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Project Report

On

"To construct a project schedule that identifies critical activities and the Time-Cost Trade-Off of the entire project"

Submitted By

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This is to certify that this project entitled **“To construct a project schedule that identifies critical activities and the Time-Cost Trade-Off of the entire project”** is my original work carried out in the year 2020, and has been submitted for partial fulfillment of the requirements of the course M.Sc. Operational Research (M.A./M.Sc. Applied Operational Research). This project report has not been submitted earlier in full or in part for any other diploma or degree to any other university or institute to the best of my knowledge.

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M.Sc. Operational Research

(Semester-IV)

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INDEX

CHAPTER - 1

INTRODUCTION TO OPERATIONAL RESEARCH

OPERATIONAL RESEARCH – AN OVERVIEW:

Operational Research (OR) is an interdisciplinary branch of applied mathematics and formal science that uses methods like mathematical modeling, statistics, queuing theory, game theory, decision analysis, and simulation to arrive at optimal or near optimal solutions to complex problems. Because of the computational nature of these fields, OR also has ties to computer science, and operations researchers regularly use custom-written or off-the-shelf software.

Operational research is "the body of methods which makes possible a rational determination of the most efficient or economical solution in policy-decision problems concerning the management of an economic or human phenomenon, drawing upon statistical – mathematical procedures which sometimes requires the use of high-speed computers. These methods are based upon a prior analysis of the relationships among the technical and psychological factors in the phenomenon's structure, which is achieved by resources to the various appropriate scientific disciplines".

Literally, the word 'operation' may be defined as some action that we apply to some problem or hypothesis and the word 'research' is an organized process of seeking out facts about the same. O.R. has been described as the "science of use", "quantitative common sense", "and scientific approach to decision making problems", etc.

O.R. is mainly concerned with the techniques of applying scientific knowledge, besides the development of science. It provides an understanding which gives the expert/manager new insights and capabilities to determine better solutions in his decision-making problems, with great speed, competence and confidence.

The term operational research was first coined in 1940 by McClosky and Trefthen in a small town Bowdsey, of United Kingdom. The new science came into existence in military context during World War II. The procedures of operations research gave effective assistance during World War II in missions such as deploying radar, searching for enemy submarines, and getting supplies where they were most needed. Following the war, new analytical methods were developed and numerous peacetime applications emerged, leading to the use of operations research in many industries and occupations.

O.R. draws upon ideas from engineering, management, mathematics, and psychology to contribute to a wide variety of application domains; the field is closely related to several other fields in the "decision sciences" -- applied mathematics, computer science, economics, industrial engineering, and systems engineering.

The prevalence of operations research in the Nation's economy reflects the growing complexity of managing large organizations that require the effective use of money, materials, equipment, and people. Operations researches analysts help determine better ways to coordinate these elements by applying analytical methods from mathematics, science, and engineering. They solve problems in different ways and propose alternative solutions to management, which then chooses the course of action that best meets the organization's goals. In general, operations research analysts may be concerned with diverse issues such as top-level strategy, planning, forecasting, resource allocation, performance measurement, scheduling, design of production facilities and systems, supply chain management, pricing, transportation and distribution, and analysis of data in large databases.

O.R. is distinguished by its broad applicability and by the wide variety of career opportunities and work styles it embraces. OR specialists may be theoreticians or practitioners. They may work in academia, in industry, or in public service, teaching, doing research, consulting, or implementing OR models. Within the field, some OR professionals remain generalists while others specialize in particular tools or problem domains. Some O.R. professionals move from technical positions into managerial functions. Because the concepts and methods of O.R. are so pervasive, O.R. offers very flexible career paths.

Today thousands of individuals pursue careers in operations research, the management sciences and closely related professions. Their work has achieved an increasingly important role in both the public and private sectors. O.R. professionals inform public officials on such topics as energy policy; design and operation of urban emergency systems; defense; health care; water resource planning; and criminal justice. They also address a wide variety of issues in communication systems; computer operations, design, and networking; transportation; marketing; finance; inventory planning; manufacturing; and many other topics that aim to improve business productivity.

In a nutshell, operations research (O.R.) is the discipline of applying advanced analytical methods to help make better decisions. By using techniques such as mathematical modelling to analyze complex situations, operations research gives executives the power to make more effective decisions and build more productive systems based on:

- More complete data
- Consideration of all available options
- Careful predictions of outcomes and estimates of risk
- The latest decision tools and techniques

SOME DEFINITIONS OF OPERATIONAL RESEARCH:

- Operations Research is the discipline of applying advanced analytical methods to help make better decisions. By using techniques such as mathematical modelling to analyze complex situations, operations research gives executives the power to make more effective decisions and build more productive systems.
- OR is the application of scientific and mathematical methods to the study and analysis of problems involving complex systems. Employing techniques from other mathematical sciences, such as mathematical modelling, statistical analysis, and mathematical optimization, operational research arrives at optimal or near-optimal solutions to complex decision-making problems.
- O.R. is the science of rational decision making and the study, design and integration of complex situations and systems with the goal of predicting system behavior and improving or optimizing system performance. It

encompasses managerial decision making, mathematical and computer modelling and the use of information technology for informed decision-making.

- OR is a scientific knowledge through interdisciplinary team effort for the purpose of determining the best utilizations of limited resources.
- OR is the art of giving bad answers to the problems which otherwise have worse answers.
- Operational research is often concerned with determining the maximum (of profit, performance, or yield) or minimum (of loss, risk, or cost) of some real-world objective. Originating in military efforts before World War II, its techniques have grown to concern problems in a variety of industries.

HISTORY OF OPERATIONAL RESEARCH:

O.R. has its beginning in World War II. The term Operational Research was coined by McClosky and Trefthen in 1940 in U.K. British scientists set up the first field installations of radar's during the battle and observed air operations. Their analysis of these led to suggestions that greatly improved and increased the effectiveness of British fighters, and contributed to successful British defense. Operations Research was then extended to antisubmarine warfare and to all phases of military, naval, and air operations both in Britain and the United States, and was incorporated in the post-war military establishments of both the countries.

In India, Operational Research came into existence in 1949 with the opening of an O.R unit at the Regional Research Laboratory at Hyderabad. At the same time, another group was set up I Defense Science Laboratory which devoted itself to problem of stores, purchase and planning. In 1953, an O.R unit was established in the Indian Statistical Institute, Calcutta, for the application of O.R methods in national planning and survey. The O.R society of India was formed in 1955. It became a member of the International Federation of O.R Societies in 1959.

MODELS IN OPERATIONAL RESEARCH:

A model in O.R. is 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. Constructing a model aids to input the complexities and possible uncertainties attending a decision-making problem, into a logical framework amenable to comprehensive analysis. Such a model clarifies the decision alternatives, their anticipated effects, indicate the relevant data for analyzing the alternatives, and leads to informative conclusions.

A model which has the possibilities of measuring observations may be called a Quantitative Model. A product, a device or any tangible thing used for experimentation may represent a physical model.

The objective of a model is to provide a means for analyzing the behavior of the system for the purpose of improving its performance.

CLASSIFICATION OF MODELS:

Although the classification of models is a subjective problem, they may be distinguished as follows:

MODELS BY DEGREE OF ABSTRACTION:

These models are based on the past data/information of the problems under consideration and can be categorized into:

(a) Language Models

(b) Case Studies.

MODELS BY FUNCTION:

These models consist of:

(a) Descriptive Models

These models describe explain and predict facts and relationships among the various activities of the problem. These are used to describe mathematically some particular aspects of the system being modelled. These models do not have an objective function as a part of the model to evaluate decision alternatives. Thus, in a descriptive model it is possible to get information as to how one or more factors charge as a result of changes in other factors.

(b) Predictive Models

These models indicate that "if this occurs then that will follow". They relate independent and dependent variables and permit trying out, 'what if' questions. In other words, these models are used to predict the outcomes due to a given set of the alternatives for the problem. These models do not have an objective function as a part of the model to evaluate decision alternatives.

(c) Normative Models

These models provide the "best" or "optimal" solution to the problems subject to limitation on the use of resources. These models provide recommended courses of action. For example, in mathematical programming, models are formulated for optimizing the given objective function, subject to certain restrictions and non-negativity of the decision variables.

MODELS BY STRUCTURE:

(a) Iconic Models

Iconic model retains some of the physical properties and characteristics of the system they represent. An iconic model is either in an idealized form of or a scaled scale version of the system. In the other words, such models represent the system as it is by scaling it up or down. Examples of iconic models are blue prints of a home, globes, photographs, drawing, atom etc. Iconic models are easy to observe, build and describe but difficult to manipulate and not very useful for the predictions. Commonly these models represent a static event.

(b) Analogue Models

Analogue models are more abstract then iconic ones for there is no 'look- alike' correspondence between these models and real-life items. They are built by utilizing one set of properties to represent another set of properties. For instance, a network of pipes through which water is running could be used as a parallel for understanding a distribution of electric current. Graphs and maps parallel in various colors are analogue models, in which different color correspond to different characteristics. A floe process chart is analogue model which represents the order of occurrence of various events to make a product.

(c) Symbolic Models

These models are more abstract in nature. They employ asset of mathematical symbols to represent the components of the real system. These models are more general and precise.

MODELS BASED ON DEGREE OF CERTAINITY:

These models are represented by:

(a) Deterministic Models

If all the parameters, constants and functional relationships are assumed to be known with certainty when decision is made, then the model is said to be deterministic. Thus, in such a case, the outcome associated with

particular course of action is known. That is for a specific set of input values there is uniquely determined output which represents the solution of the model under conditions of certainty. Linear programming models are example of deterministic models.

(b) Probabilistic (Stochastic) Models

Models in which at least one parameters or decision variables is a random variable are called probabilistic models. These models reflect, to some

extent the complexity of the real world and the uncertainty surrounding it.

MODELS BY EXTENT OF GENERALITY:

These models are represented by:

(a) Specific Models

When a model presents a system at some specific time, it is known as a specific model. In these models if time factor is not considered, then they are termed as static model and dynamic model otherwise.

(b) General Models

Simulation and heuristic models fall under general models. These models are mainly used to explore alternative strategies which have been overlooked previously. These models do not yield any optimum solution to the problem, but give a solution to the problem depending on the assumptions based on the past experience.

METHODOLOGY OF OPERATIONAL RESEARCH:

The systematic methodology developed for operations research study deals with problems involving conflicting multiple objectives, policies and alternatives. O.R. in the final analysis is a scientific methodology which is applied to the study of operations of large complex organization and activities with a view to assessing the overall implications of various alternative courses of action, thus providing an improved basis for managerial decision.

Then O.R. approach to problem solving consists of the following six steps:

1. Formulation of the problem: It involves analysis of the physical system, setting up of objectives, determination of restriction constraints against which decision should be adopted, alternative courses of action and measurement of effectiveness.
2. Construction of a mathematical model: after formulation of the problem, the next step is to express all the relevant variables of the problem into a mathematical model. a generalized mathematical model might take the form:

$$E = f(x_i , y_j).$$

3. Deriving the solution from the model: once the mathematical model is formulated, the next step is to determine the values of the decision variables that optimize the given objective function. This deals with the mathematical calculations for obtaining the solution to the model.

4. Validity of the model: the model should be validated to measure its accuracy. That is in the order for a model to be useful, the degree to which it actually represents the system or problem being modeled must be established. A model is valid or accurate if
(a) It contains all the objectives, constraints, and the decision variables relevant to the problem,

(b) The objectives, constraints, and the decision variables are all relevant to, or the actually part of the problem, and

(c) The functional relationships are valid.

5. Establishing control over the solution: After testing the model and its solution, the next step of the study is to establish control over the solution, by proper feedback of the information on the variables which deviated significantly. As soon as one or more of the control variables change significantly, the solution goes out of the control in such as, situation the model may accordingly be modified.

6. Implementation of the final results: Finally, the tested results of the model are implemented to work. This would basically involve a careful explanation of the solution to be adopted and its relationship with the operating realities. This stage of O.R. investigation is executed primarily through the cooperation of both the O.R. experts and those who are responsible for managing and operating the system.

SCIENTIFIC METHODS IN OPERATIONAL RESEARCH:

The scientific method in operations research consists of the following three phases:

Judgement phase: This phase includes:

(I) Identification of the real-life problem.

(II) Selection of an appropriate goal and the values of the various variables

related to the goals.

(III) Appropriate scale of measurement

(IV) Formulation of an appropriate model of the problem, abstracting the essential formulation so that the solution at the decision makers can be

sought.

Research phase: this phase is the largest and longest among the other two. However other two also equally important as they provide basis for a

scientific method. This phase utilizes

(i) Observations and data collection for better understanding of what the problem is.

(ii) Formulation of hypothesis and models.

(iii) Observation and experiment to test the hypothesis on the basis of

additional data.

(iv) Analysis of the available information and verification of the hypothesis using pre-established measures of effectiveness.

(v) Predictions of the various results from the hypothesis, and

(vi) Generalization of the results and consideration of alternative methods.

Action phase: This phase consists of making recommendations for decision process by those who first posed the problem for consideration, or by anyone in a position to make a decision influencing the operation in which the problem occurred.

APPLICATIONS OF OPERATIONAL RESEARCH:

O.R is mainly concerned with the techniques of applying scientific knowledge, besides the development of science. In recent years, O.R. has successfully entered many different areas of research in Defense, Govt. service organizations and Industry. Some applications of O.R. in the functional areas of management are:

FINANCE, BUDGETING AND INVESTMENT:

- Cash flow analysis, long-range capital requirement, investment

portfolios, dividend policies, etc.

- Credit policies, credit risks etc.

PHYSICAL DISTRIBUTION:

- Location, size of warehouses, distribution centers, retail outlet etc.
- Distribution policy.

PURCHASE, PROCUREMENT AND EXPLORATION:

- Determining the quantity and timing of purchase of raw materials,

machinery etc.

- Bidding policies.
- Equipment replacement policies.

MANUFACTURING AND FACILITY PLANNING:

- Production scheduling.
- Project scheduling and allocation of resources
- Number and location of factories, warehouse and their size.
- Determining the optimum production mix.
- Maintaining crew sizes.
- Maintenance policies and preventive maintenance.

MARKETING:

- Product selection, timing competitive actions.
- Advertising strategy and choice of different media of advertising.
- Number of salesmen, frequency of calling of accounts, etc.
- Effectiveness of market research.
- Size of stock to meet the future demand.

PERSONAL:

- Recruitment policies and assignment of jobs.
- Selection of suitable personal on minimum salary.

