1. Observation: Author has made departure from classical thinking that expediting of activities is the only or predominant way for reducing project duration and addresses the issue in proposing methodology for the same.

Extract of clarification incorporated at page 30

3.3 Strategies for Reducing Project Duration

Fariborz et al (1993) in their model have considered various strategies for reducing the duration of any project. Summary of these strategies is given as under:

i. Control: Making people work harder and more efficiently by better organizing, closer monitoring and giving incentive to people for higher productivity

ii. More time: Working for more time (without increasing project duration) by operating in shifts and overtime

iii. Resources: Extra resources (people, equipment and material) may be added to complete the tasks faster

iv. Change contract: Off-load work by sub-contracting activities and changing terms of contract for expeditious execution at higher cost

v. Change specification: Changing the specification of work to enable it to be done faster.

vi. Abort: Give up expediting and let a project overrun its schedule time. If possible it may be expedited later on to bring it progress closer to schedule.

In this thesis, the strategies for reducing the duration of any project may be referred to as 'Expediting Strategies'. Effectiveness of expediting will depend upon selection of expediting strategies and the intensity with which these strategies are implemented. An index for specifying the effectiveness of expediting may be defined as, “a factor ‘k’, by which the original duration of a project is reduced when the project is expedited”. So if original expected duration of a project is $d_e$ with standard deviation $\sigma$, on expediting its expected duration will become \[(1-k)d_e\]
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with standard deviation \( \sigma \sqrt{T-k} \). The term 'k' may be referred as "Expediting Index".

Expediting a project will involve cost. A more effective strategy will normally involve greater cost. So expediting should be done only where it is necessary and appropriate expediting strategy should be adopted based on cost criteria. There is also a limit to the amount of work that can be expedited. For this, priority of individual project should be determined for selecting appropriate expediting strategy. Normally, this is done by informal and intuitive method. But it is desirable to follow a scientific basis for taking decisions relating to expediting of different projects.

2. Observation: Author has made departure from classical thinking that analytical methods are time consuming and simulation is the way forward. However, this has not been illustrated. The normal understanding is that simulation is more time consuming compared to analytical approach.

Extract of clarification incorporated at page 42

The analytical method involves lot of computation work and is difficult to apply even to a medium sized project consisting of hundreds of activities (Panagiotakopouols, 1977). So to apply analytical methods the problems are usually simplified by making various assumptions.

For example, CPM-based analytical method assumes (i) existence of unlimited resources, (ii) linear time-cost relationship and (iii) time-cost function to be continuous. In the absence of simplifying assumptions, the complexities of real life situations pose hindrance in determining analytical solution.

The discrete time-cost trade-off problem is also called the 'activity mode selection' problem. There may be several ways (modes) of doing an activity. Time and cost of activity will be different for different modes. Activity mode selection involves choosing the right mode for each activity for optimization of time and cost. When project deadline is specified, it involves choosing the right activities for execution in expedited mode so that the cost is less.

The literature for the case where the time-cost relationships are defined at discrete points (representing distinct alternatives) has been rather sparse. This is perhaps
due to the inherent difficulty of solving the problem in this case. The discrete time-cost tradeoff problem is known to be strongly NP-hard (De et al., 1997). So for these problems it is futile to search for analytical methods (i.e. exact algorithms) and one should instead search for heuristics as an effective procedure (Anagnostopoulos, 2002). Due to unlikely existence of any polynomial algorithm to solve this problem optimally, the efforts have turned to finding approximation and heuristics methods (Skutella, 1998; Tareghian, 2006; Rahimi, 2008).

3. Observation: Author has made departure from classical thinking that discrete duration set has been assumed for activity duration as opposed to range on a continuous basis.

Extract of clarification incorporated at page 41

Time-cost trade-off models can be classified according to their time-cost curve. The first type is composed of linear time-cost trade-off problems in which we assume a linear linkage between the duration and cost of an activity. The second type is composed of nonlinear time-cost trade-off, when this linkage is not linear. Additionally, there are cases in which we can refer to the time-cost curve as continuous, as opposed to cases in which the curve is discrete.

