CHAPTER - VI
COST-EFFECTIVENESS ANALYSIS

6.1 GENERAL

6.1.1 The project appraisal technique of cost-effectiveness analysis holds a special place of importance. It was considered necessary that this technique was also evaluated from all the angles.

6.1.2 The technique was developed in defence spending, where the return from investment in a military weapon could not be valued, but the effectiveness of the weapon in destroying a target could be quantified.

6.1.3 In cost effectiveness analysis, the "inputs" are measured in monetary terms but the "output" (effectiveness) is measured in non-monetary terms. The values used on the input side must still reflect economic scarcities, and the discounting is still appropriate.

6.1.4 There are two forms in which the cost-effectiveness criterion can be expressed:-

a) Maximum output for a given input ("efficiency").

b) Minimum input for a given output ("economy").
It is to be noted that "least cost" by itself is not valid - it must be "least cost for a given output".

6.2 CROSS OVER DISCOUNT RATE

6.2.1 When the output of two alternatives is exactly the same in each case, and easily defined, we can either:

- Discount each cost stream and choose the least cost project
- OR
- Discount the difference between the cost stream.

6.2.2 Both methods give a mathematically equivalent result. Both can be used to determine the discount rate at which the two projects have the same discounted cost streams - the "crossover discount rate". This is in effect the IRR on the additional initial investment required for one of the alternatives.

6.3 WHEN BENEFITS CANNOT MEASURABLE IN MONETARY TERMS

6.3.1 This is uncommon in Industrial projects where the outputs are normally marketable products and so measurable in monetary terms. But this is common in day to day functioning of control organisations such as "Law
Enforcements", "fire fighting", in welfare and other similar projects like "Health and Education Projects".

6.3.2 In infrastructure projects like "Transport Projects" a common objective is "to save time" or to carry a fixed amount of cargo and it is better to find out effectiveness on such non-monetary output per unit of money spent. "Employment Generation" objective is fairly frequent in many countries and it is customary to use "Cost-effectiveness Analysis" to arrive at incremental manpower employed per unit of money invested.

6.3.3 The incremental effectiveness analysis is done in the following logical steps:-

a) Enumeration of "Objectives", main criteria and detailed criteria.

b) Alternatives to meet the detailed criteria.

c) Incremental cost analysis for the alternatives to arrive at the ratio:- Incremental Effectiveness divided by Incremental Cost

6.4 MEASURES OF EFFECTIVENESS : THE PROBLEM OF DEFINITION (When outputs are in Non-monetary terms)

It is important that what is measured as the "output" should truly reflect the objectives
of the project, e.g. "lives saved" by a clinic, but not "number of doctors employed". In Government, however, it is not always easy to determine objectives or to find out the true cost of meeting any specific objective. The technique of "output budgeting" (performance budgeting) helps to ease this task. To measure effectiveness in meeting these objectives, "proximate criteria" are often used - criteria which come as near as possible to the objective, which is in itself unquantifiable. Several criteria may be needed to measure one objective. When expanding programmes or making budget costs, it is more relevant to compare the increment of cost with the increment of effectiveness, than to compare total costs with total effectiveness.

6.5 COST-EFFECTIVENESS FUNCTION

6.5.1 In systems analysis, where we face such problems of cost-effectiveness (rather than of cost-benefit) it is best to get into the optimisation procedure of marginal analysis or mathematical (linear) programming so as to arrive at what is called "cost-effectiveness functions". This is done firstly by arriving at
the technological functions or lines of "equal outputs" or what are called ISOQUANTS, secondly to draw the "equal cost lines" or what are called ISOCOSTS with factor prices and thereby arrive at the optimal points of "minimum costs" for all levels of outputs, finally drawing the "expansion path", (figure on next page) can be drawn for "COST EFFECTIVENESS FUNCTION)" with the axes as "outputs" and "costs".

6.5.2 The cost effectiveness function works as a guide for decision makers for choice of an optimum system, i.e. the combination of "output" and "cost" which gives the most cost effective solution.

