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Petroleum pipeline construction planning: a conceptual framework

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A cross-country pipeline construction project is exposed to an uncertain environment due to its enormous size (physical, manpower requirement and financial value), complexity in design technology and involvement of external factors. These uncertainties can lead to several changes in project scope during the process of project execution. Unless the changes are properly controlled, the time, cost and quality goals of the project may never be achieved. A methodology is proposed for project control through risk analysis, contingency allocation and hierarchical planning models. Risk analysis is carried out through the analytic hierarchy process (AHP) due to the subjective nature of risks in construction projects. The results of risk analysis are used to determine the logical contingency for project control with the application of probability theory. Ultimate project control is carried out by hierarchical planning model which enables decision makers to take vital decisions during the changing environment of the construction period. Goal programming (GP), a multiple criteria decision-making technique, is proposed for model formulation because of its flexibility and priority-base structure. The project is planned hierarchically in three levels—project, work package and activity. GP is applied separately at each level. Decision variables of each model are different planning parameters of the project. In this study, models are formulated from the owner's perspective and its effectiveness in project control is demonstrated. Copyright © 1996 Elsevier Science Ltd and IPMA

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A cross-country petroleum pipeline construction project is characterized by the complexity in its execution with respect to a 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 environmental impacts, government laws and regulations and changes in the economic and political environments. Cost and time overrun and the unsatisfactory performance of a project are the general sources of disappointment to the management of a pipeline organization.

In these circumstances, a conventional approach to project planning for execution is inadequate, as it does not enable the project management team to establish an adequate relationship between the essential design parameters (technical requirements, construction schedules, investment planning and related expenditures) and to create reference documents (time schedules, cost estimation and specifications) at the early feasibility stages of the project. The relationships and documents are needed to improve the evaluation accuracy, formulate a monitoring scheme for various phases of the project, provide rapid and easy reference to technical and economic information for the project team and establish close cooperation between members of the project team.

The main objective of this paper is to set forth a systematic procedure of project control by forming project breakdown structure (PBS) through risk analysis and deriving logical contingency provision for the project. The paper also attempts to establish an execution planning model for controlling and managing changes that arise during project execution.

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A methodology for controlling changes

The proposed methodology for cross-country petroleum pipeline control under risk environment is described in the following steps:

1. Determination of the scope of the project.
2. Preparation of a work breakdown structure (WBS) for the project.
3. Preparation of an organization breakdown structure (OBS).
4. Identification of risk factors related to specific work packages.
5. Assessment of the effect of risk factors on project objectives by estimating the probability and severity of risk factors for each work package from the construction perspective.
6. Establishment of project breakdown structure through a logical responsibility matrix.
7. Derivation of contingency provisions for the work packages using the results of risk analysis and activity analysis.
8. Cost and scope control through contingency appropriation.
9. Formulation of a strategic execution planning model for controlling changes in project parameters due to risk environment during execution stages.

The project

The project is to lay a cross-country petroleum pipeline in the western part of India. The pipeline size is 22 in diameter for a length of 1112 km, 18 in for a length of 218 km and 10.75 in 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. A detailed description of the project is available elsewhere[1].

Work breakdown structure (WBS)

The total scope of the project is classified to form a WBS. It consists of project systems, functions, work packages, activities and work items in hierarchical order. Typical work packages are different pipeline spreads, pump stations, pumping-cum-delivery stations, delivery stations, scraper stations, terminal stations, cathodic protection system in different spreads and stations, telesupervisory and telecommunication system, survey and field engineering, land acquisition, building and colony construction.

Organization breakdown structure (OBS)

The cross-country pipeline construction project is characterized by the application of comparatively new technology, high complexity in construction, long project duration, and large work volume. These cause uncertainties in its achievement during execution. A typical matrix structure is common in designing OBS for project control.

Risk analysis

Risk analysis consists of two processes:

1. The identification of risk factors and
2. The assessment of their effect on the project.

Risk factors and subfactors are identified for each work package. Hierarchical risk structure is formed for the work package concerned. Various techniques, ranging from simple interviews and the application of the analyst's own experience to the Delphi technique can be used for the identification of risk factors and subfactors.

Risks are by nature subjective. Therefore the analytic hierarchy process (AHP) developed by Saaty[2] is used to assess the effect of risk factors on specific work packages. The relative weights of the various risk factors and subfactors are determined by pairwise comparison of the same from severity of risk perspective. These create a detailed analysis of the ranking of the risk factors and sub-factors for the work package under consideration. The level of likelihood of each sub-factor is determined with respect to high, medium and low risk by pairwise comparison. The likelihood of high, medium and low total risk of the work package are determined by aggregating the relative weights through the hierarchy. The likelihood levels of risk and weights of different levels of risk are combined to determine the overall risks of the work package. Detailed risk analysis for a petroleum pipeline-laying project is demonstrated by Ogunlana *et al.*[3].

Project breakdown structure (PBS)

WBS and OBS are combined to form PBS. It provides a responsibility matrix of individuals working under organization. The results from risk analysis gives a logical base for combining work with organization. Relatively risky work packages remain under strict organizational control and the degree of control varies across work packages from risk perspective during implementation. Scasso and Larenas,[4] have described the concept of PBS as a tool for project management.