- Mixer of age and skills.
- Establishing equitable bonus systems.

RESEARCH AND DEVELOPMENT:

- Determination of areas of concentration of research and development.
- Reliability and evaluation of alternative designs.
- Control of development projects.
- Co-ordination of multiple research projects.

OR.: A TOOL IN DECISION-MAKING:

"Operations research is a tool employed to increase the effectiveness of managerial

decision as an objective supplement to the subjective feeling of the decision-maker".

1. Better Decisions.

2. Better Coordination

3. Better Control

4. Better Systems.

USES OF OPERATIONAL RESEARCH:

Formulation of industrial problems may be generalized into different groups of classical problems, the package program for which is available for mechanization and manual solutions. Various problem of optimization can be brought to the model of linear program for which solution is available. While formulating the problem, the class of the problem is to be decided and the parameters are to be defined accordingly. Inventory control, production planning, product mix, transportation problem, etc. are very common to the industries. The cost reduction with the help of these tools is very much powerful in comparison to any other conventional method. We can enumerate the advantages of these techniques as:

1. Optimum use of production factors: linear programming techniques indicate how a manager can most effectively employ his production factors by more efficiently selecting and distributing these elements.
2. Improved quality of decision: the computation table gives a clear picture of happenings within the basic restriction and the possibilities of compound behavior of the elements involved in the problems. The effect on the profitability due to changes in the production pattern will be clearly indicated in the table. e.g. simplex table.
3. Preparations of future managers: these methods substitute a means for improving knowledge and skills of your manager.
4. Modification of mathematical solution: O.R. presents a possible practical solution when one exists, but it is always a responsibility of the manager to accept or modify the solution before its use. The effects of these modifications may be evaluated from the computational steps and tables.
5. Alternative solution: O.R. techniques will suggest all the alternative solution available for the same profit so that the management may decide on the basis of its strategies.

CHARACTERISTICS OF OPERATIONAL RESEARCH:

1. Such a team, when confronted with a problem, determines the solution of the problem by following inter-disciplinary approach. Every expert of the team tries to abstract the essence of the problem and determines if the same type of problem has been previously undertaken or not. If a similar problem

has been dealt previously then it becomes quite easy to apply the same technique to determine the solution of current problem as well. In this way, each member of the team, by utilizing his experience and expertise may be in a position to suggest an approach that otherwise may not be thought of. Thus, Operational Research makes use of experience Interdisciplinary Team Approach. It is an important characteristic of operational research. According to this characteristic, no single individual can be an expert on all aspects of a problem under consideration. Thus, Operational Research utilizes the inter-disciplinary approach i.e., an Operational Research team comprises of experts from different disciplines and expertise of people from different disciplines for developing new methods and procedures.

2. Operational Research is a continuing process. It cannot stop on the application of the model to one problem, for this may create new problems in other sectors and in the implementation of the decision taken. Operational Research must also specify the organizational changes required to implement decisions and control the result thereof. Without this, the work of Operational Research practitioner is incomplete.
3. Objective. Operational Research attempts to find the best or optimal solution to the problem under consideration. To do this, it is necessary to define a measure of effectiveness that takes into account the goals (objective) of the organization. In other words, "Operational Research is the scientific study of large systems with a view to identify problem areas and provide the managers with a quantitative basis for decisions which will enhance their effectiveness in achieving the specified objectives."
4. Operational Research increases the creative ability of a decision-maker.
5. Operational Research is a decision-making science.
6. Uncovers new problems for study methods.
7. Examine functional relationship from a systems overview.
8. Operational Research gives only bad answers to the problem where only worse could be given i.e.; it cannot give perfect answers to the problems. Thus, Operational Research improves only the quality of the solution.
9. Methodological Approach. Operational Research utilizes the scientific method. Specifically, the process begins with the careful observation and formulation of the problem. The next step is to construct a scientific (typically mathematical or simulation) model that attempts to abstract the essence of the real problem. From this model, conclusions or solutions are obtained

which are also valid for the real problem. In an iterative fashion, the model is then verified through appropriate experimentation.

10. Operational Research replaces management by personality.
11. Operational Research is for operations economy. Operational Research is a problem solving and a decision-making science. Whenever we have conflicts, uncertainty and complexity in a situation, Operational Research can help in the end to reduce costs and improve profits and effect substantial "Operations Economy."

TECHNIQUES OF OPERATIONAL RESEARCH:

The techniques discussed below can be freely used by a progressive manager in the decision-making process.

1. PROBABILITY: It is rarely possible to predict the future of the business world with complete certainty. There is always an element of uncertainty as far as the future courses of events are concerned. The probability concepts try to analyze the uncertainties and bring out necessary data with reasonable accuracy for the purpose of decision making. Probabilities are of two types: Objective probability and Subjective probability. The objective probability is a probability for which there is a definite historical evidence and common experience. On the other hand, the subjective probability is a probability where historical evidence is not available and the businessman has to rely on own estimation of a situation and the likelihood of various outcomes. The probability of any given action must be between 0 and 1 and the sum of all these probabilities must be 1. If the probability is '0' to an occurrence, it will not take place and in the case the probability is 1 to an occurrence, it is certain that the occurrence will take place.

2. DECISION THEORY: The basic elements in a decision theory are:

(i) Alternative course of action(strategies)
(ii) Various states of nature.
(iii) Knowledge about the likelihood of occurrence of each state of nature.
(iv) Net value (pay-off) to decision-maker for each outcome.
(v) Decision maker's objectives.

The basic premise of decision theory is that the behavior of the future is probabilistic and not deterministic. Various probabilities are assigned to the state of nature on the basis of available information or subjective judgment and the likely outcomes of the alternative courses of action are evaluated accordingly before a particular alternative is selected. This technique of decision making is based on expected monetary value and utility. By analyzing the monetary value of utility from a given set of circumstances, a model is constructed and accordingly decisions are taken. It is a well-known fact that the environment within which decisions are taken can be logically divided into three parts: certainty, risk and uncertainty. Certainty exists when one can specify exactly what will happen when during the period for which the decision is being made. Risk refers to a situation where one can specify a probability distribution for the possible outcomes. Uncertainty refers to the condition when one cannot specify the relative likelihood of the outcomes. Although some business decision can be made under condition nearing certainty, elements of risk and uncertainty underline most of the decisions which mangers make.

3. LINEAR PROGRAMMING: It is a method for selecting an optimum combination of Factors from a series of inter-related alternatives, each subjective to limitation. It involves the development of linear equations to obtain the best solution for the allocation problem. An allocation problem "...arise whenever there are a number of activities to perform but limitations on either the amount of resources or the way they can be spent prevent us from performing each activity in the most effective way conceivable. In such situations we wish to allot the available resources to the activities in a way that will optimize the effectiveness".

Linear programming consists of:

(a) The Simplex Method. This aims at maximizing or minimizing a given function, subject to constraints in respect of each variable.

(b) The Transportation Problem. This deals with problems of matching the origins (stores, warehouse, and factories) with the outlets (process center, market etc.) at a minimum cost of distribution and transportation.

(c) The Assignment Problem. It can handle the problems of assigning a given number of agents each one to the same number of tasks so as to result in maximum efficiency or minimum cost.

4. DYNAMIC PROGRAMMING: This technique deals with the problems that arise in connection with multi period analysis and decisions. In contrast to Linear Programming there does not exists a standard mathematical formulation of Dynamic Programming, rather it is a general type of approach to problem solving and particular equation must be developed to fit each individual situation. However, the basic approach used in Dynamic programming is to break down a problem into series of problems in such a way that answer to the first sub problem can be used in deriving the solution to the next sub-problem and so forth finally giving solution to the whole problem.

5. SEQUENCING: This method solves problem where effectiveness measure (in terms of cost, time, mileage, etc.), depends upon the sequence of performing given jobs. This helps to determine a sequence in which given jobs should be performed if the objective is to minimize the total efforts.

6. GAME THEORY: Developed by Jon Von Neumann and Morgenson, this is a mathematical theory applicable to competitive business problems. This technique deals with situations where two or more (finite) individuals are making decisions involving conflicting interests. However, the final decision depends upon the decisions of the parties concerned.

7. INVENTORY CONTROL AND MANAGEMENT: Inventory problems(models) are mainly concerned with inventory decisions, the basic inventory decisions are:

i. How much to order at one time?
ii. When to order this quantity?

The first decision namely – how much to order at one time, is to be balanced between two pressures – the first pressure is to order huge lots so as to minimize ordering costs and the other pressure is order small lots so as to minimize carrying costs. The optimum course of action is a compromise between the two extremes. Arriving at a model for deriving the economic order quantity (E.O.Q) can do this. The second decision namely – when to order this quantity, is decided by ascertaining the re-ordering level. The re-ordering level is the point lying between the maximum and the minimum levels at which time it is essential to intimate the purchase department for fresh supplies of the material. This point will usually be slightly higher than the minimum stock, to cover such emergencies as abnormal usage of material or unexpected delay in delivery of fresh supplies. Re-ordering level depends upon lead-time, rate of consumption and economic ordering quantity.

8. QUEUING THEORY: Waiting lines at any service center are common phenomena and Queuing theory is devoted to mathematical study of waiting lines. Various alternative models have been used to describe such situations, but they basically share the following common features:

i. Units requiring services are generated from an input source from different kinds of queues for service,
ii. a service discipline by which the queue members are selected for receiving service,
iii. a service mechanism which defines the type of service, after the completion of which unit leaves the system or rejoins it for further processing. Many alternative assumptions can be made about these common elements, and these give rise to the different queuing problems.

9. NETWORK ANALYSIS (PERT/CPM): PERT or Program Evaluation and Review technique and CPM or Critical Path Method are powerful management tools for planning and control of complex jobs involving a large number of activities. A project consists of well-defined collection of jobs or activities, some of which can be started independently of others and all the jobs, have to be carried out in technological sequence. The objective of PERT/CPM technique is to establish time duration for each activity and to shorten the total duration acquired for the completion of the project incurring the optimum cost. CPM introduces the concept of critical path, i.e., the longest time required to complete a project and emphasizes the reduction of the duration of the activities by the application of more resources by obtaining a trade-off between cost and time completion.

10. SIMULATION: It is highly versatile technique of operational research. It has a wide-ranging application in business situations. Simulation is particularly appropriate where it is difficult to build a model for the real-life situation mathematically or if at all it is modeled, it is difficult to solve the model analytically. It may be noted that simulation is a manipulation of a model constructed from the formal statements of mathematical representation in respect of logical relations between the elements in a structure or a system expressed in measurable terms. Thus, simulation is a process of designing an experiment, which will duplicate or present as nearly as possible the real situation and then watching what does happen. In every walk of life, the test of adequacy of our decisions is the test of our reality. However, in practical life, modern business cannot afford the luxury of testing the consequences of the major decisions in the real-life world. Instead of finding out the characteristics of an aircraft or a skyscraper, by actually building or constructing it, we can simulate its performance on the basis of its characteristics. In this way we can experiment without incurring the cost of failure. The simulation techniques allow the modern managers to examine the probable consequences of his decisions without the risk of real-life experimentation.

11. REPLACEMENT THEORY: This theory suggested the determination of the time when items of plant should be replaced. The replacement of items is necessary because the efficiency of an item deteriorates with time, or sometimes the item may fail completely. Replacement, on the one hand, requires investment, on the other, saves operating cost which otherwise is more while using old parts. Thus, a problem arises when the part should be replaced so that cost is minimum. The replacement problems arise in three conditions:

(i) Replacements of item that fail completely and are expensive to be replaced.
(ii) Replacement of items whose efficiency deteriorates with time: and
(iii) Replacement of items because of obsolescence.

12. RELIABILITY: Reliability theory is concerned with quantifying the frequency of failures and developing an indicator of quality and dependability of a product. It is closely associated with probability theory and therefore facilitates statistical analysis and measurement. The assessment of reliability of equipment is most useful to the designer in improving the quality of critical parts as well as in deciding how much to provide by way of standby.

13. SOME ADVANCE O.R. TECHNIQUES.

(i) **NON-LINEAR PROGRAMMING:** It is that form of programming in which some or all of the variables are curvilinear. In other words, this means that either the objective functions or the constraints or both are not in liner form. In most of the practical situations, we encounter with non-linear programming problems.

(ii) **INTEGER PROGRAMMING:** Integer programming applies when the values of decision variables are restricted to integers. Applications include Financial Management and Plant Location.

(iii) **GOAL PROGRAMMING:** Goal programming deals with the problems having multiple objectives. It is a technique quite similar to linear programming. Applications include production scheduling, transportation problems, portfolio analysis and crop selection in agriculture.

(iv) **HEURISTIC PROGRAMMING:** It is also known as discovery method refers to step by step search towards an optimal when a problem cannot be expressed in mathematical programming form. The search procedure examines successively a series of combinations that lead to stepwise improvement in the solution and the search stops when near optimal has been found.

(v) **ALGORITHMIC PROGRAMMING:** It is just the opposite of Heuristic programming. It may also be termed as mathematical programming. This programming refers to a thorough and exhaustive mathematical approach to investigate all aspects of given variables in order to obtain optimal solution.

(vi) **QUADRATIC PROGRAMMING:** It refers to a modification of linear programming, in which the objective function and constraint equations appear in quadratic form, i.e., they contain squared terms.

(vii) **PROBABILISTIC PROGRAMMING:** It is also known as stochastic programming refers to linear programming that includes an evaluation of relative risks and uncertainties in various alternatives of choice for management decision.

LIMITATIONS OF OPERATIONAL RESEARCH:

O.R. has certain limitations. These limitations are as follows:

(a) MAGNITUDE OF COMPUTATION: O.R. tries to find out the optimal solution taking all the factors into account. In the modern society, these factors are numerous and expressing them in quantity and establishing relationship among these, require huge calculations. All these calculations cannot be handled manually and require electronic computers which bear a very heavy cost. Thus, the use of O.R. is limited to only very large organizations.

(b) ABSENCE OF QUALIFICATION: O.R. provides solution only when all the elements related to a problem can be quantified. The tangible factors such as product, price, etc., can be expressed in terms of quantity, but intangible factors such as human relations etc. cannot be quantified. Thus, these intangible elements of the problem are excluded from the study, though these might be equal or more important than quantifiable intangible factors as far as possible.

(c) DISTANCE BETWEEN MANAGERS AND OPERATIONS RESEARCH: O.R. being specialist job requires a mathematician or a statistician, who might not be aware of business problems. Similarly, a manager may fail to understand the complex working of O.R. Thus, there is a gap between one who provides the solution and one who uses a solution. Thus, the manager who becomes suspicious about the optimal solution. This problem is mainly of training. Both the persons should have a working knowledge of each other’s job to have better understanding of insights of the problem and its optimal solution.

