Chapter 20

TRANSPORTATION ECONOMICS

20.1 INTRODUCTION

Engineers concerned with infrastructure are involved to some degree, directly or indirectly, with the costs, time value, and economic viability of the project with which they are associated. Engineers in developing countries are often required to quickly come up with recommendations on the feasibility of a project in situations where economists are either not readily available or deemed unnecessary by the decision-makers. In such cases, there is a danger that the engineers are likely to present technical feasibility recommendations with comparative costs based on constant monies alone as a substitute for the various criteria and economic analysis involved in a proper feasibility study.

This chapter is intended i) to provide a minimum conceptual background to engineers on the time value of money, and various terms and techniques related to economic analysis, and ii) to highlight, to economists or engineers with advanced knowledge on transportation economics, the methods of a long-run economic analysis framework and the need for a revised outlook at the use of internal rate of return in a cash flow analysis approach to economic analysis relating to the feasibility studies of major projects.

20.2 BASIC CONCEPTS

20.2.1 *Time Value of Money*

Money has a time value. For the purpose of economic evaluation, or for any matter relating to the management of money, it is essential to understand the time value concept. The future value of a single amount or present single amount is given by:

$$F = P\ (1+i)^n$$

where,

F	=	future amount,
P	=	present amount,
i	=	interest rate, usually per one year, and
n	=	number of periods of times, usually in years.

The present amount of P of a future amount F is then given by:

$$P = \frac{F}{(1+i)^n}.$$

Often, payments or receipts occur at regular intervals. The future value of a series of uniform payments at equal intervals can be expressed by:

$$F = A \left[\frac{(1+i)^n - 1}{i}\right]$$

where,

A = uniform end-of-period payments or receipts at a rate of interest i, and
F = total equivalent amount at the end of the n periods.

The present value of a series of end-of-period uniform payments can be derived from the above equations and is given by:

$$P = A \left[\frac{(1+i)^n - 1}{i\,(1+i)^n}\right].$$

The equivalent uniform series of end-of-period values A can, for a present value p or future value F, be obtained from the above equations as follows:

$$A = P \left[\frac{i\,(1+i)^n}{(1+i)^n - 1}\right] = F = \left[\frac{i}{(1+i)^n - 1}\right].$$

20.2.2 *Common Terms in Economic Analysis*

Prices

For economic analysis, it is necessary to bring the streams of costs or benefits at different times over the life of a project to one common unit or base line.

Inflation

The issue of incorporating inflation (differential or general) is an extremely complex matter. Some authorities have recommended the use of differential prices only when there is overwhelming evidence that certain inputs, such as land costs, are expected to experience significant changes relative to the general price level. The inflation, price changes, or interest rates should not be confused with the discount rate.

Because of the uncertainty associated with predicting future rates of inflation, it has been the practice usually to remove the effect of inflation in economic analysis for road projects. Road project costs or prices estimated for future years are normally expressed in constant monetary terms for the first, or base year, of analysis. In most cases, it can be assumed that future inflation will affect both costs and benefits equally and hence its effects can be ignored. However, there may be exceptions to this and, in these cases, differential rates of inflation will need to be assumed for different elements in the project.

Discounting

The discount rate is used to bring back all future expected costs or benefits to the base line (usually present day value) to allow comparison of alternatives.

Discount rate is the opportunity cost of capital. Money used to invest in the project in one sector could be invested elsewhere and earn a dividend. The loss of this opportunity to earn a dividend by using the capital in a project is accounted for by use of a discount rate in the economic analysis. The choice of discount rates considerably influences the outcome of economic analysis. The discount rates for economic evaluation are normally those provided by the planning authority responsible for the project.

Shadow Prices

Resource costs for a project aimed at economic growth could be exaggerated or underestimated when the market prices are used in economic evaluation. The market prices, which include taxes, fees, and duties imposed by the public agencies to generate revenues, do not reflect a real demand on resources. There could be other distortions such as quotas, subsidies, and imperfect competition in a regulated economy. The real resource required is reflected by using the concept of economic price:

where,

economic price = market price - transfer charges + effect of other distortions.

20.2.3 *Costs and Benefits*

Economic evaluation, irrespective of the method used, requires determination of costs and benefits. The approach to costs and benefits differs for the type of project under evaluation. The consumer surplus approach is a traditional approach and is adopted in situations where considerable economic activity already exists and traffic levels are relatively high. For rural roads with low existing economic activity and low traffic levels an integrated approach may be necessary. The developmental effect is a focus of the analysis by this approach. Figure 20.1 illustrates the demand curve for the consumer surplus approach and Figure 20.2 illustrates the supply curve for the producer surplus approach.

Direct Costs or Road Costs

Direct costs may be divided as follows.

1) <u>Agency Costs</u>

a. Initial construction costs.
b. Future construction, rehabilitation, or upgrading costs.
c. Maintenance costs recurring throughout the design period.
d. Salvage return or residual value at the end of the design period.
e. Engineering and administration costs.
f. Traffic control costs.
g. Land acquisition costs.
h. Agricultural production costs.

2) <u>User Costs</u>

a. Travel time costs.
b. Vehicle operation costs.
c. Accident costs.
d. Discomfort costs.
e. Time delay and extra vehicle operation costs during resurfacing, major improvements, or reinstatements.

Indirect Costs or Non-Road Costs

These are additional costs normally incurred in constructing roads based on an integrated development approach and may include the following.

1) <u>Agency Costs</u>

a. Agricultural production costs.
b. Costs of other development infrastructures, e.g., tourism and other industries, education, and health.

2) <u>User Costs</u>

a. Agricultural transport (vehicle operation) costs.
b. Other vehicle operation costs.

3) <u>Environmental Costs</u>

a. Loss of physical resources such as top soil, land value, forests, minerals, and quality of water and air.
b. Loss of ecological resources such as wildlife, fisheries, plants, and vegetation.
c. Loss of quality of life resources such as culture, monuments, public health, and safety.

Benefits

Benefits may accrue from a road project, either as road benefits that are of direct benefit to the road user, as a result of the improved transportation facility, or as non-road benefits that are indirect benefits contributing to the integrated development of the areas under the influence of the road. Benefits are nothing but the difference in costs and value of production between, with, and without the proposed road situations.

Assessment of Costs and Benefits

Road construction and maintenance costs are dependent upon the standard of the road and the terrain through which the road passes. Several road costing models such as the HDM (Highway Development Manual) developed by the World Bank (1987) and the RTIM (Road Transport Investment Model) developed by the Transport and Road Research Laboratory (TRRL 1982), U.K., are available. Care must be exercised in using the existing models so that the conditions specific to the project are represented properly. Hill roads in mountain areas have to pass through terrain that is steep and of marginal stability and this means that special factors such as instability hazards should be considered.

Vehicle operation costs, travel time costs, and accident costs are influenced by road standards and type and condition of vehicle. Parameters such as roughness of the road and vehicle speed are used to determine fuel consumption, tire wear, vehicle maintenance, oil consumption, vehicle depreciation, parts' replacement, user travel time, total accidents, non-fatal accidents, and property damage.

Determining indirect costs is a complex and uncertain task. Currently, no method exists to quantify appropriately the environmental costs for use in economic analysis. The assessment of the costs of agricultural production and transportation is done currently for agricultural roads in developing countries by several methods. Literature produced by the World Bank or other appropriate literature may be followed for details of cost and benefit assessments of rural roads.

Stream of costs and benefits for each year and for each alternative throughout the design life of the proposed projects is calculated at constant money. These are converted to base year using an appropriate discount factor. Further analysis using the cash flow method to determine internal rate of return (IRR), benefit cost ratio (B/C), or the long-run economic planning method to determine the lowest unit cost that can be adopted.

The analysis for the appraisal of rural road projects of considerable size should take into account the current and predicted levels of economic activity in the area of influence. For low or non-existent traffic or new road in areas where the level of economic activity is low, a producer-surplus approach to analysis is adopted. Figure 20.2 illustrates the supply curve for this approach. The developmental effect is a focus of the analysis by this approach. Base line data for agricultural or other rural sectors must be collected. These data include such items as crop areas, yields, production costs, farmgate prices, marketed output, and local consumption.

The consumer surplus approach to analysis is the traditional method and is adopted in situations where considerable activity already exists and traffic levels are relatively high. See Figure 20.1 for the demand curve for the consumer surplus approach.

The following discussions give a background that is more specific to the traditional aspects of the economic analysis of road projects.

Economic analysis of a project involves some or all of the following:

- assessment of costs,
- assessment of benefits,
- calculation of benefit-cost ratio, internal rate of return, first year rate of return, and net present value,
- sensitivity analysis, and
- risk analysis.

Costs include construction costs, maintenance costs, and user costs. Benefits include savings in vehicle operation costs, reduction in accident costs, and time costs. Environmental costs and benefits, such as those accruing from noise, vibration, air pollution, socio-cultural changes, plant and animal life, changes in land use pattern, and soil loss due to erosion and landslides, are not yet built into a model for economic analysis. This shall, for the present, fall under the domain of environmental impact assessments.

<u>Assessment of Costs</u>

Several methods exist for calculating road costs. The TRRL Road Investment Model and the World Bank Highways' Design and Maintenance Standards' Model are the prominent models currently available. However, for fragile mountain areas such as in the Hindu-Kush Himalayan Region these models need to be supplemented and modified for specific conditions such as stability of hill slopes, flexibility in design standards, landslide and erosion control works, and environmental protection measures, for example, control of deforestation and indiscriminate cutting and blasting of hills.