Contingency provision

The existing method of a fixed percentage of contingency provision is overly simplistic. The logical contingency provision for the work packages provide considerable control in project achievement. Two-tier contingency developed by Yeo[5] combined with the overall percentage of risk of the work package, are used to determine the logical contingency of the work package. The methodology can be summarized briefly in the following steps:

1. Estimation of base cost.
2. Determination of range estimate by activity analysis.
3. Calculation of expected cost.
4. Calculation of anticipated contingency.
5. Determination of overall risk of work package.
6. Calculation of percentage success desired.
7. Determination of target cost.
8. Calculation of total contingency of work package.

The specifications of activities are liable to change during the actual execution as a result of the non-availability of all the information during the planning estimate. This leads to a varied scope of work of an activity and also rate changes, which causes quantity and unit cost risk. Generally quantity risk and unit cost risk are shared by the owner

and contractor, respectively. The variability of base cost estimate leads owner-management to estimate specific activity in ranges. The lower and upper bound limit depends on the specification and scope definition of activities. The statistical approach leads to determination of expected cost and variance of cost activities with consideration of 'beta' distribution of activity cost data. Accordingly, the application of the 'central limit theorem' leads to determination of even-chance estimate of work packages. Therefore, even-chance estimate conforms to quantity and unit cost risk of activities. The uncertain environment of the project imposes further risk, without consideration of which project achievement remains uncertain. The effect of risk on estimate is taken care of by considering the overall percentage of risk on a work package which corresponds to probability of cost overrun when combined with even-chance success of the project. The detailed procedure and application is illustrated elsewhere[6].

Project control through contingency appropriation

If the changes remain within the contingency limit or it is decided to spend the amount from the total contingency reserve, the corresponding contingency reserve fund has to be updated. In a case where the contingency allowance is not enough to cover an appropriation or a change request, the project manager then seeks an additional funds appropriation documenting the causes or needs. Either the project scope is reduced or the owner decides to arrange additional funds for the project. When the authorized amount is not fully used on a contract, it is transferred back into the contingency reserve.

Execution planning model

Cross-country pipeline construction demands an integrated planning model with time, cost and performance optimization. As a result of uncertainties in the project environment several changes from initial project planning are to be carried out for its achievement. Moreover, priority of construction activities are also to be changed to cope with the changing environment. These necessitate the application of goal programming (GP), a multi-criteria decision-making technique for project planning.

Goal programming approach

GP is a method that requires ordinal and cardinal information for multiple objective decision making. In GP, deviation variables (from goals) with assigned priorities and weights are minimized instead of optimizing the objective criterion directly as in LP. The general form of goal programming may be expressed as follows[5]:

$$\text{Minimize}: Z = \sum_{i=1}^{m} (P_{oi} d_i^+ + P_{ui} d_i^-)$$

Subject to

$$\sum_{j=1}^{n} (a_{ij} x_j) + d_i^- - d_i^+ = b_i, \text{ for } i = 1, 2, \ldots m$$

$$x_j, d_i^-, d_i^+ \geq 0 \text{ for } i = 1, 2, \ldots, m \& j = 1, 2, \ldots n$$

where, x_j are the variables in the goal equations, b_i are the targets or goals, a_{ij} are the coefficients of basic variables, d_i^- represent the under-achievement of goal i, d_i^+ represent the over-achievement of goal i, P_{ui} is the priority associated with d_i^-, and P_{oi} is the priority associated with d_i^+. If over-achievement is acceptable, d_i^+ can be eliminated from the objective function; if under-achievement is satisfactory, d_i^- should be left out of the objective function and if the goal must be achieved exactly as defined, both d_i^+ and d_i^- must be in the objective function. The deviational variables must be ranked according to their priorities, from the most important to the least important. If goals are classified in R ranks, the priority factor P_r $(r = 1, \ldots, R)$ should be assigned to the deviational variables. The priority factors have the following relationships: $P_r >>> NP_{r+1}$ $(r = 1, \ldots R-1)$, which implies that the multiplication of N, however large it may be, cannot make P_{r+1} greater than or equal to P_r. The algorithm procedure is carried out by a modified simplex method.

Hannan[7] demonstrated in his paper how goal programming can be used to incorporate considerations other than the project completion time and project cost into the typical CPM problem. Vrat *et al.*[8] developed a crashing model through GP to ensure non-crashing of a certain activity for quality reasons, to maintain specific budget targets and to minimize total direct costs of crashing.

The total project plan is made separately in three levels – project, work package and activity level. The output of one level planning is utilized to plan another level and vice versa. The total integrated model is depicted in *Figure 1*. Planning starts at the project level with the consideration of different constraints associated with that level. The outcome is fed for planning work packages under the project. The desired level of output from the project level acts as additional constraints to the work package planning model. The nature of the constraints in the work package level may or may not be the same as the project level. The planning variables in the work package are utilized to plan each activity. Activities related to a specific work package are planned with the consideration of different constraints related to specific activity execution. The output levels of a work package become additional constraints to activity planning.

