HDM-4

HIGHWAY DEVELOPMENT & MANAGEMENT

volume **two**

Applications Guide

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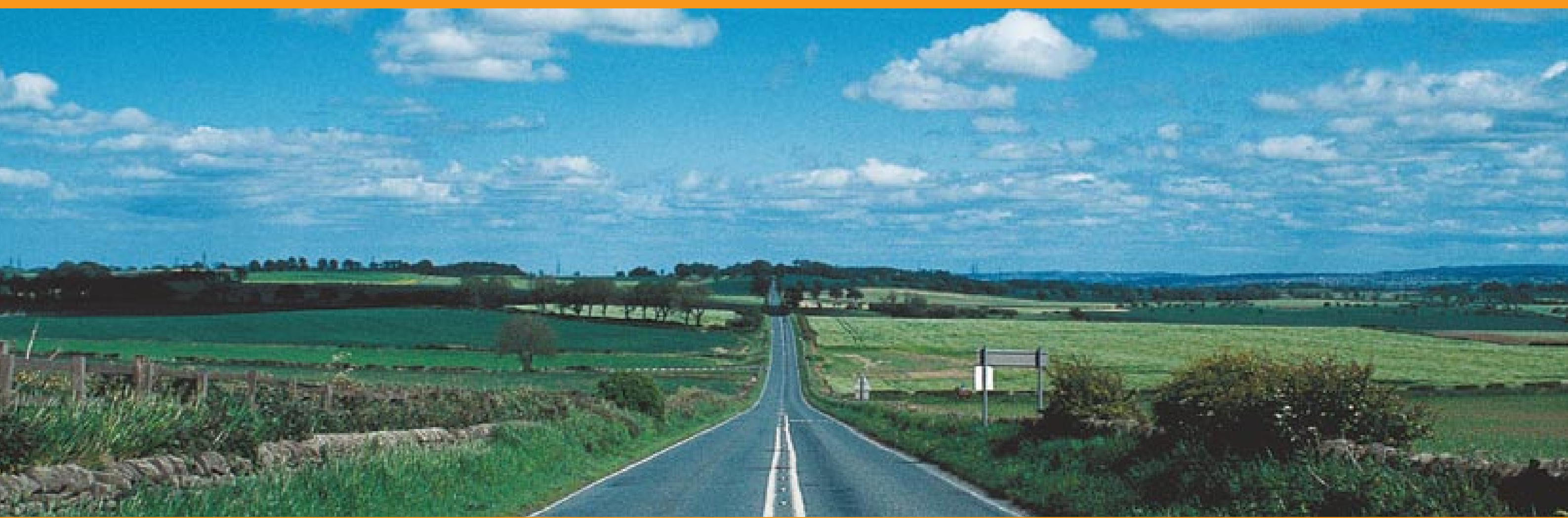

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THE HIGHWAY DEVELOPMENT AND MANAGEMENT SERIES

About This Manual

This manual is a task-oriented guide describing typical examples of different types of analyses using HDM-4 Version 2.0. It is designed for users that are familiar with HDM-4 who wish to know how to perform HDM-4 analyses or create a study. This manual is one of seven volumes comprising the suite of HDM-4 documentation as illustrated below.

Volume 1 **Overview of HDM-4**	
Volume 2 **Applications Guide**	**Volume 3** **Software User Guide**
Volume 4 **Analytical Framework and Model Descriptions**	**Volume 5** **A Guide to Calibration and Adaptation**
Volume 6 **Modelling Road Deterioration and Works Effects**	**Volume 7** **Modelling Road User and Environmental Effects**

The suite of documents comprises:

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 users who wish 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 used within the HDM-4 model. It contains comprehensive reference material describing 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-4 models to allow for local conditions existing in different countries.

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.

Structure of this Manual

The aim of this Applications Guide is to demonstrate the different applications of HDM-4 version 2.0 through selected case studies. The case studies are described in detail and may be reviewed using the data files included on the CD-ROM.

Part A contains a short description of the life-cycle analysis framework used in HDM-4. The concepts of analysis for projects, programmes and strategies are described in Parts B, C and D respectively. Example case studies for Project Analysis are given in Part E, Programme Analysis case studies in Part F and Strategy Analysis case studies in Part G.

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 *Applications Guide* should be sent to the following address:

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Change Details

The first edition of Volume 2 detailed case studies for HDM-4 version 1. This second edition details case studies for HDM-4 version 2.0.

Related 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 Manual, 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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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 organised 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**
- **The World Bank**
- **Swedish National Road Administration (SNRA)**

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 other 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 study has been co-ordinated by the ISOHDM Technical Secretariat at the University of Birmingham in the United Kingdom. A number of organisations participated in the research 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**

  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 the road deterioration relationships.

- **SNRA**

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

- **Australian Road Research Board (ARRB)**

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

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

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

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

APPLICATIONS GUIDE FOR HDM-4 VERSION 2

PART A CONCEPTS OF HDM-4 ANALYSIS

1 BACKGROUND

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 investment projects, and to analyse strategies and standards (Watanatada, et al, 1987 and Paterson, 1987). In the 1990's an international study was initiated 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 resulted in the development of 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, primarily in four key areas:

- **Project appraisal**

  For the economic appraisal of road maintenance, rehabilitation, upgrading and new construction through life-cycle analysis of proposed road investments.

- **Works programming**

  For the preparation of multi-year and rolling programmes for road network maintenance and development to facilitate the preparation of medium term budgets for road network maintenance and extension.

- **Strategic planning**

  For policy development, long term resource allocation plans and road network planning.

- **Software environment**

  A user-friendly system, built around a set of modules with the capacity to cope with a wide range of data requirements and user skill levels.

2 Life-Cycle Analysis

The underlying operation of HDM-4 is similar for a project, programme or strategy analysis. In each case, HDM-4 simulates total life-cycle conditions and costs for an analysis period under a user specified scenario of circumstances. The primary cost set for the life-cycle analysis includes the costs to the road agency of maintaining and improving the road network and costs to road users of vehicle operation, passenger time and road accidents. Environmental effects in the form of vehicle emissions and energy consumption are quantified but not included in the cost streams.

The broad concept of the life-cycle analysis is illustrated in Figure A1. Interacting sets of costs, related to those incurred by the road administration and those incurred by the road user, are added together over time in discounted present values. Costs are determined by first predicting physical quantities of resource consumption and then multiplying these quantities by their unit costs or prices. Economic benefits are then determined by comparing the total cost streams for various maintenance and construction alternatives with a base case (**do nothing** or **do minimum** alternative), usually representing minimal routine maintenance.

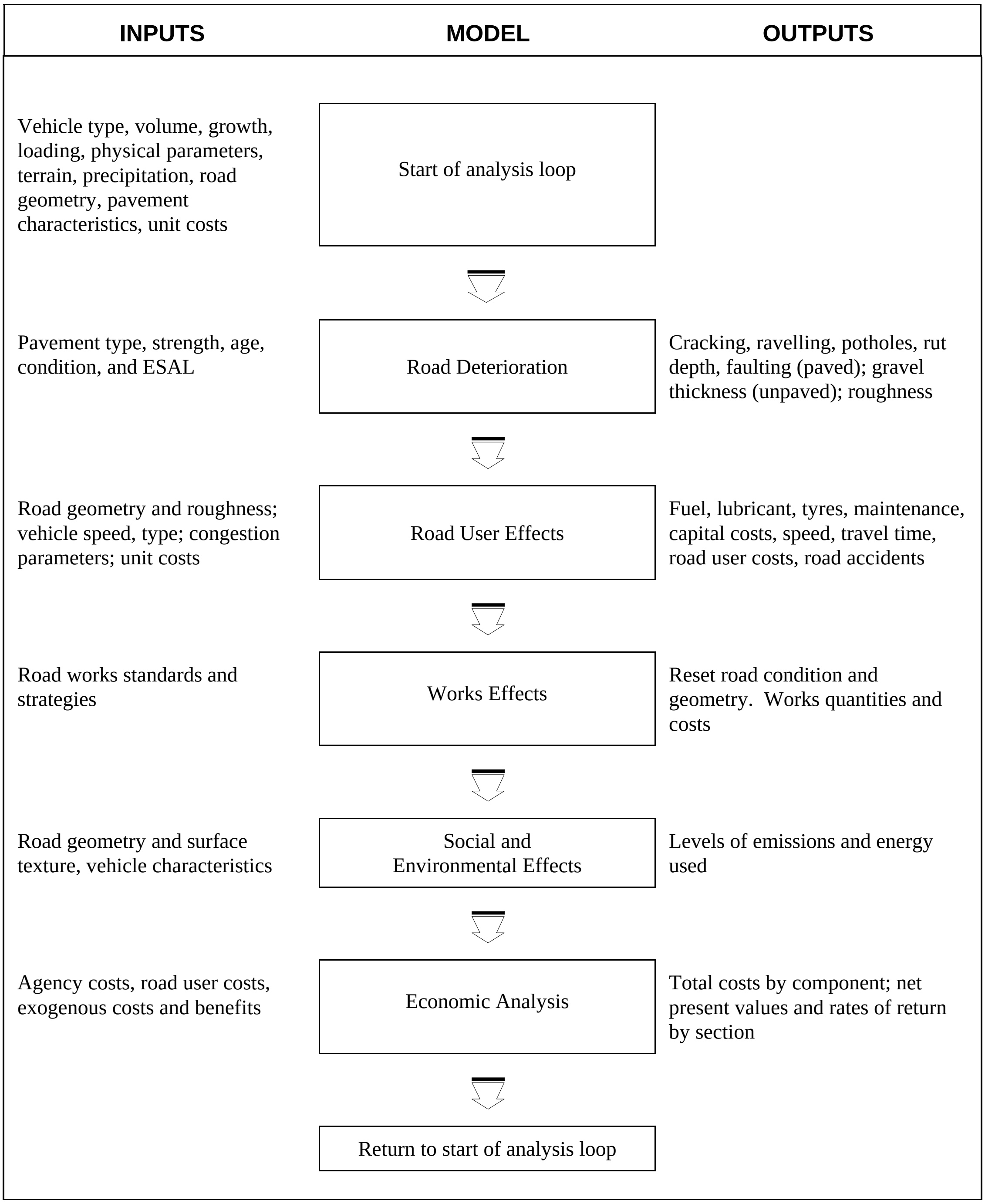


Figure A1.1
Life-cycle analysis using HDM-4

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, discounting the future costs. Rates of return, net present values (NPV), and NPV per investment unit can also be determined by HDM-4. 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.

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

Details of the benefits and costs considered in HDM-4 are included in Part G of Volume 4, the Analytical Framework and Model Descriptions manual.

The three main types of outputs produced by HDM-4 to aid decision making are as follows:

- **Economic efficiency indicators** – from analyses of individual road projects
- **Multi-year works programmes** – produced after prioritisation of several candidate road projects and associated works alternatives
- **Strategic road maintenance and development plans** – produced from long term predictions of road network performance

3 APPLICATIONS

HDM-4 can assist with:

- Project analysis for detailed economic appraisal (see Section 3.1)
- Programme analysis for annual or rolling works programme preparation (see Section 3.2)
- Strategic analysis for long term planning (see Section 3.2)
- Research and policy studies (see Section 0)

3.1 Project Analysis

Project Analysis is concerned with:

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

This is essentially the use for which the earlier generations of HDM systems were developed. Project analysis is used to estimate the economic or engineering viability of road investment projects by considering the following issues:

- Pavement surface and structural performance
- Life-cycle predictions of road deterioration, maintenance 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. Case studies demonstrating the application of Project Analysis are presented in Section E.

The philosophy of this analysis has not fundamentally changed from the HDM-III version, 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 have been updated and extended to include the impacts of road accidents. Environmental impacts assessment and energy balance analysis are also included.

3.2 Programme and Strategy Analyses

It is in the areas of Programme Analysis and Strategy Analysis that HDM-4 offers significant improvements over HDM-III.

Programme Analysis is concerned with:

> Preparation of a multi-year rolling programme for a road network in which candidate investment options are identified and selected, subject to resource constraints. Road networks are analysed section by section and estimates are produced of road works and expenditure requirements for each section for each year of the funding period.

Strategy Analysis is concerned with:

> Analysis of a chosen network as a whole, for preparing long range planning estimates of expenditure needs for road development and conservation under different budget scenarios. The road network is characterised by lengths of road in different categories defined by parameters such as road class, surface type, and pavement condition or traffic flow. Estimates are produced of expenditure requirements for medium to long term periods of 5 - 40 years.

The main difference between strategy and programme analysis is the way in which sections are physically identified:

- **Programme Analysis**
  Deals with sections that are unique physical units identifiable from the road network throughout the analysis.

- **Strategy Analysis**
  Considered as grouped representative sections typical of the road network to be analysed. The road system essentially loses its individual section characteristics.

For both types of 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 the maximisation of NPV (Net Present Value), the problem can be defined as:

> Select that combination of treatment options for all sections, with one treatment strategy selected per section, that maximises NPV for the whole network subject to the sum of the treatment costs being less than the budget available.

An important difference between strategic and programme analysis, and that for project analysis, is in the detail at which data are 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 are specified in terms of measured defects (IQL-II), whereas the specification of data for strategic and programme analyses can be more generic (IQL-III).

For example at project level analysis, roughness would be specified in terms of m/km IRI, whereas at programme and strategy level analyses, roughness may be specified as good, fair or poor.

Case studies demonstrating the application of Programme and Strategy analyses are included in Section F and G respectively.

3.3 Research and Policy Studies

HDM-4 can be used to conduct a number of road sector policy studies including:

- Funding policies for competing needs; for example, feeder roads versus main roads
- Road user charges for setting up road funds
- Impacts of road transport policy changes on energy consumption
- Impact of axle load limits
- Pavement maintenance and rehabilitation standards

4 IMPROVEMENTS IN HDM-4 VERSION 2.0

HDM-4 version 1.0 was first released in January 2000, followed by three updated versions (versions 1.1, 1.2 & 1.3) over the following couple of years Feedback provided by users of these versions of HDM-4 on the usability and functionality of the software led to the further development and improvement of HDM-4. This resulted in the release of version 2.0 of the HDM-4 software in August 2005.

Improvements that are included in version 2.0 of HDM-4 can be categorised as follows:

- **Improved Analysis Models**
  Sensitivity Analysis
  Budget Scenario Analysis
  Multi-Criteria Analysis (MCA)
  Estimation of Social Benefits
  Asset Valuation
- **Improved Connectivity**
  Run-data in MS Access format
  Import/Export in MS Access
  Import Validation
- **Improved Data Handling & Organisation**
  Updated Database Technology
  Re-design of New Section Facilities
  Traffic Re-design
  Report Management

- **Improved Technical Models**
- Bituminous Road Deterioration
- Bituminous Work Effects
- Unsealed Road Deterioration
- Unsealed Work Effects
- Road User Effects
-

Improved Usability & Configuration
Intervention Editor & Work Item Triggering Logic
Alternatives User-Interface
The model DLL architecture
Post-Improvement Maintenance Standards
Temporary Exclusion of Sections from Study
Calibration Sets
Improved Configuration - Accident Classes
Improved Configuration - Speed Flow Types
Improved Configuration - Traffic Flow Patterns

A brief description of these improvements is given in the Getting Started With HDM-4 Version 2.0 manual and detailed descriptions of each category given in the updated version of the Software User Guide (Volume 3). As this document focuses on the analytical applications in HDM-4, only the improvements to the analysis models are described below.

5 IMPROVED ANALYSIS MODELS

5.1 Sensitivity Analysis

Sensitivity Analysis has been introduced to Project Analysis to allow a user to investigate the impact of variations in key parameters on the analysis results. A user can define any number of sensitivity scenarios in which any of the 18 key parameters can be varied. These key parameters cover unit costs, vehicle use, traffic levels and growth, and net benefits. One or more key parameters are varied by defining a multiplication factor and the effects on the outcome of the analysis will be determined. A user determines which variables to vary and this judgment will depend upon the kind of investigation being conducted. Typically the key parameters will be varied to reflect the potential range of forecasts for the parameters.

5.2 Budget Scenario Analysis

HDM-4 version 2.0 allows the user to specify an unlimited number of budget scenarios within the Programme Analysis or Strategy Analysis applications. Each budget scenario defines the road agency financial resources available over the analysis period. The optimised work programme will be produced for each of the selected budget scenarios therefore allowing the user to compare the effects of different funding levels on the network being analysed.

5.3 Multi-Criteria Analysis (MCA)

Multi-Criteria Analysis (MCA) provides a means of comparing projects using criteria that cannot easily be assigned an economic cost. MCA can only be used in the Project Analysis application in HDM-4 and supports 9 criteria to evaluate:

- Economic (Road User Costs - RUC, Net Present Value - NPV)
- Functional (Comfort, Congestion)
- Energy (Energy Efficiency)
- Political
- Safety (Accident Analysis)
- Environmental (Air Pollution)
- Social (Social Benefits)

5.4 Estimation of Social Benefits

It has often been necessary to include the social benefits of road investments within HDM-4. The simple framework for including social benefits has now been made more transparent by incorporating them within the exogenous costs and benefits user interface.

5.5 Asset Valuation

A road network is a considerable resource that has a significant asset value. It is therefore important to effectively manage this asset and to be able to estimate the financial and economic value of road assets as a function of the level of investment. This optional component of HDM-4 Version 2.0 allows a user to estimate the asset value of a network being analysed during the time period of the analysis.

PART B PROJECT ANALYSIS

1 INTRODUCTION

Project analysis allows users to assess the physical, functional and economic feasibility of specified project alternatives by comparison against a base case, or a without-project alternative. The key processes of the analysis are:

Prediction of road deterioration

Estimation of road user costs (vehicle operating costs, travel time and accidents)

Modelling of road works effects and the costs of these to the road administration

Calculation of economic benefits from comparisons of the project alternatives

The aim is to determine which project alternative is most cost-effective. Four case studies to demonstrate this application are described in Section E.

Project analysis is associated with the following types of road projects:

- **Maintenance of existing roads**

  These works cover a wide range of maintenance techniques for different pavement types. This type of works also includes those that arise when a road pavement has received insufficient maintenance over its life, or because the pavement was not built to the standards of quality required by the original design.

- **Improvement of existing roads**

  These projects aim to provide additional capacity when a road is nearing the end of its life or because there has been an unforeseen change in use of the road. Works include measures to improve the quality of service, such as relieving traffic congestion, road safety, road passibility, the need to accommodate increased vehicle axle loads, etc. Typical examples of road improvement projects are:

- Pavement reconstruction
- Pavement upgrading
- The paving of gravel roads, the provision of concrete pavements in places where the subgrade soils may be very poor, etc.
- Road widening and geometric improvements
- Includes widening of existing carriageways, the provision of additional lanes, dual-carriageways, overtaking lanes, climbing lanes, and the betterment of shoulders.
- Realignment and pavement upgrading of the existing roadway
- Combines the activities described in pavement upgrading and road widening.

- **New construction**

  Involves the construction of a new pavement in an entirely new location, although in many cases they follow existing alignments. New alignments are required, for example, for bypasses, or in difficult terrain, or to connect other new infrastructure developments.

- **Stage construction**

  Consists of planned improvements to the pavement standards of a road at fixed stages throughout the project life. Often, the road alignment needed at the final stages of the project is provided from the outset. A typical strategy might be initially to construct a gravel road that will be paved when traffic flows have reached a given level.

- **Evaluation of past projects**

  Assesses the performance of a completed project to see if objectives set out during appraisal have been met. Project evaluation requires project data that have been collected and recorded in a systematic way throughout all stages of the project cycle. The evaluation should result in specific recommendations about improving aspects of the project design that can be used to improve ongoing and future planning.

2 ANALYSIS METHODS

Two methods of analysing investment options are provided in HDM-4 Project Analysis:

- Analysis by Section
- Analysis by Project

2.1 Analysis by Section

In Analysis by Section, each of the road sections selected for the project are analysed separately. Several alternatives (i.e. maintenance and/or improvement standards) can be defined for each section as shown in Table B2.1 (e.g. three alternatives for section A, four alternatives for section B, etc.), with one alternative designated by the user as the **base alternative** against which all the other alternatives will be compared. Economic indicators (e.g. NPV, IRR and NPV/C) are calculated for each section alternative.

Table B2.1
Analysis by Section

Road Section	Section Alternative				
	1 Base Alternative	2	3	4	5
Section A	Routine Maintenance	Resealing	Overlay		
Section B	Routine Maintenance	Overlay	Reconstruction	Widening	
Section C	Routine Maintenance	Resealing	Rehabilitation	Lane addition	Realignment
Section D	Grading 1 / year	Regravelling	Paving		

2.2 Analysis by Project

In Analysis by Project, a project is defined as the set of road works to be carried out on one or more road sections that can be grouped together conveniently to be undertaken as one contract or work instruction. Several project alternatives can be analysed to determine, for example, which is the most cost-effective to implement. A project alternative can consist of different works options applied to various sections making up the project as shown in Table B2.2.

Using this method, road sections are analysed together as a package by considering project alternatives as the basic unit for performing economic analysis. First, the annual costs and benefits are summed over all the section alternatives within each project alternative to give yearly totals. Economic indicators are then calculated for each project alternative by comparison against the **base alternative**.

Table B2.2
Analysis by Project

Road Section	Project Alternative			
	1 Base Alternative	**2**	**3**	**4**
Section A	Routine Maintenance	Resealing	Reconstruction	Realignment
Section B	Routine Maintenance	Overlay	Mill and replace	Widening
Section C	Routine Maintenance	Inlay	Reconstruction	Lane addition
Section D	Grading 1 / year	Regravelling	Widening	Upgrading
ΣProject NPV	0	ΣNPV	ΣNPV	ΣNPV

Analyses involving new sections and diverted traffic can only be performed using this method. Table B2.3 shows the definition of a project involving the construction of a new section (e.g. a by-pass), and the maintenance of four existing road sections which are affected by the introduction of the new link, mainly in terms of traffic diversion effects.

Table B2.3
Analysis Involving New Sections

Road Section	Project Alternatives			
	1 Base Alternative	**2**	**3**	**4**
Section A	Routine Maintenance	Routine Maintenance	Routine Maintenance	Routine Maintenance
Section B	Routine Maintenance	Routine Maintenance	Routine Maintenance	Routine Maintenance
Section C	Routine Maintenance	Routine Maintenance	Routine Maintenance	Routine Maintenance
Section D	Routine Maintenance	Routine Maintenance	Routine Maintenance	Routine Maintenance
New Section		AMSB 2-lane	AMSB 4-lane	STGB 4-lane
ΣProject NPV	0	ΣNPV	ΣNPV	ΣNPV

3 PROCEDURE FOR PROJECT ANALYSIS

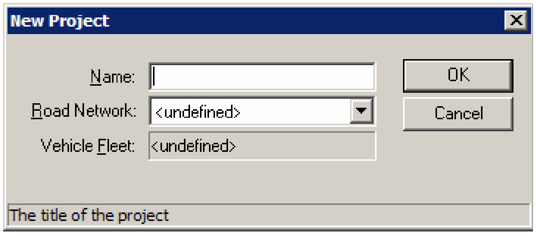
The procedure for project analysis is summarised below and described in the following sections.

1. Create the road project to be analysed by giving it a title and specifying the road network to be analysed.
2. Define the project by specifying the following:
   a) general information about the project
   b) method of analysis
   c) road sections to be analysed

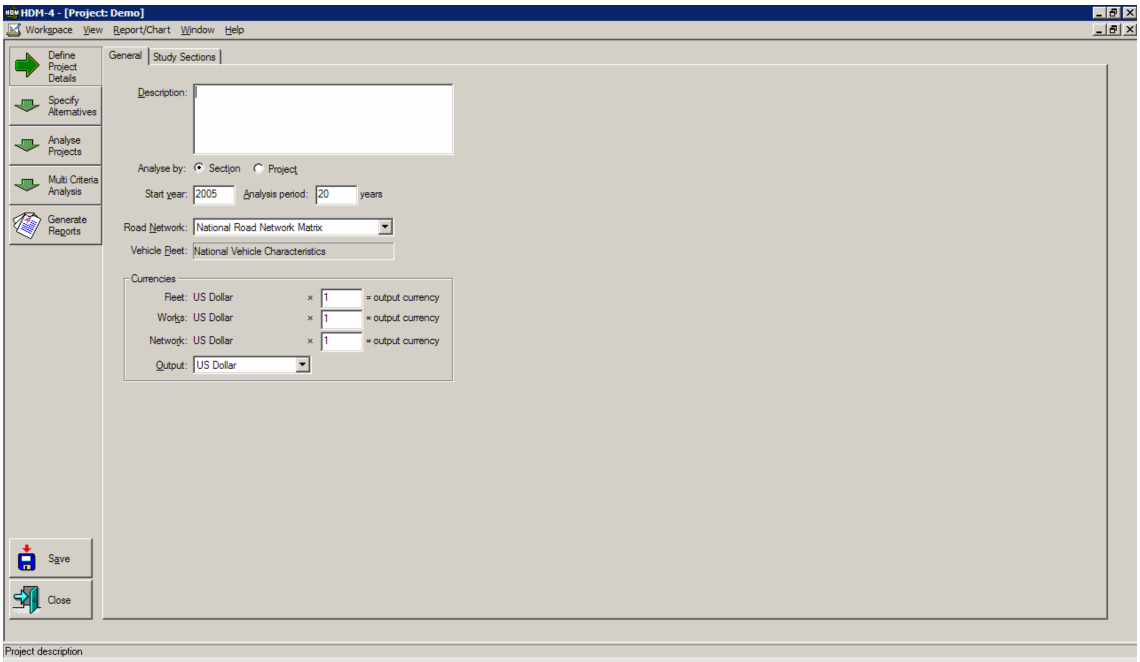
3. Specify maintenance and improvement standards to be analysed for each selected road section.Set-up and run the analysis. Optionally carry out sensitivity analysis.
4. Generate the reports and if necessary, print the required outputs.

3.1 Creating a Project

To create a project, give the project a title and select a previously created road network as shown in the screen below. In version 2.0 of HDM-4 the vehicle fleet that uses the road network needs to be specified at the time that the road network is created. Thus by specifying the road network to be used in the analysis, the vehicle fleet is automatically selected.



Having created a new Project Analysis, the following screen is displayed:



The information required to define and run a Project Analysis is described below.

3.2 Define Project Details

Project details that need to be defined are as follows:

3.2.1 General

Description

A brief description of the works involved in the project.

Analysis method

Select the method of analysis as either:

- Analysis by Section
  or
- Analysis by Project

Start year of the analysis period

Duration of the analysis period

Output currency

The units of currency in which the project outputs are to be presented.

Conversion rate

The conversion factors between the output and vehicle fleet currency units, and that between output and road works currency units used in the analysis.

3.2.2 Study Sections

All the sections in the selected road network are available for analysis. The sections to be included in an analysis can be selected using the following methods:

Selecting sections individually

Individual sections are selected by clicking on the box in the Study column at the left of the section. Sections can be unselected by clicking on the boxes of the sections that have been selected

Selecting sections by criteria

An alternative approach to selecting sections is to define criteria to be used to select sections. The following criteria are available:

- **Pavement**

  Surface class – options are All, Bituminous, Concrete or Unsealed
  Structural Adequacy – options are All, or one of the pre-defined categories

- **Speed Flow Type**

  Options are All, or one of the pre-defined categories

- **Traffic Volume**

  Options are All, or one of the pre-defined categories

- **Geometry**

  Minimum and/or maximum values of Rise and Fall (m/km), Horizontal Curvature (deg/km) and Carriageway Width (m)

The selection criteria can be used to add new sections to those already selected, or to replace those selected.

Traffic Growth

A pre-defined traffic growth set has to be assigned to each selected section. A copy facility is available to copy a growth set that has been assigned to one section to other sections.

3.3 Specify Alternatives

Certain road works may generate additional traffic on a road section, or cause traffic to divert from other roads to a road section. The generated and/or diverted traffic characteristics need to be specified for such works. The method of specifying alternatives is dependent of whether Analysis by Section or Analysis by Project has been selected in the Project Details dialog screen.

- **Analysis by Section**

The assignment of one or more Maintenance and/or Improvement Standards to a road section results in the formation of a Section Alternative. A section alternative is one of a set of mutually exclusive works alternatives specified as options to be analysed for an applicable road section within a project. The basic unit of analysis in HDM-4 is the section alternative.

In Analysis by Section, an alternative entitled Base Alternative is automatically created for each selected section, to which Maintenance and/or Improvement Standards can be assigned. The user can add as many alternatives to a section as required for the analysis of that section. An example is shown in Table B2.1.

A section alternative is defined by firstly giving the alternative a name. Maintenance and/or Improvement Standards are then assigned, specifying the date from which the standard is effective. For Improvement Standards, the user has the option of including generated traffic and exogenous benefits and costs.

- **Analysis by Project**

In Analysis by Project, the user needs to define an alternative. A project alternative is defined by firstly giving the alternative a name. All selected sections are assigned to the alternative. Maintenance and/or Improvement Standards are then assigned to each section, specifying the date from which the standard is effective. For example, each of the columns numbered 1 to 4 in Table B2.2 constitutes a project alternative.

For Improvement Standards, the user has the option of including generated traffic and exogenous benefits and costs. If the project includes the construction of a new section, the user has the option of including diverted traffic.

3.4 Analyse Projects

3.4.1 Setup Run

In Setup Run, the user specifies the scope of the analysis to be undertaken.

Conduct Economic Analysis

If economic analysis is to be performed, the base alternative needs to be selected if Analysis by Project is being undertaken. If Analysis by Section is being undertaken, the base alternative is automatically selected. For both types of analysis, the **discount rate** needs to be specified.

Accident Costs

If accident analysis is to be included, then unit costs for accidents should be specified for fatal, injury, damage only or all accidents.

Other Models

Other models that can be included in the analysis are energy balance, vehicle emissions and acceleration effects.

Asset Valuation

This optional component estimates the asset value of a network that is being analysed during the analysis period. This option is new in version 2 of HDM-4.

3.4.2 Sensitivity

The impact of variations in key parameters on the analysis results can be investigated using this option. Any number of sensitivity scenarios can be investigated by varying any of the 18 parameters that are displayed. Multiplication factors are defined for the parameters and the effects on the outcome of the analysis will be determined.

3.4.3 Run Analysis

Selecting the **Start** button runs the project analysis. During the run, the status is displayed in terms of the stage of analysis reached and the percentage completion. The analysis can be stopped at any time by clicking the **Abort** button.

3.5 Multi Criteria Analysis

MCA Setup

The user can choose from 9 criteria, and set the relative importance of each criterion. The base criterion also needs to be selected from one of the 9 criteria. The relative importance of the base criterion is automatically set to ‘equally preferred’. Having selected the base criterion and at least one other criterion, then clicking the Start button commences the MCA.

Results

The results of the MCA are displayed on this screen.

3.6 Generate Reports

The reports that are generated by HDM-4 can be categorised as input data or analyses results. These reports, presented in tabular format and in some cases a graphical format, are stored in the following folders:

- **Traffic**
- **Deterioration / Works Effects**
- **Road User Effects**
- **Environmental Effects**
- **Cost Streams and Economic Evaluation**
- **Input Data Multi Criteria Analysis**
- **Asset Valuation**

PART C PROGRAMME ANALYSIS

1 INTRODUCTION

Programme Analysis deals primarily with the prioritisation of a defined list of candidate road projects into a one-year or multi-year works programme under defined budget constraints. The candidate road projects are 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.

When all candidate projects have been identified, the HDM-4 programme analysis application can be used to compare the life-cycle costs predicted under an existing pavement management scenario (i.e. the base alternative) against the life-cycle costs predicted for the periodic maintenance, road improvement or development alternative (i.e. the other user-specified alternatives). This provides the basis for estimating the economic benefits that would be derived by including each candidate project within the budget timeframe.

The programme analysis application may be used to prepare a multi-year rolling works programme, subject to resource constraints. The prioritisation method employs the incremental NPV/cost ratio as the ranking index, which provides an efficient and robust index for prioritisation purposes. Indices such as the NPV, economic rate of return (ERR), or predicted pavement condition attributes (e.g. 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.

2 ANALYSIS METHODS

The purpose of programme analysis is to evaluate maintenance or improvement options, and to try and select the set of investments to be made on a number of road sections in a road network, which will optimise an objective function. Programme analysis is concerned with short to medium term planning and preparation where budget levels are known with reasonable certainty. Thus the problem can be posed as one of searching for the combination of investment alternatives that optimises the objective function, under a budget constraint.

Two methods of analysis are provided in programme analysis:

Life-cycle analysis

Multi-year forward programme

In both cases, optimisation is done using the incremental NPV/Cost ratio where the problem can be defined as the selection of that combination of investment options on sections that maximises total NPV for the selected sections in the road network subject to the sum of the investment costs being less than the budget available.

Note that the set of investment options to be optimised is user-defined and is not the set of all possible options for the particular network; hence the problem is not true optimisation since all possible solutions are not normally considered. Note also that the investment options on any one section are mutually exclusive.

2.1 Life-Cycle Analysis

The life-cycle analysis for the development of an unconstrained works programme is identical to that for project analysis as described in Section A0 and illustrated in Figure A1.1.

To produce a constrained works programme under budget optimisation, the user must specify a set of section alternatives which offer different timing alternatives for the assigned maintenance and/or improvement standards, or different standards, which provide a means by which costs can be delayed or reduced.

A typical need is to specify sufficient timing alternatives so that any investment backlog can be substantially removed or deferred to a period where unconstrained funding may exist. The problem is normally a short-medium term constraint, where typically single ‘constrained’ budget periods may be specified for a number of years, and an unconstrained budget is provided beyond.

An example is shown below:

Section alternatives	Assignments	Year
Base Alternative	Minimum maintenance	from Year 1
Year 1 – Periodic maintenance	Periodic Maintenance	from Year 1
Year 2 – Periodic maintenance	Minimum maintenance	from Year 1
	Periodic maintenance	from Year 2
Year 3 – Periodic maintenance	Minimum maintenance	from Year 1
	Periodic maintenance	from Year 3
etc	etc	etc

The need to specify timing alternatives is to provide sufficient section-alternatives so that where the ‘ideal’ section-alternative cannot be selected in the year where it appears on the unconstrained works programme due to budget constraints, then a possibility of it being selected in another year will exist. This can only occur if a reasonable number of choices are given. The method is illustrated in Programme Case Study No.1 in Sectiion F.

2.2 Multi-Year Forward Programme

For many road agencies, the short term planning cycle is normally based on a one year budget period. However, other road agencies adopt a multi-year tactical planning period. A common example of a multi-year forward programme is a three-year works programme, which could be considered as three calendar year budget periods.

The multi-year forward programme option is a simplification of the life-cycle analysis method based on comparison of the following alternatives:

- Apply the assigned road works within the budget period

  or

- Postpone road works until the first year after the budget period

This simplification is normal practice in works programming – if there is insufficient budget, then works are postponed - and it can be used to keep the analysis simple and reduce run times when there is a large number of road sections to be analysed.

Economic calculations are done by comparing investments made within the budget period against deferring the action to the first year after the budget period as illustrated in Figure C2.1. For example, an overlay applied in the first year of the budget period year would be compared against the road works required in the year after the budget period. The deferred road works are not necessarily the same because the road could be in worse condition after postponement of the overlay, and a higher level of investment may be needed.

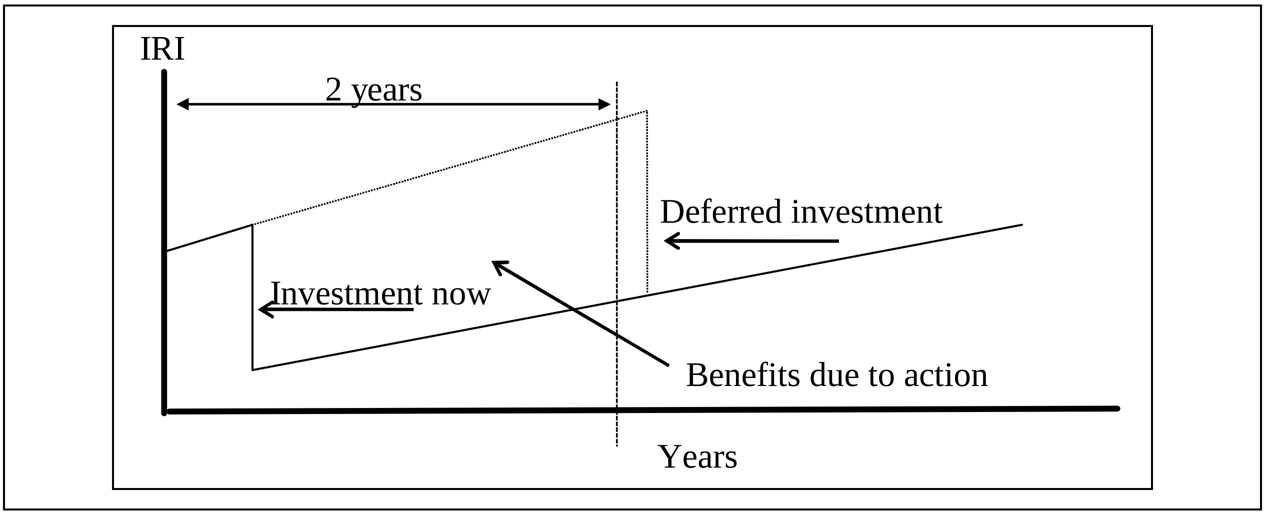


Figure C2.1
Calculation of benefits for a multi-year works programme

A simplifying assumption is made that the deferred action will be less effective in improving pavement condition as shown in Figure C2.1. It is also assumed that the pavement performance after the next year will be similar for both alternatives. Therefore, there is no need to calculate pavement deterioration and road user costs beyond the first year after the budget period. This approach is a modification of that used in the United States Highway Economics Requirements System (HERS) and in the UK Highway Agencies PMS (HAPMS*)*.

The following two examples in Table C2.1 and Table C2.2 illustrate the above process.

Table C2.1
Example of one-year forward programme

Section	Works required in Year 1	Works required in Year 2
S1	Overlay	Overlay
S2	Overlay	Reconstruct
S3	Overlay	Overlay

In Table C2.1, a one-year works programme for three sections is analysed. An overlay is triggered for all sections in year 1, but the budget is insufficient for all these works. If the work is deferred to year 2, section S2 requires reconstruction. Both alternatives are generated for each road section in order to calculate the economic indicators used in the optimisation.

The first alternative is user specified in terms of maintenance or improvement standards with their associated intervention levels. The base alternative is automatically generated by HDM, applying the same maintenance or improvement standards, with the works that been deferred until the first year after the budget period,

The second example in Table C2.2 illustrates a 3-year works programme for four sections.

Table C2.2
Example of three-year forward programme

Section	Programme Period Alternative 1			Deferred Works Alternative 2
	Year 1	Year 2	Year 3	Year 4
S1	Reseal			Overlay
S2	Overlay			Reconstruct
S3		Reseal		Overlay
S4			Reseal	Reseal

When defining a multi-year forward programme analysis, only one maintenance standard and/or one improvement standard is specified for each section. Normally this would be effective from the first year of the programme period. The interventions for the standards should be condition related. In the example shown in Table C2.2, the intervention criteria may have been of the form:

Reseal	when	3 <	Roughness < 4 IRI
Overlay	when	4 <	Roughness < 6 IRI
Reconstruct	when		Roughness > 6 IRI

Thus, in the case of section S1, the roughness was between 3 and 4 IRI at the end of the first year (reseal) but had increased to value between 4 & 6 IRI at the end of the year 4, requiring an overlay. The base alternative in this example is Alternative 2 (works in the first year after the budget period), and the economic benefits are calculated by comparing Alternative 1 for each section against Alternative 2.