20.2.4 *Methods of Economic Evaluation*

The purposes of economic evaluation are:

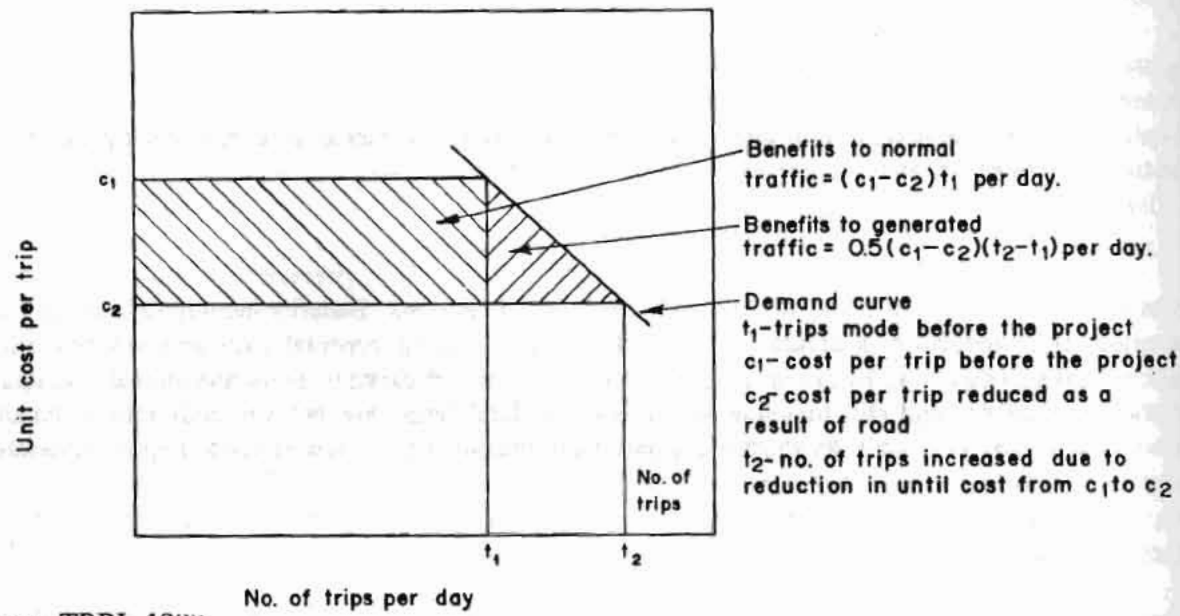
- to ensure that an adequate return in terms of benefits results from making a capital investment, and
- to ensure that the investment option adopted gives the highest return in terms of such things as choice of route, the design and structural standards, and the timing of the project.

The methods of evaluation depend on:

- planning level,
- management levels,
- agency, and
- size of project.

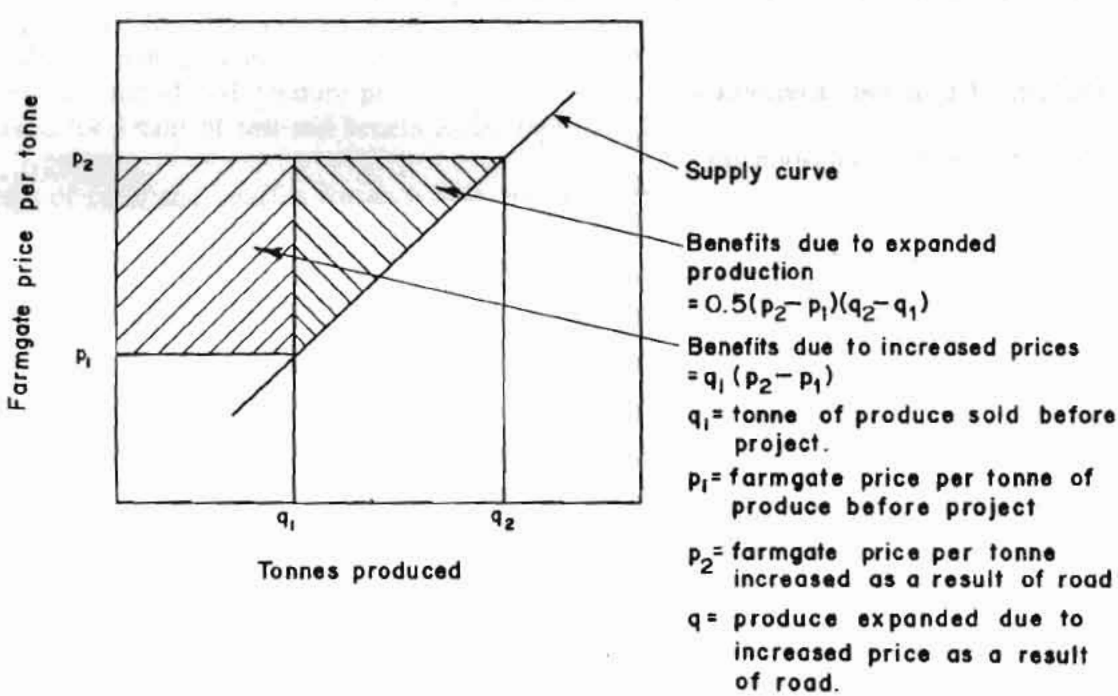
The private agencies are concerned with economic costs and benefits rather than financial ones, whereas public agencies would like to assess the net contribution that the investment will make to the country as a whole.

At the network level, the aim is to compare several investments in terms of their ability to contribute to the national economy, whereas at the project level the aim is to maximize cost effectiveness from the choices available for the given project.



Source: TRRL 1988

Fig. 20.1 Benefits measured as consumer surplus



Source: TRRL 1988

Fig. 20.2 Benefits measured as producer surplus

Since the level of resources required is related to the size of the work, the costs and manpower or equipment required to investigate, analyze, and interpret the economic evaluation become increasingly important and simpler methods become more desirable for smaller works.

There are different methods of economic analysis that are applicable to road projects for selection of investment options and design strategies. They are cited below.

1) *Cash Flow Method*

a) Equivalent Uniform Annual Cost Method, often simply treated as " annual cost method".

b) Present Worth Method for:
   - o costs,
   - o benefits, or
   - o benefits minus cost, usually termed the "net present worth" or "net present value method".

c) Rate-of-Return Method for:

   i) first year rate of return,
      - o economic, and
      - o financial.

   ii) Internal rate-of-return,
      - o economic, and
      - o financial.

d) Benefit-Cost Ratio Method

2) *Long-Run Economic Planning*

In long-run economic planning, the relationship between supply and demand is analysed over a longer period by examining the implications of changes in traffic flow under changing impacts and inputs.

3) *Generalized Heuristics*

The cash flow method of economic analysis is generally followed in most economic analysis. The cash flow analysis method of economic evaluation is suited to roads where the alternatives are not likely to be subject to major variations in terms of size of investments, technological levels, road standards, and demand growth.

A long-run economic planning method is desirable for comparing alternatives where the implications of change in traffic level, at various costs; because of differences in technology, alignment, expansion, maintenance, and economic growth; are likely to be considerable.

For smaller rural road projects, it may not be justifiable to carry out either cash flow or long-run methods of analysis because of the amount of work involved, in comparison to the size of investment and available facilities, and also because of several indirect benefits that need to be considered. A generalized heuristics' method of evaluation should be adequate for such projects. Section 20.4 discusses revised rules relating to the use of the IRR in the Cash Flow Analysis Method. Section 20.3 discusses the Long-Run Economic Planning Method.

20.2.5 *Terms Related to Cash Flow Analysis Method*

Net Present Value (NPV)

This is simply the difference between the discounted benefits and costs over the analysis period.

$$NPV = \sum_{i=0}^{n-1} \frac{b_i - c_i}{(\frac{1+r}{100})^i}$$

where,

- n = analysis period in years,
- i = current year, with i=o in first year,
- b_i = sum of all benefits in year,
- c_i = sum of all costs in year i, and
- r = planning discount rate in percentage.

Use of net present value is possible only when there are alternatives to be compared and discount rates are given.

Benefit-Cost Ratio (BCR)

This is the ratio between discounted total costs and discounted total benefits:

$$BCR = \frac{\sum_{i=0}^{n-1} \frac{b_i}{(\frac{1+r}{100})^i}}{\sum_{i=0}^{n-1} \frac{c_i}{(\frac{1+r}{100})^i}} = 0.$$

Internal Rate of Return (IRR)

This is the discount rate at which the present value of costs and benefits are equal; in other words the NPV=0:

$$\sum_{i=0}^{n-i} \frac{b_i - c_i}{(\frac{1 + r}{100})^i} = 0$$

where, r = IRR.

The solutions are normally obtained graphically or by iterations. IRR gives an indication of the profitability of investment and does not provide any idea of the size of profit.

First Year Rate of Return (FYRR)

The FYRR is simply the sum of benefits, in the first year of trafficking after project completion, divided by the present value of capital cost, grossed up by the discount rate to the same year, and expressed as a percentage:

$$FYRR = \frac{100\ bj}{\sum_{i=0}^{j-i} c_i \ (\frac{1+r}{100})^{j-1}}$$

where,

j = first year of benefits, with j = 0 in the base year.