CHAPTER 2

PROJECT MANAGEMENT

INTRODUCTION TO PROJECT MANAGEMENT:

In today's business environment, two factors have become common: change and complexity. The nature of business has incorporated these factors into our everyday lives. We work in an environment of constant change and increasing complexity, and must be competitive, productive, customer focused, and profitable.

Much has been written about change in the business community. Indeed, we all know the one constant is the existence of change. Marketing strategies, manufacturing strategies, service strategies - all must accept the realization that as soon as the details are spelled out, factors in the marketplace will demand that the strategy be revisited.

Managing change has become a key ingredient for today's successful business. Business has also become extremely complicated. This complexity is related to the number of factors involved in the effort, the global scope of markets, and the sheer size of the efforts being undertaken. Even small decisions often involve the interplay of hundreds of variables.

Project management is both an art and a science. The processes presented in this document illustrate the science of project management. The science consists of a systematic approach using a standard methodology. The art consists of "soft skills" including leadership, trust, credibility, problem solving, and managing expectations. The art of project management is developed through experience, practice, and intuition.

WHAT IS A PROJECT?

Projects have become the new way of accomplishing and managing business activities. Projects are the temporary assemblage of key personnel designed to accomplish specific business objectives with identifiable customers in mind. A project has a beginning and an end. The project team dissolves once the objectives are met. It is fluid and driven by the specific needs of that business. The project approach to managing business activities embraces change and complexity.

Projects can be defined in many different ways. However, there are some traits that all projects have in common. Typically, these traits are used to identify what a project is. The most distinguishing feature is a specific time frame. All projects have a beginning and an end. Many efforts are called “projects” but actually become programs as they extend indefinitely and cover broader, less specific business objectives. Projects must have a clear, definitive goal or objective. The objective is specific, identifiable, and can be accomplished. A project usually involves varied activities, which produce quantifiable and qualifiable deliverables that when added together, accomplish the overall objective.

KEY CHARACTERISTICS OF PROJECTS:

A project has boundaries, so its extent is defined. A project is a one-time effort, usually requiring finite resources. There are distinct start and end dates for projects. You know when you have reached the end of the project.

WHAT IS PROJECT MANAGEMENT?

Project Management is the process of achieving project objectives (schedule, budget and performance) through a set of activities that start and end at certain points in time and produce quantifiable and qualifiable deliverables.

Successful project management is the art of bringing together the tasks, resources and people necessary to accomplish the business goals and objectives within the specified time constraints and within the monetary allowance. Projects and Programs are linked directly to the strategic goals and initiatives of the organization supported.

WHAT IS A PROJECT MANAGEMENT LIFE CYCLE?

The process each manager follows during the life of a project is called the Project Management Life Cycle. A proven methodical life cycle is necessary to repeatedly implement and manage projects successfully.

During the life cycle of any project, proven and tested project management processes or best practices are should be initiated. The types and extent of processes initiated depend on the nature of the project, i.e. size, probability of failure and consequences of failure. Strong and effective leaders apply process to protect all projects.

The Project Management Institute (PMI) provides guidance for project management in the Project Management Body of Knowledge (PMBOK). Every project has a life cycle, with a beginning, a life and an end (defined by accomplishing the objective). The following defines a typical project life cycle and shows the relationship between PMBOK.

Life Cycle Phases and our Life Cycle Phases:

- Initiation
- Planning
- Executing
- Controlling
- Execution and Control
- Closing Close-out

There are 9 major knowledge areas of project management that PMBOK describes as required expertise for all project managers. They are:

- Scope Management
- Risk Management
- Human Resources Management
- Procurement Management

- Time Management
- Cost Management
- Quality Management
- Integration Management

THE SIX PHASES OF PROJECT MANAGEMENT:

INITIATION PHASE:

The initiation phase is the beginning of the project. In this phase, the idea for the project is explored and elaborated. The goal of this phase is to examine the feasibility of the project. In addition, decisions are made concerning who is to carry out the project, which party (or parties) will be involved and whether the project has an ad equate base of support among those who are involved.

In this phase, the current or prospective project leader writes a proposal, which contains a description of the above-mentioned matters. Examples of this type of project proposal include business plans and grant applications. The prospective sponsors of the project evaluate the proposal and, upon approval, provide the necessary financing. The project officially begins at the time of approval.

Questions to be answered in the initiation phase include the following:

- Why this project?
- Is it feasible?
- Who are possible partners in this project?
- What should the results be?
- What are the boundaries of this project (what is outside the scope of the project)?

DEFINITION PHASE:

After the project plan (which was developed in the initiation phase) has been approved, the project enters the second phase: the definition phase. In this phase, the requirements that are associated with a project result are specified as clearly as possible. This involves identifying the expectations that all of the involved parties have with regard to the project result. How many files are to be archived? Should the metadata conform to the Data Documentation Initiative format, or will the Dublin Core (DC) format suffice? May files be deposited in their original format, or will only those that conform to the 'Preferred Standards' be accepted? Must the depositor of a dataset ensure that it has been processed adequately in the archive, or is this the responsibility of the archivist? Which guarantees will be made on the results of the project? The list of questions goes on and on. It is important to identify the requirements as early in the process as possible. Wijnen (2004) distinguishes several categories of project requirements that can serve as a memory aid:

- Preconditions
- Functional requirements
- Operational requirements
- Design limitations

DESIGN PHASE:

The list of requirements that is developed in the definition phase can be used to make design choices. In the design phase, one or more designs are developed, with which the project result can apparently be achieved. Depending on the subject of the project, the products of the design phase can include dioramas, sketches, flow charts, site trees, HTML screen designs, prototypes, photo impressions and UML schemas. The project supervisors use these designs to choose the definitive design that will be produced in the project. This is followed by the development phase. As in the definition phase, once the design has been chosen, it cannot be changed in a later stage of the project. One project involved producing a number of designs, which were quite important to the success of the project. A young designer on the project team created the designs. Although the head of the design department had ultimate responsibility for the designs, he never attended the meetings of the project team when the designs were to be discussed.

DEVELOPMENT PHASE:

During the development phase, everything that will be needed to implement the project is arranged. Potential suppliers or subcontractors are brought in, a schedule is made, materials and tools are ordered, instructions are given to the personnel and so forth. The development phase is complete when implementation is ready to start. All matters must be clear for the parties that will carry out the implementation. In some projects, particularly smaller ones, a formal development phase is probably not necessary. The important point is that it must be clear what must be done in the implementation phase, by whom and when.

IMPLEMENTATION PHASE:

The project takes shape during the implementation phase. This phase involves the construction of the actual project result. Programmers are occupied with encoding, designers are involved in developing graphic material, contractors are building, the actual reorganization takes place. It is during this phase that the project becomes visible to outsiders, to whom it may appear that the project has just begun. The implementation phase is the 'doing' phase, and it is important to maintain the momentum.

In one project, it had escaped the project team's attention that one of the most important team members was expecting to become a father at any moment and would thereafter be completely unavailable for about a month. When the time came, an external specialist was brought in to take over his work, in order to keep the team from grinding to a halt. Although the team was able to proceed, the external expertise put a considerable dent in the budget.

FOLLOW - UP PHASE:

Although it is extremely important, the follow-up phase is often neglected. During this phase, everything is arranged that is necessary to bring the project to a successful completion. Examples of activities in the follow-up phase include writing handbooks, providing instruction and training for users, setting up a help desk, maintaining the result, evaluating the project itself, writing the project report, holding a party to celebrate the result that has been achieved, transferring to the directors and dismantling the project team.

CHAPTER 3

NETWORK ANALYSIS

NETWORK TECHNIQUES:

To achieve the objectives of project management network techniques is widely used. It is commonly known as PERT (Programmed Evaluation and Review Technique), CPM (Critical Path Method). PERT is used in Research type of projects whereas CPM is used in all of non-research type projects.

EVOLUTION OF NETWORK TECHNIQUES:

By the end of 18th century, the decision-making process was mainly depended on the managerial capabilities, experiences and academic background of managers. In the early stage of 19th century, the pioneers of scientific management started developing the scientific management techniques. During World War I, Henry L. Gantt developed Gantt Chart for production scheduling which was later on modified to bar chart for the purpose of project and production scheduling. The network techniques of PERT and CPM were concurrently developed in 1957. In the beginning, CPM was used for planning and scheduling of constructional projects. It was also used for scheduling the maintenance shutdown. The construction industry in general and the petrochemical industry in particular were the major areas of CPM applications.

PERT was developed by US Navy for scheduling the research and development work for the Polaris Fleet Ballistic Missiles Programmed whose activities were subject to a considerable degree of uncertainty. Initially, this technique was named as “Programmed Evaluation and Review Technique” after 1958, this technique was used by Russian Scientists for the utilization and management of their huge ammunition. But after 1960, this technique came up as a revolutionary technique for the purpose of decision -making.

With the passage of time, PERT and CPM applications started over-lapping and now they are used almost as single technique and the difference between the two is only of the historical and academic interest.

Types of Networks:

1. AOA Network: Activity on Arrow Network
2. PDM/AON Network: Precedence Diagram Method / Activity on Node Network

NETWORK BASIC COMPONENTS:

A network is a graphic representation of a project's operations and is composed of activities and events that must be completed to reach the end objective of a project, showing the planning sequence of their accomplishments, their dependence and inter-relationships.

The basic components of a network are:

ACTIVITY: An activity is a task or item of work to be done, that consumes time, effort, money or other resources. It lies between two events, called the 'preceding' and 'succeeding' ones. An activity is represented by an arrow with its head indicating the sequence in which the events are to occur.

EVENT: An event represents the start (beginning) or completion (end) of some activity and it has no time duration and does not consumes any other resources. An event is nothing but a node and is generally represented on the network by a circle, rectangle, hexagon or some other geometric shape. An event is not complete until all the activities flowing into it are completed.

CRITICAL ACTIVITY: An activity in a network diagram is said to be critical, if the delay in its start will further delay the project completion time.

NON-CRITICAL ACTIVITY: A non-critical activity allows some scheduling slack, so that the start time of the activity may be advanced or delayed within limits without affecting the completion date of the entire project.

DURATION: The amount of time required to complete an activity assuming all prerequisites have been completed and estimated manpower is available.

EARLY START: The earliest start date that the necessary prerequisites can be completed for a task or activity to begin.

EARLY FINISH: The earliest date that a task or activity can be completed.

LATEST START: The latest date that an activity can be begin and still not affect the overall project completion date.

LATE FINISH: The latest date that an activity can be completed and still not affect the overall project completion date.

CRITICAL PATH: The critical activities of a network that constitute an uninterrupted path which spans the entire network from start to finish is known as critical path.

CPM (CRITICAL PATH METHOD):

Despite its past reputation as an extremely complex and time-consuming method of scheduling, the Critical Path Method (CPM) is actually a simple concept and is being used by more and more design firms. Most computerized project management programs are designed to include CPM as the primary scheduling technique.

In contrast to the simpler scheduling techniques (milestone lists and simple bar charts), CPM focuses on two extremely important areas. It:

- Highlights the interrelationships and dependencies among individual tasks
- Identifies those tasks or activities that are critical to completing the project on time

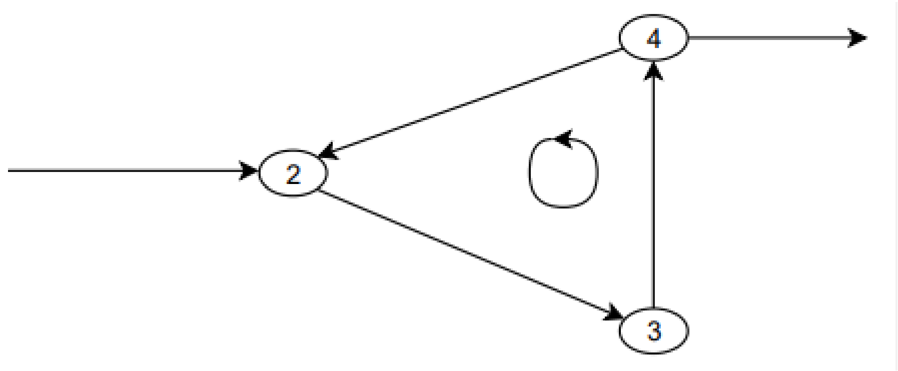
Just as important, the PM must know which tasks are most critical to completing the project on time. A change in the completion date of any of these tasks (either earlier or later) impacts the final completion date by the same amount. Again, the CPM highlights these “special” tasks so that more management attend ion can be directed at their completion.

But keep in mind that you may not need to use all the details of the CPM technique to monitor your project on a daily basis. Instead, perform the initial planning and scheduling of your project at the start using the CPM technique. Then immediately convert the plan to a bar chart format (or have the computer program generate bar charts that will be useful for the team), and use the bar charts for routine monitoring. Go back to the CPM format only if there is a major change in your project scope or schedule. In addition, it is prudent to review the CPM baseline tasks and assumptions on a periodic basis to make sure the bar charts reflect the latest information.