Care must be taken that the maintenance and improvement standards used are compatible. For example, if the works programme requires maintenance and the deferred work is a major improvement (due to a threshold being reached in the intervention criteria for the improvement standard) a distorted result will occur. This is because no benefits are estimated for the effects of the improvement as it is applied in the final year of the analysis. So an abnormally high NPV will be calculated due to the large difference in cost between the maintenance and improvement works.

When specifying an improvement standard, there is a field for the residual value of the new work in the asset valuation window. This is the value of the work remaining at the end of the analysis period and is deducted from the agency costs in the last analysis year.

3 PROCEDURE FOR PROGRAMME ANALYSIS

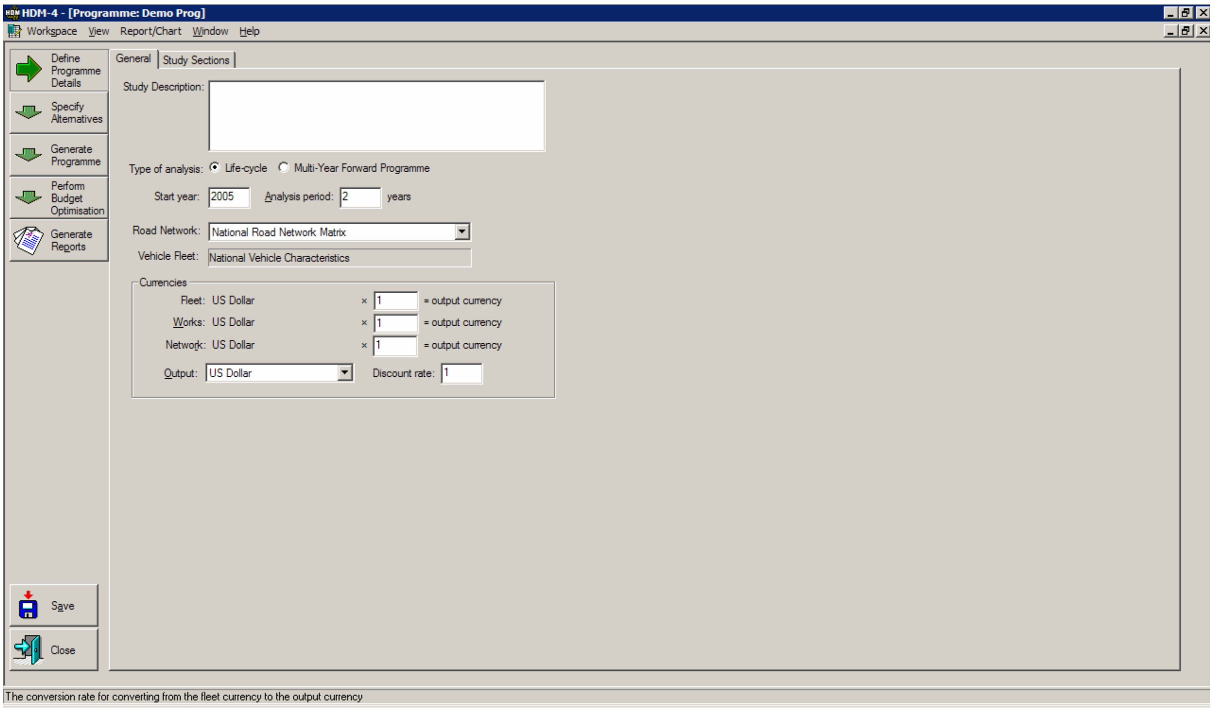
The procedure for programme analysis is summarised below and described in the following sections.

1. Create the programme analysis by giving it a title and specifying the road network to be analysed.
2. Define the programme by specifying:
   a) general information about the programme
   b) method of analysis
   c) road sections to be analysed
3. Specify maintenance and/or improvement standards to be analysed for each selected road section
4. Generate an unconstrained works programme analysis
5. Define budget constraints
6. Generate an optimised works programme within the constrained budget
7. Generate the required outputs

3.1 Creating a Programme

To create a programme, give the programme a title and select a previously created road network. In version 2.0 of HDM-4 the vehicle fleet that uses the road network needs to be specified at the time that the road network is created. Thus by specifying the road network to be used in the analysis, the vehicle fleet is automatically selected.

Having created a new Programme Analysis, the following screen is displayed.



The information required to define and run a Programme Analysis is described below.

3.2 Define Programme Details

Programme details that need to be defined are as follows:

3.2.1 General

Description

A brief description of the works involved in the programme.

Analysis method

Select the method of analysis as either:

- Life-Cycle
  or
- Multi-Year Forward Programme

Start year of the analysis period

Duration of the analysis period

Output currency

The units of currency in which the programme analysis outputs are to be presented.

Conversion rate

The conversion factors between the output and vehicle fleet currency units, and that between output and road works currency units used in the analysis.

3.2.2 Study Sections

All the sections in the selected road network are available for analysis. The sections to be included in an analysis can be selected using the same two methods as described for Project Analysis (see Section B3.2.2).

A pre-defined traffic growth set has to be assigned to each selected section. A copy facility is available to copy a growth set that has been assigned to one section to other sections.

3.3 Specify Alternatives

The method of specifying alternatives is dependent on whether Life-Cycle or Multi-Year Forward Programme has been selected as the analysis method.

- **Life-Cycle**

If Life-Cycle has been selected then an alternative entitled Base Alternative is automatically created for each selected section, to which Maintenance and/or Improvement Standards can be assigned. The user can add as many alternatives to a section as required for the analysis of that section.

A section alternative is defined by firstly giving the alternative a name. Maintenance and/or Improvement Standards are then assigned, specifying the date from which the standard is effective. For Improvement Standards, the user has the option of including generated traffic and exogenous benefits and costs.

This process is similar to the specification of alternatives for Project Analysis. However, timing alternatives should be considered where a budget constraint is applicable (i.e. same maintenance / improvement alternatives assigned to different years (see Section C.2.1).

- **Multi-Year Forward Programme**

For Multi-Year Forward Programme, only one maintenance standard is allowed per road section except where an improvement standard has been specified, in which case it must be followed by a maintenance standard. The analysis will be carried out by applying only one maintenance or improvement standard for each section, and selecting one works item (highest in the hierarchy) from the given standard for each year of the analysis period.

3.4 Generate Programme

3.4.1 Perform Run

The options available in Perform Run depend on whether Life-Cycle or Multi-Year Forward Programme analysis has been selected.

- **Life-Cycle**

The Base Alternative is automatically selected using the Maintenance and/or Improvement Standards that have been previously assigned to this alternative.

- **Multi-Year Forward Programme**

The user has the options of running an analysis with or without economic analysis.

The other options are common for both types of analysis.

Accident Costs

If accident analysis is to be included, then unit costs for accidents should be specified for fatal, injury, damage only or all accidents.

Other Models

Other models that can be included in the analysis are **energy balance**, **vehicle emissions** and **acceleration effects**.

Asset Valuation

This optional component estimates the asset value of a network that is being analysed during the analysis period. This option is new in version 2 of HDM-4.

Selecting the **Start** button initiates the analysis. During the run, the status is displayed in terms of the stage of analysis reached and the percentage completion. The analysis can be stopped at any time by clicking the **Abort** button.

3.4.2 Unconstrained Programme

After either multi-year forward programme **or** life-cycle analysis, the options with the highest NPV (net present value) are assigned for each section. The result of this process is a tentative, unconstrained works programme, determined from the maintenance or improvement standards defined by the user.

One of the key aspects of road management is the ability to intervene and select projects that should be carried out for reasons other than economic priority alone. Practitioners have stressed the need for user intervention to select discrete projects to be assigned high priorities for maintenance. Such projects should meet the minimum criterion of a positive economic return in order to qualify for the user selected list.

Users may select projects to be committed (i.e. given high priority for funding) from the unconstrained programme. The pre-defined works will then be submitted to the optimisation routines to schedule projects that can be undertaken within the budget constraints taking into account the pre-defined projects.

The costs of works classified by the user as recurrent are not initially displayed in the unconstrained works programme. The user has the option to display the costs of the recurrent works.

3.5 Perform Budget Optimisation

The user can specify any number of budget scenarios to investigate. For each scenario the user specifies the budget available for different budget periods of the analysis period. Separate analyses are conducted for each budget scenario.

If the needed budget for each budget period is below the given budget constraints, no further economic analysis is necessarily needed. However, if the budget needs are higher than the available budgets, the user has two choices:

1. Review maintenance and improvement standards and then run the analysis again
2. Execute an economic analysis and optimisation

Two methods for budget optimisation are used in programme analysis.

- Total enumeration
- Incremental NPV/cost ranking

Both methods are described in detail in Volume 4 of the HDM-4 series – Analytical Framework and Model Descriptions.

Once the budget optimisation has been performed, an optimised programme is generated for each budget scenario. The user needs to select from the pull-down menu the appropriate budget scenario to view the optimised programme for that budget scenario.

3.6 Generate Reports

The input data and the results of the analysis are presented in appropriately named reports that are stored in folders as listed in Section B3.6

PART D STRATEGY ANALYSIS

1 INTRODUCTION

Strategic planning of medium to long term road network expenditures considers the requirements of an entire road network asset which may be a network or sub-network managed by one road organisation or situated within an administrative area (a state or county for example). Examples of sub-networks might be; all motorways or expressways, all main roads, all paved roads etc.

Strategy analysis is primarily a tool for resource allocation by, or for, managers within a road agency. Typical applications of strategy analysis would include:

Medium to long term forecasts of funding requirements for specified target road maintenance standards.

Forecasts of long term road network performance under varying levels of funding.

Optimal allocation of funds according to defined budget heads; for example routine maintenance, periodic maintenance and development (capital) budgets.

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

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.

In order to predict the medium to long term requirements of a road network or sub-network, strategy analysis normally applies the concept of a matrix of representative road sections, comprising categories of the road network defined according to the key attributes that most influence road agency and road user costs. Although it is possible to model individual road sections in a strategy analysis, road administrations will often be responsible for several thousand kilometres of roads, thereby making it cumbersome to set up and run an analysis for each road segment.

The road network matrix is defined by the most important factors affecting transport costs on the network. For example, a road network matrix could be modelled using; three traffic categories (high, medium, low), four pavement condition levels (good, fair, poor, bad) and three levels of structural adequacy (good, fair, poor). The resulting road network matrix would therefore comprise 36 (3 x 4 x 3) representative sections. In this example, it is assumed that other parameters throughout the network are similar (road geometry, environment, etc). Such a network matrix might be used to examine maintenance and/or improvement funding requirements for each cell (representative section) of the matrix.

The road length assigned to each representative section is the total length of all the road segments in the network that fall within the parameters defining the matrix cell. In the example above, the length of the first representative section would be the total length of all road sections in the network with high traffic, in good condition and having good structural adequacy.

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 more representative sections that could potentially provide more accurate results.

If the analysis uses optimisation under constrained budgets, it must be ensured that the cost of works on a single representative section does not exceed the defined constraint in a budget period. If it does it will never be selected as HDM-4 does not have the facility to "split" a section and spread the work over two or more budget periods.

Also, sufficient timing alternatives and/or standards should be specified, as for programme analysis, to ensure viable section-alternatives exist to be selected in years which differ from that identified in the unconstrained analysis.

2 ANALYSIS METHODS

The primary purpose of conducting a road network strategy analysis is to determine network-wide resource requirements and the impacts of various development and preservation options on the road network performance. The objective of the analysis can be defined as either:

1. Determining funding levels required to meet a given set of network performance standards
2. Determining network performance for given funding levels

In strategy analysis, three optimisation methods are available, each with an objective function and a constraint.

Objective Function	**Constraint**
Maximise benefits (NPV)	Financial agency costs
Maximise improvement in network condition (roughness)	Financial agency costs
Minimise agency costs	Target network condition (roughness)

To minimise road agency costs in order to achieve specified target road network condition, HDM-4 selects from amongst the specified road work standards, the combination which will minimise road agency costs in achieving the target road network condition.

It should be noted that the network development or preservation standards to be used in the analysis are user-defined and are not therefore the set of all possible standards for the network being analysed.

3 PROCEDURE FOR STRATEGY ANALYSIS

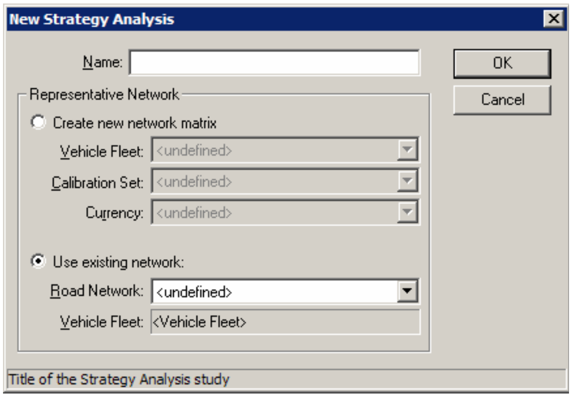
The procedure for strategy analysis is summarised below and described in the following sections.

1. Create the strategy analysis by giving it a title and specifying the road network to be analysed.
2. Define the strategy by specifying:
   a) general information about the strategy
   b) method of analysis
   c) road sections to be analysed
3. Specify maintenance and/or improvement standards to be analysed for each selected road section
4. Generate an unconstrained works programme analysis

5. Define budget constraints
6. Generate an optimised works programme within the constrained budget
7. Generate the required outputs

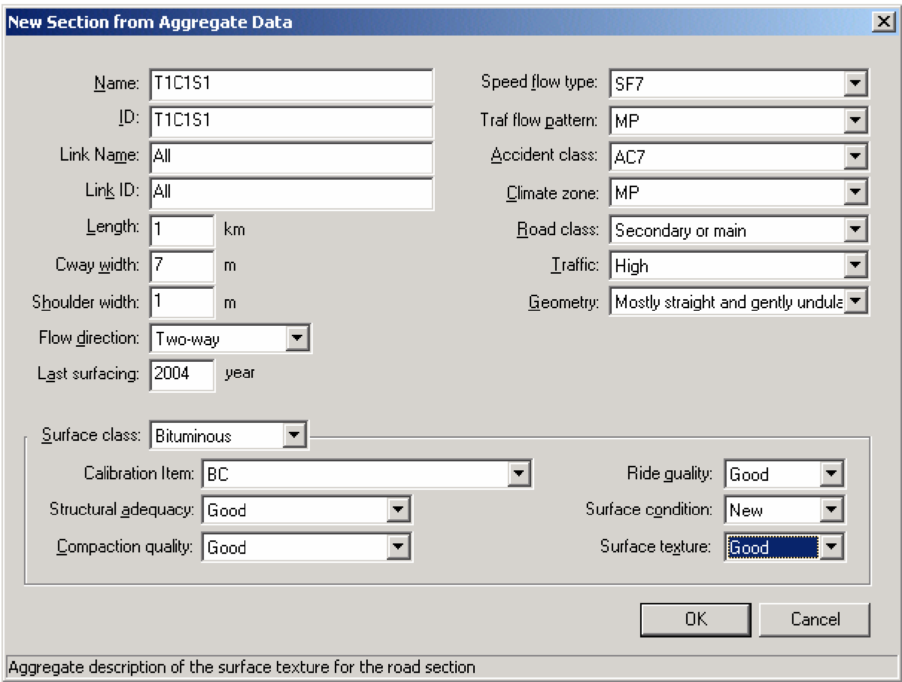
3.1 Creating a Strategy

To create a new strategy analysis, the user has a choice of creating a new network matrix or using an existing network as shown in the screen below.



- Create new network matrix

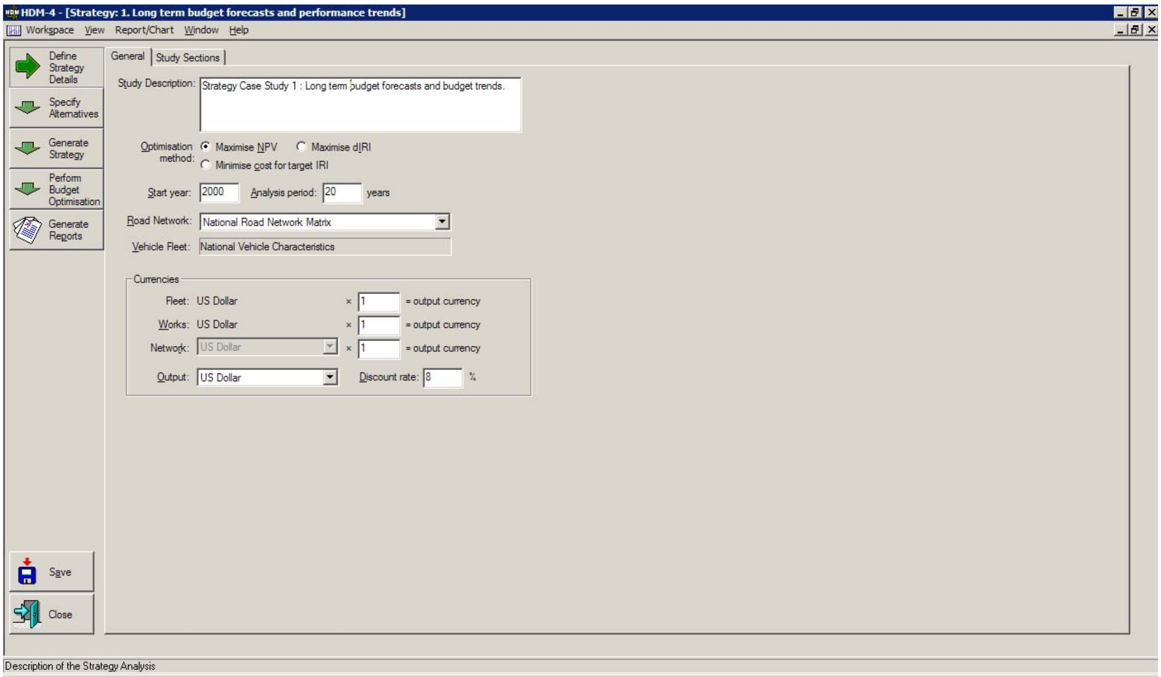
  The user needs to select previously defined vehicle fleet, calibration set and currency. The network can then be created by adding new sections based on the aggregate data as shown in the screen below. (In this example, high traffic, good condition and good structural adequacy have been selected).



- Use existing network

  The user can select a previously created road network. In version 2.0 of HDM-4 the vehicle fleet that uses the road network needs to be specified at the time that the road network is created. Thus by specifying the road network to be used in the analysis, the vehicle fleet is automatically selected.

Having created a new Strategy Analysis, the following screen is displayed.



3.2 Define Strategy Details

Strategy details that need to be defined are as follows:

3.2.1 General

Description

A brief description of the works involved in the strategy.

Optimisation method

Select the optimisation method as either:

- Maximise NPV
- Maximise dIRI
- Minimise cost for target IRI

Start year of the analysis period

Duration of the analysis period

Output currency

The units of currency in which the strategy analysis outputs are to be presented.

Conversion rate

The conversion factors between the output and vehicle fleet currency units, and that between output and road works currency units used in the analysis.

3.2.2 Study Sections

All the sections in the selected road network are available for analysis. The sections to be included in an analysis can be selected using the same two methods as described for Project Analysis (see Section B.3.2.2).

A pre-defined traffic growth set has to be assigned to each selected section. A copy facility is available to copy a growth set that has been assigned to one section to other sections.

3.3 Specify Alternatives

An alternative entitled Base Alternative is automatically created for each selected section, to which Maintenance and/or Improvement Standards can be assigned. The user can add as many alternatives to a section as required for the analysis of that section.

A section alternative is defined by firstly giving the alternative a name. Maintenance and/or Improvement Standards are then assigned, specifying the date from which the standard is effective. For Improvement Standards, the user has the option of including generated traffic and exogenous benefits and costs.

3.4 Generate Strategy

3.4.1 Perform Run

In strategy analysis, the only analysis option available in Perform Run is Life-Cycle Analysis. The Base Alternative is automatically selected using the Maintenance and/or Improvement Standards that have been previously assigned to this alternative.

Also in Perform Run, the user specifies the scope of the analysis to be undertaken.

Accident Costs

If accidents analysis is to be included, then unit costs for accidents should be specified for fatal, injury, damage only or all accidents.

Other Models

Other models that can be included in the analysis are **energy balance**, **vehicle emissions** and **acceleration effects**.

Asset Valuation

This optional component estimates the asset value of a network that is being analysed during the analysis period. This option is new in version 2 of HDM-4.

Selecting the **Start** button initiates the analysis. During the run, the status is displayed in terms of the stage of analysis reached and the percentage completion. The analysis can be stopped at any time by clicking the **Abort** button.

3.4.2 Unconstrained Programme

After running the analysis, the options with the highest NPV (net present value) are assigned for each representative section. This produces an unconstrained works programme, determined from the maintenance or improvement standards defined by the user. This result reflects the overall needs for road works.

If the needed budget for each budget period is below the given budget constraints, no further economic analysis is necessarily needed, and the unconstrained solution can be used as an optimal strategy. However, if the budget needs are higher than the available budgets, the user has two choices:

1. Review maintenance and improvement standards and then run the analysis again
2. Execute optimisation

As for programme analysis, users may select representative sections to be committed (i.e. given high priority for funding) from the unconstrained programme. The cost of the works for the manually selected sections will then be subtracted from the budgets before allocation of resources to other sections. If manual selection is used, there must be sufficient budget to cover the manual selections plus the base alternatives for all other sections.

The costs of works classified by the user as recurrent are not initially displayed in the unconstrained works programme. The user has the option to display the costs of the recurrent works.

3.5 Perform Budget Optimisation

The user can specify any number of budget scenarios to investigate. For each scenario the user specifies the budget available for different budget periods of the analysis period. Separate analyses are conducted for each budget scenario.

Once the budget optimisation has been performed, an optimised programme is generated for each budget scenario. The user needs to select from the pull-down menu the appropriate budget scenario to view the optimised programme for that budget scenario.

3.6 Generate Reports

The input data and the results of the analysis are presented in appropriately named reports that are stored in folders as listed in Section B3.6.

PART E PROJECT ANALYSIS CASE STUDIES

1 CASE STUDY 1 – UPGRADING A GRAVEL ROAD

1.1 Introduction

This case study 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 this analysis the road has been split into three sections based on geometry, pavement condition and traffic volume. Traffic and condition data are available from surveys undertaken in 2005.

The purpose of the analysis 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 (maintaining the existing gravel road). The timing of the upgrading is examined in the case study, as this is considered vital to its feasibility.

The example described below is an Analysis by Project case study, **Project 1a. Upgrading a gravel road (by project) – without sensitivity analysis**. Two further case studies exist in the same folder which are based on the same overall project.

Project 1b. Upgrading a gravel road (by project) – with sensitivity analysis investigates the effect of changes in the value of a number of key variables on the outcome of the economic analysis.

Project 1c. Upgrading a gravel road (by section) uses the Analysis by Section method to examine the viability of the individual physical sections of the overall project. In this case sensitivity analysis is not examined.

Projects 1b and 1c case studies are discussed later in this section.

These case studies are located in the **Projects** folder in the Workspace. Double-click on Project case study **1a. Upgrading a Gravel Road (by Project) – without sensitivity analysis**.

1.2 Define Project Details

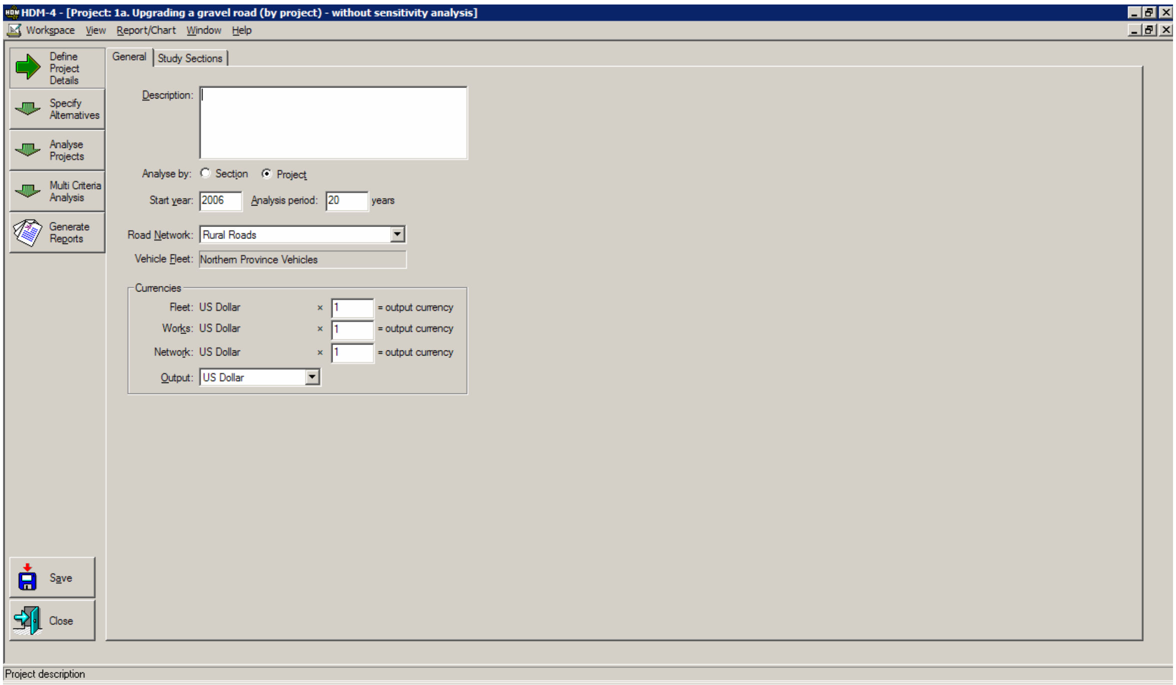
In the **Define Project Details** screen, the following tab pages may be displayed:

- General
- Study Sections

1.2.1 General

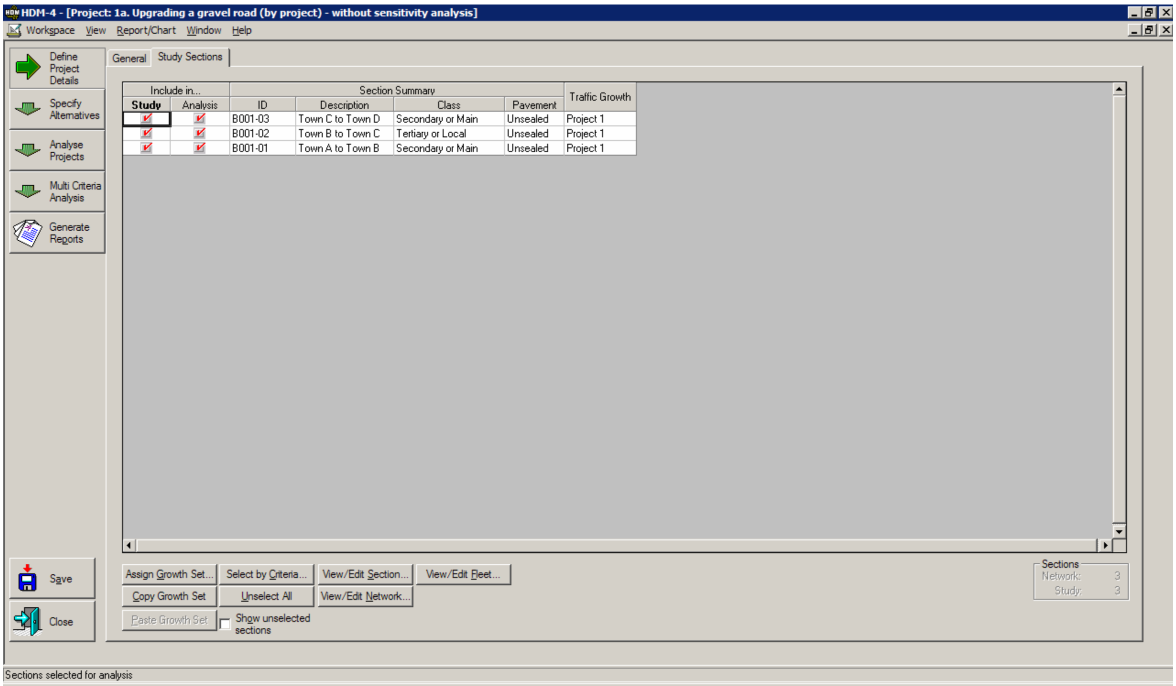
The information displayed in the General screen includes the study description, analysis type, analysis period, the pre-defined Road Network and Vehicle Fleet, and the currency to be used for the analysis.

This case study is presented as an Analysis by Project example. The analysis period is defined by the start year 2006 and a duration of 20 years (i.e. 2006 – 2025). The sections to be analysed are in the Road Network entitled Rural Roads, to which the Northern Province Vehicles have been previously assigned as the vehicle fleet. The currency being used in this analysis is US dollars.



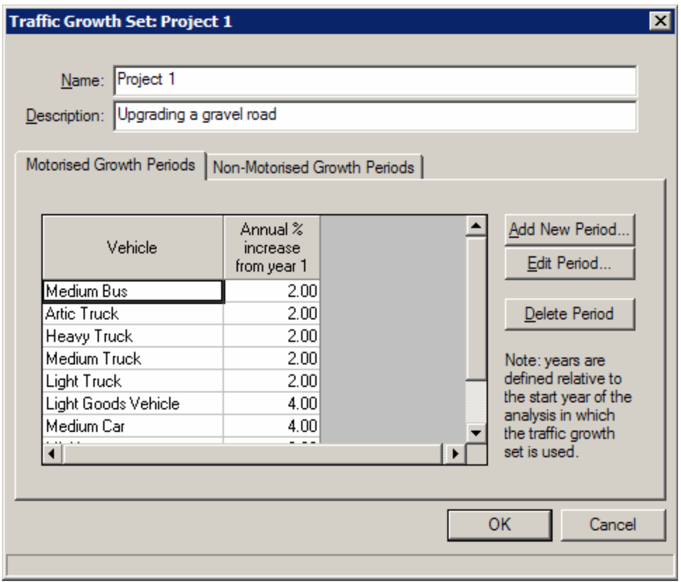
1.2.2 Study Sections

Three road sections have been selected for analysis, namely Town A to Town B (B001-01), Town B to Town C (B001-02) & Town C to Town D (B001-03).



By double-clicking on the section gives access to the section details. However, the **Traffic Growth** details can only be seen and edited through the **Vehicle Fleets** folder. To access the Traffic Growth Sets that have been previously created, the user needs to open the appropriate vehicle fleet (in this case Northern Province Vehicles) in the Vehicle Fleet folder and click on the Edit Traffic Growth Sets button which then displays all the previously created sets. Double-clicking on the appropriate set (in this case Project 1) displays the details of the traffic changes over the analysis period.

The traffic growth rates for the motorised traffic in this case study are displayed below (non-motorised traffic not used in this case study).



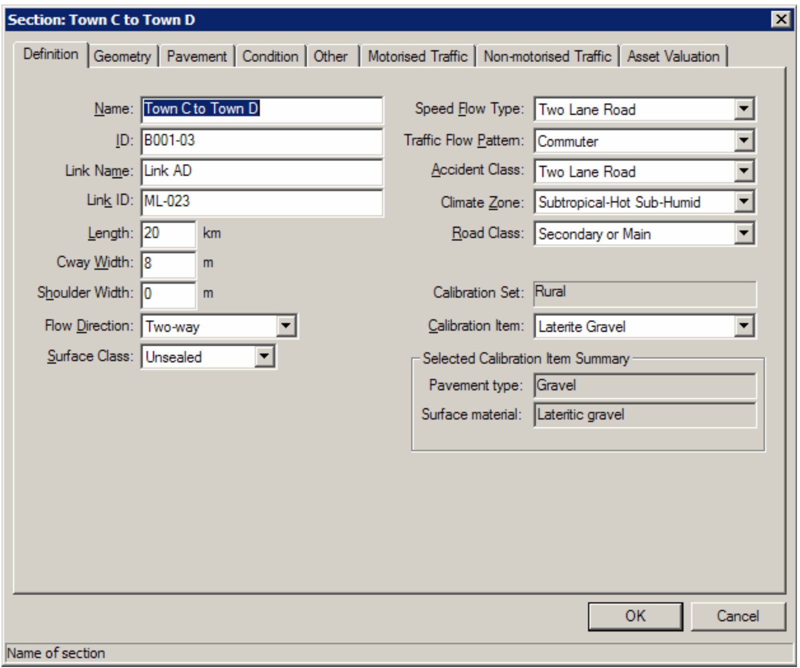
For this case study, the road has been divided into three sections based on those physical attributes that vary along its length. The main characteristics of these three sections are summarised in Table E1.1.

Table E1.1
Characteristics of the Sections

Section ID	**B001-01**	**B001-02**	**B001-03**
Section Name	**Town A to Town B**	**Town B to Town C**	**Town C to Town D**
Length (km)	20	10	20
Carriageway width (m)	7	6	8
Number of lanes	2	2	2
AADT (2005)	500	250	750
Rise and Fall (m/km)	10	15	30
Horizontal curvature (º/km)	50	300	15
Altitude (m)	120	295	370
Year of last regravelling	2003	2003	2003
Gravel Thickness (mm) (in 2005)	100	100	100
Roughness (IRI) (in 2005)	7	7	7

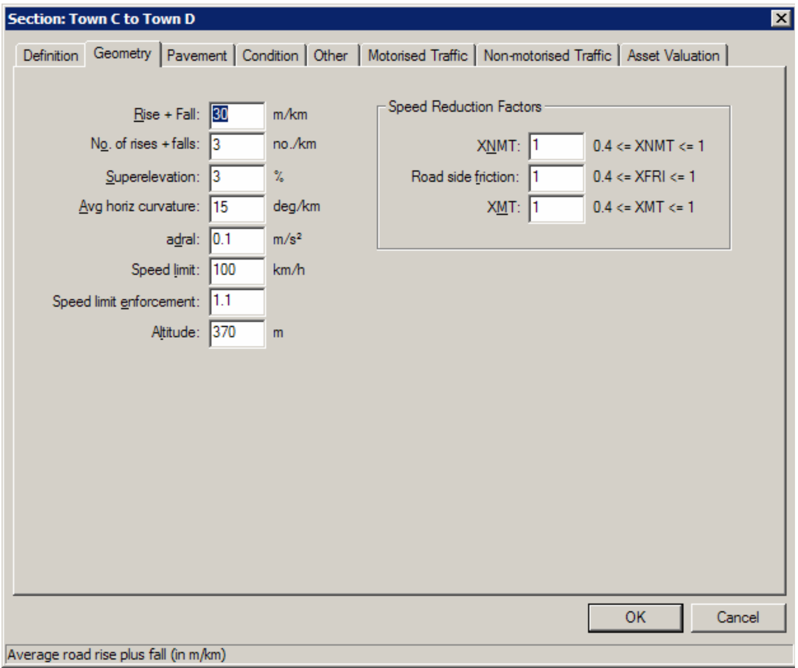
- **Definition**

Each road section is considered homogeneous in terms of its physical attributes (e.g. road class, climate, carriageway width, geometry, pavement condition, traffic flow, and axle loading). Note that no shoulders are specified, and the full width of gravel surfacing is assigned as carriageway width, since in practice shoulders on a gravel road are maintained as part of the carriageway. The selected road deterioration model calibration information is also identified on this screen, including the selection of material properties.



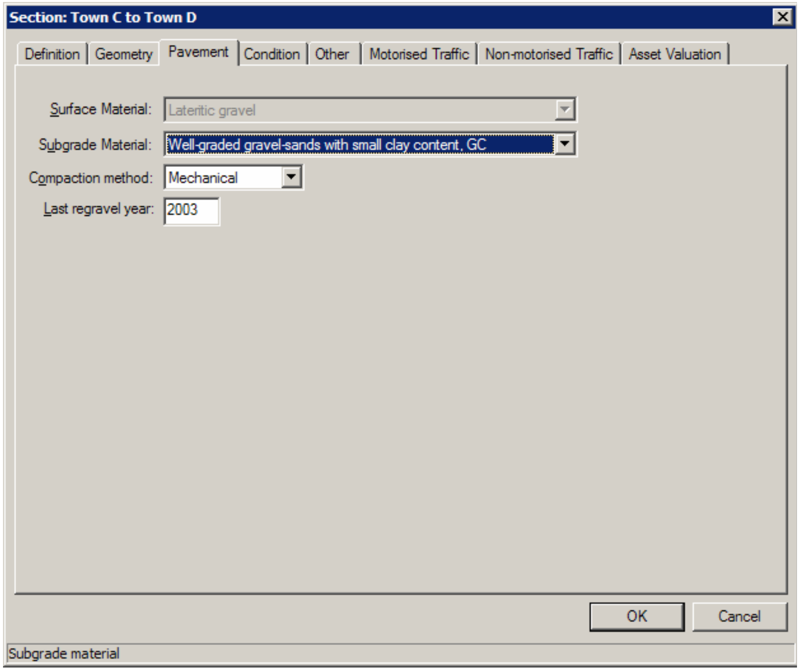
- **Geometry**

This screen summarises existing geometric parameters (before upgrading) including those for horizontal and vertical alignment.

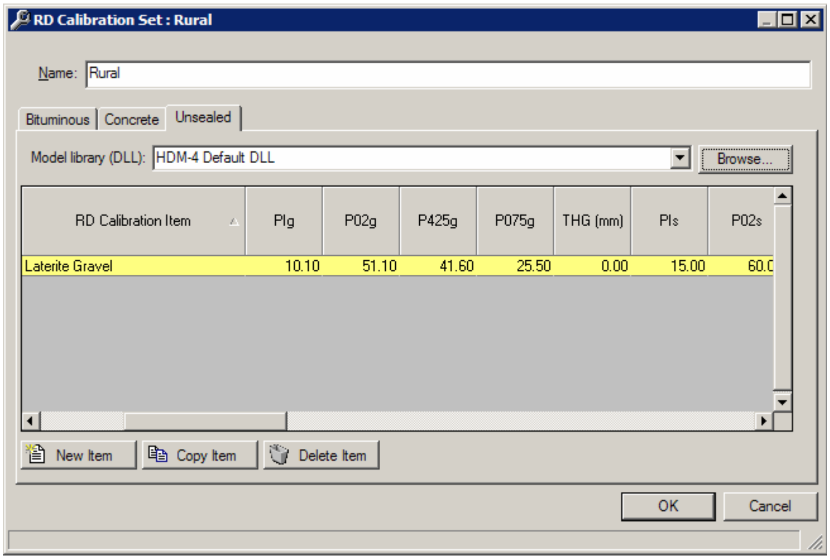


- **Pavement**

The surface and subgrade material types are given in this screen, together with the year of last regravelling (2003 for this case study).

