Overview of HDM-4

Henry G. R. Kerali
About This Manual

This Version 1.0 edition of *Overview of HDM-4* provides a short executive summary describing the HDM-4 system. Where necessary it highlights the differences between the HDM-III and the HDM-4 models.

It is intended to be used by all readers new to HDM-4, particularly high-level management within a road organisation.

The *Overview of HDM-4* is one of five manuals comprising the suite of HDM-4 documentation (see Figure 1).

![Figure 1 HDM-4 documentation suite](image)

The suite of documents comprise:

- **Overview of HDM-4 (Volume 1)**  
  A short executive summary describing the HDM-4 system. It is intended to be used by all readers new to HDM-4, particularly high level management within a road organisation.

- **Applications Guide (Volume 2)**  
  A task oriented guide describing typical examples of different types of analyses. It is to be used by the frequent user who wishes to know how to perform a task or create a study.
Software User Guide (Volume 3)

Describes the HDM-4 software. It is a general purpose document which provides an understanding of the software user interface.

Analytical Framework and Model Descriptions (Volume 4)

Describes the analytical framework and the technical relationships of objects within the HDM-4 model. It contains very comprehensive reference material describing, in detail, the characteristics of the modelling and strategy incorporated in HDM-4. It is to be used by specialists or experts whose task is to carry out a detailed study for a road management organisation.

A Guide to Calibration and Adaptation (Volume 5)

Suggests methods for calibrating and adapting HDM models (as used in HDM-III and HDM-4), to allow for local conditions existing in different countries. It discusses how to calibrate HDM-4 through its various calibration factors. It is intended to be used by experienced practitioners who wish to understand the detailed framework and models built into the HDM-4 system.

Notes:

1. Volumes 1, 2 and 3 are designed for the general user.
2. Volumes 4 and 5 will be of greatest relevance to experts who wish to obtain low level technical detail. However, Volume 5, in particular, presents very important concepts, which will be of interest to all users.

Structure of ‘Overview of HDM-4’

The information in this Overview of HDM-4 document is structured as follows:

- **Section 1 - Introduction**
  Provides a general description of HDM-4 and its scope.

- **Section 2 - Background**
  Provides a historical perspective to the design of HDM-4.

- **Section 3 - The Role of HDM-4 in Highway Management**
  Describes the application of HDM-4 in terms of the following highway management functions:
  - Planning
  - Programming
  - Preparations
  - Operations

- **Section 4 - Analytical Framework**
  Describes the fundamental analytical framework applied in HDM-4 to model road deterioration, road user effects, works effects, and social and environmental effects, followed by the economic analysis framework.
Section 5 - HDM-4 Applications
Describes the three analysis tools used to cater for different types of highway studies, namely:
- Strategy analysis
- Programme analysis
- Project analysis

Section 6 - HDM-4 Modules
Describes the modular structure and the main functions of the various modules:
- Data managers
- Models

Section 7 - Data Requirements
Describes the data management facilities:
- HDM-4 Configuration
  Used to customise the characteristics of road sections, vehicles, and the environment under which the road system will be analysed.
- Road Network Manager
  Defines the road sections in the network or sub-network to be analysed.
- Vehicle Fleet
  Defines the characteristics of vehicles in the fleet that operate on the road network being analysed.
- Road Works
  Defines maintenance and improvement standards that are applied to different road sections being analysed.
- Importing and Exporting Data
  Indicates how HDM-4 can exchange data with other systems.

Section 8 - User interface
Describes the user interface and compares its improvement to previous models.

Section 9 - Nomenclature
This provides a reference to the Nomenclature and Glossary of terms used in the HDM-4 suite of documents.

Section 10 - References
Gives a list of references to relevant documentation sources.
ISOHDM Products

The products of the International Study of Highway Development and Management Tools (ISOHDM) consist of the HDM-4 suite of software, associated example case study databases, and the Highway Development and Management Series collection of guides and reference manuals. This Volume is a member of that document collection.

Customer contact

Should you have any difficulties with the information provided in this suite of documentation please do not hesitate to report details of the problem you are experiencing. You may send an E-mail or an annotated copy of the manual page by fax to the number provided below.

The ISOHDM Technical Secretariat welcomes any comments or suggestions from users of HDM-4. Comments on the Overview of HDM-4 should be sent to the following address:

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Change details

This is the first formal edition (Version 1.0) of the HDM-4 documentation.

Related documentation

HDM-4 documents

The Highway Development and Management Series Collection is ISBN: 2-84060-058-7, and comprises:

Future documentation

The following documents will be issued at a later release:


Volume 7 - Modelling Road User and Environmental Effects, ISBN: 2-84060-103-6

Terminology handbooks


General reference information

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- **Finnra**
  Specification of the strategic and programme analysis applications.

- **FICEM**
  Development of deterioration and maintenance relationships for Portland cement concrete roads.

- **The Highway Research Group**, School of Civil Engineering, The University of Birmingham
  Responsible for system design and software development.

- **Road Research Institute (IKRAM) in Malaysia supported by N.D.Lea International (NDLI)**
  Responsible for providing updated relationships for road deterioration and road user costs.

- **Transport Research Laboratory (TRL) in the United Kingdom**
  Responsible for review and update of flexible pavement deterioration relationships.

- **SNRA**
  Responsible for developing deterioration relationships for cold climates, road safety, environmental effects, and supporting HRG with system design.

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Overview of HDM-4

Version 1.0
1 Introduction

The Highway Design and Maintenance Standards Model (HDM-III), developed by the World Bank, has been used for over two decades to combine technical and economic appraisals of road projects, to prepare road investment programmes and to analyse road network strategies. The International Study of Highway Development and Management (ISOHDM) has been carried out to extend the scope of the HDM-III model, and to provide a harmonised systems approach to road management, with adaptable and user-friendly software tools. This has produced the Highway Development and Management Tool (HDM-4).

The scope of HDM-4 has been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives. Emphasis was placed on collating and applying existing knowledge, rather than undertaking extensive new empirical studies, although some limited data collection was undertaken. Wherever possible, creative new approaches were developed for applying up-to-date knowledge to the technical problems and management needs of different countries.

Figure 1.1 shows a view of the HDM-4 documentation suite comprising a series of five volumes. This Overview document is Volume 1 of the series. It contains a short executive summary describing the HDM-4 system. All readers new to HDM-4, particularly high level management within a road organisation, should use this document.

Volumes 2 and 3 are considered as guides for users of the HDM-4 software, where user tasks are documented and an understanding of the product can soon be learnt. Volume 2 is a task-oriented guide describing typical examples of different types of analyses. Volume 3 describes the HDM-4 software and is a general-purpose document that provides an understanding of the software user interface.