When time-cost function is considered continuous and linear, the time-cost trade off problem is addressed by traditional CPM-based analytical methods (Kelly, 1961). The analytical methods are widely known and are contained in standard texts (Moder et al. 1983).

But in many practical situations, the nature of resources is discrete. So in these cases, the time-cost function is not continuous and the activities can only be crashed stepwise. For example, one worker might finish a job in 5 days (mode 1), whereas 2 workers might finish the same job in 3 days (mode 2) and 3 workers in 2 days (mode 3). Here it may be noted that the time-cost function is nonlinear as well as discrete. Another example may be in selection of equipment. A job may take 7 days to be done in low capacity equipment (mode 1). But a high capacity machine may finish the same job in 1 day (mode 2). Similarly a vital component required for a project may be ordered to be delivered by road transport in which case it may take 15 days (mode 1) but the same consignment may be delivered in 1 day by air (mode 2). So the discrete time, cost trade-off problem, hereafter referred to as
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DTCTP, is a well known problem in the project management literature.

4. Observation: *Term like “Expediting Index” and “Criticality Index” have been used in the approach but have not been clarified appropriately.*

**Extract of clarification incorporated at page 31 - 32**

The two indexes, 'Expediting Index' and 'Criticality Index' used in the model are defined below.

When a certain work component is expedited, its duration is reduced or crashed. Extent to which the duration is reduced will depend upon effectiveness of expediting. The effectiveness of expediting may be expressed in quantitative terms by an index 'k' and determined as under.

\[
\text{Expediting index, } k = \frac{\text{Normal duration} - \text{Expedited duration}}{\text{Normal duration}}
\]

A project can have many paths having different durations. The path having the longest expected duration is called the critical path. The expected duration of critical path determines the project duration. But duration of some non-critical paths may be slightly less than the duration of critical path. If the activities of these paths are delayed, it may also delay the project. So to some extent these paths may also be considered as critical. Extent to which a path of a project is critical may be specified by an index, which is termed in this thesis as 'Criticality Index'.

The criticality index \( \rho_i \) of a path \( i \) may be defined as the ratio between expected duration of given path to expected duration of project.

\[
\rho_i = \frac{\text{expected duration of the given path 'i'} }{\text{expected duration of project}}
\]

When expected duration of a path is same as expected duration of project, the criticality index of path is 1 or the path is the critical path. For non-critical paths, the value of criticality index is less than 1.

5. Observation: *In page 24 “traditional PERT method to crash” have been mentioned. Usually crashing is done in CPM and crashing PERT is rather uncommon.*
Haga and Marold (2004) have proposed a simulation-based method that deals with the time-cost trade-off problem in PERT. The traditional method of crashing PERT networks has been to convert the model to a deterministic model by using the means of the activity times. The network is then crashed in a series of iterative steps until the expected completion time of the project is acceptable, the cost of crashing exceeds the benefits, or all activities have been crashed as much as possible. This method of crashing a PERT network is identical to the CPM method. Haga and Marold (2004) contend that little research has been conducted which addresses crashing in a stochastic environment and that the crashing algorithm for the CPM model is not suitable for the PERT model. They state that the complete distribution of project completion time needs to be considered when crashing.

Van Slyke (1963) was the first of many researchers to apply Monte Carlo simulations to study PERT. Van Slyke demonstrated several advantages of using simulation including more accurate estimates of the true project length, flexibility in selecting any distribution for activity times, and the ability to calculate "criticality indexes" which are the probability of various activities being on the critical path.

Kuhl and Tolentino-Pena (2008) have presented a simulation-based methodology to evaluate project networks and determine an optimal crashing strategy. The methodology has two phases: (1) crashing applied prior to the start of the project, and (2) dynamic crashing applied during the project life to update the crashing strategy. In the first phase of crashing the average cost is reduced. In the second phase all the uncertainties are taken into account to produce an updated crashing strategy to yield lowest project costs.