The work precedence relations (WPR) of the whole project

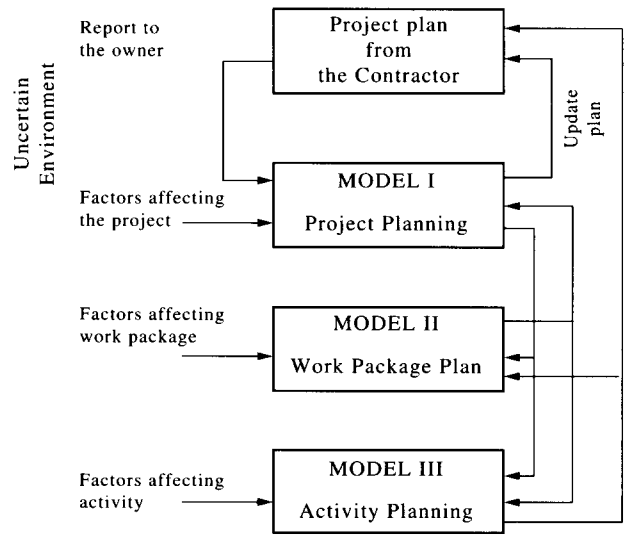

Figure 1 Heirarchical planning model

is prepared in line with WBS. Each level provides WPR as per the content of the level, i.e. for project level planning WPR is prepared for all work packages under the project, and for work package level planning WPR is prepared for all activities under the corresponding work package. Then the overall project duration is determined from the total work content of each activity in a critical path. Accordingly, the owner makes a contract with the contractor to complete the project within that duration. These provide the base for designing the whole project. The owner's next task is to classify the total project duration into some periods for planning as well as controlling the project achievement. The number of periods depend on the requirement of the owner about the frequency of review of the achievement of project parameters. To keep track of the project achievement, project parameters are to be controlled over periods as the situation demands. Accordingly, the owner fixes up the initial project duration breakdown period. However, the number of periods may be varied according to requirements during the changing project environment in line with project objectives. The number of planning periods also varies across the levels according to the criticality of activities.

Aspiration levels of goal constraints are established from available input data, project objectives and the planning environment. Goal programming models are priority based. In this study, models are formulated in different levels with the consideration of different priorities according to the owner's requirements regarding the project achievement. Various techniques, ranging from simple interview to the Delphi technique, may be used to establish initial priorities for different levels.

The detailed project planning procedures are as follows:

Model 1: project level planning

The whole project is classified into some work packages, the execution of which can be planned through goal programming according to the aspiration level of the management in the environment of different constraints. The input data to the project levels are work breakdown structures of the project, precedence relations of the work packages, estimates in work package level and corresponding contingencies, as well as policies of the contractors and owner. Provision of necessary updating of input data has been provided for coping with environmental fluctuations. The aspiration levels for different goals are fixed from available input data, project objectives and the planning environment. The ultimate project plan is in the form of the percentage progress of different work packages in the specific planning horizon, which are derived in the environment of few system and goal constraints. The decision variables of project level planning act as constraints to the next level of planning, i.e. work package planning. Priorities of the goals vary with the situations. Therefore, it is initially fixed through the perception of the planner in line with his organizational and project objectives. The flexibility of the model has been provided through provisions for updating of input data with the changing environment, consideration of the effect of planning on other levels, changes in priorities and changes in constraints.

The mathematical model in project level planning is shown in the following sections:

Decision variables

$x_{(k,t)}$ = percentage progress of work package k during time period t.

Goal constraints

(i) Cost constraint

$$\Sigma_k c_{(1,k)} x_{(k,t)} + d^- - d^+ = C_1$$

where, C_1 = aspiration level of cost in specific period, and $c_{(1,k)}$ = unit percentage cost of work package.

(ii) Percentage progress of work package

Percentage progress of work packages during specific planning horizon may be aspired to be achieved. Therefore,

$$x_{(k,t)} + d^- - d^+ = X_1$$
$$\Sigma_t x_{(k,t)} + d^- - d^+ = X_2$$

where, X_1 = aspiration level of percentage progress of work package k during specific time period t, and X_2 = aspiration level of percentage progress of specific work package in different period.

(iii) Percentage progress of project

Aspiration level of achievement is possible through the setting of goals of percentage execution in the project level. Therefore,

$$\Sigma_k W_k \cdot x_{(k,t)} + d^- - d^+ = P_1$$

where, W_k = weightage of work packages, and P_1 = aspirated level percentage progress of project during the specific planning horizon.

(iv) Cost of specific work package to be kept within aspiration limit and specific cost flow to be maintained for specific time period. Therefore,

$$c_{(1,k)} \Sigma_t x_{(k,t)} + d^- - d^+ = C_2$$
$$c_{(1,k)} \cdot x_{(k,t)} + d^- - d^+ = C_3$$

where, $c_{(1,k)}$ = unit percentage cost work package k, C_2 = aspirated level of cost of work package k, and C_3 = aspirated level of cost flow for specific work package during specific planning horizon.