Volumes 4 and 5 contain more detailed reference material that is not vital to getting started using HDM-4, but is designed to provide detailed guidance to the more advanced users. Volume 4 describes the analytical framework and the technical relationships incorporated in HDM-4. It is to be used by specialists or experts whose task is to carry out a detailed study for a road management organisation. Volume 5 describes methods for adapting and calibrating HDM-4 in different countries. It is intended to be used by experienced practitioners who wish to understand the detailed framework and models incorporated into the HDM-4 system.
Overview of HDM-4
Volume 1

Applications Guide
Volume 2

Software User Guide
Volume 3

Analytical Framework and
Model Descriptions
Volume 4

A Guide to Calibration and Adaptation
Volume 5

Figure 1.1 Documentation suite
2 Background

2.1 Past Developments

The first move towards producing a road project appraisal model was made in 1968 by the World Bank. The first model was produced in response to terms of reference for a highway design study produced by the World Bank in conjunction with the Transport and Road Research Laboratory (TRRL) and the Laboratoire Central des Ponts et Chaussées (LCPC). Thereafter, the World Bank commissioned the Massachusetts Institute of Technology (MIT) to carry out a literature survey and to construct a model based on information available. The resulting Highway Cost Model (HCM) produced by MIT (Moavenzadeh 1971, 1972) was a considerable advance over other models used for examining the interactions between the following:

- Road work costs
- Vehicle operating costs

The HCM model highlighted areas where more research was needed to provide a model that was more appropriate to developing country environments with additional relationships specific to that environment.

Following this, TRRL, in collaboration with the World Bank, undertook a major field study in Kenya to investigate the deterioration of paved and unpaved roads as well as the factors affecting vehicle-operating costs in a developing country. The results of this study were used by TRRL to produce the first prototype version of the Road Transport Investment Model (RTIM) for developing countries (Abaynayaka, 1977). In 1976, the World Bank funded further developments of the HCM at MIT that produced the first version of the Highway Design and Maintenance Standards model (HDM) (Harral, 1979).

Further work was undertaken in a number of countries to extend the geographic scope of the RTIM and HDM models:

- **The Caribbean Study** (by TRRL)
  - Investigated the effects of road geometry on vehicle operating costs (Morosiuk and Abaynayaka, 1982; Hide, 1982)
- **India Study** (by the Central Road Research Institute - CRRI)
  - Studied particular operational problems of Indian roads in terms of narrow pavements and large proportions of non-motorised transport (CRRI, 1982)
- **Brazil Study** (funded by UNDP)
  - Extended the validity of all of the model relationships (GEIPOT, 1982)

The results of the TRRL studies were used to develop the RTIM2 model (Parsley and Robinson, 1982), whilst the World Bank developed a more comprehensive model incorporating the findings from all previous studies and this led to HDM-III (Watanatada et al., 1987). Both models were originally designed to operate on mainframe computers and, as computer technology advanced, the University of Birmingham (Kerali et al., 1985) produced a microcomputer version of RTIM2 for TRRL. Later, the World Bank produced HDM-PC, a microcomputer version of HDM-III (Archondo-Callao and Purohit, 1989).
Further developments of both models continued with the TRRL producing RTIM3 in 1993 to provide a user-friendly version of the software running as a spreadsheet (Cundill and Withnall, 1995), and in 1994, the World Bank produced two further versions of HDM:

- **HDM-Q**
  
  Incorporating the effects of traffic congestion into the HDM-III program (Hoban, 1987).

- **HDM Manager**
  
  Providing a menu-driven front end to HDM-III (Archondo-Callao, 1994).

### 2.2 Objectives of the HDM-4 Development

The various versions of the models have been widely used in a number of countries, and have been instrumental in justifying increased road maintenance and rehabilitation budgets in many countries. The models have been used to investigate the economic viability of road projects in over 100 countries and to optimise economic benefits to road users under different levels of expenditures. As such, they provide advanced road investment analysis tools with broad-based applicability in diverse climates and conditions. However, it was recognised that there was a need for a fundamental redevelopment of the various models to incorporate a wider range of pavements and conditions of use, and to reflect modern computing practice and expectations.

The technical relationships contained in the RTIM3 and HDM-III models were in excess of 10 years old by 1995. Although much of the road deterioration models were still relevant, there was a need to incorporate the results of the extensive research that has been undertaken around the world in the intervening period. In the case of vehicle operating costs, it was recognised that vehicle technology has improved dramatically since 1980 with the result that typical vehicle operating costs could be significantly less than those predicted by RTIM3 and HDM-III models. It was therefore necessary to update the technical relationships to reflect the state-of-the-art. Whilst most applications of the various models have been utilised in developing countries, in recent years many industrialised countries have begun to make use of the model. This has resulted in the need for additional capabilities to be included, such as models for:

- **Traffic congestion effects**
- **Cold climate effects**
- **A wider range of pavement types and structures**
- **Road safety**
- **Environmental effects** (energy consumption, traffic noise and vehicle emissions)

It is against this background that the development of HDM-4 was undertaken.
3 The Role of HDM-4 in Highway Management

3.1 Highway management

When considering the applications of HDM-4, it is necessary to look at the highway management process in terms of the following functions:

- Planning
- Programming
- Preparation
- Operations

Each of these functions is carried out as a sequence of activities known as the management cycle (Robinson et al., 1998) described in Section 3.2.

Planning

Planning involves the analysis of the road system as a whole, typically requiring the preparation of medium to long term, or strategic, estimates of expenditure for road development and preservation under various budget and economic scenarios. Predictions may be made of road network conditions under a variety of funding levels in terms of key indicators together with forecasts of required expenditure under defined budget heads. The physical highway system is usually characterised at the planning stage by:

- Characteristics of the road network
  Grouped in various categories and defined by parameters such as:
  - road class or hierarchy
  - traffic flow/loading/congestion
  - pavement types
  - pavement condition

- Length of road in each category

- Characteristics of the vehicle fleet which use the road network

The results of the planning exercise are of most interest to senior policy makers in the roads sector, both political and professional. A planning unit will often undertake this work.

Programming

Programming involves the preparation, under budget constraints, of multi-year road work and expenditure programmes in which sections of the network likely to require maintenance, improvement or new construction, are selected and analysed. It is a tactical planning exercise. Ideally, cost-benefit analysis should be undertaken to determine the economic feasibility of each set of works. The physical road network is considered at the programming stage on a link-by-link basis, with each link characterised by homogeneous pavement sections defined in terms of physical attributes. The programming activity produces estimates of expenditure in each year, under defined budget heads, for different types of roadwork and for each road section. Budgets are typically constrained, and a key aspect of programming is to prioritise the road works in order to find the best use of the constrained budget. Typical applications are the
preparation of a budget for an annual or a rolling multi-year work programme for a road network, or sub-network. Managerial-level professionals within a road organisation normally undertake programming activities, perhaps within a planning or a maintenance department.

**Preparation**

This is the short-term planning stage where road schemes are packaged for implementation. At this stage, designs are refined and prepared in more detail; bills of quantities and detailed costing are made, together with work instructions and contracts. Detailed specifications and costing are likely to be drawn up, and detailed cost-benefit analysis may be carried out to confirm the feasibility of the final scheme. Works on adjacent road sections may be combined into packages of a size that is cost-effective for execution. Typical preparation activities are the detailed design of:

- **An overlay scheme**
- **Road improvement works**

  For example, construction along a new alignment, road widening, pavement reconstruction, etc.

For these activities, budgets will normally already have been approved. Preparation activities are normally undertaken by middle to junior professional staff and technicians within a design or implementation department of a road organisation, and by contracts and procurement staff.

**Operations**

These activities cover the on-going operation of an organisation. Decisions about the management of operations are made typically on a daily or weekly basis, including the scheduling of work to be carried out, monitoring in terms of labour, equipment and materials, the recording of work completed, and use of this information for monitoring and control. Activities are normally focused on individual sections or sub-sections of a road, with measurements often being made at a relatively detailed level. Operations are normally managed by sub-professional staff, including works supervisors, technicians, clerks of works, and others.

