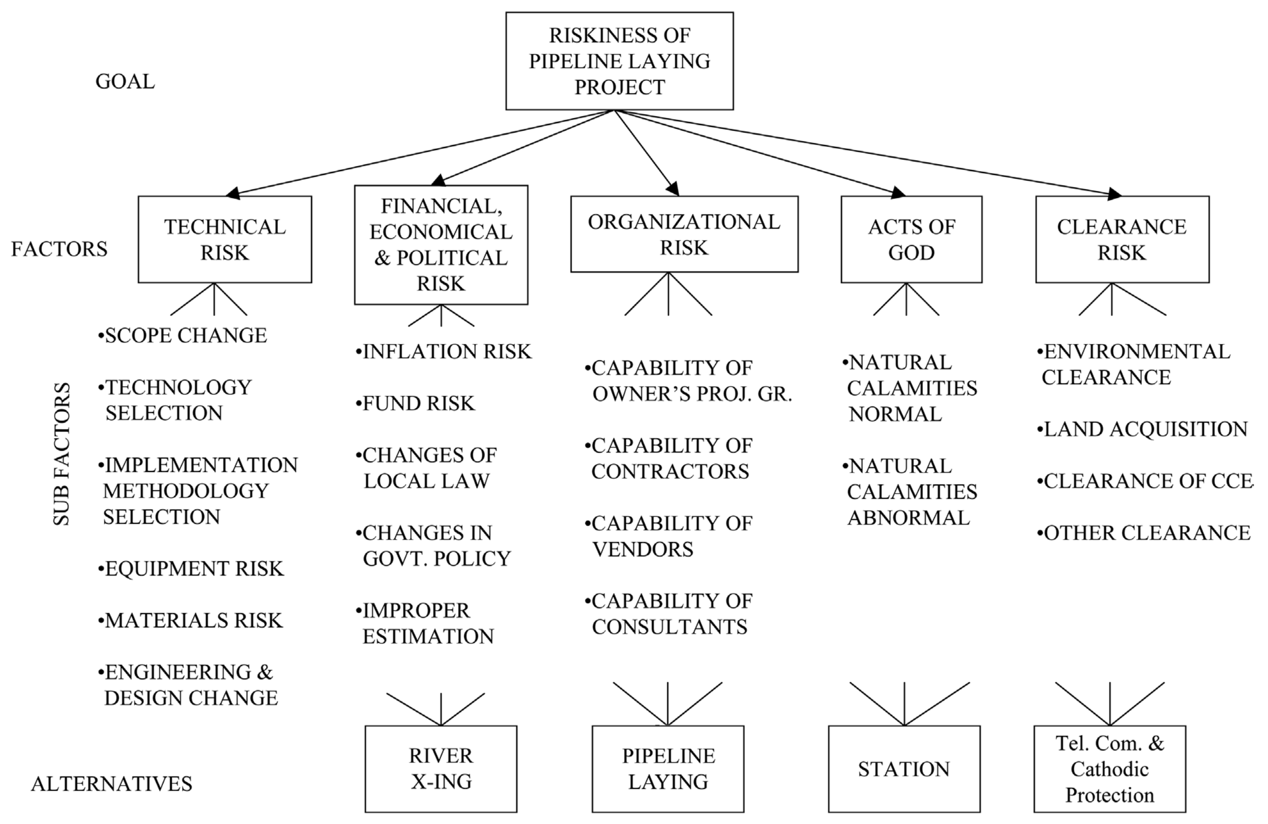


Table I
Comparison matrices in factor level

Factors	Technical risk	Financial and economical risk	Organizational risk	Acts of God risk	Clearance risk	Likelihood
Technical risk	1	3	4	5	5	0.479
Financial and economical 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

Note: Consistency ratio: 0.042, hence acceptable

cost) characteristics as indicated in Table III. 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 program. These will cause considerable time and cost overrun in project. The factors like, land