Haga and Marold (2005) developed a method to monitor and control a project. The output of this method is a list of dates at which the project manager “should review the project to decide if activities need to be crashed”. These dates are called crashing points, and they are determined by a backward run through the project network. The crashing points are established at the beginning of the project and they remain fixed during the entire project life.

6. Observation: Time-Cost-Quality trade off has been discussed. Normally, quality parameters are decided before commencement of the project and effort to achieve
the same is made during implementation. Usually, quality trade off is not considered at the implementation phase. This needs some clarification.

Extract of clarification incorporated at page 63

Duration, cost and quality are the three main performance criteria of a project. The alternate mode to be meaningful must be preferable to normal mode in at least one criterion. The activities should be selected for execution in alternate mode based on these three parameters. The goodness of a solution/decision may be evaluated based on extent to which it meets the three objectives of time, cost and quality.

First, the maximum allowable target duration/deadline, maximum allowable cost and minimum acceptable quality is first decided during planning for time-cost-quality trade-off. The acceptable solution should meet all the above three objectives in an efficient manner.

7. Observation: Project Quality has been defined as average quality, whereas usually the lowest quality decides the overall quality.

Extract of clarification incorporated at page 60-62

5.1 Quality Measurement Approach

In activity mode selection problem it is assumed that there are choices for completing the activities that vary in quality, time, and cost.

In 1996, Babu and Suresh proposed a framework to study the trade-off among time, cost and quality using three inter-related linear programming models. Babu and Suresh developed their method by assuming that each activity has a normal time of completion and a crash time of completion. Associated with the normal time are normal cost and normal performance quality, and with crash time are the crash cost and the crash quality. The total project cost is simply the sum of individual activity costs, and the total project quality is measured by the average of the individual activity quality measures. They assumed that the cost and quality of an activity vary as linear functions of the completion time.

Khang and Myint (1999) have applied the Babu and Suresh method to an actual cement factory construction project in Thailand. Since the relative quality reduction due to crashing activities is the focus of interest, they assumed expected quality under the normal conditions to be at 100% level for each activity.
activity on crashing was taken as relative quality with respect to quality achieved under normal condition. The project's overall quality was calculated as the weighted average of the individual activity qualities where weights are proportional to the contractual values of the activities.

Bruce and Matthew [2006] have given a simple example to illustrate the use of the Analytic Hierarchy Method (AHP) for determining the quality of a work product. Consider a situation for completing a foundation for a building. The quality of foundation will depend on two parameters; (i) strength of concrete used, and (ii) the depth of the excavation. If we have three quality levels say, 'Excellent', 'Good', and 'Fair' for each of the two above parameters, we will have nine quality levels for the quality of foundation.

For quantification of quality, different points may be assigned to the subjecting ratings. For example, say ratings 'Excellent', 'Good', and 'Fair' may be assigned points 1.0, 0.7 and 0.3 respectively. Similarly different weights may also be assigned to relevant parameters, say weight 0.6 is assigned to concrete strength and 0.4 is assigned to depth of excavation. Then quality of foundation is determined as the weighted average of strength of concrete and depth of excavation. For the above example, quality of foundation for different levels of concrete strength and depth of excavation is shown in table given below.