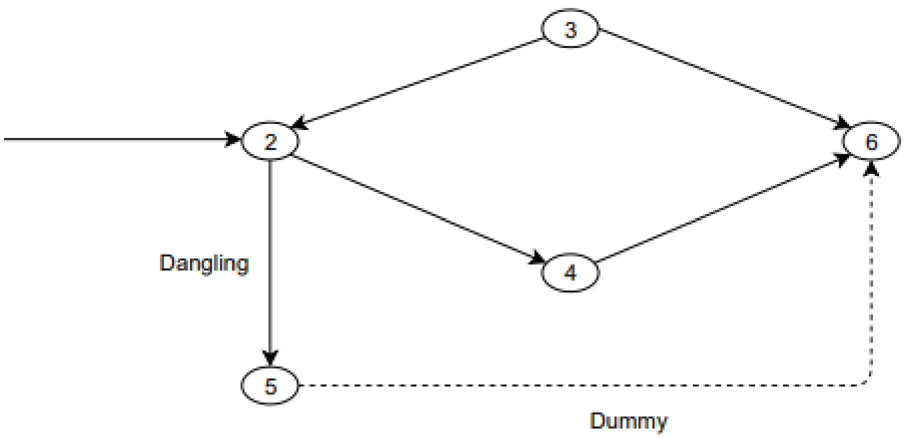
There are six basic steps involved in the CPM technique:

1. Develop the work breakdown structure (task outline)
2. Establish the relationships between tasks
3. Complete the network diagram
4. Add task durations
5. Create the CPM schedule
6. Critical path analysis

1) **DEVELOP THE WORK BREAKDOWN STRUCTURE (TASK OUTLINE):** The task outline forms the foundation of the CPM technique. Just as with milestone and bar charts, the various tasks that will be accomplished to complete the project must reflect the scope of work in the contract. The project team must ensure that all tasks are identified clearly, with well-defined work assignments and project deliverables. If the CPM technique is to provide the correct results, the foundation (task outline) must be solid.
2) **ESTABLISH THE RELATIONSHIPS BETWEEN TASKS (LOGICAL SEQUENCING):** All the projects consist of certain activities that can begin only after certain others are completed. In fact, the entire project may be considered as a series of activities that may begin only after another activity or activities are completed. In a network schedule, these types of relationships are called constraints and are represented by inequalities. In logical sequencing, there are three types of most common errors while drawing a network diagram:
   a) **LOOPING:** If an activity were represented as going back in time. A closed loop would occur as shown below:



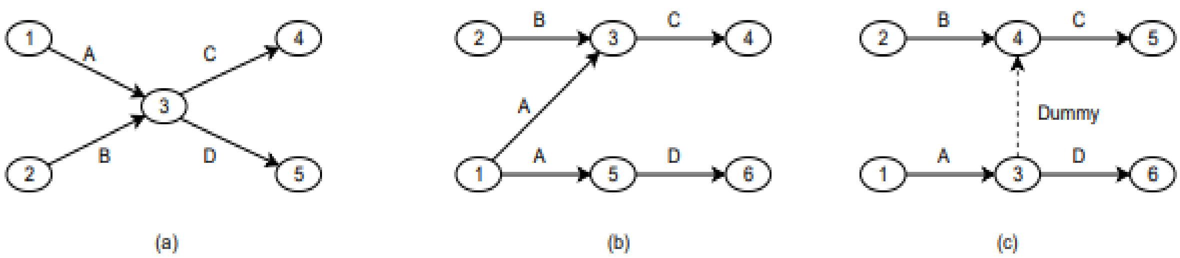
b) **DANGLING:** No activity should end without being joined to the end event. If it is not so, a dummy activity is introduced in order to maintain the continuity of the system. Such end-events other than the end of the project as a whole are called dangling system.



c) **DEPENDENCY RELATIONSHIPS:** When two chains of activities have a common event, wholly or partly independent of each other, a dummy activity is used to establish proper logical relationships. Given below are the two cases of dependency relationships:

(1) Activity C is dependent upon both A and B.

(2) Activity D is dependent upon A alone.



From the above three figures, we observe that (a) is clearly wrong since it shows D as dependent upon not only A but D also which is not desired. (b) is also wrong since A has been shown twice and thus contravenes the fundamental axioms of the network that there must be one arrow for each activity. The way out to this dilemma shows that is representation by means of a dummy activity. (c) shows that C is dependent upon A and B (via dummy) whereas D is dependent upon just A.

3) **COMPLETE THE NETWORK DIAGRAM:** After determining the relationships that exist—either type 1, 2, or 3 for each individual task in the outline put the tasks into a single interface diagram. This network precedence diagram, sometimes also known as a "task interface diagram," will now display graphically the sequence of tasks and their dependency on all other tasks. For the construction of a network, generally, the following rules are followed:

   Each activity is represented by one and only one arrow.

   Each activity must be identified its starting and end node which implies that

   a) Two activities should not be identified by the same completion events, and
   b) Activities must be represented either by their symbols or by the corresponding ordered pair of starting-completion events.

   Nodes are numbered to identify an activity uniquely. Tail node (starting point) should be lower than the head node (end point) of an activity.

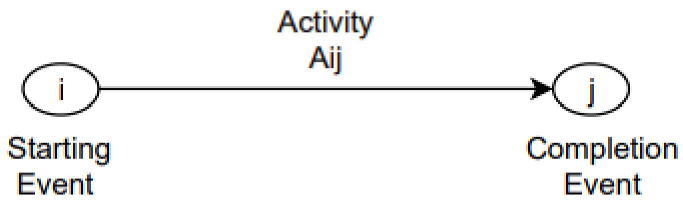
   Between any pair of nodes, there should be one and only one activity; however more than one activity may emanate from and terminate to a node.

   Arrows should be kept straight and not curve or bent.

   The inter-relationship between activities must follow the following rules:

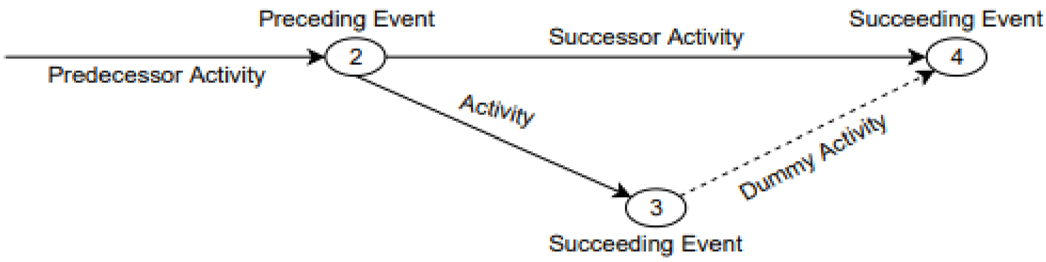
   a) An event cannot occur until all the incoming activities into it have been completed.
   b) An activity cannot start unless all the preceding activities on which it depends, have been completed.
   c) Dummy activity should only be introduced if absolutely necessary.

4) **ADD TASK DURATIONS:** Once the precedence diagram is prepared, the next step is to estimate the number of calendar days it should take to perform each task. This duration should be estimated following a review of the scope contained in each task and the estimated number of resources that will be applied. The durations can be recorded by simply putting the estimated duration beside each task on your task list. One thing to keep in mind is that the length of the overall project will determine the task of project management. Do not assign a specific duration to the project management task directly; instead, simply indicate that it will be completed 60 days after the completion of all other activities. Activities are identified by the numbers on their starting event and completion event. An arrow (i, j) is extended between two events; the tail event i represents the start of activity and the head event j, represents the completion of the activity as shown below:



An event representing the joint completion of more than one activity is called a merge event. If an event represents the joint initiation of more than one activity is called a burst event. The activities further can be classified into the following three categories:

a) **PREDECESSOR ACTIVITY:** An activity which must be completed before one or more other activities start is known as predecessor activity.
b) **SUCCESSOR ACTIVITY:** An activity which started immediately after one or more of the other activities are completed is known as successor activity.
c) **DUMMY ACTIVITY:** An activity which does note consume either any resource and time is known as dummy activity. A dummy activity is depicted by dotted line in the network diagram as shown below:



5) **CREATE THE CPM SCHEDULE:** The duration of each task can be combined with the precedence diagram that you prepared previously by joining them in a bar-chart-like diagram that indicates both duration and the interdependency of the tasks. Most computer CPM scheduling programs will create the schedule showing the calendar time frame and the task inter-dependencies after the durations and project start dates are entered into the program.

FLOAT (OR SLACK) OF AN ACTIVITY AND EVENT:

The float of an activity is the amount of time by which it is possible to delay its completion time without affecting the total project completion time.

EVENT FLOAT: The float that is also called 'slack' of an event is the difference between its latest time (L_i) and its earliest time (E_i). That is Event float = L_i - E_i. It is a measure of how much later than expected a particular event could occur without delaying the completion of the entire project.

❖ **ACTIVITY FLOAT:** Activity float of an activity is the time slack. There are mainly four types of activity floats as discussed below:

- **TOTAL FLOAT:** The total float of an activity represents the amount of time by which an activity can be delayed without delay in the project completion time. The total float is given by

$$\text{Total Float } (TF_{ij}) = L_j - (E_i + t_{ij}) = LF_{ij} - EF_{ij}$$

$$= (L_j - t_{ij}) - E_i = LS_{ij} - ES_{ij}.$$

- **FREE FLOAT:** Free float is that portion of the total float within which an activity can be manipulated without affecting the float of subsequent activities. In other words, it is the amount of time associated with an activity when all its preceding and succeeding activities are started as soon as possible.

$$\text{Free Float } (FF_{ij}) = E_j - E_i - t_{ij}.$$

- **INDEPENDENT FLOAT:** Independent float of an activity is that portion of the total float within which an activity can be delayed for start without affecting the floats of the preceding activities. In other words, it is amount of spare time associated with an activity when its preceding activities are completed as late as possible and succeeding activities are started as early as possible.

$$\text{Independent Float } (IF_{ij}) = E_j - L_i - t_{ij}.$$

- **SAFETY (INTERFERING) FLOAT:** Safety float is that portion of total float which causes a reduction in the total float of the successor activities. In other words, it is the amount of spare time associated with an activity when all its preceding and succeeding activities are completed as late as possible.

$$\text{Safety Float } (SF_{ij}) = L_j - L_i - t_{ij}.$$

SEQUENCE OF FLOATS:

Safety Float <= Independent Float <= Free Float <= Total Float

FLOATS FOR CRITICAL ACTIVITIES:

Safety Float = Independent Float = Free Float = Total Float = 0

6) **CRITICAL PATH ANALYSIS:** The purpose of analysis is to find critical path i.e. the sequence of activities with the longest duration and to find the float associated with each non-critical activity. This helps in checking actual progress against the scheduled duration of the project. To achieve this objective, we carry out the special computations that produce the following information:
   a) Total duration needed for the completion of the project.
   b) Categorization of the activities of the project as being critical or non-critical.

c) To accomplish the above-mentioned objectives, the following factors should be known to prepare project scheduling:
d) Time schedule for each activity, i.e. the time which an activity must begin and the time before which it is completed.
e) Earlier and latest start time as well as earlier finish and latest finish of each activity.
f) Float of each activity that is the spare time associated with each activity.
g) Critical activities and critical path for the network.

For the purpose of calculating various times of events and activities, the following terms shall be used in critical path calculations:

E_i = Earliest occurrence time of event i

L_j = Latest occurrence time of event j

t_{ij} = Duration of activity (i,j)

The critical path calculations are done in the following two ways:

i) Forward pass calculations, and
ii) Backward pass calculations.

i) FORWARD PASS CALCULATIONS: We start from the initial node 1 or event 1 with starting time of the project as zero. Proceed through the network visiting nodes in an increasing order of node number and end at the final node of the network. At each node we calculate earliest start time and finish times for each activity by considering E_i as the earliest occurrence time of node i. The method may be summarized as follows:

STEP 1: Set $E_1 = 0$; i =1 (initial node)

STEP 2: Set the earliest start time for each activity that begins at the node i as $ES_{ij} = E_i$ for all activities (i, j) that start at node i.

STEP 3: Compute the earliest finish time of each activity that begin at node i by adding the earliest start time of the activity to the duration of the activity. Thus,

$$EF_{ij} = ES_{ij} + t_{ij} = E_i + t_{ij}$$

STEP 4: Move on to the next node, say node j (j > i) and compute the earliest occurrence for node j, using

$$E_j = \max \{EF_{ij}\} = \max \{E_i + t_{ij}\},$$

for all immediate predecessor activities.

STEP 5: If j = n (final node), then the earliest finish time for the project is given by

$$E_n = \max \{EF_{ij}\} = \max \{E_{n-1} + t_{ij}\}$$

BACKWARD PASS CALCULATIONS: We start from the final (last) node (event) n of the network, proceed through the network visiting node in the decreasing order of node numbers and end at the initial node 1. At each node, we calculate the least finish and start times for each activity by considering L_j as the latest occurrence of node j. the method may be summarized as follows:

STEP 1: $L_n = E_n$; for j = n.

STEP 2: Set the latest finish time of each activity that ends at node j as

$$LF_{ij} = L_j$$

STEP 3: Compute the latest occurrence times for all activities ending at j by subtracting the duration of each activity from the latest finish time of the activity. Thus,

$$LF_{ij} = LF_{ij} - t_{ij} = L_i - t_{ij}.$$

STEP 4: Proceed backward to the node in the sequence, that decrease j by 1. Also compute the latest occurrence time of node i (i < j) using

$$L_j = \min \{LS_{ij}\} = \min \{L_j - t_{ij}\},$$

For all immediate successor activities.

If j = 1 (initial node), then

$$L_1 = \min \{LS_{ij}\} = \min \{L_2 - t_{ij}\}.$$

Base on the above calculations, an activity (i, j) will be critical if it satisfies the following conditions:

$E_i = L_i$ and $E_j = L_j$

$E_i - E_j = L_j - L_i = t_{ij}$

An activity that does not satisfies the above conditions is termed as non-critical.

PERT (PROGRAM EVALUATION AND REVIEW TECHNIQUE):

The network methods discussed so far may be termed as deterministic, since estimated activity times are assumed to be the expected values. But no recognition is given to the fact that expected activity time is the mean of a distribution of possible values which could occur.

Under the conditions of uncertainty, the estimated time for each activity for PERT network is represented by a probability distribution. The probability distribution of activity time is based upon three different time estimates made for each activity. These are as follows:

1) **Optimistic time:** It is the shortest possible time to complete the activity if all goes well. It is represented by a.
2) **Pessimistic time:** It is the longest possible time to complete the activity if all goes wrong. It is represented by b.
3) **Most likely time:** It is the time which is expected to occur most often when activity gets repeated several times. It is represented by m.

In PERT analysis, a Beta distribution is assumed because it is unimodal, has non-negative end points, and is approximately symmetric. So,

$$\text{Expected Time } \mu = \frac{\text{a} + \text{b} + 4\text{m}}{6}$$

$$\text{Variance } \sigma = \frac{(b-a)^2}{6}$$

PROBABILITY OF MEETING THE SCHEDULE TIME:

With PERT, it is possible to determine the probability of completing a contract on schedule. The scheduled dates are expressed as a number of time units from the present time. Initially, they may be the latest times, T_L, for each event, but after a project is started, we shall know how far it has progressed at any given date, and the scheduled time will be the latest time if the project is to be completed on its original schedule.

The probability distribution of times for completing an event can be approximated by the normal distribution due to the central limit theorem. Thus, the probability of completing the project by scheduled time T_s is given by $Prob(Z < \frac{T_s - T_e}{\sigma_e})$.

The standard normal variance (SNV) is given by,

$$Z = \frac{T_s - T_e}{\sigma_e}$$

Where, T_e = expected completion time of the project and

S_e = number of standard deviations the scheduled time lies from the expected (mean) time, i.e., the standard deviation of the scheduled time.