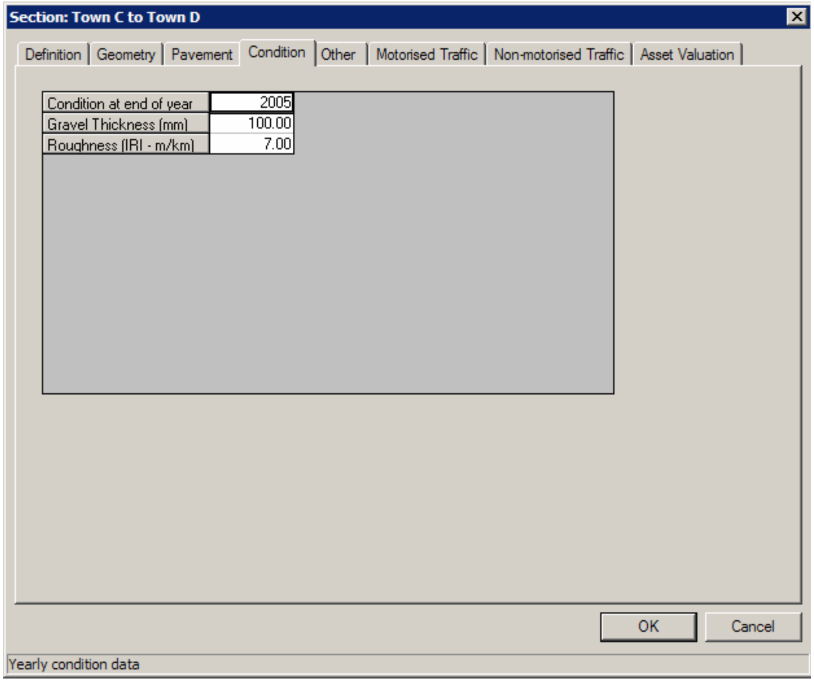


The material properties can be reviewed under **Configuration/RD Calibration Sets/Rural** in the Unsealed tab page.



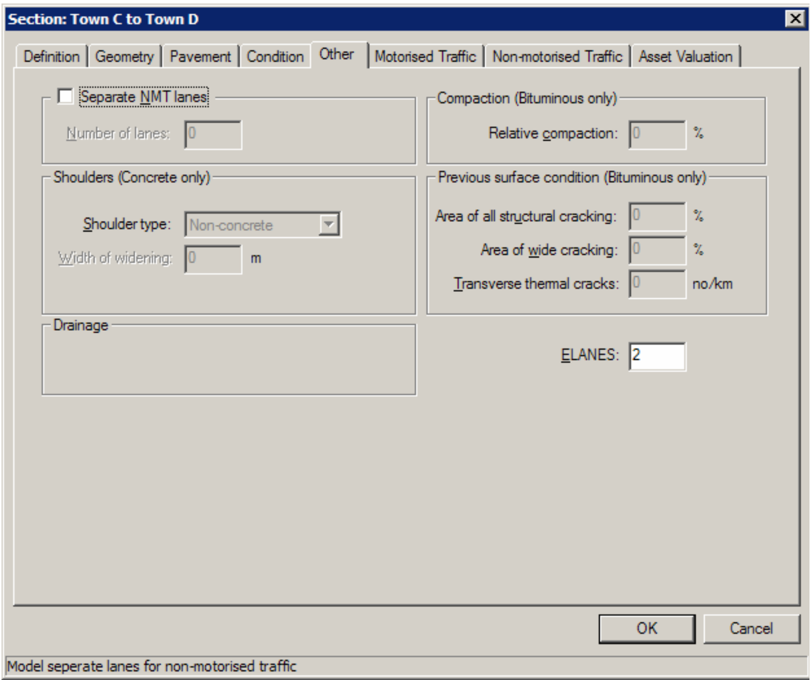
- **Condition**

The information on this screen confirms a gravel thickness of 100 mm and a roughness of 7 IRI in 2005. Note that, to enable road condition to be modelled through the analysis period, condition data must be specified for the year prior to the start of the analysis period. In this case study the condition data refer to the end of 2005, with an analysis start year of 2006.



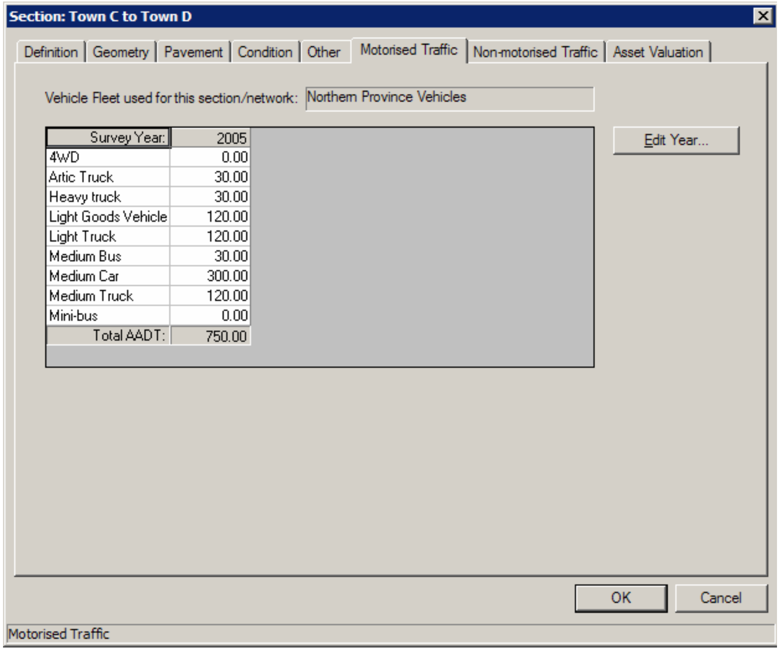
- **Other**

The number of lanes (ELANES) is specified as 2 for the existing road. The ELANES of the road after improvement is defined within the Improvement Standard.



- **Motorised Traffic**

The AADT for the section B001-03 (Town C to Town D) is 750 divided as shown between the various vehicle types within the Vehicle Fleet. If certain vehicle types are not represented on the road section being analysed, then a value of zero should be entered (as for 4WD & Minibus in this case study).



- **Non-motorised Traffic**

For this case study no NMT is specified.

- **Asset Valuation**

Asset valuation is not considered in this case study (see Section 0 for an example of the use of the asset valuation functionality).

1.3 Specify Alternatives

A total of five project alternatives are considered in this case study for each section. The first alternative, **Base Alternative**, represents a continuation of current maintenance practice. The 2nd to 5th alternatives represent the implementation of the project to upgrade the existing gravel road to paved standard. The duration of the upgrade is two years for road sections B001-01 and B001-03, and one year for section B001-02. The upgrade alternatives include upgrading the road starting in the year 2006, 2008, 2010 or 2012.

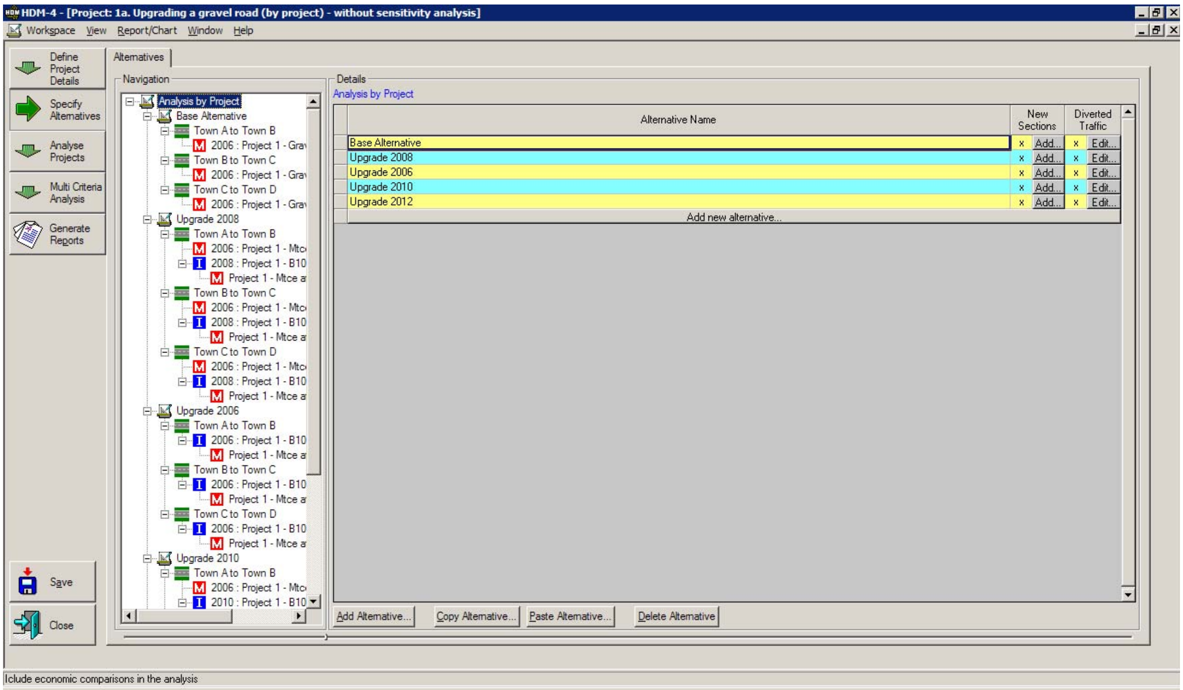
The maintenance and improvement (upgrading) standards for the project alternatives are summarised in Table E1.2. The maintenance standards are stored in the **Works Standards / Maintenance Standards** folder and the improvement standards are stored in the **Works Standards / Improvement Standards** folder.

For the Base Alternative the Gravel Road Maintenance standard is applied to the three sections from the start of the analysis period (i.e. from 2006). For the Upgrading alternatives, the Upgrading improvement standard is applied in either year 2006, 2008, 2010, or 2012, with the Maintenance before Upgrading standard applied for the years prior to the start of the upgrading, followed by the Maintenance after Upgrading standard applied once the Upgrading has been completed.

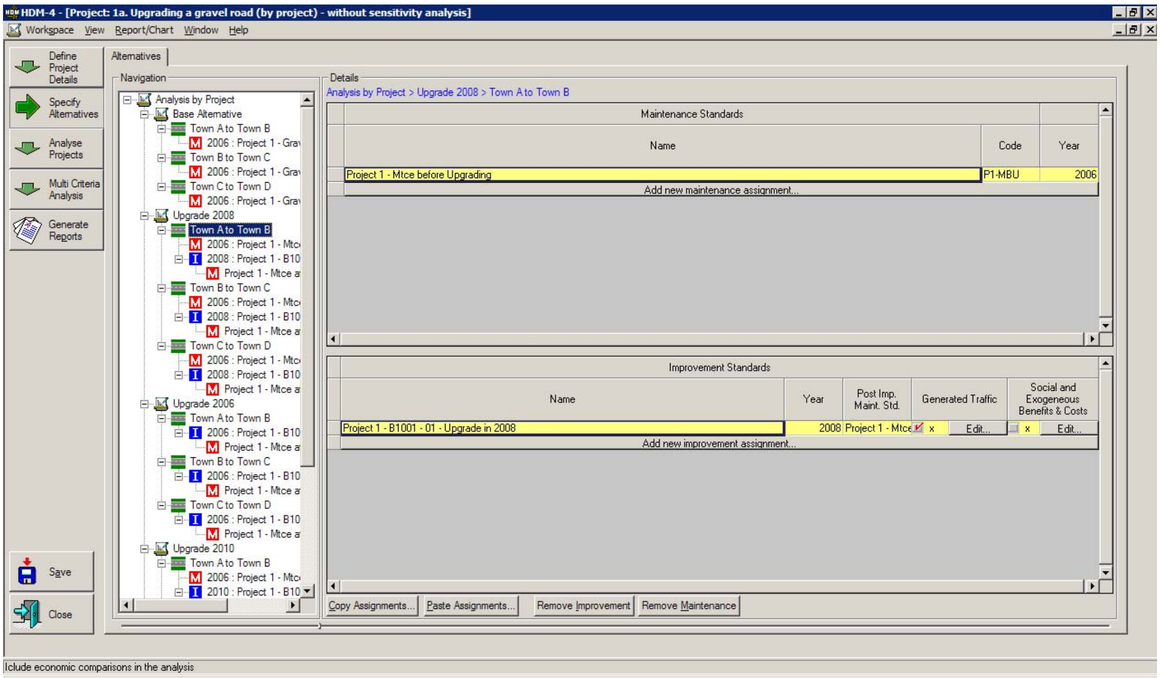
It should be noted that only one Maintenance Standard or Improvement Standard will be effective in any analysis year. However a Maintenance Standard may include more than one **works item** which could be implemented in a given year, for example, grading and spot regravelling on unsealed roads, crack sealing and patching on bituminous roads. Details on the implementation of works are given in Volume 4, Analytical Framework and Model Descriptions.

Table E1.2
Maintenance and Improvement Standards

	Standard	Works Items	Criteria
Maintenance	Gravel Road Maintenance & Maintenance before Upgrading	Spot Regravelling	Gravel thickness < 100 mm Max quantity 100 m^3/km/yr
		Heavy Motorised Grading	Every 180 days
		Regravelling	Gravel thickness < 50 mm Final gravel thickness = 150 mm Initial IRI = 4
	Maintenance after Upgrading	Patch Potholes	Potholes > 50 no./km
		15 mm Reseal	Cracked carriageway area > 15%
		50 mm Overlay	6 < IRI < 12.5
		Reconstruction with 25 mm surface dressing	IRI > 10
Improvement	Upgrading	25 mm surface dressing	Scheduled for specified years Duration 2 years



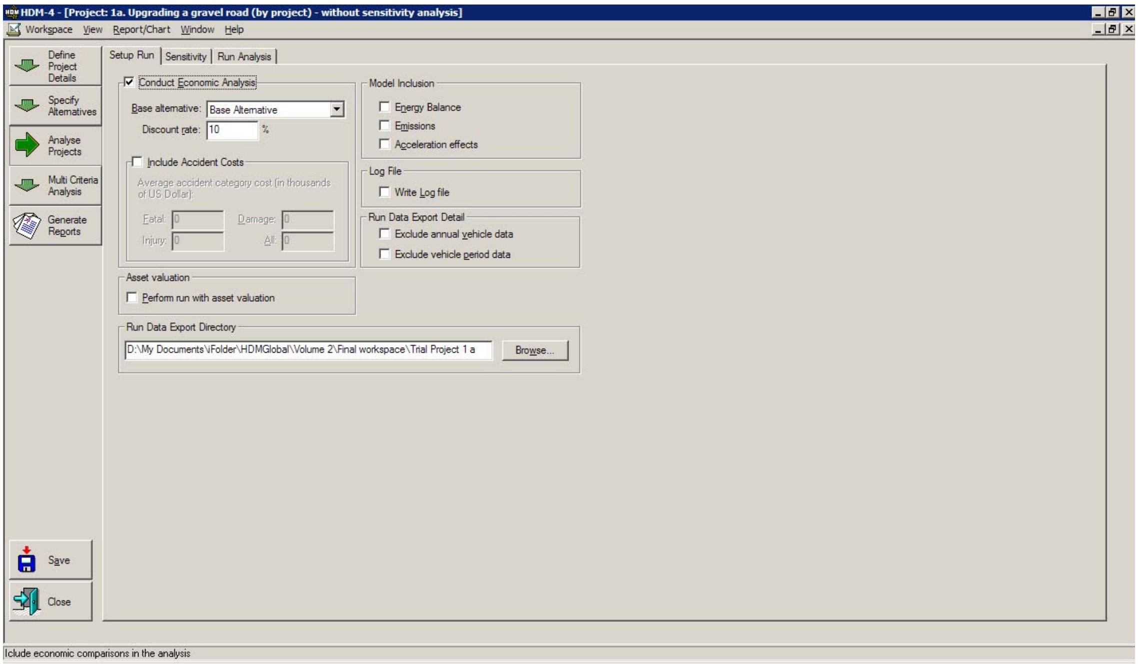
The **Alternatives** Tab provides the means to showing the Works Standards (assignments) associated with each project alternative. For the selected alternative, the Works Standards assigned to a section can be reviewed by selecting that section as shown below. In this example, both **Maintenance Standards** and **Improvement Standards** are assigned. Post Improvement Maintenance Standards are also assigned at this point, as well as Generated Traffic and Social & Exogenous Costs and Benefits should they be included in the study.



1.4 Analyse Projects

1.4.1 Setup Run

The options selected in the **Setup Run** screen include the project base alternative for the economic analysis and the discount rate (10% in this case study, based on the published Government Accounting Rate of Interest, or advised by the appropriate Planning Authority). The additional models for accidents, energy balance, emissions, acceleration effects and asset valuation are not included in this analysis.



For this case study **(Project 1a),** sensitivity analysis has not been selected (see **Project 1b** for sensitivity analysis).

1.4.2 Run Analysis

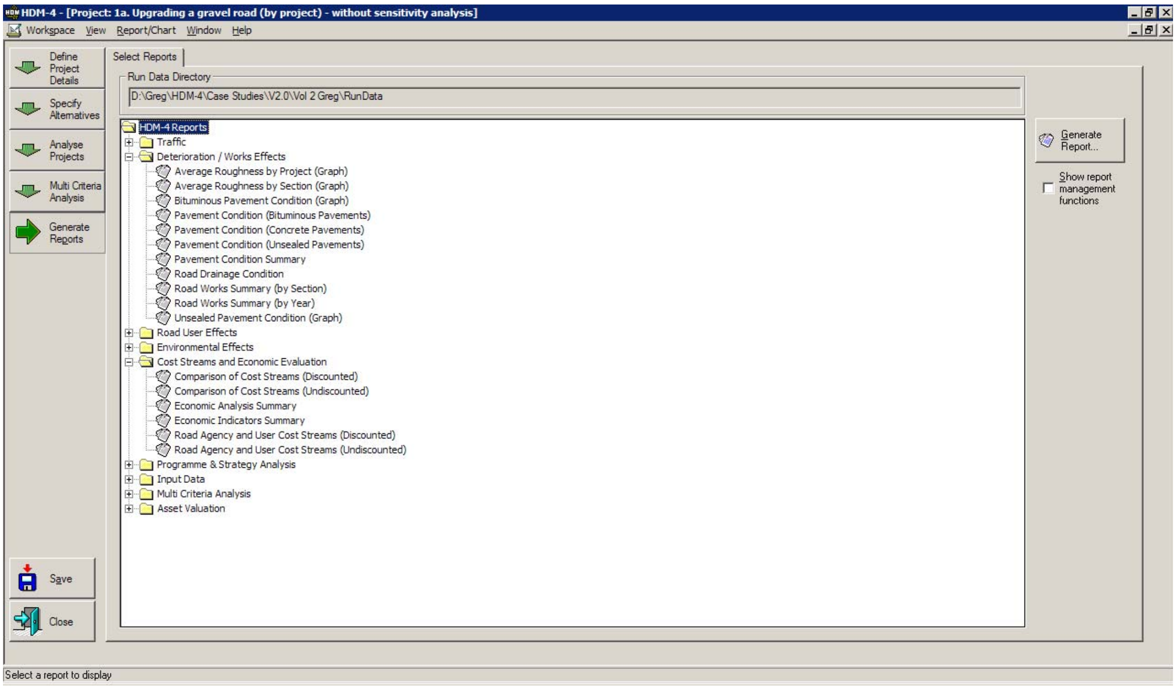
This starts the analysis and produces the output necessary for report generation.

1.5 Multi Criteria Analysis

Multi criteria analysis has not been used in this case study.

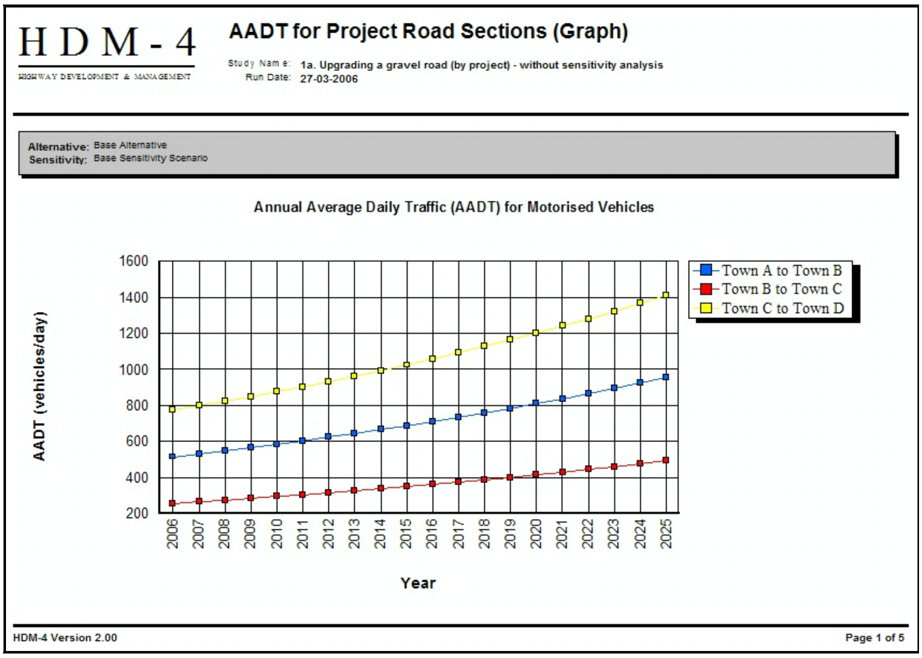
1.6 Generate Reports

The output reports from the analysis are produced and stored in the appropriate folders. The user may select **Generate Reports** to display the folders holding pre-defined report options. The pre-defined report categories are shown in the following screen in which two of the most relevant folders for this case study are open.



- **Traffic**

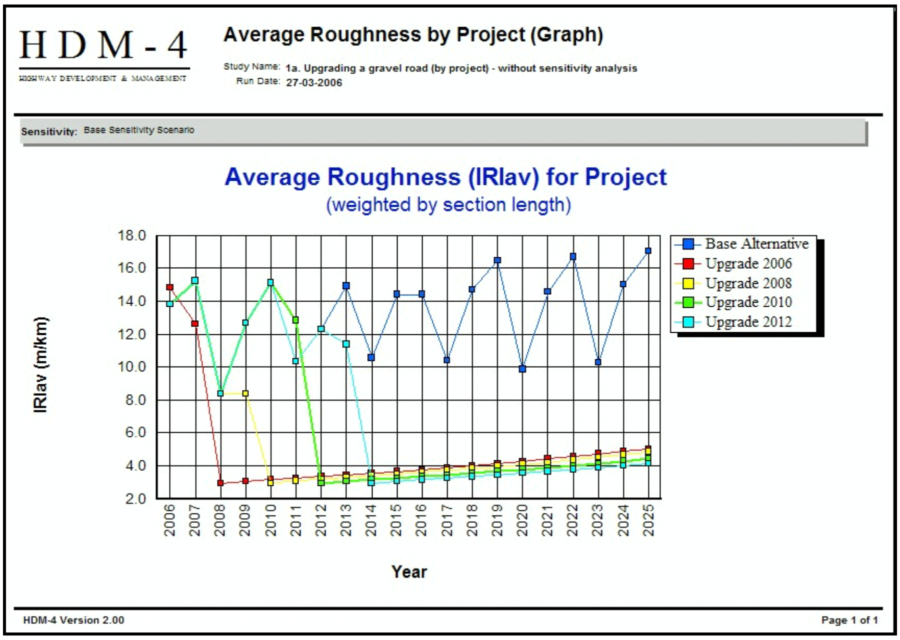
Details on the traffic flows for each alternative over the 20-year analysis period are reported in this folder in both graphical and tabular form. For eample, the **AADT for Project Road Sections** graph illustrates the growth in AADT for each section. Traffic volumes are inextricably linked with project viability and therefore correct data and trends are critical. All trends are consistent with the input data.



- **Deterioration / Works Effects**

The progressions of the various distresses for each alternative over the analysis period are reported in this folder in both graphical and tabular form. Also reported in this folder are the timings of the works carried out for each alternative during the 20-year period.

For example, the **Average Roughness by Project** graph displays the average annual roughness trend for each section-alternative. It helps confirm that modelled trends and works effects have been entered and modelled correctly. Failing to make such checks can lead to wasted effort. Users should also seek to get a 'feel' of model responses and relate this to real life experience. As shown in this example, the Base Alternative maintains a poor condition, with some variation due to maintenance, whereas the various upgrade alternatives are shown to improve in roughness at the specified time, and roughness slowly increases over a period of time, much as expected.



Other reports in this folder provide useful information for this case study. For example, the Pavement Condition Summary report provides in tabular form a summary of the performance of each section-alternative before and after upgrading. It is useful to identify changes in condition, both deterioration over time and improvements following treatment for each case, such as gravel loss, crack initiation and propagation, etc.

The Pavement Condition (Unsealed Pavements) report gives the condition of each unsealed section for each alternative up to the time that it is upgraded to a bituminous pavement, as shown for the upgrade in 2012 in the screen below.

H D M - 4 **Pavement Condition (Unsealed Pavements)**

Section: Town A to Town B
Alternative: Upgrade 2012
Sensitivity: Base Sensitivity Scenario

Length: 20.00km | Width: 7.00m | Rise + Fall: 10.00m/km | Curvature: 50.00deg/km | Road Class: Secondary or Main

Year	MT AADT		Pavement Type	Unsealed Pavement: Gravel Thickness (mm) THG	Unsealed Pavement: Mean Roughness IRI (m/km)
2006	516	Before works	Gravel	63.54	13.96
		After works	Gravel	74.48	
2007	533	Before works	Gravel	37.29	15.46
		After works	Gravel	150.00	
2008	550	Before works	Gravel	112.05	8.32
		After works	Gravel	112.05	
2009	567	Before works	Gravel	73.30	12.80
		After works	Gravel	84.93	
2010	586	Before works	Gravel	45.37	15.36
		After works	Gravel	150.00	
2011	605	Before works	Gravel	109.60	8.67
		After works	Gravel	109.60	
2012	625	Before works	Gravel	68.32	13.29
		After works	Gravel	68.32	
2013	645	Before works	Gravel	68.32	13.29
		After works	STGB	* Upgraded to a Bituminous Pavement	

The Road Works Summary (by Section) report is useful for checking that treatments are triggered, and quantities and costs are calculated properly. Unsealed road treatments are shown to trigger at regular intervals, up to the point of upgrading. Beyond this a set of bituminous maintenance treatments are triggered in response to significant surface distress.

- **Road User Effects**

The various components of road user effects are reported in this folder.

- **Cost Streams and Economic Evaluation**

This folder contains the results of the economic analysis. Having verified the physical performance of the sections and the associated agency costs, it is appropriate to examine the economic data. The **Economics Indicator Summary** report shown below provides an appropriate summary and can be used to select the most viable alternative. Alternatively, the **Economic Analysis Summary** may be used to extract relevant information, but this is more useful when examining project sensitivity and the changes in costs and associated with individual components of a cost benefit analysis (see **Project 1b**).

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Economic Indicators Summary

Study Name: 1a. Upgrading a gravel road (by project) - without sensitivity analysis
Run Date: 27-03-2006
Currency: US Dollar (millions)
Discount Rate: 10.00%

Sensitivity: Base Sensitivity Scenario

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B+E-C)	NPV/Cost Ratio (NPV/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
Base Alternative	2.610	1.665	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upgrade 2008	10.983	10.738	8.374	12.810	0.000	4.437	0.404	0.413	16.3 (1)
Upgrade 2006	13.417	13.417	10.807	13.756	0.000	2.949	0.220	0.220	12.9 (1)
Upgrade 2010	9.935	9.529	7.325	9.308	0.000	1.983	0.200	0.208	13.2 (1)
Upgrade 2012	8.710	8.198	6.100	8.084	0.000	1.985	0.228	0.242	14.5 (1)

Figure in brackets is number of IRR solutions in range -90 to +900

A positive Net Present Value (NPV) is indicative of project economic viability, with the best timing coinciding with the maximum value. In this case a positive NPV is found immediately, therefore the project is viable. The NPV then increases as the project is delayed (to 2008), producing net benefits almost 50% greater than those estimated for the earlier timing. The NPV then tends to fall as upgrading is delayed further, to less than half that of the Upgrade 2008 alternative, thus confirming the importance of examining a range of timing alternatives.

A high NPV/C, similar to the Benefit Cost Ratio, confirms the relative value of the benefits per investment unit. Whilst this indicator is usually employed in ranking (or prioritisation) under budget constraint, it provides confirmation of the positive result. An Economic Internal Rate of Return (EIRR) greater than the discount rate is also indicative of project viability.

1.7 Sensitivity Analysis

Sensitivity analysis is carried out to examine the robustness of a project, in economic or financial terms, to changes in the magnitude of important variables. It may be undertaken as part of a broader scenario or risk analysis because the results of an appraisal are subject to uncertainty. However, for the latter to be done comprehensively, ideally a probability based approach should be used. This is usually only appropriate where risks (and associated probabilities) are well defined.

The ‘sensitivity analysis’ functionality within HDM-4 allows a relatively simplified examination of uncertainty by allowing the user to employ higher and lower figures than those expected, and to determine how sensitive the economic decision criteria are to such changes. The variables chosen are a matter of judgement, but for most ‘capital’ road projects, project viability should be tested for variations in traffic, project costs and timing. Depending on the project other factors may be examined, including generated traffic, time and accident savings, shadow prices, maintenance and special factors, such as the effects of complementary investments, or the effect of management or regulatory actions.

Project 1b. Upgrading a gravel road (by project) – with sensitivity analysis investigates the effect of changes in the value of a number of key variables on the outcome of the economic analysis.

The effect of timing was considered in Proejct 1a, and therefore the additional scenarios which were examined included variations in the following variables, each one at a time:

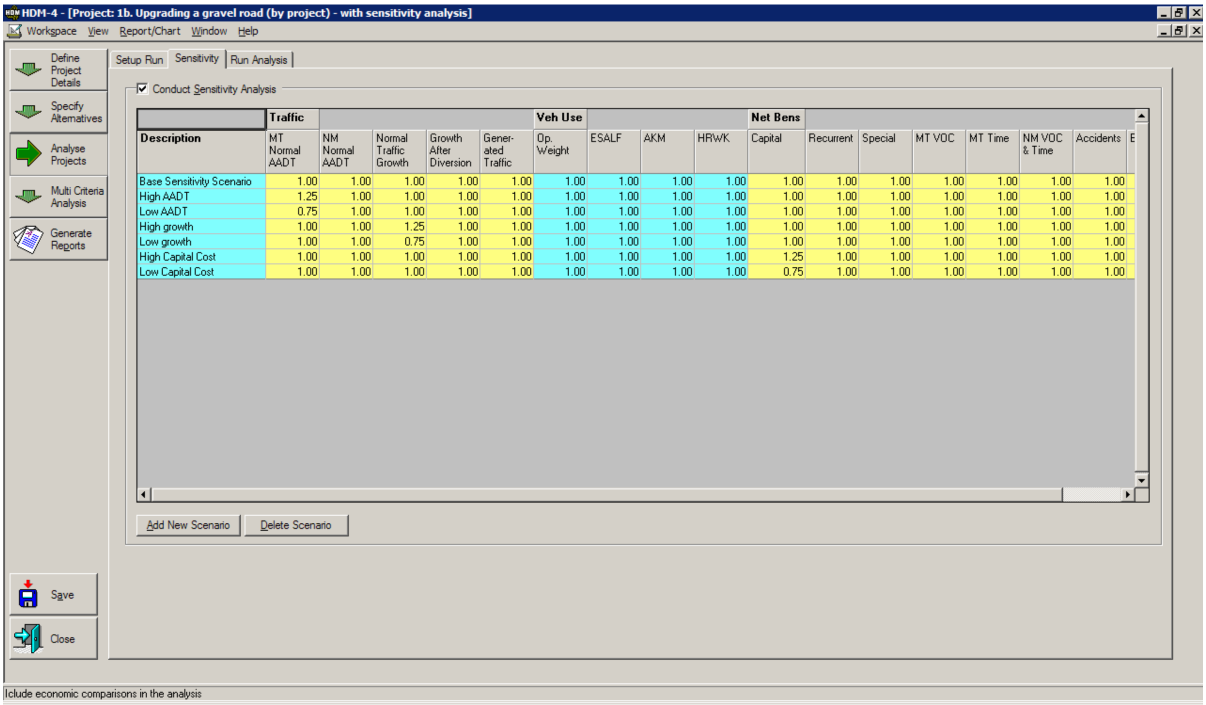
- Base (or Normal) AADT (+/- 25%)
- Normal traffic growth (+/- 25%)
- Capital costs (+/- 25%)

This case study is located in the **Projects** folder in the Workspace. Double-click on Project case study **1b. Upgrading a Gravel Road (by project) – with sensitivity analysis**.

The additional steps and results are described below.

1.7.1 Defining Scenarios

Scenarios to be examined in a sensitivity analysis are defined in the following screen, which is accessed through **Analyse Projects/Sensitivity** tab page.



In Project 1a this screen would have been blank except for the presence of the Base Sensitvity Scenario, therefore the other scenarios have been added. The % variations noted in the above scenarios have been introduced as multiplication factors (e.g. 25% is presented by the factor 1.25, etc).

1.7.2 Run Analysis

This starts the analysis and produces the output necessary for report generation, and is executed in the normal manner.

1.7.3 Generate Reports

A full set of reports are available for all scenarios. The user may select **Generate Reports** to display the folders holding pre-defined report options which they consider relevant to interpreting the results of this case study. Both input and output/analysis reports should be examined. The following discussion concentrates on the latter, specifically those contained in the **Cost Streams and Economic Evaluation** folder.

- **Comparison of Cost Stream (Discounted and Undiscounted)**

These comprise two separate reports (see below) which contain a summary of the changes in road agency cost and road user costs, and the net social/exogenous benefits and total benefits. Each project alternative/scenario is reported separately. Having verified that traffic and physical parameters have changed in accordance with expectations, these reports are useful for verifying changes in costs have been computed and reported correctly as they are key to the project outcomes.

In the Base Sensitivity Scenario shown below, the first year capital costs are of the order of $2.55 million. In the high capital cost scenario shown in the following figure, the first year costs have risen to approximately $3.2 million (+ 25%) thus confirming the desired change.

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HIGHWAY DEVELOPMENT & MANAGEMENT

Comparison of Cost Streams (Discounted)

Study Name: 1b. Upgrading a gravel road (by project) - with sensitivity analysis
Run Date: 27-03-2006
Currency: US Dollar (millions)
Discount rate: 10.00 %

Section: Town A to Town B
Alternative: Upgrade 2006
Sensitivity: Base Sensitivity Scenario

Sect ID: B001-01 Road Class: Secondary or Main
Length: 20.00 km Width: 7.00 m Rise+Fall: 10.00 m/km Curvature: 50.00 deg/km

Year	Increase in Road Agency Costs			Savings in Road User Costs							Net Social / Exogenous Benefits	Total Net Benefits
	Capital Works	Recurrent Works	Special Works	Normal (+ Diverted) Traffic			Generated Traffic			Accident Cost Reduction		
				MT VOC	MT Time	NMT Time & Operation	MT VOC	MT Time	NMT Time & Operation			
2006	2.550	-0.047	0.000	-0.061	-0.015	0.000	0.000	0.000	0.000	0.000	0.000	-2.579
2007	2.148	-0.026	0.000	0.026	0.006	0.000	0.000	0.000	0.000	0.000	0.000	-2.090
2008	0.000	-0.024	0.000	0.186	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.242
2009	0.000	-0.036	0.000	0.357	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.471
2010	-0.120	-0.020	0.000	0.441	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.681
2011	0.000	-0.018	0.000	0.155	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.201
2012	0.000	-0.028	0.000	0.298	0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.394
2013	-0.096	-0.015	0.000	0.365	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.560
2014	0.000	-0.014	0.000	0.129	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.169
2015	0.000	-0.021	0.000	0.250	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.329
2016	-0.078	-0.011	0.000	0.306	0.073	0.000	0.000	0.000	0.000	0.000	0.000	0.469
2017	0.000	-0.010	0.000	0.106	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.139
2018	0.000	-0.017	0.000	0.212	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.280
2019	-0.062	-0.008	0.000	0.250	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.381
2020	0.000	-0.007	0.000	0.088	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.116
2021	0.000	-0.013	0.000	0.177	0.043	0.000	0.000	0.000	0.000	0.000	0.000	0.233
2022	-0.051	-0.010	0.000	0.208	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.320
2023	0.112	-0.011	0.000	0.075	0.018	0.000	0.000	0.000	0.000	0.000	0.000	-0.008
2024	0.000	-0.010	0.000	0.147	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.193

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HDM - 4 Comparison of Cost Streams (Discounted)

Section: Town A to Town B
Alternative: Upgrade 2006
Sensitivity: High Capital Cost

Sect ID: B001-01 Road Class: Secondary or Main
Length: 20.00 km Width: 7.00 m Rise+Fall: 10.00 m/km Curvature: 50.00 deg/km

Year	Increase in Road Agency Costs			Savings in Road User Costs							Net Social / Exogenous Benefits	Total Net Benefits
	Capital Works	Recurrent Works	Special Works	Normal (+ Diverted) Traffic			Generated Traffic			Accident Cost Reduction		
				MT VOC	MT Time	NMT Time & Operation	MT VOC	MT Time	NMT Time & Operation			
2006	3.188	-0.047	0.000	-0.061	-0.015	0.000	0.000	0.000	0.000	0.000	0.000	-3.217
2007	2.685	-0.026	0.000	0.026	0.006	0.000	0.000	0.000	0.000	0.000	0.000	-2.627
2008	0.000	-0.024	0.000	0.186	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.242
2009	0.000	-0.036	0.000	0.357	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.471

- **Economic Analysis Summary**

This report (shown below) contains a summary of the key economic values for each project alternative/sensitivity scenario.

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Economic Analysis Summary

Study Name: 1b. Upgrading a gravel road (by project) - with sensitiv
Run Date: 27-03-2006
Currency: US Dollar (millions)
Discount: 10.00%
Analysis Mode: Analysis-by-Project

Alternative: Upgrade 2006 vs Alternative: Base Alternative
Sensitivity Scenario: Base Sensitivity Scenario

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings ir NMT Trave & Operating Cost:	Reductior in Accident Costs	Ne Social / Exogenous Benefit:	Ne Economic Benefit: (NPV
	Capital	Recurrent	Special						
Undiscounted	11.21	-2.06	0.00	30.34	6.70	0.00	0.00	0.00	27.89
Discounted	11.75	-0.94	0.00	11.32	2.43	0.00	0.00	0.00	2.95

Economic Internal Rate of Return (EIRR) = 12.9% (No. of solutions = 1)

Results of the sensitivity analysis have been summarised in Table E1.3, Table E1.4 and Table E1.5. For this analysis, only the 2008 timing alternative was examined as this was previously shown to provide the most viable option.

Table E1.3
Comparison of NPV (millions) and EIRR by AADT Scenario

Economic Indicator	Low	Most Likely	High
NPV (Discounted)	- 0.02	4.44	8.81
EIRR	10.0	16.3	21.6

Table E1.4
Comparison of NPV (millions) and EIRR by Normal Traffic Growth Scenario

Economic Indicator	Low	Most Likely	High
NPV (Discounted)	3.2	4.44	5.73
EIRR	14.8	16.3	17.7

Table E1.5
Comparison of NPV (millions) and EIRR by Capital Cost Scenario

Economic Indicator	Low	Most Likely	High
NPV (Discounted)	6.7	4.44	2.17
EIRR	22.0	16.3	12.6

In the above tables, the ‘Most Likely’ scenario corresponds with the Base Alternative Scenario.

