Contents

Volume 4 - Analytical Framework & Model Descriptions: Part A

Part A Road Map

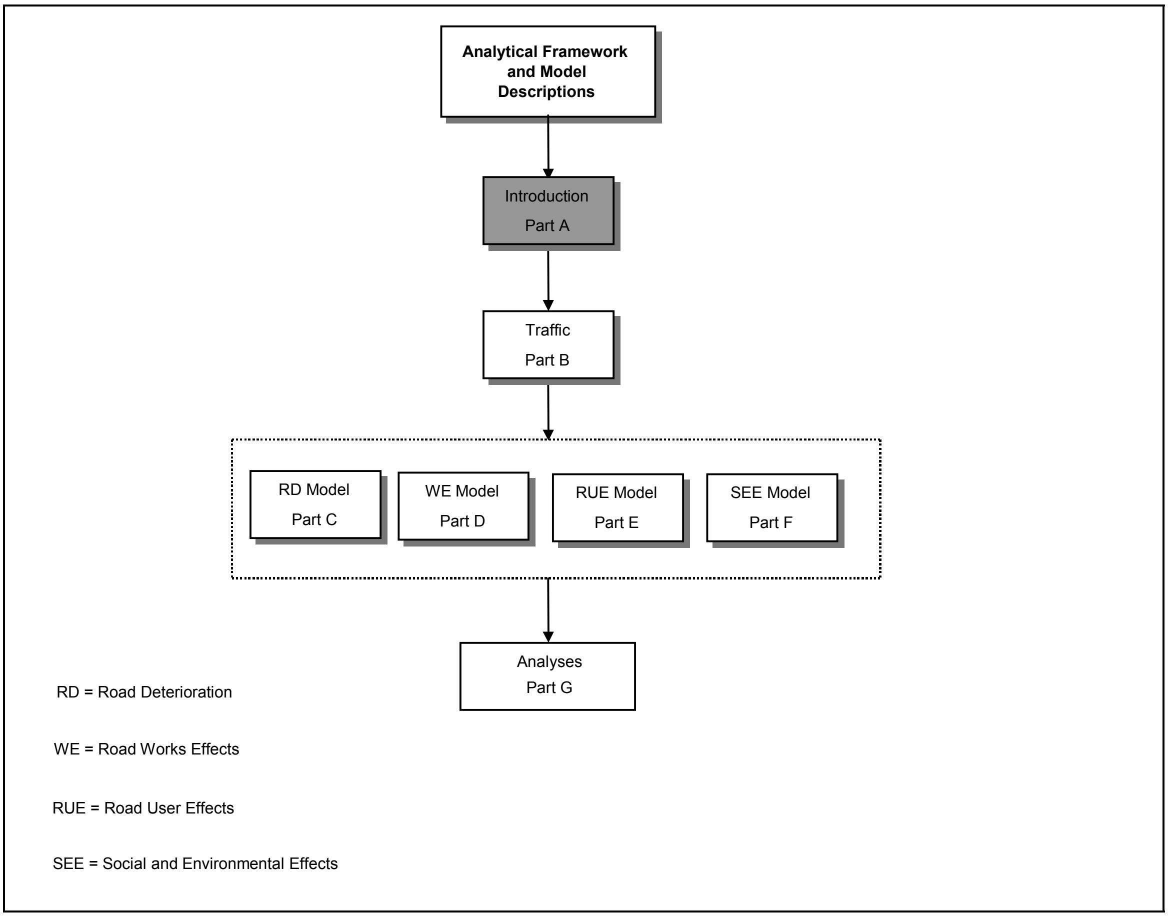

Figure A Analytical Framework and Model Descriptions Road Map

A1 Introduction

1 Structure of this manual

This manual describes the analytical framework and the technical relationships used within the HDM-4 model. Before reading this overview it is suggested that you should refer to the more general Overview of HDM-4 - Volume 1 which outlines the features and functions of the HDM-4 model.

Figure A1.1 shows a schematic view of the HDM-4 documentation suite. The Overview is shown as Volume 1 because that needs to be the first document to be read by new users as it contains introductory material. Volumes 2 and 3 are considered to be guides for users of the software, where tasks are documented and an understanding of the product can soon be learnt. Volumes 4 and 5 contain more detailed reference material that is intended for more advanced users who wish to acquire detailed knowledge of the HDM-4 system.

This manual is split into seven descriptive parts and two appendices. The appendices are numbered as parts H and I for consistency. Within each part are a number of chapters which each describe a major topic. Each chapter is then split into sections each describing part of the topic. The following gives a brief overview of each part:

- **Part A - Introduction**

  Provides an overview of the manual, and a summary discussion of road investment appraisal and prioritisation.