6.6 USES OF "COST-EFFECTIVENESS" ANALYSIS (APART FROM MILITARY AND SPACE INVESTMENTS

The uses include:-

6.6.1 A. Where outputs are definable in terms of money but are the same for the purpose of choice among different alternatives.

a) In Industrial Fields - choice of process or technology such as labour or capital intensive, etc.

b) In the Infrastructure Field - choice of technology, such as Hydro vs. Thermal Power, Concrete Vs. Asphalt Road
Vs. Gravel Road, Reservoir Vs. Drainage Channel in Flood control projects, Dieselisation Vs. Electrification, etc.

c) In the Agricultural Field - choice of a process such as manual Vs. machine cultivation, etc.

6.6.2 B. When outputs are not defined in monetary terms

a) In Health Planning - with appropriate criteria, say "saving life" or "saving number of hours of productive work lost due to illness", etc.

b) In Educational Planning - both within the system and in meeting external output requirements in manpower planning.

6.6.3 C. In "Interprogramming" comparisons, where there is a common objective.

6.6.4 Within the Projects, cost effectiveness is used for many internal choices of design or dimension. This is valid as long as we constantly check for compatibility with the main objective.
6.7 PROBLEM OF MINIMUM COST

6.7.1 There are two types of cost effectiveness analysis based on minimum cost, viz:
   a) Break-even Analysis
   b) Minimum Cost Analysis

6.7.2 In many situations in economic analysis the cost of an alternative may be a function of a single variable. When two or more alternatives are functions of the same variable, it is often necessary to find the value of the variable that will result in equal cost for the alternatives considered. The value of such a variable is known as Break Even Point.

6.7.3 In a number of situations an alternative may possess two or more cost components that are modified differently by a common variable. Certain cost components may vary directly with an increase in the value of the variable while others may vary inversely. When the total cost of an alternative is a function of increasing and decreasing cost components, most likely a value exists for the common variable that will result in a minimum cost for the alternative. The value of such a variable is known as the Minimum Cost Point.
6.8 BREAK-EVEN ANALYSIS - (Break-even Point)

6.8.1 This can be found either mathematically where the cost of each alternative can be mathematically expressed as a function of common variables. For example, in an electronic manufacturing firm, a circuit board can be either hand wired with low cost of equipment (but high labour cost) or by a printed equivalent of the required circuit with high capital cost (but low labour cost), it may be necessary to find out the common variable (here the number of circuit boards to be produced say annually) for the two methods to break-even in equivalent annual costs.

6.8.2 Alternatively, where cost patterns of two or more alternatives can be found from experiment or calculation.

6.9 MINIMUM COST ANALYSIS

6.9.1 Cost optimisation, i.e. to have the minimum net costs of a system which is made up of two mutually interdependent variables, is possible in any of the following ways:-

a) mathematically;

b) graphically; or

c) by tabulation
a) Mathematical Analysis

The general solution of the situation for an increasing cost component and a decreasing cost component may be given mathematically as follows:

$$TC = Ax + \frac{B}{x} + C$$

Where

- $TC$: total cost per time period or per project, etc.
- $x$: a common variable such as size, or time period or quality, etc.
- $A$, $B$, and $C$: Constants

Taking the first derivative, equating the result to zero, and solving for the common variable $x$ will result in:

$$\frac{d(TC)}{dx} = A - \frac{Bx}{x^2} = 0 \quad \text{or} \quad x = \frac{\sqrt{B}}{\sqrt{A}}$$

The value for $x$ found in this manner will be a minimum.

b) Graphical Analysis

The same problem can be dealt with graphically as shown on next page.

Here one type of cost decreases with the increase of variable $X$ (i.e. curve I).
MINIMUM COST ANALYSIS

FIGURE 4

COSTS

CURVE III

CURVE II

CURVE I

VARIABLE X

FIGURE 4
This is similar to $Bx^{-2}$.

Another type of cost rises as variable $X$ rises (i.e. curve II). This is similar to "Ax" in the equation in a).

