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USE OF OPTIMIZATION TECHNIQUES FOR CONSTRUCTION PROJECTS: STUDY & APPLICATION

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***Abstract*— Construction projects is high-rise buildings, highways, power stations, pipelines etc are involving thousands of activities. Planning, Scheduling of such projects using traditional network techniques like CPM/PERT have many disadvantages due to large number of activities. Alternate methods using to model such as graphical methods, linear scheduling methods, line of balance methods. The advantages of these graphical approaches are simplicity and visualize whole project. Planning, scheduling of construction projects are affected by unpredictable factors such as cash flow, design changes etc. Conventionally project scheduling by using critical path method has been used. The project scheduling using software's like ms-project, primavera are used. However optimized project scheduling using linear programming and software's are being attempted. The optimized project scheduling using linear programming and different software are proposed to be used. This method is simple, applicable to a large network, and generates shorter computational time at low cost, along with in an increase in robustness. Operations research is mainly concerned with management problems and involves the construction of mathematical models and the application of mathematical tools and modern computer technology.**

Keywords—CPM/PERT, cash flow, design changes, network, low cost

1. Introduction

Operations Research (OR) is a science which deals with problem, formulation, solutions and finally appropriate decision making. This subject is new and started after World War II, when the failures of missions were very high. Scientists and technocrates formed team to study the problem arising out of difficult situations and at the later stage solutions to these problems. It is research designed to determine most efficient way to do something new. OR is the use of mathematical models, statistics and algorithm to aid in decision-making. It is most often used to analyze complex real life problems typically with the goal of improving or optimizing performance. Decision making is the main activity of an engineer/manager. Some decisions can be taken by common sense, sound judgment and experience without using mathematics, and some cases this may not be possible and use of other techniques is inevitable.

1.1 Features of Optimization Techniques

The significant features of operations research include the followings:

(*i*) **Decision-making.** Every industrial organisation faces multifacet problems to identify best possible solution to their problems. OR aims to help the executives to obtain optimal solution with the use of OR techniques. It also helps the decision maker to improve his creative and judicious capabilities, analyse and understand the problem situation leading to better control, better co ordination, better systems and finally better decisions.

(*ii*) **Scientific Approach.** OR applies scientific methods, techniques and tools for the purpose of analysis and solution of the complex problems. In this approach there is no place for guess work and the person bias of the decision maker.

(*iii*) **Inter-disciplinary Team Approach.** Basically the industrial problems are of complex nature and therefore require a team effort to handle it. This team comprises of scientist/mathematician and technocrates. Who jointly use the OR tools to obtain a optimal solution of the problem. The tries to analyse the cause and effect relationship between various parameters of the problem
and evaluates the outcome of various alternative strategies.

(*iv*) **System Approach.** The main aim of the system approach is to trace for each proposal all significant and indirect effects on all sub-system on a system and to evaluate each action in terms of effects for the system as a whole. The interrelationship and interaction of each sub-system can be handled with the help of mathematical/analytical models of OR to obtain acceptable solution.

(*v*) **Use of Computers.** The models of OR need lot of computation and therefore, the use of computers becomes necessary. With the use of computers it is possible to handle complex.

1.2 Phases of Optimization in Construction

OR is a logical and systematic approach to provide a rational basis for decision-making. The phases of OR must be logical and systematic. The various steps required for the analysis of a problem under OR are as follows:

Step I. Observe the Problem Environment

The first step of OR study is the observation of the environment in which the problem exists. The activities that constitute this step are visits, conferences, observations, research etc. with the help of such activities, the OR analyst gets sufficient information and support to proceed and is better prepared to formulate the problem.

Step II. Analyse and Define the Problem

In this step not only the problem is defined but also uses, objectives and limitations of the study that are stressed in the light of the problem. The end results of this step are clear grasp of need for a solution and understanding of its nature.

Step III. Develop a Model

The next step is to develop model, which is representation of same real or abstract situation. OR models are basically mathematical models representing systems, process or

environment in form of equations, relationships or formulae. The activities in this step is to defining interrelationships among variables, formulating equations, using known OR models or searching suitable alternate models. The proposed model may be field tested and modified in order to work under stated environmental constraints. A model may also be modified if the management is not satisfied with the answer that it gives.

Step IV. Selection of Data Input

It is a established fact that without authentic and appropriate data the results of the OR models cannot be trusted. Hence, taping right kind of data is a vital step in OR process. Important activities in this step are analysing internal-external data and facts, collecting opinions and using computer data banks. The purpose of this step is to have sufficient input to operate and test the model.