- **Part B - Traffic**

  Describes the traffic characteristics used in HDM-4, and provides details of the traffic data that are required.

- **Part C - Road Deterioration Models**

  - C1 Modelling Concepts and Approach

    Describes the pavement types and classification for the following pavements:

    - Bituminous
    - Concrete
    - Unsealed

    It includes the modelling approach and a discussion on the key variables that affect deterioration, which include climate and environment effects, traffic, pavement history.

  - C2 Bituminous Pavements

    Describes the specifications for modelling the performance of bituminous pavements. Details of the modelling logic, distress modes, pavement strength, construction quality, and the relationships are discussed.

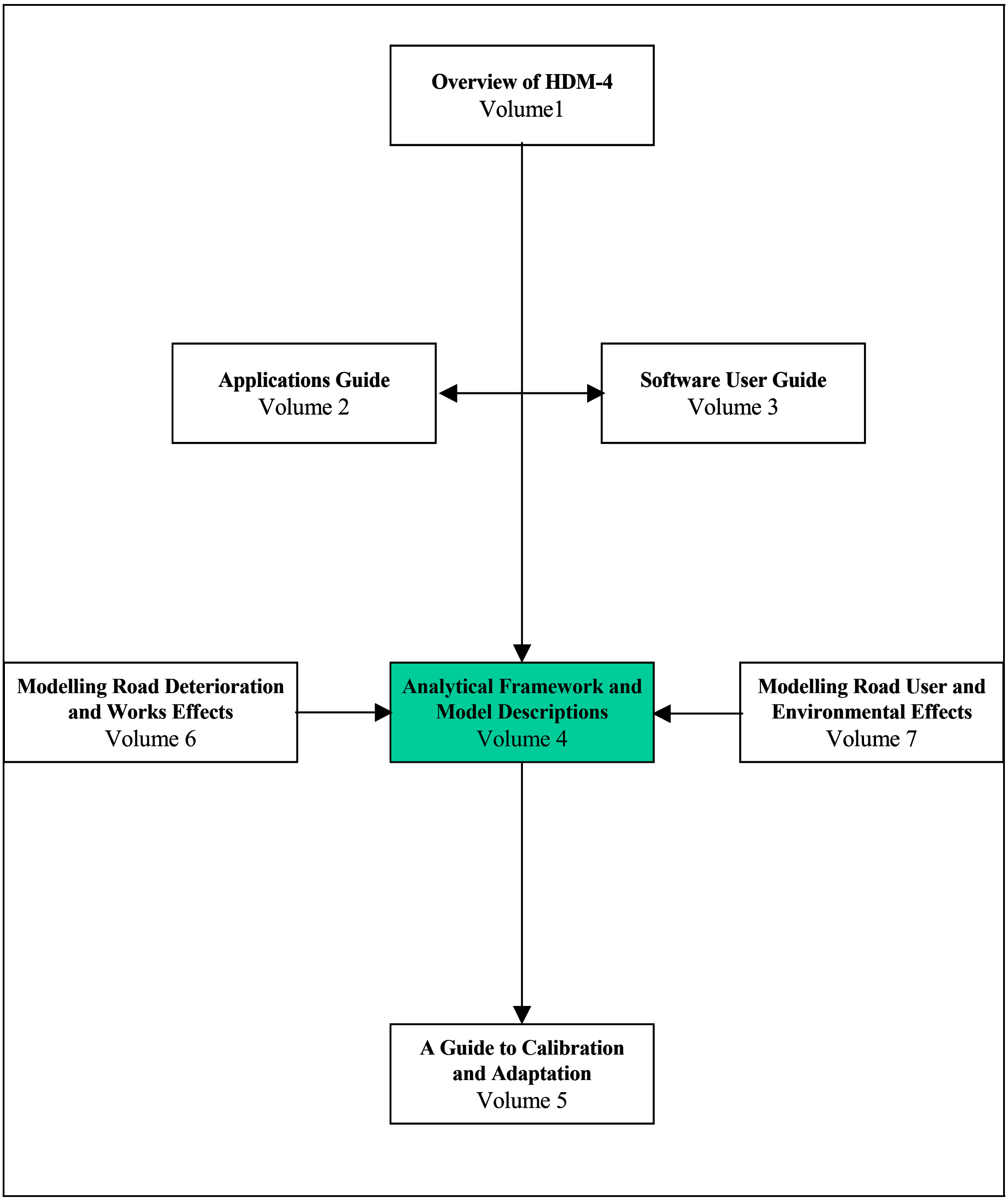

Figure A1.1 HDM-4 Documentation suite

- C3 Concrete Pavements

  Describes the implementation of Road Deterioration models for concrete pavements. It provides an overview of the modelling framework, a brief analysis of the concrete pavement types and distresses considered, and a description of the models.