The FYRR assists in deciding the timing of project commencement without sensitivity analysis which, whenever possible, is more desirable. The project is timely if FYRR is greater than the planning discount rate. Figure 20.3 is a diagram for calculating IRR graphically.

20.2.6 *Equations Relating to Cash Flow Analysis*

A) *Equivalent Uniform Annual Cost Method*

This method is applied for assessing costs only. All costs at different times are expressed in terms of equal annual payments over the analysis period. This can be expressed by (1):

$$AC_{x_i},n = Crf_x\ (ICC)_{x_i} + (AAMO)_{x_i} + (AAUC)_{x_i} - Crf_{i,n}\ (SV)_{x_{i,n}}$$

where,

AC_{x1}	=	equivalent uniform annual cost for alternative x_1, for a service life or analysis period of n years,
$crf_{i,n}$	=	capital recovery factor for interest rate i and n years,
	=	$[i(1+i)n/[(1+i)n - 1]$
$(ICC)x_1$	=	initial capital costs of construction (including actual construction costs, materials costs, engineering costs, etc.),
$(AAMO)x_1$	=	average annual user costs for alternative x_1 (including vehicle operation, travel time, accidents, and discomfort if designated), and
$(SV)x_{1,n}$	=	salvage value, if any, for alternative x_1 at the end of n years.

The above equation considers annual maintenance and operating costs, and user costs, on an average basis. This can be satisfactory for many purposes. Where such costs do not increase uniformly, however, an exponential growth factor can easily be applied.

When additional capital expenditure occurs before the end of the analysis period, i.e., when the service life is less than the analysis period; and future rehabilitation, such as overlays or seal coats, is needed. The equation for this situation may be modified and expressed by:

$$AC_{x_1,n} = Crf_{i,n}\ [(ICC)_{x_1} + R_1\ pwf_i,\ a_1 + R_2\ pwf_i,\ a_2 + \ldots\ R_j\ pwf_i,\ a_j + (AAMO)x_1 + (AAVC)_{x_1} - Crf_{i,n}(SY)_{x_1,n}]$$

where,

$ACx_{1,n}$	=	equivalent uniform annual cost for alternative x_1, for an analysis period of n years,
$R_1, R_2, \ldots R_j$	=	cost of first, second,....., j^{th} resurfacings respectively,
$a_1, a_2, \ldots a_j$	=	ages at which the first, second,...., j^{th} resurfacings occur respectively,
pwf	=	present worth factor = $1/(1+i)^n$.
i	=	discount rate, and
n	=	number of years.

BASIS AND DERIVATION OF THE DIAGRAM FOR DETERMINING RATE OF RETURN

The diagram (which is, in effect, a nomogram combined with a family of curves) solves a relatively simplistic model involving:

(a) a cost, or investment (I);
(b) the 'base-year benefits' (b) resulting from that investment;
(c) the annual rate of growth of those benefits (i);
(d) the number of years considered (n), (i.e., the "economic life"); and
(e) the internal rate of return on the investment (d).

The annual rate of growth of benefits (i) is considered constant over the economic life. For an indication of how to adapt the diagram when the growth rate is not constant, see note 4 across.

Associated with any investment there are, normally, some notional base-year benefits (B_o). In practice there is a lag between the investment being incurred and the first benefits arising from the investment. The model on which the diagram is based assumes that the investment (I_o) is made in year '0', and that the notional first-year benefits materialize only in year 1. In tabular form, the model is as follows:

Year	Investment	Benefits
0	I_o	
1		$B_o (1 + i)$
2		$B_o (1 + i)^2$
3		$B_o (1 + i)^3$
n		$B_o (1 + i)^n$

The rate of return (d) will be such that:

$$I_o = B_o \frac{(1+i)}{(1+d)} + B_o \frac{(1+i)^2}{(1+d)^2} + \dots \; B_o \frac{(1+i)^n}{(1+d)^n} \; \dots\dots \qquad (1)$$

or,

$$I_o = \frac{(1+i)}{(1+d)} + \frac{(1+i)^2}{(1+d)^2} + \dots\dots\dots\dots \frac{(1+i)^n}{(1+d)^n} \dots\dots \qquad (2)$$

that is,

$$\frac{I_o}{B_o} = k + k^2 + k^3 + \dots\dots\dots \; k^n \dots\dots \qquad (3)$$

where,

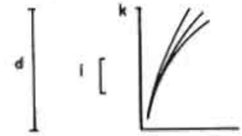
$$k = \frac{1+i}{1+d} \dots\dots \qquad (4)$$

Although the family of curves was plotted using the ratio of I_o/B_o (i.e., cost/first year benefits) on the abscissa, in the diagram this has been converted to, and shown as, the reciprocal (first year benefits/cost) since the ratio is more commonly used in this form.

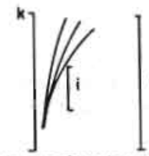
Fig. 20.3 Diagram for calculation of internal rate of return (IRR)

Derivation of the Diagram

The family of curves in the diagram represents the relationship expressed in equation (3), with the right hand side of the equation represented as the sum of a geometrical progression to n terms; 'k' has been plotted on the vertical axis. The k-axis also forms one of the three axes comprising the three-line nomogram, which 'solves' equation (4), (the other two axes being the 'i' [or rate of growth] axis, and the 'd' [or rate of return] axis). The diagram, basically, therefore is as follows:



For the sake of compactness, the nomogram has been 'folded over' the family of curves, thus:



The scale of k-axis is of course common to both the family of curves and the nomogram. Since, in use, the k-axis is only a transfer line, the scale markings of this axis have been suppressed in the diagram.

NOTES

1. The diagram can also be used to examine sensitivity. For example, the straight edge may be rotated about point 'B' to examine the variation in IRR for various values of the growth of benefits; or, in other words, to examine the sensitivity of IRR with respect to change in the rate of growth of benefits. Then again, for a given first year benefit/cost ratio, point 'A' may be located on different curves to examine the sensitivity of the internal rate of return to variation in the economic life.

2. The diagram can also be used "in reverse". For example, if the IRR and the rate of growth of benefits are given, then by working backwards through the diagram the appropriate combinations of economic life and first year benefit/cost ratios can be determined. Quite generally, the diagram uses four variables: if any three are given, the fourth can be determined directly.

3. The diagram indicates certain aspects of the relationship between first year benefit/cost ratio (FYB/C), n, i, and d, which are not readily appreciated from equations (1) and (2), across; the diagram gives one a better "feel" for the relationship. For example, the curves for n=10 years and n=15 years run together at a point which corresponds to a FYB/C ratio of about one-third. Thus, if the first year benefits are at least one-third of the investment, then there is no advantage in taking an économic life greater than 10 years. Again, the diagram indicates how little is gained (in terms of an increase in IRR) by extending the economic life beyond, say, 30 years; the increase in IRR moving from 30 to 50 years will, under the most favourable circumstances, be at the most about one percentage point.

4. Although the model assumes, as standard, investment in year '0' and the base-year benefits starting in year '1', and just one rate of growth of benefits throughout the economic life considered, non-standard conditions can readily be adapted to conform to these requirements of the model and still give results which are tolerably acceptable. For example:

   (1) if the rate of growth of benefits is not constant but is i_1 for the first period, followed by a rate of growth of i_2 for the second period, then an 'average' rate of growth should be used, between i_1 and i_2, but obviously nearer to i_1 since it is the early years that count in the discounting process.

   (2) if the investment is spread over two years instead of one, with the benefits starting to materialize in the following year, the first year investment should be compounded to the second year using an intelligent guess for the compounding rate and then added to the investment in the second year, and that year then termed year '0'. Thus we would have, effectively, an investment in year '0'. Thus we would have, effectively, an investment in year '0', benefits starting in year '1', and the diagram would apply. If by chance it transpired, having worked out the rate of return, that the intelligent guess for the compounding factor for the initial year's investment was wildly wrong, it would be appropriate to carry out a second iteration using as the compounding factor for the first year investment the rate of return determined in the first 'pass'.

5. Line X-X (near the top of the diagram) has some significance for the relationship between (i) annual rate of growth of benefits, and (ii) internal rate of return. If point 'A' (see "use of the diagram", over) falls anywhere below line X-X, the IRR will always be greater than the rate of growth of benefits; if 'A' falls above line X-X, the IRR will always be less than the rate of growth of benefits. If point 'A' is located anywhere on line X-X, then the IRR will equal the rate of growth of benefits.

Source: Schuster 1973

Fig. 20.3 Diagram for calculation of internal rate of return (IRR) (Cont)

B) *Present Worth Method*

The present worth method can be used to assess costs alone, benefits alone, or the costs and benefits together of all the future streams of costs in terms of the present value by using an appropriate discount rate. The present worth method for costs alone can be expressed in terms of the equation:

$$TWPC_{x_1,n} = (ICC)_{x_1} + \sum_{t=0}^{t=n} pwf_{i,t}\,[(cc)_{x_1,t} + (MO)_{x_1,t} + (UC)_{x_1,t}] - (SV)_{x_1,n}\,pwf_{i,n}$$

where,

$TWPCx_{1,n}$ = total present worth of costs for alternative x_1, for an analysis period of n years,

$(ICC)_{x1}$ = initial capital costs of construction, etc., for alternative x_1,

$(CC)_{x1,t}$ = capital costs of construction, etc., for alternative x_1, in year t, where t is less than n,

$pwf_{i,t}$ = present worth factor for discount rate, i, for t years,
= $I/(1+i)^t$

$(M0)x_{1,t}$ = maintenance plus operation costs for alternative x_1 in year t,

$(UC)x_{1,t}$ = user costs (including vehicle operation, travel time accidents, and discomfort if designated) for alternative x_1, in year t,

$(SV)x_{1,n}$ = salvage value, if any, for alternative x_1, at the end of the design period, n years,

where,

$$TPWB_{x_1,n} = \sum_{t=0}^{n} p\,w\,f_{i,t}\,[(DUB)_{x_1,t} + (IUB)_{x_1,t} + (NUB)_{x_1,t}]$$

$TPWBx_{1,t}$ = total present worth of benefits for alternative x_1 for an analysis of n years,

$(DUB)x_{1,t}$ = direct user benefits accruing from alternative x_1 in year t,

$(IUB)x_{1,t}$ = indirect user benefits accruing from alternative x_1 in year t, and

$(NUB)x_{1,t}$ = non-user benefits accruing from project x_1 in year t.

