H D M - 4

HIGHWAY DEVELOPMENT & MANAGEMENT

volume **one**

Overview of HDM-4

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1

THE HIGHWAY DEVELOPMENT AND MANAGEMENT SERIES

About This Manual

This Version 2.0 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 seven manuals comprising the suite of HDM-4 documentation (see Figure 1).

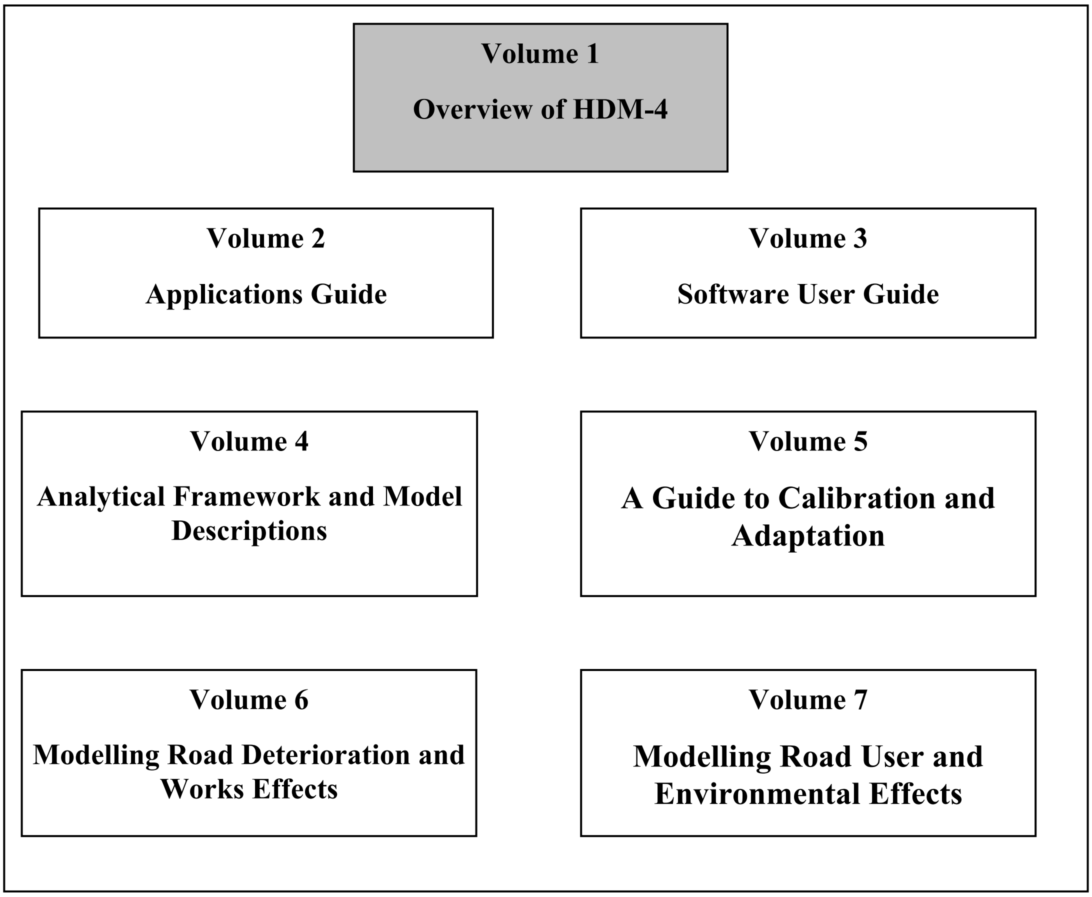

Figure 1 HDM-4 documentation suite

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.

- **Modelling Road Deterioration and Works Effects (Volume 6)**

  Describes the development and basis for the relationships in HDM-4 used for modelling road deterioration and works effects.

- **Modelling Road User and Environmental Effects (Volume 7)**

  Describes the development and basis for the relationships in HDM-4 used for modelling road user and environmental effects.

Notes:

1 Volumes 1, 2 and 3 are designed for the general user.

2 Volumes 4, 5, 6 and 7 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.

  - Vehicle Fleet

    Defines the characteristics of vehicles in the fleet that operate on the road network being analysed.

  - Road Network Manager

    Defines the road sections in the network or sub-network to be 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 - 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.

HDMGlobal 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

A first edition (Version 1) of Volume 1 was produced in 2000.

This is the second edition (Version 2.0) of Volume 1 of the HDM-4 documentation.

HDM-4 documents

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

Volume 1 - Overview of HDM-4, ISBN: 2-284060-183-4

Volume 2 - Applications Guide, ISBN: 2-284060-184-2

Volume 3 - Software User Guide, ISBN: 2-284060-185-0

Volume 4 - Analytical Framework and Model Descriptions, ISBN: 2-284060-186-9

Volume 5 - A Guide to Calibration and Adaptation, ISBN: 2-84060-063-3

Volume 6 - Modelling Road Deterioration and Works Effects, ISBN: 2-84060-102-8

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

Terminology handbooks

PIARC Lexicon of Road and Traffic Engineering - First edition. Permanent International Association of Road Congresses (PIARC), Paris 1991. ISBN: 2-84060-000-5

Technical Dictionary of Road Terms - Seventh edition, English - French. PIARC Commission on Terminology, Paris 1997. ISBN: 2-84060-053-6

General reference information

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Acknowledgements

The World Road Association (PIARC) has managed the International Study of Highway Development and Management (ISOHDM) project since 1998, following the action supported by the World Bank when the research and development efforts of several years reached the point when HDM Technology products could be brought into practice. Under PIARC management, the first products, the Highway Development and Management Series publications, and the software suite HDM-4 Version 1, were released in early 2000, dissemination was organized in addition to training of users. In 2002, PIARC launched the development of a Version 2 of the software.

The initial part of the development of HDM-4 has been sponsored by several agencies, primarily:

- **Asian Development Bank (ADB)**
- **Department for International Development (DFID)** in the United Kingdom
- **Swedish National Road Administration (SNRA)**
- **The World Bank**

with significant contributions made by:

- **Finnish Road Administration (FinnRA)**
- **Intra-American Federation of Cement Producers (FICEM)**

The development of Versions 1 and 2 has been made by funding from the World Road Association with sponsorship received from the governments of the following countries:

Algeria, Australia, Canada-Québec, France, Italy, Japan, Latvia, Madagascar, Mongolia, New-Zealand, Norway, Portugal, Sweden, Switzerland, Tanzania, United-Kingdom, USA

and from

- **Asian Development Bank (ADB)**
- **The World Bank.**

Many organisations and individuals in a number of countries have also contributed in terms of providing information, or undertaking technical review of products being produced.

The development of the software was carried out by the ISOHDM Technical Secretariat at the University of Birmingham in the United Kingdom. A number of organisations participated in the development including:

- **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, UK

  Responsible for system design and software development.

- **Laboratoire Central des Ponts et Chaussées (LCPC)** in France

  Responsible for overseeing the definition of the specifications for Version 2 and the software development.

- **Training and Research Institute (IKRAM)** in Malaysia supported by N D Lea International (NDLI)

  Responsible for providing updated relationships for road deterioration and road user costs.

- **TRL Limited** in the United Kingdom

  Responsible for review of the specifications of the bituminous pavement and unsealed road deterioration relationships.

- **ARRB Group Ltd** in Australia

  Responsible for review and update of bituminous pavement and unsealed road deterioration relationships.

- **SNRA**

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

All research organisations received support from local and regional staff, visiting experts and external advisers, to ensure that a high standard of quality and international consensus was achieved. A number of other countries and individuals have supported this work through supplying expert advice and reviewing the products.

Copyright statement

Contents

Volume 1 - Overview of HDM-4

Overview of HDM-4

1 Introduction

The Highway Design and Maintenance Standards Model (HDM-III), developed by the World Bank, was 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) was carried out between 1994 – 2000 to extend the scope of the World Bank HDM-III model, and to provide a harmonised systems approach to road management, with adaptable and user-friendly software tools. This resulted in Version 1 of the Highway Development and Management Tool (HDM-4), which was released in 2000.

The scope of HDM-4 Version 1 was 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 shows a view of the HDM-4 documentation suite comprising a series of seven 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 read 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, 5, 6 and 7 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. Version 2 of HDM-4 also includes the release of Volume 6 (Modelling Road Deterioration and Works Effects), and Volume 7 (Modelling Road User And Environmental Effects).