With the exception of the low initial AADT scenario, all scenarios have confirmed the viability of the project in terms of a) positive NPV, and b) an EIRR greater than the test discount rate of 10%. However, even the low initial AADT scenario was marginal, thus confirming that the viability of the project is relatively robust.

1.8 Comparison with Analysis by Section

As a more general comment, whilst the NPV is positive in all Alternatives in the above case study, the relatively low NPV/C and EIRR suggest certain aspects of the overall project are marginal. This has been investigated further using the **Analysis by Section** method of analysis, (see **Project 1c. Upgrading a gravel road (by section)** in the Projects folder).

Results from this analysis are shown in Table E1.6. These results confirm that each section is viable to a greater or lesser degree, with the section with the lowest AADT of 250 being the non-viable for all of the the alternatives investigated, and that with the highest AADT of 750 being the most viable. Such analysis confirms the concept of 'Breakeven Traffic Volume' associated with improvement standards.

Table E1.6
Comparison of NPV from Analysis by Section and Analysis by Project

Section	AADT	Net Present Value (millions)			
		Upgrade 2006	Upgrade 2008	Upgrade 2010	Upgrade 2012
A - B	500	0.761	1.037*	0.524	0.576
B – C	250	- 0.856	- 0.698	- 0.523	- 0.453
C - D	750	3.044	3.129*	1.982	1.862
Total NPV (for All sections)		2.949	3.438*	1.983	1.985

* Most viable timing alternative for each section, and for All sections
B - C is not viable for any of the chosen investment alternatives

2 CASE STUDY 2 – PAVED ROAD REHABILITATION

2.1 Introduction

The name of this case study is **2. Paved Road Rehabilitation**. This case study presents the economic analysis of alternative rehabilitation standards for two typical study sections chosen from a representative set of strategic sections for the entire road network. The two sections represent existing roads which carry 12,500 and 40,000 vehicles per day (AADT) and exhibit moderate levels of roughness and surface distress. This case study evaluates several possible future rehabilitation alternatives including a thin overlay to restore surface smoothness, a structural overlay and full pavement reconstruction.

The objective of the case study is to present the definition of section alternatives appropriate to this type of analysis and demonstrate the HDM-4 deterioration model for paved roads. The definition and timing of the Maintenance Standards are discussed, and the results are examined.

The case study is located in the **Projects** folder in the Workspace. Double-click on the Project case study **2. Paved Road Rehabilitation** to open the case study.

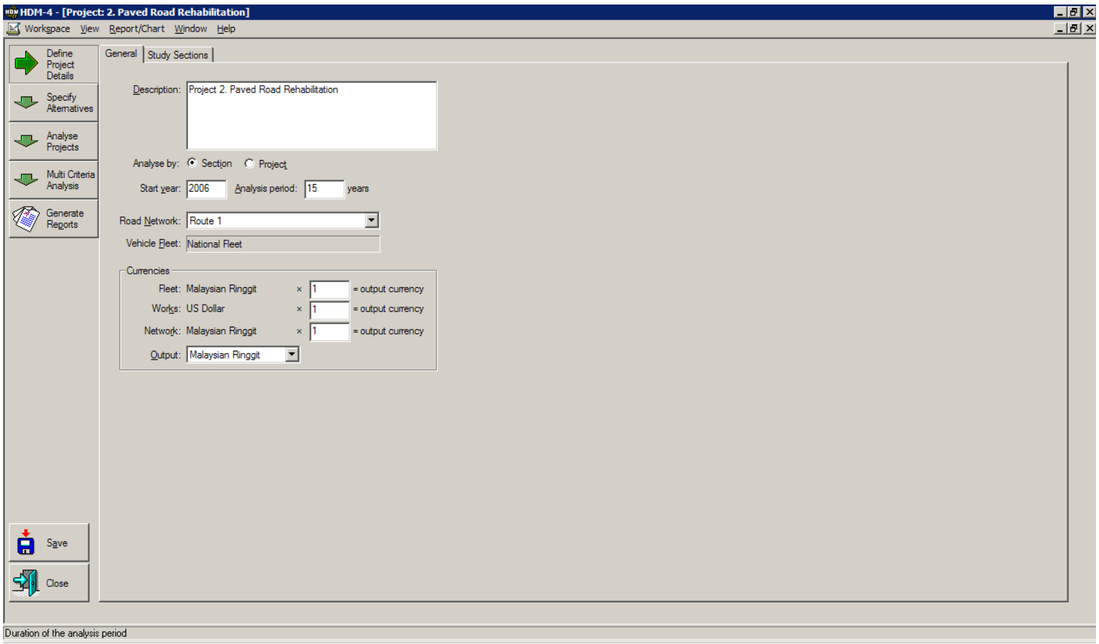
2.2 Define Project Details

In the **Define Project Details** screen, the following tab pages may be displayed:

- General
- Study Sections

2.2.1 General

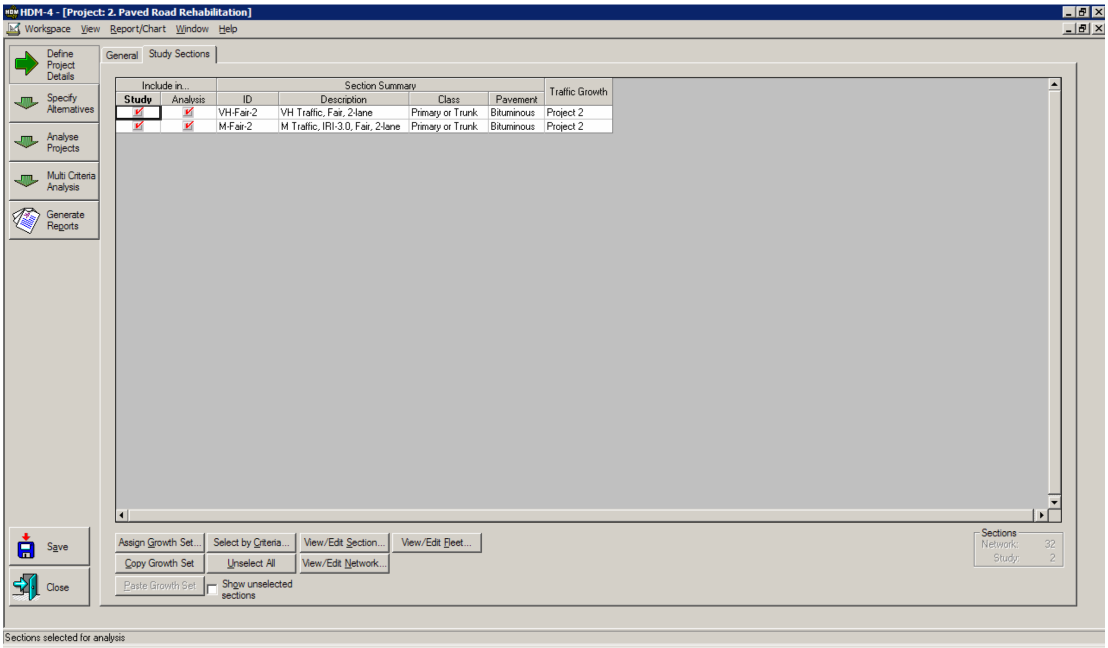
The information displayed in the General screen includes the study description, analysis type, analysis period, the pre-defined Road Network and Vehicle Fleet, and the currency to be used for the analysis.



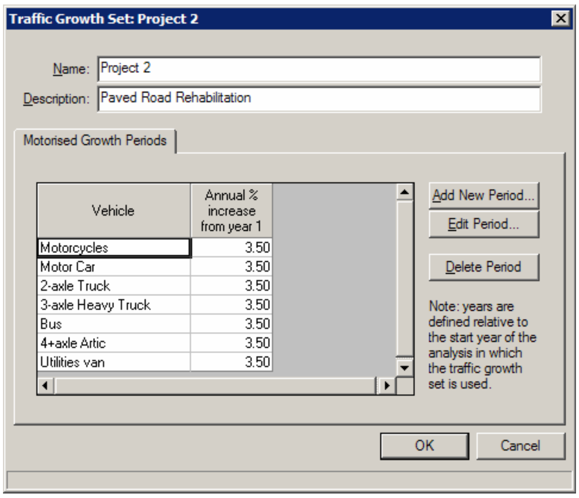
This case study is presented as an Analysis by Section example. The analysis period is defined by the start year 2006 and a duration of 15 years (i.e. 2006 - 2025). The section to be analysed is in the Road Network entitled Route 1, to which the National Fleet has been previously assigned as the Vehicle Fleet. The currency being used for this analysis is the Malaysian Ringgit.

2.2.2 Study Sections

The road sections selected for analysis are VH-Fair-2 and M-Fair-2.



By double-clicking on the section gives access to the section details. However, the **Traffic Growth** details can only be seen and edited through the **Vehicle Fleets** folder. To access the Traffic Growth Sets that have been previously created, the user needs to open the appropriate vehicle fleet (in this case National Fleet) in the Vehicle Fleet folder and click on the Edit Traffic Growth Sets button which then displays all the previously created sets. Double-clicking on the appropriate set (in this case Project 2) displays the details of the traffic changes over the analysis period.

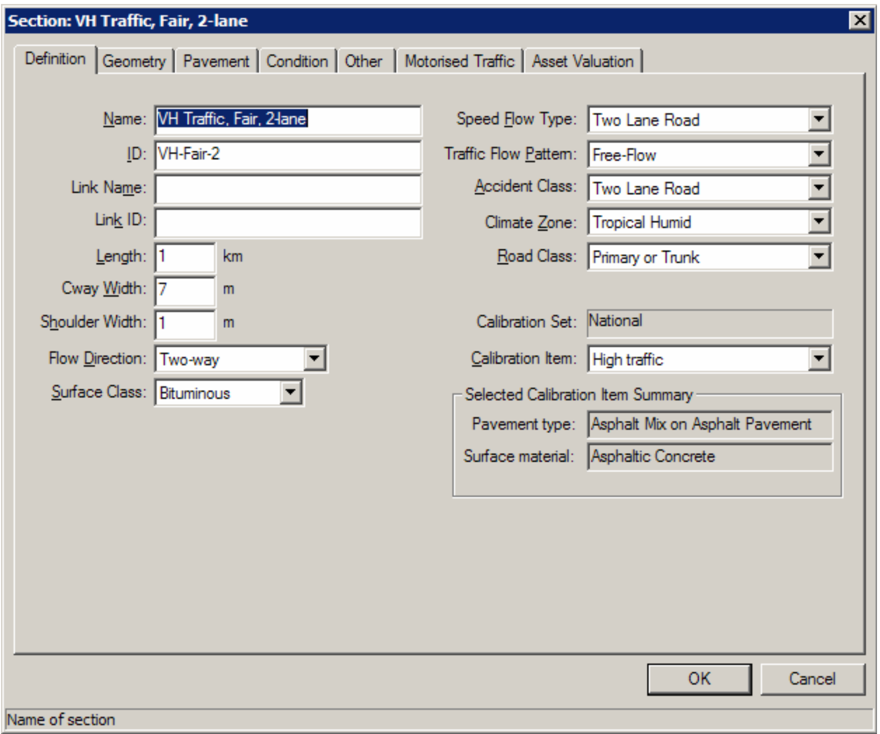


The traffic growth rates for the motorised traffic in this case study indicate that the motorised traffic is expected to grow by 3.5% per year. Non-motorised traffic is not used in this case study.

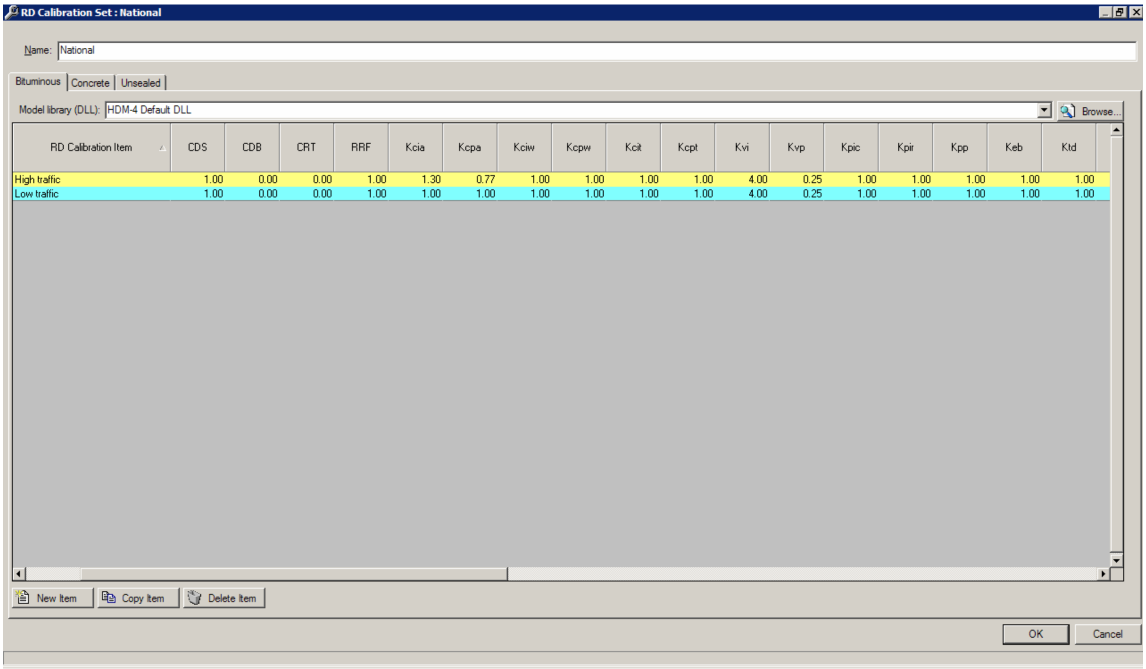
Section details are described below, concentrating on section VH-Fair-2.

- **Definition**

The speed-flow type and the traffic flow pattern of the existing road is illustrated in this screen. The carriageway width is 7m, with two directional traffic flow. The pavement type is an asphalt mix on an asphalt pavement, and this pavement type will be retained except in the case where full reconstruction takes place.

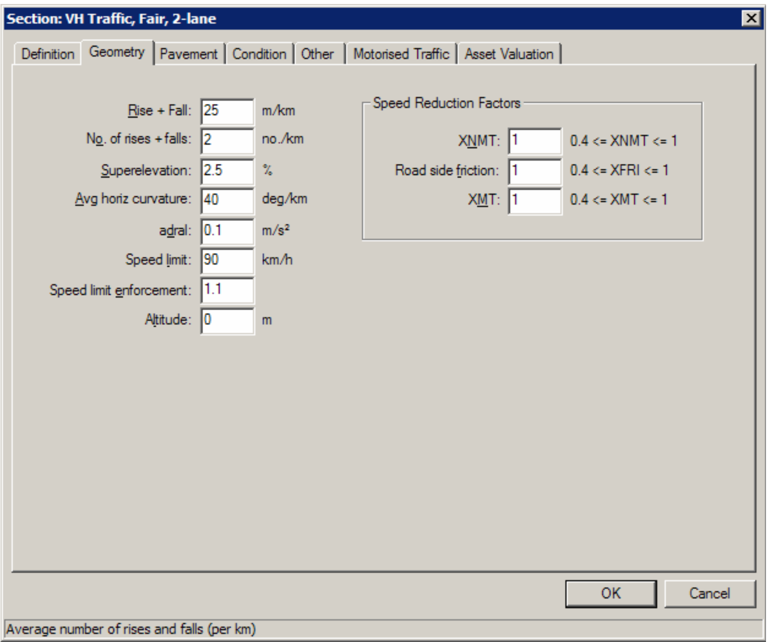


The **Calibration Set** assigned to the section is the National set. Two **Calibration Items** are used in this case study; High Traffic (used for VH-Fair-2) and Low Traffic (used for M-Fair-2). These alter the performance characteristics of the network, and include differences related to the calibration of the cracking and roughness models, and structural rutting. Details may be viewed from within the Configuration folder, as illustrated with the National calibration set below.



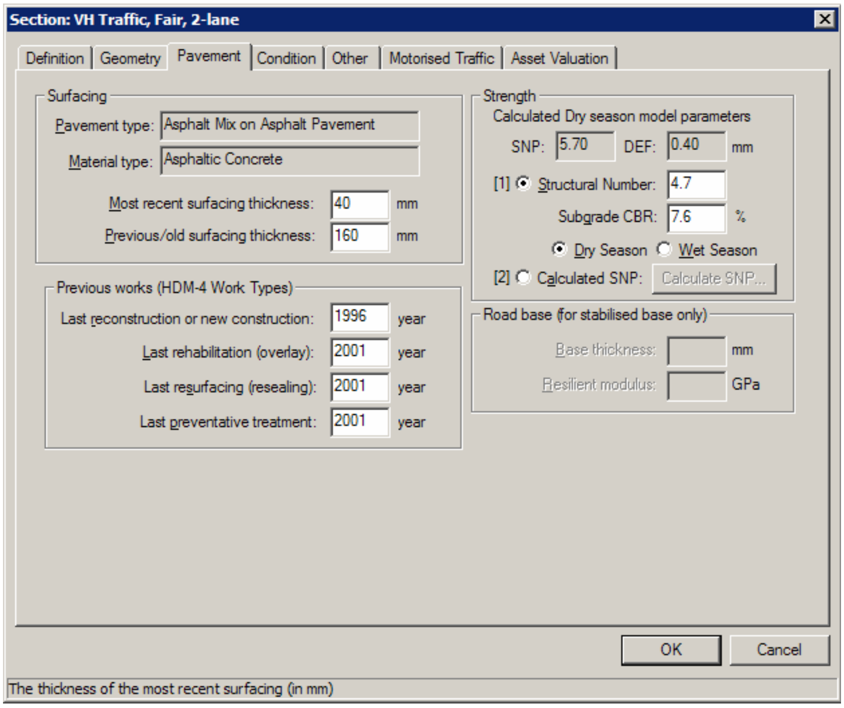
- **Geometry**

Typical geometry characteristics have been employed based on network-wide averages.



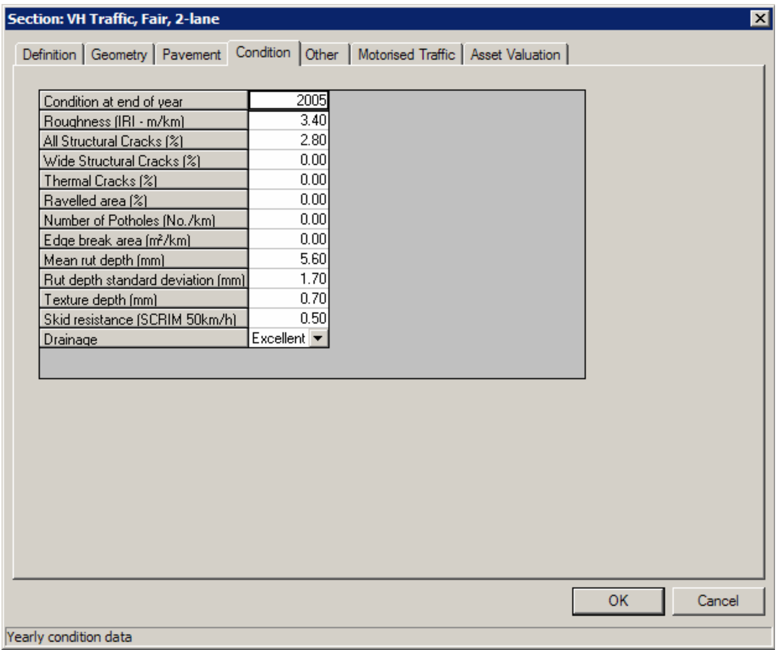
- **Pavement**

The pavement type has been defined as asphalt mix on asphalt pavement (AMAP) and was last reconstructed in 1996, with a rehabilitation applied in 2001 as entered under Previous works. The structural number, SN, of the pavement layers above the subgrade is 4.7, with a subgrade of 7.6% CBR, giving a SNP value of 5.7. For the pavement reconstruction alternative assigned to this case study, a similar SN value has been assigned.



- **Condition**

The condition of the road section at the end of 2005 is specified, with the analysis commencing in 2006. At a roughness of 3.4 IRI, it is possible that an intervention could be justified given the level of traffic applied to each section. Cracking has also initiated, and therefore can be expected to progress if left untreated.

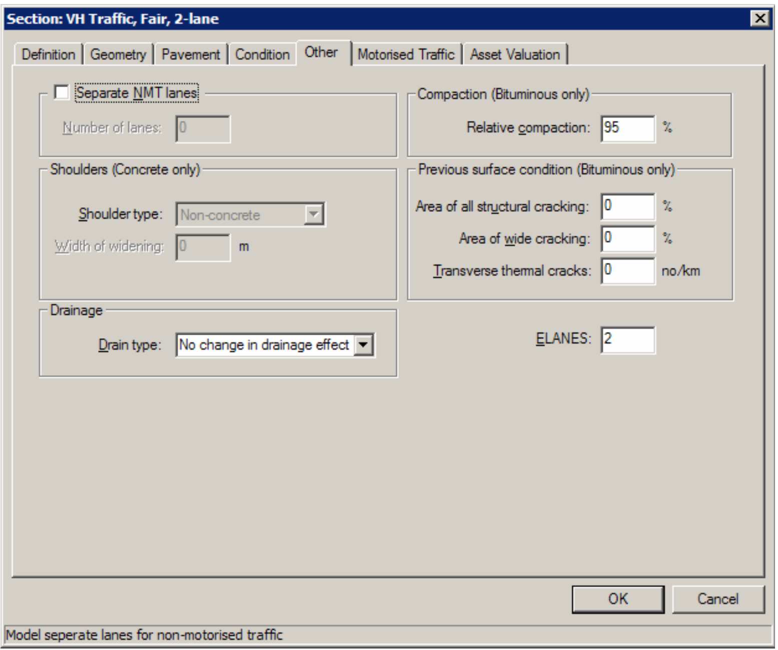


- **Other**
  For this case, this screen provides the possibility of selecting or specifying a number of relevant parameters, whose significance is as follows:

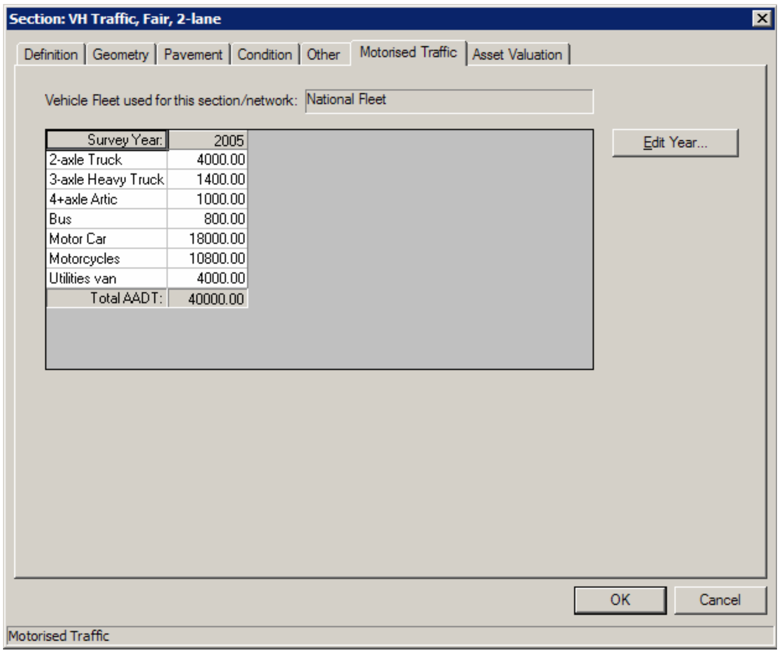
- **Drainage -** enables the selection of drain type, including 'No change in drainage effects'

- **Relative compaction** - affects the initial densification component of pavement rutting, and the structural component of rut progression

- **Previous surface condition** - in practice affects the effectiveness of particularly thin layers, through relection cracking



- **Motorised Traffic**
  The AADT of 40000 in 2005 has been distributed between the various vehicle types in the selected Vehicle Fleet. If certain vehicle types do not operate on the selected road section, then a value of zero should be assigned for those particular types. The National vehicle fleet has no NMT vehicles.



- **Asset Valuation**

Asset valuation is not considered in this case study.

2.3 Specify Alternatives

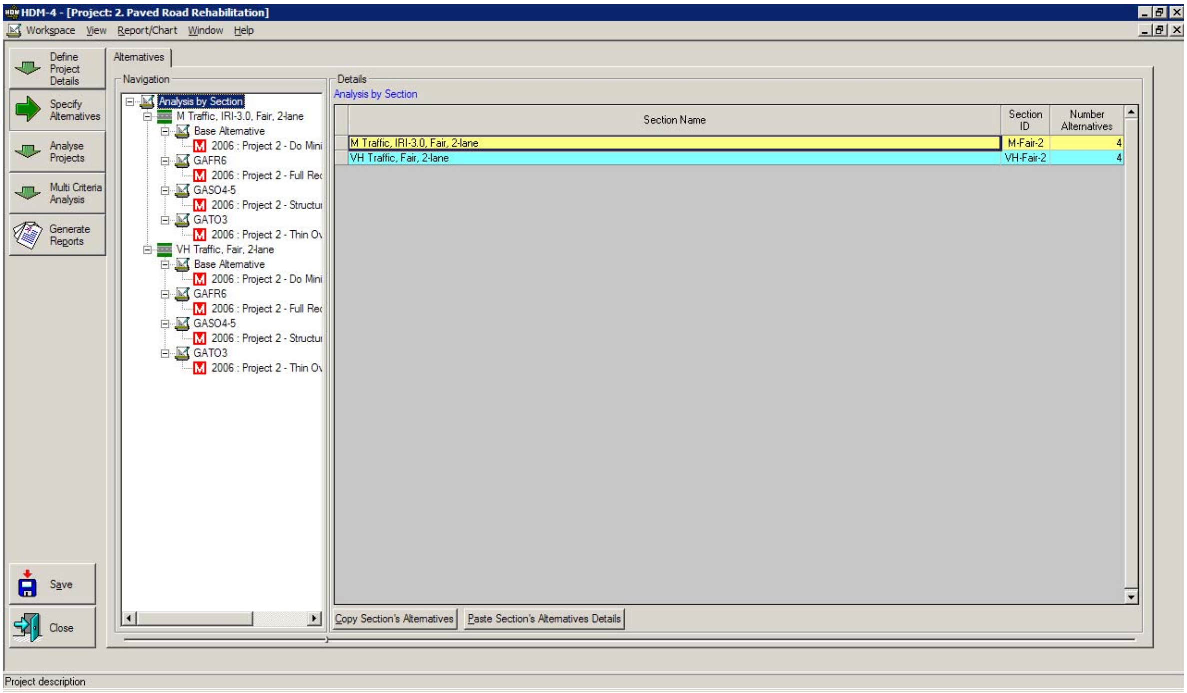
The four alternatives considered in this case study are described in Table E2.7.

Table E2.7
Maintenance Alternatives

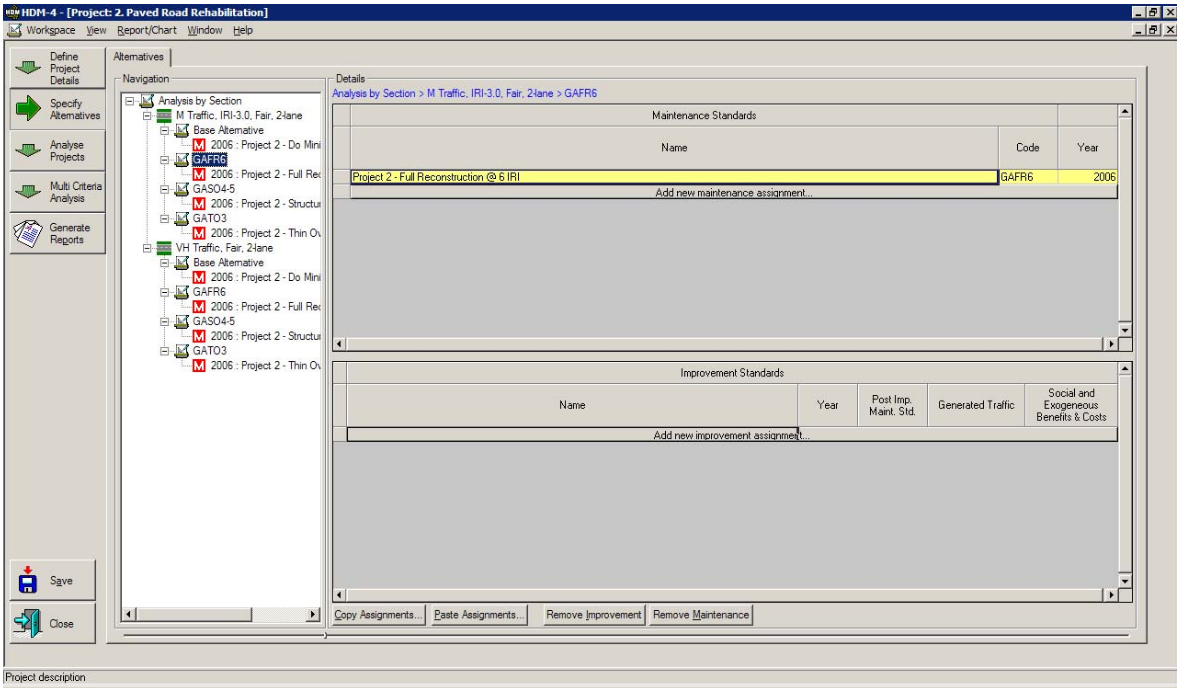
Alternative	Works Items	Criteria
1 Base Alternative	Edge Repair	Edge break > 1 m^2/km
	Pothole Patching	Potholes > 1 no./km
	Patching Wide Cracks	Wide Cracks > 5%
	Pavement Reconstruction – 150mm asphalt	IRI > 10
2 GAT03	Edge Repair	Edge break > 1 m^2/km
	Pothole Patching	Potholes > 1 no./km
	Patching Wide Cracks	Wide Cracks > 5%
	40mm Overlay	3 < IRI < 5 Minimum interval 5 years
3 GASO4-5	Edge Repair	Edge break > 1 m^2/km
	Pothole Patching	Potholes > 1 no./km
	Patching Wide Cracks	Wide Cracks > 5%
	80mm Overlay	4.5 < IRI < 6.5 Minimum interval 7 years
4 GAFR6	Edge Repair	Edge break > 1 m^2/km
	Pothole Patching	Potholes > 1 no./km
	Patching Wide Cracks	Wide Cracks > 5%
	Pavement Reconstruction – 150mm asphalt	IRI > 6

Alternative 1 is the Base Alternative. It comprises routine maintenance which includes edge repairs, pothole patching and patching of areas affected by wide cracks. In addition, a reconstruction is applied if the roughness level reaches 10 IRI. A high standard of routine maintenance is specified because of the traffic level and road importance. The three other alternatives include the same routine maintenance, with different periodic maintenance items.

The four alternatives are assigned to the two road sections as shown in the Specify Alternatives screen below.



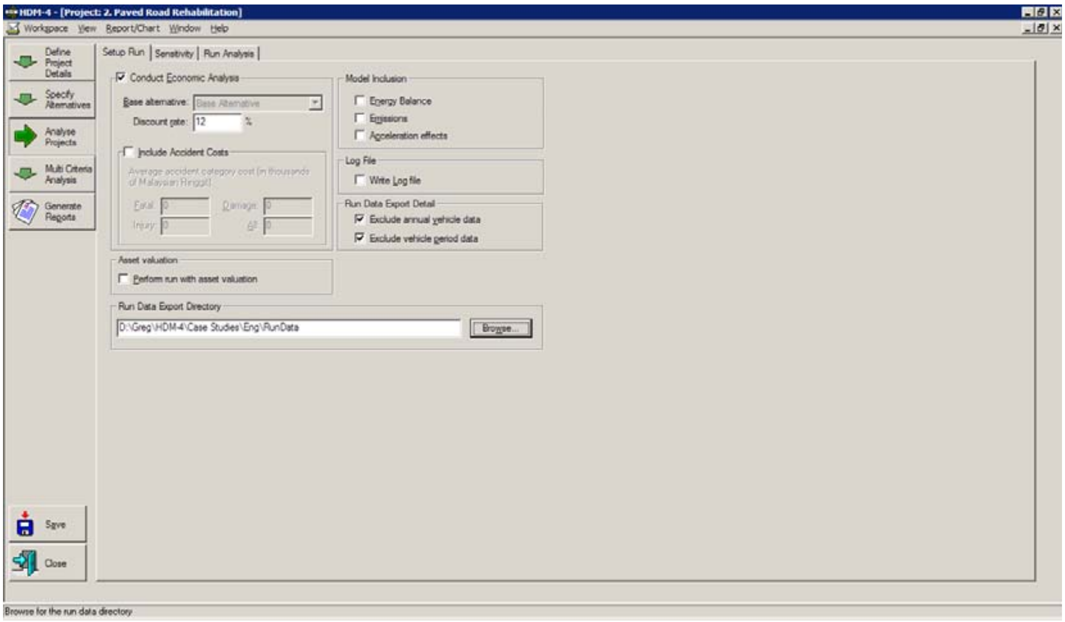
The Alternatives tab provides the means of showing the Works Standards associated with each section alternative. For the selected alternative, the Works Standards assigned to a different section can be reviewed by selecting that section as shown below. In this example, only Maintenance Standards are assigned.



2.4 Analyse Projects

2.4.1 Setup Run

The options selected in the Setup Run screen are Conduct Economic Analysis using a discount rate of 12%. The additional models for accidents, energy balance, emissions, acceleration effects and asset valuation are not included in this analysis.



2.4.2 Run Analysis

This starts the analysis and produces the output necessary for report generation.

2.5 Multi Criteria Analysis

Multi criteria analysis has not been used in this case study.

2.6 Generate Reports

The output reports from the analysis can be found by clicking Generate Reports. The following selection of reports are recommended for this case study and comments are made on the outcome of the case study.

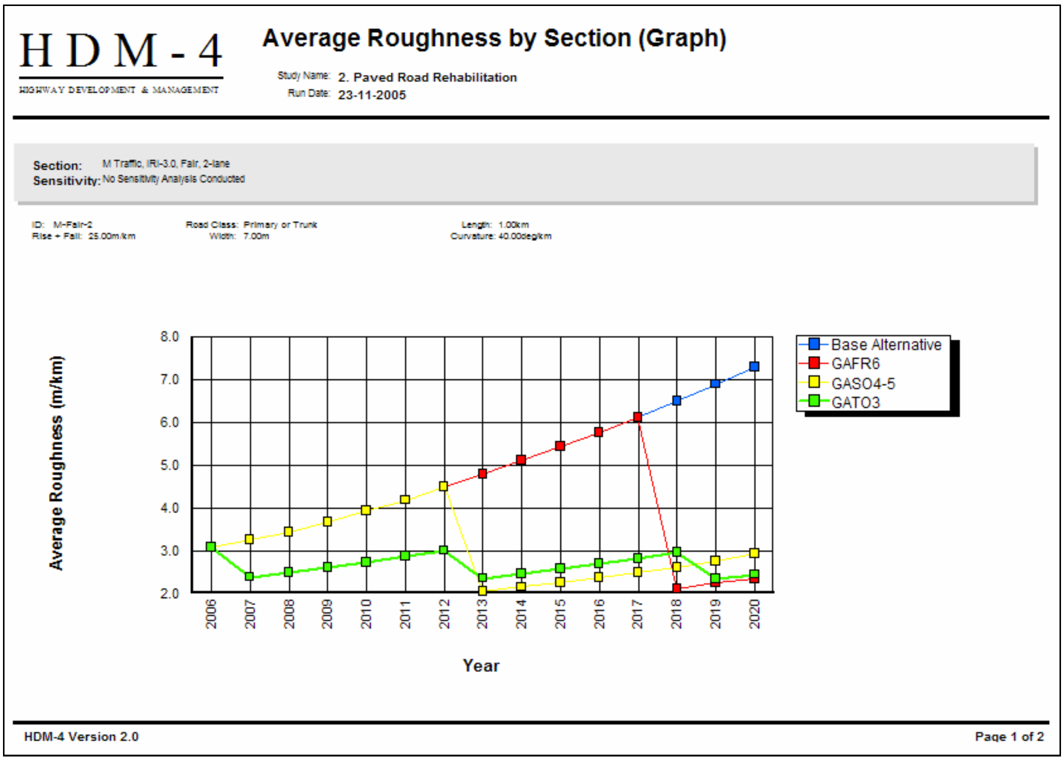
- **Traffic**

The AADT for Section Alternative (Graph) report allows the user to view the growth in AADT for each section. Traffic volume is inextricably linked with project viability and therefore correct data and trends are critical. Inspection of this report will confirm that trends are consistent for both sections.

- **Deterioration / Works Effects**

The Average Roughness by Section (Graph) report is useful for verifying trends in roughness, and to confirm that the resetting of roughness after works. These are revealed to be consistent with the specification of the works standards as shown by the graph below.

The deterioration trends are also consistent for each section-alternative, suggesting that the routine works are being triggered in a similar manner.



The Pavement Condition (Bituminous Pavement) report lists in tabular form the individual distresses and other parameters, such as AADT, traffic loading (YE4) and pavement strength (SNP). Trends can be examined for each section-alternative

The Road Works Summary (by Section) report is useful for checking treatments are triggered, and quantities and costs are calculated correctly. In this case study, the 40 mm overlay specified in Alternative 2 (see Table E2.7) is triggered in Year 1, which is consistent with the intervention level being exceeded.

H D M - 4 **Road Works Summary (by Section)**

Section:	M Traffic, IRI-3.0, Fair, 2-lane		
Alternative:	GATO3		
Sensitivity:	No Sensitivity Analysis Conducted		
Surface Class:	Bituminous	**Road Class:**	Primary or Trunk
Length:	1.00km	**Width:**	7.00m

Year	Description	Code	Economic Cost	Financial Cost	Work Quantity
2006	40 mm Overlay @ 3 IRI	OV403	77,700.0	85,400.0	7,000.00 sq. m
	Prep. Edge Repair		748.6	828.4	25.73 sq. m
2007	Routine edge	ROEDGE	482.8	581.1	42.73 sq. m
2008	Routine edge	ROEDGE	517.5	622.8	45.79 sq. m
2009	Routine edge	ROEDGE	555.9	669.1	49.20 sq. m
2010	Routine edge	ROEDGE	597.3	718.9	52.86 sq. m
2011	Routine edge	ROEDGE	641.9	772.5	56.80 sq. m
2012	40 mm Overlay @ 3 IRI	OV403	77,700.0	85,400.0	7,000.00 sq. m
	Prep. Edge Repair		1,776.5	1,965.8	61.05 sq. m
2013	Routine edge	ROEDGE	741.6	892.5	65.63 sq. m
2014	Routine edge	ROEDGE	795.5	957.4	70.40 sq. m
2015	Routine edge	ROEDGE	855.1	1,029.2	75.68 sq. m
2016	Routine edge	ROEDGE	919.4	1,106.6	81.37 sq. m
2017	Routine edge	ROEDGE	988.8	1,190.0	87.50 sq. m
2018	40 mm Overlay @ 3 IRI	OV403	77,700.0	85,400.0	7,000.00 sq. m
	Prep. Edge Repair		2,738.7	3,030.4	94.11 sq. m
2019	Routine edge	ROEDGE	1,144.1	1,376.9	101.25 sq. m
2020	Routine edge	ROEDGE	1,228.4	1,478.4	108.71 sq. m
Total cost for the section:			247,832.0	273,419.9	

- **Cost Streams and Economic Evaluation**

This folder contains the results of the economic analysis. The Economic Analysis Summary report indicates that:

- The thin overlay solution produces the maximum Net Present Value (NPV) for each section, this being indicative of the most viable section-alternative. In this case it confirms that early intervention is beneficial.
- The NPV/CAP indicator identifies the structural overlay as being the best solution, and is applicable in circumstances where ranking (or prioritisation) under budget constraint is appropriate. Whilst this is not appropriate in this case, it is an interesting finding.
- An Economic Internal Rate of Return (EIRR) greater than the specified discount rate is also indicative of project viability. For this case the maximum EIRR coincides with the most viable section-alternative. The values are extremely high, again confirming the benefits of selecting a thin overlay.