Table II
Likelihood of risk in project

Factors	Likelihood	Sub-factors	Likelihood LP	Likelihood GP	River X-ing LP	River X-ing GP	Pipeline laying LP	Pipeline laying GP	Station construction LP	Station construction GP	Other work packages LP	Other work packages GP
Technical risk	0.479	Scope change	0.360	0.172	0.170	0.029	0.390	0.067	0.310	0.053	0.130	0.022
		Technology selection	0.124	0.059	0.290	0.017	0.230	0.014	0.110	0.007	0.370	0.022
		Implementation methodology	0.130	0.062	0.470	0.029	0.260	0.016	0.170	0.011	0.100	0.006
		Equipment risk	0.073	0.035	0.330	0.012	0.210	0.007	0.280	0.010	0.180	0.006
		Materials risk	0.080	0.038	0.170	0.007	0.350	0.013	0.260	0.010	0.220	0.008
		Engineering and design change	0.233	0.112	0.370	0.041	0.330	0.037	0.130	0.015	0.170	0.019
Financial and economical risk	0.228	Inflation risk	0.152	0.035	0.250	0.009	0.250	0.009	0.250	0.009	0.250	0.009
		Fund risk	0.383	0.087	0.250	0.022	0.250	0.022	0.250	0.022	0.250	0.022
		Changes in local law	0.105	0.024	0.180	0.004	0.180	0.004	0.190	0.005	0.250	0.006
		Changes in government policy	0.105	0.024	0.250	0.006	0.250	0.006	0.250	0.006	0.250	0.006
		Improper estimate	0.255	0.058	0.430	0.025	0.430	0.025	0.170	0.010	0.080	0.005
Organizational risk	0.146	Capability of owner's project group	0.106	0.015	0.330	0.005	0.300	0.005	0.270	0.004	0.100	0.002
		Contractor's capability	0.283	0.041	0.370	0.015	0.330	0.014	0.220	0.009	0.080	0.003
		Vendor's capability	0.448	0.065	0.210	0.014	0.290	0.019	0.400	0.026	0.100	0.007
		Consultant's capability	0.163	0.024	0.490	0.012	0.130	0.003	0.150	0.004	0.230	0.005
Acts of God	0.064	Calamity normal	0.440	0.028	0.410	0.012	0.350	0.010	0.140	0.004	0.100	0.003
		Calamity abnormal	0.560	0.036	0.320	0.011	0.470	0.017	0.090	0.003	0.120	0.004
Clearance risk	0.083	Environmental clearance	0.026	0.022	0.250	0.005	0.250	0.005	0.250	0.005	0.250	0.005
		Land acquisition	0.461	0.038	0.130	0.005	0.510	0.020	0.300	0.011	0.060	0.002
		Explosive clearance	0.133	0.011	0.250	0.003	0.280	0.003	0.360	0.004	0.110	0.001
		Other clearances	0.142	0.012	0.250	0.003	0.250	0.003	0.150	0.002	0.350	0.004
Overall likelihood of failure						0.286		0.317		0.229		0.169
Rank						2		1		3		4

Note: LP = local percentage; GP = global percentage

Management Decision
39/8 [2001] 634–649

acquisition, technology selection, engineering and design change, contractor's capability, vendor's 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.

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 IV shows the probability and severity of all risk factors.

The results in Table IV were used to derive the expected time and cost overrun along with the respective standard deviations using the following formula (Canavos, 1984).

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

$$\mu'_r = E(X^r) = \sum_x x^r p(x) \quad \text{if } X \text{ is discrete, or} \tag{1}$$

$$\mu'_r = E(X^r) = \int_{-\alpha}^{\alpha} X^r f(x)dx = \quad \text{if } X \text{ is continuous.} \tag{2}$$

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:

$$\mu'_r = E(X-\mu)^r = \Sigma_x (x-\mu)^r p(x) \quad \text{if } X \text{ is discrete, or} \tag{3}$$

$$\mu_r = E(X-\mu)^r = \int_{-\alpha}^{\alpha} a_(x-\mu)^r f(x)dx \quad \text{if } X \text{ is continuous.} \tag{4}$$

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 IV 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;
- the expected cost overrun = US$26.44 million;
- the standard deviation = US$34.72 million; and
- the approved cost was US$600 million.

No management can be satisfied with a 50 percent 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:

$$[X_t - \mu]/\sigma = Z, \tag{5}$$

where:

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; and
Z = corresponding value from normal distribution chart against probability value (90 percent confidence level in this case), 1.29.