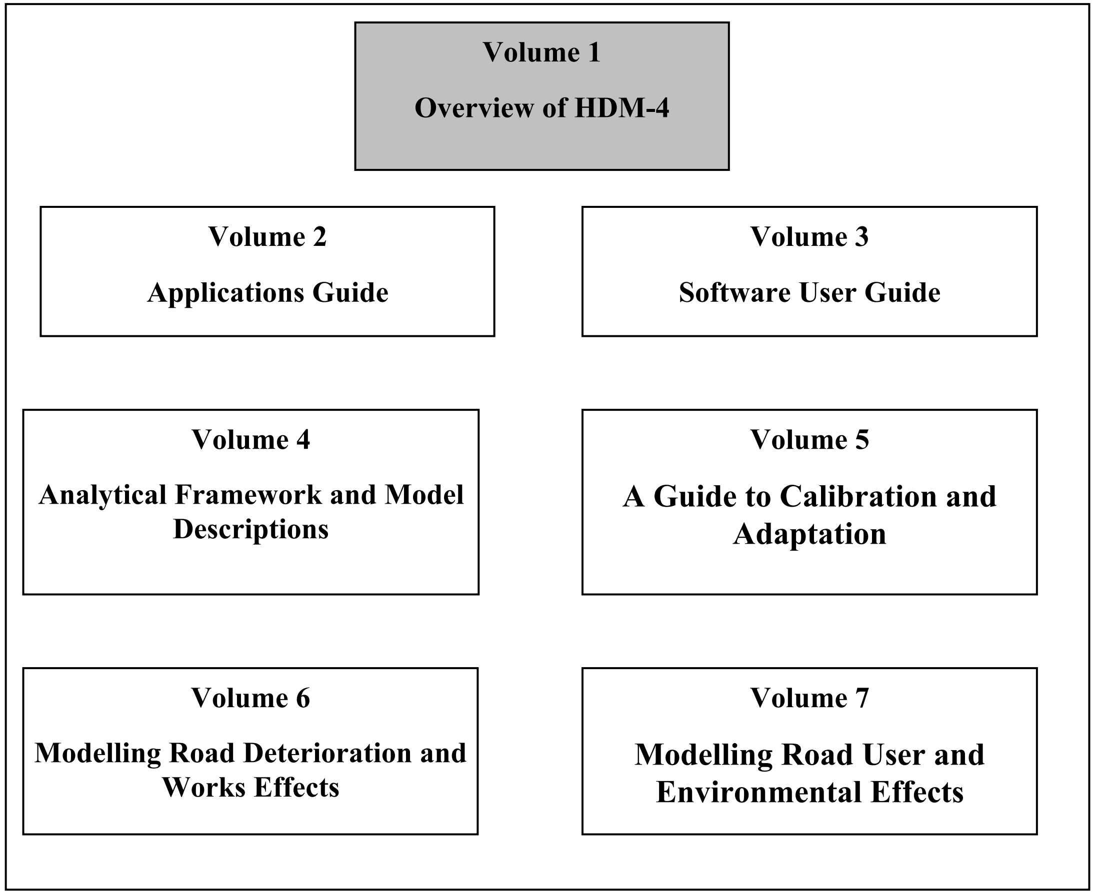


Figure 1 Documentation suite

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 Version 1 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.

2.3 Development of HDM-4 Version 2

Following the release of HDM-4 Version 1 it was used by government road administrations and agencies, transportation consultants, and education and transportation research institutions. Many feedback mechanisms where implemented to receive views on user satisfaction, user's requirements and enhancements to the existing software by the project team. Also PIARC undertook a survey of user opinions about the ISOHDM products and their impact on road management practice.

A commissioned study was conducted in 2000 of the requirements of senior management of road administrations for decision support for road investment planning *(McCoubrey, 2000)*. The reporting requirements identified by McCoubrey were delivered in the HDM-4 Version

1.2 update released in July 2001. The report also highlighted a three-tier structure necessary to target a wide range of users

- Level 1 – Senior Decision Maker. *Level 1 would utilise a reduced input data set and permit use of summary/aggregate data, primarily for high level strategy and policy analysis.*
- Level 2 – Practitioner. *Level 2 would provide a user interface for all HDM-4 applications, but utilise more detailed data than required in Level 1.*
- Level 3 – Systems Level. *Level 3 would permit adaptation of HDM-4 data and technical models to local conditions.*

A discussion paper on the requirements for improvements was produced by the ISOHDM Project (in particular the Technical Secretariat) which took into account the priority issues raised by HDM Technology users, together with identified technology demands to maintain market relevance. This discussion document was widely reviewed and the priorities were discussed by the World Road Council during a Seminar on Road Management and HDM-4, held with the Council meeting in Rome in October 2001. As a result the business case for HDM-4 Version 2 was drafted (*PIARC 2002*), and the improvements recommended implemented and released as HDM-4 Version 2.0 in August 2005 as is introduced in this document.

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 vehicle fleet which use the road network**
- **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**

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).

Table 3.1 Change in management processes

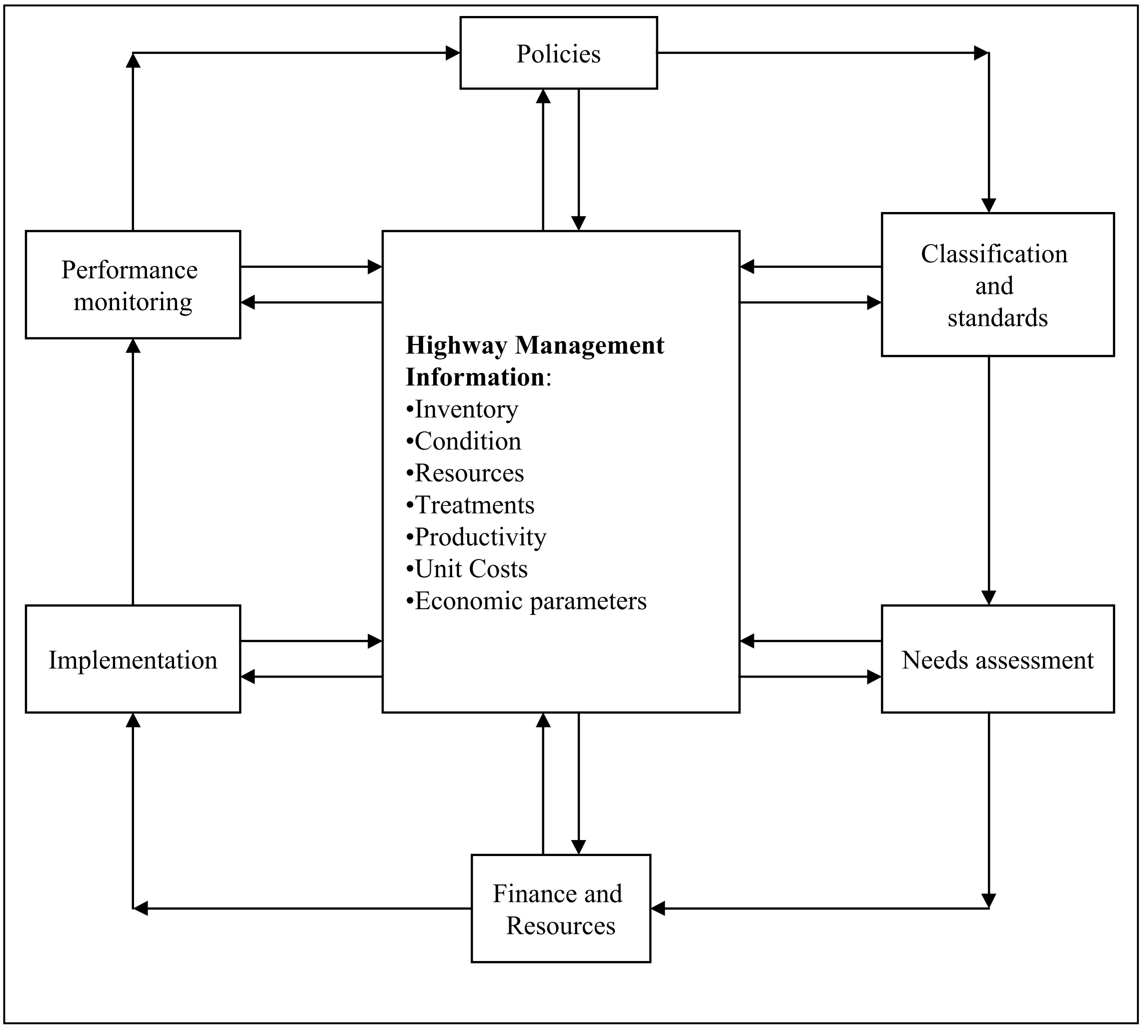
Activity	Time horizon	Staff responsible	Spatial coverage	Data detail	Mode of computer operation
Planning	Long term (strategic)	Senior management and policy level	Network-wide	Coarse/ summary	Automatic
Programming	Medium term (tactical)	Middle-level professionals	Network or sub-network	↓	↓
Preparation	Budget year	Junior professionals	Scheme level/ sections	↓	↓
Operations	Immediate/ very short term	Technicians/ sub-professionals	Scheme level/ sub-sections	Fine/detailed	Interactive

Source: *Paterson and Scullion (1990); Paterson and Robinson (1991)*

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.