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Indicators Summary

Study Name: 2. Paved Road Rehabilitation
Run Date: 11-07-2006
Currency: Malaysian Ringgit (millions)
Discount Rate: 12.00%

Section: M Traffic, IRI-3.0, Fair, 2-lane
Sensitivity No Sensitivity Analysis Conducted

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
Base Alternative	0.086	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GAFR6	0.178	0.107	0.092	0.301	0.000	0.209	1.178	1.947	107.4 (1)
GASO4-5	0.124	0.087	0.039	0.688	0.000	0.649	5.226	7.485	131.4 (1)
GATO3	0.143	0.137	0.058	0.900	0.000	0.842	5.874	6.148	62.9 (1)

Figure in brackets is number of IRR solutions in range -90 to +900

Section: VH Traffic, Fair, 2-lane
Sensitivity No Sensitivity Analysis Conducted

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
Base Alternative	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GAFR6	0.174	0.096	0.092	0.666	0.000	0.573	3.301	5.974	387.9 (1)
GASO4-5	0.176	0.097	0.094	2.530	0.000	2.435	13.858	25.078	267.6 (1)
GATO3	0.222	0.142	0.140	3.332	0.000	3.192	14.394	22.521	203.4 (1)

Figure in brackets is number of IRR solutions in range -90 to +900

3 CASE STUDY 3 – CAPACITY IMPROVEMENTS

3.1 Introduction

This case study presents the economic analysis of widening a paved road. The existing road is 7m wide, with an AADT of 15,000 in 2005. In addition, the non-motorised transport (NMT) was 400 in 2005, comprising pedestrians, animal carts, and bicycles. Three widening alternatives are considered, widening by 1m, widening by 3m, and adding two extra lanes. The analysis assumes that routine maintenance is undertaken on a condition responsive basis for all alternatives.

The objective of this case study is to demonstrate the congestion analysis of HDM-4, with particular reference to specification of the input data and examination of the results.

This case study is located in the **Projects** folder in the Workspace. Double-click on the Project case study **3a. Capacity Improvements – without sensitivity analysis** to open the case study. A second case study, **3b. Capacity Improvements – with sensitivity analysis** exists in the same folder, which is based on the same overall project, and is discussed later in this section.

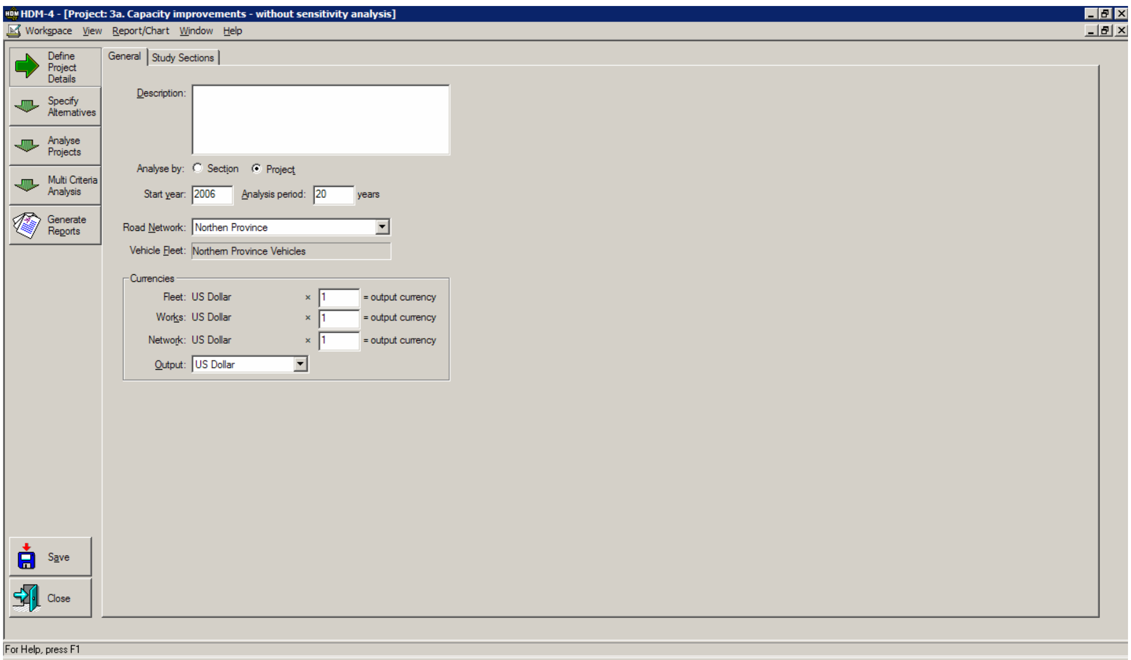
3.2 Define Project Details

In the **Define Project Details** screen, the following tab pages may be displayed:

- General
- Study Sections

3.2.1 General

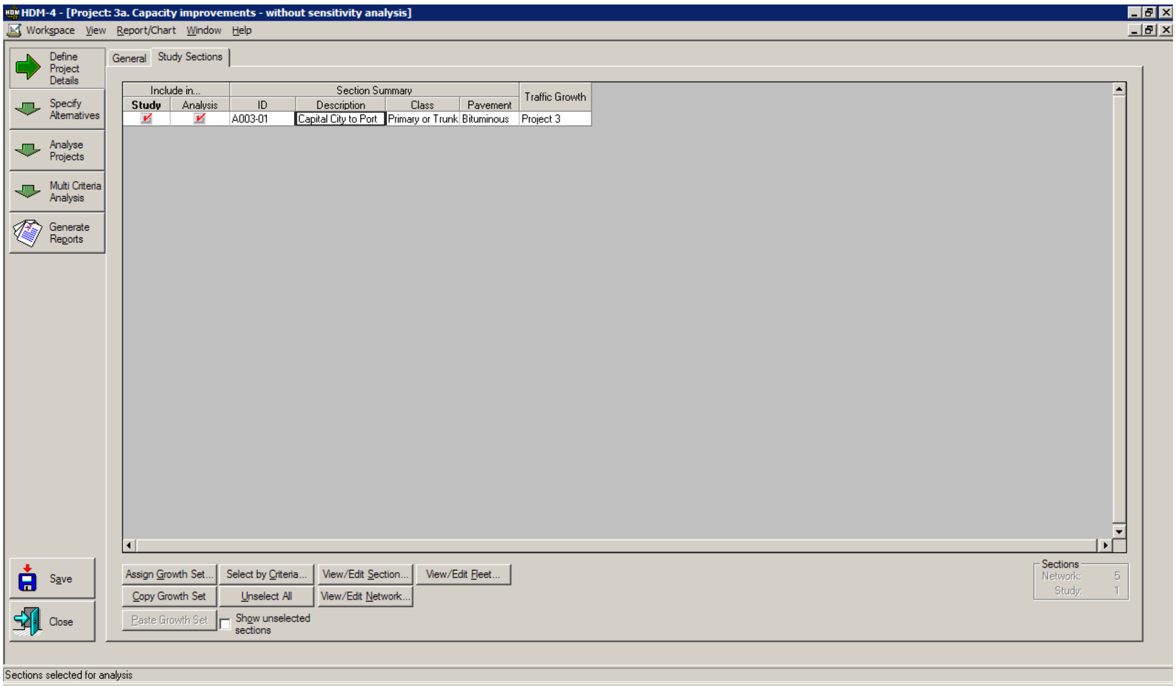
The information displayed in the General screen includes the study description, analysis type, analysis period, the pre-defined Road Network and Vehicle Fleet, and the currency to be used for the analysis.



This case study is presented as an Analysis by Project example. The analysis period is defined by the start year 2006 and a duration of 20 years (i.e. 2006 - 2025). The section to be analysed is in the Road Network entitled Northern Province, to which the Northern Province Vehicles have been previously assigned as the Vehicle Fleet. The currency being used for this analysis is US dollars.

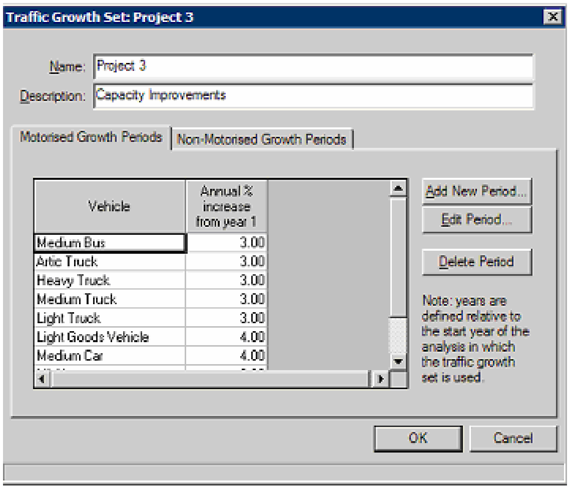
3.2.2 Study Sections

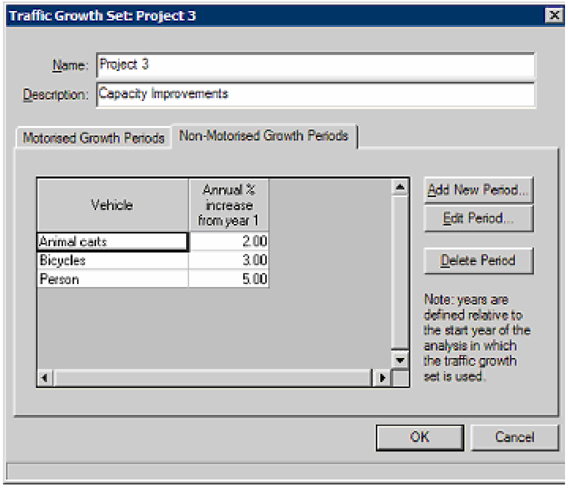
The only road section selected for analysis is the Capital City to Port section.



By double-clicking on the section gives access to the section details. However, the **Traffic Growth** details can only be seen and edited through the **Vehicle Fleets** folder. To access the Traffic Growth Sets that have been previously created, the user needs to open the appropriate vehicle fleet (in this case Northern Province Vehicles) in the Vehicle Fleet folder and click on the Edit Traffic Growth Sets button which then displays all the previously created sets. Double-clicking on the appropriate set (in this case Project 3) displays the details of the traffic changes over the analysis period.

The traffic growth rates for both the motorised and non motorised traffic in this case study are displayed below.

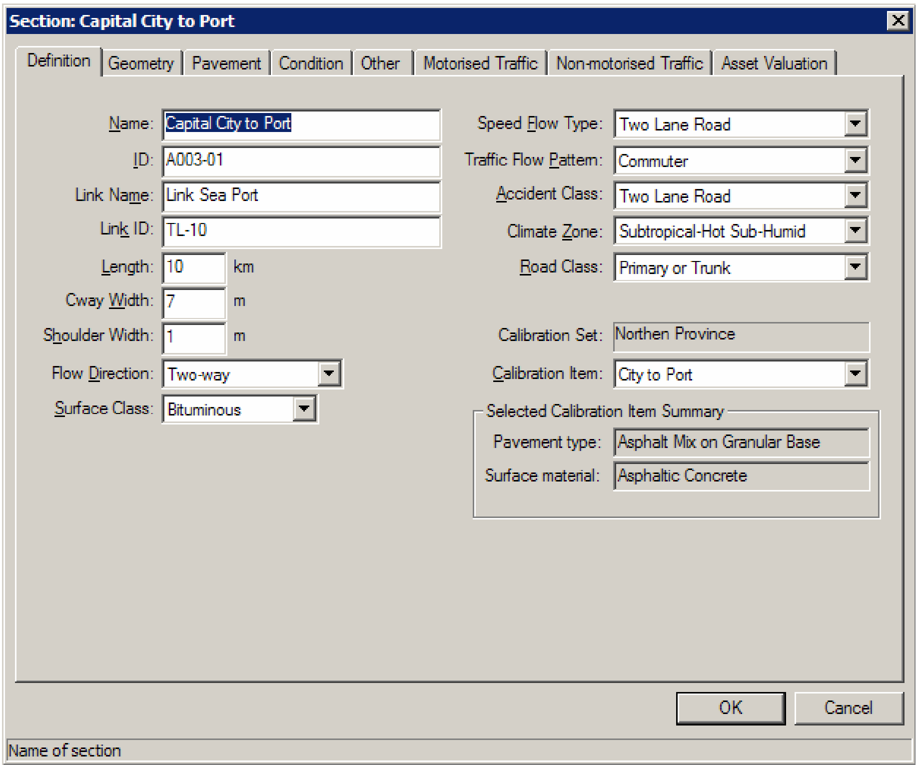




The section details that have particular relevance to this case study are described below.

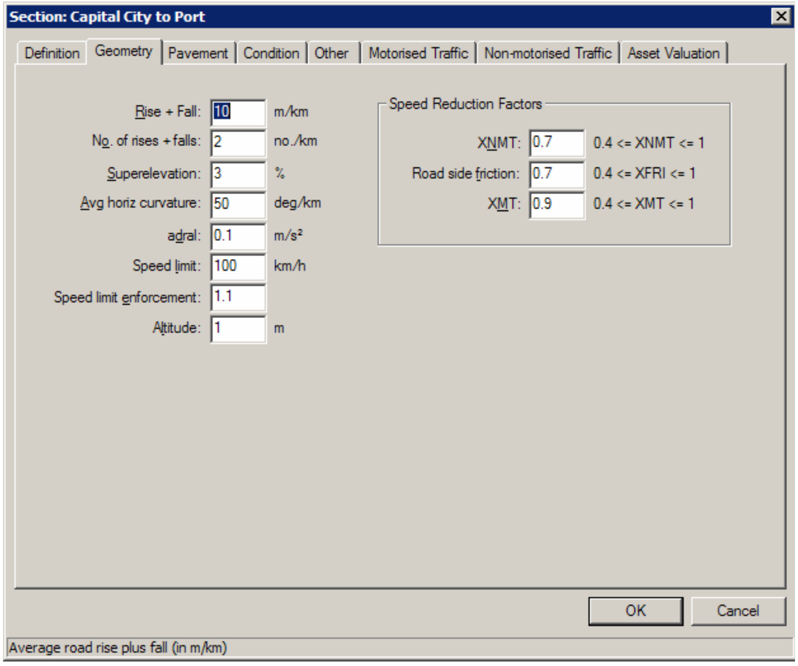
- **Definition**

The speed flow type of the existing road is specified as Two Lane Road. The existing carriageway width is 7 m, with two directional traffic flow. The speed flow type defines the capacity of the existing road. In this case study, the capacity of the road will be increased as a result of Improvement works. The capacity of the road after improvement is defined by the speed flow type specified within the Improvement Standard.



- **Geometry**

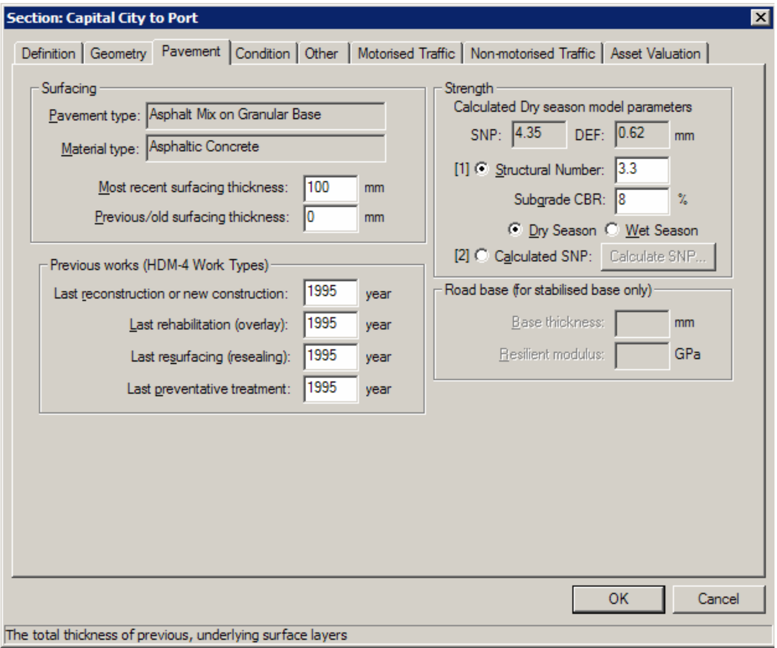
As there are NMT's on the existing road, speed reduction factors have been assigned for the non motorised traffic as well as for the motorised traffic.



- **Pavement**

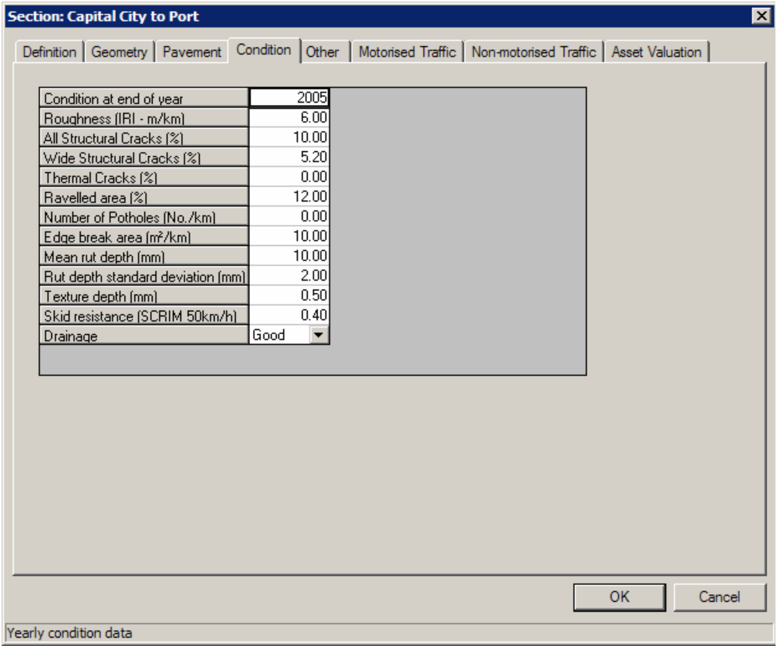
The pavement type has been defined as asphalt mix on granular base (AMGB) and was originally constructed in 1995. The Previous works indicates that the pavement type is unchanged as no periodic maintenance (i.e. overlay, surface dressings, etc) has been carried out to date.

The structural number, SN, of the pavement layers above the subgarde is 3.3, with a subgrade of 8% CBR, giving a SNP value of 4.35. For the improvement works assigned to this case study, a value of 3,3 has been specified for the structural number, SN.



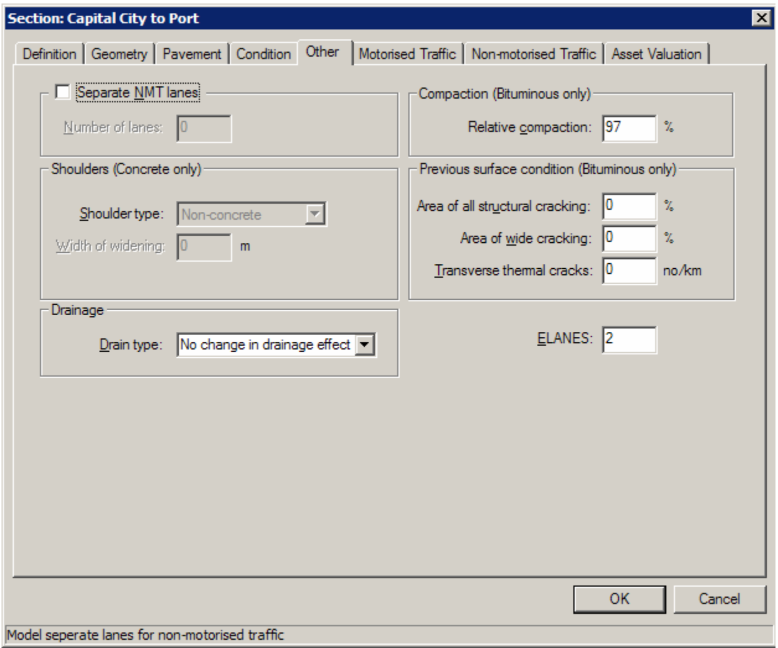
- **Condition**

The condition of the road section at the end of 2005 is specified, with the analysis commencing in 2006.



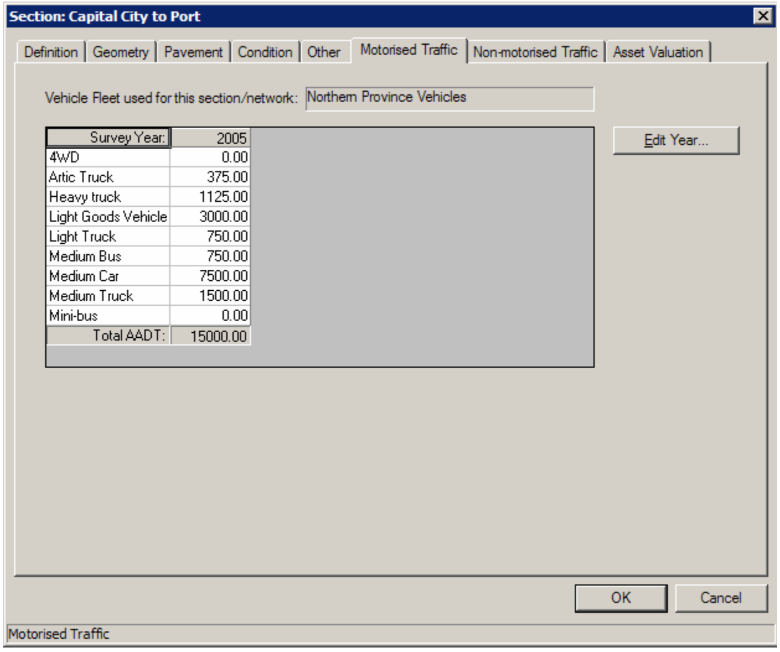
- **Other**

The number of lanes (ELANES) is specified as 2 for the existing road. The ELANES of the road after improvement is defined within the Improvement Standard.



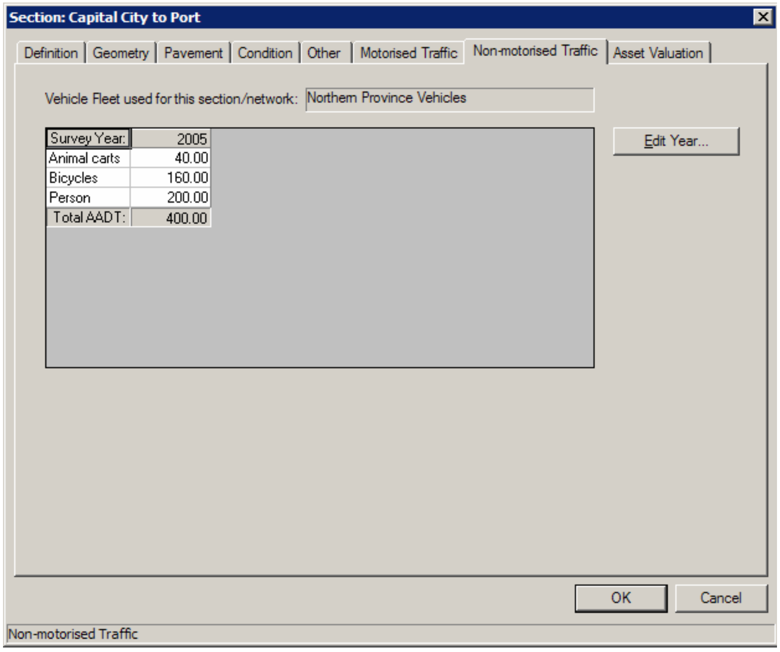
- **Motorised Traffic**

The AADT of 1500 in 2005 has been classified between the various vehicle types in the selected Vehicle Fleet. If certain vehicle types do not operate on the selected road section, then a value of zero should be assigned for those particular types (4WD and Mini bus in this case study).



- **Non Motorised Traffic**

Similarly the NMT of 400 have been classified between the NMT types created in the selected Vehicle Fleet.



- **Asset Valuation**

Asset valuation is not considered in this case study.

3.3 Specify Alternatives

The four alternatives considered in this case study are described in Table E3.1.

Table E3.1
Project Alternatives

Alternative	Description
1	This is the base alternative. Routine maintenance (crack sealing and pothole patching) 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.
2	With this alternative, the existing road is widened by 1 m during the first 2 years of the analysis period (i.e. in 2006-07). The maintenance regime of Alternative 1 (Routine + 50 mm overlay), which is condition responsive, is effective from year 3 (i.e. from 2008).
3	With this alternative, the existing road is widened by 3 m during the first 2 years of the analysis period (i.e. in 2006-07). The condition responsive maintenance regime of Alternative 1 is effective from year 3 (i.e. from 2008).
4	With this alternative, the existing road is widened by adding two lanes during the first 3 years of the analysis period (i.e. in 2006-08). The condition responsive maintenance regime of Alternative 1 is effective from year 4 (i.e. from 2009).

The Maintenance Standard (Routine + 50 mm overlay) comprises the following works items:

Crack sealing if area of wide structural cracking ≥ 10% of carriageway area

Patching potholes if no. of potholes ≥ 10 / km

50 mm overlay if roughness > 6 IRI

Each widening alternative includes this Maintenance Standard providing condition responsive routine pavement works and condition responsive overlay, effective from the year following completion of the widening works. This Maintenance Standard has been defined as the base alternative.

Each widening alternative is scheduled to start in year 1 of the analysis period (year 2006), with a construction period of two or three years A summary of the costs and widths of the widening alternatives is given in Table 2, together with the existing road.

Table E3.2
Summary of Widening Alternatives

Alternative	Widening	Duration of works (years)	Economic cost of widening (US$/km)	After Widening	
				Carriageway width (m)	Speed-flow relationship
1	None	-	-	(7)	(Two lane road)
2	+1 m	2	32,000	8	Two lane road
3	+3 m	2	102,000	10	Wide two lane
4	+2 lanes	3	238,000	14	Four lane road

The speed-flow type determines the capacity of the road section. The base alternative (Alternative 1) has been assigned the speed-flow type for a two-lane road. The same speed-flow type has been assigned to Alternative 2. For Alternatives 3 and 4, the capacity of the widened road section will be increased and therefore revised speed-flow types have been specified under the respective Improvement Standards. The capacities and jam speeds for the four alternatives are given in Table E3.3.

Table E3.3
Capacities of the Alternatives

Alternative	Speed Flow	Free Flow Capacity	Nominal Capacity	Ultimate Capacity	Jam Speed km/h
1 & 2	Two lane road	140	1260	1400	25
3	Wide two lane	320	1440	1600	30
4	Four lane road	800	1900	2000	40

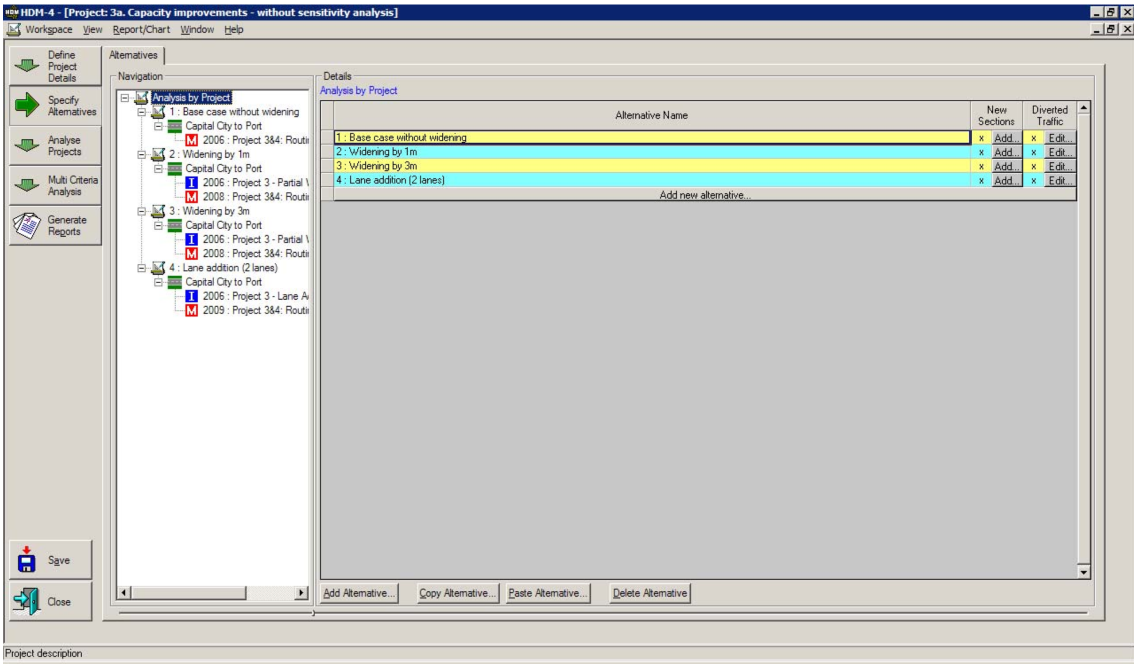
Note: Capacities are in PCSE / lane / hr

The various widening alternatives have an impact on the speed reduction due to NMT, MT, and roadside friction. For the existing road section, these data are specified under Geometry in the section details (see Section 3.2.2). For the widening alternatives, the data are specified under Geometry within the Improvement Standard. The values assigned for each alternative are given in Table E3.4.

Table E3.4
Speed Limit and Speed Reduction Factors

Alternative	Widening	Speed limit km/h	Speed reduction factors		
			NMT	MT	Roadside friction
1	None	100	0.7	0.9	0.7
2	+1 m	100	0.75	0.9	0.7
3	+3 m	100	0.9	1	0.8
4	+2 lanes	120	1	1	1

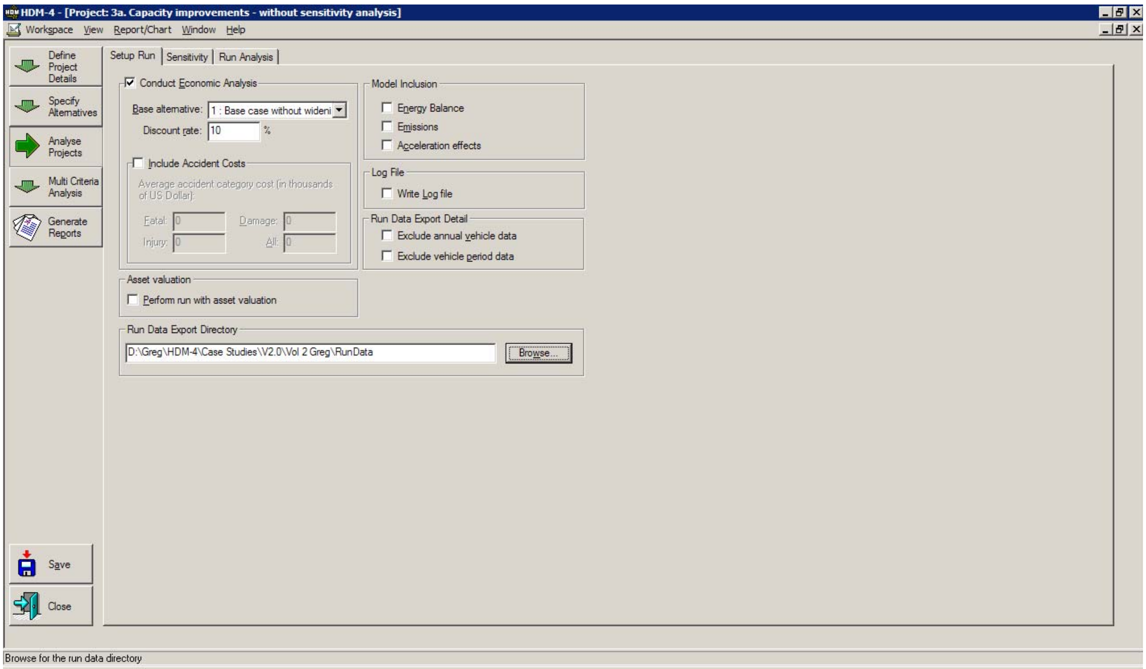
The alternatives are assigned to the selected road section as shown in the Specify Alternatives screen below.



3.4 Analyse Projects

3.4.1 Setup Run

The options selected in the Setup Run screen are Conduct Economic Analysis using a discount rate of 10%, with the ‘without widening’ alternative selected as the base alternative. The additional models for accidents, energy balance, emissions, acceleration effects and asset valuation are not included in this analysis.



For this case study **(Project 3a),** sensitivity analysis has not been selected (see **Project 3b** for sensitivity analysis relevant to this case study).

3.4.2 Run Analysis

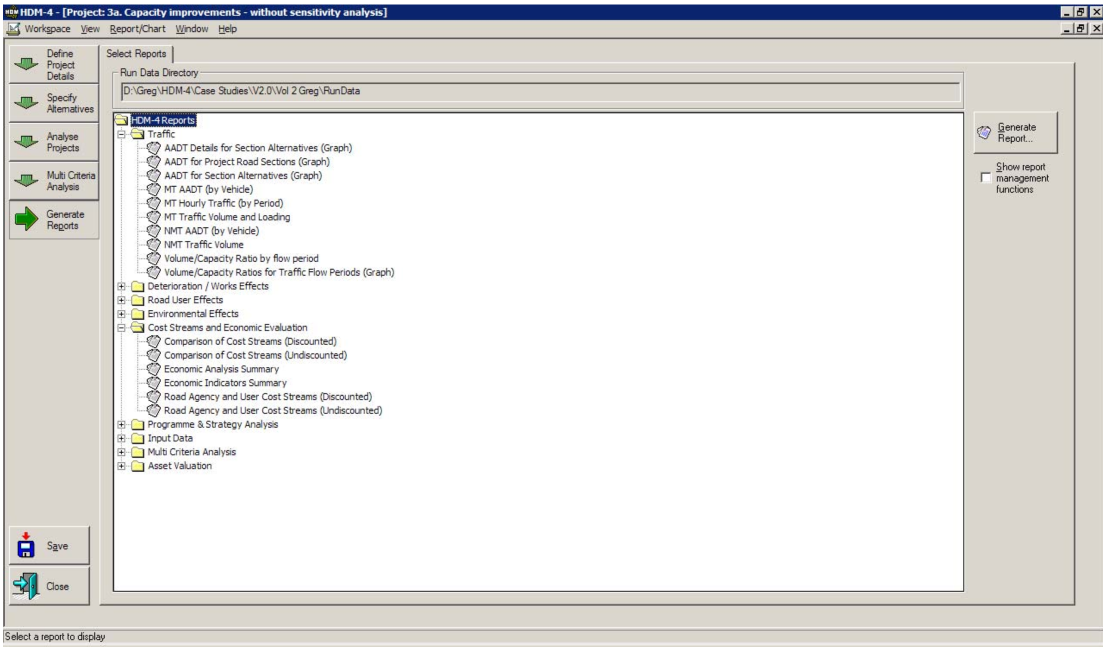
This starts the analysis and produces the output necessary for report generation.

3.5 Multi Criteria Analysis

Multi criteria analysis has not been used in this case study.

3.6 Generate Reports

The output reports from the analysis are produced and stored in the appropriate folders.



- **Traffic**

Details on the AADT, motorised and non motorised traffic flows for each alternative over the 20-year analysis period are reported in this folder in both graphical and tabular form.

Also reported are the volume/capacity ratios, which are of particular relevance to this case study. The volume/capacity ratios are reported for 5 time periods for Alternative 1 because the traffic flow pattern, Commuter, was split into these periods. For the widening alternatives volume/capacity ratios are reported for only one time period, once construction has been completed, because the Free Flow traffic pattern was used, which had been defined with one traffic period. However, during the construction period of the widening (i.e. initial 2 or 3 years), the five time periods of the Commuter traffic flow pattern were applicable.

HDM-4 Volume/Capacity Ratio by flow period

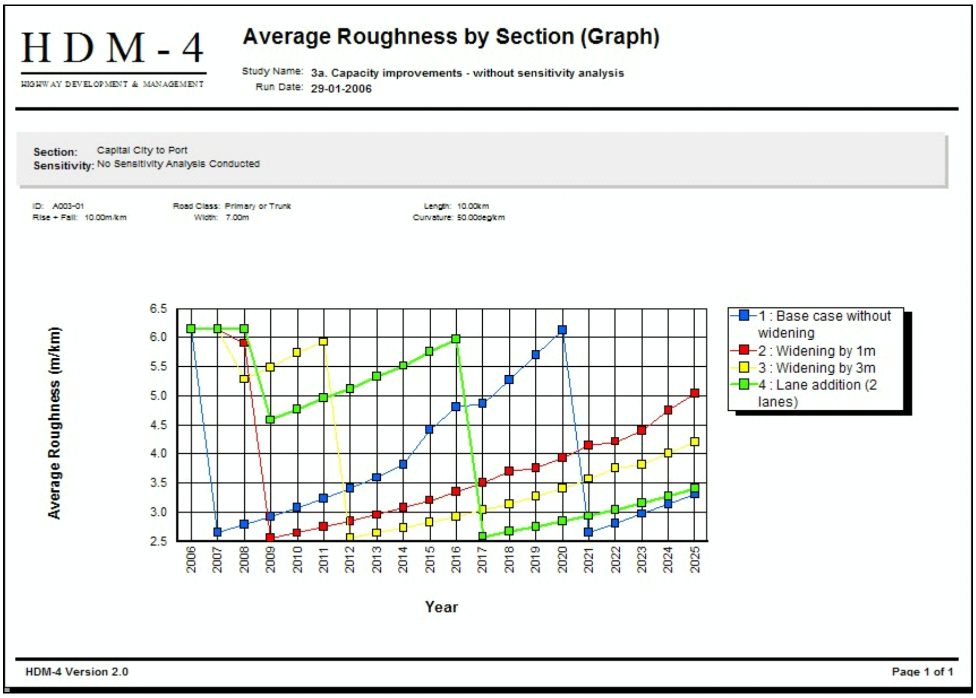
Section: Capital City to Port
Alternative: 4 : Lane addition (2 lanes)
Sensitivity: No Sensitivity Analysis Conducted

Sect ID: A003-01 Road Class: Primary or trunk
Length: 10.00 km Width: 7.00 m Rise+Fall: 10.00 m/km Curvature: 50.00 deg/km

	Period 1	Period 2	Period 3	Period 4	Period 5
2006	0.830	0.760	0.640	0.440	0.060
2007	0.860	0.790	0.660	0.460	0.070
2008	0.890	0.820	0.680	0.480	0.070
2009	0.100				
2010	0.100				
2011	0.110				
2012	0.110				
2013	0.110				
2014	0.120				
2015	0.120				
2016	0.130				
2017	0.130				
2018	0.140				
2019	0.140				
2020	0.150				

- **Deterioration / Works Effects**

The progression of the various distresses for each alternative over the analysis period are reported in this folder in both graphical and tabular form. The Average Roughness by Section (Graph) report illustrates the roughness progression for each alternative. In the graph shown below, for example, the roughness of the base alternative is reduced at the end of the first year because the overlay works item has been triggered.