- C4 Unsealed Roads

  Describes the specifications for modelling unsealed Road Deterioration. It provides an overview of the modelling logic and the relationships for each of the distresses modelled.

- **Part D - Road Works Effects**

  - D1 Types of Works

    Describes the classification of road works and the generic framework for modelling works quantities, costs and effects for the three road surface classes bituminous, concrete and unsealed.

  - D2 Bituminous Pavements

    Describes the detailed modelling of Road Works Effects for bituminous pavements. The methods of defining works activities and intervention criteria, the calculation of physical quantities of works and the costs to road administration, and works effects on road characteristics and road use are discussed for different road works classes.

  - D3 Concrete Pavements

    Describes the detailed modelling of Road Works Effects for concrete pavements.

    The methods of defining works activities and intervention criteria, the calculation of physical quantities of works and the costs to road administration, and works effects on road characteristics and road use are discussed for different works classes.

  - D4 Unsealed Roads

    Describes the detailed modelling of Road Works Effects for unsealed roads.

    The methods of defining works activities and intervention criteria, the calculation of physical quantities of works and the costs to road administration, and works effects on road characteristics and road use are discussed for different works classes.

- **Part E - Road User Effects**

  - E1 Introduction

    Describes the Road User Effects (RUE) components modelled in HDM-4. It provides an overview of the HDM-4 representative vehicle framework, which considers both motorised vehicles and non-motorised transport.

  - E2 Vehicle Speeds and Operating Costs

    Describes the Road User Effects models for calculating motorised vehicle speeds, operating costs and travel time.

  - E3 Non-Motorised Transport

    Discusses the use of non-motorised modes of transport and its effects on motorised transport. Since non-motorised modes of transport account for the vast majority of the movement of people and goods in many developing countries it was essential to include this model in HDM-4.

  - E4 Road Safety

    Describes the specification for implementing road safety analysis. The model allows users to define a series of **look-up tables** of accident rates.

- **Part F - Social and Environmental Effects**
  - F1 Introduction

    Introduces the modelling of **energy balance** and **vehicle emissions**.

  - F2 Energy Balance Analysis

    The energy used in the road transport sector forms a significant share of the total energy consumption in most countries. It is therefore important for planners and decision-makers to be able to understand the energy implications of alternative transport projects, strategies and policies.

  - F3 Vehicle Emissions

    Describes the implementation of Vehicle Emissions analysis. The document presents the emissions model together with default parameters for the 16 HDM-4 standard vehicle types.

- **Part G - Analyses**
  - G1 Economic Analysis

  Describes how HDM-4 is used to determine the benefits and costs associated with a road investment, and how these are used in economic analysis and optimisation procedures.

  - G2 Sensitivity Analysis

  This provides an outline on how the user can investigate the impact of variations in key parameters on the analysis results.

  - G3 Budget Scenario Analysis

  Each budget scenario defines the road agency financial resources available over the analysis period. The document outlines how the user can compare the effects of different funding levels on the network being analysed.

  - G4 Asset Valuation

  A road network is a considerable resource that has a significant asset value. It is therefore important to manage this asset effectively and to be able to estimate the financial and economic value of road assets as a function of the level of investment. The document describes the methodology for road asset valuation.

  - G5 Multiple Criteria Analysis (MCA)

  Describes how multi-criteria analysis can be used to compare projects using criteria that cannot easily be assigned an economic cost. The methodology provided is based on the Analytical Hierarchy Process (AHP).

2 Economic appraisal of road projects

2.1 Purpose

The purpose of road investment appraisal is to select projects with high economic returns. The decision of whether to invest in roads or in some other infrastructure development is not the primary objective of road investment appraisal since in most cases such a decision will already have been made. The purpose of an economic appraisal of road projects therefore is to determine how much to invest and what economic returns to expect. The size of the investment is determined by the costs of construction and annual road maintenance. The economic returns are mainly in the form of savings in road user costs due to the provision of a better road facility. These three costs constitute what is commonly referred to as the total (road) transport cost or the whole life cycle cost.