Source: *Robinson et al. (1998)*

Figure 3.1 Highway management cycle

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

Management function	Common descriptions	HDM-4 applications
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.

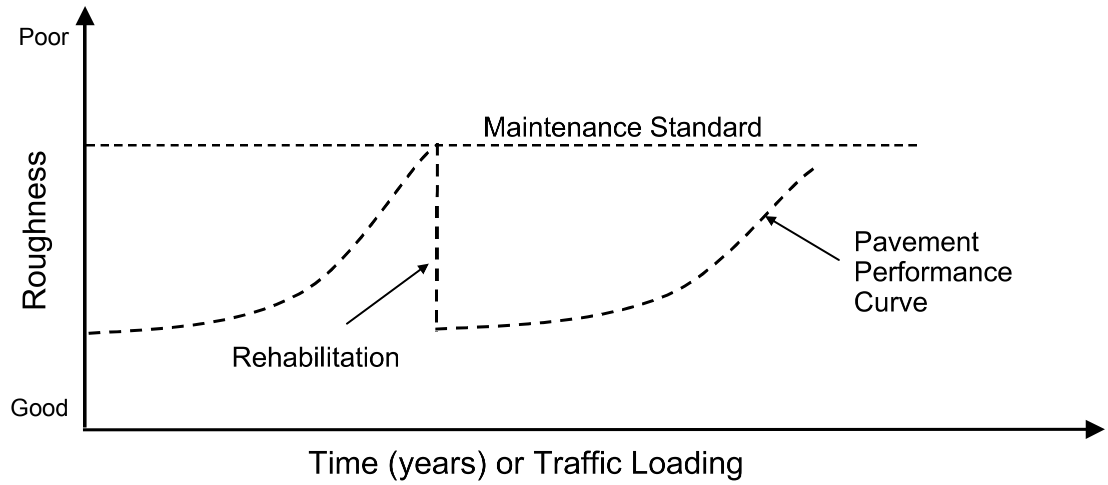


Figure 4.1 Concept of Life-cycle analysis in HDM-4

The impacts of the road condition, as well 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.

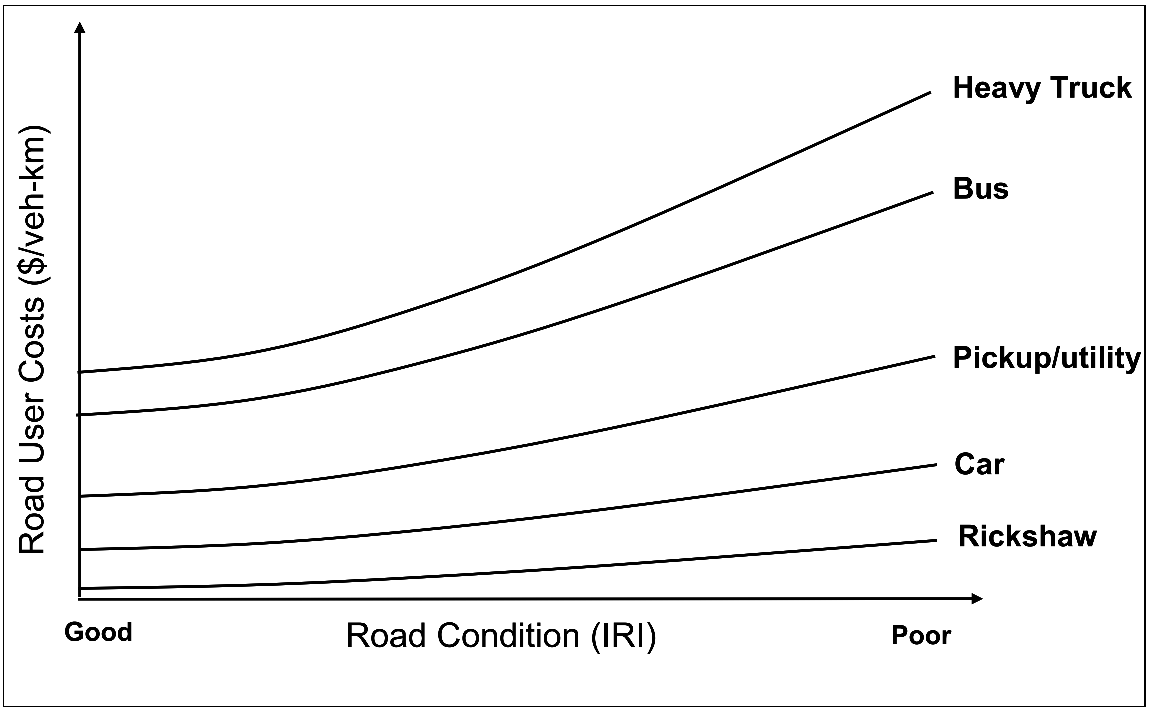


Figure 4.2 Effect of Road Condition on Vehicle Operating Costs for Rolling Terrain

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.

A road network represents a large part of a country's assets. Placing a financial value on the components of a road network highlights the importance of effective maintenance. Evaluating how the road network's asset value changes with time and investment strategies can provide decision makers with key information for the effective management, operation, preservation and enhancement of the road network. Users can use HDM-4 to determine the road network's asset value using Strategy, Programme, or Project analysis.

5.1.1 Asset Valuation

The purpose of preparing annual asset valuations for a road network is to provide a means of checking on the success or otherwise of the road authority in preserving the assets it holds on behalf of the nation. Assets can be valued in a number of ways. Most types of asset are included in the balance sheets of commercial firms at historical cost, less depreciation. When an asset is acquired and paid for, the amount paid is added into the firm's balance sheet. The value of the asset is then reduced annually, by the depreciation, an amount representing the consumption of the asset during each year. This valuation method is referred to as the *optimised* depreciation method.

Road asset components

For the implementation of road asset valuation in HDM-4, only the following components are relevant:

- Road formation, drainage channels, and sub-grade, i.e. earthworks
- Road pavement layers
- Footways, footpaths and cycle-ways
- Bridges and structures
- Traffic facilities, signs and road furniture

Other components of road assets not considered in HDM-4 include the following: land, buildings, plant and equipment, materials and supplies, existing plans and designs, and financial assets.

Basis of valuation

Depreciation accounting is based on the assumption that depreciation of the network equals the sum of the depreciation of all of the asset components making up the network. The basis of valuation used in HDM-4 Version 2 is as follows:

- The *Optimised Replacement Cost* (ORC) of each component of the road asset, which is defined in general terms as the cost of a replacement asset that most efficiently provides the same utility as the existing asset. This can be estimated to be equivalent to the initial financial cost of construction, adjusted to current year prices.
- The *Optimised Depreciated Replacement Cost* (ODRC) of each component; ODRC is the replacement cost of an existing asset after deducting an allowance for wear or consumption to reflect the remaining useful life of the asset. The depreciation can be modelled using straight line depreciation, production-based depreciation, or condition based depreciation.

The ODRC methods are used for valuation of the road components in HDM-4 Version 2 are as follows:

- The *Straight line depreciation* yields a fixed annual loss in the value of an asset component.
- *Production based depreciation* estimates the annual economic benefit or consumption of the asset component. In HDM-4, this can be measured in terms of the cumulative annual equivalent standard axle loads (paved roads) or the cumulative annual gravel loss (unsealed roads).
- *Condition-based depreciation* is based on the ratio of the current condition to the estimated terminal condition of the asset, measured in terms of the pavement roughness (IRI).

The relevant basis of valuation and depreciation method for the road components considered in HDM-4 is presented in Table 7.2.