System constraints

(i) Percentage progress of specific work package during whole planning periods should indicate its full achievement. Therefore,

$$\Sigma_t x_{(k,t)} = 100$$

(ii) 100% achievement is possible by multiplying achievement of all work packages throughout the planning horizon with their corresponding weightage. Therefore,

$$\Sigma_t \Sigma_k W_{(1,k)} \cdot x_{(k,t)} = 100$$

The merits of the model lies in its simplicity and ease of understanding on one hand, and on the other the possibility of integrating it with other models through which planning of work packages as well as activity levels can be carried out.

Model 2: work package planning

Activities of work packages can be planned over periods in the environment of several constraints. The necessary input data comes from specifications, precedence relations of

activities under specific work packages, detailed estimates of work packages, corresponding contingency, productivity of deployed labor and equipment, management decisions about planning horizons, etc. These input data may be collected from tender documents, risk analysis reports, project networks etc. along with the necessary additional documents. The system constraints for the model generally derived from activity scope limitation, environmental effect, economics etc. Goal constraints come from the aspiration level of management at the work package level. These are the execution of specific activities, resource utilization, cost flow, percentage progress of work package etc. Additional constraints may arise from project level planning, which are to be maintained for the proper integration of the total model. The priorities vary from situation to situation. Initially it may be decided according to management policy. The output of work package planning is the level of achievement of activities and the corresponding resources requirement. The output of work package level planning is input of activity level planning during the initial planning as well as during the changing environment. The output also acts as input to the planning project level in varied situations.

The mathematical model has been derived and enumerated below in line with the above discussion.

Decision variable

(i) $x_{(j)}$, execution level of different activities during a specific time horizon
(ii) $M_{(a,i,j)}$, type a labor-hour for i operation, j activity
(iii) $E_{(b,i,j)}$, type b equipment-hour for operation i, activity j
(iv) P, type of materials

Goal constraints

(i) Achievement of execution of some activities during the planning horizon

$$\Sigma_j x_{(j,t)} + d^- - d^+ = A$$

where, A = aspiration level of execution of activity

(ii) Certain activity or specific portion of it is to be completed during a specific time period. Therefore,

$$x_j + d^- - d^+ = A_1$$

where, A_1 = aspiration level of achievement

(iii) Labor and equipment requirement

$$Q_{(i,j)} \cdot x_j - R_{(a,i,j)} \cdot M_{(a,i,j)} + d^- - d^+ = 0$$

Similarly,

$$Q_{(i,j)} \cdot x_j - R_{(b,i,j)} \cdot E_{(b,i,j)} + d^- - d^+ = 0$$

where, $Q_{(i,j)}$ = job involved per unit execution for i operation j activity, $R_{(a,i,j)}$ = execution per a type labor-hour for i operation j activity, $R_{(b,i,j)}$ = execution per b type equipment-hour for i operation j activity.

(iv) Material requirement goal

$$P - \Sigma_j p_{(p,j)} \cdot x_j + d^- - d^+ = 0$$

where, $p_{(p,j)}$ = unit p type material requirement for activity j.

(v) Cost control goal
Field cost:

$$\Sigma_j C_{(1,j)} \cdot x_j + d^- - d^+ = C_1(T)$$

where, $C_{(1,j)}$ = unit cost of activity j and $C_1(T)$ = aspirated level of field cost.
Material cost:

$$\Sigma_p C_{(2,p)} \cdot P + d^- - d^+ = C_2(T)$$

where, $C_{(2,p)}$ = unit cost of p type materials, and $C_2(T)$ = aspirated level of materials cost.

(vi) Percentage progress of work package during specific time period.

$$\Sigma_j w_j \cdot x_j + d^- - d^+ = w_1$$

Where, w_1 = aspiration level of percentage progress. w_j = weightage of activity j.

System constraints

(i) Achievement cannot be more than quantum of job related to certain activity. Therefore,

$$x_j \leq A_2$$

where, A_2 = total execution involved with certain activity.

(ii) Quantum of job related to certain activities taken all together

$$\Sigma_j x_j \leq A_3$$

where, A_3 = total execution involved with the activities.

(iii) Achievement of some activities is not required during a specific time period. Therefore,

$$\Sigma_j x_j = 0$$

(iv) Certain activity execution is required to be achieved.

$$x_j = A_4$$

where, A_4 = quantum of execution of activity required.

(v) Achievement during a planning horizon should not be more than the job involved in several activities for the work package. Therefore,

$$\Sigma_j x_j \leq A_5$$

where, A_5 = total job involved in a work package.