Table III
Risk mapping in project level

	Probability		
Severity	**Low**	**Medium**	**High**
High	Calamity normal	Land acquisition Technology selection Engineering and 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 clearance Other clearances		

Management Decision
39/8 [2001] 634–649

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

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

Risk responses

Risk analysis results lead 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 through brainstorming session derived the following responses for the project under study:

- carrying out detailed survey with the objective of minimum scope and design change;
- selecting technology and implementation methodology on the basis of owner's/consultant's expertise, availability of contractors and vendors and lifecycle costing;
- executing design and detailed engineering on the basis of selected technology and implementation methodology and detailed survey;
- selecting superior contractors, consultants and vendors on the basis of past performance;
- scheduling project by accommodating seasonal calamities;
- planning contingencies and acquiring insurance; and
- ensuring the availability of all statutory clearance before design and detailed engineering.

Table V shows the estimated cost of the above risk responses for each work package. Sources for cost data are the detailed

Table IV
Probability and severity of risk factors

Risk factors	Probability	Severity: Time overrun (in months)	Severity: Cost overrun (in US$million)
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

Table V
The cost data (US$ million) for each package against various responses

Responses	Pipeline laying	River crossing	Station construction	Tele-communication and CP	Building and 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 of 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		

Management Decision
39/8 [2001] 634–649

feasibility report and cost estimate for the project concerned based on other recently completed projects and quotations from vendors and contractors.

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

The group decided the following decision alternatives:

- do nothing;
- carrying out detailed survey (additional);
- using superior technology;
- engaging expert project team; and
- taking all responses as indicated in Table V.

Figures 5-8 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 expert opinion through brainstorming.

The expected money values (EMV) are then calculated for each alternative decision for all the packages. Tables VI-IX show the calculations of decision tree approach of risk management.

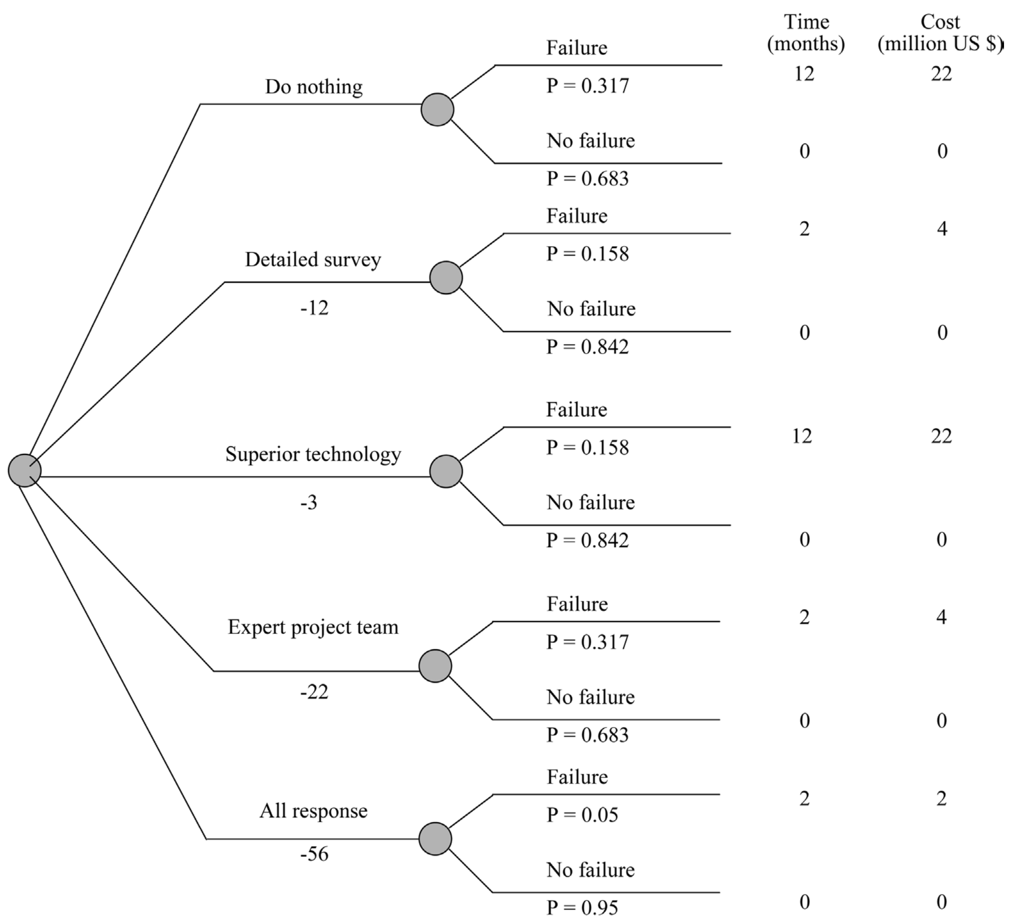
Table X shows the decisions that emerge from the decision tree approach of risk management:

Total cost for risk responses is US$65.65 million which is much lower than US$140 million.