Table 5.1. Valuation methods for road assets considered in HDM-4

Feature/component	Basis of valuation	Depreciation method
Road formation and sub-grade	ORC	
Road pavement layers	ODRC	Production or Condition-based
Footways, footpaths, cycle-ways, and NMT lanes	ODRC	Straight Line
Bridges and structures	ODRC	Straight Line
Traffic facilities, signs and road furniture	ODRC	Straight Line

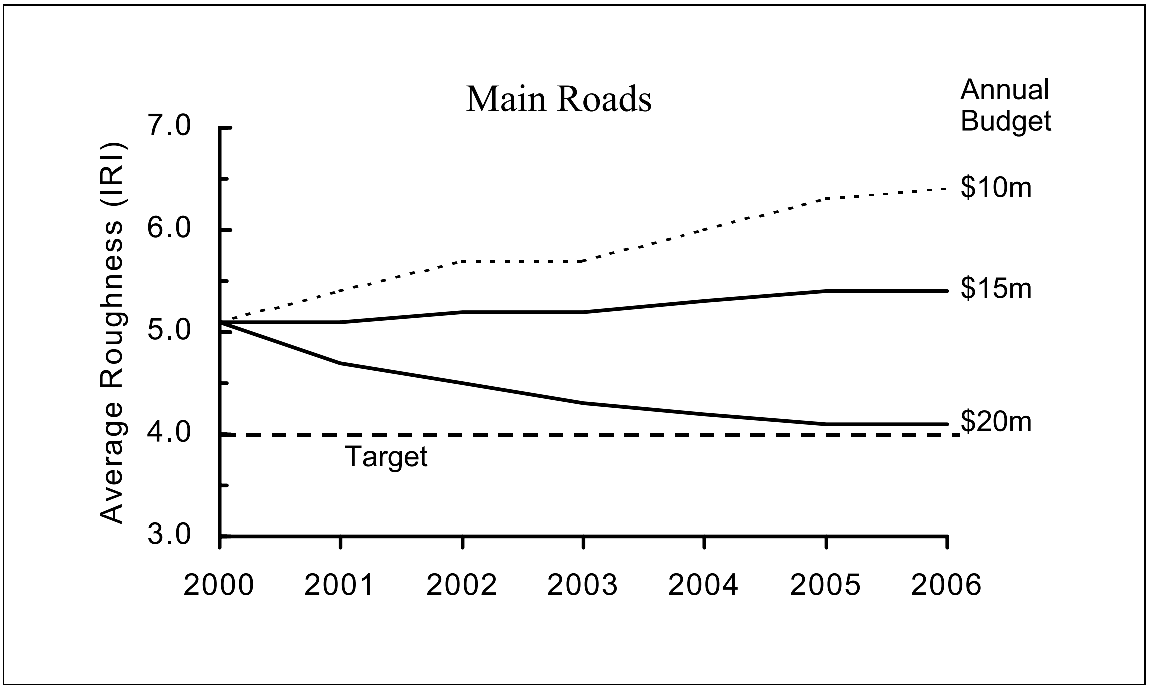


Figure 5.1a Effect of funding levels on road network performance

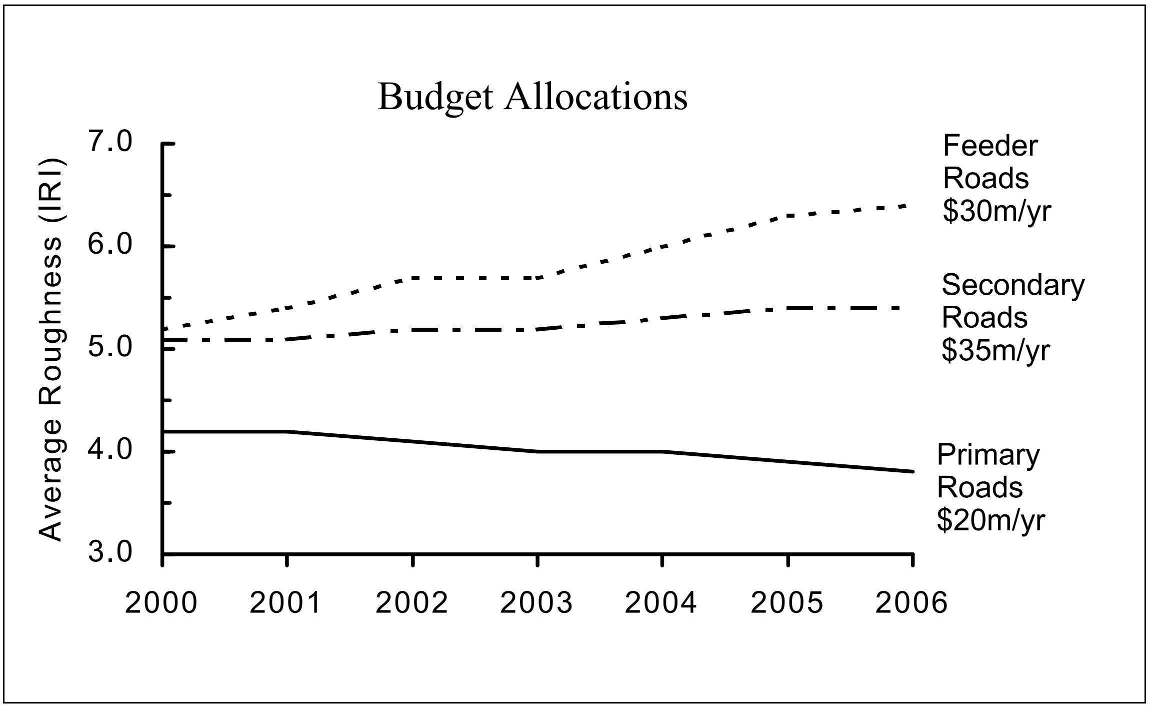


Figure 5.1b Effect of budget allocations on sub-network performance

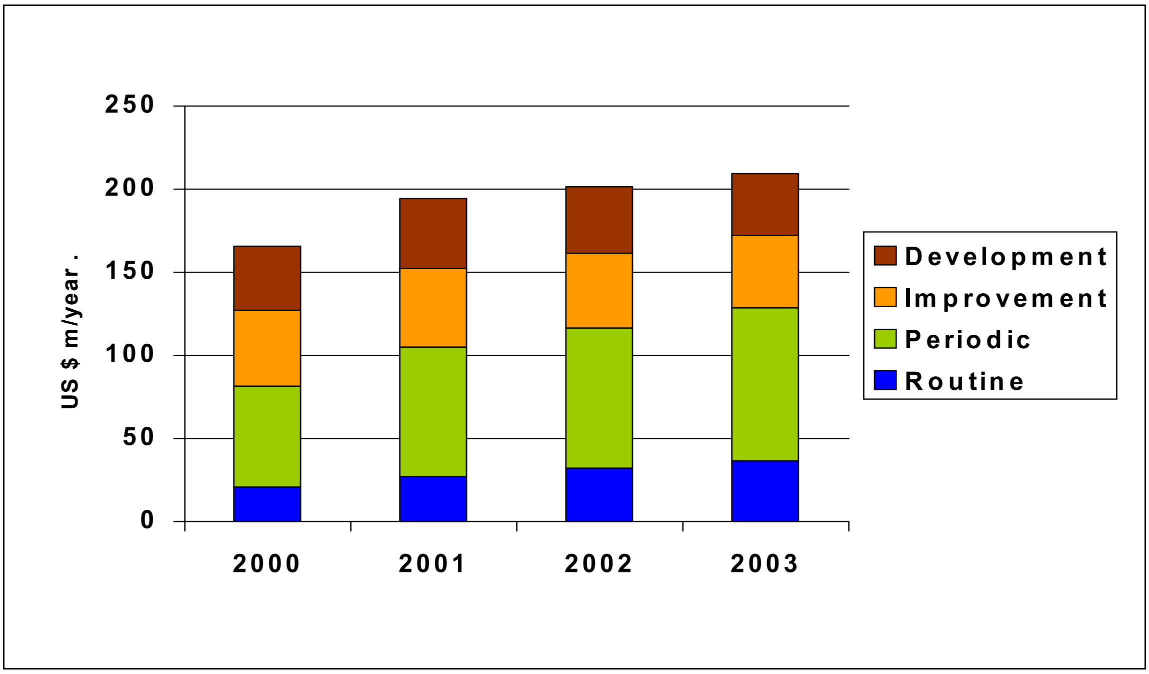


Figure 5.1c Optimal budget allocations to sub-heads

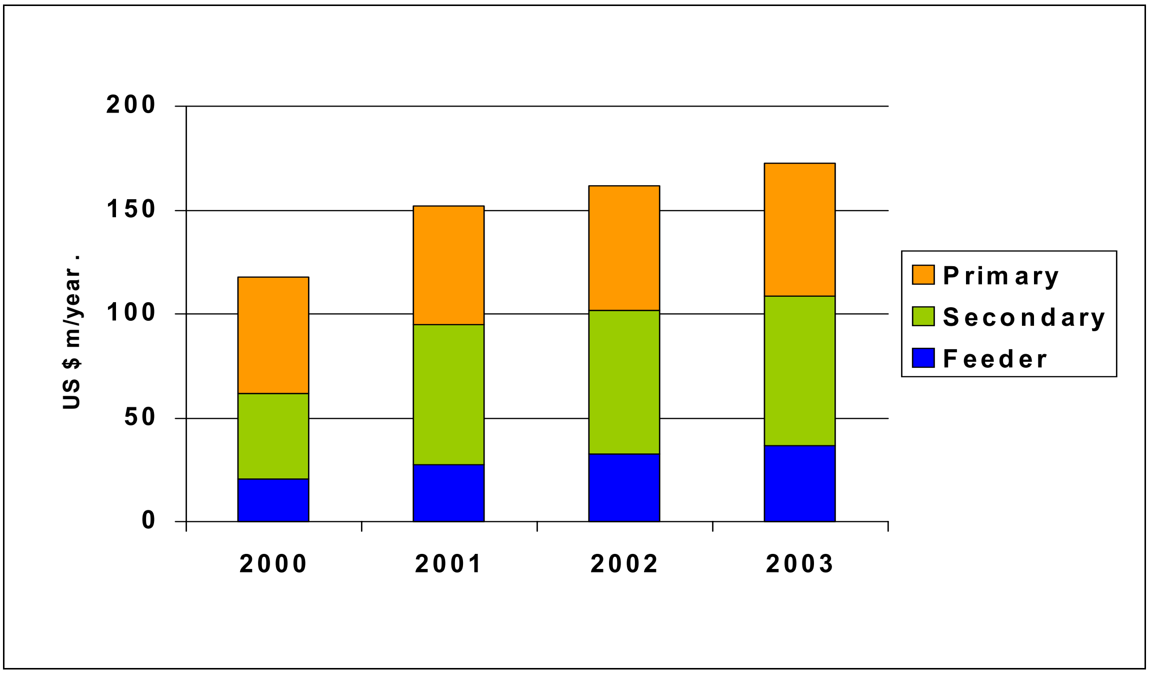


Figure 5.1d Optimal budget allocations to sub-networks

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. Each budget constraint defines a Budget Scenario. 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.**