Four primary objectives of road investment appraisal can therefore be identified as follows:

- To determine the appropriate size of investment and the returns expected from this investment,
- To determine the appropriate geometric and structural design standards for the size of investment in order to obtain the expected returns,
- To determine the relative priorities for investment among competing road projects when there is a budget constraint, and
- To assess the economic and socio-economic impact of investments in roads such as the improvement to the community of industrial, agricultural, educational, and health services.

The assessment of the socio-economic benefits of road investments however is difficult to quantify in monetary terms. This is usually done separately after an economic appraisal has been carried out using a road investment appraisal model.

The primary function of a road investment appraisal model is therefore to calculate the costs of road construction, road maintenance and road user costs for a specified analysis period. This is accomplished by modelling the interrelationships between the environment, construction standards, maintenance standards, geometric standards and road user costs.

A road investment appraisal model may be used to assist with the selection of appropriate road design and maintenance standards which minimise the total transport cost. The effect of providing better road standards on the components of the total transport cost is illustrated in Figure A1.2. If a low standard road is constructed, high maintenance and road user costs can be expected resulting in a high total transport cost despite the low cost of construction. Conversely, if a high standard road is constructed, the very high cost of construction will outweigh the low maintenance and road user costs. A road investment appraisal model can therefore be used to search for the road design or maintenance standard for which the total transport cost is a minimum. This alternative is represented by the dotted vertical line in Figure A1.2. The interaction between the transport cost components however is more intricate than is suggested in Figure A1.2. For example a high construction cost will not necessarily lead to lower road user costs, for example, the construction of a very wide but structurally weak road.

When planning investments in the roads sector, it is necessary to evaluate all costs associated with the proposed project. These include construction costs, maintenance and rehabilitation costs, road user costs, and all other external or exogenous costs or benefits that can be directly attributed to the road project. It is normal to consider such costs or benefits over an extended analysis period usually equal to a longer than the expected life of the road, hence the term 'life-cycle' cost analysis. The costs of construction, routine and periodic maintenance are usually borne by the agency or authority in charge of the road network. However, road user

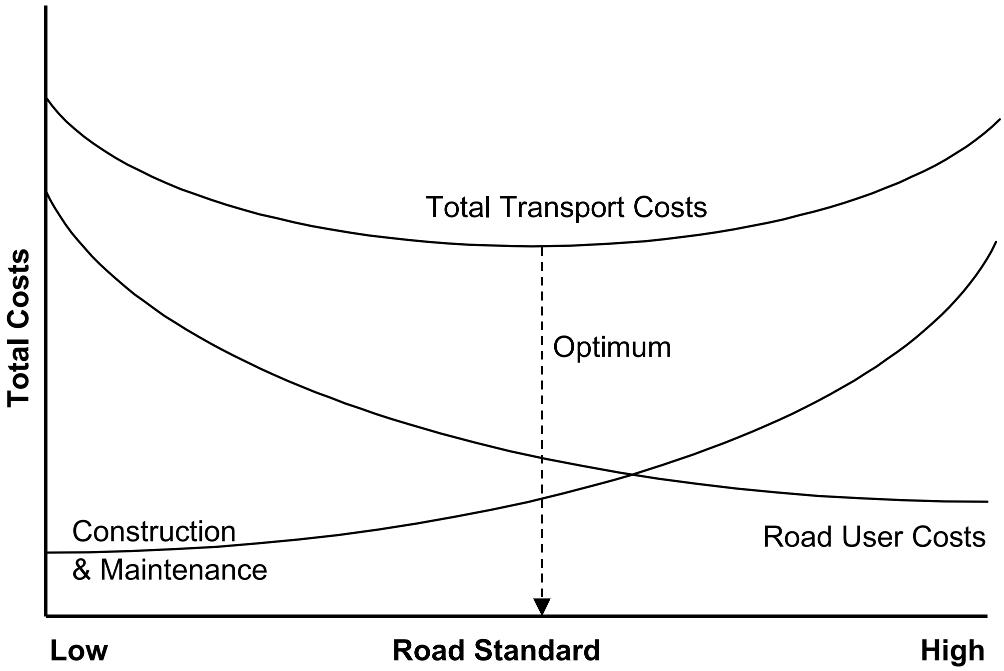

Figure A1.2 HDM-4 Documentation suite

costs are borne by the community at large in the form of vehicle operating costs (VOC), travel time costs, accident costs and other indirect costs.

A road investment model simulates the interaction between pavement construction standards, maintenance standards and the effects of the environment and traffic loading in order to predict the annual trend in road condition. This, together with the geometric standards of the road, has a direct effect on vehicle speeds and on the costs of vehicle operation and accident rates on the road.