As the management process moves from Planning through to operations, it will be seen that changes occur to the data required. The data detail starts as a coarse summary but progressively moves towards a detailed level (see Table 3.1).
3.2 The management cycle

Traditionally, in many road organisations, budgets and programmes for road works have been prepared on a historical basis, in which each year’s budget is based upon that for the previous year, with an adjustment for inflation. Under such a regime, there is no way of telling whether funding levels, or the detailed allocation, are either adequate or fair. Clearly, there is a requirement for an objective needs-based approach, using knowledge of the content, structure and condition of the roads being managed. It will be seen that the functions of Planning, Programming, Preparation and Operations provide a suitable framework within which a needs-based approach can operate (Robinson et al., 1998).

In order to undertake each of these four management functions, an integrated system is recommended. An appropriate approach is to use the management cycle concept that is illustrated in Figure 3.1 (Robinson et al., 1998). The cycle provides a series of well-defined steps helping the management process through their decision-making activities. The management cycle is typically completed once in each year or in one budgeting period.
3.3 **Cycles within management functions**

The highway management process as a whole can, therefore, be considered as a cycle of activities that are undertaken within each of the management functions of Planning, Programming, Preparation and Operations. Table 3.2 outlines this concept and provides the framework within which HDM-4 meets the needs of a road management organisation.
### Table 3.2
Management functions and the corresponding HDM-4 applications

<table>
<thead>
<tr>
<th>Management function</th>
<th>Common descriptions</th>
<th>HDM-4 applications</th>
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| Planning            | Strategic analysis system  
                      | Network planning system 
                      | Pavement management system | HDM-4: Strategy Analysis |
| Programming         | Programme analysis system  
                      | Pavement management system  
                      | Budgeting system | HDM-4: Programme Analysis |
| Preparation         | Project analysis system  
                      | Pavement management system  
                      | Bridge management system  
                      | Pavement/overlay design system  
                      | Contract procurement system | HDM-4: Project Analysis |
| Operations          | Project management system  
                      | Maintenance management system  
                      | Equipment management system  
                      | Financial management/accounting system | (Not addressed by HDM-4) |

Source: Kerali, Paterson and Robinson (1998)
4 Analytical Framework

The HDM-4 analytical framework is based on the concept of pavement life cycle analysis. This is applied to predict the following over the life cycle of a road pavement, which is typically 15 to 40 years:

- Road deterioration
- Road work effects
- Road user effects
- Socio - Economic and Environmental effects

Once constructed, road pavements deteriorate as a consequence of several factors, most notably:

- Traffic loading
- Environmental weathering
- Effect of inadequate drainage systems

The rate of pavement deterioration is directly affected by the standards of maintenance applied to repair defects on the pavement surface such as cracking, ravelling, potholes, etc., or to preserve the structural integrity of the pavement (for example, surface treatments, overlays, etc.), thereby permitting the road to carry traffic in accordance with its design function. The overall long-term condition of road pavements directly depends on the maintenance or improvement standards applied to the road. Figure 4.1 illustrates the predicted trend in pavement performance represented by the riding quality that is often measured in terms of the international roughness index (IRI). When a maintenance standard is defined, it imposes a limit to the level of deterioration that a pavement is permitted to attain. Consequently, in addition to the capital costs of road construction, the total costs that are incurred by road agencies will depend on the standards of maintenance and improvement applied to road networks.

It is essential to note that the accuracy of the predicted pavement performance depends on the extent of calibration applied to adapt the default HDM-4 models to local conditions. For further details, refer to A Guide to Calibration and Adaptation - Volume 5.
The impacts of the road condition, as well as the road design standards, on road users are measured in terms of road user costs, and other social and environmental effects. Road user costs comprise:

- **Vehicle operation costs** (fuel, tyres, oil, spare parts consumption; vehicle depreciation and utilisation, etc.),
- **Costs of travel time** - for both passengers and cargo, and
- **Costs to the economy of road accidents** (that is, loss of life, injury to road users, damage to vehicles and other roadside objects).

The social and environmental effects comprise vehicle emissions, energy consumption, traffic noise and other welfare benefits to the population served by the roads. Although the social and environmental effects are often difficult to quantify in monetary terms, they can be incorporated within the HDM-4 economic analyses if quantified exogenously.

It should be noted that in HDM-4, road user effects can be calculated for both motorised transport (motorcycles, cars, buses, trucks, etc.) and non-motorised transport (bicycles, human powered tricycles, animal pulled carts, etc.).

Figure 4.2 illustrates the impact of road condition (represented in terms of the IRI) on the costs of different modes of transport.
Road User Costs in HDM-4 are calculated by predicting physical quantities of resource consumption and then multiplying these quantities by the corresponding user specified unit costs. It is necessary to ensure that the vehicle resource quantities predicted are in keeping with the range of values observed in the area of application. For further details, refer to A Guide to Calibration and Adaptation - Volume 5.

Economic benefits from road investments are then determined by comparing the total cost streams for various road works and construction alternatives against a base case (without project or do minimum) alternative, usually representing the minimum standard of routine maintenance. HDM-4 is designed to make comparative cost estimates and economic analyses of different investment options. It estimates the costs for a large number of alternatives year-by-year for a user-defined analysis period. All future costs are discounted to the specified base year. In order to make these comparisons, detailed specifications of investment programmes, design standards, and maintenance alternatives are needed, together with unit costs, projected traffic volumes, and environmental conditions.
5 HDM-4 Applications

5.1 Strategy analysis

The concept of strategic planning of medium to long term road network expenditures requires that a road organisation should consider the requirements of its entire road network asset. Thus, strategy analysis deals with entire networks or sub-networks managed by one road organisation. Examples of road networks include: the main (or trunk) road network, the rural (or feeder) road network, urban (or municipal) road network, etc. Examples of sub-networks include; all motorways (or expressways), all paved (or unpaved roads), different road classes, etc.

In order to predict the medium to long term requirements of an entire road network or sub-network, HDM-4 applies the concept of a road network matrix comprising categories of the road network defined according to the key attributes that most influence pavement performance and road user costs. Although it is possible to model individual road sections in the strategy analysis application, most road administrations will often be responsible for several thousand kilometres of roads, thereby making it cumbersome to individually model each road segment. The road network matrix can be defined by users to represent the most important factors affecting transport costs in the country. A typical road network matrix could be categorised according to the following:

- Traffic volume or loading
- Pavement types
- Pavement condition
- Environment or climatic zones
- Functional classification (if required)

For example, a road network matrix could be modelled using; three traffic categories (high, medium, low), two pavement types (asphalt concrete, surface treatments), and three pavement condition levels (good, fair, poor). In this case, it is assumed that the environment throughout the study area is similar and that the road administration is responsible for one road class (for example, main roads). The resulting road network matrix for this would therefore comprise (3 x 2 x 3 =) 18 representative pavement sections. There is no limit to the number of representative pavement sections that can be used in a strategy analysis. The trade-off is usually between a simple representative road network matrix that would give rather coarse results compared against a detailed road network matrix with several representative sections that could potentially provide more accurate results.