5.2.1 Budget Scenario Analysis

The amount of financial resources available to a road agency determines what road investment works would be affordable. The level of budget is not always constant over time due to a variety of factors including competing demands from other sectors, changes in a country's macro economic performance, etc. This variation of budget levels over time affects the functional standards as well as the size of road network that can be sustainable. Programme or Strategy Analysis applications provides for several budget scenarios to be specified and optimised simultaneously. This permits comparisons to be made between the effects of different budget scenarios and to produce desired reports. A budget scenario represents the available resources defined for each budget period, excluding the costs of annual routine maintenance and special works.

5.2.2 Multi-year Work Programme

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.

Priority Rank	Road Section	Length (km)	Province or District	Type of Road Work	Scheduled Year	Cost $m	Cumulative S$m
1	N1-2	20.5	2	Resealing	2000	5.4	5.4
2	N4-7	23.5	7	Overlay 40mm	2000	10.9	16.3
3	N2-5	12.5	5	Reconstruct	2000	8.6	24.9
4	R312-1	30	4	Widen 4 lane	2000	31.4	56.3
5	R458-3	36.2	3	Overlay 60mm	2000	16.3	72.6
:	:	:	:	:	:	:	:
1	N4-16	32.1	6	Reconstruct	2001	22.8	22.8
2	R13-23	22.4	4	Overlay 40mm	2001	9.7	32.5
3	N521-5	45.2	2	Widen 4 lane	2001	41.3	73.8
:	:	:	:	:	:	:	:
1	N1-6	30.2	4	Resealing	2002	8.2	8.2
2	N7-9	17.8	3	Overlay 60mm	2002	9.2	17.4
3	F2140-8	56.1	1	Reconstruct	2002	34.9	52.3
:	:	:	:	:	:	:	:

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

				2000		2001		2002		2003	
Priority Rank	Road Section	Length (km)	Province or District	Road Work	Cost $m	Road Work	Cost $m	Road Work	Cost $m	Road Work	Cost $m
1	N1-2	20.5	2	RESEAL	5.4	R.M.	0.185	R.M.	0.185	R.M.	0.185
2	N4-7	23.5	7	OVL40MM	10.9	R.M.	0.212	R.M.	0.212	R.M.	0.212
3	N2-5	12.5	5	RECON	8.6	R.M.	0.113	R.M.	0.113	R.M.	0.113
4	R312-1	30	4	WIDEN-4	31.4	R.M.	0.180	R.M.	0.180	R.M.	0.180
5	R458-3	36.2	3	OVL60MM	16.3	R.M.	0.217	R.M.	0.217	R.M.	0.217
:	:	:	:	:	:	:	:	:	:	:	:
16	N4-16	32.1	6	R.M.	0.289	RECON	22.8	R.M.	0.289	R.M.	0.289
17	R13-23	22.4	4	R.M.	0.134	OVL40MM	9.7	R.M.	0.134	R.M.	0.134
18	N521-5	45.2	2	R.M.	0.407	WIDEN-4	41.3	R.M.	0.407	R.M.	0.407
:	:	:	:	:	:	:	:	:	:	:	:
28	N1-6	30.2	4	R.M.	0.272	R.M.	0.272	RESEAL	8.2	R.M.	0.272
29	N7-9	17.8	3	INLAY	0.240	R.M.	0.200	OVL60MM	9.2	R.M.	0.160
30	F2140-8	56.1	1	PATCH	0.202	R.M.	0.202	RECON	34.9	R.M.	0.168

Note: RM = Routine Maintenance

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

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**
- **Preservation of the road network's asset value**
- **Sensitivity of a road project measured by technical and economic indicators to changes in one parameter**
- **Viability of a road project to the road project subject to a broad range of input scenarios**.

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. The road network's depreciating asset value and the impact road maintenance and improvements can be included to determine the success or otherwise of project in preserving the assets.

> **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.

The technical and economic assessment of road investment projects does not explicitly consider social, political and environmental aspects of road investments, and does not necessarily correctly reflect the desired priorities for investments by all stakeholders. For example, the following:

- a low trafficked rural road that serves a socially sensitive area
- strategic importance, for example, roads connecting the main airport with the capital city

For these instances where non-quantifiable factors should be considered when prioritising road investments, HDM-4 provides Multi-criteria Analysis.

5.3.1 Multi-Criteria Analysis

Multi-criteria analysis provides a systematic framework for breaking a problem into its constituent parts in order to understand the problem and consequently arrive at a decision. It provides a means to investigate a number of choices or alternatives, in light of conflicting priorities. By structuring a problem within the multiple criteria analysis framework, road investment alternatives may be evaluated according to pre-established preferences in order to achieve defined objectives.

MCA requires clear definition of possible alternatives, together with the criteria under which the relative *performance* of the *alternatives* in achieving pre-established *objectives* is to be measured. Thereafter it requires the assignment of *preferences* (i.e. a measure of relative importance, or weighting) to each of the criteria.

Perhaps the most important component of the MCA process is the identification of the *objectives* relevant to the problem of defining investment alternatives, together with their associated *criteria*. For example, from an *economic* viewpoint, the main objective would be the minimisation of total transport costs (i.e. maximisation of NPV), and from an *environment* viewpoint the objective would be minimisation of all negative impacts of traffic and road works. The multi-criteria prioritisation of investment alternatives depends on the relative importance (or weights) assigned to each criterion. Ideally, weights should be determined in consultation with all stakeholders.

Table 5.2 Criteria Supported in HDM-4 Multi-criteria Analysis

Category	Criteria/Objectives	Attributes
Economic	Minimise road user costs (RUC)	Total road user costs are calculated internally within HDM-4 for each alternative.
	Maximise net present value (NPV)	Economic net benefit to society is calculated internally within HDM-4 for each alternative.
Safety	Reduce accidents	Total number and severity of road accidents. These are calculated internally within HDM-4.
Functional service level	Provide comfort	Provide good riding quality to road users. This is defined on the basis of average IRI (international roughness index). The average IRI is calculated internally within HDM-4.
	Reduce road congestion	Delay and congestion effects. Level of congestion is defined in terms of volume-capacity ratio (VCR). VCR values are calculated internally within HDM-4.
Environment	Reduce air pollution	Air pollution is measured in terms of quantities of pollutants from vehicle emissions, which are computed internally within HDM-4.
Energy	Maximise energy efficiency	Efficiency in both global and national energy use in the road transport sector. Energy use is calculated internally within HDM-4.
Social	Maximise social benefits	Social benefits include improved access to social services (e.g. schools, health centres, markets, etc.). A representative value is externally user-defined for each alternative.
Political	Consider political issues	Fairness in providing road access, promotion of political stability, strategic importance of roads, etc. A representative value is externally user-defined for each alternative.

5.3.2 Social Benefits and Costs

Although there are no universally accepted models for estimating the social benefits derived from road improvements, it is generally acknowledged that the provision of basic access through low cost roads provides benefits to communities that live alongside such roads. HDM-4 provides facilities for users to specify the social benefits and/or costs that are to be included in the HDM-4 economic analysis. HDM-4 makes it explicit where user-defined social benefits and costs can be specified where the appropriate descriptions are used for reporting purposes.

Social benefits and costs can also be included in Programme and Strategy analyses.

5.3.3 Sensitivity and Scenario Analysis

Sensitivity analysis is used to study the effects of changes in one parameter on the overall viability of a road project as measured by various technical and economic indicators. This analysis should indicate which of the parameters examined are likely to have the most significant effect on the feasibility of the project because of the inherent uncertainty. **Scenario** analysis is used to determine the broad range of parameters which would affect the viability of a road project. For example, a review of government long-term development plans could yield alternative economic growth rates. Investment projects should be chosen on their ability to deliver a satisfactory level of service across a range of scenarios. In this way, the economic return of a project need not be the sole criterion since social and strategic reasons can also be taken into account.