It is questionable whether or not non-user benefits and indirect user benefits can be measured adequately. Consequently, it is perhaps reasonable to consider only direct user benefits until such time as the state-of-the-art is sufficiently advanced to allow the other factors to be measured.

Net Present Value Method

The net present value method follows on from the foregoing methods, because it is simply the difference between the present worth of benefits and the present worth of costs. Obviously, benefits must exceed costs if a project is to be justified on economic grounds. The equation for net present value is:

$$NPV_{x1} = TPWB_{x1,n} - TPWC_{x1,n}$$

where,

NPV_{x1} = net present value of alternative x_1 (and $TPWB_{x1,n}$ and $TPWC_{x1,n}$ are as previously defined).

However, for road projects' alternative, x_1, this equation is not applicable directly to x_1 itself, but rather to the difference between it and some other suitable alternative, say x_o. Considering only direct user benefits, these are then calculated as the user savings (resulting from lower vehicle operating costs, lower travel time costs, lower accident costs, and lower discomfort costs) realized by x_1 over x_o.

Thus, the net present value method can be applied to projects only on the basis of project comparison, where the project alternatives are mutually exclusive. When a project alternative is evaluated, it needs to be compared not only with some standard or base alternative but also with all the other project alternatives. In the case of roads, the base alternative may be that of 'do-nothing' or 'do-minimum'. The equation form of the net present value method for pavements may then be expressed as:

$$NPV_{x1} = TPWC_{xo,n} - TPWC_{x1,n}$$

where,

NPV_{x1}, = net present value of alternative x1,

$TPWC_{xo,n}$ = total present worth of costs, for alternative x_o (where x_o can be the standard or base alternative, or any other feasible mutually exclusive alternative $x_1, x_2, \ldots x_k$) for an analysis period of n years, and $TPWC_{x1,n}$ is as previously defined.

20.2.7 *Sensitivity Analysis and Risk Analysis*

Sensitivity analysis is carried out to assess the sensitivity of the economic indicators such as IRR, NPV, and BCR to the variability of important items of the project. The effect of staged constructions and uncertainties of the base line figures of parameters such as traffic, costs, prices, and management inputs can be assessed by varying the inputs normally one at a time, and determining the total costs, total benefits, IRR, and NPV.

When the combined effect of several variables on the IRR or NPV is to be assessed, risk analysis becomes essential. Risk analysis provides a better basis of judging the relative merits of alternative projects, but it does nothing to reduce the risks. Risk analysis may be carried out by identifying important variables from the sensitivity analysis and specifying the probability of each important variable attaining a range of values. The probability distribution of NPV or IRR can then be obtained. Risk analysis is time consuming for complex projects such as roads. Such an analysis should be considered for highly critical cases such as for roads, which are high cost, and alternates to already existing major traffic diversions or susceptible to them, or washouts. However, the existence of computer facilities and appropriate models for risk analysis can significantly reduce the odds against risk analysis.

20.3 ANALYTICAL FRAMEWORK FOR ECONOMIC ANALYSIS USING LONG-RUN ECONOMIC PLANNING (LREP)

Economic planning of transportation projects consists of exercising basic investment planning principles to determine if any facility is economically desirable and, if so, then which facility is economically most desirable. The economically optimal decisions determined by investment planning are called long-run decisions, which means that the decisions relate to infrastructural changes. Long-run investment planning principles can be applied to compare different modes of transportation (such as roads and ropeways), alternative technologies within a particular mode of transport (such as the use of tunnels or low-volume roads) or both. Social, political, and legal considerations are not within the scope of economic investment planning; they should be brought to bear on the overall investment decision separately.

This section provides an application-oriented explanation of the Long-Run Economic Planning (LREP) approach to investment planning. Part II contains considerations that indicate the specific problem contexts in which the LREP Method, as presented here, is applicable. Further readings are suggested in the references. Figures in this section were extracted from Wohl and Hendrickson (1984).

20.3.1 *Long-Run Economic Planning (LREP)*

Introduction

LREP is based on an analysis of the relationship of the supply, or cost, curve to the demand curve. LREP provides a framework for analysing supply and demand as functions of the quantity of traffic flow over the planning horizon. The LREP model is particularly useful in analysing the implications of changes in traffic flow, at various costs, caused by differences in facilities, technology, alignment, expansion, maintenance, and economic growth. The implications are summarized as the total net benefit or the consumer's surplus.

Definition of Concepts

The cost of a given facility is dependent on the technology and level of usage. Mathematically, costs are defined as a function of technology, capacity, and usage. The time period costs are defined and differentiated according to the availability of time for adjusting the technology and operation of the facility. Thus, the short-run represents the time horizon in which only minor changes can be made to the technology (i.e., to the existing facility or to the type of operation [such as tolls for trucks]). Over the long run, enough time would be available to alter the technology substantially. Extra costs in the short run arise from increases in usage that cause wear and tear as well as user costs, for example, travel time. Cost changes in the long run arise from changes in either the technology, usage, or both. Long-run cost functions are used to determine which technology should be built and how large it should be. Short-run cost functions can be used to determine optimal operating policies but will only be of interest in this chapter as they relate to working with the longrun cost function.

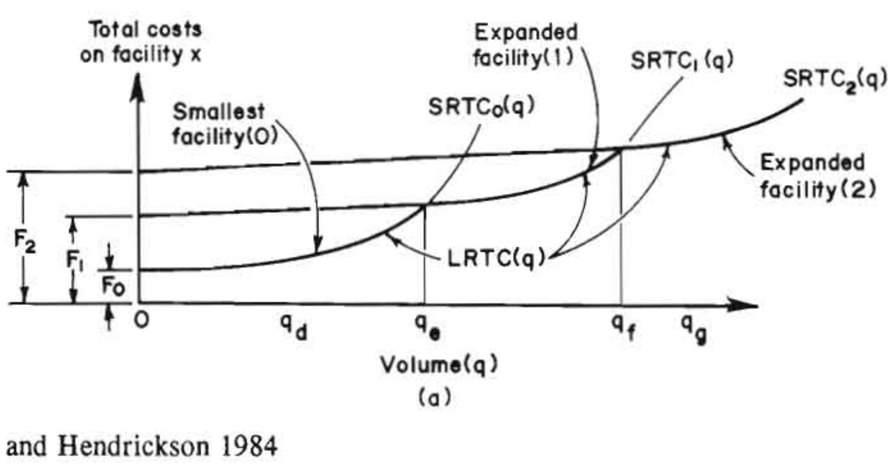
The short-run cost function is as follows:

$$SRTC_{x,t}\ (q) = F_{x,t} + SRVC_{x,t}\ (q)$$

where,

$SRTC_{x,t}$ (q)	=	the short-run total costs for a volume q (in AADT) using facility x during year t,
$F_{x,t}$	=	the fixed cost for facility x in year t, and
$SRVC_{x,t}$ (q)	=	short-run variable costs for a volume q using facility x in year t.

Fixed costs are usage independent costs for the facility in a given year such as rights-of-way, maintenance facilities, and garages. Variable costs are usage dependent and include such factors as facility and vehicle wear and tear. It should be noted that SRTC include both agency costs as well as user costs (and may be constructed to include external costs incurred, by the environment for example). The long-run cost function, or the planning cost function, represents the minimum cost of serving a given travel volume. This long-run cost function (LRTC) represents the envelope of the various short-run cost curves associated with each alternative facility. Figure 20.4 shows the long-run and short-run cost functions.