Also reported in this folder are the timing of the works carried out for each alternative during the 20-year period. In the Road Works Summary (by Section) report shown below, the overlay being triggered for the base alternative in year 2006 discussed above, is listed.

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Road Works Summary (by Section)

Study Name: **3a. Capacity improvements - without sensitivity analysis**
Run Date: **11-07-2006**
Currency: **US Dollar**

Note: only sections that have works triggered are displayed.

Section: Capital City to Port
Alternative: 1 : Base case without widening
Sensitivity: No Sensitivity Analysis Conducted
Surface Class: Bituminous — **Road Class:** Primary or Trunk
Length: 10.00km — **Width:** 7.00m

Year	Description	Code	Economic Cost	Financial Cost	Work Quantity
2006	Overlay 50mm at 6 IRI	OVL50	1,050,000.0	1,260,000.0	70,000.00 sq. m
	Prep. Edge Repair		9,386.7	11,264.0	670.48 sq. m
2014	Crack Sealing	CRKSL	0.0	0.0	0.00 sq. m
2015	Crack Sealing	CRKSL	0.0	0.0	0.00 sq. m
2016	Patching Potholes	PATPOT	2,996.5	3,595.8	249.71 sq. m
	Crack Sealing	CRKSL	0.0	0.0	0.00 sq. m
2017	Patching Potholes	PATPOT	1,483.6	1,780.3	123.63 sq. m
	Crack Sealing	CRKSL	0.0	0.0	0.00 sq. m
2018	Patching Potholes	PATPOT	1,979.5	2,375.4	164.96 sq. m
	Crack Sealing	CRKSL	0.0	0.0	0.00 sq. m
2019	Patching Potholes	PATPOT	2,396.4	2,875.7	199.70 sq. m
	Crack Sealing	CRKSL	0.0	0.0	0.00 sq. m
2020	Overlay 50mm at 6 IRI	OVL50	1,050,000.0	1,260,000.0	70,000.00 sq. m
	Prep. Patching		2,596.9	3,116.2	216.40 sq. m
	Prep. Edge Repair		176,400.0	211,680.0	12,600.00 sq. m
2021	Patching Potholes	PATPOT	0.0	0.0	0.00 sq. m
Total cost for the section:			2,297,239.5	2,756,687.3	

- **Road User Effects**

The various components of road user effects are reported in this folder. Also reported in this folder are the road user costs for the non motorised traffic. Of particular relevance to this case study are the effects of the widening alternatives on vehicle speeds of both the motorised and non motorised traffic.

- **Cost Streams and Economic Evaluation**

This folder contains the results of the economic analysis. The Economic Analysis Summary report indicates that the widening by 3 m alternative produces the highest benefit (NPV).

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Indicators Summary

Study Name: **3a. Capacity improvements - without sensitivity analysis**
Run Date: **11-07-2006**
Currency: **US Dollar (millions)**
Discount Rate: **10.00%**

Sensitivity: No Sensitivity Analysis Conducted

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B+E-C)	NPV/Cost Ratio (NPV/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
1 : Base case without widening	1.386	1.326	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2 : Widening by 1m	1.674	1.316	0.288	26.344	0.000	26.055	15.562	19.795	72.0 (2)
3 : Widening by 3m	2.279	1.905	0.893	31.669	0.000	30.776	13.504	16.155	63.7 (2)
4 : Lane addition (2 lanes)	3.366	2.982	1.980	24.148	0.000	22.168	6.586	7.434	33.7 (1)

Figure in brackets is number of IRR solutions in range -90 to +900

3.7 Sensitivity Analysis

Project 3b. Capacity improvements – with sensitivity analysis investigates the effect of changes in the value of a number of key variables on the outcome of the economic analysis.

The scenarios which were examined included variations in the following variables, each one at a time:

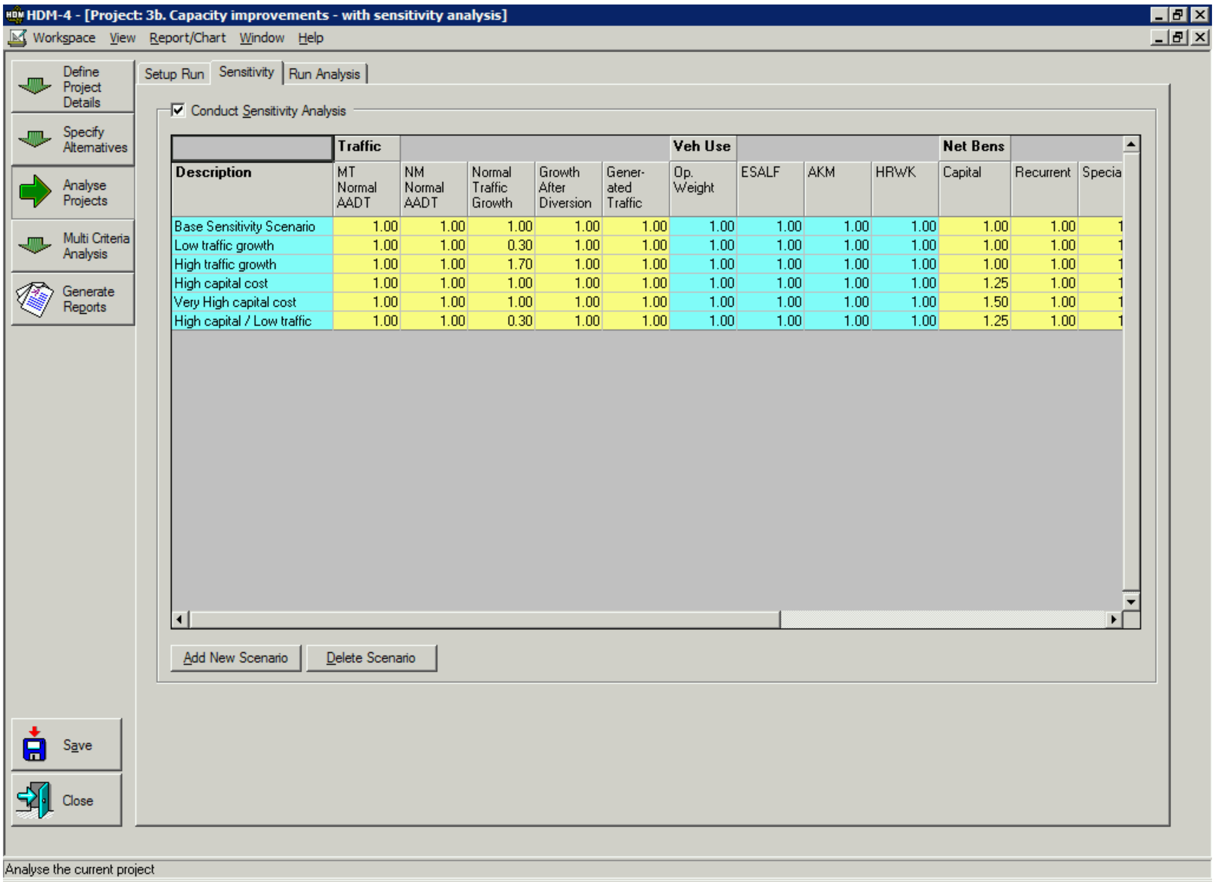
- Normal traffic growth (+/- 70%), equivalent to a growth of between 1% and 5% for most vehicles
- Capital costs (+ 25% and + 50%)
- A combination of high capital cost (+25%) and low traffic growth (-70%)

This case study is located in the **Projects** folder in the Workspace. Double-click on Project case study **3b. Capacity improvements – with sensitivity**.

The additional steps and results are described below.

3.7.1 Defining Scenarios

The various scenarios are defined in the following screen, and accessed through the **Analyse Projects/Sensitivity** tab page.



	Traffic					Veh Use				Net Bens		
Description	MT Normal AADT	NM Normal AADT	Normal Traffic Growth	Growth After Diversion	Gener-ated Traffic	Op. Weight	ESALF	AKM	HRWK	Capital	Recurrent	Specia
Base Sensitivity Scenario	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1
Low traffic growth	1.00	1.00	0.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1
High traffic growth	1.00	1.00	1.70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1
High capital cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.25	1.00	1
Very High capital cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.50	1.00	1
High capital / Low traffic	1.00	1.00	0.30	1.00	1.00	1.00	1.00	1.00	1.00	1.25	1.00	1

3.7.2 Run Analysis

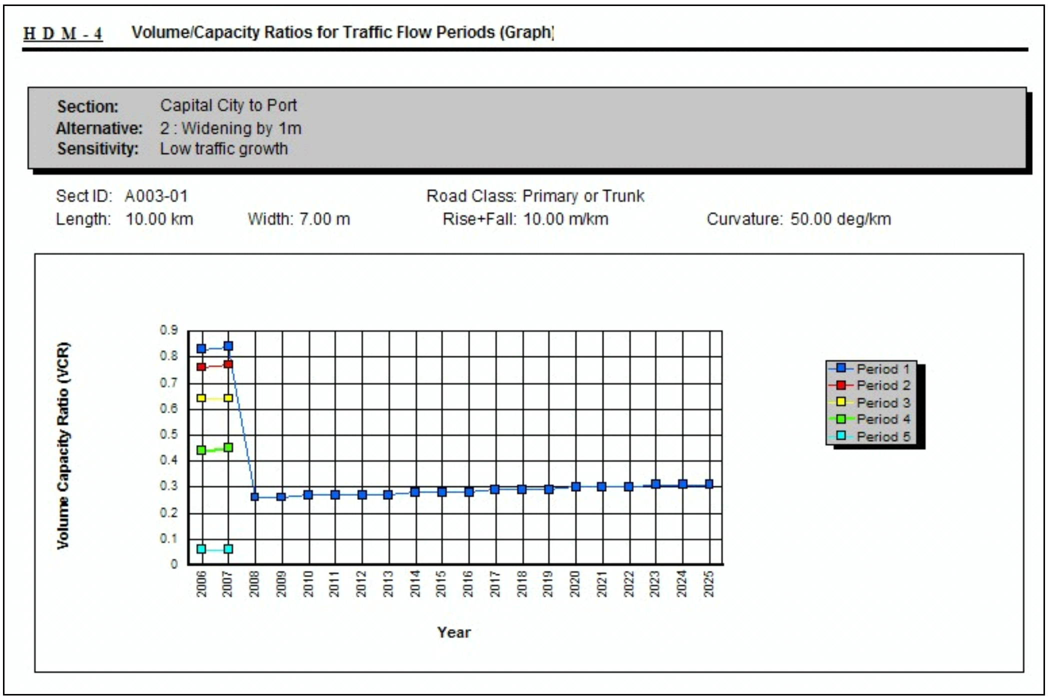
This starts the analysis and produces the output necessary for report generation, and is executed in the normal manner.

3.7.3 Generate Reports

A full set of reports are available for all scenarios. The user may select **Generate Reports** to display the folders holding pre-defined report options which they consider relevant to interpreting the results of this case study. Both input and output/analysis reports should be examined. The following discussion concentrates on the effects of the scenarios examined on the congestion performance of the alternatives, and effect on economic viability.

- **Volume/Capacity Ratios by Traffic Flow Period (Graph)**

This report is accessed through the Traffic folder. The resulting graph for the 1m widening alternative/low traffic growth scenario is shown below, noting that excess capacity exists for the duration of the project analysis.



- **Economic Analysis Summary**

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: 3b. Capacity improvements - with sensitivity analysis
Run Date: 11-07-2006
Currency: US Dollar (millions)
Discount: 10.00%
Analysis Mode: Analysis-by-Project

Alternative: 2 : Widening by 1m vs Alternative: 1 : Base case without widening
Sensitivity Scenario: Base Sensitivity Scenario

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Social / Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	-0.56	0.37	0.00	41.79	43.32	-0.01	0.00	0.00	85.29
Discounted	-0.01	0.30	0.00	12.15	14.21	-0.01	0.00	0.00	26.06

Economic Internal Rate of Return (EIRR) = 72.0% (No. of solutions = 2)

The Economic Analysis Summary report has been used to populate Table E3.5, Table and Table E3.7 which form the basis for interpreting the results of the sensitivity analysis.

Table E3.5
Comparison of NPV (millions) and EIRR by Traffic Growth Scenario

Widening Alternative	Indicator	Low	Most Likely	High
1 m	NPV	10.37	26.06	35.69
	EIRI	48.8	72.0	119.7
3 m	NPV	12.37	30.78	46.33
	EIRI	42.6	63.7	93.0
Additional lanes	NPV	4.97	22.17	36.64
	EIRI	18.3	33.7	48.0

Table E3.6
Comparison of NPV (millions) and EIRR by Capital Cost Scenario

Widening Alternative	Indicator	Most Likely	High	Very High
1 m	NPV	26.06	26.06	26.06
	EIRI	72.0	80.8	No solution
3 m	NPV	30.78	30.63	30.49
	EIRI	63.7	64.6	65.8
Additional lanes	NPV	22.17	21.75	21.34
	EIRI	33.7	32.5	31.4

Table E3.7
Comparison of NPV (millions) and EIRR by High Cost/Low Growth Scenario

Widening Alternative	Indicator	Most Likely	High Capital Cost / Low Growth
1 m	NPV	26.06	10.35
	EIRI	72.0	50.8
3 m	NPV	30.78	12.21
	EIRI	63.7	42.2
Additional lanes	NPV	22.17	4.54
	EIRI	33.7	17.3

All of the scenarios confirm the 3m widening alternative as the most viable, even where combinations of factors are examined as shown in Table E3.7.

4 CASE STUDY 4 – CONSTRUCTION OF A NEW BYPASS

4.1 Introduction

This case study presents the economic analysis of a project to construct a bypass around a town centre. The objective is to demonstrate the specification of the bypass (as a section alternative within a project alternative), and to examine the resulting traffic diversion effects.

Four existing road sections, A, B, C & D represent the network at a town centre. The proposed project is the construction of a bypass, represented by one section (Section E), 10 km long. The case study considers four project alternatives as follows:

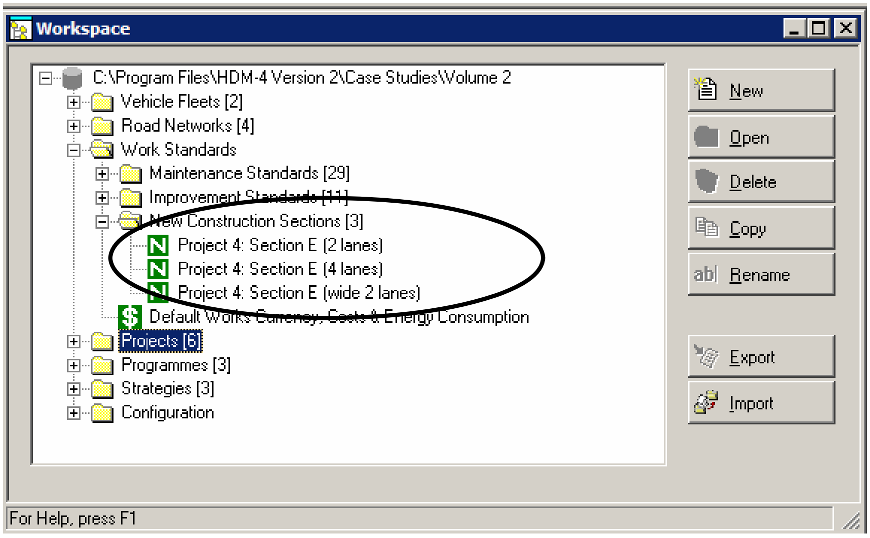
- Alternative 1: Base alternative without the bypass
- Alternative 2: Bypass constructed to a width of 8 m over a period of 2 years
- Alternative 3: Bypass constructed to a width of 10 m over a period of 3 years
- Alternative 4: Bypass constructed to a width of 14 m over a period of 4 years

The AADT values on the four existing sections at the start of the analysis period are as follows:

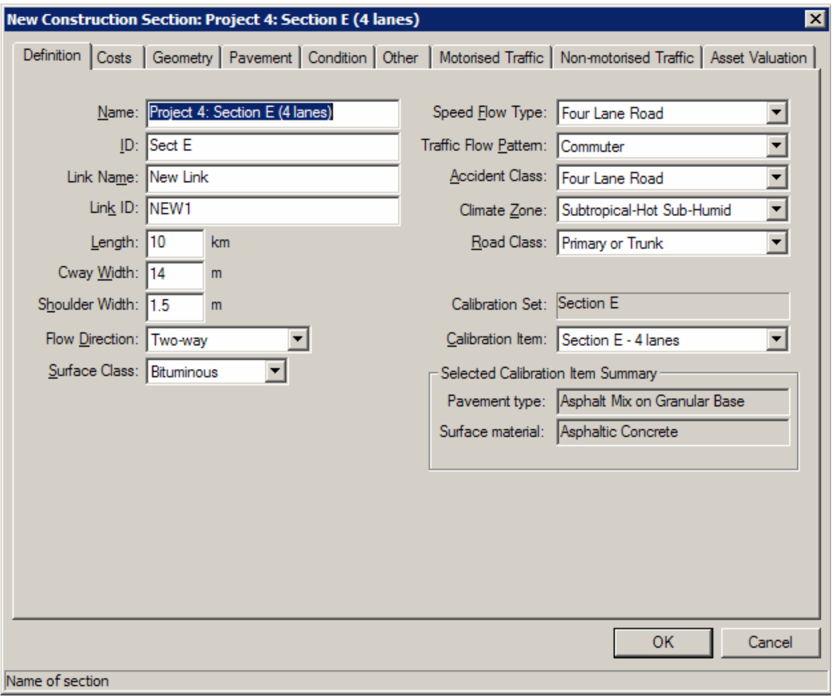
Section A	10,000
Section B	4,000
Section C	6,000
Section D	8,000

The traffic flows (AADT) on each section after bypass construction will normally be derived using an external traffic demand model (i.e. derived outside HDM-4). In this case study the AADT on Sections A & B are assumed to be only marginally affected after the construction of the bypass, whereas on Sections C & D there are significant reductions in the traffic flows after construction. The AADT is reduced on Section C to 1,000 and on Section D to 3,000. The bypass section (Section E) will have an AADT of 5,000 when opened (i.e. 2008 for Alternative 2, 2009 for Alternative 3 and 2010 for Alternative 4).

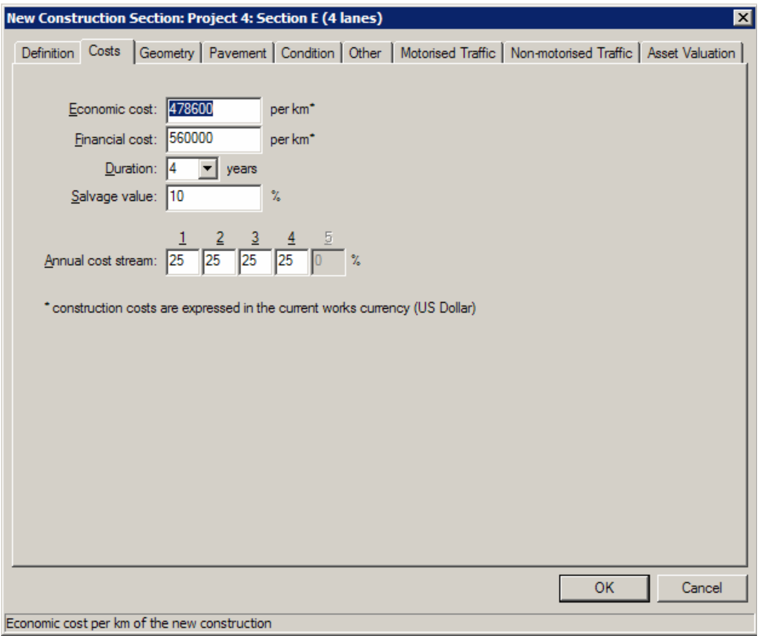
New construction sections, such as a bypass, need to be created in the **New Construction Sections** folder in the Workspace, prior to their inclusion in an analysis.



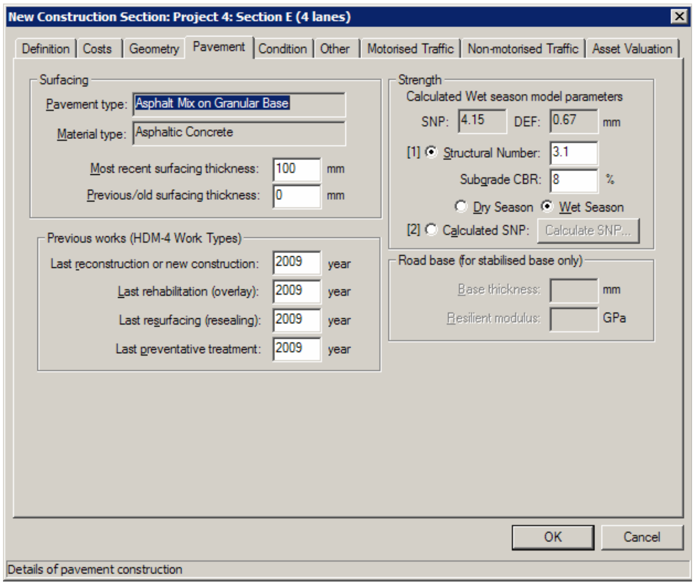
For this case study, three new construction sections have been created, each representing the three construction options for the bypass. The screen from the 4 lanes alternative shown below, indicates that the Speed Flow Type has been set to Four Lane Road as the width of the new bypass is 14 metres.



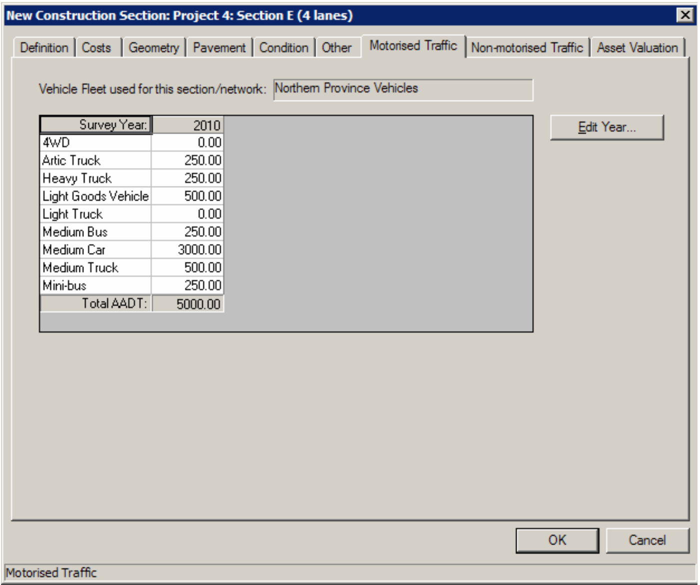
The construction of the 4 lanes bypass will take 4 years as described in the Costs tab page.



The construction is 100 mm of asphalt on a granular base (AMGB) and will be completed in 2009 (i.e. in the fourth year of the analysis period).



The AADT on the new bypass will be 5,000 when opened (i.e. in 2010 for the 4 lanes alternative) as specified in the Motorised Traffic tab page.



The case study is located in the **Projects** folder in the Workspace. Double-click on the Project case study **4. Construction of a new bypass** to open the case study.

4.2 Define Project Details

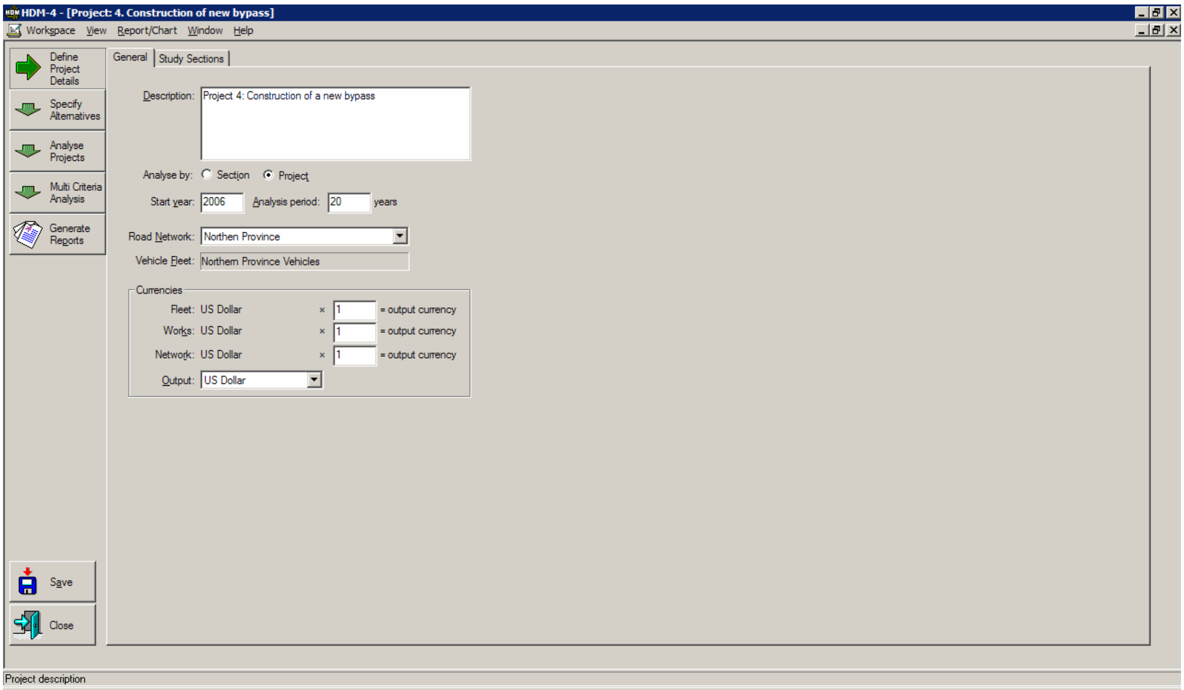
In the **Define Project Details** screen, the following tab pages may be displayed:

- General
- Study Sections

4.2.1 General

The information displayed in the General screen includes the study description, analysis type, analysis period, the pre-defined Road Network and Vehicle Fleet, and the currency to be used for the analysis.

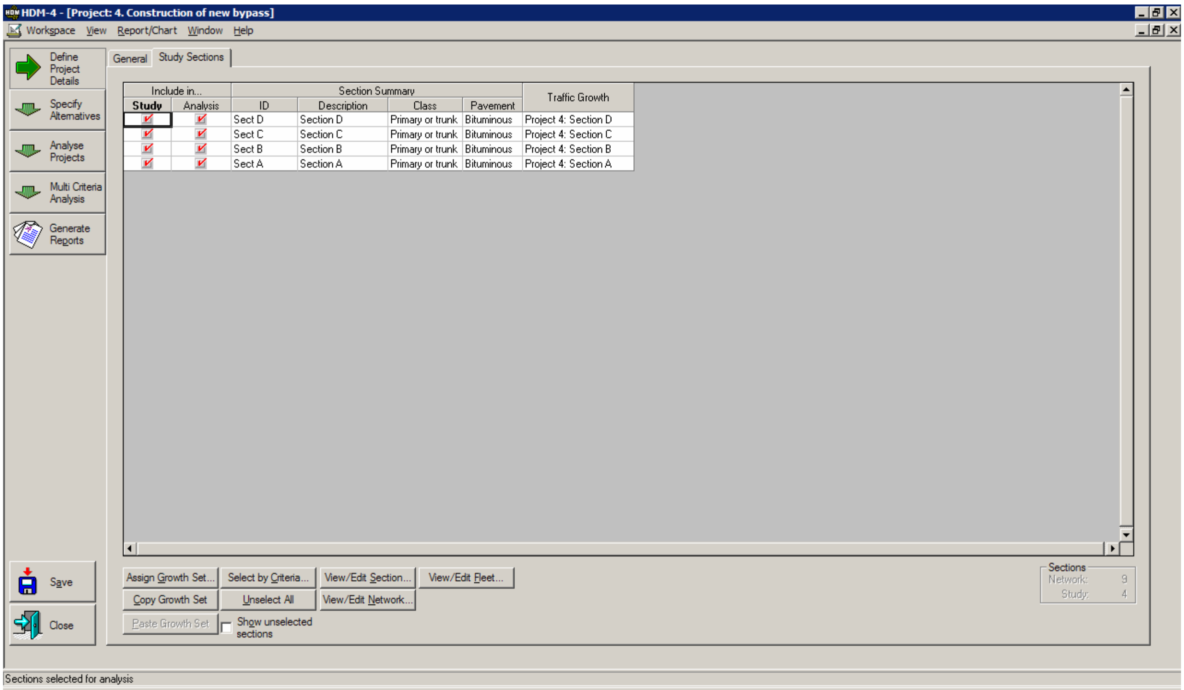
As mentioned in Section B2.2, analyses involving new sections and diverted traffic can only be performed using the Analysis by Project method of analysis.



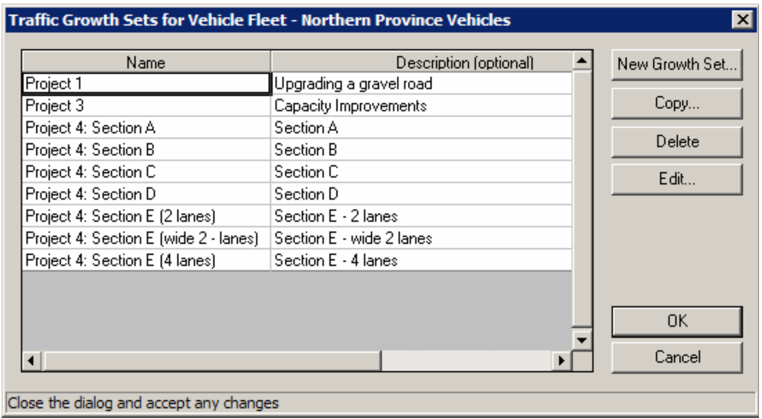
The analysis period is defined by the start year 2006 and a duration of 20 years (i.e. 2006 - 2025). The existing sections (A, B, C & D) to be analysed are in the Road Network entitled Northern Province, to which the Northern Province Vehicles have been previously assigned as the Vehicle Fleet. The currency being used for this analysis is US dollars.

4.2.2 Study Sections

The four sections in the Northern Province road network selected for this analysis are displayed below. The new bypass (Section E) will be added in the Specify Alternatives screen (see Section E4.3).

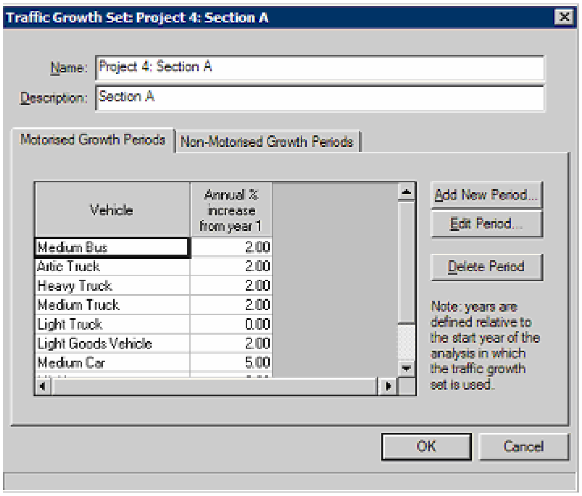


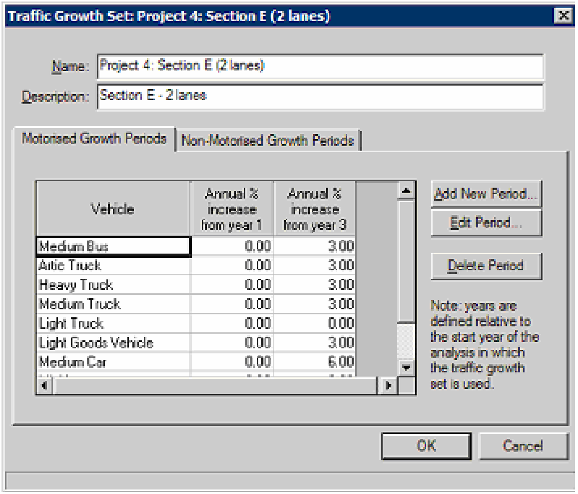
By double-clicking on the section gives access to the section details. However, the **Traffic Growth** details can only be seen and edited through the **Vehicle Fleets** folder. To access the Traffic Growth Sets that have been previously created, the user needs to open the appropriate vehicle fleet (in this case Northern Province Vehicles) in the Vehicle Fleet folder and click on the Edit Traffic Growth Sets button which then displays all the previously created sets.



For this case study (Project 4) several traffic growth sets have been created: one for each of the existing four sections and one for each of the three bypass construction alternatives. Double-clicking on one of the sets displays the details of the traffic changes over the analysis period for that set.

The traffic growth rates for Sections A, B, C & D are the same (Section A displayed below), Section E takes 2, 3 or 4 years to construct as described in Section E4.1. Therefore the growth rate is specified from the year that the bypass is opened (in year 3 for the 2 lanes altenative shown below).



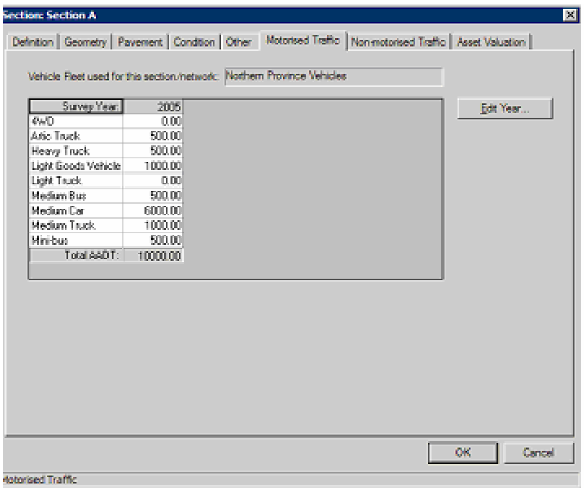


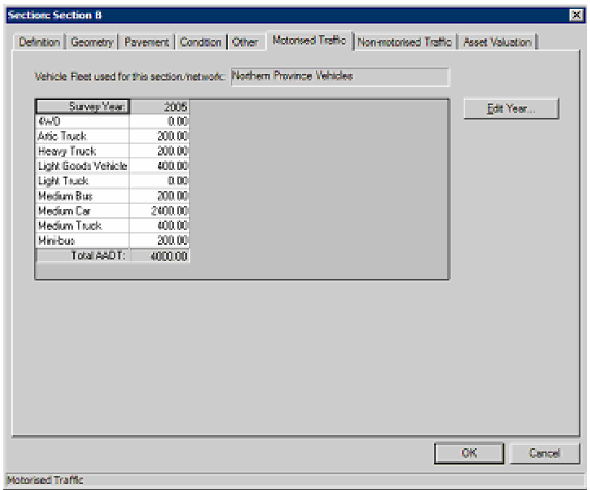
The section details can be accessed by double-clicking on the section shown in the Study Sections tab page. All four sections were originally constructed in 2002. The construction was 100 mm of asphalt on a granular base (AMGB) in all cases. Other basic section details are given in Table .

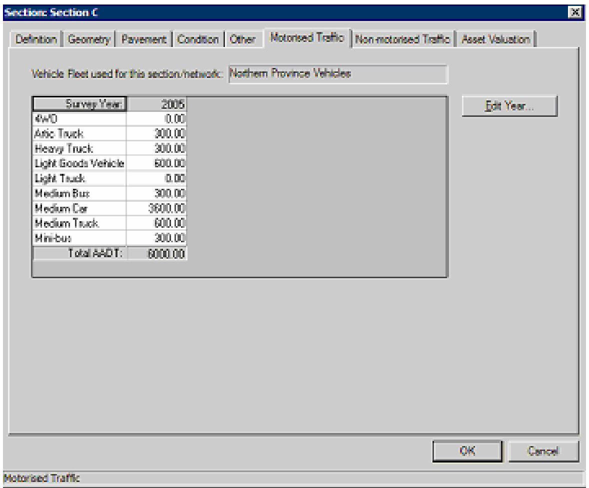
Table E4.1
Section Details

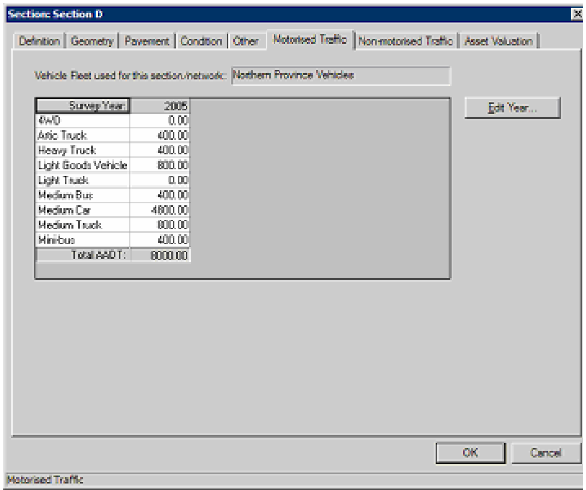
	Section A	Section B	Section C	Section D
Length (km)	6	3	5	7
Carriageway width (m)	8	7.3	7.3	8
Speed Flow Type	Two Lane Wide	Two Lane Standard	Two Lane Standard	Two Lane Wide
AADT (2005)	10,000	4,000	6,000	8,000

The traffic composition for each section is given in the Motorised Traffic tab page which are shown below.









4.3 Specify Alternatives

The four alternatives considered in this case study are described in Table E4.2.

Table E4.2
Project Alternatives

Alternative	Description
1	This is the base alternative. Routine maintenance (crack sealing and pothole patching) is undertaken each year on all four sections based on their pavement condition. In addition, a 50 mm overlay is applied when the roughness level reaches 6 IRI.
2	With this alternative, the existing four sections are maintained as in Alternative 1. In addition the new bypass is constructed to a width of 8 metres over the first 2 years of the analysis period and then maintained using the condition responsive maintenance regime of Alternative 1.
3	With this alternative, the existing four sections are maintained as in Alternative 1. In addition the new bypass is constructed to a width of 10 metres over the first 3 years of the analysis period and then maintained using the condition responsive maintenance regime of Alternative 1.
4	With this alternative, the existing four sections are maintained as in Alternative 1. In addition the new bypass is constructed to a width of 14 metres over the first 4 years of the analysis period and then maintained using the condition responsive maintenance regime of Alternative 1.