For all the three applications (Project, Programme and Strategy analysis) the underlying operation of HDM-4 is based on the concept of life cycle analysis under a user-specified scenario of circumstances. A scenario is represented by a complete set of HDM-4 input data. Several scenarios can be specified to be analysed simultaneously. In project analysis, scenarios are defined based on the requirements to conduct sensitivity analysis, whereas in Programme and Strategy analysis, scenarios are defined based on different budget levels to be optimised.

The important variables that should normally be considered in a sensitivity analysis using HDM-4 are:

- Traffic levels – baseline flows and future growth rates
- Vehicle use - loading and utilisation
- Net benefits streams – reflecting variations in transport costs

The choice of which variables to test will depend upon the kind of study being conducted and is a matter of judgement on the part of the user.

Traffic Levels

The economic viability of most road investment projects will depend significantly on the traffic data used. However, it is difficult to obtain reliable estimates of traffic and to forecast future growth rates. Thus sensitivity analysis should be carried out, both of baseline flows and of forecast growth.

Vehicle Use

Several parameters related to vehicle loading and annual utilisation can be used to conduct for sensitivity analysis on the economic indicators (IRR, NPV). The vehicle use parameters include the average vehicle operating weight, equivalent standard axle load factor, baseline annual number of vehicle kilometres, and baseline annual number of working hours. The impact of these parameters can be studied by specifying multiplication factors to adjust the ‘base’ values for each scenario.

Net Benefits Streams

The total net benefits stream can be adjusted separately for three components, namely:

- Net benefits from savings in road agency costs
- Net benefits from savings in road user costs
- Net benefits related to savings in exogenous costs

Multiplication factors can be specified to adjust the above factors in order to perform the sensitivity analysis.

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:

- **Vehicle Fleet**

  Defines the characteristics of the vehicle fleet that operate on the road network to be analysed.

- **Road Network**

  Defines the physical characteristics of road sections in a network or sub-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.

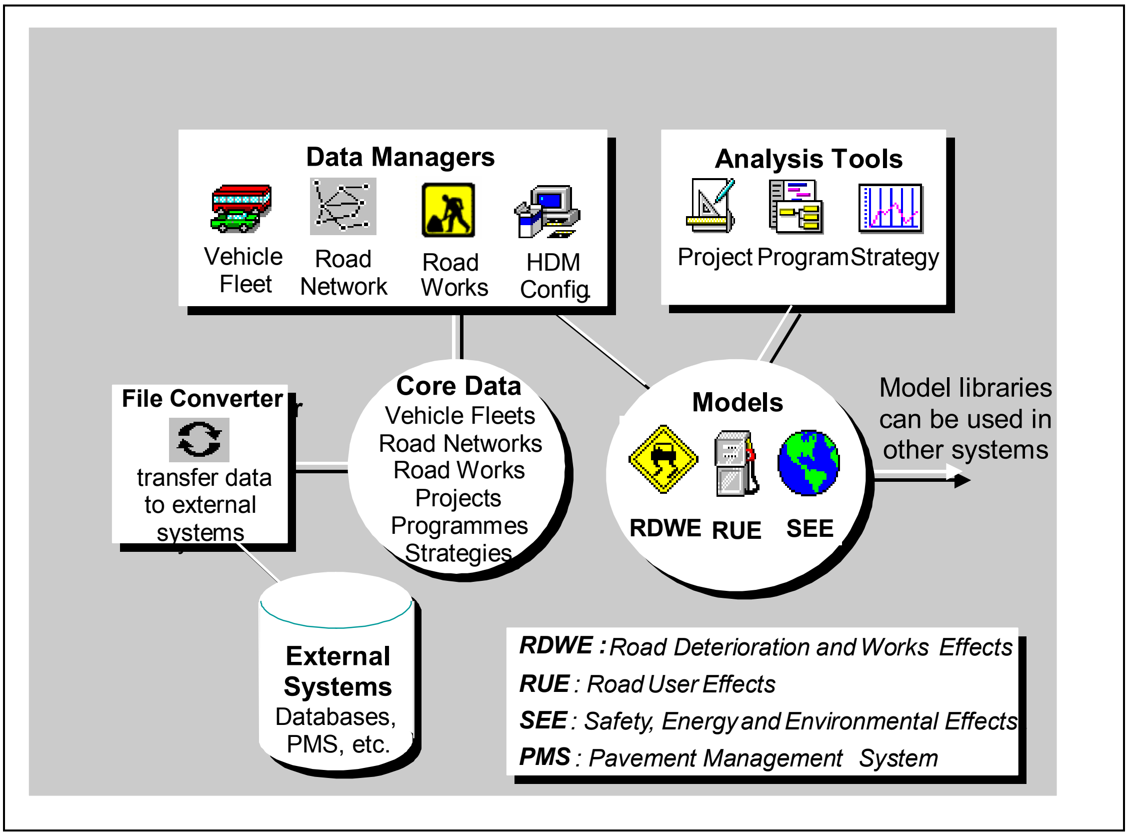


Figure 6.1 HDM-4 System Architecture

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 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.

7.4 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**

  A section may make reference to a link description for purposes of compatibility of the network referencing system with existing pavement management systems.

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.

7.5 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. New construction sections may also be defined. 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, and 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. 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. Comprehensive online documentation is provided in the form of the HDM-4 documentation series, of which this volume forms part. Figure 9.1 illustrates the HDM-4 Workspace. Detailed instructions for the operation of the individual modules are given in the Software User Guide - Volume 3.

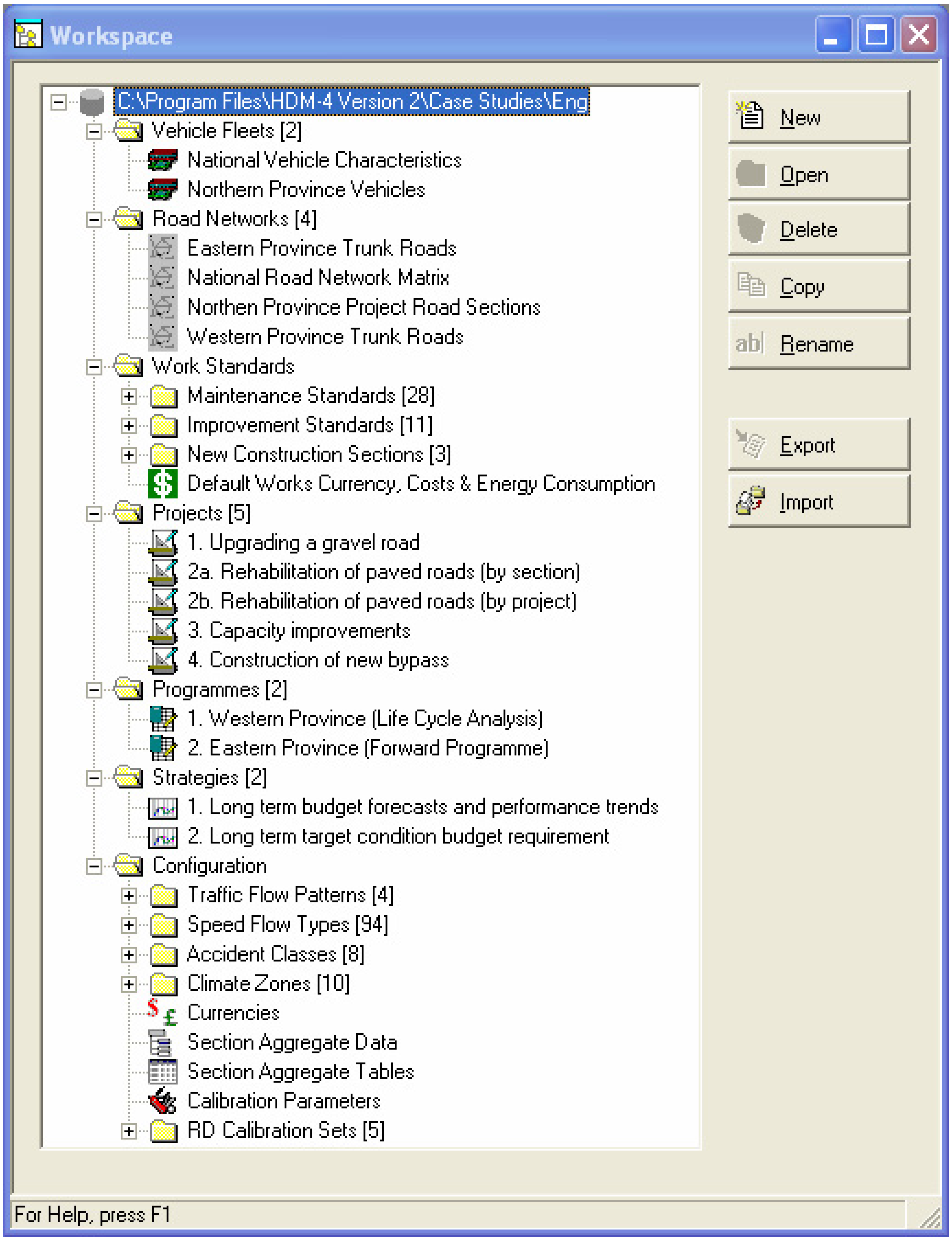


Figure 9.1 HDM-4 Workspace

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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 (**high**, **medium**, **low**), and three pavement condition classes (**good**, **fair**, **poor**), and the unpaved road network has been categorised into two traffic categories only (**medium** and **low**). The resulting road network matrix is summarised in Table A.1:

Table A.1
Road Network Length in each Matrix Category

	Traffic categories		
Paved roads:	**High** (AADT > 4000)	**Medium** (4000>AADT>1000)	**Low** (AADT < 1,000)
Good condition	234 km	306 km	410 km
Fair condition	392 km	483 km	670 km
Poor condition	437 km	615 km	720 km
Unpaved roads:		**Medium** (AADT > 100)	**Low** (AADT < 100)
Gravel surface		1,760 km	1,385 km

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 that could be generated from HDM-4 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).