DISTINCTION BETWEEN PERT AND CPM:

Both PERT and CPM are managerial techniques for planning and control of large complex projects. Both are techniques to network analysis wherein a network is prepared to analyze inter-relationships between different activities of a project. However, there are several differences between the two techniques:

1) CPM is used for repetitive jobs like planning the construction of a house. On the other hand, PERT is used for non-repetitive jobs like planning the assembly of the space platform.
2) PERT is probabilistic model with uncertainty in activity duration. Multiple time estimates are made to calculate the probability of completing the project within schedule time. On the contrary, CPM is a deterministic model with well-known activity times based upon past experience. It, therefore, does not deal with uncertainty in project duration.
3) PERT is said to be event oriented as the results of analysis are expressed in terms of events or distinct points in time indicative of progress. CPM is, on the other hand, activity oriented as the results of calculations are considered in terms of activities or operations of the project.
4) PERT is applied mainly for planning and scheduling research programs. On the other hand, CPM is employed in construction and business problems.
5) PERT incorporates statistical analysis and there by enables the determination of probabilities concerning the time by which each activity and the entire project would be completed. On the other hand, CPM does not incorporate statistical analysis in determining time estimates because time is precise and known.
6) PERT serves a useful control device as it assists the management in controlling a project by calling attention through constant review to such delays in activities which might lead to a delay in the project completion date. But it is difficult to use CPM as a controlling device for the simple reason that one must repeat the entire evaluation of the project each time the changes are incorporated into the network.

APPLICATIONS OF NETWORK TECHNIQUES:

The list containing PERT and CPM applications is very large and the applications are expending to many new areas. Following are the few typical areas in which these techniques are widely accepted:

1. **ADMINISTRATION:** Networks have been used by the administration for streamlining paperwork system, for making major administrative system revisions, for long range planning and developing staffing plans, etc.
2. **CONSTRUCTION INDUSTRY:** It is one of the largest areas in which the network techniques are of project management have found application. These techniques are used in the construction of building, roads, highways, bridges, dams and irrigation projects.
3. **MANUFACTURING:** The design, development and testing of new machines, installing machines and plant layouts are a few examples of how it can be applied to the manufacturing function of a firm. It has been used in manufacturing of ships, aero planes, etc.
4. **MAINTENANCE PLANNING:** R&D has been the most extensive area where PERT has been used for development of new products, processes and systems. It has been used in missile development, space programs, strategic and tactical military operations, etc.
5. **INVENTORY PLANNING:** Installation of production and inventory control, acquisition of spare parts, etc. have been greatly helped by network techniques.
6. **MARKETING:** Networks have been used for advertising programs, for development and launching of new products and for planning for their distribution.
7. Other areas of Application are preparation of budget and auditing, installation of computers and large machinery, organization of big conferences and public works, advertising and sales promotion strategies, etc.

ADVANTAGES OF NETWORK TECHNIQUES:

1. These are most powerful and valuable for planning, scheduling and control of operations in large and complex projects.

2. The techniques are useful tools to evaluate the level of performance by comparing actual performance against the planned targets.
3. These techniques help to determine the dependence of various activities for proper integration and co-ordination of various operations.
4. These techniques help to evaluate the time-cost trade off and determine the optimum schedule.
5. These techniques are simple and can be easily oriented towards computers.
6. The networks clearly designate the responsibilities of different supervisors. Supervisor of an activity knows his time schedule precisely and also the supervisors of other activities with whom he has to co-ordinate.

LIMITATIONS AND DIFFICULTIES IN USING NETWORK:

1. Construction of a network for complex projects is complicated and time consuming due to trial and error approach.
2. Difficulty in securing the realistic time estimates. In the case of new and non-repetitive type projects, the time estimates are more fictitious.
3. Estimation of reliable and accurate duration of various activities is a difficult exercise.
4. The natural tendency to oppose changes results in the difficulty of persuading the management to accept these techniques.
5. The planning and implementation of networks require personnel trained in the network methodology. Managements are reluctant to spare the existing staff to learn these techniques or to recruit trained personnel.
6. Developing a clear logical network is also troublesome. This depends upon the data input and thus the plan can be no better than the personnel who provides the data.
7. Determination of the level of network detail is another troublesome area. The level of detail varies from planner to planner and depends upon the judgement and experience.

CHAPTER – 4

RESOURCE ANALYSIS IN NETWORK SCHEDULING

1. **PROJECT COST:** In order to include the cost aspects in project scheduling we must first define the cost-duration relationships for various activities in the project. The total project cost comprises direct and indirect cost.

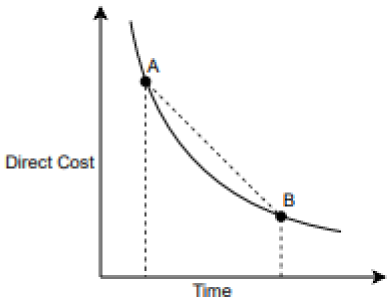
   a) **DIRECT COST:** The direct costs are associated with the individual activities such as manpower loading, equipment utilized, materials consumed directly, etc. in respect of various activities. Direct costs go high as the time for individual activity is reduced.
   b) **INDIRECT COST:** The indirect costs are those expenditures which cannot be allocated to individual activities of the project. These may include administration or supervision costs, loss of revenue, fixed overheads, and so on. Indirect costs allocated to a project goes up with the increase in project duration.

   This calls for reviewing the project duration and think of measures to reduce this duration. Such deliberate reduction of activity times by putting an extra effort is called the crashing of the activity.

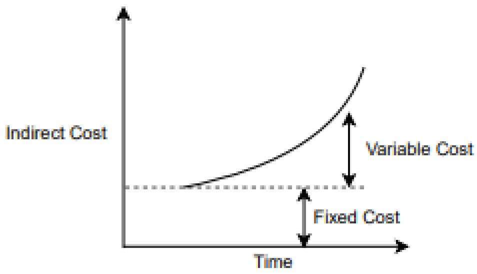
2. **PROJECT CRASHING:** Crashing is the technique to use when fast tracking has not saved enough time on the schedule. It is a technique in which resources are added to the project for the least cost possible. Cost and schedule tradeoffs are analyzed to determine how to obtain the greatest amount of compression for the least incremental cost. Some basic terms in project crashing:
   a. **CRASH TIME:** This represents the fully expedited or the minimum activity duration time that is possible, and any attempt to further crash would only raise the activity direct costs without reducing the time.

b. **CRASH COST:** The activity cost corresponding to the crash time is called crash cost which equals the minimum direct cost required to achieve the crash performance time.
c. **NORMAL COST:** The normal cost is equal to the absolute minimum of direct cost required to perform an activity.
d. **NORMAL TIME:** Duration to perform an activity with normal cost is known as normal time.

The direct cost relationship and indirect-cost relationship are shown in (a) and (b) respectively.



(a)

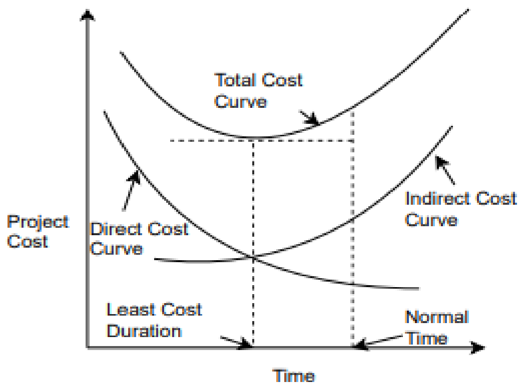


(b)

The point A in (a) denotes the normal time for completion of an activity whereas point B denotes the crash time which indicates the least duration in which the particular activity can be completed. The cost curve is non-linear and asymptotic but for the sake of simplicity it can be approximated by straight line with its slope given by

$$\text{Cost Slope} = \frac{Crash\ Cost - Normal\ Cost}{Normal\ Time - Crash\ Time}$$

The cost slope represents the rate of increase in the cost of performing the activity per unit decrease in time and is called **cost/time trade-off**. It varies activity to activity. Having assessed the direct and indirect project costs, the total cost can be found out.



Total Project Cost = Total Direct Cost + Total Indirect Cost

Above graph shows both the direct cost and indirect cost curves. As these two curves have been plotted against the same time scale, at each ordinate, the project direct and indirect cost can be added to obtain the various points to obtain the various points on the graph, indicating the total project cost corresponding to the various project durations.

TIME-COST OPTIMIZATION ALGORITHM:

The process of shortening a project is called crashing and is usually achieved by adding extra resources to an activity. Project crashing involves following steps:

STEP 1: Schedule a project with all its activities at their normal duration. Identify the critical path and critical activities and calculate total completion time using CPM/PERT.

STEP 2: Calculate the cost slope for the different activities and rank the activities in the ascending order of cost slope.

STEP 3: Crash the critical activities on the critical path as per the ranking, i.e., activity having lower cost slope would be crashed first to the maximum extent possible.

STEP 4: As the critical path duration is reduced by the crashing in step 3, other paths may also become critical, i.e., we get parallel critical paths. This means that project duration can be reduced by simultaneous crashing of activities in the parallel critical paths.

STEP 5: Crashing as per step 3 and 4, one reaches a point when further crashing is either not possible or does not result in the reduction of crashing of project duration.

STEP 6: Compute the total project cost by adding corresponding fixed cost to the direct cost, which is obtained by adding the crashing cost cumulatively to the normal cost.

TIME-COST OPTIMIZATION ALGORITHM AS A LINEAR PROGRAMMING PROBLEM:

After step 2 of **Time-Cost Optimization Algorithm:**

Let, h_{ij} be the cost slope,

y_{ij} be the reduction in normal time of activity (i, j),

x_i be the earliest start time of i^{th} node,

λ be the desired completion time,

N be number of nodes in diagram,

NT_{ij} be the normal time for activity (i, j),

CT_{ij} be the crash time for activity (i, j).

$d_{ij} = NT_{ij} - CT_{ij}$.

Then, formulation as LPP

If Indirect cost is not given but desired completion time is given:

Min Total_Crashing_Cost = $h_{ij} * y_{ij}$

Subject to:

$0 \leq y_{ij} \leq d_{ij}$; $\forall$ i & j and i<j;

$x_1 = 0$;

$x_j - x_i + y_{ij} >= NT_{ij}; \forall\ 1 \leq i < j \leq n;$

$x_n \leq \lambda;$

If Indirect cost is given and desired completion time is given as well:

Let c be the indirect cost per period

Min Total_Project_Cost = $h_{ij} * y_{ij} + c * x_n$

Subject to:

$0 \leq y_{ij} \leq d_{ij}; \forall$ i & j and i<j;

$x_1 = 0;$

$x_j - x_i + y_{ij} >= NT_{ij}; \forall\ 1 \leq i < j \leq n;$

$x_n \leq \lambda$; x_n be the optimal project completion time in respect of minimum total project cost;

CHAPTER – 5

LINGO

INTRODUCTION TO LINGO:

LINGO is a comprehensive tool designed to make building and solving Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratically Constrained, Second Order Cone, Semi-Definite, Stochastic, and Integer optimization models faster, easier and more efficient. LINGO provides a completely integrated package that includes a powerful language for expressing optimization models, a full featured environment for building and editing problems, and a set of fast built-in solvers.

KEY BENEFITS OF LINGO:

1. Easy Model Expression: LINGO will help you cut your development time. It lets you formulate your linear, nonlinear and integer problems quickly in a highly readable form. LINGO's modeling language allows you to express models in a straightforward intuitive manner using summations and subscripted variables - much like you would with pencil and paper. Models are easier to build, easier to understand, and, therefore, easier to maintain. LINGO can exploit multiple CPU cores for faster model generation.
2. Convenient Data Options: LINGO takes the time and hassle out of managing your data. It allows you to build models that pull information directly from databases and spreadsheets. Similarly, LINGO can output solution information right into a database or spreadsheet making it easier for you to generate reports in the application of your choice.
3. Powerful Solvers: LINGO is available with a comprehensive set of fast, built-in solvers for Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratically Constrained, Second Order Cone, Stochastic, and Integer optimization. You never have to specify or load a separate solver, because LINGO reads your formulation and automatically selects the appropriate one.

4. Extensive Documentation and Help: LINGO provides all of the tools you will need to get up and running quickly. You get the LINGO User Manual (in printed form and available via the online Help), which fully describes the commands and features of the program. Also included with super versions and larger is a copy of Optimization Modeling with LINGO, a comprehensive modeling text discussing all major classes of linear, integer and nonlinear optimization problems. LINGO also comes with dozens of real-world based examples for you to modify and expand.

CHAPTER – 6

COMPANY PROFILE

COMPANY NEW DELHI MUNICIPAL COUNCIL (NDMC)

CIVIL ENGINEERING DEPARTMENT:

- This department is further divided into 2 sub-departments:
- **CIVIL I:** This sub-department is in charge of resurfacing and maintenance of the roads within the NDMC jurisdiction.
- **CIVIL II:** Execution of various construction projects and the maintenance of the same are the primary duties of this sub-department.

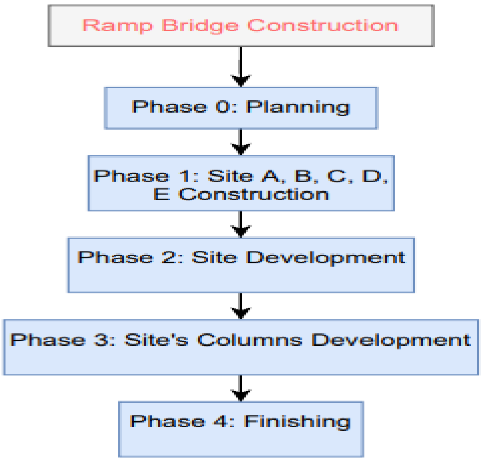
ROLES:

- Resurfacing & Strengthening of Roads/ Lanes/ Colony Roads etc.
- Maintenance of Roads and footpath / walkways.
- Road Cut Permissions, feasibility and monitoring at site.
- Installation & Maintenance of Road Signage and Street furniture's.
- Removal of excavated soil from Public Streets.
- Construction & Maintenance of Subways, Underpasses & Foot Over Bridges.
- Construction & Maintenance of PTU's and CTU's.
- Executing the construction of various buildings like Commercial Complexes, Office Buildings, Schools, Barat-Ghars, Community Centers, Markets Hospitals/ Dispensaries, Electric-Sub-Station and Residential Complexes, including accommodations for NDMC employees.