Step V. Solution and Testing

In this step the solution of the problems is obtained with the help of model and data input. Such a solution is not implemented immediately and this solution is used to test the model and to find its limitations if any. If the solution is not reasonable or if the model is not behaving properly, updating and modification of the model is considered at this stage. The end result of this step is solution that is desirable and supports current organisational objectives.

Step VI. Implementation of the Solution

This is the last phase of the OR study. In OR the decision-making is scientific but implementation of decision involves many behavioural issues. Therefore, implementation authority has to resolve the behavioural issues, involving the workers and supervisors to avoid further conflicts. The gap between management and OR scientist may offer some resistance but must be eliminated before solution is accepted in totality. Both the parties should play positive role, since the implementation will help the organisation as a whole. A properly implemented solution obtained through OR techniques results in improved working conditions and wins management support.

Outlines of Optimization Techniques

In OR the problem is expressed in the form of a model. Where, a model is a theoretical abstraction

(approximation) of a real-life problem. It can be defined as a simplified representation of an operation or a process in which only the basic aspects or the most important features of a typical problem under investigation are considered. OR analysts have given special impetus to the development and use of techniques like, linear programming, waiting line theory, game theory, inventory controls and simulation. In addition, some other common tools are non-linear programming, integer programming, dynamic programming, sequencing theory, Markov process, network scheduling—PERT and CPM, symbolic logic, information theory and utility/value theory. The list, of course, is not exhaustive. The detailed discussion on above will be presented in appropriate chapters, however, brief explanation of these is given below:

(i) Linear Programming (L.P.)

Linear programming is basically a constrained optimisation technique which tries to optimise some criterion within some constraints. It consists of an objective function which is some measure of effectiveness like profit, loss or return on investment and several boundary conditions putting restriction on the use of resources. Objective function and boundary conditions are linear in nature. There are methods available to solve a linear programming problem.

(ii) Waiting Line or Queuing Theory

This deals with the situation in which queue is formed or the customers have to wait for service or machines wait for repairmen and therefore concept of a queue is involved. If we assume that there are costs associated with waiting in line, and if there are costs of adding more service facilities, we want to minimize the sum of costs of waiting and the costs of providing service facilities. Waiting line theory helps to make calculations like number of expected member of people in queue, expected waiting time in the queue, expected idle time for the server, etc. These calculations then can be used to determine the desirable number of service facilities or number of servers.

(iii) Game Theory

It is used for decision-making under conflicting situations where there are one or more opponents. The opponents, in game theory, are called players. The motives of the players are dictomized. The success of one player tends to be at the cost of others and hence they are in conflict. Game theory models, a conflict situation arises and helps to improve the decision process by formulating appropriate strategy.

(iv) Inventory Control Models

These models deal with the quantities which are either to be purchased or stocked since each factor involves cost. The purchase and material managers are normally encounter such situations. Therefore, inventory models provide rational answer to these questions in different situations of supply and demand for different kind of materials. Inventory control models help managers to decide ordering time, reordering level and optimal ordering quantity. The approach is to prepare a mathematical model of the situation that expressed total inventory costs in terms of demand, size of order, possible over or under stocking and other relevant factors and then to determine optimal order size, optimum order level etc. using calculus or some other technique.

(v) Simulation

It is basically data generating technique, where sometimes it is risky, cumbersome, or time consuming to conduct real study or experiment to know more about situation or problem. The available analytical methods cannot be used in all situations due to large number of variables or large number of interrelationships among the variables and the complexity of relationship, it is not possible to develop an analytical model representing the real situation. Some times, even building of model is possible but its solution may not be possible. Under such situations simulation is used. It should be noted that simulation does not solve the problem by itself, but it only generates the required information or data needed for decision problem or decision-making.

(vi) Non-Linear Programming

These models may be used when either the objective function or some of the constraints are not linear in nature. Non-linearity may be introduced by such factors as discount on price of purchase of large quantities and graduated income tax etc. Linear programming may be employed to approximate the non-linear conditions, but the approximation becomes poorer as the range is extended. Non-linear methods may be used to determine the approximate area in which a solution lies and linear methods
may be used to obtain a more exact solution.

(vii) Integer Programming

This method can be used when one or more of the variables can only take integer values. Examples are the number of trucks in a fleet, the number of generators in a power house and so on. Approximate solutions can be obtained without using integer programming methods, but the approximation
generally becomes poorer as the number becomes smaller. There are techniques to obtain solution of integer programming problems.

(viii) Dynamic Programming

This is a method of analyzing multistage decision processes, in which each elementary decision is dependent upon those preceding it as well as upon external factors. It drastically reduces the computational efforts otherwise necessary to analyze results of all possible combinations of elementary decisions.