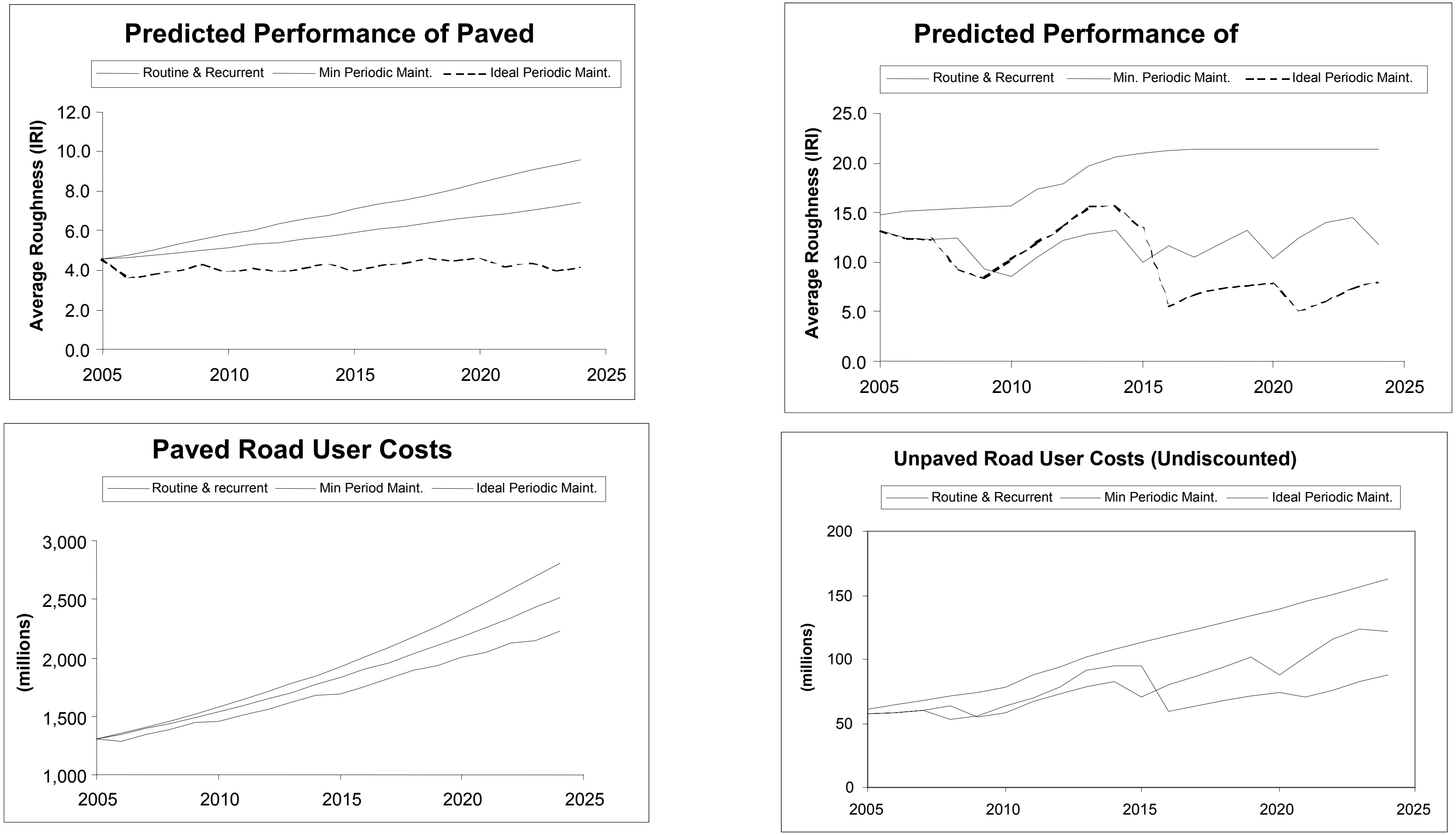


Figure A.1 Summary Output from HDM-4 Strategy Analysis

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 that could be generated from HDM-4 can be summarised as 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 Unrestrained Work Programme

HDM-4 **Unconstrained Work Programme**

Study Name: **Western Province 3 Year Road Investment Programme** Run Date: **19-08-2005**

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

Road No.	Section	Length (km)	AADT	Year	Work Description	NPV/C	Financial Costs	Cumulative Costs	Equivalent US$(m)
MSC 112	km 35 - 80	21.0	1711	2005	Overlay 50mm	4.91	23.15	23.15	0.609
MSE 203	km 80 - 90	10.0	1152	2005	Overlay 50mm	2.51	11.03	34.18	0.899
MSC 138	km 5 - 10 & 65 - 70	10.0	1271	2005	Single Seal	2.41	3.80	37.98	0.999
MAN 446	km 53.7 - 57.0	3.3	983	2005	Overlay 50mm	2.40	3.31	41.29	1.086
MSE 932	km 36.2 - 52.2	16.0	809	2005	Overlay 50mm	2.19	17.64	58.93	1.551
MSE 334	km 3.8 - 12.8	9.0	932	2005	Overlay 50mm	1.98	9.92	68.85	1.812
MAN 203	km 185 - 190	5.0	1248	2005	Single Seal	1.72	1.90	70.75	1.862
MAN 243	km 0 - 21	21.0	1009	2005	Overlay 50mm	1.55	23.15	93.90	2.471
MTS 549	km 0 - 1.0	1.0	2438	2005	Overlay 50mm	1.37	1.10	95.00	2.500
MSC 142	km 12.5 - 20	7.5	942	2005	Single Seal	0.98	3.04	98.04	2.580
MSW 131	km 10 - 16.5	6.5	428	2005	Overlay 50mm	0.92	7.72	105.76	2.783
MSW 905	km 128 - 170	42.0	717	2005	Single Seal	0.92	15.96	121.73	3.203
MSV 449	km 45 - 59.6	14.6	671	2005	Single Seal	0.46	5.70	127.43	3.353
MTN 748	km 30 - 60	30.0	589	2005	Single Seal	0.21	11.40	138.83	3.653
MTN 831	km 0 - 3.7	3.7	205	2005	Overlay 50mm	0.17	4.41	143.24	3.770

HDM-4 Unconstrained Work Programme

Study Name: **Western Province 3 Year Road Investment Programme** Run Date: **19-08-2005**

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

Road No.	Section	Length (km)	AADT	Year	Work Description	NPV/C	Financial Costs	Cumulative Costs	Equivalent US$(m)
MTN 830	km 8.6 - 20	11.4	680	2005	Pavement Reconstruction	0.10	51.63	194.87	5.128
MTN 805	km 145 - 152.6	7.6	844	2005	Pavement Reconstruction	0.05	37.80	232.67	6.123
MSW 901	km 180 - 330	60.0	1623	2006	Overlay 50mm	3.16	66.15	298.82	7.864
MSV 537	km 43 - 45	2.0	937	2006	Overlay 50mm	1.42	2.21	301.03	7.922
MSW 935	km 16 - 30	14.0	532	2006	Overlay 50mm	0.33	15.44	316.46	8.328
MSC 131	km 16.5 - 26	9.5	2253	2007	Overlay 50mm	4.91	11.03	327.49	8.618
MSC 141	km 28 - 49.5	21.5	2253	2007	Overlay 50mm	4.88	24.26	351.74	9.256
MSW 956	km 10 - 75	30.0	1733	2007	Overlay 50mm	3.31	33.08	384.82	10.127
MSC 155	km 50 - 55	5.0	1353	2007	Overlay 50mm	2.61	5.51	390.33	10.272
MSW 938	km 3.2 - 10	6.8	913	2007	Overlay 50mm	1.30	7.72	398.05	10.475
MSW 150	km 0.0 - 16.5	16.5	800	2007	Overlay 50mm	0.99	18.74	416.79	10.968
MAN 214	km 90 - 97.7	7.7	759	2007	Overlay 50mm	0.86	8.82	425.61	11.200
MAN 409	km 110 - 115	5.0	512	2007	Overlay 50mm	0.28	5.51	431.12	11.345