Strategy analysis may be used to analyse a chosen network as a whole, to prepare medium to long range planning estimates of expenditure needs for road development and conservation under different budget scenarios. Estimates are produced of expenditure requirements for medium to long term periods of usually 5-40 years. Typical applications of strategy analysis by road administrations would include:

- Medium to long term forecasts of funding requirements for specified target road maintenance standards (see Figure 5.1a).
- Forecasts of long term road network performance under varying levels of funding (see Figure 5.1b).
Optimal allocation of funds according to defined budget heads; for example routine maintenance, periodic maintenance and development (capital) budgets (see Figure 5.1c).

Optimal allocations of funds to sub-networks; for example by functional road class (main, feeder and urban roads, etc.) or by administrative region (see Figure 5.1d).

Policy studies such as impact of changes to the axle load limit, pavement maintenance standards, energy balance analysis, provision of NMT facilities, sustainable road network size, evaluation of pavement design standards, etc.

A typical sample application of the HDM-4 Strategy Analysis is given in Appendix A.
**Figure 5.1a Effect of funding levels on road network performance**

**Figure 5.1b Effect of budget allocations on sub-network performance**
**Figure 5.1c** Optimal budget allocations to sub-heads

**Figure 5.1d** Optimal budget allocations to sub-networks
5.2 Programme analysis

This deals primarily with the prioritisation of a defined long list of candidate road projects into a one-year or multi-year work programme under defined budget constraints. It is essential to note that here, we are dealing with a long list of candidate road projects selected as discrete segments of a road network. The selection criteria will normally depend on the maintenance, improvement or development standards that a road administration may have defined (for example, from the output produced by the strategy analysis application). Examples of selection criteria that may be used to identify candidate projects include:

- Periodic maintenance thresholds (for example, reseal pavement surface at 20% damage).
- Improvement thresholds (for example, widen roads with volume/capacity ratio greater than 0.8).
- Development standards (for example, upgrade gravel roads to sealed pavements when the annual average daily traffic exceeds 200 vehicles per day).

The above examples do not imply firm recommendations to be used by road authorities.

When all candidate projects have been identified, the HDM-4 programme analysis application can then be used to compare the life cycle costs predicted under the existing regimen of pavement management (that is, the without project case) against the life cycle costs predicted for the periodic maintenance, road improvement or development alternative (that is, with project case). This provides the basis for estimating the economic benefits that would be derived by including each candidate project within the budget timeframe.

It should be noted that the main difference between strategy analysis and programme analysis is the way in which road links and sections are physically identified. Programme analysis deals with individual links and sections that are unique physical units identifiable from the road network throughout the analysis. In strategy analysis, the road system essentially loses its individual link and section characteristics by grouping all road segments with similar characteristics into the road network matrix categories.

For both strategy and programme analysis, the problem can be posed as one of seeking that combination of treatment alternatives across a number of sections in the network that optimises an objective function under budget constraint. If, for example, the objective function is to maximise the Net Present Value (NPV), the problem can be defined as:

Select that combination of treatment options for sections that maximises NPV for the whole network subject to the sum of the treatment costs being less than the budget available.

The HDM-4 programme analysis application may be used to prepare a multi-year rolling programme, subject to resource constraints (see Figure 5.2a and Figure 5.2b). The prioritisation method employs the incremental NPV/cost ratio as the ranking index, described in more detail in Analytical Framework and Model Descriptions - Volume 4. This provides an efficient and robust index for prioritisation purposes. Indices such as the NPV, economic rate of return (ERR), or predicted pavement condition attributes (for example, road roughness) are not recommended as ranking criteria. The incremental NPV/cost ratio satisfies the objective of maximising economic benefits for each additional unit of expenditure (that is, maximise net benefits for each additional $1 of the available budget invested).

A typical sample application of the HDM-4 programme analysis application is given in Appendix B.
### Overview

<table>
<thead>
<tr>
<th>Priority Rank</th>
<th>Road Section</th>
<th>Length (km)</th>
<th>Province or District</th>
<th>Type of Road Work</th>
<th>Scheduled Year</th>
<th>Cost $m</th>
<th>Cumulative Cost $m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N1-2</td>
<td>20.5</td>
<td>2</td>
<td>Resealing</td>
<td>2000</td>
<td>5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>2</td>
<td>N4-7</td>
<td>23.5</td>
<td>7</td>
<td>Overlay 40mm</td>
<td>2000</td>
<td>10.9</td>
<td>16.3</td>
</tr>
<tr>
<td>3</td>
<td>N2-5</td>
<td>12.5</td>
<td>5</td>
<td>Reconstruct</td>
<td>2000</td>
<td>8.6</td>
<td>24.9</td>
</tr>
<tr>
<td>4</td>
<td>R312-1</td>
<td>30</td>
<td>4</td>
<td>Widen 4 lane</td>
<td>2000</td>
<td>31.4</td>
<td>56.3</td>
</tr>
<tr>
<td>5</td>
<td>R458-3</td>
<td>36.2</td>
<td>3</td>
<td>Overlay 60mm</td>
<td>2000</td>
<td>16.3</td>
<td>72.6</td>
</tr>
</tbody>
</table>

... and so on...

### Figure 5.2a Sample output from Programme analysis (Format 1)

<table>
<thead>
<tr>
<th>Priority Rank</th>
<th>Road Section</th>
<th>Length (km)</th>
<th>Province or District</th>
<th>Cost $m</th>
<th>Routine Maintenance Cost $m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N1-2</td>
<td>20.5</td>
<td>2</td>
<td>5.4</td>
<td>R.M. 0.185</td>
</tr>
<tr>
<td>2</td>
<td>N4-7</td>
<td>23.5</td>
<td>7</td>
<td>10.9</td>
<td>R.M. 0.212</td>
</tr>
<tr>
<td>3</td>
<td>N2-5</td>
<td>12.5</td>
<td>5</td>
<td>8.6</td>
<td>R.M. 0.113</td>
</tr>
<tr>
<td>4</td>
<td>R312-1</td>
<td>30</td>
<td>4</td>
<td>31.4</td>
<td>R.M. 0.180</td>
</tr>
<tr>
<td>5</td>
<td>R458-3</td>
<td>36.2</td>
<td>3</td>
<td>16.3</td>
<td>R.M. 0.217</td>
</tr>
</tbody>
</table>

... and so on...

### Figure 5.2b Sample output from Programme analysis (Format 2)

<table>
<thead>
<tr>
<th>Priority Rank</th>
<th>Road Section</th>
<th>Length (km)</th>
<th>Province or District</th>
<th>Cost $m</th>
<th>Routine Maintenance Cost $m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N1-2</td>
<td>20.5</td>
<td>2</td>
<td>5.4</td>
<td>R.M. 0.272</td>
</tr>
<tr>
<td>2</td>
<td>N7-9</td>
<td>17.8</td>
<td>3</td>
<td>9.2</td>
<td>R.M. 0.160</td>
</tr>
<tr>
<td>3</td>
<td>F2140-8</td>
<td>56.1</td>
<td>1</td>
<td>34.9</td>
<td>R.M. 0.168</td>
</tr>
</tbody>
</table>

Note: RM = Routine Maintenance
5.3 **Project analysis**

Project analysis is concerned with the following:

- Evaluation of one or more road projects or investment options. The application analyses a road link or section with user-selected treatments, with associated costs and benefits, projected annually over the analysis period.
- Economic indicators are determined for the different investment options.