CHAPTER – 7

PROJECT ANALYSIS

PROBLEM DEFINITION: New Delhi Municipal Council (NDMC) want to construct a ramp bridge in NP Co-Education Senior Secondary School, Moti Bagh, New Delhi. There are following phases in the problem:



OBJECTIVE: The objective is to construct a project schedule that identifies critical activities and the Time-Cost Trade-Off of the entire project.

Note: Project data is made on the bases of the old projects done by seniors.

PROJECT GUIDELINES:

- The start date of the project is taken to be 19th of June, 2020.
- Project should be completed before 12th of November, 2020
- All days of the week are considered to be working days.
- The durations of all the activities are taken to be deterministic.

TOOLS & ALGORITHMS, ARE USED:

1. All the calculations before crashing are done by excel, network diagrams are made by Diagram Editor.
2. Time-Cost Trade Off (Crashing) is done by Lingo Software.

PROJECT DATA:

Activity	Task Name	Normal Duration	Crash Duration	Predecessors	Normal Cost	Crash Cost
Phase 0	Planning					
A1	Request for Construction of Bridge	1	1		1000	1000
A2	Arbitrary Estimate by Account Branch	2	2	1	2000	2000
A3	Engineering Drawing in architecture branch	3	2	1	12000	16000
A4	Detailed Estimate	1	1	2,3	4000	4000
A5	Material List for Construction (Raw materials)	1	1	4	2000	2000
A6	Site Selection & Measurement	2	2	5	9000	9000

A7	Site Covered by Security Barrier & Prepare Temporary Warehouse at Construction Site	7	6	6	12000	13000
A8	Procurement of Raw Material	4	4	5,6,7	2000000	2000000
A9	Material Strength Testing	2	2	8	2000	2000
A10	Planning Phase Completed (Checked by Executive Engineer)	1	1	9	5000	5000
Phase 1	Construction					
A11	Start Civil Work for A	1	1	10	1000	1000
A12	Excavation in Earthwork	7	5	11	5000	6428.5714
A13	Layout	3	2	12	1000	1333.3333
A14	Water Level Check	1	1	13	1000	1000
A15	PCC (Plain Cement Concrete)	2	1	14	3000	4500
A16	Layout	2	1	15	1000	1500
A17	Reinforcement (Steel Work)	3	2	16	2000	2666.6667
A18	Formwork(shuttering)	2	2	17	1500	1500

A19	Check by engineer	1	1	18	2000	2000
A20	RCC (Reinforced Cement Concrete)	1	1	19	3000	3000
A21	Start Civil Work for B	1	1	10	1000	1000
A22	Excavation in Earthwork	7	5	21	5000	6428.5714
A23	Layout	3	2	22	1000	1333.3333
A24	Water Level Check	1	1	23	1000	1000
A25	PCC (Plain Cement Concrete)	2	1	24	3000	4500
A26	Layout	2	1	25	1000	1500
A27	Reinforcement (Steel Work)	3	2	26	2000	2666.6666
A28	Formwork(shuttering)	2	2	27	1500	1500
A29	Check by engineer	1	1	28	2000	2000
A30	RCC (Reinforced Cement Concrete)	1	1	29	3000	3000
A31	Start Civil Work for C	1	1	10	1000	1000
A32	Excavation in Earthwork	5	4	31	5000	6000
A33	Layout	3	2	32	1000	1333.3333
A34	Water Level Check	1	1	33	1000	1000
A35	PCC	2	1	34	3000	4500
A36	Layout	2	1	35	1000	1500

A37	Reinforcement (Steel Work)	3	2	36	2000	2666.6667
A38	Formwork(shuttering)	2	2	37	1500	1500
A39	Check by engineer	1	1	38	2000	2000
A40	RCC	1	1	39	3000	3000
A41	Start Civil Work for D and E	1	1	10	1000	1000
A42	Excavation in Earthwork	4	4	41	5000	5000
A43	Layout	3	2	42	1000	1333.3333
A44	Water Level Check	1	1	43	1000	1000
A45	PCC	2	1	44	3000	4500
A46	Layout	2	1	45	1000	1500
A47	Reinforcement (Steel Work)	3	2	46	2000	2666.6667
A48	Formwork(shuttering)	2	2	47	1500	1500
A49	Check by engineer	1	1	48	2000	2000
A50	RCC	1	1	49	3000	3000
A51	Phase 1 Completed (Checked by Executive Engineer)	1	1	20, 30, 40, 50	5000	5000
Phase 2	Site Development 1					

A52	Site Development for Plinth Beam A, B, C, D, E	3	2	51	5000	6666.6667
A53	Removal & Storage of Top Soil	3	2	52	2000	2666.6667
A54	Excavation	4	3	53	3000	3750
A55	Storing excavated Soil (Use for Earth Filling)	1	1	54	1000	1000
A56	Plinth Beam Reinforcement (Steal Work)	4	3	55	7000	8750
A57	Levelling Site	1	1	56	1000	1000
A58	Formwork for Plinth Beam	2	2	57	4000	4000
A59	Check by Engineer	1	1	58	2000	2000
A60	Concreting of Plinth Beam	4	3	59	5000	6250
A61	Remove Formwork	2	2	60	2000	2000
A62	Earth Filling by soil	5	3	61	4500	6300
A63	Phase 2 Completed (Checked by Executive Engineer)	1	1	62	5000	5000
Phase 3	Site Development 2					

A64	Site Development for Column Beam (A)	2	2	63	4000	4000
A65	Reinforcement (Steal Work) of Column Beam	3	2	64	8000	10666.6667
A66	Check by Engineer	1	1	65	2000	2000
A67	Concreting of Column Beam	3	2	66	8000	10666.6667
A68	Site Development for Column Beam (B)	2	2	63	4000	4000
A69	Reinforcement (Steal Work) of Column Beam	3	2	68	8000	10666.6667
A70	Check by Engineer	1	1	69	2000	2000
A71	Concreting of Column Beam	3	2	70	8000	10666.6667
A72	Site Development for Column Beam (C)	2	2	63	4000	4000
A73	Reinforcement (Steal Work) of Column Beam	2	1	72	8000	12000
A74	Check by Engineer	1	1	73	2000	2000

A75	Concreting of Column Beam	2	2	74	8000	8000
A76	Site Development for Column Beam (D)	2	2	63	4000	4000
A77	Reinforcement (Steal Work) of Column Beam	2	1	76	8000	12000
A78	Check by Engineer	1	1	77	2000	2000
A79	Concreting of Column Beam	2	1	78	8000	12000
A80	Site Development for Column Beam (E)	1	1	63	4000	4000
A81	Reinforcement (Steal Work) of Column Beam	2	1	80	8000	12000
A82	Check by Engineer	1	1	81	2000	2000
A83	Concreting of Column Beam	1	1	82	10000	10000
A84	Phase 3 Completed (Checked by Executive Engineer)	1	1	67, 71, 75, 79, 83	5000	5000
Phase 4	Finishing					
A85	Beam and Slab B1 and B2	5	4	84	14000	16500

A86	Beam and Slab B3 and B4	6	5	84	13500	15000
A87	Beam and Slab B5 and B6	4	3	84	17000	20000
A88	Completion of Beam and Slab	1	1	85, 86, 87	10000	15000
A89	Plastering of Column for section A, B, C, D and E	10	8	88	10000	12500
A90	Pasting Tiles on Slabs B1, B2, B3, B4, B5 and B6	13	10	89	8000	12000
A91	Prepare Base for Painting (Wall Putty)	5	3	90	6700	9380
A92	Painting of Bridge	4	3	91	6300	7875
A93	GI Pipe Fitting Vertical	3	2	92	4500	6000
A94	Framing Ramp Bridge with Shed	6	5	93	4500	5250
A95	Painting of GI Pipes	2	1	94	2780	4170
A96	Fitting SS Hand Rail on walls	4	2	95	2000	3000
A97	CC Paver on Ground	6	4	96	5900	7866.6667
A98	Remove of Warehouse at site	3	2	97	4600	6133.3333

A99	Polishing of SS Hand Rail	2	1	98	2450	3675
A100	Electrical Works on Bridge	3	2	99	4295	5726.6667
A101	Quality Check by Engineer	2	2	100	10000	10000
A102	Project Completed (Checked by Executive Engineer)	1	1	101	5000	5000

The project is completed into two phases:

- Phase 1: Normal Schedule using CPM technique.
- Phase 2: Optimal Schedule using Time-Cost trade off technique.

PHASE 1: NORMAL SCHEDULE USING CPM TECHNIQUE

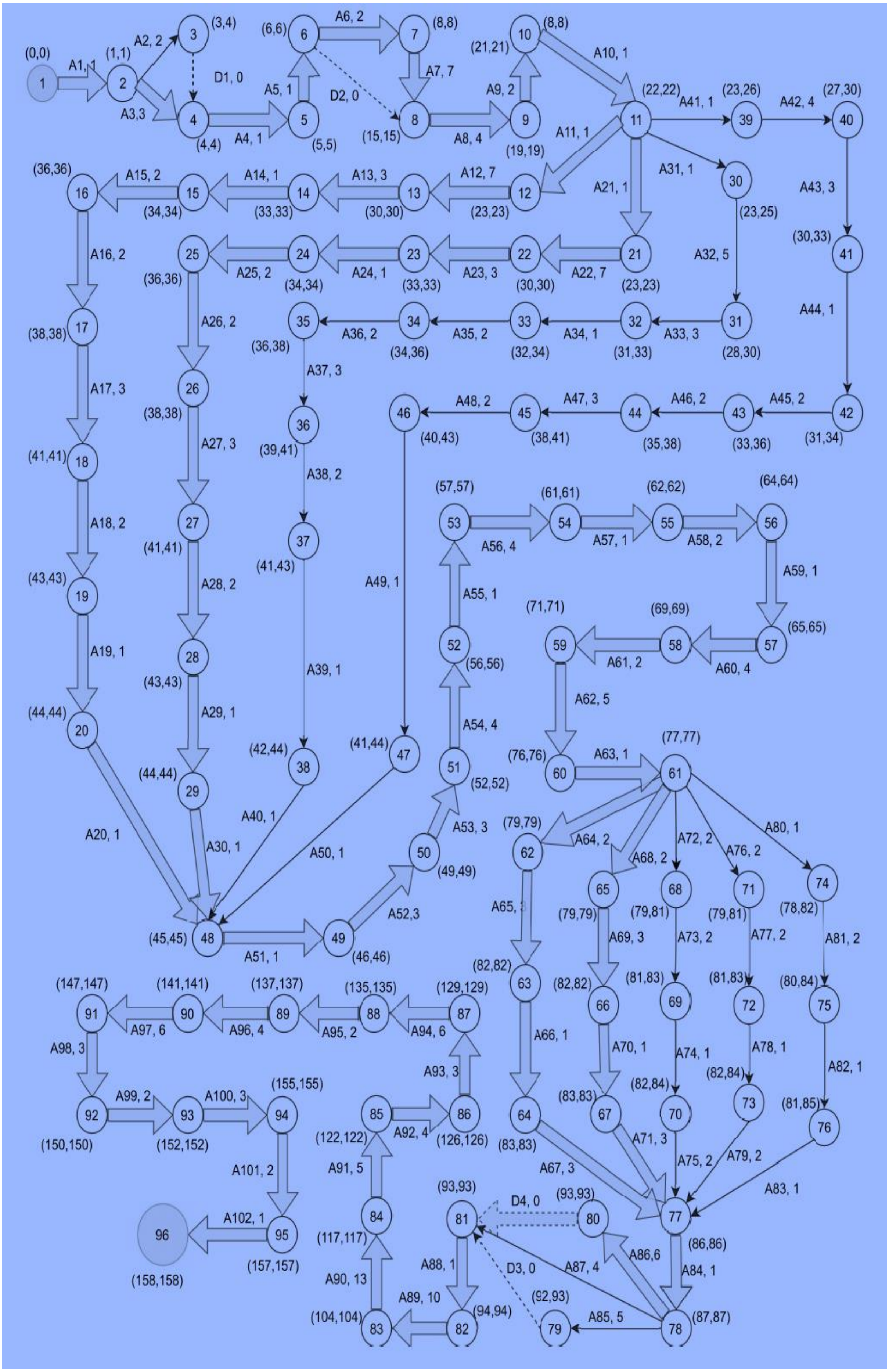
As we discussed earlier, there are six basic steps involved in the CPM technique:

1) Develop the work breakdown structure (task outline)

   Work Break Down Structure.pdf

2) Establish the relationships between tasks
3) Complete the network diagram
4) Add task durations
5) Create the CPM schedule
6) Critical path analysis

NETWORK DIAGRAM:



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(135,135)
A95, 2
89
(137,137)
A96, 4
90
(141,141)
A97, 6
91
(147,147)
A98, 3
92
(150,150)
A99, 2
93
(152,152)
A100, 3
94
(155,155)
A101, 2
95
(157,157)
A102, 1
96
(158,158)

CRITICAL ACTIVITIES: Where LS – ES == 0 is Critical Activity and is presented in red color.