Table B.1b Restrained Work Programme

HDM-4 Constrained Work Programme

Study Name: **Western Province 3 Year Road Investment Programme** Run Date: **19-08-2005**

All costs are expressed in: Local Currency (millions). Available Budget: **300 million (2005 – 2007)**

Road No.	Section	Length (km)	AADT	Year	Work Description	NPV/C	Financial Costs	Cumulative Costs	Equivalent US$(m)
MSC 112	km 35 - 80	21.0	1711	2005	Overlay 50mm	4.91	23.15	23.15	0.609
MSE 203	km 80 - 90	10.0	1152	2005	Overlay 50mm	2.51	11.03	34.18	0.899
MSC 138	km 5 - 10 & 65 - 70	10.0	1271	2005	Single Seal	2.41	3.80	37.98	0.999
MAN 446	km 53.7 - 57.0	3.3	983	2005	Overlay 50mm	2.40	3.31	41.29	1.086
MSE 932	km 36.2 - 52.2	16.0	809	2005	Overlay 50mm	2.19	17.64	58.93	1.551
MSE 334	km 3.8 - 12.8	9.0	932	2005	Overlay 50mm	1.98	9.92	68.85	1.812
MAN 203	km 185 - 190	5.0	1248	2005	Single Seal	1.72	1.90	70.75	1.862
MAN 243	km 0 - 21	21.0	1009	2005	Overlay 50mm	1.55	23.15	93.90	2.471
MTS 549	km 0 - 1.0	1.0	2438	2005	Overlay 50mm	1.37	1.10	95.00	2.500
MSC 142	km 12.5 - 20	7.5	942	2005	Single Seal	0.98	3.04	98.04	2.580
MSW 131	km 10 - 16.5	6.5	428	2005	Overlay 50mm	0.92	7.72	105.76	2.783
MSW 905	km 128 - 170	42.0	717	2005	Single Seal	0.92	15.96	121.73	3.203
MSW 901	km 180 - 330	60.0	1623	2006	Overlay 50mm	3.16	66.15	187.88	4.944
MSV 537	km 43 - 45	2.0	937	2006	Overlay 50mm	1.42	2.21	190.08	5.002

... Continued

HDM-4 **Constrained Work Programme**

Study Name: **Western Province 3 Year Road Investment Programme** Run Date: **19-08-2005**

All costs are expressed in: Local Currency (millions). Available Budget: **300 million (2005 – 2007)**

Road No.	Section	Length (km)	AADT	Year	Work Description	NPV/C	Financial Costs	Cumulative Costs	Equivalent US$(m)
MSC 131	km 16.5 - 26	9.5	2253	2007	Overlay 50mm	4.91	11.03	201.11	5.292
MSC 141	km 28 - 49.5	21.5	2253	2007	Overlay 50mm	4.88	24.26	225.36	5.931
MSW 956	km 10 - 75	30.0	1733	2007	Overlay 50mm	3.31	33.08	258.44	6.801
MSC 155	km 50 - 55	5.0	1353	2007	Overlay 50mm	2.61	5.51	263.95	6.946
MSW 938	km 3.2 - 10	6.8	913	2007	Overlay 50mm	1.30	7.72	271.67	7.149
MSW 150	km 0.0 - 16.5	16.5	800	2007	Overlay 50mm	0.99	18.74	290.41	7.642
MAN 214	km 90 - 97.7	7.7	759	2007	Overlay 50mm	0.86	8.82	299.23	7.874

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)

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 2004. The gravel thickness in 2004 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 2003. Non-motorised transport contributed an extra 400 **vehicles** in 2003, 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 2005 and duration 20 years (that is, 2005 - 2024). 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 (2005-2006). The maintenance regime of Alternative 1 (Routine + 50 mm overlay), which is condition responsive, is effective from year 3 (2007).
3	With this alternative, the existing road is widened by 3 m during the period (2005-2006). The condition responsive maintenance regime of Alternative 1 is effective from year 3 (2007).
4	With this alternative, the existing road is widened by adding two lanes during the period (2005-2007). The condition responsive maintenance regime of Alternative 1 (Routine + 50 mm Overlay) is effective from year 4 (2008).

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 generated from HDM-4 would indicate that Alternatives 3 and 4 give a positive NPV, whereas Alternative 2 (widening by 1m only) gives a negative value of NPV.

Alternative	Widening	NPV (US$ millions)
2	1m	-3.31
3	3m	+6.69
4	2 lanes	+12.18

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 proposed project is the construction of a bypass, represented by Section E, which is 10 km long.

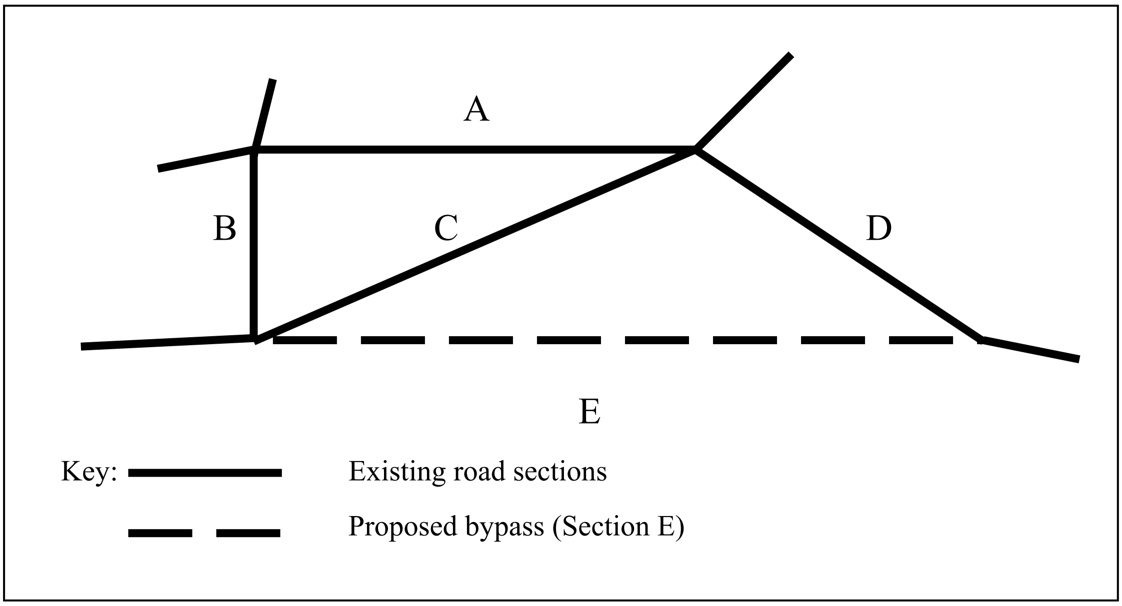


Figure C.1 Construction of a new bypass

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 2005 to 2024).

Alternative	Description
1	This alternative represents the **base case** situation without the bypass.
2	Construct Section E: A two-lane AMGB (Asphalt Mix on Granular Base) road, with a two-year construction period (2005-2006), and opening in year 2007.
3	Construct Section E: A wide two-lane AMGB road, with a three-year construction period (2005-2007), and opening in year 2008.
4	Construct Section E: A four-lane AMGB road, with a four-year construction period (2005-2008), and opening year 2009.

C.6.3 Traffic Diversion

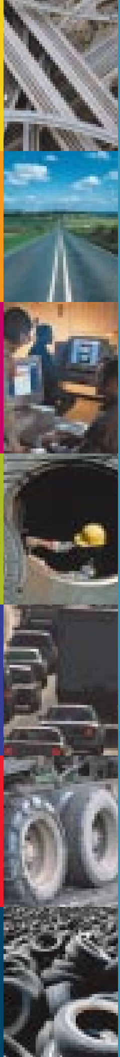
The construction of the bypass (Section E) will cause a significant redistribution of traffic between the existing roads and the new road. The table below summarises the expected change in normal traffic after completion of the new section.

Section	AADT (2003) before bypass	AADT bypass opening year
A	10,000	10,000
B	4,000	4,000
C	6,000	1,000
D	8,000	3,000
E	n/a	5,000

C.6.4 Results

The Economic Analysis Summary that could be generated from HDM-4 would indicate 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.

Alternative	New Section Option	NPV (US$ millions)	EIRR (%)
2	Standard 2 lane	66.360	66.71
3	Wide 2 lane	60.355	52.25
4	Standard 4 lane	49.820	35.69



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