Project analysis may be used to estimate the economic or engineering viability of road investment projects by considering the following issues:

- The structural performance of road pavements
- Life-cycle predictions of road deterioration, road works effects and costs
- Road user costs and benefits
- Economic comparisons of project alternatives

Typical appraisal projects would include the maintenance and rehabilitation of existing roads, widening or geometric improvement schemes, pavement upgrading and new construction. There are no fundamental changes to the philosophy of the system in this area, but improved road deterioration relationships have been extended to cover a wider range of pavements and the performance of materials in temperate and cold climates. Road user cost relationships include impacts on road safety.

**Typical examples of project analysis applications using HDM-4 are given in Appendix C.**

In terms of data requirements, the key difference between the strategy and programme analyses, with that for project analysis, is in the detail at which data is defined. Use is made of the concept of **information quality levels** (IQL) recommended by the *World Bank* (*Paterson and Scullion, 1990*). Project level analysis data is specified in terms of measured defects (IQL-II), whereas the specification for strategy and programme analyses can be more generic (IQL-III). For example; for project level analysis, road roughness would be specified in terms of the IRI value (m/km); but for strategy and programme analyses, roughness could be specified as **good**, **fair** or **poor**. The relationship between IQL-II and IQL-III level data is user-defined in the **HDM Configuration** depending on road class, pavement surface type and traffic class.
6 **HDM-4 Modules**

The overall structure of HDM-4 is illustrated in Figure 6.1. The three analysis tools (Strategy, Programme and Project) operate on data defined in one of four data managers:

- **Road Network**
  Defines the physical characteristics of road sections in a network or sub-network to be analysed.

- **Vehicle Fleet**
  Defines the characteristics of the vehicle fleet that operate on the road network to be analysed.

- **Road Works**
  Defines maintenance and improvement standards, together with their unit costs, which will be applied to the different road sections to be analysed.

- **HDM Configuration**
  Defines the default data to be used in the applications. A set of default data is provided when HDM-4 is first installed, but users should modify these to reflect local environments and circumstances.

Technical analysis within the HDM-4 is undertaken using four sets of models:

- **RD (Road Deterioration)**
  Predicts pavement deterioration for bituminous, concrete and unsealed roads.

- **WE (Works Effects)**
  Simulates the effects of road works on pavement condition and determines the corresponding costs.

- **RUE (Road User Effects)**
  Determines costs of vehicle operation, road accidents and travel time.

- **SEE (Social and Environment Effects)**
  Determines the effects of vehicle emissions and energy consumption.

The model simulates, for each road section, year-by-year, the road condition and resources used for maintenance under each strategy, as well as the vehicle speeds and physical resources consumed by vehicle operation. After physical quantities involved in construction, road works and vehicle operation are estimated, user-specified prices and unit costs are applied to determine financial and economic costs. Relative benefits are then calculated for different alternatives, followed by present value and rate of return computations.

These models are described in detail in *Analytical Framework and Model Descriptions - Volume 4*, and were largely derived from the equivalent models used in HDM-III.

The HDM-4 system is designed to interface with external systems such as:

- **Databases**
  Road network information systems, pavement management systems, etc., through intermediate Import/Export files.
Technical models

Accessed directly by external systems for research applications or other studies.

The system design is modular in structure to enable users to implement the HDM-4 modules independently within their road management systems. The technical relationships can easily be calibrated to match local conditions by using HDM-4 Configuration in addition to country specific default data.

Figure 6.1 HDM-4 System Architecture
7 Data requirements

7.1 Overview

The HDM-4 applications have been designed to work with a wide range of data type and quality. For example, pavement condition data collected by visual inspection according to condition classes (for example, Very good, good, fair, poor condition) can be converted to the HDM-4 model requirements prior to running any of the applications (see section below on Importing and Exporting Data). Similarly, HDM-4 can work with very detailed measurements of pavement condition if the data is available. This flexibility in data requirements should permit all potential users with a variety of data to integrate HDM-4 into their road management functions. For further details, refer to Applications Guide - Volume 2.

7.2 HDM-4 Configuration

Since HDM-4 will be used in a wide range of environments, HDM Configuration provides the facility to customise system operation to reflect the norms that are customary in the environment under study. Default data and calibration coefficients can be defined in a flexible manner to minimise the amount of data that must be changed for each application of HDM-4. Default values are supplied with HDM-4, but these are all user-definable and facilities are provided to enable this data to be modified. The HDM-4 set of tools may be used as additional modules to current pavement management systems. Import and Export functions, built into the modules, provide a mechanism for data transfer between existing databases and HDM-4 modules. The data exchange format uses standard data file formats to encourage its wide adaptation by road organisations.

7.3 Road Networks

Road Networks provides the basic facilities for storing characteristics of one or more road sections. It allows users to define different networks and sub-networks, and to define road sections, which is the fundamental unit of analysis. The data entities supported within the road network are:

- **Sections**
  
  Lengths of road over which physical characteristics are reasonably constant.

- **Links**
  
  Comprise one or more sections over which traffic is reasonably constant. This is provided for purposes of compatibility of the network referencing system with existing pavement management systems.

- **Nodes**
  
  Intersections which connect links or other points at which there is a significant change in traffic, carriageway characteristics, or administrative boundaries.

All network data is entered using the Road Network folder, and facilities are also available for editing, deleting and maintaining this data. The approach to network referencing is considerably more flexible than that used in HDM-III, and is designed to handle a wide range of external referencing conventions as might be used by other systems with which HDM-4 may need to interface.
7.4 **Vehicle Fleets**

*Vehicle Fleets* provide facilities for the storage and retrieval of vehicle characteristics required for calculating vehicle speeds, operating costs, travel time costs and other vehicle effects. The method used to represent a vehicle fleet is considerably more adaptable than that used in HDM-III with no limit on the numbers or types of vehicles that can be specified. Motorcycles and non-motorised vehicles are included. Multiple vehicle fleet data sets can be set up for use in different analyses, with a wide range of default data provided.

7.5 **Road Works**

*Road Works Standards* refer to the targets or levels of conditions and response that a road management organisation aims to achieve. Road organisations normally set up different standards that can be applied in practical situations in order to meet specific objectives which are related to functional characteristics of the road network system.