Activity Name	Task Name	Normal Duration	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Slack (LS-ES)	Is Critical Activity
A1	Request for Construction of Bridge	1	0	1	0	1	0	Yes
A2	Arbitrary Estimate by Account Branch	2	1	3	2	4	1	No
D1	Dummy	0	3	3	4	4	1	No
A3	Engineering Drawing in architecture branch	3	1	4	1	4	0	Yes
A4	Detailed Estimate	1	4	5	4	5	0	Yes
A5	Material List for Construction (Raw materials)	1	5	6	5	6	0	Yes
A6	Site Selection & Measurement	2	6	8	6	8	0	Yes
D2	Dummy	0	6	6	15	15	9	No
A7	Site Covered by Security Barrier & Prepare Temporary Warehouse at Construction Site	7	8	15	8	15	0	Yes

A8	Procurement of Raw Material	4	15	19	15	19	0	Yes
A9	Material Strength Testing	2	19	21	19	21	0	Yes
A10	Planning Phase Completed (Checked by Executive Engineer)	1	21	22	21	22	0	Yes
A11	Start Civil Work for A	1	22	23	22	23	0	Yes
A12	Excavation in Earthwork	7	23	30	23	30	0	Yes
A13	Layout	3	30	33	30	33	0	Yes
A14	Water Level Check	1	33	34	33	34	0	Yes
A15	PCC (Plain Cement Concrete)	2	34	36	34	36	0	Yes
A16	Layout	2	36	38	36	38	0	Yes
A17	Reinforcement (Steel Work)	3	38	41	38	41	0	Yes
A18	Formwork(shuttering)	2	41	43	41	43	0	Yes
A19	Check by engineer	1	43	44	43	44	0	Yes
A20	RCC (Reinforced Cement Concrete)	1	44	45	44	45	0	Yes
A21	Start Civil Work for B	1	22	23	22	23	0	Yes
A22	Excavation in Earthwork	7	23	30	23	30	0	Yes
A23	Layout	3	30	33	30	33	0	Yes

A24	Water Level Check	1	33	34	33	34	0	Yes
A25	PCC (Plain Cement Concrete)	2	34	36	34	36	0	Yes
A26	Layout	2	36	38	36	38	0	Yes
A27	Reinforcement (Steel Work)	3	38	41	38	41	0	Yes
A28	Formwork(shuttering)	2	41	43	41	43	0	Yes
A29	Check by engineer	1	43	44	43	44	0	Yes
A30	RCC (Reinforced Cement Concrete)	1	44	45	44	45	0	Yes
A31	Start Civil Work for C	1	22	23	24	25	2	No
A32	Excavation in Earthwork	5	23	28	25	30	2	No
A33	Layout	3	28	31	30	33	2	No
A34	Water Level Check	1	31	32	33	34	2	No
A35	PCC	2	32	34	34	36	2	No
A36	Layout	2	34	36	36	38	2	No
A37	Reinforcement (Steel Work)	3	36	39	38	41	2	No
A38	Formwork(shuttering)	2	39	41	41	43	2	No
A39	Check by engineer	1	41	42	43	44	2	No
A40	RCC	1	42	43	44	45	2	No
A41	Start Civil Work for D and E	1	22	23	25	26	3	No
A42	Excavation in Earthwork	4	23	27	26	30	3	No

A43	Layout	3	27	30	30	33	3	No
A44	Water Level Check	1	30	31	33	34	3	No
A45	PCC	2	31	33	34	36	3	No
A46	Layout	2	33	35	36	38	3	No
A47	Reinforcement (Steel Work)	3	35	38	38	41	3	No
A48	Formwork(shuttering)	2	38	40	41	43	3	No
A49	Check by engineer	1	40	41	43	44	3	No
A50	RCC	1	41	42	44	45	3	No
A51	Phase 1 Completed (Checked by Executive Engineer)	1	45	46	45	46	0	Yes
A52	Site Development for Plinth Beam A, B, C, D, E	3	46	49	46	49	0	Yes
A53	Removal & Storage of Top Soil	3	49	52	49	52	0	Yes
A54	Excavation	4	52	56	52	56	0	Yes
A55	Storing excavated Soil (Use for Earth Filling)	1	56	57	56	57	0	Yes
A56	Plinth Beam Reinforcement (Steal Work)	4	57	61	57	61	0	Yes
A57	Levelling Site	1	61	62	61	62	0	Yes

A58	Formwork for Plinth Beam	2	62	64	62	64	0	Yes
A59	Check by Engineer	1	64	65	64	65	0	Yes
A60	Concreting of Plinth Beam	4	65	69	65	69	0	Yes
A61	Remove Formwork	2	69	71	69	71	0	Yes
A62	Earth Filling by soil	5	71	76	71	76	0	Yes
A63	Phase 2 Completed (Checked by Executive Engineer)	1	76	77	76	77	0	Yes
A64	Site Development for Column Beam (A)	2	77	79	77	79	0	Yes
A65	Reinforcement (Steal Work) of Column Beam	3	79	82	79	82	0	Yes
A66	Check by Engineer	1	82	83	82	83	0	Yes
A67	Concreting of Column Beam	3	83	86	83	86	0	Yes
A68	Site Development for Column Beam (B)	2	77	79	77	79	0	Yes
A69	Reinforcement (Steal Work) of Column Beam	3	79	82	79	82	0	Yes
A70	Check by Engineer	1	82	83	82	83	0	Yes

A71	Concreting of Column Beam	3	83	86	83	86	0	Yes
A72	Site Development for Column Beam (C)	2	77	79	79	81	2	No
A73	Reinforcement (Steal Work) of Column Beam	2	79	81	81	83	2	No
A74	Check by Engineer	1	81	82	83	84	2	No
A75	Concreting of Column Beam	2	82	84	84	86	2	No
A76	Site Development for Column Beam (D)	2	77	79	79	81	2	No
A77	Reinforcement (Steal Work) of Column Beam	2	79	81	81	83	2	No
A78	Check by Engineer	1	81	82	83	84	2	No
A79	Concreting of Column Beam	2	82	84	84	86	2	No
A80	Site Development for Column Beam (E)	1	77	78	81	82	4	No
A81	Reinforcement (Steal Work) of Column Beam	2	78	80	82	84	4	No

A82	Check by Engineer	1	80	81	84	85	4	No
A83	Concreting of Column Beam	1	81	82	85	86	4	No
A84	Phase 3 Completed (Checked by Executive Engineer)	1	86	87	86	87	0	Yes
A85	Beam and Slab B1 and B2	5	87	92	88	93	1	No
A86	Beam and Slab B3 and B4	6	87	93	87	93	0	Yes
A87	Beam and Slab B5 and B6	4	87	91	89	93	2	No
D3	Dummy	0	92	92	93	93	1	No
D4	Dummy	0	93	93	93	93	0	Yes
A88	Completion of Beam and Slab	1	93	94	93	94	0	Yes
A89	Plastering of Column for section A, B, C, D and E	10	94	104	94	104	0	Yes
A90	Pasting Tiles on Slabs B1, B2, B3, B4, B5 and B6	13	104	117	104	117	0	Yes
A91	Prepare Base for Painting (Wall Putty)	5	117	122	117	122	0	Yes
A92	Painting of Bridge	4	122	126	122	126	0	Yes
A93	GI Pipe Fitting Vertical	3	126	129	126	129	0	Yes

A94	Framing Ramp Bridge with Shed	6	129	135	129	135	0	Yes
A95	Painting of GI Pipes	2	135	137	135	137	0	Yes
A96	Fitting SS Hand Rail on walls	4	137	141	137	141	0	Yes
A97	CC Paver on Ground	6	141	147	141	147	0	Yes
A98	Remove of Warehouse at site	3	147	150	147	150	0	Yes
A99	Polishing of SS Hand Rail	2	150	152	150	152	0	Yes
A100	Electrical Works on Bridge	3	152	155	152	155	0	Yes
A101	Quality Check by Engineer	2	155	157	155	157	0	Yes
A102	Project Completed (Checked by Executive Engineer)	1	157	158	157	158	0	Yes

CRITICAL PATHS:

PATH 1:

A1->A3->A4->A5->A6->A7->A8->A9->A10->A11->A12->A13->A14->A15->A16->A17->A18->A19->A20->A51->A52->A53->A54->A55->A56->A57->A58->A59->A60->A61->A62->A63->A64->A65->A66->A67->A84->A86->D4->A88->A89->A90->A91->A92->A93->A94->A95->A96->A97->A98->A99->A100->A101->A102

PATH 2:

A1->A3->A4->A5->A6->A7->A8->A9->A10->A11->A12->A13->A14->A15->A16->A17->A18->A19->A20->A51->A52->A53->A54->A55->A56->A57->A58->A59->A60->A61->A68->A69->A70->A71->A84->A86->D4->A88->A89->A90->A91->A92->A93->A94->A95->A96->A97->A98->A99->A100->A101->A102

PATH 3:

A1->A3->A4->A5->A6->A7->A8->A9->A10->A11->A21->A22->A23->A24->A25->A26->A27->A28->A29->A30->A51->A52->A53->A54->A55->A56->A57->A58->A59->A60->A61->A62->A63->A64->A65->A66->A67->A84->A86->D4->A88->A89->A90->A91->A92->A93->A94->A95->A96->A97->A98->A99->A100->A101->A102

PATH 4:

A1->A3->A4->A5->A6->A7->A8->A9->A10->A11->A21->A22->A23->A24->A25->A26->A27->A28->A29->A30->A51->A52->A53->A54->A55->A56->A57->A58->A59->A60->A61->A68->A69->A70->A71->A84->A86->D4->A88->A89->A90->A91->A92->A93->A94->A95->A96->A97->A98->A99->A100->A101->A102

NORMAL SCHEDULE: Normal Solution.xlsx

Task Name	Duration	Start Date	Finish Date
Ramp Bridge Construction	158 days	19-Jun-20	24-Nov-20
Phase 0: Planning	22 days	19-Jun-20	11-Jul-20
Phase 1: Site A, B, C, D, E Construction	24 days	11-Jul-20	4-Aug-20
Phase 2: Site Development	31 days	4-Aug-20	4-Sep-20
Phase 3: Site's Columns Development	10 days	4-Sep-20	14-Sep-20
Phase 4: Finishing	71 days	14-Sep-20	24-Nov-20

PHASE 2: OPTIMAL SCHEDULE USING TIME-COST TRADE-OFF TECHNIQUE:

LINEAR PROGRAMMING FORMULATION FOR CRASHING:

!OBJECTIVE FUNCTION;

Min=4000*Y3+1000*Y7+714.2857*Y12+333.3333*Y13+1500*Y15+500*Y16+666.6667*Y17+714.2857*Y22+333.3333*Y23+1500*Y25+500*Y26+666.6667*Y27+1000*Y32+333.3333*Y33+1500*Y35+500*Y36+666.6667*Y37+333.3333*Y43+1500*Y45+500*Y46+666.6667*Y47+1666.6667*Y52+666.6667*Y53+750*Y54+1750*Y56+1250*Y60+900*Y62+2666.6667*Y65+2666.6667*Y67+2666.6667*Y69+2666.6667*Y71+4000*Y73+4000*Y77+4000*Y79+4000*Y81+2500*Y85+1500*Y86+3000*Y87+1250*Y89+1333.3333*Y90+1340*Y91+1575*Y92+1500*Y93+750*Y94+1390*Y95+500*Y96+983.3333*Y97+1533.3333*Y98+1225*Y99+1431.6667*Y100;

!SUBJECT TO THE CONSTRAINTS;

!CRASH TIME (ACTIVITY CONSTRAINTS) CONSTRAINTS;

Y1<=0; Y2<=0; D1<=0; Y3<=1; Y4<=0; Y5<=0; Y6<=0; D2<=0; Y7<=1; Y8<=0; Y9<=0; Y10<=0; Y11<=0; Y12<=2; Y13<=1; Y14<=0; Y15<=1; Y16<=1; Y17<=1; Y18<=0; Y19<=0; Y20<=0; Y21<=0; Y22<=2; Y23<=1; Y24<=0; Y25<=1; Y26<=1; Y27<=1; Y28<=0; Y29<=0; Y30<=0; Y31<=0; Y32<=1; Y33<=1; Y34<=0; Y35<=1; Y36<=1; Y37<=1; Y38<=0; Y39<=0; Y40<=0; Y41<=0; Y42<=0; Y43<=1; Y44<=0; Y45<=1; Y46<=1; Y47<=1; Y48<=0; Y49<=0; Y50<=0; Y51<=0; Y52<=1; Y53<=1; Y54<=1; Y55<=0; Y56<=1; Y57<=0; Y58<=0; Y59<=0; Y60<=1; Y61<=0;Y62<=2; Y63<=0; Y64<=0; Y65<=1; Y66<=0; Y67<=1; Y68<=0; Y69<=1; Y70<=0; Y71<=1; Y72<=0; Y73<=1; Y74<=0; Y75<=0; Y76<=0; Y77<=1; Y78<=0; Y79<=1; Y80<=0; Y81<=1; Y82<=0; Y83<=0; Y84<=0; Y85<=1; Y86<=1; Y87<=1; D3<=0; D4<=0; Y88<=0; Y89<=2; Y90<=3; Y91<=2; Y92<=1; Y93<=1; Y94<=1; Y95<=1; Y96<=2; Y97<=2; Y98<=1; Y99<=1; Y100<=1; Y101<=0; Y102<=0;

!NODE CONSTRAINTS;

X1=0;

X2-X1+Y1>=1; X3-X2+Y2>=2; X4-X3+D1>=0; X4-X2+Y3>=3; X5-X4+Y4>=1; X6-X5+Y5>=1; X7-X6+Y6>=2; X8-X6+D2>=0; X8-X7+Y7>=7; X9-X8+Y8>=4; X10-X9+Y9>=2; X11-X10+Y10>=1; X12-X11+Y11>=1; X13-X12+Y12>=7; X14-X13+Y13>=3; X15-X14+Y14>=1; X16-X15+Y15>=2; X17-X16+Y16>=2; X18-X17+Y17>=3; X19-X18+Y18>=2; X20-X19+Y19>=1; X48-X20+Y20>=1; X21-X11+Y21>=1; X22-X21+Y22>=7; X23-X22+Y23>=3; X24-X23+Y24>=1; X25-X24+Y25>=2; X26-X25+Y26>=2; X27-

X26+Y27>=3; X28-X27+Y28>=2; X29-X28+Y29>=1; X48-X29+Y30>=1; X30-X11+Y31>=1; X31-X30+Y32>=5; X32-X31+Y33>=3; X33-X32+Y34>=1; X34-X33+Y35>=2; X35-X34+Y36>=2; X36-X35+Y37>=3; X37-X36+Y38>=2; X38-X37+Y39>=1; X48-X38+Y40>=1; X39-X11+Y41>=1; X40-X39+Y42>=4; X41-X40+Y43>=3; X42-X41+Y44>=1; X43-X42+Y45>=2; X44-X43+Y46>=2; X45-X44+Y47>=3; X46-X45+Y48>=2; X47-X46+Y49>=1; X48-X47+Y50>=1; X49-X48+Y51>=1; X50-X49+Y52>=3; X51-X50+Y53>=3; X52-X51+Y54>=4; X53-X52+Y55>=1; X54-X53+Y56>=4; X55-X54+Y57>=1; X56-X55+Y58>=2; X57-X56+Y59>=1; X58-X57+Y60>=4; X59-X58+Y61>=2;X60-X59+Y62>=5; X61-X60+Y63>=1; X62-X61+Y64>=2; X63-X62+Y65>=3; X64-X63+Y66>=1; X77-X64+Y67>=3; X65-X61+Y68>=2; X66-X65+Y69>=3; X67-X66+Y70>=1; X77-X67+Y71>=3; X68-X61+Y72>=2; X69-X68+Y73>=2; X70-X69+Y74>=1; X77-X70+Y75>=2; X71-X61+Y76>=2; X72-X71+Y77>=2; X73-X72+Y78>=1; X77-X73+Y79>=2; X74-X61+Y80>=1; X75-X74+Y81>=2; X76-X75+Y82>=1; X77-X76+Y83>=1; X78-X77+Y84>=1; X79-X78+Y85>=5; X80-X78+Y86>=6; X81-X78+Y87>=4; X81-X79+D3>=0; X81-X80+D4>=0; X82-X81+Y88>=1; X83-X82+Y89>=10; X84-X83+Y90>=13; X85-X84+Y91>=5; X86-X85+Y92>=4; X87-X86+Y93>=3; X88-X87+Y94>=6; X89-X88+Y95>=2; X90-X89+Y96>=4; X91-X90+Y97>=6; X92-X91+Y98>=3; X93-X92+Y99>=2; X94-X93+Y100>=3; X95-X94+Y101>=2; X96-X95+Y102>=1;