Source: Wohl and Hendrickson 1984

Fig. 20.4 Long-run and short-run cost functions

Unit cost functions of SRTC and LRTC are the curves of interest during the problem-solving exercise in equilibrium analysis. Regarding the SRTC, three unit cost functions are of interest: the short-run average total cost at flow q - **$sratc_{x,t}(q)$**, the short-run average variable cost at flow q - **$sravc_{x,t}(q)$**, and the short-run marginal cost at flow q - **$srmc_{x,t}(q)$**. Mathematically, these functions are defined as follows:

$$sratc_{x,t}(q) = \frac{SRTC_{x,t}(q)}{q} \tag{1}$$

$$sravc_{x,t}(q) = \frac{SRVC_{x,t}(q)}{q} \tag{2}$$

$$srmc_{x,t}(q) = \frac{\partial SRTC_{x,t}(q)}{\partial q} = \frac{\Delta SRVC_{x,t}(q)}{\Delta q} \quad . \tag{3}$$

Similarly, in the long-run, two unit cost curves are of interest: the long-run average total cost for a volume and the long-run marginal cost curve for a volume (lrmc). Mathematically these are:

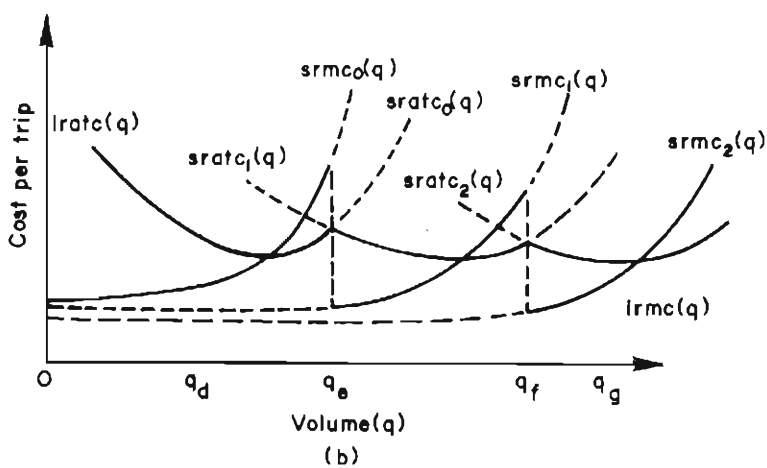
$$lratc(q) = \frac{LRTC(q)}{q} \tag{4}$$

$$lrmc(q) = \frac{\partial LRTC(q)}{\partial q} = \frac{\Delta LRTC(q)}{\Delta q} \tag{5}$$

or,

$$lrmc(q) = LRTC(q) - LRTC(q-1) \quad . \tag{6}$$

Figure 20.5, below, illustrates graphically the unit cost curves for the total cost curves shown in Figure 20.4.



Source: Wohl and Hendrickson 1984

Fig. 20.5 Unit cost curves

The benefits of transportation have to be carefully identified and represented mathematically. Proper understanding of the sources of travel benefits is needed to quantify and compare benefits to the costs of travel.

The demand function expresses the dependency of travel desire to the cost (or price) of travel. The price of travel is the total expense incurred by travellers in terms of private time, effort, and money expenses. In other words, the demand function explains the price travellers are willing to pay for travel. The marginal benefit function (mb), which is the inverse of the demand function, is used for analytical purposes here. The value of a trip, which is the price of that trip, is defined as the marginal benefit gained from the trip. Functionally, for a linear demand schedule of the form:

$$q = \alpha - \beta p \tag{7}$$

where,

p = the price of travel, and

α,ß = case-specific equation calibration coefficients.

The corresponding price or marginal benefit function is:

$$p(q) = mb(q) = \frac{\alpha}{\beta} - \frac{q}{B} \tag{8}$$

where,

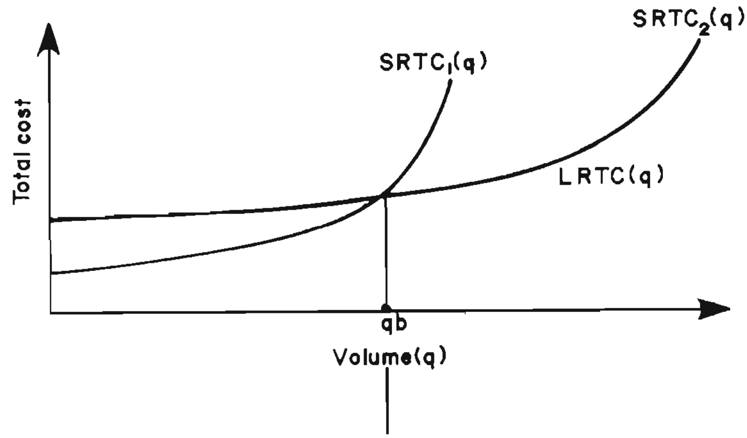
mb(q) = the marginal benefit to travellers by increasing travel volume from q-1 to q.

Investment Planning for Economic Efficiency in the Long Run

From the economic perspective, the net social benefit is the parameter of interest in solving the optimal facility. The net social benefit will be measured in monetary terms as expressed by a simultaneous solution of the **lrmc** and **mb** functions. Problems this approach is suited to, as well as guidelines for estimating the parameters, are given in the Section entitled "Considerations for Practice Using LREP".

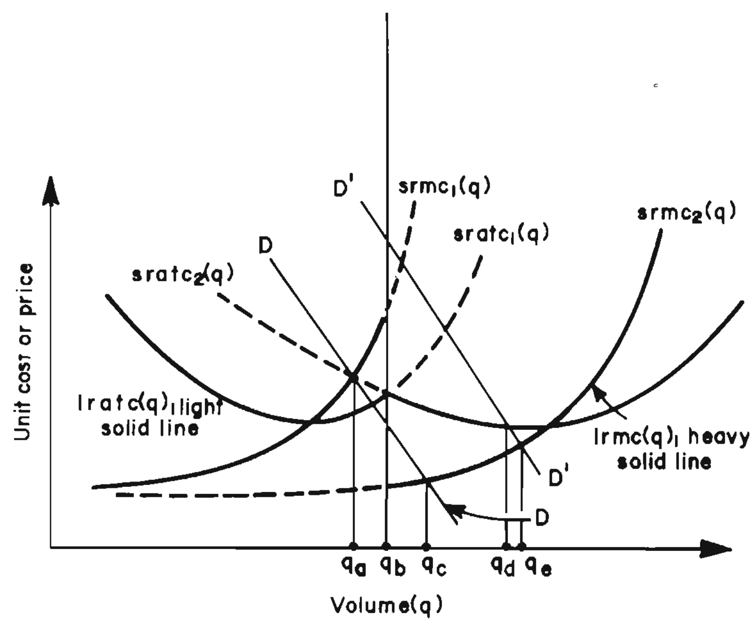
The graph in Figure 20.4 is used to explain the analytical process. The situation shown in Figure 20.4 is a basic problem. Considerations for more involved cases will be elaborated upon in the section on Considerations for Practice.

Figure 20.6 (a) represents the total cost functions of the two facility options while the curves in Figure 20.6(b) are the corresponding unit cost curves. Only two facility options are represented by the cost curves while the travel demand is shown as either low (DD) or high ($D'D'$). The first task is to estimate curves (discussed later) such as those in Figure 20.4 - this will result in a set of curves that are to be analysed as follows.



Source: Wohl and Hendrickson 1984

Fig. 20.6 (a) Total cost functions of two facility options



Source: Wohl and Hendrickson 1984

Fig.20.6 (b) Corresponding unit cost curves

Economically, the optimal pricing policy is to set the **mb** = **lrmc**. This implies constructing a facility that serves a volume q_o such that $mb(q_o) = lrmc(q_o)$ it is also necessary that the total benefits must satisfy the equation:

$$\sum_{q=1}^{q_a} mb(q) \geq \sum_{q=1}^{q_a} lrmc(q) + F \geq LRTC(q_a) \tag{9}$$

the total costs, to ensure economic efficiency. Analytically, to determine which facility to build at what capacity, the solution can be obtained by solving the above conditions*. In the case of higher demand ($D'D'$) in Figure 20.6(b), **mb > lrmc** from **q=1 to** q_e;**qc** would set **mb=lrmc**. Furthermore, as $mb = sratc_2(q) = ratc(q)$ at **qd** and **mb > lrmc** between q_d and q_e, it can be concluded that:

$$\sum_{q=1}^{q_e} mb \geq LRTC(q_e)$$

Thus, for the higher demand case, the optimal decision would be to construct facility 2 at a capacity of q_e. The lower demand case is less straightforward. Up to q_a, both conditions are satisfied, i.e., **mb > lrmc** and:

$$\sum_{q=1}^{q_a} mb(q) > LRTC(q_a) \quad .$$

Beyond q_a, **mb > lrmc** on facility 2 but is:

$$\sum_{q=q_a}^{q_e} mb(q) \geq \sum_{q=q_a}^{q_e} lrmc(q)?$$

If this is true then the optimal decision is to construct facility 2 at q_e, otherwise the optimal decision is to construct facility 1 at q_a. To resolve this inequality, it is necessary to know the exact shape of the curves and sum up the quantities of interest numerically.

The considerations made above are typical of the analysis to answer the question concerning which facility to build and how large it should be. Facilities 1 and 2 could represent different road standards, alignments, and technologies in addition to capacity. The demand curves in Figure 20.6 could represent expected growth in traffic over the road's life.

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* Conditions of very low land demand, where no such condition exists will be discussed in the section on Considerations for Practice.

Considerations for Practice using LREP

1. It is important to realize that problem definitions make implicit assumptions. The application of any approach to solving the problem will have to account for such assumptions to provide valid results. Two specific problems to illustrate this point are given below.

   i. The decision whether or not to build a road between two points can be made on one or more of economic, social, political, and legal grounds. Often, it is only social or political considerations that effectively have a bearing on the decision. In such situations, the engineering community is handed the task of making a road between two points and not asked to decide if it is economically advisable to make a road (or any other transport facility). In such cases, investment planning must determine the economically most desirable transport facility in the long run, between the pre-determined terminal points. The determination of the most desirable transport facility would involve options such as alternative alignments, road standards, road technologies, and rural development components.

   ii. Whereas the previous problem considers the economic efficiency of investing in a single project, this problem addresses the economic efficiency in deciding to invest in a number of alternative projects. Decisions, regarding which of several alternative terminal points to build a road across, tend to involve terminal points with similar characteristics of development potential (such as natural resource endowment, population, production patterns, and income levels). In such cases, it is desirable to base the selection of one alternative on economically cognizant social and political considerations. Long-run investment planning needs to determine the prioritization of the alternatives from an economic point of view as well as to determine the corresponding transport facilities.