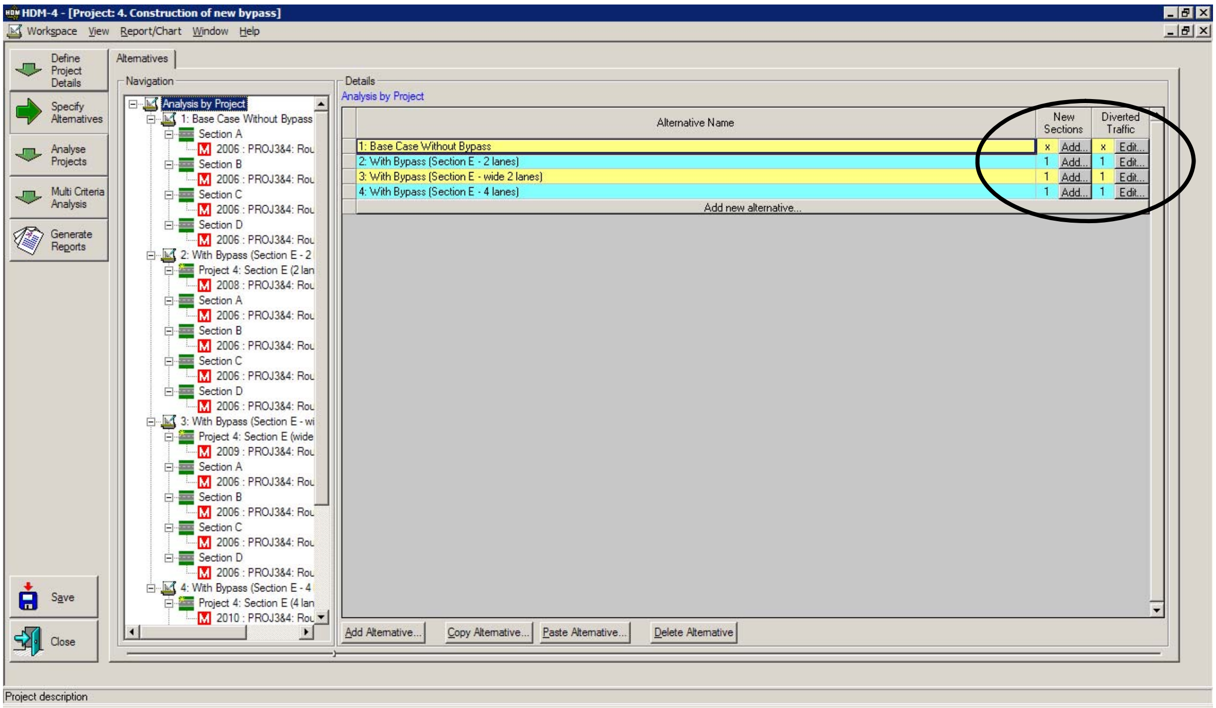
The Maintenance Standard (Routine + 50 mm overlay) comprises the following works items:

Crack sealing if area of wide structural cracking ≥ 10% of carriageway area

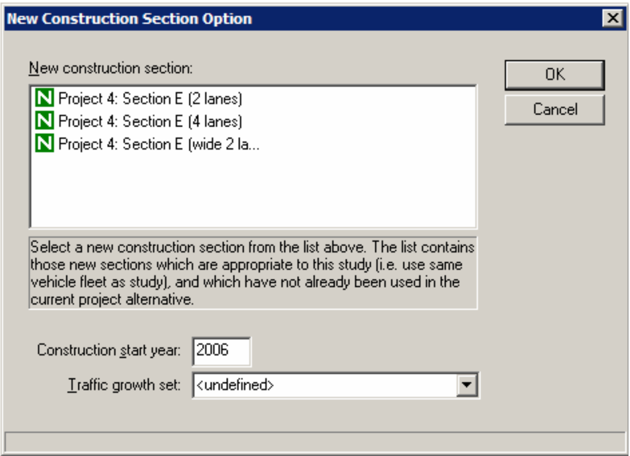
Patching potholes if no. of potholes ≥ 10 / km

50 mm overlay if roughness > 6 IRI

To assign a new section to a project alternative, the user needs to click on the **Add** button in the **New Sections** column of the alternative being created.



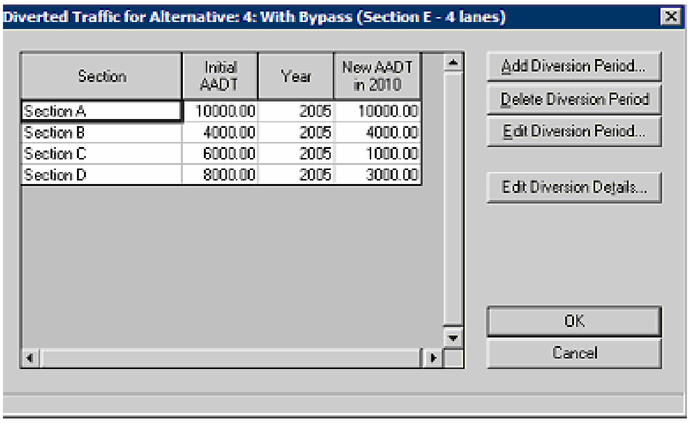
The options available to add as a new section are those that have been previously created in the **New Construction Section** folder (see Section 4.1). A Construction start year needs to be specified and a Traffic growth set needs to be selected from those previously created. In this case study, three traffic growth sets have been created – one for each bypass construction alternative. The appropriate one should be assigned to each alternative.

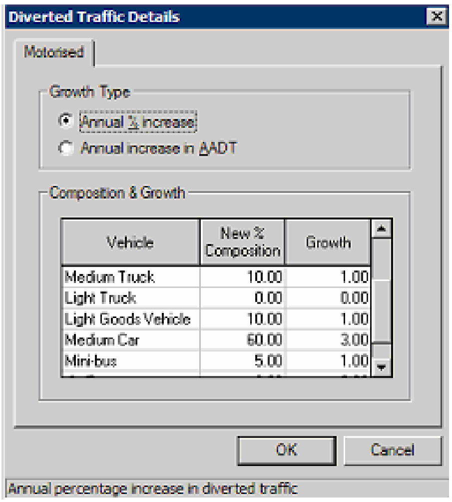


As a result of new construction, traffic may be diverted from existing road sections. To assign new traffic levels for existing sections, the user needs to click on the **Edit** button in the **Diverted Traffic** column for the appropriate alternative.

In this case study, the AADT on Sections A & B are marginally reduced to the values at the start of the analysis period, whereas on Sections C & D the AADT are significantly reduced upon opening of the new bypass. The AADT for the four sections are specified for the first year of opening for each bypass construction alternative. For example, for the 4 lanes alternative shown below, the AADT is specified for the year 2010.

For the new traffic levels on each existing section, the traffic composition and the traffic growth rates need to be specified. The screen for entering this information is accessed by either clicking on the Edit Diversion Details button or by double-clicking on the New AADT value. The growth rates for the new AADT on the existing sections have been reduced from those specified for the base alternative.



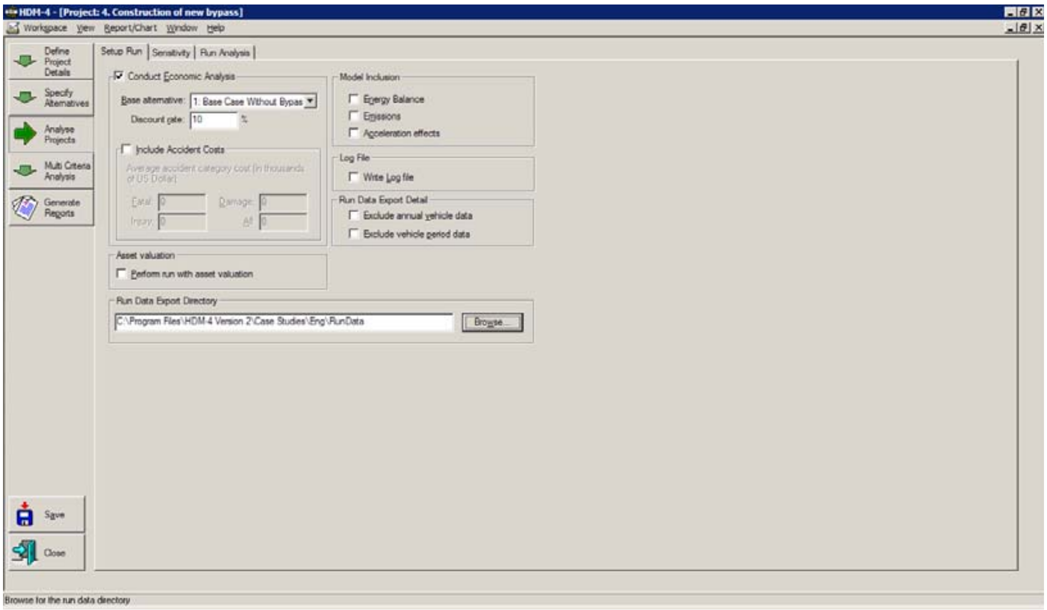


The Maintenance Standard (Routine + 50 mm overlay) is assigned from the year 2006 to Sections A, B, C & D in all four alternatives. The same maintenance standard is assigned to Section E (new bypass) from the year of opening of the bypass (2008 for 2 lanes, 2009 for wide 2 lanes and 2010 for 4 lanes).

4.4 Analyse Projects

4.4.1 Setup Run

The options selected in the Setup Run screen are Conduct Economic Analysis using a discount rate of 10%, with the 'base case without bypass' alternative selected as the base alternative. The additional models for accidents, energy balance, emissions, acceleration effects and asset valuation are not included in this analysis.



For this case study, sensitivity analysis has not been selected.

4.4.2 Run Analysis

This starts the analysis and produces the output necessary for report generation.

4.5 Multi Criteria Analysis

Multi criteria analysis has not been used in this case study.

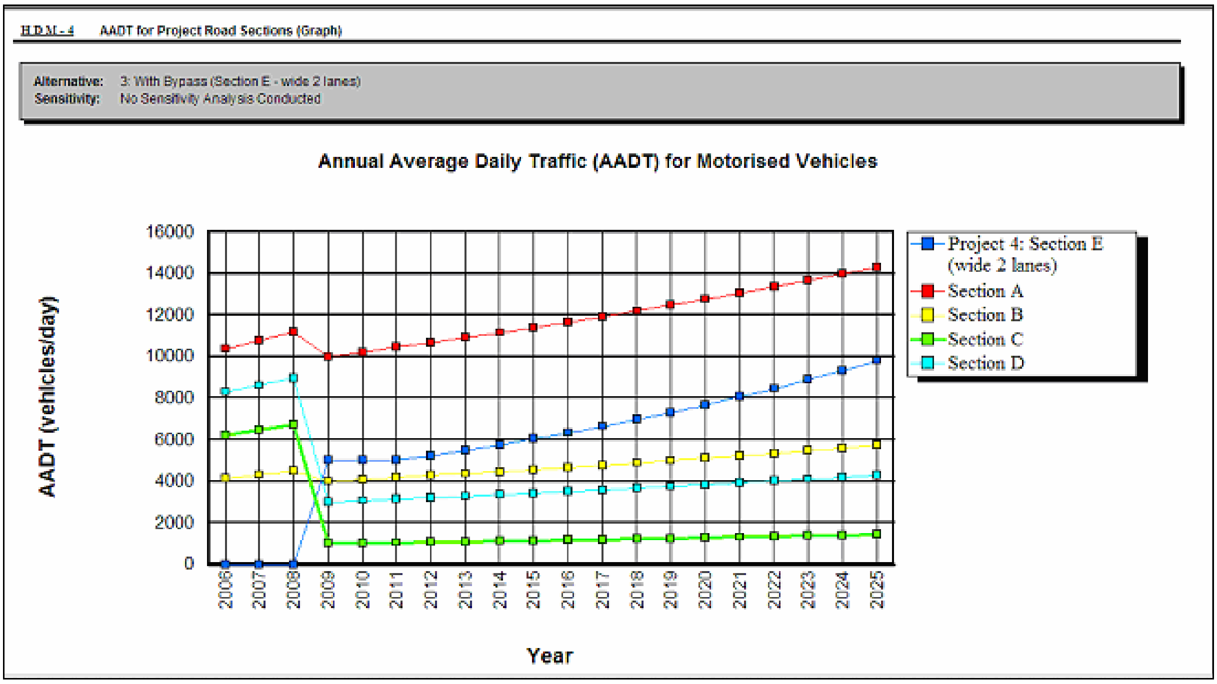
4.6 Generate Reports

The output reports from the analysis are produced and stored in the appropriate folders.

- **Traffic**

Details on the traffic flows for each alternative over the 20-year analysis period are reported in this folder in both graphical and tabular form. Also reported are the volume/capacity ratios.

The traffic levels over the analysis period are shown below for the 'wide 2 lanes' alternative. The graph illustrates the reductions in AADT for Sections A, B, C & D when the bypass is opened in year 4.



- **Deterioration / Works Effects**

The progression of the various distresses for each alternative over the analysis period are reported in this folder in both graphical and tabular form. Also reported in this folder are the timing of the works carried out for each alternative during the 20-year period.

The Road Works Summary (by Year) report lists the works activities for each alternative, year by year. As shown in this report for Alternative 3, the 'wide 2 lanes' construction takes place during the first 3 years. Routine maintenance activities that occur on the existing sections in the first few years of the analysis period are also shown below.

Alternative: 3: With Bypass (Section E - wide 2 lanes)
Sensitivity: No Sensitivity Analysis Conducted

Year	Section	Works Description	Code	Economic Cost	Financial Cost	Work Quantity
2006	Project 4: Section E (New Section: Project 4: Sectio			1,162,120.0	1,360,000.0	1.00 km
			Total Annual Cost:	1,162,120.0	1,360,000.0	
2007	Project 4: Section E (New Section: Project 4: Sectio			1,127,940.0	1,320,000.0	1.00 km
			Total Annual Cost:	1,127,940.0	1,320,000.0	
2008	Project 4: Section E (New Section: Project 4: Sectio			1,127,940.0	1,320,000.0	1.00 km
			Total Annual Cost:	1,127,940.0	1,320,000.0	
2010	Section A	Crack Sealing	CRKSL	26,316.8	31,580.2	5,263.36 sq. m
			Total Annual Cost:	26,316.8	31,580.2	
2011	Section A	Patching Potholes	PATPOT	516.7	620.1	43.06 sq. m
	Section B	Patching Potholes	PATPOT	112.0	134.4	9.33 sq. m
	Section D	Patching Potholes	PATPOT	190.9	229.1	15.91 sq. m
			Total Annual Cost:	819.7	983.6	
2012	Section A	Patching Potholes	PATPOT	221.1	265.3	18.43 sq. m
		Crack Sealing	CRKSL	26,316.8	31,580.2	5,263.36 sq. m
	Section B	Patching Potholes	PATPOT	47.5	57.1	3.96 sq. m
		Crack Sealing	CRKSL	12,007.1	14,408.5	2,401.41 sq. m
	Section D	Patching Potholes	PATPOT	76.9	92.3	6.41 sq. m
		Crack Sealing	CRKSL	32,624.7	39,149.6	6,524.94 sq. m
			Total Annual Cost:	71,294.1	85,552.9	

At the end of this report the total costs for each alternative for each year are summarised.

Summary of Total Annual Costs

	ase Case Without Bypass	ɔass (Section E - 2 lanes)	Section E - wide 2 lanes)	ɔass (Section E - 4 lanes)
2006	0.00	1,367,500.00	1,162,120.00	1,196,500.00
2007	0.00	1,367,500.00	1,127,940.00	1,196,500.00
2008	0.00	0.00	1,127,940.00	1,196,500.00
2009	0.00	0.00	0.00	1,196,500.00
2010	57,019.78	26,316.82	26,316.82	57,019.78
2011	21,660.90	825.79	819.66	803.03
2012	69,744.01	71,473.90	71,294.10	69,471.32
2013	20,717.16	21,305.17	21,363.56	21,232.92
2014	69,727.91	69,639.09	69,550.85	69,618.86
2015	20,609.77	20,252.07	20,239.02	20,260.85
2016	69,584.97	69,196.95	69,200.35	69,312.60

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- **Road User Effects**

The various components of road user effects are reported in this folder.

- **Cost Streams and Economic Evaluation**

This folder contains the results of the economic analysis. In the Economic Indicators Summary report, the results of this analysis indicates that Alternative 2 (2 lanes) produces the highest benefits of the three bypass construction alternatives.

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Indicators Summary

Study Name: **4. Construction of new bypass**
Run Date: **12-07-2006**
Currency: **US Dollar (millions)**
Discount Rate: **10.00%**

Sensitivity: No Sensitivity Analysis Conducted

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B+E-C)	NPV/Cost Ratio (NPV/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
1: Base Case Without Bypass	0.691	0.454	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2: With Bypass (Section E - 2 lanes)	3.016	2.752	2.325	30.536	0.000	28.210	9.352	10.252	74.4 (1)
3: With Bypass (Section E - wide 2 lanes)	3.499	3.232	2.807	31.287	0.000	28.480	8.140	8.813	59.1 (1)
4: With Bypass (Section E - 4 lanes)	4.537	4.250	3.846	31.795	0.000	27.949	6.160	6.576	45.6 (1)

Figure in brackets is number of IRR solutions in range -90 to +900

PART F PROGRAMME ANALYSIS CASE STUDIES

1 CASE STUDY 1 – PRIORITISED WORKS PROGRAMME

1.1 Introduction

This case study demonstrates the application of Programme Analysis in the production of a prioritised works programme for part of a road network, using the life cycle analysis method described in Section 0.

The objective is to prepare a prioritised list of road projects from a candidate list of road sections that are in a range of conditions. The analysis is expected to investigate the long term investment levels to meet the agency's target intervention levels, and to examine the impact of possible budget constraints.

The case study is located in the **Programmes** folder in the Workspace. Double-click on **1. Works Programme** to open the case study.

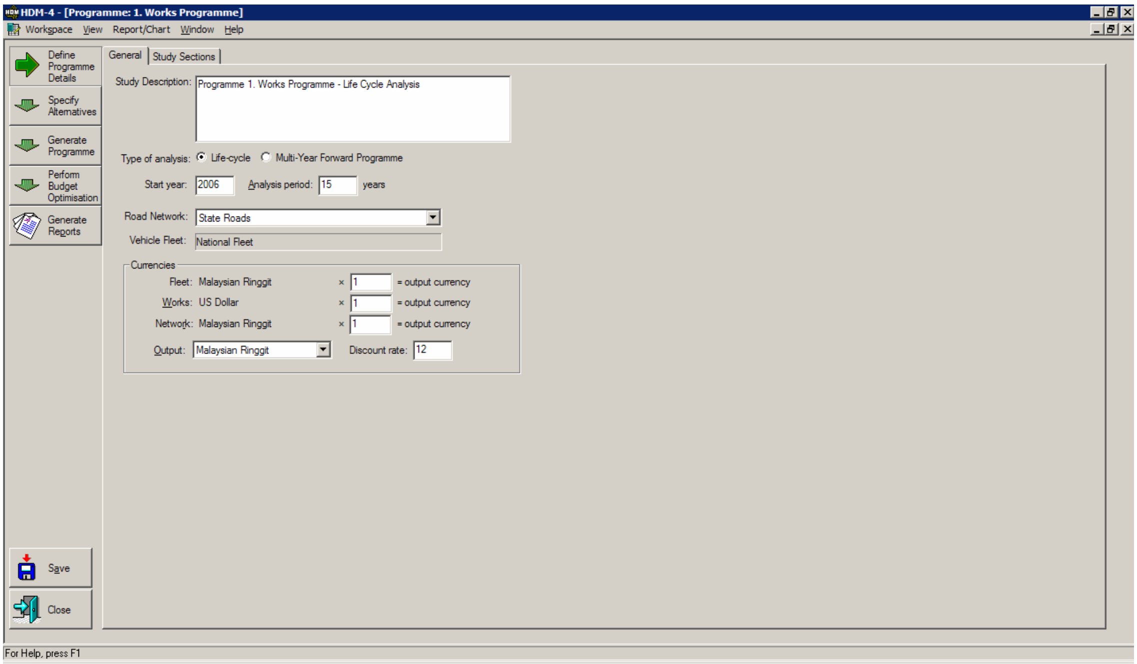
1.2 Define Project Details

In the **Define Programme Details** screen, the following tab pages may be displayed:

- General
- Study Sections

1.2.1 General

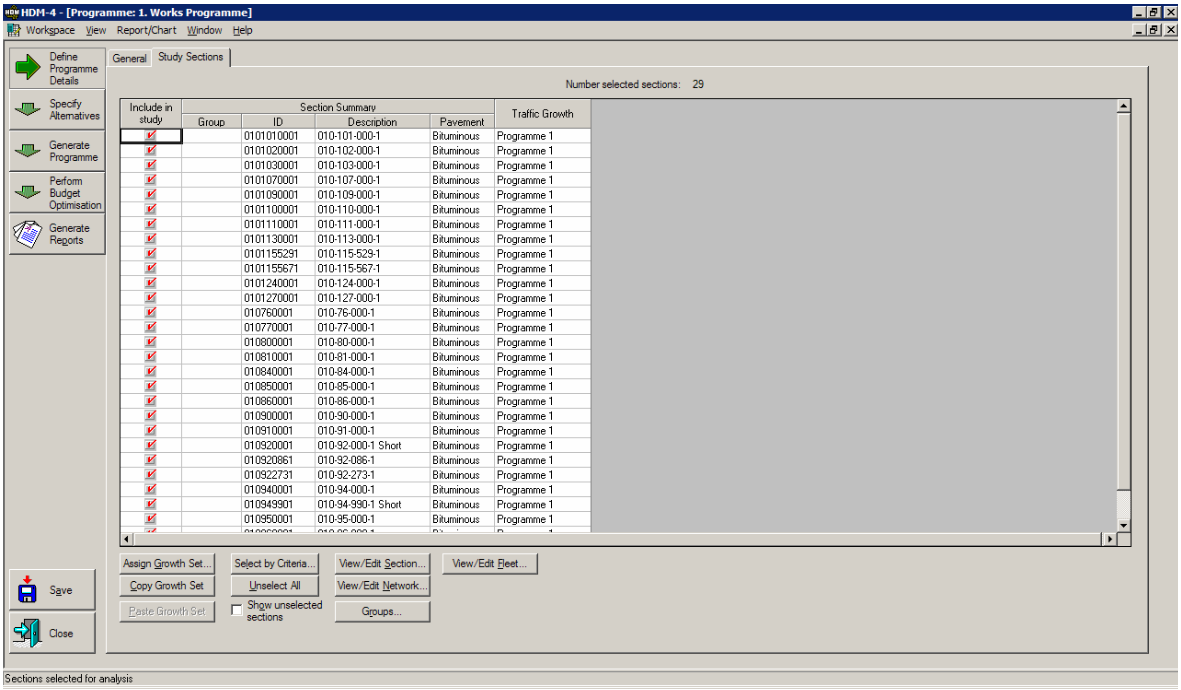
The information displayed in the General screen includes the study description, analysis type, analysis period, the pre-defined Road Network and Vehicle Fleet, and the currency to be used for the analysis.



This case study uses the life-cycle method of analysis. The analysis period is defined by the start year 2006 and a duration of 15 years (i.e. 2006 - 2020). The sections to be analysed are in the Road Network entitled State Roads, to which the National Fleet has been previously assigned as the Vehicle Fleet. The discount rate has been selected as 12% and the currency being used for this analysis is Malaysian Ringgit.

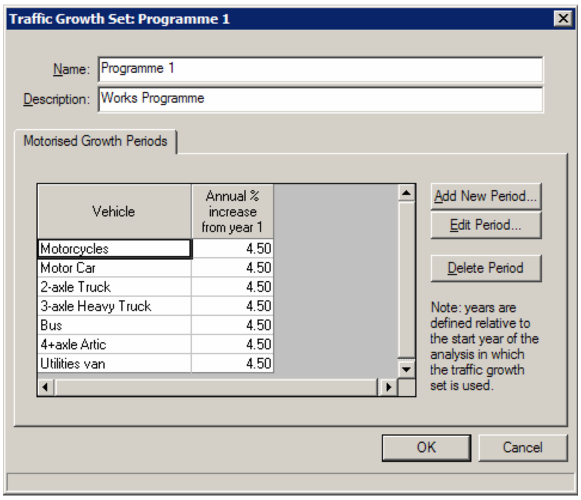
1.2 Study Sections

The road sections selected for analysis comprise a total of 29 bituminous sections.

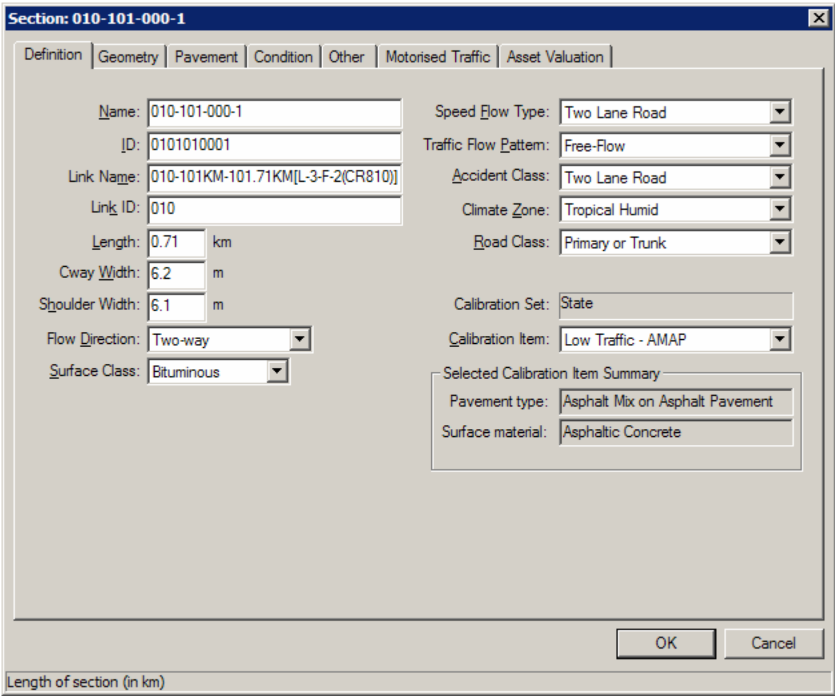


Double-clicking on a section gives access to the section details. However, the **Traffic Growth** details can only be seen and edited through the **Vehicle Fleets** folder. To access the Traffic Growth Sets that have been previously created, the user needs to open the appropriate vehicle fleet (in this case National Fleet) in the Vehicle Fleet folder and click on the Edit Traffic Growth Sets button which then displays all the previously created sets.

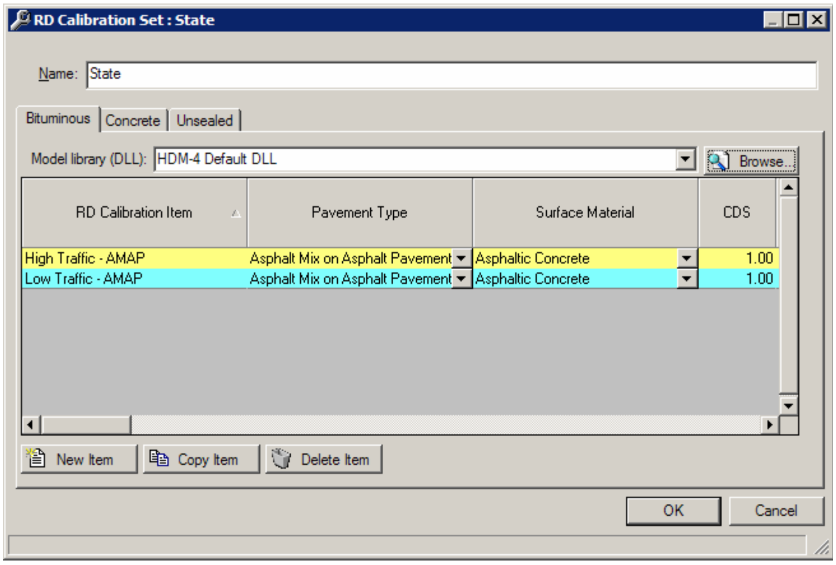
Double-clicking on the appropriate set (in this case Programme 1) displays the details of the traffic changes over the analysis period. The traffic growth rates for this case study indicate that the traffic is expected to increase at a rate of 4.5% per year.



- **Definition**

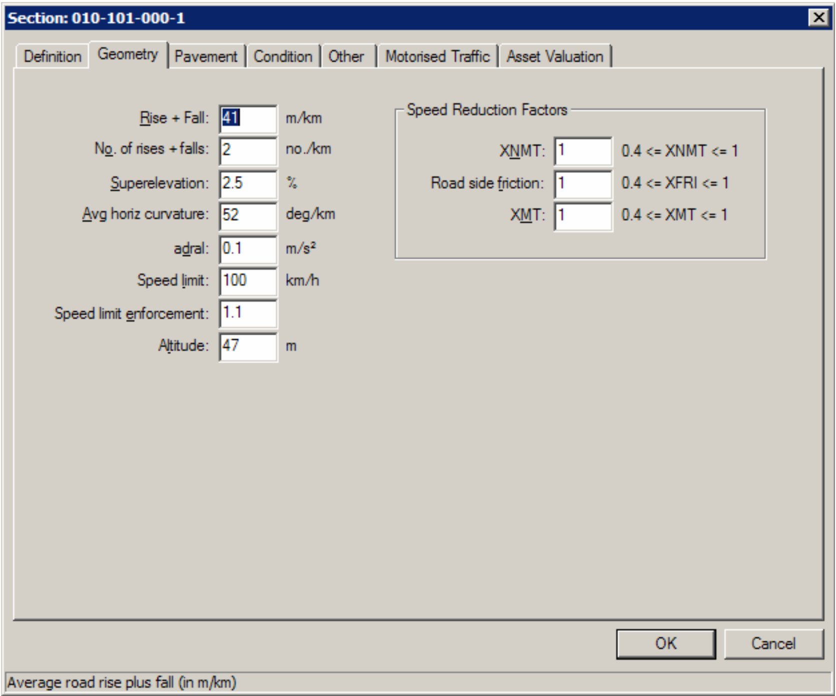


The State calibration set is assigned to the road sections in this case study. Details may be viewed within the Configuration folder. The State calibration set has two **Calibration Items** defined: High Traffic – AMAP and Low Traffic – AMAP. These calibration factors alter the performance characteristics of the network for each associated distress.



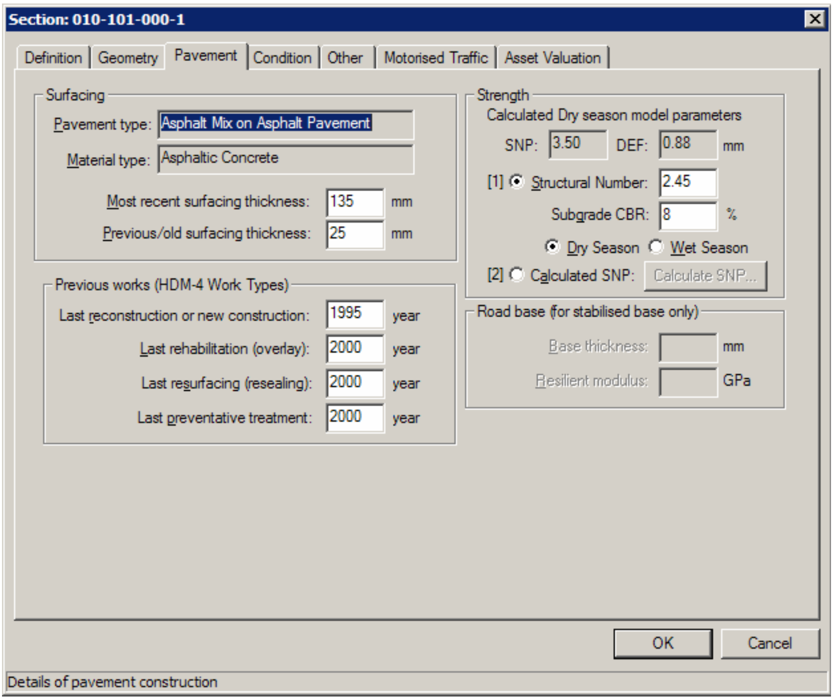
- **Geometry**

The geometry characteristics of each section are described in this screen.



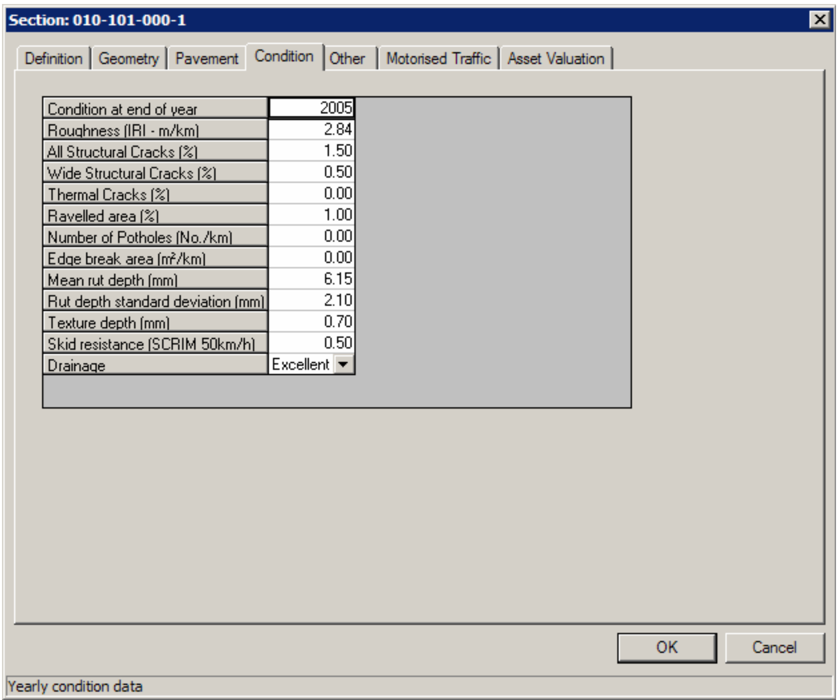
- **Pavement**

The pavement type, years of construction and periodic maintenance, and pavement strength are detailed on this screen.



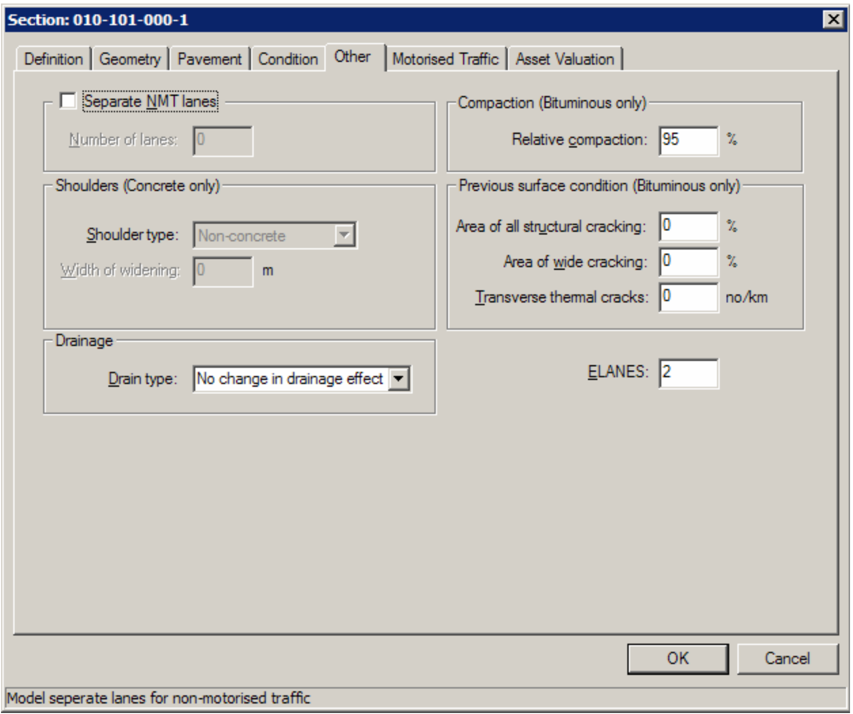
- **Condition**

The roughness of the selected sections varies from approximately 2 to 6.5. This indicates that some sections are overdue for treatment whereas others are likely to last a considerable time before requiring periodic maintenance. Many sections are also affected by low to moderate amounts of surface cracking and rutting of varying extent.



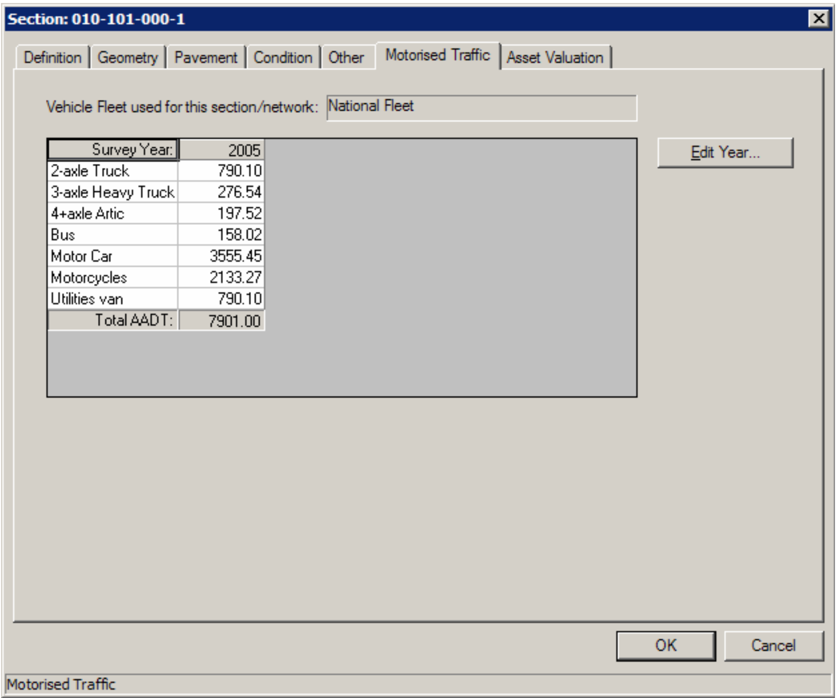
- **Other**

The value of ELANES for all the sections is 2.



- **Motorised Traffic**

The initial AADT values in 2005 for the sections in this case study range from approximately 8,000 to 12,000.



- **Asset Valuation**

Asset valuation is not considered in this case study.

1.3 Specify Alternatives

The two Maintenance Standards that are considered in this case study are described in Table F1.1.