Summary and conclusions

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

Figure 5
Decision tree for "pipeline laying" work package



Management Decision
39/8 [2001] 634–649

Figure 6
Decision tree for "river crossing" work package

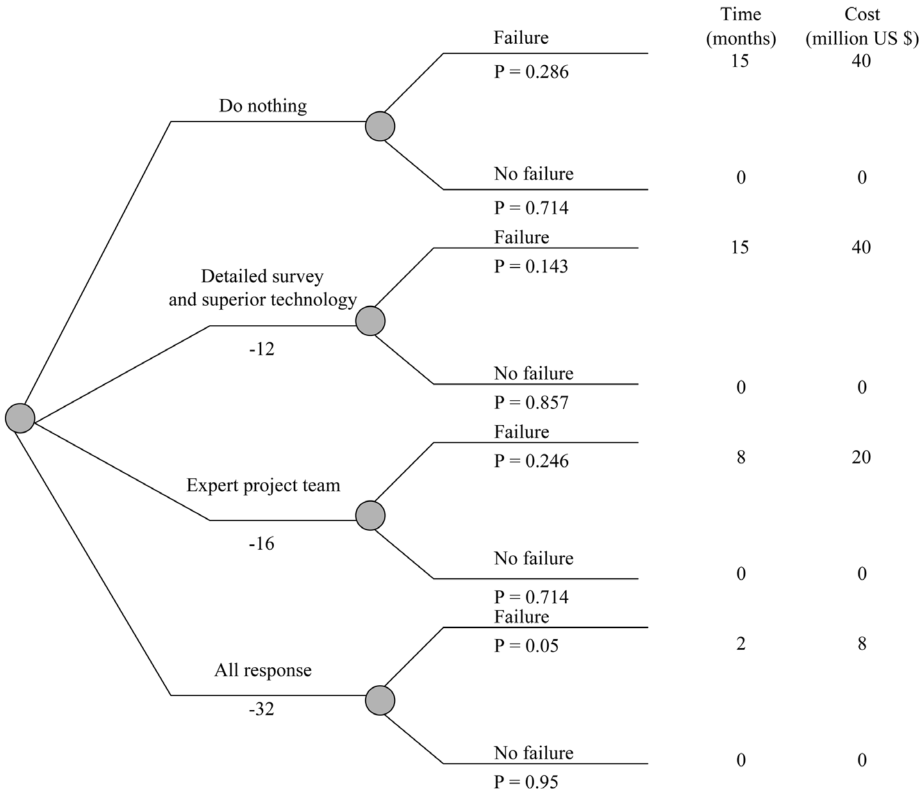


Figure 7
Decision tree for "station construction" work package

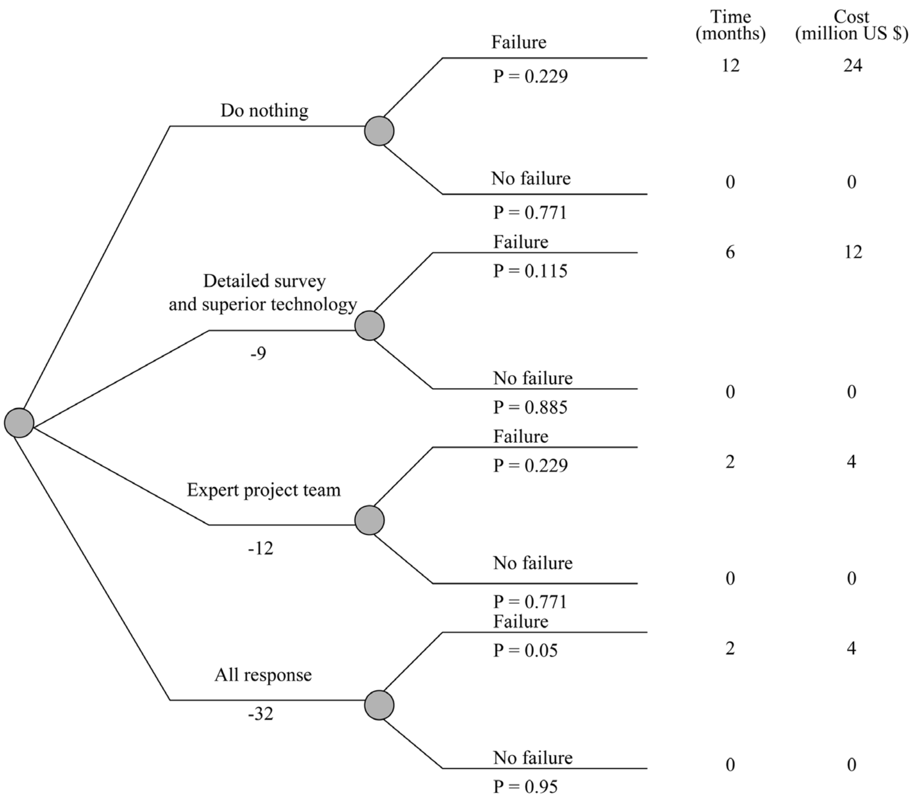
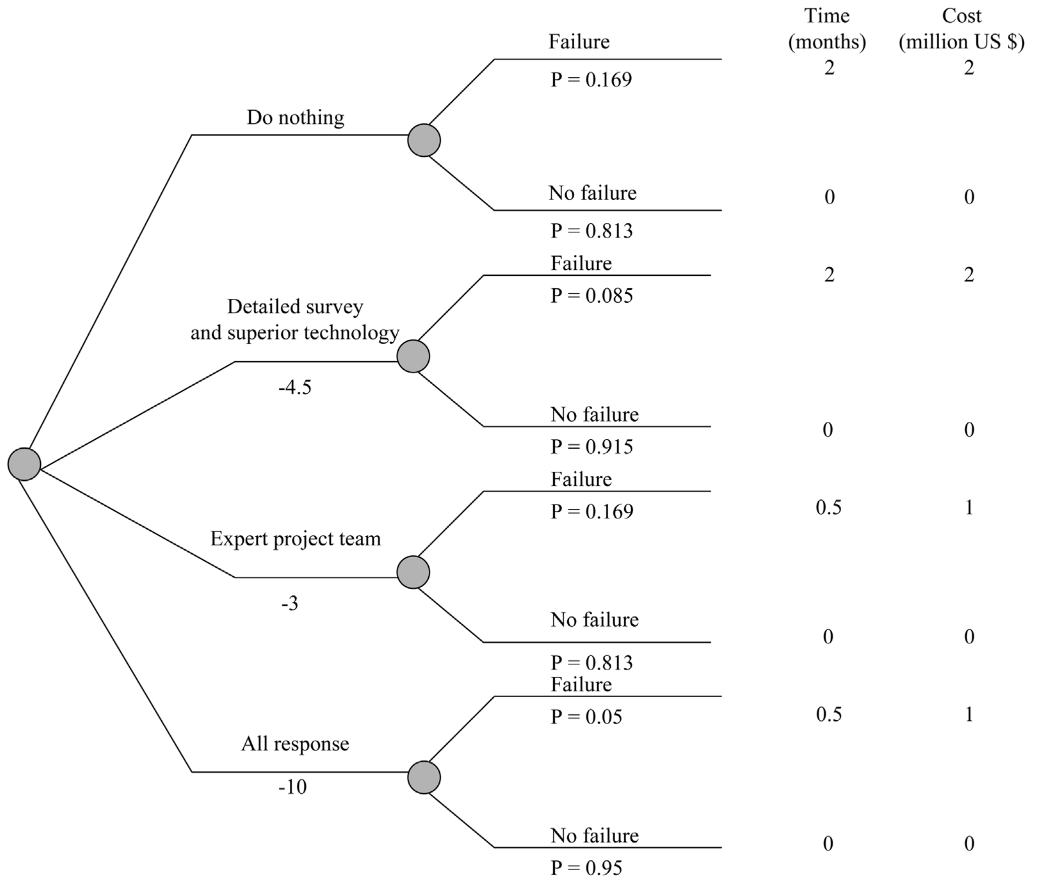


Figure 8
Decision tree for "telecommunication and cathodic protection" work package



Risk is by nature subjective. However, AHP allows analysis of the effect of risk on project very objectively by determining the probability of their occurrences. The probability and severity of each risk factor are determined 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. Additionally, sensitivity utility of AHP provides an opportunity to the risk management group to observe the nature of model outcome in different alternative decision situations. DTA helps in selecting one among various decision alternatives.