   The first problem assumes that the decision to build a transportation facility has already been made. This means that indirect benefits (i.e., those benefits that arise as a secondary impact of a road - such as higher income from the establishment of industries) are irrelevant to deciding the type of facility to be constructed. The travel demand function will define all benefits that accrue to road users and it is for this group above that investment planning will define benefit and determine the economically efficient transport facility. However, the demand function will include secondary benefits to the extent that they give rise to travel demand (modelled by shifts in the demand curve).

   In the second problem, the critical assumption is that of similar terminal points that an economic comparison is made across. Here, the fact that the terminal points are similar makes it possible to assume that indirect benefits will be the same among the alternatives. Thus, we are faced with comparing only the direct benefits of travelling on the road which are captured by the demand function.

   If indirect benefits were estimated independently, the LREP approach could be used to account for total benefits. This modified application of LREP would enable more than the two problems given above to be addressed by LREP.

2. The Long-run Total Cost (LRTC) function is the envelope of the lowest cost, Short-run Total Cost (SRTC), curves. For low traffic volumes, a given facility (standard, technology, alignment) might

be the lowest cost alternative, while, at larger flows, the maintenance and user costs may make another facility the cheapest. Thus, a wide range of facilities should be represented by the cost curves to examine the broadest range of investment options. Large investments in slope stabilization, tunnels, express alignments, staged construction, and various road standards are examples of such options. It is also worthwhile to carry out a parallel analysis for alternative modes of transport such as ropeways and electric bus lanes. Moreover, it is important to build rural development investment packages into the cost curves of facility options to study possibilities of enhancing the catalyst role of rural roads for rural development.

3. In estimating a SRTC (thereby estimating part of the LRTC) curve, there are a few categories from which the costs arise. First of all, there are the usage independent, or fixed, costs for the facility. In contrast, there are the usage dependent costs or variable costs. Both fixed and variable costs for a given facility can be experienced by the road-building agency, vehicle-operating agency, or the road user. The categories that the cost function should have are:

- fixed facility and social dislocation costs,
- variable facility costs,
- fixed vehicle ownership costs,
- variable vehicle costs,
- variable user costs, and
- external costs (environmental).

In order to estimate the SRTC, the first task is to estimate these costs in a format such as the one shown below in Table 20.1.

Table 20.1 SRTC costs

Year	Ft Fixed Costs	VARIABLE COSTS ($SRVC_j$) by TRAFFIC FLOW LEVELS (AADT)						
		Q_1	Q_2	Q_3	Q_4	Q_5	Q_{j-1}	Q_j
0								
1								
2								
3								
.								
.								
.								
n-1								
n								

Source: Wohl and Hendrickson 1984

The information tabulated in Table 20.1 has to be transformed into a cost function $\mathbf{SRTC_t(q) = F_t + SRVC_t(q)}$ to year **0** for all **q**. Plotting the function **STRC (q)** will result in a graph similar to Figure 20.4 Repeated plots of other SRTC functions for alternate facilities will enable the identification of **LRTC (q).**

4. Unit cost functions are to be derived in a similar manner. Average costs and marginal costs are to be calculated using relationships (1) and (3). Discounting to year 0 is to be done as for **SRTC**.

5. The variable user costs consist only of the variable part of the total user costs of travel. Whereas, the user costs of travel, p, consist of the monetary charges for travel as well as user costs. Examples of travel charges are tolls, fares, and vehicle operation costs while user costs are usually taken as the travel time. In other terms, a simple representation of p is:

$$p = vt + f \tag{10}$$

where,

f = travel fare in monetary terms,
t = travel time, and
v = user time cost parameter.

Furthermore, $t = t_o + \sigma q$, i.e, travel time is a minimum $\mathbf{t_o}$ and time increased by congestion at flow **q** by $\boldsymbol{\sigma}\mathbf{q}$ (σ being the travel time congestion parameter).

Combining the two expressions:

$$p = v\,t_o + v\,\partial q + f \quad = \tau + \xi q + f \tag{11}$$

thus,

the variable user costs are $\tau + \xi q$.

6. The construction of a demand curve requires careful thinking to identify the sources of travel benefits. Some basic concepts are needed to proceed with the construction of a demand and marginal benefit curve.

   6.1 The demand function represents the desire, in terms of the willingness to pay under certain circumstances. Mathematically this is expressed as q = f (p, SE), where q is the travel volume demanded under the terms of a function f of the price of travel and socioeconomic conditions SE. This is an aggregate demand function for a population that includes people with high and low demands for travel.

   6.2 The construction of a demand curve involves the collection of data and fitting them to a curve using regression analysis. The data needed for the construction of a demand curve are usually of three types: (1) socioeconomic attributes of the origin and destination (income, population, food deficit, etc.), (2) user costs for the facility under consideration, and (3) user costs on alternative routes (such as walking on trails). The specific variables to be considered within these categories are discussed below. The variables discussed below are meant to be indicative only; it is possible that other variables could give a better explanation of demand under special circumstances.

6.3 The estimation of the user costs for either the facility under construction or an alternate mode of travel is based on Equation (11). The user costs, in terms of the costs of travel time or the monetary charges, fall into categories which have to be estimated independently and summed to arrive at the total user costs at various flows, as expressed in Equation (11). At the outset, the travel time congestion parameters have to be estimated by observations of the travel time at various flow levels beyond the flow level that causes no congestion and results in the minimum travel time t_o.

Estimating:

$$\delta = \sum_{t=1}^{n} \frac{\frac{t_i}{\xi_i}}{n}$$

for all i observations will suffice.

The traffic flow q is to be measured in average annual daily traffic flow (AADT) as for the cost curves. This and other observations should be made on an existing road with as closely matching facilities and socioeconomic attributes as possible.

6.3.1 The user time cost parameter varies for vehicle occupants according to the type of travel undertaken. If the traveller is on official travel, v is the sum of the traveller's wage rate and overheads the employer incurs in the travel of the user. If the traveller is on leisure travel (including commuting), v = o in Nepal, although studies show v = 25 per cent of the traveller's earnings in other developing countries.

6.3.2 For freight transportation, v is the sum of the interest rate of the goods and the costs due to spoilage during travel time (and not due to road smoothness). These vary by commodity and a careful study is required to estimate v for freight transportation.

6.3.3 The monetary changes, f, are the sum of the fares charged to commercial passengers and to the transport of goods.

6.4 The socioeconomic attributes are critical to the construction of a reliable demand function. Various parameters could be relevant such as the total population of the origin, destination, and towns in between; the mean employment or income of the origin, destination, and towns in between, service differentials between nodes, the food deficit in the influence area, and the potentials for expansion of production (tourism, horticulture, mining, forestry, etc). Aside from the care needed to measure such attributes, care should be taken to define the variables to account for the salient features of the major linkages among the socioeconomic factors the demand is likely to be influenced by. Traffic growth estimating heuristics, given in Section 20.5 are useful in this respect.

6.4.1 The test of significance of using various socioeconomic attributes can be done statistically. The estimation of the growth rate of those variables is another problem that requires serious thought. Simple techniques are available, for example, to estimate the income growth rate; one can use the country's GDP growth rate multiplied by the per cent of the national GDP the region accounts for. Such techniques can be very misleading, however, and, given the importance of estimating a realistic growth rate for the socioeconomic variables used in the demand curve, it is worth the effort to consult an economist.

6.5 The data used for developing a demand curve can either be time series or cross-sectional. The choice of which type is used will be dependant on data availability. The choice of the location selected from which to gather the data must be done taking into consideration the similarity of the area where the data are to be gathered to the area where the road is to be built. The similarity is defined by the socioeconomic variables. Finally, a standard text on regression analysis should be consulted for its technique and a computer programme (such as MINITAB or SPSS) should be used for the regression analysis.

20.4 CASH FLOW ANALYSIS AND REVISED RULES FOR THE IRR METHOD

The conventional definition of the IRR Method may lead to ambiguous or incorrect conclusions regarding the economic viability of a project or the most viable alternative. While the Revised Rules for the IRR Method (RIRR) are given below, it should be noted that the RIRR Method requires lengthy calculations which provide the same result as those obtained by using the simpler NPV method. Barring unavoidable circumstances, it is recommended that the NPV or BCR methods be used instead of the RIRR Method. The complete set of rules for the RIRR Method, presented below, were extracted from Wohl and Hendrickson 1984; a critique on the theoretical problems of the IRR Method regarding, among other things, reinvestment implications and Effective Rate of Return (ERR) can be found there.

An appropriate and consistent set of decision rules is outlined below for determining project acceptability when using the IRR Method. The rules widely apply for both single and multiple rates of return, for borrowing or investment situations, and for pure or mixed projects. They are given in the following section.