<table>
<thead>
<tr>
<th>Strength of Concrete (0.6)</th>
<th>Excellent (1.0)</th>
<th>Good (0.7)</th>
<th>Fair (0.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.72</td>
<td>0.54</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>0.88</td>
<td>0.7</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth of Excavation (0.4)</th>
<th>Excellent (1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fair (0.3)</td>
<td>0.58</td>
</tr>
<tr>
<td>Good (0.7)</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Here it may be noted that quality of strength of concrete and depth of excavation both may be at acceptable level, but still quality of foundation may not be acceptable. Supposing minimum level for quality of foundation required is 0.5, then if quality of strength of concrete is fair, the quality of depth of excavation should be excellent. Similarly if quality of depth of excavation is fair, the quality of strength of concrete should at least be good, for quality of foundation to be acceptable.
Khaled El-Rayes and Amr Kandil (2005) have also used simple weighted approach to determine overall quality of project. Their approach involved identification of quality indicators for each activity and assign weight to each quality indicator depending on its importance to quality of activity. For illustration purpose they have given some construction activities and corresponding quality indicators of as given below.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Possible quality indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete pavement</td>
<td>Water concrete ratio, consolidation/density, air content,</td>
</tr>
<tr>
<td></td>
<td>thickness, compressive strength, flexural strength, ride</td>
</tr>
<tr>
<td></td>
<td>quality</td>
</tr>
<tr>
<td>Bituminous pavement</td>
<td>Compaction density, asphalt content, gradation, surface</td>
</tr>
<tr>
<td></td>
<td>smoothness, thickness, aggregate quality, void ratio, skid</td>
</tr>
<tr>
<td></td>
<td>resistance</td>
</tr>
<tr>
<td>Bridge deck</td>
<td>Consolidation/density, rebar cover, W/C ratio, density,</td>
</tr>
<tr>
<td></td>
<td>curing, air content, strength</td>
</tr>
<tr>
<td>Structural concrete</td>
<td>Consolidation/density, rebar cover, W/C ratio, density,</td>
</tr>
<tr>
<td></td>
<td>curing, air content, strength</td>
</tr>
<tr>
<td>Base course</td>
<td>Aggregate quality, drainage, gradation, thickness,</td>
</tr>
<tr>
<td></td>
<td>compaction/density, moisture content</td>
</tr>
<tr>
<td>Embankment</td>
<td>Compaction/density, moisture content, material quality,</td>
</tr>
<tr>
<td></td>
<td>uniformity, drainage</td>
</tr>
</tbody>
</table>

Their method required identification of two types of weights: (i) weight assigned to different quality indicators of each activity that signify their relative importance towards the quality of the activity and (ii) weight of the activity to represent its contribution to the overall quality of the project. So quality of an activity can be determined as weighted average of various quality indicators and project quality can be taken as weighted average of all its activity quality.

8. Observation: The genesis/ assumption/ source of data for table 5.1 have not been indicated.

Extract of clarification incorporated at page 74 - 75

The sample problem given in table 5.1 is taken from paper by Bruce and Matthew Dynamic Model for Monitoring and Expediting of Projects under Uncertainty
Clarifications to Observations Incorporated in the Thesis

(2006) for illustrating the approach for time-cost-quality trade-off presented in this thesis. The verification of the algorithm was done by applying it to number of sample problems on discrete time, cost and quality trade-off. For example, we applied it on a bigger problems used by Bruce and Matthew (2006). The problem is shown in annexure-2a. It consisted of 49 activities having up to three execution modes. Project time, cost and quality for execution of activities in these three modes is as follows.

<table>
<thead>
<tr>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Duration</td>
<td>64</td>
<td>53</td>
</tr>
<tr>
<td>Cost</td>
<td>32600</td>
<td>41900</td>
</tr>
<tr>
<td>Quality</td>
<td>72.73</td>
<td>74.78</td>
</tr>
</tbody>
</table>

The proposed method was applied to solve this problem to reduce the project duration to 45, within cost limit of 45000 and minimum quality level of 75.

This problem was solved in two stages. In the first stage, the first and the second modes were taken was normal mode and expedited mode respectively. The solution obtained from the first stage was taken as normal mode for the second stage. The third mode was taken as expedited mode. The solution obtained from the second stage was deemed as an efficient solution. The result is shown in table 5.5.

<table>
<thead>
<tr>
<th>Project Parameters</th>
<th>Project Target</th>
<th>Solution obtained by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Limited trials using Simulation</td>
</tr>
<tr>
<td>1. Target duration</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>2. Maximum allowable cost</td>
<td>45000</td>
<td>40200</td>
</tr>
<tr>
<td>3. Minimum allowable quality</td>
<td>75</td>
<td>77.34</td>
</tr>
<tr>
<td>4. Index for goodness of solution*</td>
<td>--</td>
<td>0.54</td>
</tr>
</tbody>
</table>

* Evaluation Index determined by assigning equal weight to cost and quality

It is found that quality of solution obtained from limited trials using Simulation was comparable to that obtained by using other sophisticated method such as Genetic Algorithm.