Model 3: activity planning

The lowest level of planning domain of an owner's management can be kept in an activity level. However, the nature of the activity model depends on how much detail is needed for a given situation. Generally, the input sources are tender documents, activity analysis and risk analysis report, detailed survey report, various related reports and correspondence for the project concerned, which gives value for planning specific activities. In these models the following are considered as input information, such as: specification of activities; duration; field and materials cost; man-hour and equipment-hour rate; productivity information; risk factors; type of resources; activity relations; planning periods; and contingencies etc. The input information leads to the derivation of a preliminary plan which structured the model for the ultimate determination of aspiration level, priority structure, system and goal constraints. In this model system constraints are availability of man-power and equipment, design constraints, environmental impact, economic and political effects etc., and goal constraints are execution level during a specific planning

horizon, deployment of men and equipment, achievement of specific man and equipment hours, expenditure on activity to match with the availability of cash. Additional constraints should be considered and/or the existing constraints should be updated to match with the output of work package level planning. The decision variables that are derived from the activity level of planning are the period related achievement in execution, type and amount of man and equipment hours, materials requirement, extra payments that are related to an increase or decrease in scope. The variables may be the input to other levels of planning in the changing environment.

The mathematical model is derived from the above situation and enumerated below in detail.

Decision variable

x_t = Production related to activity in different time period t (where $t = 1, \ldots n$), $M_{(a,i,t)} = a$ type labor-hour for operation i in period t. $E_{(b,i,t)} = b$ type equipment-hour for operation i, in period t, L = amount of money that is to be paid to the contractor for deploying extra man-hours for executing the activity in the stipulated time period, and N = amount of money that is to be paid to the contractor for limiting the scope of work compared to that envisaged in the tender document on the basis of which the contractor indicated the unit rate for some activities.

Goal constraints

1. Aspiration level of output in specific time period is

$$x_t + d^- - d^+ = A_t$$

A_t = aspiration level of activity achievement in period t.

2. Aspiration cost level of activity is

$$C_1 \Sigma_{t=1}^n x_t + d^- - d^+ = K_1$$

C_1 = cost per unit field activity in period t, and K_1 = total approved cost of the activity (aspiration level of field cost) in period t.

The formula has to be modified if the unit cost varies for different periods. The formula will be

$$\Sigma_{t=1}^n C_t x_t + d^- - d^+ = K_1$$

3. Materials cost level

$$C_2 \Sigma_{t=1}^n x_t + d^- - d^+ = K_2$$

C_2 = cost of material for per unit activity during period t, and K_2 = total cost of materials (aspiration level).

An alternative equation like the previous one can be established if the unit cost of materials varies with the period.

4. Activity is to be fully loaded with men and equipment. Therefore,

$$Qx_t - RM_{(a,i)} + d^- - d^+ = 0$$

R = production per labor-hour and Q = job involved per unit execution.

5. Quantum of job planned to be completed within stipulated time period. Therefore,

$$\Sigma_{t=1}^n x_t + d^- - d^+ = B$$

where, B = aspiration level of job.

System constraints

1. Extra payment for changes in scope of work:

$$\Sigma_{m=1}^n \Sigma_{t=1} C_{mi} M_{(a,i,t)} + \Sigma_{e=1}^n \Sigma_{t=1} C_{ei} E_{(a,i,t)} - L \leq K_3$$

where, C_{mt} = unit cost of a type labor-hour for activity operation i at different period t ($t = 1,2,\ldots$), C_{et} = unit cost of b type equipment-hour for activity operation i at different period t, and K_3 = labor-hour and equipment-hour cost for aspirated activity level.

2. Labor-hour limitation in specific operation

$$M_{(a,i,t)} \leq m$$

$m = a$ type labor-hour available for activity operation i during period t.

3. Equipment-hour limitation for specific operation due to non-availability

$$E_{(b,i,t)} \leq e$$

$e = b$ type equipment hour available for activity operation i during period t.

Note: All d^+ and d^- are subscripted. But for ease of presentation these are not indicated when presenting within equations.

The whole model is initially designed with an established work precedence relationship (WPR) and desired project duration breakdown in line with project objectives, planning environment and planner's perception. Accordingly, planning variables are determined for controlling time, cost and quality goals. However, changing the project environment demands alteration of WPR to cope with changed situations. The models can be adapted to new environments by changing the aspiration level of goal constraints as the situation demands and planning variables are established along with requisite resource requirements accordingly.

Application

The project is classified into a few work packages through hierarchy[6]. Risk analysis is applied in work package level and the results are tabulated in *Table 1* for three work packages. Logical contingencies are derived for project control through the proposed methodology and shown in *Table 2* for the same three work packages.

The work package precedence relations are developed through network (*Figure 2*). The weights of the work packages are derived as per the works involved within these, along with the complexity of construction (ranking method)[9]. The project duration is considered to be 18 months and planning is made for six distinct periods of 3 months each. The output of the project level planning is the percentage progress of work packages in different planning periods. These are derived by considering the following priorities within the model:

(a) Priority 1: Completion of project in the total planning horizon.
(b) Priority 2: Aspirated percentage completion of specific work package during a specific planning period.
(c) Priority 3: Aspirated cash flow for the work package in a specific period.
(d) Priority 4: Specific percentage progress of project in a different planning period.
(e) Priority 5: Aspirated level of cost flow for the project during a specific period of planning.