!PROJECT COMPLETION CONSTRAINTS;

X96<=145;

!AND

NON-NEGATIVITY CONSTRAINTS;

Xi>=0 for all i = 1 to 96;

Yj>=0 for all j = 1 to 102;

LINGO SOLUTION:

Global Optimal Solution Found	
Objective Value	10825.00
Infeasibilities:	0
Total Solver Iterations:	4
Variable	**Value**
Y3	0
Y7	1
Y12	0
Y13	1
Y15	0
Y16	1
Y17	0
Y22	0
Y23	1
Y25	0
Y26	1
Y27	0
Y32	0
Y33	0
Y35	0
Y36	0
Y37	0
Y43	0
Y45	0
Y46	0
Y47	0
Y52	0
Y53	1
Y54	1
Y56	0
Y60	0
Y62	2
Y65	0
Y67	0

Y69	0
Y71	0
Y73	0
Y77	0
Y79	0
Y81	0
Y85	0
Y86	0
Y87	0
Y89	0
Y90	0
Y91	0
Y92	0
Y93	0
Y94	1
Y95	0
Y96	2
Y97	2
Y98	0
Y99	1
Y100	0
Y1	0
Y2	0
D1	0
Y4	0
Y5	0
Y6	0
D2	0
Y8	0
Y9	0
Y10	0
Y11	0
Y14	0
Y18	0
Y19	0
Y20	0

Y21	0
Y24	0
Y28	0
Y29	0
Y30	0
Y31	0
Y34	0
Y38	0
Y39	0
Y40	0
Y41	0
Y42	0
Y44	0
Y48	0
Y49	0
Y50	0
Y51	0
Y55	0
Y57	0
Y58	0
Y59	0
Y61	0
Y63	0
Y64	0
Y66	0
Y68	0
Y70	0
Y72	0
Y74	0
Y75	0
Y76	0
Y78	0
Y80	0
Y82	0
Y83	0
Y84	0

D3	0
D4	0
Y88	0
Y101	0
Y102	0
X1	0
X2	1
X3	3
X4	4
X5	5
X6	6
X7	8
X8	14
X9	18
X10	20
X11	21
X12	22
X13	29
X14	31
X15	32
X16	34
X17	35
X18	38
X19	40
X20	41
X48	42
X21	22
X22	29
X23	31
X24	32
X25	34
X26	35
X27	38
X28	40
X29	41

X30	22
X31	27
X32	30
X33	31
X34	33
X35	35
X36	38
X37	40
X38	41
X39	22
X40	26
X41	29
X42	30
X43	32
X44	34
X45	37
X46	39
X47	40
X49	43
X50	46
X51	48
X52	51
X53	52
X54	56
X55	57
X56	59
X57	60
X58	64
X59	66
X60	69
X61	70
X62	72
X63	75
X64	76
X77	79
X65	72

X66	75
X67	76
X68	72
X69	74
X70	75
X71	72
X72	74
X73	75
X74	71
X75	73
X76	74
X78	80
X79	85
X80	86
X81	86
X82	87
X83	97
X84	110
X85	115
X86	119
X87	122
X88	127
X89	129
X90	131
X91	135
X92	138
X93	139
X94	142
X95	144
X96	145

OPTIMAL SOLUTION:

Activity Name	Task Name	Crashed Duration	Crashed Time	Marginal Cost	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Slack (LS-ES)	Is Critical Activity
	Planning									
A1	Request for Construction of Bridge	1	0	0	0	1	0	1	0	Yes
A2	Arbitrary Estimate by Account Branch	2	0	0	1	3	2	4	1	No
D1	Dummy	0	0	0	3	3	4	4	1	No
A3	Engineering Drawing in architecture branch	3	0	4000	1	4	1	4	0	Yes
A4	Detailed Estimate	1	0	0	4	5	4	5	0	Yes
A5	Material List for Construction (Raw materials)	1	0	0	5	6	5	6	0	Yes
A6	Site Selection & Measurement	2	0	0	6	8	6	8	0	Yes
D2	Dummy	0	0	0	6	6	14	14	8	No

A7	Site Covered by Security Barrier & Prepare Temporary Warehouse at Construction Site	6	1	1000	8	14	8	14	0	Yes
A8	Procurement of Raw Material	4	0	0	14	18	14	18	0	Yes
A9	Material Strength Testing	2	0	0	18	20	18	20	0	Yes
A10	Planning Phase Completed (Checked by Executive Engineer)	1	0	0	20	21	20	21	0	Yes
	Construction Phase									

A11	Start Civil Work for A	1	0	0	21	22	21	22	0	Yes
A12	Excavation in Earthwork	7	0	714.2857	22	29	22	29	0	Yes
A13	Layout	2	1	333.3333	29	31	29	31	0	Yes
A14	Water Level Check	1	0	0	31	32	31	32	0	Yes
A15	PCC (Plain Cement Concrete)	2	0	1500	32	34	32	34	0	Yes
A16	Layout	1	1	500	34	35	34	35	0	Yes
A17	Reinforcement (Steel Work)	3	0	666.6667	35	38	35	38	0	Yes
A18	Formwork(shuttering)	2	0	0	38	40	38	40	0	Yes
A19	Check by engineer	1	0	0	40	41	40	41	0	Yes
A20	RCC (Reinforced Cement Concrete)	1	0	0	41	42	41	42	0	Yes
A21	Start Civil Work for B	1	0	0	21	22	21	22	0	Yes
A22	Excavation in Earthwork	7	0	714.2857	22	29	22	29	0	Yes
A23	Layout	2	1	333.3333	29	31	29	31	0	Yes

A24	Water Level Check	1	0	0	31	32	31	32	0	Yes
A25	PCC (Plain Cement Concrete)	2	0	1500	32	34	32	34	0	Yes
A26	Layout	1	1	500	34	35	34	35	0	Yes
A27	Reinforcement (Steel Work)	3	0	666.6667	35	38	35	38	0	Yes
A28	Formwork(shuttering)	2	0	0	38	40	38	40	0	Yes
A29	Check by engineer	1	0	0	40	41	40	41	0	Yes
A30	RCC (Reinforced Cement Concrete)	1	0	0	41	42	41	42	0	Yes
A31	Start Civil Work for C	1	0	0	21	22	21	22	0	Yes
A32	Excavation in Earthwork	5	0	1000	22	27	22	27	0	Yes
A33	Layout	3	0	333.3333	27	30	27	30	0	Yes
A34	Water Level Check	1	0	0	30	31	30	31	0	Yes
A35	PCC	2	0	1500	31	33	31	33	0	Yes
A36	Layout	2	0	500	33	35	33	35	0	Yes
A37	Reinforcement (Steel Work)	3	0	666.6667	35	38	35	38	0	Yes

A38	Formwork(shuttering)	2	0	0	38	40	38	40	0	Yes
A39	Check by engineer	1	0	0	40	41	40	41	0	Yes
A40	RCC	1	0	0	41	42	41	42	0	Yes
A41	Start Civil Work for D and E	1	0	0	21	22	22	23	1	No
A42	Excavation in Earthwork	4	0	0	22	26	23	27	1	No
A43	Layout	3	0	333.3333	26	29	27	30	1	No
A44	Water Level Check	1	0	0	29	30	30	31	1	No
A45	PCC	2	0	1500	30	32	31	33	1	No
A46	Layout	2	0	500	32	34	33	35	1	No
A47	Reinforcement (Steel Work)	3	0	666.6667	34	37	35	38	1	No
A48	Formwork(shuttering)	2	0	0	37	39	38	40	1	No
A49	Check by engineer	1	0	0	39	40	40	41	1	No
A50	RCC	1	0	0	40	41	41	42	1	No
A51	Phase 1 Completed (Checked by Executive Engineer)	1	0	0	42	43	42	43	0	Yes

	Development Phase 1									
A52	Site Development for Plinth Beam A, B, C, D, E	3	0	1666.667	43	46	43	46	0	Yes
A53	Removal & Storage of Top Soil	2	1	666.6667	46	48	46	48	0	Yes
A54	Excavation	3	1	750	48	51	48	51	0	Yes
A55	Storing excavated Soil (Use for Earth Filling)	1	0	0	51	52	51	52	0	Yes
A56	Plinth Beam Reinforcement (Steal Work)	4	0	1750	52	56	52	56	0	Yes
A57	Levelling Site	1	0	0	56	57	56	57	0	Yes
A58	Formwork for Plinth Beam	2	0	0	57	59	57	59	0	Yes
A59	Check by Engineer	1	0	0	59	60	59	60	0	Yes

A60	Concreting of Plinth Beam	4	0	1250	60	64	60	64	0	Yes
A61	Remove Formwork	2	0	0	64	66	64	66	0	Yes
A62	Earth Filling by soil	3	2	900	66	69	66	69	0	Yes
A63	Phase 2 Completed (Checked by Executive Engineer)	1	0	0	69	70	69	70	0	Yes
	Development Phase 2									
A64	Site Development for Column Beam (A)	2	0	0	70	72	70	72	0	Yes
A65	Reinforcement (Steal Work) of Column Beam	3	0	2666.667	72	75	72	75	0	Yes
A66	Check by Engineer	1	0	0	75	76	75	76	0	Yes
A67	Concreting of Column Beam	3	0	2666.667	76	79	76	79	0	Yes

A68	Site Development for Column Beam (B)	2	0	0	70	72	70	72	0	Yes
A69	Reinforcement (Steal Work) of Column Beam	3	0	2666.667	72	75	72	75	0	Yes
A70	Check by Engineer	1	0	0	75	76	75	76	0	Yes
A71	Concreting of Column Beam	3	0	2666.667	76	79	76	79	0	Yes
A72	Site Development for Column Beam (C)	2	0	0	70	72	72	74	2	No
A73	Reinforcement (Steal Work) of Column Beam	2	0	4000	72	74	74	76	2	No
A74	Check by Engineer	1	0	0	74	75	76	77	2	No
A75	Concreting of Column Beam	2	0	0	75	77	77	79	2	No
A76	Site Development for Column Beam (D)	2	0	0	70	72	72	74	2	No

A77	Reinforcement (Steal Work) of Column Beam	2	0	4000	72	74	74	76	2	No
A78	Check by Engineer	1	0	0	74	75	76	77	2	No
A79	Concreting of Column Beam	2	0	4000	75	77	77	79	2	No
A80	Site Development for Column Beam (E)	1	0	0	70	71	74	75	4	No
A81	Reinforcement (Steal Work) of Column Beam	2	0	4000	71	73	75	77	4	No
A82	Check by Engineer	1	0	0	73	74	77	78	4	No
A83	Concreting of Column Beam	1	0	0	74	75	78	79	4	No
A84	Phase 3 Completed (Checked by Executive Engineer)	1	0	0	79	80	79	80	0	Yes
	Finishing									

A85	Beam and Slab B1 and B2	5	0	2500	80	85	81	86	1	No
A86	Beam and Slab B3 and B4	6	0	1500	80	86	80	86	0	Yes
A87	Beam and Slab B5 and B6	4	0	3000	80	84	82	86	2	No
D3	Dummy	0	0	0	85	85	86	86	1	No
D4	Dummy	0	0	0	86	86	86	86	0	Yes
A88	Completion of Beam and Slab	1	0	0	86	87	86	87	0	Yes
A89	Plastering of Column for section A, B, C, D and E	10	0	1250	87	97	87	97	0	Yes
A90	Pasting Tiles on Slabs B1, B2, B3, B4, B5 and B6	13	0	1333.333	97	110	97	110	0	Yes
A91	Prepare Base for Painting (Wall Putty)	5	0	1340	110	115	110	115	0	Yes
A92	Painting of Bridge	4	0	1575	115	119	115	119	0	Yes
A93	GI Pipe Fitting Vertical	3	0	1500	119	122	119	122	0	Yes

A94	Framing Ramp Bridge with Shed	5	1	750	122	127	122	127	0	Yes
A95	Painting of GI Pipes	2	0	1390	127	129	127	129	0	Yes
A96	Fitting SS Hand Rail on walls	2	2	500	129	131	129	131	0	Yes
A97	CC Paver on Ground	4	2	983.3333	131	135	131	135	0	Yes
A98	Remove of Warehouse at site	3	0	1533.333	135	138	135	138	0	Yes
A99	Polishing of SS Hand Rail	1	1	1225	138	139	138	139	0	Yes
A100	Electrical Works on Bridge	3	0	1431.667	139	142	139	142	0	Yes
A101	Quality Check by Engineer	2	0	0	142	144	142	144	0	Yes
A102	Project Completed (Checked by Executive Engineer)	1	0	0	144	145	144	145	0	Yes

OPTIMAL SCHEDULE: Final Solution.xlsx

Task Name	Duration	Start Date	Finish Date
Ramp Bridge Construction	145 days	19-Jun-20	24-Nov-20
Phase 0: Planning	22 days	19-Jun-20	11-Jul-20
Phase 1: Site A, B, C, D, E Construction	21 days	11-Jul-20	1-Aug-20
Phase 2: Site Development	27 days	1-Aug-20	28-Aug-20
Phase 3: Site's Columns Development	10 days	28-Aug-20	7-Sep-20
Phase 4: Finishing	65 days	7-Sep-20	11-Nov-20

CONCLUSIONS:

This model will provide us a systematic and logical approach for decision making and ultimately increases the effectiveness of the decision. As the solution provide us the starting time of the activities, this can be used for monitoring the project.

Total Project Completion Time without Crashing is 158 days.

As the manager wants to complete the project within 145 days, so the last event should be completed before or on 145th day.

Total Project Completion time after Crashing is 145 days

Total Project Crashing Cost is RS. 10825.

Total Normal Cost is RS. 2426025.

Total Project Cost is 2436850.

Start of Project Date = Friday 19th of June, 2020.

Complete of Project Date = Thursday 11th of November, 2020.

CHAPTER – 8

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