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

Table VI
The EMV for "pipeline laying project"

			Effect		Expected value		EMV[a] (US$ million)
Decision alternatives	Cost (US$ million)	Probability of failure	Time (months)	Cost (US$ million)	Time (months)	Cost (US$ million)	
Do nothing	0	0.317	12	22	3.80	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	1.90	3.50	21
Engaging expert project team	22	0.317	2	4	0.64	1.30	28
Taking all responses as indicated in table	56	0.050	2	2	0.10	0.10	56.9

Note: [a]EMV = 0 + 3.8 X 7.5 + 6.97 = 35.5; Return on investment is $US7.5 million per month i.e. 15 percent of $US600 million per annum

Management Decision
39/8 [2001] 634–649

- The issue/problems of the project are clarified understood and allowed for right from the start.
- 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 risks that materialize.
- Clearer definitions of the specific risk associated with a project.
- It buildsup a statistical profile of historical risk to allow better modeling for future projects.
- It encourages problem solving and providing innovative solutions to the risk problems within a project.
- It provides a basis for project organization structure and appropriate responsibility matrix.

Specific benefits that were achieved by applying risk management technique in managing project under study are shown below:

- Problems that were encountered while executing a project were identified during planning phase. These helped in making suitable responses for effective project management by alternative design and

Table VII
The EMV for "pipeline laying across river"

Decision alternatives	Cost (US$ million)	Probability of failure	Effect: Time (months)	Effect: Cost (US$ million)	Expected value: Time (months)	Expected value: Cost (US$ million)	EMV[a] (US$ million)
Do nothing	0	0.286	15	40	4.30	11.44	43.70
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	2.30	5.72	39
Taking all responses as indicated in table	32	0.050	2	8	0.10	0.40	33.15

Note: [a]EMV = 0 + 3.8 X 7.5 + 6.97 = 35.5; Return on investment is US$7.5 million per month i.e. 15 percent of US$600 million per annum)

Table VIII
The EMV for "station construction"

Decision alternatives	Cost (US$ million)	Probability of failure	Effect: Time (months)	Effect: Cost (US$ million)	Expected value: Time (months)	Expected value: Cost (US$ million)	EMV[a] (US$ million)
Do nothing	0	0.229	12	24	2.75	5.50	26.2
Carrying out detailed survey and using superior technology	9	0.115	6	12	0.70	1.32	15.6
Engaging expert project team	10	0.229	2	4	0.46	0.92	14.5
Taking all responses as indicated in table	32	0.050	2	4	0.10	0.20	33

Note: [a]EMV = 0 + 3.8 X 7.5 + 6.97 = 35.5; Return on investment is US$7.5 million per month i.e. 15 percent of US$600 million per annum)

Table IX
The EMV for "telecommunication and cathodic protection"

Decision alternatives	Cost (US$ million)	Probability of failure	Effect: Time (months)	Effect: Cost (US$ million)	Expected value: Time (months)	Expected value: Cost (US$ million)	EMV[a] (US$ million)
Do nothing	0	0.169	2	2	0.340	0.34	3
Carrying out detailed survey and using superior technology	4.5	0.085	2	2	0.170	0.17	5
Engaging expert project team	3	0.169	0.5	1	0.085	0.17	3.80
Taking all responses as indicated in table	10	0.050	0.5	1	0.025	0.05	10.25

Note: [a]EMV = 0 + 3.8 X 7.5 + 6.97 = 35.5; Return on investment is US$7.5 million per month i.e. 15 percent of US$600 million per annum)

Management Decision
39/8 [2001] 634–649

Table X
The decisions that 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	Taking all responses as indicated in table
Station construction	Engaging expert project team
Telecommunication and cathodic protection	Do nothing

engineering, engaging superior consultants, contractors and vendors.