The priorities are in line with the project objectives, planning environment and planner's perception. In this model, project achievement is considered to follow a typical

Table 1 Risk ranking of some work packages

Sl. no.	Work package	Likelihood of risk			Weightage			Overall wt.	Rank
		High	Medium	Low	High	Medium	Low		
1.	Pipeline construction (Spread I)	0.602	0.209	0.188	0.6	0.2	0.1	0.422	1
2.	Pipeline construction (Spread II)	0.508	0.367	0.124	0.6	0.2	0.1	0.391	2
3.	Pipeline construction (Spread III)	0.4	0.434	0.167	0.6	0.2	0.1	0.344	3

Table 2 Contingency calculation for some work packages

Sl. no.	Work package	Overall risk	Prob. of cost more than mean	Z value from table	Base cost estimate	Expected cost	Variance	S.D.	Contingency	
									Amount	%
1.	Pipeline construction (Spread I)	0.42	0.92	1.75	9613.04	9986.35	431399.91	656.81	1522.73	15.84
2.	Pipeline construction (Spread II)	0.39	0.89	1.17	1103.44	1144.38	6962.77	83.44	138.56	12.56
3.	Pipeline construction (Spread III)	0.34	0.84	1.14	521.80	543.00	1327.71	36.44	62.74	12.02

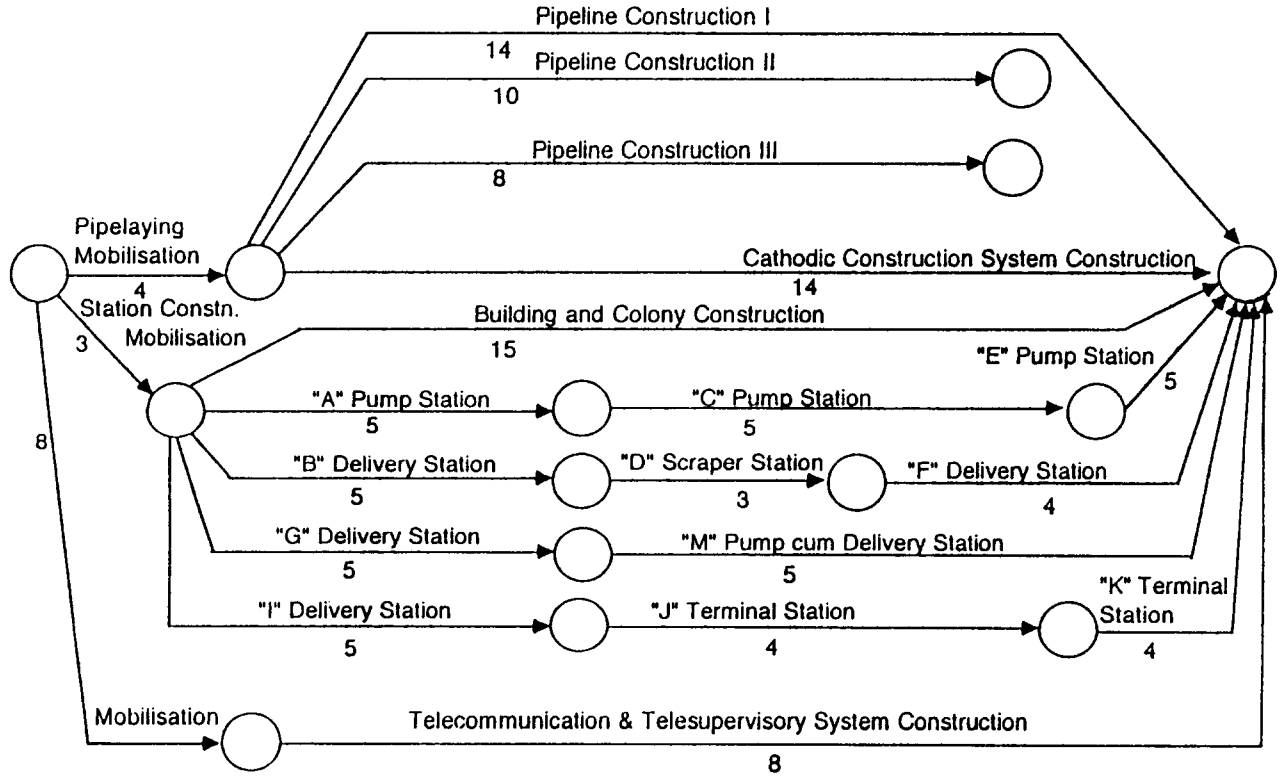

Figure 2 Work package precedence relationships for the project

'S' curve i.e. one quarter of the project's progress is planned to occur in the first third of the contract programme, one half in the middle third and the remainder in the last third of the programme. The project expenditure pattern is also planned to follow the same lines. Accordingly, the aspiration levels of the models are fixed.