Total cost curve III which is a combination of curve I and II, shows a minimum at point "p" which is the optimum value of variable $X$.

c) Analysis by Tabulation

We can find out the least cost and by that have an optimum solution of a variable by tabulating the different cost estimates for a large number of cases of the variable.

6.9.2 Examples of Minimum Cost Problem

A few of them are given below:-

a) Optimum time for replacement of an asset (Determination of economic life)

To find out a point in time when one should replace an asset. This is extremely important in determining project life and also an optimal point in time for replacement of any part of a project's asset during the project life.
b) **Economic Production Quantity of LOT-SIZE in a manufacturing plant**

To arrive at the most economical (minimum cost) lot-size with large lot giving "economies of scale" in the unit preparation cost on the one hand and with small lot giving low unit storage and holding costs on the other. This can be used in railways for procuring material for construction projects and maintenance.

c) **Economic Order Quantity in "Inventory"**

To determine the most economic order quantity in "inventory" problem, so as to arrive at the warehouse requirements of a project.

d) **Project Selection**

Given the objective of a project and the alternative projects which can fulfil these objectives, 'Minimum Cost Analysis' can be used to determine the minimum total cost for each project which will be a great help in the selection of the optimal project. Determination of the minimum total cost is done by examining the inter-relationship between the costs and benefits.
e) Optimum size of a container or a wagon

It can be worked out by selecting that size which minimises the total system cost.

6.10 A DISCUSSION OF THE PRACTICAL APPLICATION OF COST-EFFECTIVENESS TECHNIQUE

6.10.1 Conventional Methods of evaluation of transportation alternatives

Their drawbacks are related to their inadequacy to deal with the concepts of efficiency and effectiveness. The concept of efficiency is concerned with obtaining one's "money's worth" from a project i.e. obtaining on an investment returns that are worthwhile. In general, Net Present Worth, Benefit/Cost Ratio and rate of return are all concerned with measuring the efficiency of alternative projects. These techniques for measuring efficiency require that all times for consideration are reduced to a common metric, generally in rupees. This shows that efficiency is measured simply in monetary terms and only those items of costs and benefits are taken which can be reduced to a common metric. This leads to a very narrow set of consequence being considered and is liable to yield decisions that are seriously sub-optimal.
6.2 Need for an alternative evaluation technique

6.10.2.1 Those impacts of transportation investments which are difficult to quantify or difficult to express in monetary terms cause major concern and problems for the transportation systems analyst. Cost-effectiveness analysis is considered suitable for dealing with non-quantifiable impacts or the impacts that are subject to ordinal classification only.

6.10.2.2 The concept of effectiveness emanates from the application of systems analysis framework to the formulation and evaluation of alternative solutions for transportation problems. In the system-analysis framework the goals and objectives are first determined and then these are used for generating alternatives. The extent to which a project attains the objectives is a measure of its effectiveness. Generally the alternatives will attain different levels of objective fulfilment. Hence it is appropriate to assess alternatives not only in terms of efficiency but also in terms of effectiveness. The techniques of cost effectiveness analysis can be used to represent, in a decision oriented framework, the relative efficiency and effectiveness of alternative project/strategy.
6.10.3 Weighting Effectiveness

6.10.3.1 Major requirement of the use of cost effectiveness analysis is to assign weights to the objectives and the extent of objective achievement. Particular problem may arise when two or more objectives are to some extent in conflict. It then becomes necessary to have information on the difference in importance between two such objectives. If there are only two objectives which are in conflict, the technique of indifference curves (figures on next page) can be used for assigning proper weights. Again the problem exists as to who should establish the weights so that subjective biases may be reduced. In some of the countries in transportation evaluation, the weights are generally determined by engineers and planners modified by the elected Regional representatives. It has been observed by them that the decisions made by the Analysts alone are not generally the best basis when viewed from the regional point of view. They are, therefore, consulting the inhabitants of the concerned region before establishing weights.
Indifference Curves Relating To Two Conflicting Objectives

FIGURE 5
6.10.3.2 This leads to the problem of obtaining informations from people on the trade-off between objectives. The information may be obtained by survey techniques, but such surveys rely on the rationality of human judgement and the ability of people to form reliable judgements of abstract concepts and ideas. However, opinions and attitudes to currently non-existent alternatives are rarely reliable guides to values because opinions and attitudes are highly dependent upon current and past-experience.