20.4.1 *Revised IRR Decision Rules for Determining Project Acceptability*

(a) Determine the sum of undiscounted (net) annual cash flows of the project over the **n** year analysis period, that is:

$$S = \sum_{t=0}^{n} [B_{x,t} - C_{x,t}] = [NPV_{x,n}]\ 0\%$$

where,

S is the sum of (net) annual cash flows; $\mathbf{B_{x,t}}$ and $\mathbf{C_{x,t}}$ are the benefits and costs, respectively, for project *x* during year *t* of the *n* year analysis period.

(b) Determine r_x the internal rate of return for project x, i.e., determine the non-negative discount rate or rates at which the discounted benefits just equal the discounted costs over the n-year analysis period). If there are multiple rates of return, list them in ascending order, as follows: $r_x', r_x'', r_x''', r_x''''$, ...; however, exclude all non-positive rates from this list; also, list each positive, repeating the rate separately.

(c) When there is a single internal rate of return r_x or no positive rate of return and the sum of the annual cash flows is not equal to zero, accept or reject project x according to the following rules:

Condition	Sum of Annual Cash Flows is Positive	Sum of Annual Flows is Negative
MARR < r_x	Accept project	Reject project
MARR > r_x	Reject project	Accept project
No positive r_x	Accept project	Reject project

When Marginal Average Rate of Return (MARR) and the internal rate of return are equal, one would be indifferent between acceptance and rejection.

Applying these rules to the example in Table 20.2 we would reject the project if the MARR was below 20 per cent accept it if the MARR was above 20 per cent, and be indifferent between acceptance and rejection if the MARR was just equal to 20 per cent.

(d) When there are multiple rates of return and the sum of the annual cash flow is not equal to zero, accept or reject project according to the following rules, where r_x' is the first positive IRR, r_x'' the second positive IRR, and so on:

Condition	Sum of Annual Cash Flows is Positive	Sum of Annual Cash Flows is Negative
MARR < r_x'	Accept	Reject
r_x' **<MARR >** r_x''	Reject	Accept
r_x'' **<MARR <** r_x'''	Accept	Reject
r_x'''**<MARR <** r_x''''	Reject	Accept

Note: Reversal pattern continues for additional rates of return.

Also, when MARR and an internal rate of return are equal, one would be indifferent between acceptance and rejection.

Table 20.2 Third example of the internal rate-of-return

Year	Cash Flow
0	+220
1	-144
2	-144
Sum of annual cash flow -68	
Internal rate of return 20%	

Source: Wohl and Hendrickson 1984

For the example in Table 20.3, for which the annual cash flow sum is positive, the project would be accepted for a MARR below 8.52 per cent, rejected for a MARR between 8.52 and 18.66 per cent, accepted for a MARR between 18.66 and 73.57 per cent, and rejected for a MARR above 73.57 per cent. By contrast, for the example in Table 20.4, for which the annual cash flow sum is negative, the project would be rejected for a MARR below 3.85 per cent, accepted for a MARR between 3.85 and 4.99 per cent, and rejected for a MARR above 4.99 per cent.

Table 20.3 Annual cash flows (in $10,000s) for a bridge improvement

End of Year t	Benefits B_t	Costs C_t	Benefits Less Costs $B_t - C_t$
0	-	50	-50
1	61	55	+6
2	63	0	+63
.	.	.	.
.	.	.	.
.	.	.	.
9	77	0	+77
10	79	70	-626
11	81	610	-529
12	83	495	-412
13	85	0	+85
.	.	.	.
.	.	.	.
.	.	.	.
29	117	0	+117
30	119	0	+119

Source and date: Wohl and Hendrickson 1984

Notes: Rates of return: $r_x' = 8.52\%, r_x'' = 18.66\%, r_x''' = 7.35\%$
Sum of net annual cash flows = +785

(e) When the sum of the undiscounted (net) annual cash flows, or S, is zero, a more complex procedure must be adopted. Stated succinctly, we need to know the slope of the discounted cash flow function evaluated for an interest rate of zero. To this end, recall that the discounted value of the project's cash flow stream for an interest rate i is:

$$f(i) = \sum_{t=0}^{n} \frac{B_{x,t} - C_{x,t}}{(1 + i)^t}$$

where,

$f(i)$ is the discounted value of the cash flow stream, expressed as a function of the interest rate i. In turn, the slope of the above discounted cash flow function is simply equal to the derivative of the function with respect to i or:

$$f'(i) = -\sum_{t=1}^{n} t \frac{[B_{x,t} - C_{x,t}]}{(1 + i)^t + 1}$$

where,

$f'(i)$ is the discounted cash flow function for a project, expressed as a function of the interest rate i. When the slope of the function is evaluated at i equal to zero, the slope will be as follows:

$$f'(O) = -\sum_{t=1}^{n} t\,[B_{x,t} - C_{x,t}] \qquad (12)$$

an expression which can easily be evaluated.

Do not overlook the negative sign for the slope in Equation 12. When there is a single internal rate of return, and thus r_x is equal to 0 per cent, accept the project when the slope, as computed by Equation 12, is positive and reject it when the slope is negative.

When there are multiple rates of return, the acceptance or rejection decision rules for a project, having an undiscounted cash flow stream equal to zero and a slope, as computed with Equation 12, will be as follows:

Condition	Slope of Discounted Cash Flow Function at $i = 0\%$ Positive	Negative
MARR < r_x'	Accept	Reject
r_x' < MARR > r_x''	Reject	Accept
r_x'' < MARR < r_x'''	Accept	Reject
r_x''' < MARR < r_x''''	Reject	Accept

Note: Reversal pattern continues for additional rates of return.

Table 20.4 Annual cash flows (in $ 10,000s) for a local streetcar extension example

End of Year f	Benefits B_t	Costs C_t	Benefits Less Costs B_t-C_t
0	175	-175	
1	0	1265	-1265
2	250	0	+250
3	240	0	+240
4	230	0	+240
5	220	0	+220
.	.	.	.
.	.	.	.
.	.	.	.
19	80	0	+80
20	70	0	+70
21	60	0	+60
22	0	1900	-1900

Source: Wohl and Hendrickson 1984

Note: $r_x' = 3.85\%, r_x'' = 4.99\%$

Sum of net annual cash flows = -240

Also, when the MARR and an IRR are equal, one will be indifferent between acceptance and rejection.

For both projects, in Table 20.5 the sum of the undiscounted cash flows is zero and, thus, the above decision rules apply. Accordingly, and using Equation 12, the slope for the discounted cash flow function (at i equal to 0) is -200 for Alternative 1 and +200 for Alternative 2. Thus, Alternative 1 is acceptable when MARR is between 100 and 200 per cent and unacceptable when MARR is below 100 or above 200 per cent. Alternative 2 is acceptable when **MARR** is between 0 and 81.6 per cent and unacceptable when MARR is above 81.6 per cent. (Recall, however, that when listing and (labeling the internal rates of return any non-positive rates must be excluded.)

Table 20.5 Fourth example of cash flows and the internal rate-of-return method

Year	Alternative 1	Alternative 2
0	-100	-300
1	+600	+900
2	-1100	-700
3	+600	+100
Sum of annual cash flows	0	0
Rate of return r_x	$r_1' = 100\%$ $r_1'' = 200\%$	$r_2' = 81.6\%$
$r_{1/2}' = 85.1\%$		

Source: Wohl and Hendrickson 1984

Table 20.4 Annual cash flows (in $ 10,000s) for a local streetcar extension example

End of Year t	Benefits B_t	Costs C_t	Benefits Less Costs B_t-C_t
0	175	-175	
1	0	1265	-1265
2	250	0	+250
3	240	0	+240
4	230	0	+240
5	220	0	+220
.	.	.	.
.	.	.	.
.	.	.	.
19	80	0	+80
20	70	0	+70
21	60	0	+60
22	0	1900	-1900

Source: Wohl and Hendrickson 1984

Note: $r_x' = 3.85\%, r_x'' = 4.99\%$

Sum of net annual cash flows = -240

Also, when the MARR and an IRR are equal, one will be indifferent between acceptance and rejection.

For both projects, in Table 20.5 the sum of the undiscounted cash flows is zero and, thus, the above decision rules apply. Accordingly, and using Equation 12, the slope for the discounted cash flow function (at i equal to 0) is -200 for Alternative 1 and +200 for Alternative 2. Thus, Alternative 1 is acceptable when MARR is between 100 and 200 per cent and unacceptable when MARR is below 100 or above 200 per cent. Alternative 2 is acceptable when **MARR** is between 0 and 81.6 per cent and unacceptable when MARR is above 81.6 per cent. (Recall, however, that when listing and (labeling the internal rates of return any non-positive rates must be excluded.)

Table 20.5 Fourth example of cash flows and the internal rate-of-return method

Year	Alternative 1	Alternative 2
0	-100	-300
1	+600	+900
2	-1100	-700
3	+600	+100
Sum of annual cash flows	0	0
Rate of return r_x	$r_1' = 100\%$ $r_1'' = 200\%$	$r_2' = 81.6\%$
$r_{1/2}' = 85.1\%$		

Source: Wohl and Hendrickson 1984

Note: Zero rates of return have been excluded for r_1, r_2 and $r_{1/2}$

20.4.2 *Revised Procedure for Ordering Mutually Exclusive Alternatives*

An appropriate procedure for ordering mutually exclusive alternatives is crucial to a proper analysis and determination of the best project. The pitfalls of ordering on the basis of increasing initial costs are all too evident for examples similar to Tables 20.6 and 20.7. To avoid these and other problems, a revised ordering procedure has been developed, and this is given below.