The mathematical models are formed in each level through GP and processed through the MICRO MANAGER computer package. Detailed model formulations have been described elsewhere[1]. The results are as follows:

1. Percentage progress in pipeline construction spread I during periods 1, 2 and 3: 41.88, 26.12 and 32, respectively.
2. Percentage progress in pipeline construction spread II during periods 2 and 3: 20 and 80, respectively.
3. Percentage progress in pipeline construction spread II during periods 2 and 3: 50 and 50, respectively.
4. Percentage progress of 'A' pump station construction during periods 1 and 2: 70 and 30, respectively.
5. Percentage progress of 'B' delivery station construction during periods 1 and 2: 90 and 10, respectively.
6. Percentage progress of 'C' pump station construction during periods 2 and 3: 80 and 20, respectively.
7. Percentage progress of 'D' scraper station construction during period 2: 100.
8. Percentage progress of 'E' pump station construction during period 3: 100.
9. Percentage progress of 'F' delivery station construction during period 3: 100.
10. Percentage progress of 'G' delivery station construction during period 2: 100.

11. Percentage progress of 'H' pump-cum-delivery station construction during period 3: 100.
12. Percentage progress of 'I' delivery station construction during periods 1 and 2: 80 and 20, respectively.
13. Percentage progress of 'J' terminal station construction during periods 2 and 3: 20 and 30, respectively.
14. Percentage progress of 'K' terminal station construction during period 3: 100.
15. Percentage progress of telecommunication system construction during periods 2 and 3: 30 and 70, respectively.
16. Percentage progress of telesupervisory system construction during period 3: 100.
17. Percentage progress of cathodic protection system construction during periods 1, 2 and 3: 49.92, 24.96 and 25.12, respectively.
18. Percentage progress of building and colony construction during periods 1, 2 and 3: 33.25, 33.51 and 33.25, respectively.
19. Percentage progress of mobilization for construction during period 1: 100.

When percentage progress of all the work packages during a specific time are combined with its corresponding weights, percentage project progress during that period can be derived. The percentage progress of projects and work packages for a specific period gives the basis for more detailed planning of work packages. The output of work package level planning for the pipeline construction I for the first planning period are as follows:

1. Laying of pipe in 'A'–'B' at first 20 km stretch: 5000 m
2. Laying of pipe at 'B'–'F' in normal terrain: 10 000 m
3. Laying of pipe at 'F'–'H' in normal terrain: 141 570 m
4. Laying of pipe in submerged crossing: 2000 m
5. Laying of pipe in uncased crossing at first 20 km stretch: 50 m
6. Labor-hours required for welding in activity 1: 1296
7. Labor-hours required for welding in activity 2: 2160
8. Labor-hours required for welding in activity 3: 30 579
9. Labor-hours required for welding in activity 4: 519
10. Labor-hours required for welding in activity 5: 13
11. Labor-hours required for lowering and backfilling trench in activity 1: 481
12. Labor-hours required for lowering and backfilling trench in activity 2: 800
13. Labor-hours required for lowering and backfilling trench in activity 3: 11 325
14. Labor-hours required for lowering and backfilling trench in activity 4: 1334
15. Labor-hours required for lowering and backfilling trench in activity 5: 15
16. Requirement of pipes 22″ dia. and 0.281″ wt.: 162 179 m
17. Requirement of pipes 22″ dia. and 0.325″ wt.: 7490 m
18. Requirement of pipes 22″ dia. and 0.312″ wt.: 53.50 m

Similarly, detailed planning to the work package level is carried out for other work packages through the proposed model with the application of the same software program. Activity level planning is carried out on the basis of planning output work package level. Planning periods for each activity are determined as per the importance of the activity from the overall project perspective. However, the total duration of activities is derived from the work package model. The planning variables of typical activity 'Laying pipe in 'A'–'B' at 1st 20 km stretch' are as follows:

1. Progress in pipe laying in first month: 1852 m
2. Progress in pipe laying in second month: 15 280 m
3. Progress in pipe laying in third month: 2778 m
4. Progress in pipe laying in fourth month: 4600 m
5. Labor-hours for welding and backfilling in first month: 480 and 177, respectively.
6. Labor-hours for welding and backfilling in second month: 3961 and 1467, respectively.
7. Labor-hours for welding and backfilling in third month: 720 and 267, respectively.
8. Labor-hours for welding and backfilling in fourth month: 1192 and 442, respectively.

Equipment-hours for welding, lowering and backfilling are same as labor-hours. Sensitivity analysis of the models is carried out for project level planning for the following three conditions:

1. Environmental effect.
2. Resource balancing (labor-hours).
3. Scope increase.

Table 3 shows the overall percentage progress of the project for referred varied conditions along with the aspirated progress. Sensitivity analysis results at work package level for welding man-hours and cost flow analysis are shown in *Figure 3*. *Table 4* shows sensitivity analysis on activity level planning for varied situations as indicated. These validate the applicability of the model in the changing project environment.

The aspiration level, in line with project objectives, gives the basis of initial planning. However, projects seldom operate as per plan. The dynamic environment demands changes in project plans for proper achievement during different phases of construction. The proposed model can easily be updated by changing priorities according to demand, changing co-efficient of variables and aspiration levels. Thus, it provides a decision support system for project control for time, cost and quality achievement.