2.2 Transport cost components

The economic evaluation carried out in the road investment models is based on the generated annual cost streams for road construction, road maintenance and road user costs. The cost streams will usually begin in a specified base year which may either be the first year of construction, the first year of trafficking or simply the current calendar year. The number of years for which costs are calculated depend on the specified analysis period usually chosen to equal the design life of new roads.

2.2.1 Cost of road construction

The cost of new road construction is calculated from the sum of the costs of site preparation, earthworks, pavement construction, bridge and drainage structures, and overheads. Site preparation includes clearing vegetation from the right-of-way, and the stripping and disposal of topsoil. The cost of earthworks however is greatly influenced by the land terrain and the geometric standard specified for the road. This includes the costs of excavations, material haulage and compaction. The cost of pavement construction is a function of the number, thickness and type of pavement layers, and includes the costs of shoulders and kerbs.

A sizeable percentage of road construction costs can be attributed to the costs of bridges and the provision of adequate drainage facilities. Road construction will usually involve the setting up of temporary site camps and the transportation of equipment, materials and manpower to the construction site. The costs of these activities together with the profit margin for the contractor and consultants fees are usually grouped into an overhead cost which may be specified as a fixed cost per kilometre or as a percentage of the total cost of construction. At the end of the analysis period, a **salvage value** may be specified, representing the percentage of total costs incurred on permanent structures such as embankments, cuttings, bridges and drainage facilities.

In HDM-4, the costs of construction or any other major road improvements, are user specified.

2.2.2 Road deterioration

Pavement deterioration is modelled in terms of a number of defects including; road roughness, pavement cracking, rutting, ravelling, potholes, gravel loss on unsealed roads, and joint faulting and spalling on concrete pavements. The rate of deterioration is as a function of the initial pavement design standard, traffic loading, maintenance standards, and the effects of the environment. The amount of maintenance carried out in a given year depends on user specified maintenance standards and the predicted road condition.

Pavement performance is largely modelled as a function of several factors (see Part C). Two of the most important factors are:

- Pavement strength
- Road roughness

Pavement strength is represented by the Structural Number (SNP), an index which represents pavement strength such that all pavements with the same SNP are assumed to have similar performance. The concept of pavement structural numbers is described in more detail in Part C. The structural number of a pavement is defined by an empirical relationship in which the thickness and strength of each pavement layer are combined using the sum of their product. The pavement layer strength mainly depends on the type and quality of the constituent materials. The structural number of a pavement includes the contribution to pavement strength made by the **subgrade**. In general, pavements with high structural numbers will have a low rate of deterioration under the same regime of traffic and environmental loading.

Road roughness is the second important parameter used in modelling pavement performance. It is the most significant pavement condition which is used in the calculation of road user costs, particularly VOC. It represents the unevenness of a road surface and is taken to be the primary cause of wear and tear in vehicles. Roughness is commonly measured using one of three systems:

- The towed fifth wheel bump integrator (BI) in mm/km,
- The Portland Cement Association (PCA) road meter which simulates the vertical motion of a standard Quarter-car Index (QI) measured in counts per km,
- Cumulative vertical profile movements, represented in terms of the International Roughness Index (IRI) measured in m/km.

The following relationships, developed by the World Bank, are used to convert roughness values between the three units:

$$BI = 55 \times QI \qquad \ldots(2.1)$$

$$BI = 630 \times IRI^{1.12} \qquad \ldots(2.2)$$

$$BI = 900\,IRI - 1000 \quad \text{(linear estimate)} \qquad \ldots(2.3)$$

A new road has to be assigned a structural number and an initial roughness. The high dependence of road user costs on roughness, and of roughness progression on the pavement structural number, suggests that the results of an economic analysis will be affected by the values assigned to these two variables at the beginning of the analysis.

2.2.3 Cost of road works

The annual cost of road works is calculated from the amounts of reactive routine maintenance, periodic maintenance, and any road improvements applied in a given year. These depend on the predicted pavement condition and the specified maintenance or improvement standard which may include a combination of one or more of different types of road works (see Part D).

Cyclic routine maintenance works which includes activities that are required regardless of the condition of the road or the traffic level, for example, grass cutting, road sign painting, drainage clearance, etc., may be specified as fixed annual costs per kilometre. Emergency maintenance works such as repairs to flood damage, debris clearance, etc., may also be specified as an overhead cost since such have to be carried out regardless of pavement condition.