(ix) Sequencing Theory

This is related to waiting line theory and is applicable when the facilities are fixed, but the order of servicing may be controlled. The scheduling of service or the sequencing of jobs is done to minimize the relevant costs and time.

(x) Markov Process

It is used for decision-making in situations where various states are defined. The probability of going from one state to another is known and depends on the present state and is independent of how we have arrived at that state. Theory of Markov process helps us to calculate long run probability of being in a particular state (steady state probability), which is used for decision-making.

(xi) Network Scheduling—PERT and CPM

These techniques are used to plan, schedule and monitor large projects such as building construction, maintenance of computer system installation, research and development design etc. The technique aims at minimizing trouble spots, such as, delays, interruptions and production bottlenecks, by identifying critical factors and coordinating various parts of overall job/project. The project/job is diagrammatically represented with the help of network made of arrows representing different activities and interrelationships among them. Such a representation is used for identifying critical activities and critical path. Two basic techniques in network scheduling are Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM). CPM is used when time taken by activities in a project are known for sure and PERT is used when activities time is not known for sure—only probabilistic estimate of time is available to the users.

(xii) Symbolic Logic

It deals with substituting symbols for words, classes of things or functional systems. Symbolic logic involves rules, algebra of logic and propositions. There have been only limited attempts to apply this technique to business problems; however has had extensive application in the design of computing machinery.

(xiii) Information Theory

Information theory is an analytical process transferred from the electrical communications field to operations research. It seeks to evaluate the effectiveness of information flow within a given system. Despite its application mainly to communication networks, it has had a indirect influence in simulating the examination of business organizational structures with a view to improving information or communication flow.

(xiv) Utility/Value Theory

It deals with assigning numerical significance to the worth of alternative choices. To date, this has been only a concept and is in the stage of elementary model formulation and experimentation and can be useful in decision-making process.

2. Computers in Optimization Techniques

As has been presented earlier that OR tries to find optimal solutions with multiple variables. In most of the cases a large number of iterations are required to reach optimal solution. Manually this task becomes time consuming and single mistake at any point can generate erroneous results. With the development of computers and P.C's this has reduced manual efforts considerably and solutions can be obtained in a short period of time and possibility of errors is also minimized considerably. Storage of information/data is easy and faster with the use of computers because of its memory. The computational time requirements are also less and no paper work is required. Transfer of data from one place to another is also possible through net/computers. The reliability of solutions is also high. For the large size problems, where simulation was to be used, it was not possible to carry it out manually, which is now possible with the use of computers. To handle linear programming problem with multiple variables use to be cumbersome and time taking; can be done at wink of moment without any manual efforts.

3. BENEFITS OF OPERATION RESEARCH TO MANAGEMENT:

i. ***Structured approach to problem solving and decision making-*** Predetermined or a substantial amount of time and effort can be saved in developing and solving or models if a logical and consistent approach is followed.

ii. ***Critical approach to problem solving and decision making -***The decision maker will come to understand various components of the problem and accordingly select a mathematical model for solving the given problem. And problem solutions are examined critically and the effect of any assumptions' and limitations of such models.

3.1 Time-Cost Optimization with Network Analysis

There is availability of various techniques for optimization and project control software, still many construction projects do not achieve their cost and time objectives. The basic scheduling techniques commonly used in practice include the Critical Path Method (CPM) and Program Evaluation Review Technique (PERT).

3.2 Critical Path Method

Critical Path Method (CPM) was developed to optimize the organization of complex procedures of an activity network and also to identify critical activities in a network critical path. Because activities in the network can be carried out in parallel, the critical path is the length of the longest path from the start of project to its finish. An activity is said to be critical if there is no delay in determining its start and finish times. Once the duration of all the activities is estimated, the project duration can be calculated with CPM, the project duration is the sum of the durations of all activities on the critical path.

3.2.1 METHODOLOGY:

The deterministic approach is based on critical path method and has been the most widely used method in planning and controlling of the construction projects. The important objective of the critical path method implementation was to determine how best to reduce the time required to perform routine and repetitive tasks that are needed to support an organization. Various Terms used in Time Cost Optimization

1) Normal Cost: It is the lowest cost of completing an activity in minimum time employing normal means that is not using overtime or special resources.

2) Normal Time: It is minimum time required to achieve the normal cost.

3) Crash Cost: It is a least cost of completing an activity by employing all possible means like overtime, additional machinery and proper materials.

4) Crash Time: It is an absolute minimum time associated with the crash cost.

5) Critical Path: It is the sequence of project network terminal elements with the longest overall duration, determining the shortest time to complete the project. Following Steps are carried out while performing the time and cost optimization.

Step1. The Schedule required for completing the project is developed based on the normal duration and normal cost of activities involved.