Conclusions

Projects exposed to uncertain environments must deal with the effective integration of various planning elements, optimization of project parameters and risk management throughout their life. Risk analysis combined with logical contingency provision provide effective tools for decision making for project control of a pipeline laying project. The changes that arise during implementation are controlled through a hierarchical planning model which optimizes

Table 3 Schedule plan of project (percentage progress cumulative)

Sl. no.	Planning horizon	Aspiration level	Environmental effect	Resource balancing	Scope increase
1.	Period 1	12.50	12.32	20.00	21.00
2.	Period 2	25.00	24.64	40.00	42.21
3.	Period 3	50.00	38.44	64.00	55.21
4.	Period 4	75.00	52.24	80.00	68.21
5.	Period 5	87.00	75.76	90.00	84.21
6.	Period 6	100.00	100.00	100.00	100.00

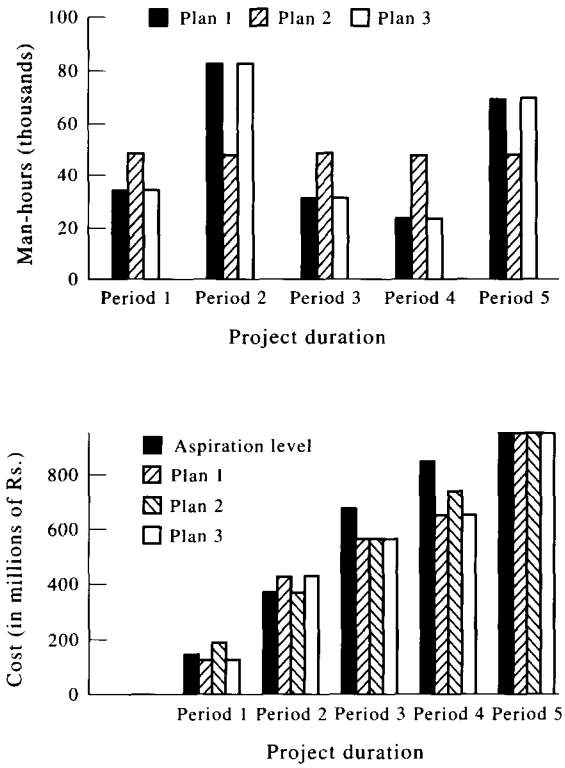

Figure 3 Man-hours and cost flow analysis of work package

Table 4 Welding man-hour for the activity of laying pipe in normal terrain of first 20 km stretch

Sl. no.	Description	Period 1	2	3	4	5	Total
1.	Aspiration level of activity achievement	1192	1985	1985	1192	0	6354
2.	Activity achievement normal	480	3961	720	1193	0	6354
3.	Scope increase by 2 km (accommodate in next period)	480	3961	720	1193	518	6872
4.	Scope increase by 6 km (accommodate in next period)	480	3961	720	1452	1296	7909
5.	Special condition (no work in 2nd period)	480	0	720	3169	1985	6354
6.	Scope decrease	480	3532	720	648	0	5380
7.	Scope increase (accommodate in same period)	480	4220	720	1452	0	6872
8.	Finishing the activity within 3 months (crashing)	480	5154	720	0	0	6354

different conflicting objectives of management for successful project achievement.

In a typical PERT and CPM network, activity precedence relations along with corresponding durations are indicated which lead to the determination of a critical path for the project, thereby providing a basis for project planning and control. Though the network model results in different planning variables, nothing is mentioned regarding the percentage or absolute progress in execution during specific time periods. For managing long duration activities, this is absolutely necessary. The proposed planning model provides the above facilities. Therefore its use, along with network analysis, provides a very useful project planning and control tool.

The following are the specific advantages that can be derived from the proposed methodology:

- Planning a project hierarchically automatically provides integration between WBS and OBS.

However, the cost and time integration is carried out through mathematical modelling.

- Proper communication among team members.
- Easy reporting of project status in different levels of management.
- Fast updating of plans enables a quick decision from appropriate authorities.
- Hierarchical planning allows management to plan level-wise, thereby enabling more detailed planning at each level with the involvement of more expertise of concerned personnel.

The hierarchical planning model is formulated with the assumption of the following:

- Cost is a function of activity (quantum of job) for stipulated quantity as per contract document.
- Expenditure pattern follows typical 'S' curve.
- Total project duration is segregated into few planning periods as per project review period in line with project objective.

The applicability of the model is limited to a petroleum pipeline construction project. However, the model can easily be updated for use with other types of construction projects. The application of the model demands a considerable concept of mathematical programming for effective utilization. However, a user-friendly package may be developed by interfacing mathematical models with some application software. The present study is a theoretical framework of a decision model for optimizing project parameters in dynamic project environment, for achieving completion of a project on time, within a specified budget and conforming to requirements.

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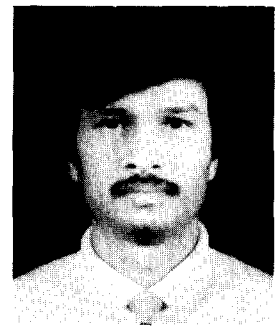

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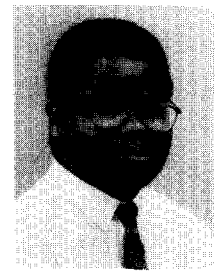
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