The *Road Works* folder provides facilities, within a flexible framework, to define a list of maintenance and improvement standards that are followed by road organisations in their network management and development activities. The standards defined in the *Road Works Standards* folder can be used in any of the three analysis tools:

- Project analysis
- Programme analysis
- Strategy analysis

7.6 **Importing and Exporting Data**

The data required for HDM-4 analyses can be imported from existing data sources such as pavement management systems (PMS), highway information systems, etc. The data import into HDM-4 (as well as the export from HDM-4) is organised according to the data objects described above (that is, road networks, vehicle fleets, maintenance and improvement standards, HDM Configuration). The physical attributes of the selected data objects must be exported to a data exchange file format defined for HDM-4. This permits all data required by HDM-4 to be imported directly from any database. Data transformation rules may need to be implemented for converting the data held in the external database to the format used by HDM-4. For example, pothole data recorded in the external database in terms of the percentage area of the pavement surface would need to be converted to the equivalent number of standard pothole units (10 litres by volume) required in HDM-4. Similarly, other data required by HDM-4, such as pavement deterioration calibration factors, should be inserted as pre-defined default values according to the type of pavement, road class, and other defined factors. Other data required for the HDM-4 analyses can be directly stored within the HDM-4 internal database. These include data on vehicle fleet characteristics, road maintenance and improvement standards, unit costs and economic analysis parameters (for example, discount rate, analysis period, etc.). For further details on exchanging data with HDM-4, refer to [Software User Guide - Volume 3](#).
8 User interface

A key objective for the development of HDM-4 is to provide a system that is user-friendlier than the original HDM-III. This has been achieved by addressing the user interface design and data requirements. The user interface has been improved by developing the system to run under a standard Microsoft Windows environment. Many computer users are already familiar with the Windows system and this should make learning HDM-4 more intuitive. A modular system design has been adopted to enable different modules to be used relatively easily and to facilitate future system operation on other non-Windows platforms. More details of system issues are described in the Software User Guide - Volume 3.

Considerable attention has also been paid to the data that must be entered by users, particularly because the total data requirement is greater than that in HDM-III in order to allow for the extended facilities included in HDM-4. The concept of data hierarchy is used, whereby default data is defined for many items in HDM Configuration, and users can choose the extent to which defaults are used. The system can be used with a level of data entry detail that is appropriate for particular applications. A comprehensive Help system is also provided. Figure 8.1 illustrates the HDM-4 Workspace. Detailed instructions for the operation of the individual modules are given in the Software User Guide - Volume 3.
Figure 8.1 HDM-4 Workspace
9 Nomenclature

A nomenclature explaining any special numbering, markings, etc., that are associated with the HDM-4 suite of documents is included in Part H of the Analytical Framework and Model Descriptions - Volume 4.

A glossary of terms is included in Part I of the Analytical Framework and Model Descriptions - Volume 4 describing the use of phrases found in the HDM-4 documentation.
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Appendix A  Example of HDM-4 Strategy Analysis Application

A.1 Background

The national road network in a country comprises 4,267 km of paved roads and 3,145 km of unpaved (gravel) roads. A recent pavement condition survey has shown that 22.3% of the paved road network is in good condition, 36.2% in fair condition and 41.5% in poor condition. Traffic surveys were also carried out in the previous year. Following an analysis of the data available together with the characteristics of the national road network, it has been decided to categorise the paved road network into three traffic classes \((\text{high}, \text{medium}, \text{low})\), and three pavement condition classes \((\text{good}, \text{fair}, \text{poor})\), and the unpaved road network has been categorised into two traffic categories only \((\text{medium and low})\). The resulting road network matrix is summarised in Table A.1:

<table>
<thead>
<tr>
<th>Traffic categories</th>
<th>Paved roads:</th>
<th>Unpaved roads:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High (\text{(AADT &gt; 4000)})</td>
<td>Medium (\text{(4000 &gt; AADT &gt; 1000)})</td>
</tr>
<tr>
<td>Good condition</td>
<td>234 km</td>
<td>306 km</td>
</tr>
<tr>
<td>Fair condition</td>
<td>392 km</td>
<td>483 km</td>
</tr>
<tr>
<td>Poor condition</td>
<td>437 km</td>
<td>615 km</td>
</tr>
<tr>
<td>Gravel surface</td>
<td></td>
<td>Medium (\text{(AADT &gt; 100)})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,760 km</td>
</tr>
</tbody>
</table>

A.2 Standards

The national road authority has a defined set of standards for road maintenance and road network improvement in accordance with its own policies and those set by the government.

- **The maintenance and improvement standards for paved roads include**
  - Widening all paved roads with volume to capacity ratio greater than 0.8.
  - Rehabilitation (structural overlay) of all paved roads in poor condition.
  - Resealing (surface dressing) paved roads when surface deterioration exceeds 30%.
  - Reactive routine maintenance comprising patching potholes immediately, sealing cracks, edge repairs, etc., as required.
  - Routine maintenance to shoulders, drainage ditches, road markings and all roadside furniture.
The maintenance and improvement standards for unpaved roads include:

- Upgrading to paved surface, all gravel roads carrying more than 250 vehicles per day.
- Regravelling when the remaining gravel thickness falls below 50 mm.
- Grading gravel roads with medium traffic twice a year, and grading once a year for gravel roads carrying less than 100 vehicles per day.
- Routine maintenance to shoulders, drainage ditches and all roadside furniture.

A.3 HDM-4 Application

The objective of this study is to determine the required funding levels for the defined maintenance and improvement standards, and to monitor the effect of budget constraints on the long-term network performance trends.

The HDM-4 procedure required to analyse the national road network comprises the following:

- Create the representative road network matrix using the Strategy application;
- Define the characteristics of the vehicles which use the road network;
- Specify traffic growth rates;
- Assign the maintenance and improvement standards to the road network matrix together with their unit costs;
- Run the HDM-4 Strategy application to determine the total budget requirement;
- Carry out constrained budget analyses;
- Review reports and graphs of the analyses conducted.

A.4 Summary of Results

The results of the analyses can be summarised in chart form as illustrated in Figure A.1. The analyses indicate that the ideal maintenance and improvement standards specified by the policy would require approximately US$ 56.2 million per year for the paved road network, and US$ 21.2 per year for the unpaved road network (based on the unit costs of the various road works). If only 50% of the required funding were available (represented by the minimum periodic maintenance option), this would result in a 54% loss in road user benefits (that is, compared against road user costs for the routine & recurrent option).
Figure A.1 Summary Output from HDM-4 Strategy Analysis

Overview of HDM-4
Version 1.0
Appendix B  Example of HDM-4 Programme Analysis Application

B.1 Background

The national road authority has drawn up a long list of candidate road sections for periodic maintenance and improvement over the next three years in Western Province. The long list of candidate road sections follows a review of pavement condition surveys carried out by consultants. The national road authority has a policy to prioritise the candidate projects and select those that will be included in the periodic maintenance programme for the three-year budget period. Given that the candidate projects are from the main road network only, the objective is to prioritise according to the economic benefits that would be derived from each candidate road project.

B.2 Standards

The standards for periodic maintenance and road improvement defined by the national road authority require the following road works to be carried out:

- **Road improvement standards**
  - Pave gravel roads with AADT greater than 150 vehicles per day.
  - Widen roads with peak volume to capacity ratio greater than 0.85.

- **Periodic maintenance standards**
  - Reconstruct failed pavements with roughness greater than 9.5 IRI.
  - Strengthen pavements in critical condition with roughness greater than 5.0 IRI.
  - Reseal pavements with observed distress on more than 30% of the pavement surface area (that is, cracking, ravelling, potholes, edge break, etc.). This includes preparatory works such as crack sealing, pothole patching and edge repairs prior to the resealing.

- **Reactive and cyclic routine maintenance**
  - Patching potholes, crack sealing and edge repairs as required.
  - Drainage maintenance, shoulder repairs, vegetation control, etc., specified as fixed costs per km per year.

B.3 HDM-4 Application

The objective of this study is to select a short list of projects for Western Province that can be carried out within the funding to be made available for periodic maintenance and road improvement over the next three years.