2.2.4 Road user costs

Road user costs may be defined as the costs incurred by vehicle operators and by the travelling public at large. The four types of road user costs usually considered are associated with vehicle operation, travel time, accidents and discomfort (see Part E). The last two costs are difficult to quantify in monetary terms, although accident costs can be estimated in several ways in terms of both the resource content (for example, cost of spares and vehicle replacement), and the injuries and fatalities. However, the lack of acceptable methods of estimating accident and discomfort costs in developing countries is the main reason why these two components of road user costs are not included in existing road investment appraisal models for developing countries.

Vehicle operating costs

These are calculated from the sum of the vehicle resource components, including:

- Fuel and lubricating oil consumption,
- Tyres and spare parts,
- Vehicle maintenance labour costs,
- Vehicle crew wages,
- Vehicle depreciation and interest on capital.

Separate sets of equations are used for the different vehicle types specified by the user. For each vehicle type, the models predict average travel speeds as a function of road geometry and road condition. The above VOC components, with the exception of vehicle depreciation and interest, depend largely on road roughness and the geometric characteristics of the road. The consumption of the above VOC components are predicted in resource terms. For example, equations for fuel consumption calculate the quantity of fuel consumed over the travel distance. Unit costs for the various resources are specified by the user in order to calculate the annual total costs of vehicle operation. Vehicle depreciation is considered to be a function of the predicted travel time and of the level of vehicle utilisation.

Travel time costs

Travel time costs are calculated from average vehicle speeds, travel distances and the unit costs per hour of road users' time. The average vehicle speeds are a function of road roughness, road width, and the vertical and horizontal alignment of the road. The values to be specified for unit time costs for road users in developing countries are not easily justifiable. Many authors on this subject recommend that projects in developing countries should be appraised without benefits from time savings. The road user benefits derived from savings in travel time costs can in this case be considered to be a "consumer surplus" in addition to the savings in VOC.

2.2.5 Other exogenous costs and benefits

Other costs or benefits that can be directly associated with a road project may be included in the economic analyses. These usually include independently assessed benefits accruing from socio-economic developments such as increased agricultural productivity, industrial output, accessibility benefits, etc. Exogenous costs could include the costs of providing diversion routes, noise barriers, and other impediments during construction. Such costs or benefits are not calculated by road investment models and therefore their inclusion in any economic analyses must be clearly justified as they can easily affect the ranking of alternative projects.

3 Economic appraisal method

3.1 Project alternatives

Roads are normally constructed to reduce costs and therefore to increase benefits derived from reduced user costs and from improvements to socio-economic services. The economic appraisal of road projects is therefore essentially a comparison of transport cost components calculated for at least two alternatives for road construction, usually referred to as the **Do Minimum** or **Without Project** alternative and one or more **Do Something** or **With Project** alternatives.

3.1.1 Without project alternative

The **Do Minimum** or **Without Project** alternative in most cases represents the current situation from which a reduction in transport costs is sought. It is usually the alternative which involves minimum input of capital, for example, a continuation with the current road standard. The annual cost matrix for a **Do Minimum** alternative will usually have little or no construction cost component but with generally high maintenance and road user costs.

3.1.2 With project alternatives

The selection of project alternatives to be analysed depends on several factors, in particular, national road standards, previous road projects, traffic levels, availability of materials as well as political and socio-economic considerations. A project alternative will usually involve the provision of a higher standard road. This could be achieved by either new construction, reconstruction, upgrading, or improvements to pavement or geometric standards, all of which can be analysed as independent project alternatives. The cost matrices from these project alternatives will have varying levels of capital and recurrent costs but with generally lower road user costs.

3.2 Discounting

It is necessary to discount the transport costs in each year of an analysis period to their value in the base year. This is carried out to reflect the time value of money represented by the opportunity cost of the capital invested in a road project. Discounting is performed by multiplying the cost in a given year by the discount factor for that year. Discount factors are derived from the equation below:

$$D.F. = \left(1 + \frac{r}{100}\right)^{-N} \qquad \ldots(3.1)$$

where:

r discount rate in percent (%)

N number of years from the base year

Table A1.1 illustrates the principle of discounted cash flow analysis (DCF) applied to a gravel road which will be paved after one year. The paved road has a design life of 10 years after construction. The economic comparisons are based on the totals of the discounted costs. This is referred to as the Present Value (PV) of costs. For example, in Table A1.1, the PV of the **Without Project** alternative is $ 23.8 million, and the PV of the **With Project** alternative is

$20.2 million, both at 12% discount rate. If the example given in Table A1.1 represents a real road project, the alternative chosen for implementation would depend on the economic criteria used to compare the alternatives. The most commonly used criteria for selecting projects are the net present value (NPV), the internal rate of return (IRR) and the Benefit Cost Ratio (BCR).