Another problem was taken from Khang and Myint (1999) and modified into discrete Dynamic Model for Monitoring and Expediting of Projects under Uncertainty.
time-cost-quality tradeoff problem. The problem is shown in annexure-2b incorporated at page 135. This consists of 50 activities. In addition to above, the problems were also taken from text books for verifying the efficiency of proposed method.

In all the cases quality of solution obtained by running simulation experiment for only 10 trials was comparable to that obtained from 2000 or more random trials. When number of activities is more, conducting large number of random trials took so much time that simulation had to be stopped. In such cases search for efficient solution around a fair solution through limited trials using simulation is a practical alternative.

9. Observation: The case study with qualitative approach is quite contrary to deliberation in the thesis.

Extract of clarification incorporated at page 77-78

There are two approaches to decision making for solving organizational problems. These are: (i) Quantitative approach and (ii) Qualitative approach.

The quantitative approach is more formal. It is based on data and facts. By using various mathematical computations on data, a manager derives the solution on paper and puts it into practice. In quantitative approach, the solution to a problem is derived by using various mathematical computations on the data. The quantitative approach is subjective whereas the qualitative approach is subjective in nature. The qualitative approach requires experience, judgment, knowledge of the various factors involved in a decision. For example, to use the qualitative approach to solve a dispute over resources between two departments of an organization, the manager must understand the complex interplay of variables in that organization, such as the interpersonal relationship among people in each department and the overall availability of resources for which the two departments are competing. The manager uses his intuitive judgment to anticipate how decisions will play out in a given situation, which comes from experience.

Activity crashing is done to reduce the duration of a project by making trade off between time and cost. The CPM-based analytical method is the traditional method to solve the time-cost problem. It is a deterministic model where the activity duration and cost are assumed to be fixed or definite. Further for simplification purposes, we
assume existence of unlimited resources and a continuous linear time-cost function. But in many practical situations, there is constraint on resources and non-linear relationship between time and cost. Further the time-cost function may be discrete and the activities can only be crashed stepwise. When complexities are more, the approximation and the heuristics are used as popular quantitative techniques of decision making. But sometimes it may still be difficult to solve time-cost trade off problem by quantitative means.

The quantitative techniques have limitations. Some problem situations have too high complexities to be specified in mathematical terms. The quantitative techniques require data which may not be readily available. In project management scenario, there is much uncertainty and also significant error in project estimate. So the exact solution obtained by quantitative techniques is also prone to error. The qualitative assessment can be useful technique in these situations. Qualitative assessment may also be done by group decision-making. Makui et al., (2010) have shown that group decision making methodology can be effectively used in project risk identification and analysis in a fuzzy environment. They have concluded that in many of such decision-making settings the theory of group decision-making can play crucial role. In an organization one or both quantitative and qualitative approaches can be used for problem solving.

This study illustrates how the complex problem of activity crashing can be solved by qualitative assessment through participation and involvement of people, and teamwork.

10. Observation: Figure 9.2 is highly general for any decision problem. Its relevance for expediting project could have been illustrated.

Problems are generally encountered during execution of any work. The problems may be referred to as "issues" that need to be resolved for execution of tasks. The issues are resolved by decision making process. As the issues are resolved the execution work is carried forward and with execution of work new issues are encountered. The Initiation of issues, decision-making and carrying out of the decisions is a cyclic process as shown in figure 9.2.

This is a general process which happens in any project work.
The managerial efficiency is derived from how fast the issues are identified and resolved through decision-making; and how fast the decisions are communicated and acted upon. This research work proposes adherence to structured approach for initiation, communication, prioritizing and monitoring of issues for timely resolution. If issues are resolved quickly, these will speed-up the execution of project.

Figure 9.2: Cycle of issues, decision-making and execution