The HDM-4 procedure required to prioritise the candidate projects comprises the following:

- Import data from the Pavement Management System or use the HDM-4 Road Network manager to create the candidate road sections.
- Define the characteristics of the vehicles that use the road network.
Specify traffic growth rates.

Assign the maintenance and improvement standards to the candidate road sections together with the unit costs.

Run the HDM-4 Programme Analysis application to determine the road works required.

The unconstrained work programme results give the total funding required for the long list of candidate road sections.

Carry out budget optimisation to prioritise and select the short list of projects that can be carried out within the available budget.

Review reports of the analyses conducted.

B.4 Summary of Results

The results of the analyses are summarised in Table B.1a and Table B.1b.

The analyses indicate that the selected road sections for periodic maintenance and road improvement would require approximately US$ 11.345 million over the three year budget period (based on the unit costs of the various road works).

If only 70% of the required funding were available, Table B.1b shows the short list of candidate sections that would be included in the three-year program.
### Table B.1a Unconstrained Work Programme

**HDM-4 Unconstrained Work Programme**

**Study Name:** Western Province 3 Year Road Investment Programme  
**Run Date:** 23-11-1999

All costs are expressed in: Local Currency (millions).

<table>
<thead>
<tr>
<th>Year</th>
<th>Road No.</th>
<th>Section</th>
<th>Length (km)</th>
<th>AADT</th>
<th>Work Description</th>
<th>NPV/C</th>
<th>Financial Costs</th>
<th>Cumulative Costs</th>
<th>Equivalent US$(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>MSC 112</td>
<td>km 35 - 80</td>
<td>21.0</td>
<td>1711</td>
<td>Overlay 20mm</td>
<td>4.91</td>
<td>23.15</td>
<td>23.15</td>
<td>0.609</td>
</tr>
<tr>
<td>2000</td>
<td>MSE 203</td>
<td>km 80 - 90</td>
<td>10.0</td>
<td>1152</td>
<td>Overlay 20mm</td>
<td>2.51</td>
<td>11.03</td>
<td>34.18</td>
<td>0.899</td>
</tr>
<tr>
<td>2000</td>
<td>MSC 138</td>
<td>km 5 - 10 &amp; 65 - 70</td>
<td>10.0</td>
<td>1271</td>
<td>Single Seal</td>
<td>2.41</td>
<td>3.80</td>
<td>37.98</td>
<td>0.999</td>
</tr>
<tr>
<td>2000</td>
<td>MAN 446</td>
<td>km 53.7 - 57.0</td>
<td>3.3</td>
<td>983</td>
<td>Overlay 20mm</td>
<td>2.40</td>
<td>3.31</td>
<td>41.29</td>
<td>1.086</td>
</tr>
<tr>
<td>2000</td>
<td>MSE 932</td>
<td>km 36.2 - 52.2</td>
<td>16.0</td>
<td>809</td>
<td>Overlay 20mm</td>
<td>2.19</td>
<td>17.64</td>
<td>58.93</td>
<td>1.551</td>
</tr>
<tr>
<td>2000</td>
<td>MSE 334</td>
<td>km 3.8 - 12.8</td>
<td>9.0</td>
<td>932</td>
<td>Overlay 20mm</td>
<td>1.98</td>
<td>9.92</td>
<td>68.85</td>
<td>1.812</td>
</tr>
<tr>
<td>2000</td>
<td>MAN 203</td>
<td>km 185 - 190</td>
<td>5.0</td>
<td>1248</td>
<td>Single Seal</td>
<td>1.72</td>
<td>1.90</td>
<td>70.75</td>
<td>1.862</td>
</tr>
<tr>
<td>2000</td>
<td>MAN 243</td>
<td>km 0 - 21</td>
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**HDM-4**  
**Unconstrained Work Programme**

Study Name: Western Province 3 Year Road Investment Programme  
Run Date: 23-11-1999

All costs are expressed in: Local Currency (millions).

<table>
<thead>
<tr>
<th>Year</th>
<th>Road No.</th>
<th>Section</th>
<th>Length (km)</th>
<th>AADT</th>
<th>Work Description</th>
<th>NPV/C</th>
<th>Financial Costs</th>
<th>Cumulative Costs</th>
<th>Equivalent US$(m)</th>
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<td>2001</td>
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<td>2.0</td>
<td>937</td>
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<tr>
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<td>33.08</td>
<td>384.82</td>
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<td>MSW 938</td>
<td>km 3.2 - 10</td>
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<td>913</td>
<td>Overlay 20mm</td>
<td>1.30</td>
<td>7.72</td>
<td>398.05</td>
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<tr>
<td>2002</td>
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<td>MAN 409</td>
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<td>0.28</td>
<td>5.51</td>
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<td>11.345</td>
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### Table B.1b Constrained Work Programme

**Study Name:** Western Province 3 Year Road Investment Programme  
**Run Date:** 23-11-1999

All costs are expressed in: Local Currency (millions).

<table>
<thead>
<tr>
<th>Year</th>
<th>Road No.</th>
<th>Section</th>
<th>Length (km)</th>
<th>AADT</th>
<th>Work Description</th>
<th>NPV/C</th>
<th>Financial Costs</th>
<th>Cumulative Costs</th>
<th>Equivalent US$(m)</th>
</tr>
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<tr>
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<td>MSE 203</td>
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<td>1152</td>
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<td>2.51</td>
<td>11.03</td>
<td>34.18</td>
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**HDM-4**

**Constrained Work Programme**

Study Name: **Western Province 3 Year Road Investment Programme**  
Run Date: **23-11-1999**

*All costs are expressed in: Local Currency (millions).*


<table>
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<tr>
<th>Year</th>
<th>Road No.</th>
<th>Section</th>
<th>Length (km)</th>
<th>AADT</th>
<th>Work Description</th>
<th>NPV/C</th>
<th>Financial Costs</th>
<th>Cumulative Costs</th>
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<td>0.86</td>
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</table>

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Appendix C  HDM-4 Project Analysis Application

C.1 Introduction

The project analysis application in HDM-4 can be used to carry out economic appraisal for a wide range of project types. These include:

- **Periodic maintenance and rehabilitation**
  - Overlays
  - Resealing
  - Pavement reconstruction

- **Upgrading**
  - Paving unsealed roads
  - Concrete pavements
  - Full depth asphalt pavements

- **Staged construction**
  - Construction of road sections in sequence

- **New road construction**
  - Road by-pass schemes
  - Traffic diversion schemes

- **Road widening**
  - Dual carriageways
  - Lane addition
  - Carriageway widening

- **Non-motorised traffic facilities**
  - Bicycle lanes
  - Carriageway separation

Note that the above list is not exhaustive.

C.2 HDM-4 Application

The objective of a project level application is to determine the best engineering and economic alternatives for individual road sections.

The HDM-4 procedure required to carry out a project application comprises the following:

- Specify characteristics of the road sections using the Road Network manager.
- Define the characteristics of the vehicles that use the road sections.
- Specify traffic growth rates.
Specify the maintenance and road improvements to be carried out together with the unit costs.

Run the HDM-4 Project Analysis application to determine the economic benefits.

Review reports of the analyses conducted.