6.10.3.3 This weighting procedure by using survey techniques would necessitate the development of aggregated opinions and attitudes. Again it is to be seen whether equal weight should be given to the opinion of all the persons or greater weights should be assigned to the opinion of some individual and what should be the basis for such greater weight. The use of theories and techniques from applied psychology particularly for determining stable attitudes as opposed to transitory opinion appears to have considerable promise in this area.
6.10.4 The Cost-effectiveness Method

6.10.4.1 The cost-effectiveness method can be used for assessing, simultaneously, both the efficiency and effectiveness of a set of alternatives. This method gives a formal framework to the usual decision making process in which the decision maker takes the inputs of an evaluation process and weighs them against the intangible consequences of the alternatives. Initially it was developed for ranking alternative weapon systems. This allowed the military decision maker to choose that alternative which might have the lowest cost for rendering a specific desirable destructive effect or he could choose that weapon system which could achieve the greatest destruction for a given availability of funds.

6.10.4.2 The technique involves the use of two sets of measures to indicate efficiency and effectiveness, costs and indicators of objective attainment. The choice of alternatives is made on the basis of these two sets of measures, thereby eliminating the need for reducing all the attributes or consequences to a single metric.
6.10.5 Costs

6.10.5.1 For the cost-effectiveness technique, costs are defined as the total monetary outlays needed for the alternative projects. This assumes that the price mechanism operates in such a way that the resources expended on each alternative project are accurately valued by the monetary unit being used, viz. the rupee. Various cost models may be used to determine the costs of a set of alternatives. Obviously that cost model which is seemed to be the most appropriate for the particular transportation project should be used. This is another advantage of the cost-effectiveness method that it permits the use of any appropriate cost model.

6.10.5.2 The conventional economic-evaluation techniques use a cost model that may be itemised as follows for a new line project in railways.

a) Land cost
b) Permanent-way cost
c) Railway station & terminal facilities cost
d) Rolling stock cost
e) Operating cost.

6.10.5.3 Such a cost model is based upon a consideration of the physical components of the system and the outlays required for each component.
6.10.5.4 Yet another cost model could evaluate the marginal cost of offering various types of services. In particular such a model could give information concerning the marginal cost of providing an additional line. It should clearly give information particularly pertinent to the determination of the trade-off between the alternatives. Cost may also be modelled on time-dependent basis, with information supplied of the cost at various points in time as a function of construction phasing or scheduled operations of the transportation plans.

6.10.5.5 Whatever be the basis of the cost model, a considerable advantage will be obtained if the costs are placed in a frame work in which they are related to objective attainment. An understanding of the alternative projects by the decision maker will be considerably aided by the apportionment of the total programme costs to the attainment of particular objectives. For instance, costs for a transportation system may be apportioned as:

a) Route kilometre of service - Rupees per kilometre;

b) Seat kilometres of service - Rupees per kilometre;
c) Passenger kilometres of service - Rupees per passenger kilometre;
d) Gross tonne kilometre of service - Rupees per Gross tonne kilometre, etc.

6.10.5.6 Discounting the costs over the project life would clearly be appropriate in assessing the cost for different alternative projects. Conditions of uncertainty should also be taken into account. Research into the application of such methods as Bayesian statistics to the determination of uncertainty of various costs being encountered overtime would be advantageous.

6.10.6 Effectiveness

6.10.6.1 Effectiveness may be defined as the degree to which objectives are attained. However, as the framework of the cost-effectiveness method is quite broad and flexible, the effectiveness may simply be defined as the characterization of all the relative consequences of the alternatives exclusive of costs. In relatively simple projects, it may be possible to assess goal achievements on the basis of a few quantitative measures, which can be formulated into a mathematical model. This mathematical model can be used with the appropriate cost model to obtain
the most suitable alternative. However, the problems facing the transportation planners and analysts are less simple and many of the consequences may be unquantifiable. Hence a quantitative model of effectiveness may not be appropriate for most of the transportation projects. So if a subjective ranking scheme is used, much information may be obscured and the decision may be too much subjective. However, by using the cost effectiveness approach goal achievement may be described mathematically, verbally or pictorially, which can enable the decision maker to construct a complete picture of the consequences of each alternative.