(a) Determine the sum of the undiscounted (net) annual cash flows for all alternatives.

(b) List all alternatives in ascending order with respect to their annual cash flow sums (as computed above). However, if the annual cashflow sums for two or more alternatives are equal, determine the slope of each of their discounted cash flow functions evaluated at i equal to zero, as defined in Equation 12, and then list these alternatives in ascending order with respect to the algebraic value of the slopes. Thus, the alternative that has the most positive or least negative slope will be the highest-ordered alternative. Also, it is possible, though highly unlikely, that two or more alternatives would have equal cash flow sums and equal slopes for their discounted cash flow functions; in such a case it would be necessary to use the second or perhaps third derivative of those functions to determine the appropriate ordering.

Using the above rules, the appropriate ordering can differ markedly from the usual ordering rule which calls for ordering alternatives according to the initialyear costs or outlays. For instance, the above rules would reverse the ordering of the alternatives as they are shown in Tables 20.6 and 20.7.

Table 20.6 Fourth example of cash flows and the internal rate-of-return method

Year	Alternative 1	Alternative 2
0	-100	-100
1	0	+20
2	+144	+120
Sum of annual cash flow	+44	+40
Rate of return	$r_1 = 20\%$ $r_{1/2} = 20\%$	$r_2 = 20\%$

Source: Wohl and Hendrickson, 1984

Note: r_x is the internal rate of return for alternative x, $r_{1/2}$ is the internal rate of return for the increment in benefits and costs between alternatives 1 and 2.

Table 20.7 Annual cash flows (in \$10,000s) for oil pump alternatives

Year	Alternative 1		Alternative 2		Difference
t	$B_{1,t}$	$C_{1,t}$	$B_{2,t}$	$C_{2,t}$	$\Delta B_t - \Delta C_t$
0	0	100	0	110	-10
1	70	0	115	0	+45
2	70	0	30	0	-40
Sum of net annual flows	+40		+35		-5
	Rate of return $r_1 = 25.69\%$		$r_2 = 26.16\%$		$r_{1/2}' = 21.92\%$ $r_{1/2}'' = 228.08\%$

Source: Wohl and Hendrickson 1984

Note: $\Delta B_t = B_{2,t} - B_{1,t}$ and $\Delta C_t = C_{2,t} - C_{1,t}$. r_x is the internal rate of return for alternative x, $r_{1/2}'$, and $r_{1/2}''$ are the internal rates of return for the increment in benefits and costs between alternatives 1 and 2.

20.4.3 *Revised Decision Rules for Determining the Best Alternative*

The decision rules for using the IRR Method, to properly and consistently determine the best among a set of mutually exclusive alternatives, are described below. Of equal importance, is the necessity for a proper ordering of the alternatives for subsequent analysis; thus, it is mandatory that the ordering procedure described in Section 20.4.2 (or some variation thereof) be adopted as part of the project selection process. The overall set of rules is as follows:

(a) put all mutually exclusive alternatives in ascending order according to the procedure described in Section 20.4.2;

(b) beginning with the two lowest-ordered alternatives, determine $r_{1/2,}$ the IRR for the increments in benefits and costs between the two alternatives; if there are multiple rates of return, list them in ascending order as follows: $r_{1/2}'$, $r_{1/2}''$, $r_{1/2}'''$,......; however, exclude all non-positive rates from this listing and list each positive repeating rate separately;

(c) when there is a single positive rate of return, the higher-ordered alternative of the two being compared will be preferable when MARR is less than r ; when MARR exceeds $r_{1/2}$ the lower-ordered alternative will be better; neither alternative is better when MARR just equals $r_{1/2;}$ however, when there is a single rate of return which is equal to zero, the higher-ordered alternative will be preferable for any MARR value; and

(d) when there are multiple rates of return, the better of the two alternatives being compared can be determined from the following rules.

Condition	Preference Rule for the Better of Two Alternatives
MARR < $r_{1/2}'$	Higher-Ordered Alternative
$r_{1/2}'$ **< MARR >** $r_{1/2}''$	Lower-Ordered Alternative
$r_{1/2}''$ **< MARR <** $r_{1/2}'''$	Higher-Ordered Alternative
$r_{1/2}''$ **< MARR <** $r_{1/2}''''$	Lower-Ordered Alternative

Note: Reversal pattern continues for additional rates of return.

Also, when MARR is equal to one of the rates of return, neither alternative is preferable.

(e) Apply the above preferability test (i.e., in rule (d) shown above) to successively higher-ordered alternatives found to be preferable to lower-ordered ones. That is, if Alternative 2 is preferable to Alternative 1, then apply the test to Alternative 3 as compared to Alternative 2, and so forth. But if Alternative 1 is preferable to Alternative 2, then apply the test to Alternative 3 as compared to Alternative 1, and so forth.

(f) Whenever all internal rates of return are non-positive or indeterminate, the higher-ordered alternative will be preferable.

Let us apply these rules to the examples in Table 20.5, 20.6, and 20.7.

For example, in Table 20.5, is first necessary to determine the slope of the discounted cash flow function (evaluated at i equal to zero) to properly order the alternatives. In this case, the slope for Alternative 1, as determined by Equation 12, was -200 and that for Alternative 2 was +200. Therefore, using the ordering rules in Section 20.4., Alternative 2 is the higher-ordered Alternative among the two and thus the ordering shown in Table 20.5 is correct. Accordingly, if MARR is less than 85.1 per cent, Alternative 2 is preferable, and if MARR is above 85.1 per cent, Alternative 1 is preferable.

For example, in Table 20.6, we first note that the two projects should be reordered with Alternative 1 being the higher-ordered one. Accordingly, we conclude that Alternative 1 is preferable if MARR is less than 20 per cent and that Alternative 2 is preferable if MARR is greater than 20 per cent.

For example, in Table 20.7 we again see that the two Alternatives should be reordered with Alternative 1 being the higher-ordered one. In turn, we conclude that Alternative 1 is preferable if MARR is less than 21.92 per cent or if MARR exceeds 228.08 per cent; Alternative 2 is preferable if MARR is between 21.92 and 228.08 per cent.

20.4.4 *Determining the Best Acceptable Alternative*

In the interest of brevity, no comprehensive treatment of this obviously important aspect of economic analysis is included here. Suffice it to say, however, that to jointly consider the aspects of acceptability and preference one simply follows the following procedure: (1) order all mutually exclusive alternatives, using the procedure described in Section 20.4.; (2) determine the lowest-ordered acceptable alternative, using the rules described in Section 20.4.; and (3) determine the highest-ordered alternative, using the rules described in Section 20.4., that is found to be preferable to all lower-ordered acceptable alternatives.

20.5 GENERALIZED HEURISTICS

Educated guesses of likely traffic growth are important to the site-selection process of a road during the prefeasibility stage. Limitations of time, funds, and manpower rule out an economic analysis to forecast traffic growth. On the other hand, a first approximation of traffic growth is essential during the prefeasibility site-selection process to eliminate certain alternatives. The heuristics presented below are oriented to enable the development of broad, but sound, judgements regarding traffic growth. The conclusions from the application of the heuristics are useful in formulating the demand function for the LREP Method during the feasibility stage of a project.

(a) Traffic growth is influenced by two categories of economic activity: potential growth areas and the existing patterns. Furthermore, the influence of growth areas on existing patterns can result in negative impacts that reduce the traffic demand from existing activities. All three systems are important for estimating the traffic growth.

(b) Growth areas include the following:

- tourism,
- mining of new materials (minerals and forests),
- future exports (agriculture, horticulture, and cottage industry), and
- development projects (imports and exports).

(c) Regarding the existing pattern, food deficits or surpluses will be important to travel demand, other existing imports (such as utensils) and exports (hides for example) will play a role in travel demand as well.

(d) Negative impacts on the existing activities may result as a consequence of the road and/or growth of new activities. Impacts such as loss of cottage industry products, as well as the corresponding loss of employment, may occur due to cheaper and higher quality imports. Such imports give rise to traffic growth. Similarly, the displacement of porters due to the road facility will cause a readjustment of that labour force that may reduce or increase the traffic growth depending upon the possibilities for readjustments.

(e) Experiences of traffic growth in other regions with similar characteristics are the substance that make educated guesses possible. Some typical experiences are given below for illustrative purposes. Impact studies on similar projects should be consulted in estimating traffic growth during the prefeasibility stage. Chapter 22.1 presents examples of some generalized heuristics' methods.

Founding of ICIMOD

The fundamental motivation for the founding of the first International Centre in the field of mountain area development was widespread recognition of the alarming environmental degradation of mountain habitats, and consequent increasing impoverishment of mountain communities. A coordinated and systematic effort on an international scale was deemed essential to design and implement more effective development responses to promote the sustained well-being of mountain communities.

The establishment of the Centre is based upon an agreement between His Majesty's Government of Nepal and the United Nations Educational, Scientific, and Cultural Organisation (UNESCO) signed in 1981. The Centre was inaugurated by the Prime Minister of Nepal in December, 1983, and began its professional activities in September, 1984.

The Centre, located in Kathmandu, the capital of the Kingdom of Nepal, enjoys the status of an autonomous international organisation.

Director : Dr. E. F. Tacke
Deputy Director : Dr. R. P. Yadav

Participating Countries of the Hindu Kush-Himalayan Region

- Afghanistan
- Bangladesh
- Bhutan
- Myanmar
- China
- India
- Nepal
- Pakistan

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