C.3 Output

There are several detailed summary reports produced by HDM-4. These include:

- **Pavement deterioration and road works**
  - Summary of annual pavement condition
  - Quantities of road works
  - Details of annual road work costs
  - Schedule of road works

- **Road user effects**
  - Summary of road user costs (vehicle operation, travel time and accidents)
  - Traffic flow details
  - Average travel speeds
  - Traffic volume to capacity ratios

- **Environmental effects**
  - Vehicle emissions
  - Energy consumption

- **Economic analysis results**
  - Annual cost streams
  - Discounted cash flows
  - Net Present Values (NPV)
  - Economic Internal Rate of Return (EIRR)
  - Benefit Cost Ratio (BCR)
  - First Year Benefits (FYB)

C.4 Example Project 1 - Upgrading a Gravel Road

C.4.1 Project Description

This example presents the economic analysis of a project to upgrade an existing gravel road to a paved standard. The existing road is 50 km long and passes through varying topography. For analysis purposes, three sections, based on geometry, pavement condition, and traffic volume can represent the road. Traffic and condition data are available from surveys undertaken in 1999. The gravel thickness in 1999 was 150 mm.

The purpose of the appraisal is to assess the economic benefits resulting from the proposed investment. This differs from a financial appraisal that is concerned with the means of
financing a project and the financial profitability of the project. The economic feasibility of the project is assessed by comparison against a base-line project alternative (that is, a without project alternative). The project alternatives are:

- **Without Project**
  Maintain the existing gravel road.

- **With Project**
  Maintain the existing gravel road before upgrading to a bituminous pavement, followed by maintenance of the bituminous pavement.

### C.4.2 Project Results

The Economic Analysis Summary (by Project) report in HDM-4 gives a summary of costs, discounted Net Present Value (NPV) and Internal Rate of Return (IRR) for the project alternative. Cost and NPV details are presented by road section in the Economic Analysis Summary (by Section) report. For this project, the overall NPV is reported as US$ 16.77 (millions). The breakdown by section indicates that all three sections give a positive NPV. The IRR for the road project is calculated as 14.2%.

### C.5 Example Project 2 - Widening a Paved Road

#### C.5.1 Project Description

This project presents the economic analysis of widening a paved road. The existing road is 7m wide, with an AADT of 15,000 in 1998. Non-motorised transport contributed an extra 400 vehicles in 1998, comprising animal carts and bicycles. The analysis assumes that routine pavement maintenance is undertaken on a condition responsive basis for all alternatives. Three widening alternatives are considered, widening by 1m, widening by 3m, and adding two extra lanes. The road under study is represented by one section, 10 km long, and the different widening proposals represent project alternatives. The analysis period is defined by the start year 2000 and duration 20 years (that is, 2000 - 2019). The project alternatives are summarised in the table below:
### Alternative Description

1. **This is the do-minimum alternative.** Routine pavement maintenance is undertaken each year, as necessary, based on the pavement condition. In addition, a 50 mm overlay is applied when the roughness level reaches 6 IRI OR when structural cracking affects 15% of the carriageway area.

2. With this alternative, the existing road is widened by 1 m during the period (2000-2001). The maintenance regime of Alternative 1 (Routine + 50 mm overlay), which is condition responsive, is effective from year 3 (2002).

3. With this alternative, the existing road is widened by 3 m during the period (2000-2001). The condition responsive maintenance regime of Alternative 1 is effective from year 3 (2002).

4. With this alternative, the existing road is widened by adding two lanes during the period (2000-2002). The condition responsive maintenance regime of Alternative 1 (Routine + 50 mm Overlay) is effective from year 4 (2003).

### C.5.2 Analysis Results

The impact of the widening alternatives can be assessed by examination of the **Volume-Capacity Ratio** report which tabulates the volume-capacity ratio (VCR) by time period and calendar year for each project alternative and road section. The effect of widening on vehicle speeds is demonstrated by the **Vehicle Speed** report.

The Economic Analysis Summary indicates that Alternatives 3 and 4 give a positive NPV, whereas Alternative 2 (widening by 1m only) gives a negative value of NPV.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Widening</th>
<th>NPV (US$ millions)</th>
</tr>
</thead>
<tbody>
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<td>2</td>
<td>1m</td>
<td>-3.31</td>
</tr>
<tr>
<td>3</td>
<td>3m</td>
<td>+6.69</td>
</tr>
<tr>
<td>4</td>
<td>2 lanes</td>
<td>+12.18</td>
</tr>
</tbody>
</table>

### C.6 Example Project 3 - Construction of a Bypass

#### C.6.1 Project Description

This example demonstrates the economic analysis of a project to construct a bypass around a town centre. The objective is to demonstrate the construction of a new road section, and to examine the resulting traffic diversion effects.

The road sections included in the project are shown schematically in Figure C.1. Road sections A, B, C and D represent the existing main road network within a town centre. The
The proposed project is the construction of a bypass, represented by Section E, which is 10 km long.

![Figure C.1 Construction of a new bypass](image)

### C.6.2 Project Alternatives

The four project alternatives considered are defined below and summarised in the table below. Alternative 1 represents the existing road sections without the bypass. Alternatives 2, 3 and 4 include the bypass (represented by section E), with carriageway width and pavement construction as described below. The analysis period is 20 years (from year 2000 to 2019).

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>This alternative represents the base case situation without the bypass.</td>
</tr>
<tr>
<td>2</td>
<td>Construct Section E: A two-lane AMGB (Asphalt Mix on Granular Base) road, with a two-year construction period (2000-2001), and opening in year 2002.</td>
</tr>
<tr>
<td>3</td>
<td>Construct Section E: A wide two-lane AMGB road, with a three-year construction period (2000-2002), and opening in year 2003.</td>
</tr>
<tr>
<td>4</td>
<td>Construct Section E: A four-lane AMGB road, with a four-year construction period (2000-2003), and opening year 2004.</td>
</tr>
</tbody>
</table>

### C.6.3 Traffic Diversion

The construction of the bypass (Section E) will cause a significant redistribution of traffic between the existing roads and the new road. The table below summarises the expected change in normal traffic after completion of the new section.
### C.6.4 Results

The Economic Analysis Summary indicates that construction of the bypass (Section E) would be viable in economic terms. The most cost-effective alternative would be a 2-lane bypass as summarised in the table below.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>New Section Option</th>
<th>NPV (US$ millions)</th>
<th>EIRR (%)</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>Standard 2 lane</td>
<td>66.360</td>
<td>66.71</td>
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<td>3</td>
<td>Wide 2 lane</td>
<td>60.355</td>
<td>52.25</td>
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<td>4</td>
<td>Standard 4 lane</td>
<td>49.820</td>
<td>35.69</td>
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</tbody>
</table>

### Table: AADT (1998) before bypass and AADT bypass opening year

<table>
<thead>
<tr>
<th>Section</th>
<th>AADT (1998) before bypass</th>
<th>AADT bypass opening year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>B</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>C</td>
<td>6,000</td>
<td>1,000</td>
</tr>
<tr>
<td>D</td>
<td>8,000</td>
<td>3,000</td>
</tr>
<tr>
<td>E</td>
<td>n/a</td>
<td>5,000</td>
</tr>
</tbody>
</table>
Highway Development and Management Series

The Highway Development and Management system (HDM-4) provides a harmonised systems approach to road management, with adaptable and user-friendly software tools. It is a powerful tool for conducting project appraisals and analyses of road management and investment alternatives.

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