6.10.6.2 The cost effectiveness framework requires the description of the consequences that still stem from each alternative. It does not restrict the ways in which these consequences are to be described. There is no attempt to over simplify the evaluation process, not to "force concentration on the structurally measurable consequence of alternative plans". In arriving at the description of consequence it would be advantageous to classify consequences into various categories, e.g.
1. Consequences of inputs
   a) Opportunities lost due to resource commitments
   b) Effect on employment
   c) Scarcities of material resources.
   d) Use of unused resources (material)
   e) Social effect due to construction of the line
   f) Modifications of human activity pattern in the affected region.
   g) Others.

2. Consequences of performance out-puts
   a) Changes in market areas, and competitiveness,
   b) Social and national integration due to increased accessibility,
   c) Expansion in the social economic and cultural realms of people due to increased accessibility,
   d) Modification of human activity pattern and resource allocation due to changes in accessibility,
   e) Changes in the prices of goods and services due to increase in accessibility.
f) Changes in employment pattern due to changes in accessibility,
g) Others.

3. Consequences of concomitant out-puts
   a) Social and psychological effects of the creation of new transportation facilities.
   b) Aesthetic impacts of facilities,
   c) Impact on the crime rate and the type of crimes,
   d) Impact on the safety,
   e) Ecological impact,
   f) Modification of human activity pattern and resource allocation because of changes in site characteristics due to concomitant outputs,
   g) Others.

6.10.6.3 With the achievement of sophistication in the application of the technique, the selection and breakdown of consequences will inevitably be developed into a more rigorous framework. The choice of consequences to be used is clearly of significant importance. Two criteria may be used to determine the consequence to be considered. These criteria are feasibility and
relavance. Feasibility refers to the level of details about various consequence and the number of consequences to be considered. As the level of complexity (number of consequences, level of details) increases, there comes a point where the quality of decision instead of improving, deteriorates. Further, as complexity increases, the associated cost of obtaining information increases, while the case of making a decision decreases rapidly. The four diagrams of the figure, given on the next page, illustrate this very clearly. In short the quality of decision making clearly has an optimum in terms of level of detail and number of factors considered. At present the level of information for decision making is well to the left of that optimum. However, it is adviseable to keep this criteria in mind and ensure that the number of factors and their level of details are within the bounds of feasibility.

6.10.6.4 The second criterion is that of relevance. Major parameters associated with it may be enumerated as follows:-

a) An understanding of the transportation system and its relevance to the economic and
The Criterion Of Feasibility In Selecting Effectiveness Data

FIGURE 6
social environment is important. Without such understanding it will be difficult to determine the relevance of various factors.

b) Relevance should be determined by the relationship between a consequence and the objectives of the project. Given that the national and project objectives have been completely specified, a consequence that has no relevance to the stated objectives is not relevant to the decision making process.

c) If a consequence is identical for all alternative projects or is in some other way unable to affect the decision between the alternatives, it is not relevant.

6.10.7 Concluding Remarks

6.10.7.1 There is clearly much more than could be dealt with in relation to the various procedures inherent within the cost effectiveness framework. However, space constraints do not allow their consideration in this dissertation. There are clearly numerous cost models that can be developed for use in the cost-effectiveness framework. There is also considerable scope for research in the measures of effectiveness. It it also clear that the cost-effectiveness frame-
work is potentially able to assist the decision maker to make better decisions than the more conventional economic-evaluation techniques. It is also clear that the efficacy of the techniques is highly dependent upon the formation of a complete spectrum of goals and the development of pertinent objectives. However the cost effectiveness framework can never be better than the goal formulation procedure that precedes it.