Step2. Then it is required to find out the crash cost and crash duration for each activity. After this cost slope is obtained with the help of following formula: Cost Slope = (Crash cost – Normal cost) / (Normal time – Crash time)

Step3. To identify the critical activities on the critical path, then identifying the critical activity that can be crashed with the least crashing slope. If there is more than one critical path, a critical activity from each path should be selected and crashed as long as the two selected activities can still be crashed and the total crash cost of the selected activities is the minimum.

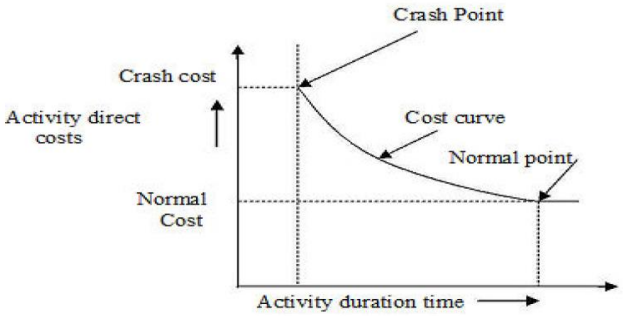

Figure 3.1: Cost function of an activity

Where, NC: Normal Cost of an activity CC:Crash Cost of an activity NT: Normal duration of an activity CT: Crash duration of an activity

Step4. Shortening the activity by the units required that is maximum crashing units is obtained by subtracting crashing time from normal time.

Step5. The new cost and duration of the project should be calculated at this step, and then steps through three to five should be repeated until the optimum solution is obtained.

3.3. Time and Cost Relationship of a Project

When the all the activities is considered in the project, the relationship between project duration and the total construction cost can be shown in Fig-2. Direct cost could be seen as the summation of all the activities' construction direct cost and indirect cost is the project site overhead. Hence, the total project construction cost can be calculated by adding direct cost to indirect cost. Fig-2 shows that when the duration for the project is reduced, the total cost of further reductions becomes quite high.

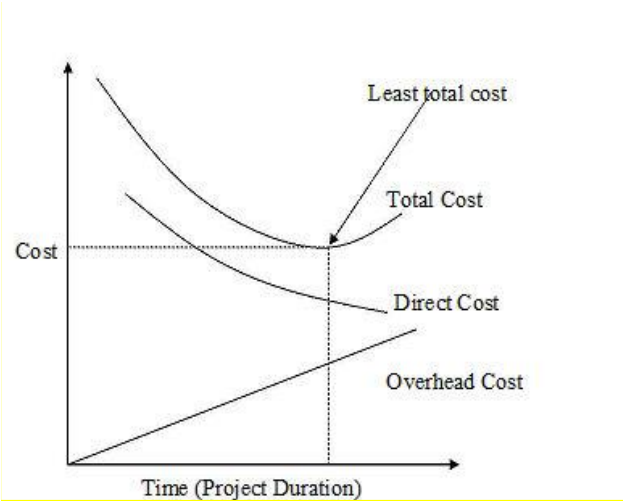

Fig. 3.2 General relationship of project construction cost to duration.

4. Program Evaluation and Review Technique

Since uncertainties such as inclement weather, unforeseen site conditions, poor labor performance, inadequate recourse allocation, low equipment performance and inferior management style incurred during a construction process, it could be difficult to estimate activity durations correctly. Program evaluation and review technique (PERT) was originally designed to orient time elements of

a project and adopted probabilistic time estimate to determine the probability that a project could be completed by a given date. This method uses weighted values of three time estimates: i.e. pessimistic, most likely and optimistic duration to estimate the mean and variance. The expected mean values then are used to determine the mean critical path.

1. Optimistic time (O): the minimum possible time required to complete a task, assuming condition that everything proceeds better than is normally expected.
2. Pessimistic time (P): the maximum possible time required to complete a task, assuming condition that everything goes wrong (but excluding major catastrophes).
3. Most likely time (M): the best estimate of the time required to complete a task, assuming condition that everything precedes as normal.
4. Expected time (TE): the best estimate of the time required to complete a task, accounting for the fact that things don't always proceed as normal

$TE = (O + 4M + P) \div 6$

Ultimately a point is reached at which the project cost cannot be realistically reduced any further even with the infusion of additional resources. As the duration increases, the total cost increase but at a rate that is lower than the daily rate.

5. CONCLUSION

It was discussed that using Optimization techniques by multidisciplinary team, value and economy are improved through study of alternative design concepts, material and construction methods without compromising functional requirement and quality. Cost effective construction techniques, material and different management strategies during the execution of project plays important role in saving time as well as cost of construction. Thus, cost reduction techniques assures best cost, value will be obtained over life cycle of the building or structure. 5

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