3.2.1 Net Present Value

The NPV is defined as the difference between the discounted benefits and costs of a project. In the economic appraisal of road projects, benefits are derived mainly from savings in road user costs and also in road maintenance costs (where possible). Thus the benefits of paving a gravel road would be obtained by subtracting the total transport cost for the sealed road from that of the gravel road. The calculation of NPV is therefore simplified by taking the difference between the present value of costs for the two alternatives being compared. Thus from Table A1.1, the NPV of the **With Project** alternative when compared against the **Without Project** alternative would be $3.6 million at a 12% discount rate.

3.2.2 Internal Rate of Return

The NPV depends on the discount rate used in the calculation of present values. When high discount rates are used, a lower NPV is obtained resulting in negative values. The IRR of a project is defined as the discount rate at which the present value of costs equals the present value of benefits, that is, when NPV is zero. In the example given in Table A1.1, the IRR would be the discount rate for which the two present value of costs are equal; in this case approximately 15.2%. Projects with high IRR values are generally preferred as this will give positive NPV at high discount rates. In general, the calculated IRR should be greater than the **test discount rate** used to assess projects funded by government.

3.2.3 Cost Ratios

The Benefit Cost Ratio (BCR) provides a simple measure of the profitability of a project (that is, amount of benefits derived for every dollar invested). It represents the dimensionless index obtained by dividing the calculated benefits of the project by the discounted capital costs of the investment. This can be estimated from the NPV as follows: (see Part G for details):

$$BCR = \frac{NPV}{C} + 1 \qquad \ldots(3.2)$$

From the example given in Table A1.1, the estimated BCR would be 1.55.

Another ratio used is the *NPV/cost* ratio which represents the magnitude of the return expected per unit of investment. This is a measure of the efficiency of an investment and is used to rank an investment when comparing projects and performing budget optimisations.

Table A1.1 Comparison of With and Without Project Alternatives

		Without Project Alternative Costs ($ m)				With Project Alternative Costs ($ m)				
Year	12% Discount Factors	Annual Maintenance	Vehicle Operation	Total Transport	Discounted Total	Road Construction	Annual Maintenance	Vehicle Operation	Total Transport	Discounted Total
0 (Base)	1.0000	0.8	1.5	2.3	2.3		0.8	1.5	2.3	2.3
1	0.8929	0.9	1.6	2.5	2.2	5.8	0.4	1.0	7.2	6.4
2	0.7972	1.0	1.8	2.8	2.2		0.5	1.1	1.6	1.3
3	0.7118	1.1	2.1	3.2	2.3		0.6	1.3	1.9	1.4
4	0.6355	1.2	2.3	3.5	2.2		0.7	1.4	2.1	1.3
5	0.5674	1.3	2.7	4.0	2.3		0.7	1.6	2.3	1.3
6	0.5066	1.4	2.9	4.3	2.2		0.8	1.8	2.6	1.3
7	0.4523	1.5	3.2	4.7	2.1		0.9	2.0	2.9	1.3
8	0.4039	1.6	3.5	5.1	2.1		0.9	2.2	3.1	1.3
9	0.3606	1.7	3.8	5.5	2.0		1.0	2.3	3.3	1.2
10	0.3220	1.8	4.0	5.8	1.9		1.0	2.5	3.5	1.1
TOTALS			29.4	PV =	23.8			18.7	PV =	20.2

4 Applications of economic appraisal

4.1 Financial and economic costs

The financial cost of a project is the sum of the market price of materials, labour, equipment, and overheads incurred in the construction of a project. The economic appraisal of road projects should be carried out using economic costs which represents the true cost of a project to the economy of a country. For example, the market price of fuel in most countries includes a percentage of government tax. The economic price of fuel would therefore be estimated from the market price less the tax. In most cases the economic cost of fuel will be less than the financial cost. This relationship is reflected in VOC since most of the components are taxed by governments, for example, vehicle tax. It is also possible for economic costs to exceed financial costs if a government subsidises instead of taxing various cost components.

4.2 Project types

Investment appraisal models can be used to perform a number of economic analyses. One important type on analysis is the choice of pavement surfacing during the design of a pavement. A simple example is the choice between a surface dressing or an asphalt concrete surfacing for a pavement to be constructed in a developing country. In this case the surface dressing is likely to have a high initial roughness with higher roughness progression rates resulting in a high VOC component but with a lower cost of construction. The choice between the two types of surfacing will therefore be governed by the total VOC calculated for the two alternatives.