- Critical activities were identified and appropriate responsibilities were prepared for managing the critical activities.
- Risk management methodology helped in completing the project without any time and cost overrun.
- It helped in forecasting the project achievement quantitatively allowing management to make decisions objectively.
- It provided a control basis for effective implementation of project.
- It accommodated changes in scope through proper study on implication of overall objectives of project.
- 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 large complex project can be easily computerized through Expert Choice software package or Microsoft Excel package.
- AHP calls for active involvement of project stakeholders in risk analysis and provides a rational basis for probability of project failure.
- Risk management using AHP integrates all project stakeholders. Hence, this not only involves them in making group decision, but also improves team spirit and motivation.
- Although decision tree approach (DTA) in deciding a specific course of action is not new method, it logically structures risk management philosophy by identifying alternative responses in mitigating risk and incorporates management perceptions.

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

Though this study makes an effort to quantify risk by modeling 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 be varying with the types of projects, risk perception of its management, organization's objectives and policies and business environment.

References

Berny, J. (1989), "A new distribution function for risk analysis", *Journal of the Operational Research Society*, Vol. 40, pp. 1121-7.

Canavos, G.C. (1984), *Applied Probability and Statistical Methods*, Little, Brown & Company, Boston, MA.

Chapman, C.B. and Cooper, D.F. (1983), "Risk analysis: testing some prejudices", *European Journal of Operational Research*, Vol. 14, pp. 238-47.

Cooper, D.F., MacDonald, D.H. and Chapman, C.B. (1985), "Risk analysis of a construction cost estimate", *International Journal of Project Management*, Vol. 3 No. 3, pp. 141-9.

Dey, P.K. (1997), "Symbiosis of organizational re-engineering and risk management for effective implementation of projects", doctoral thesis, Jadavpur University, Calcutta.

Dey, P.K. (1999), "Process re-engineering for effective implementation of projects", *International Journal of Project Management*, Vol. 17 No. 3, pp. 147-59.

Dey, P.K., Tabucanon, M.T. and Ogunlana, S.O. (1994), "Planning for project control through risk analysis; a case of petroleum pipeline laying project", *International Journal of Project Management*, Vol. 12 No. 1, pp. 23-33.

Dilworth, J.B. (2000), *Operations Management: Providing Value in Goods and Services*, The Dryden Press, Hillsdale, NJ.

Farnum, N.R. and Stanton, L.W. (1987), "Some results concerning the estimation of beta distribution parameters in PERT", *Journal of the Operational Research Society*, Vol. 38 No. 3, pp. 287-90.

Forman, E.H. and Saaty, T.L. (1983), *Expert Choice Expert Choice*, Pittsburgh, PA.

Halman, J.I.M. and Keizer, J.A. (1998), "Risk management in product innovation projects", *International Journal of Project and Business Risk Management*, Vol. 2 No. 2.

Kangari, R. and Riggs, L.S. (1989), "Construction risk assessment by linguistics", *IEEE Trans. Eng. Manag.*, Vol. 36 No. 2, pp. 126-31.

Mustafa, M.A. and Al-Bahar, J.F. (1991), "Project risk assessment using the Analytic Hierarchy

Management Decision
39/8 [2001] 634–649

Process", *IEEE Trans. Eng. Manag.*, Vol. 38 No. 1, pp. 46-52.
Perry, J.G. and Hayes, R.W. (1985), "Risk and its management in construction projects", *Proceedings of the Institute of Civil Engineering*, Vol. 78 No. 1, pp. 499-521.
Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY.
Tummala, V.M.R. and Leung, Y.H. (1999), "Applying a risk management process (RMP) to manage cost risk for an EHV transmission line project", *International Journal of Project Management*, Vol. 17 No. 4, pp. 223-35.
Turner, J.R. (1999), *The Handbook of Project-based Management*, McGraw-Hill, New York, NY.
Williams, T.M. (1995), "A classified bibliography of recent research relating to project risk management", *European Journal of Operational Research*, Vol. 85 No. 1, pp. 18-38.
Yeo, K.T. (1990), "Risks, classification of estimates and contingency", *Journal of Management Engineering*, Vol. 6 No. 4, pp. 458-70.

Application questions

1 Develop a DSS for managing risk of projects of your organization using the methodology as described in this article. Is it possible to justify its benefit for effective implementation of project?
2 Explain the human aspects of project risk management. How does it affect the selection of risk management tools and techniques?
3 Develop a scenario in which effective project risk management is used. How does the methodology used compare with the methodology proposed in this article?
4 If project risk management is not being practiced in your organization, how could you suggest its use for effective project management to the board of directors of your organization?