In the geometric design of new roads, the investment models can only be used to reject designs that would be extravagant, for example, the provision of a dual carriageway when a single carriageway would suffice. It should be noted that the geometric design of roads should be done to satisfy capacity requirements and to provide safety to road users.

Although investment appraisal models do not carry out mathematical optimisation of, for example, maintenance options or the timing of construction or maintenance, they can be used to conduct a sensitivity analysis to study the effects of changes in construction cost, maintenance cost, VOC, traffic growth, discount rates, and time values.

4.3 Sensitivity and risk analysis

All road projects involve some degree of **uncertainty** in the outcome of the project. The decision to proceed with a project therefore includes some element of **risk** taken by road authorities. Many road projects will have a significant element of risk attached to them. These will in general be due to several factors amongst which the following are the main causes:

- Unforeseen events beyond the control of the engineer; for example, improved technology, political changes.
- National economic changes; for example, future economic growth, traffic growth rates.
- Unpredictability of pavement performance due to environment, traffic, construction.
- Impact on socio-economic factors that can not be evaluated.

It is necessary to assess the impact of uncertainty on the viability of road projects for the following reasons:

- Road investments often take up a large proportion of national income, therefore any failure will be expensive,
- Alterations during implementation can be very expensive and prohibitive and should therefore be avoided by selecting the most suitable alternative at the outset,
- To determine impact of possible changes (for example, to the environment, socio-economic) on the overall viability of road projects and plan for these accordingly.

The formal method of economic appraisal is only one step in the process of quantifying risk. Some of the causes of uncertainty can be assessed by additional analyses such as:

- **Sensitivity analysis**
  - This is applied to study the effects of changes in one parameter (for example, construction cost, or traffic growth rate) on the overall viability of a road project.
- **Scenario analysis**
  - This is carried out to determine the broad range of parameters that together would affect the viability of the road project. For example, a review of government long-term policies could yield alternative economic growth rates which would affect both traffic growth rates and the cost of road construction.
- **Risk analysis**
  - Most commonly done by assigning probabilities of occurrence to project parameters and then study combined effects of changes in the parameters. This can be done by reviewing past trends in project parameters (for example, traffic growth rates, final construction costs, etc.) on other projects to arrive at a suitable probability distribution.

Sensitivity analysis is the simplest form of risk analysis. Essentially, it involves repeated economic evaluation with systematic changes made to one parameter each time. The procedure can be summarised as follows:

- Identify parameters which affect the viability of a road project, for example, discount rate used, cost of construction, traffic growth rate, road maintenance standards, etc.
- Systematically change values of these parameters and repeat the economic appraisal. Generally, changes to the parameters should be made relative to a **base** value, for example, +/- 25%, 50%, 100%.
- Study effect of changes and report on parameters to which the project is most sensitive.

4.4 Prioritisation

There are often situations when the budget available for road projects will not be sufficient to undertake all projects shown to have a positive return (that is, projects with positive NPV). In such situations, a formal method of selecting projects to be included within the budget can be applied. Capital budgeting or rationing can be applied to a group of projects that meet either of the following conditions:

- Projects that are independent of each other (for example, list of road projects from different parts of the country),
- Mutually exclusive projects (that is, projects that are alternatives to each other) when only one alternative can be selected.

The NPV capital budgeting rules can be applied in both situations where sufficient funds are available, and also when there is a budget constraint. The rules are summarised below:

- When sufficient funds are available to undertake all projects;
  - Select all independent projects with NPV > 0.
  - Select mutually exclusive project alternatives with the highest NPV.
- When capital rationing is to be applied due to shortage of funds;
  - Select independent projects with the highest NPV/Cost ratio.
  - Select mutually exclusive projects using the incremental NPV/Cost method described below.

The incremental analysis is used to test whether the ratio of the increase in NPV to the increase in financial capital cost of the mutually exclusive project alternatives is greater than a specified marginal ratio. The formula is defined as:

$$E_{ji} = \left[\frac{(NPV_j - NPV_i)}{(cost_j - cost_i)} \right] \quad ...(4.1)$$

where:

E_{ji}	the incremental NPV/cost ratio
NPV_j	the net present value of the more expensive project alternative *j*
NPV_i	the net present value of the cheaper alternative *i*
$cost_j$	the **financial capital** cost of the selected project alternatives; *j, i*