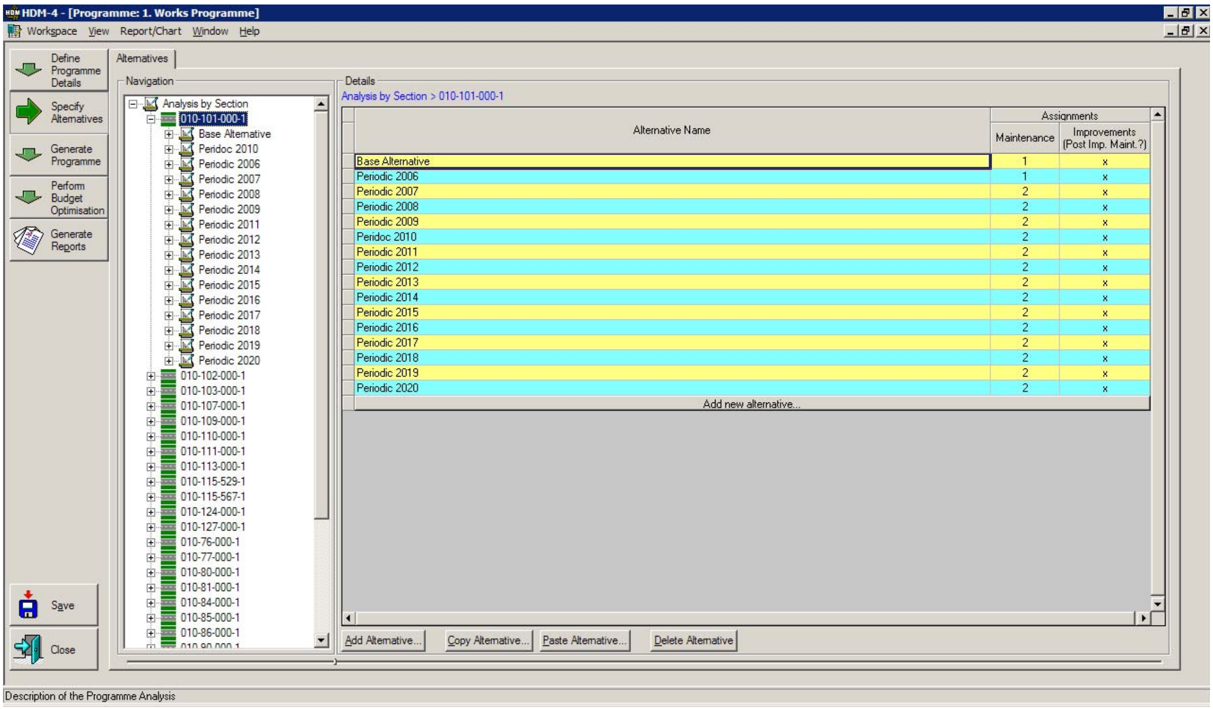
Table F1.1
Maintenance Alternatives

Alternative	Works Items	Criteria
1 Base Alternative	Edge Repair	Edge break > 1 m^2/km
	Pothole Patching	Potholes > 1 no./km
	Patching Wide Cracks	Wide Cracks > 5%
	Pavement Reconstruction – 150mm asphalt	IRI > 10
2 Compound Standard	Edge Repair	Edge break > 1 m^2/km
	Pothole Patching	Potholes > 1 no./km
	Patching Wide Cracks	Wide Cracks > 5%
	40 mm Overlay	IRI > 3 & AADT > 15000 Minimum interval 5 years
	40 mm Overlay	IRI > 4.5 & AADT < 15000 Minimum interval 5 years
	80 mm Overlay	4 < IRI < 6.5 & AADT > 15000 Minimum interval 7 years
	Reconstruction – 150 mm asphalt	IRI > 5 & AADT > 15000
	Reconstruction – 150 mm asphalt	IRI > 6 & AADT < 15000

Alternative 1 is the Base Alternative. It comprises routine maintenance which includes edge repairs, pothole patching and patching of areas affected by wide cracks. In addition, a reconstruction is applied if the roughness level reaches 10 IRI. The other alternatives include the same routine maintenance, with different periodic maintenance items.

Sixteen section-alternatives have been specified for each section. They comprise the Base Alternative and 15 periodic maintenance options comprising the Compound Standard timed to start in Year 1, Year 2, etc up to Year 15, the final year of the analysis. Where the Compound Standard is delayed, the Base Alternative is applied.

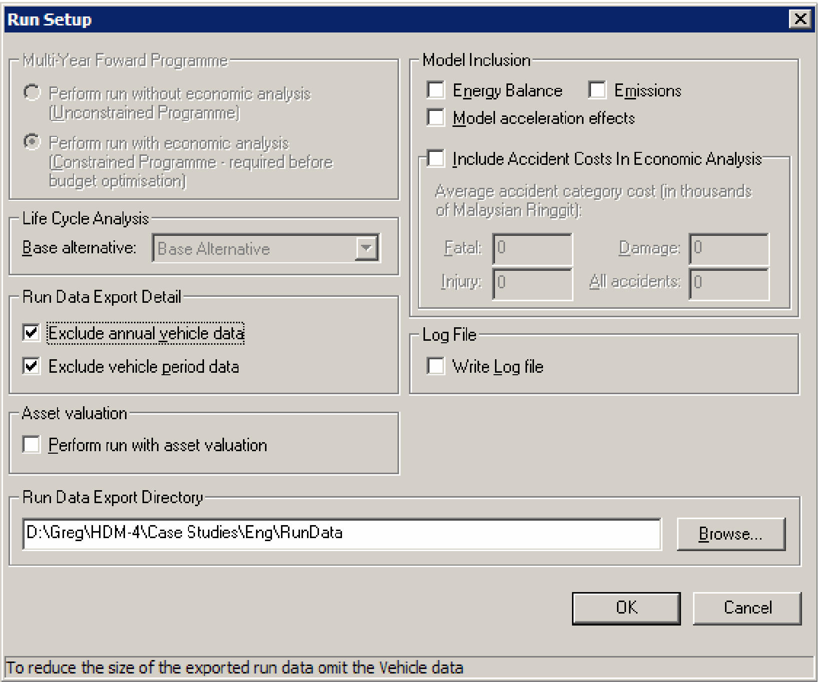
This method of creating alternatives allows the optimum timing of major treatments to be investigated, and therefore provides a wider choice of section-alternatives for analysis under budget constraint. If it is not possible to choose an alternative for a section at the ideal timing, then this method allows selection in another year still to occur.



1.4 Generate Programme

1.4.1 Perform Run

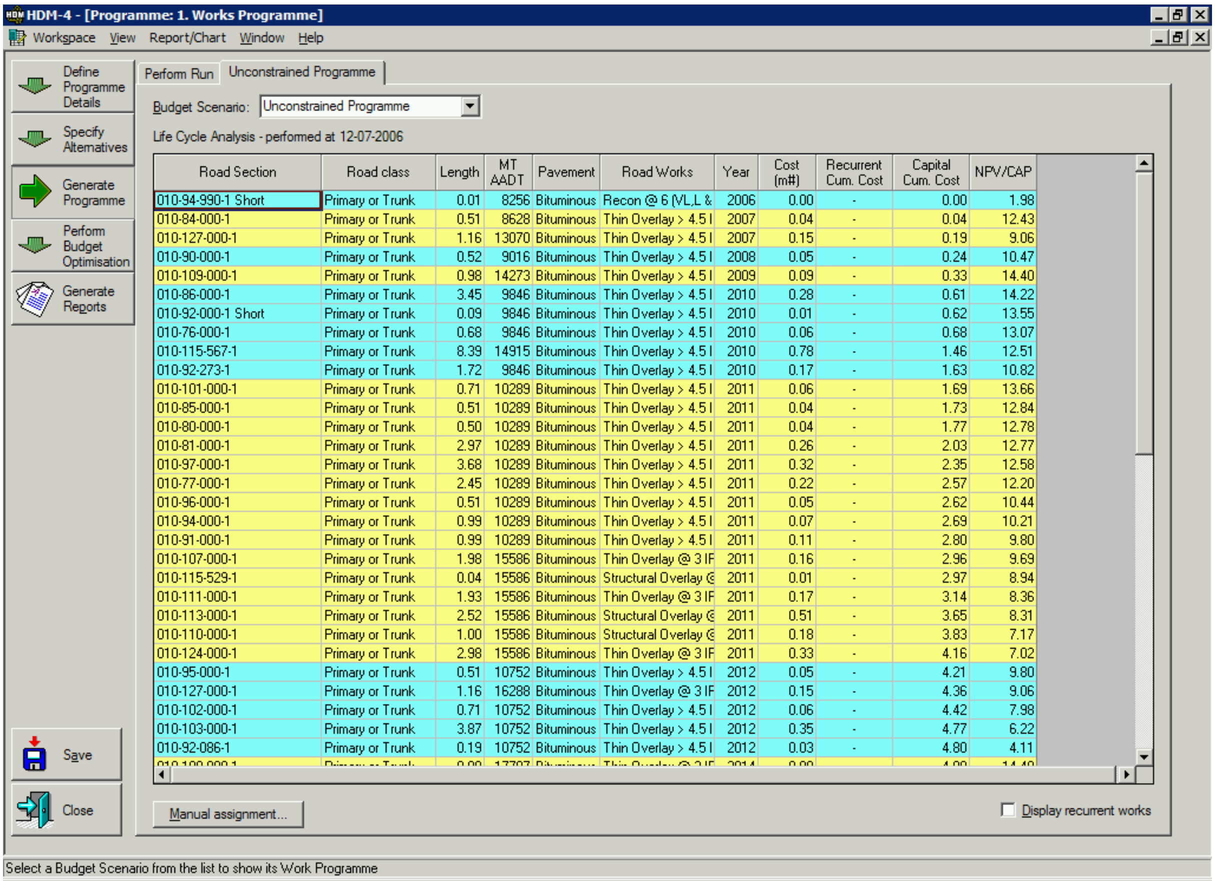
The destination of the outputs from the analysis are specified in the Run Set-up dialogue. Options are available for the inclusion of the other models.



Clicking ‘Start’ executes the run and enables the results of the unconstrained programme analysis to be viewed.

1.4.2 Unconstrained Programme

Having completed the run, the Unconstrained Programme can be viewed by pressing the associated tab.



Road Section	Road class	Length	MT AADT	Pavement	Road Works	Year	Cost (m#)	Recurrent Cum. Cost	Capital Cum. Cost	NPV/CAP
010-94-990-1 Short	Primary or Trunk	0.01	8256	Bituminous	Recon @ 6 (VL,L &	2006	0.00	-	0.00	1.98
010-84-000-1	Primary or Trunk	0.51	8628	Bituminous	Thin Overlay > 4.5 I	2007	0.04	-	0.04	12.43
010-127-000-1	Primary or Trunk	1.16	13070	Bituminous	Thin Overlay > 4.5 I	2007	0.15	-	0.19	9.06
010-90-000-1	Primary or Trunk	0.52	9016	Bituminous	Thin Overlay > 4.5 I	2008	0.05	-	0.24	10.47
010-109-000-1	Primary or Trunk	0.98	14273	Bituminous	Thin Overlay > 4.5 I	2009	0.09	-	0.33	14.40
010-86-000-1	Primary or Trunk	3.45	9846	Bituminous	Thin Overlay > 4.5 I	2010	0.28	-	0.61	14.22
010-92-000-1 Short	Primary or Trunk	0.09	9846	Bituminous	Thin Overlay > 4.5 I	2010	0.01	-	0.62	13.55
010-76-000-1	Primary or Trunk	0.68	9846	Bituminous	Thin Overlay > 4.5 I	2010	0.06	-	0.68	13.07
010-115-567-1	Primary or Trunk	8.39	14915	Bituminous	Thin Overlay > 4.5 I	2010	0.78	-	1.46	12.51
010-92-273-1	Primary or Trunk	1.72	9846	Bituminous	Thin Overlay > 4.5 I	2010	0.17	-	1.63	10.82
010-101-000-1	Primary or Trunk	0.71	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.06	-	1.69	13.66
010-85-000-1	Primary or Trunk	0.51	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.04	-	1.73	12.84
010-80-000-1	Primary or Trunk	0.50	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.04	-	1.77	12.78
010-81-000-1	Primary or Trunk	2.97	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.26	-	2.03	12.77
010-97-000-1	Primary or Trunk	3.68	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.32	-	2.35	12.58
010-77-000-1	Primary or Trunk	2.45	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.22	-	2.57	12.20
010-96-000-1	Primary or Trunk	0.51	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.05	-	2.62	10.44
010-94-000-1	Primary or Trunk	0.99	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.07	-	2.69	10.21
010-91-000-1	Primary or Trunk	0.99	10289	Bituminous	Thin Overlay > 4.5 I	2011	0.11	-	2.80	9.80
010-107-000-1	Primary or Trunk	1.98	15586	Bituminous	Thin Overlay @ 3 IF	2011	0.16	-	2.96	9.69
010-115-529-1	Primary or Trunk	0.04	15586	Bituminous	Structural Overlay @	2011	0.01	-	2.97	8.94
010-111-000-1	Primary or Trunk	1.93	15586	Bituminous	Thin Overlay @ 3 IF	2011	0.17	-	3.14	8.36
010-113-000-1	Primary or Trunk	2.52	15586	Bituminous	Structural Overlay @	2011	0.51	-	3.65	8.31
010-110-000-1	Primary or Trunk	1.00	15586	Bituminous	Structural Overlay @	2011	0.18	-	3.83	7.17
010-124-000-1	Primary or Trunk	2.98	15586	Bituminous	Thin Overlay @ 3 IF	2011	0.33	-	4.16	7.02
010-95-000-1	Primary or Trunk	0.51	10752	Bituminous	Thin Overlay > 4.5 I	2012	0.05	-	4.21	9.80
010-127-000-1	Primary or Trunk	1.16	16288	Bituminous	Thin Overlay @ 3 IF	2012	0.15	-	4.36	9.06
010-102-000-1	Primary or Trunk	0.71	10752	Bituminous	Thin Overlay > 4.5 I	2012	0.06	-	4.42	7.98
010-103-000-1	Primary or Trunk	3.87	10752	Bituminous	Thin Overlay > 4.5 I	2012	0.35	-	4.77	6.22
010-92-086-1	Primary or Trunk	0.19	10752	Bituminous	Thin Overlay > 4.5 I	2012	0.03	-	4.80	4.11

The screen displays the selected sections and treatments for the section-alternative, one per section, which has the highest NPV. This can include the base case, which by definition has a NPV of zero, or a particular section with a positive NPV. Key parameters shown include the treatment year, capital cost, cumulative capital costs and NPV/CAP, the latter being the preferred prioritisation indicator for capital budgeting.

In this screen the following two options can also be selected:

- Select sections for **Manual assignment** (shown in the bottom left of the screen). This allows works which have an NPV of zero or greater to be selected as committed works and the budget reserved for their treatment. Where budget optimisation is performed the total value of the works for these sections is removed from the available budget prior to performing budget optimisation.

- Selecting **Display recurrent works** (shown in the bottom right of the screen) shows the treatments and associated costs for all recurrent works in addition to the capital works.

It is useful at this point to scroll through the active screen and note the capital budget distribution by year as this will be important for assessing investment needs and for budget optimisation purposes.

1.5 Perform Budget Optimisation

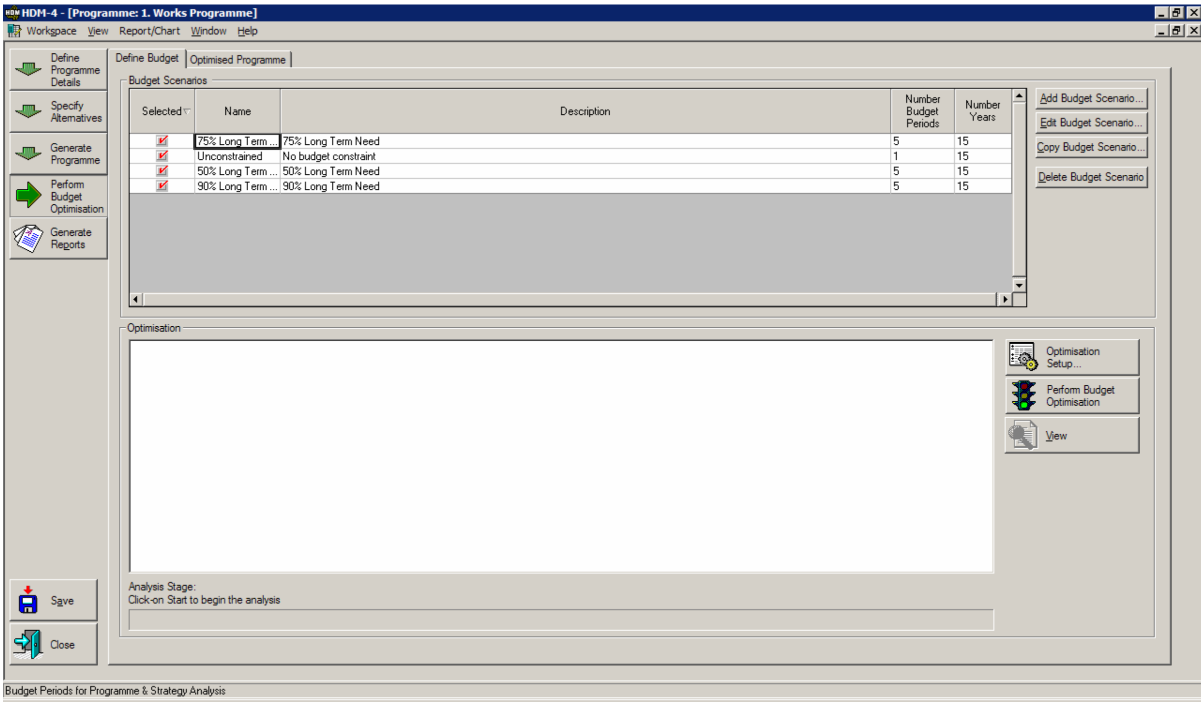
1.5.1 Define Budget

For this case study the year-by-year cumulative unconstrained capital budget is summarised in Table F1.2. A total of 10.52 million is required to cover the captal costs of the prioritised works. Three budget scenarios are also shown which require approximately 90%, 75% and 50% of the unconstrained budget over a period of 15 years. These budet scenarios will be considered, together with an unconstrained budget of 11 million, in the budget optimisation procedure.

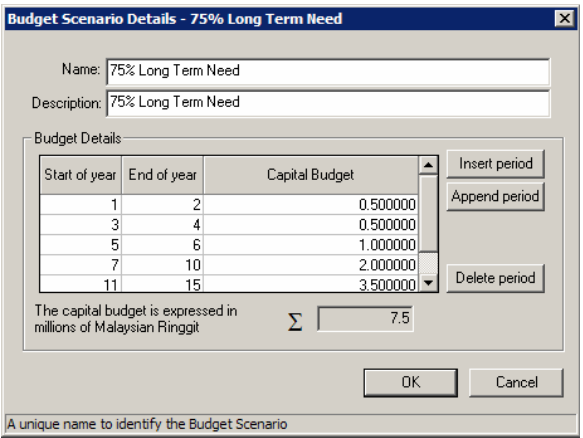
Table F1.2
Capital Costs and Budget Scenarios

Year	Cumulative Capital Cost (millions)	Budget Period	Need for Period	Budget Scenario		
				90%	75%	50%
2006	0.00	1	0.19	0.5	0.5	0.5
2007	0.19					
2008	0.24	2	0.14	0.5	0.5	0.5
2009	0.33					
2010	1.63	3	3.83	1	1	0.75
2011	4.16					
2012	4.80	4	1.51	2.5	2	1.5
2013	4.80					
2014	4.89					
2015	5.67					
2016	6.42	5	4.85	4.5	3.5	1.75
2017	6.57					
2018	7.08					
2019	8.67					
2020	10.52					
			Total	9	7.5	5.0

The budget scenarios that are to be investigated need to be defined. These include a time profile of the budget.

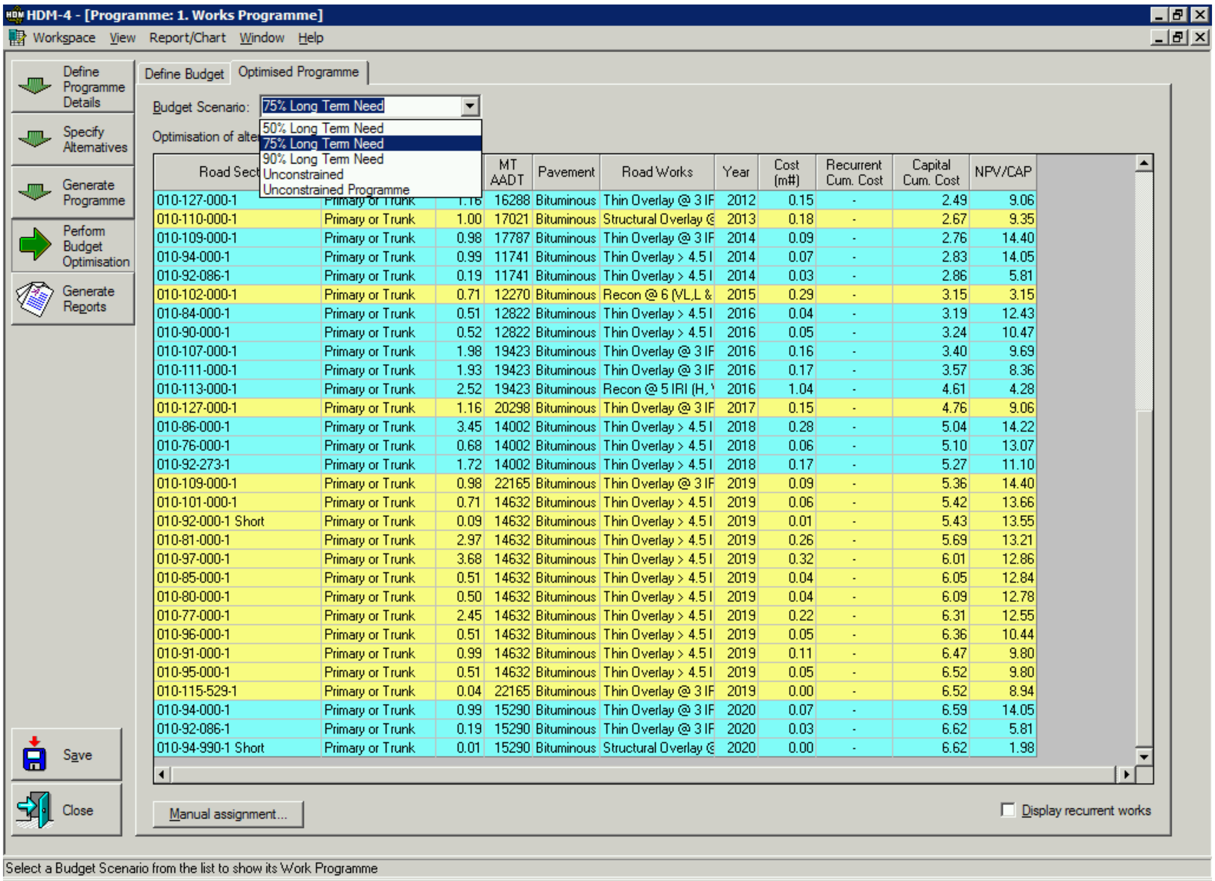


The three constrained budget scenarios have been split into 5 time periods as defined in Table F1.2.



1.5.2 Optimised Programme

Having set up the budget scenarios, then the user needs to click on Perform Budget Optimisation to produce the Optimised Programmes for each defined scenario.



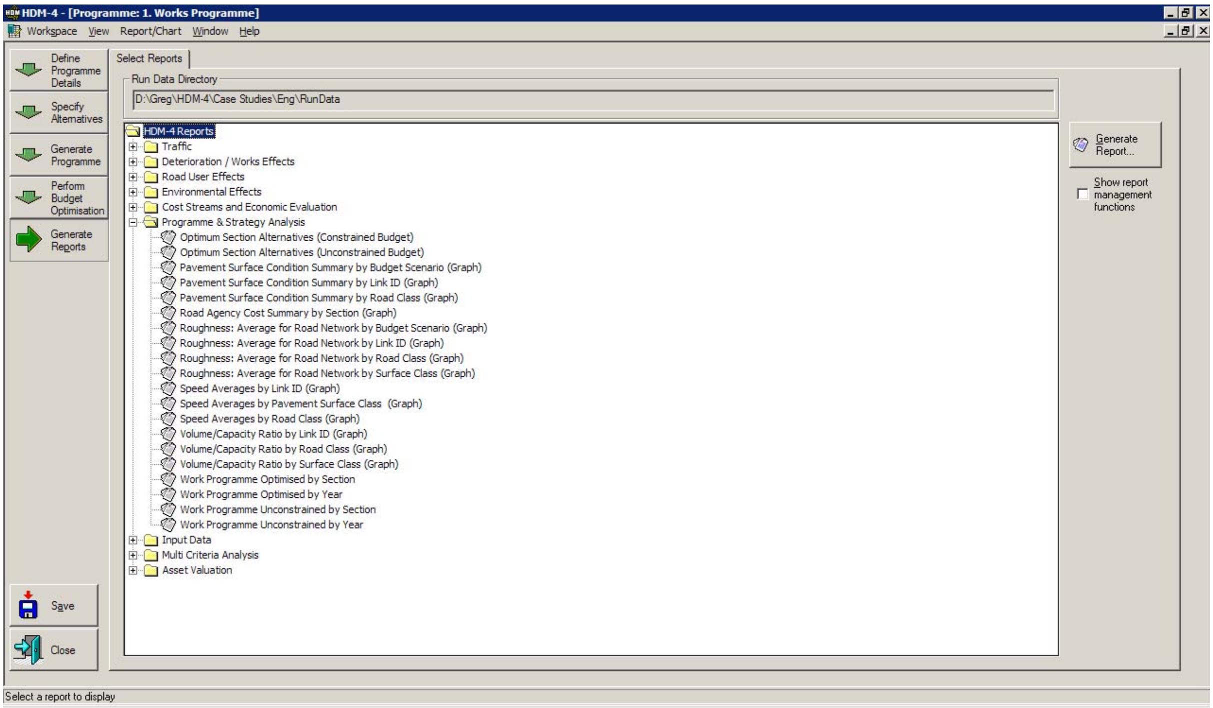
Road Sect			MT AADT	Pavement	Road Works	Year	Cost (m#)	Recurrent Cum. Cost	Capital Cum. Cost	NPV/CAP
010-127-000-1	Primary or Trunk	1.16	16288	Bituminous	Thin Overlay @ 3 IF	2012	0.15	-	2.49	9.06
010-110-000-1	Primary or Trunk	1.00	17021	Bituminous	Structural Overlay @	2013	0.18	-	2.67	9.35
010-109-000-1	Primary or Trunk	0.98	17787	Bituminous	Thin Overlay @ 3 IF	2014	0.09	-	2.76	14.40
010-94-000-1	Primary or Trunk	0.99	11741	Bituminous	Thin Overlay > 4.5 I	2014	0.07	-	2.83	14.05
010-92-086-1	Primary or Trunk	0.19	11741	Bituminous	Thin Overlay > 4.5 I	2014	0.03	-	2.86	5.81
010-102-000-1	Primary or Trunk	0.71	12270	Bituminous	Recon @ 6 (VL,L &	2015	0.29	-	3.15	3.15
010-84-000-1	Primary or Trunk	0.51	12822	Bituminous	Thin Overlay > 4.5 I	2016	0.04	-	3.19	12.43
010-90-000-1	Primary or Trunk	0.52	12822	Bituminous	Thin Overlay > 4.5 I	2016	0.05	-	3.24	10.47
010-107-000-1	Primary or Trunk	1.98	19423	Bituminous	Thin Overlay @ 3 IF	2016	0.16	-	3.40	9.69
010-111-000-1	Primary or Trunk	1.93	19423	Bituminous	Thin Overlay @ 3 IF	2016	0.17	-	3.57	8.36
010-113-000-1	Primary or Trunk	2.52	19423	Bituminous	Recon @ 5 IRI (H, '	2016	1.04	-	4.61	4.28
010-127-000-1	Primary or Trunk	1.16	20298	Bituminous	Thin Overlay @ 3 IF	2017	0.15	-	4.76	9.06
010-86-000-1	Primary or Trunk	3.45	14002	Bituminous	Thin Overlay > 4.5 I	2018	0.28	-	5.04	14.22
010-76-000-1	Primary or Trunk	0.68	14002	Bituminous	Thin Overlay > 4.5 I	2018	0.06	-	5.10	13.07
010-92-273-1	Primary or Trunk	1.72	14002	Bituminous	Thin Overlay > 4.5 I	2018	0.17	-	5.27	11.10
010-109-000-1	Primary or Trunk	0.98	22165	Bituminous	Thin Overlay @ 3 IF	2019	0.09	-	5.36	14.40
010-101-000-1	Primary or Trunk	0.71	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.06	-	5.42	13.66
010-92-000-1 Short	Primary or Trunk	0.09	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.01	-	5.43	13.55
010-81-000-1	Primary or Trunk	2.97	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.26	-	5.69	13.21
010-97-000-1	Primary or Trunk	3.68	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.32	-	6.01	12.86
010-85-000-1	Primary or Trunk	0.51	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.04	-	6.05	12.84
010-80-000-1	Primary or Trunk	0.50	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.04	-	6.09	12.78
010-77-000-1	Primary or Trunk	2.45	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.22	-	6.31	12.55
010-96-000-1	Primary or Trunk	0.51	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.05	-	6.36	10.44
010-91-000-1	Primary or Trunk	0.99	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.11	-	6.47	9.80
010-95-000-1	Primary or Trunk	0.51	14632	Bituminous	Thin Overlay > 4.5 I	2019	0.05	-	6.52	9.80
010-115-529-1	Primary or Trunk	0.04	22165	Bituminous	Thin Overlay @ 3 IF	2019	0.00	-	6.52	8.94
010-94-000-1	Primary or Trunk	0.99	15290	Bituminous	Thin Overlay @ 3 IF	2020	0.07	-	6.59	14.05
010-92-086-1	Primary or Trunk	0.19	15290	Bituminous	Thin Overlay @ 3 IF	2020	0.03	-	6.62	5.81
010-94-990-1 Short	Primary or Trunk	0.01	15290	Bituminous	Structural Overlay @	2020	0.00	-	6.62	1.98

As can be seen in the screen for the 75% budget constraint, the cumulative capital costs of 6.62 million are within the budget constraint of 7.5 million.

1.6 Generate Reports

Having run the analysis it is now possible to **Generate Reports** and perform a similar check of key reports to ensure the data inputs and modeling are as expected. These should be examined and verified as any subsequent results are dependent on the performance of individual sections, with results aggregated to represent the network.

For Programme and Strategy analysis case studies a wider selection of reports are available, and examples of a selection of useful reports for the particular case study are given below. The following screen shows the list of reports available in the Programme and Strategy Analysis folder.



The Optimum Section Alternatives (Constrained Budget/Unconstrained Budget) report presents the list of section-alternatives (one per section) chosen for each section as a result of the constrained or unconstrained analyses as shown below.

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Optimum Section Alternatives (Unconstrained Budget)

Study Name: **1. Works Programme**
Run Date: **12-07-2006**
Currency: **Malaysian Ringgit (millions)**

Section	Road Class	Length (km)	Surface Class	Initial AADT	Alternative Desc.	Average Roughness IRI	Discounted Agency Financial Capital Costs	Discounted Agency Financial Recurrent Costs	Ne Presen Value
010-101-000-1	Primary or Trunk	0.710	Bituminous	8,256	Periodic 2006	3.6	0.05	0.02	0.53
010-102-000-1	Primary or Trunk	0.710	Bituminous	8,256	Periodic 2006	3.6	0.06	0.03	0.41
010-103-000-1	Primary or Trunk	3.870	Bituminous	8,256	Periodic 2006	3.5	0.33	0.09	1.77
010-107-000-1	Primary or Trunk	1.980	Bituminous	12,507	Periodic 2006	2.8	0.15	0.05	1.19
010-109-000-1	Primary or Trunk	0.980	Bituminous	12,507	Periodic 2006	3.2	0.12	0.01	1.40
010-110-000-1	Primary or Trunk	1.000	Bituminous	12,507	Periodic 2006	2.9	0.12	0.04	0.79
010-111-000-1	Primary or Trunk	1.930	Bituminous	12,507	Periodic 2006	2.7	0.15	0.03	1.06
010-113-000-1	Primary or Trunk	2.520	Bituminous	0	Periodic 2006	3.0	0.35	0.05	2.58
010-115-529-1	Primary or Trunk	0.040	Bituminous	12,507	Periodic 2006	3.0	0.00	0.00	0.03
010-115-567-1	Primary or Trunk	8.390	Bituminous	12,507	Periodic 2006	3.3	0.93	0.18	9.80
010-124-000-1	Primary or Trunk	2.980	Bituminous	0	Periodic 2006	2.9	0.29	0.04	1.71
010-127-000-1	Primary or Trunk	1.160	Bituminous	0	Periodic 2006	3.0	0.26	0.00	1.97
010-76-000-1	Primary or Trunk	0.680	Bituminous	8,256	Periodic 2006	3.6	0.05	0.02	0.56
010-77-000-1	Primary or Trunk	2.450	Bituminous	8,256	Periodic 2006	3.6	0.17	0.06	1.76
010-80-000-1	Primary or Trunk	0.500	Bituminous	8,256	Periodic 2006	3.6	0.03	0.01	0.36
010-81-000-1	Primary or Trunk	2.970	Bituminous	8,256	Periodic 2006	3.6	0.21	0.08	2.22
010-84-000-1	Primary or Trunk	0.510	Bituminous	8,256	Periodic 2006	3.6	0.05	0.02	0.49
010-85-000-1	Primary or Trunk	0.510	Bituminous	8,256	Periodic 2006	3.6	0.03	0.01	0.37
010-86-000-1	Primary or Trunk	3.450	Bituminous	8,256	Periodic 2006	3.5	0.25	0.05	3.03

At the end of this report a summary is given for the complete set of selected alternatives, including average IRI, discounted capital and recurrent costs and the total Net Present Value of the particular scenario. Summarising this data for each scenario enables a comparison across scenarios to be made, on the assumption that a common base case has been applied.

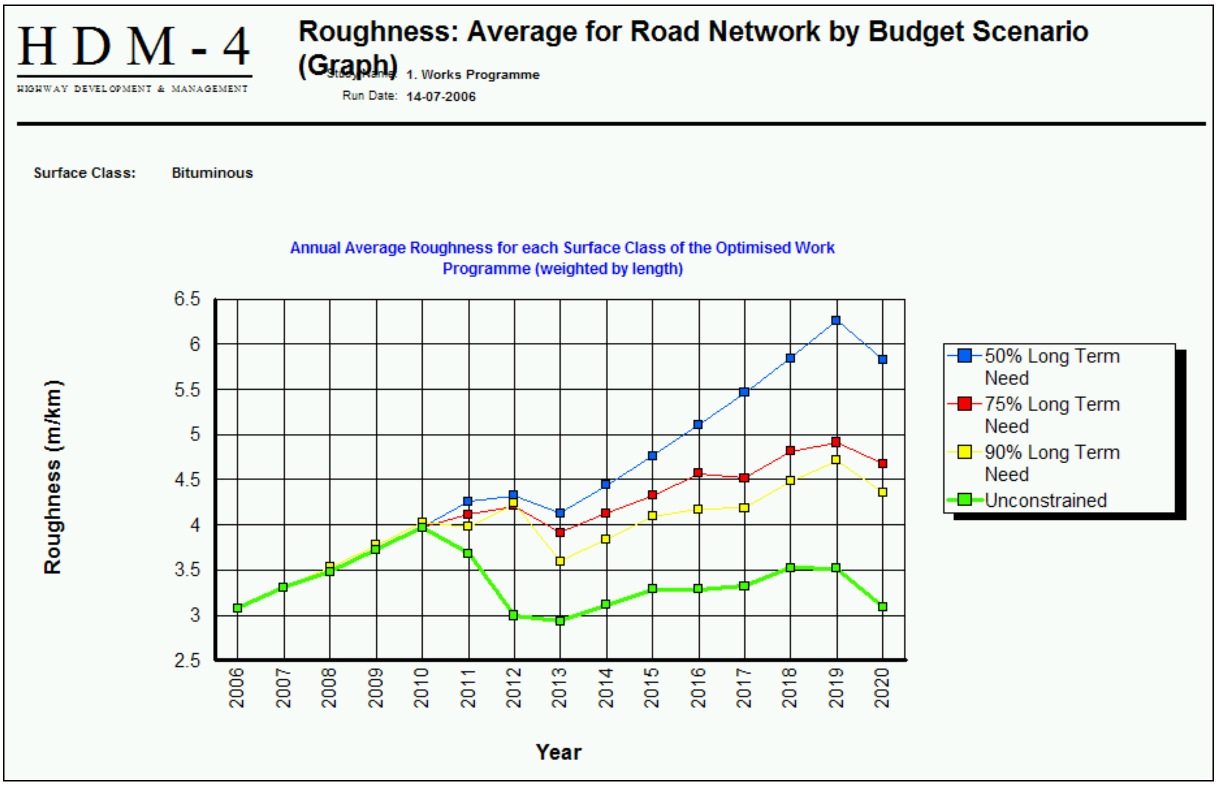
For the scenarios examined, a summary of the results is presented in Table F1.3.

Table F1.3
Summary of Constrained Budget Scenario Analysis

Scenario	Average IRI	Discounted Agency Costs			NPV
		Capital	Recurrent	Total	
Unconstrained	3.35	4.34	1.05	5.39	38.76
90% need	3.96	2.86	1.93	4.79	27.84
75% need	4.11	2.67	1.97	4.64	23.35
50% need	4.58	1.59	2.48	4.07	14.90

The results confirm the magnitude of the NPV is proportional to the investment cost. However, a relatively similar NPV/C can be achieved where funds are lower, this being a result of the optmisation process selecting the ‘optimum’ combination of section-alternatives including timing options.

The Roughness: Average for Road Network by Budget Scenario graph presents the average roughness weighted by length for each scenario.



The long term performance is shown to vary considerably depending on budget availability. In this case, the unconstrained budget enables conditions to be held relatively constant over a period of years, whereas in the other cases conditions worsen as the available budget decreases. This information assists in examining the impact of budget constraints on road users.

Reports such as the Work Programme Optimised (or Unconstrained) by Year (or by Section), display the lists of physical works carried out. They are of practical benefit to those charged with planning and implementing works and provide an indicative list of requirements. Verification of the outputs should be undertaken on a selection of sections prior to accepting the results of the analysis and commencing the project preparation stage.

HDM-4 **Work Programme Optimised by Year**

Budget Scenario: **50% Long Term Need**
50% Long Term Need

Year	Section	Road Class	Length (km)	Surface Clas	AADT	Work Description	NPV/CAP	Financial Costs	Cum. Costs
2006	010-94-990-1 Short	Primary or Trunk	0.0	Bituminous	8256	Recon @ 6 (VL,L & M)	1.982	0.004	0.004
2007	010-84-000-1	Primary or Trunk	0.5	Bituminous	8628	Thin Overlay > 4.5 IRI (V	12.425	0.039	0.043
	010-127-000-1	Primary or Trunk	1.2	Bituminous	13070	Thin Overlay > 4.5 IRI (V	9.061	0.153	0.196
2008	010-90-000-1	Primary or Trunk	0.5	Bituminous	9016	Thin Overlay > 4.5 IRI (V	10.466	0.048	0.244
2009	010-109-000-1	Primary or Trunk	1.0	Bituminous	14273	Thin Overlay > 4.5 IRI (V	14.399	0.086	0.330
2010	010-92-000-1 Short	Primary or Trunk	0.1	Bituminous	9846	Thin Overlay > 4.5 IRI (V	13.548	0.006	0.336
	010-76-000-1	Primary or Trunk	0.7	Bituminous	9846	Thin Overlay > 4.5 IRI (V	13.068	0.057	0.393
2011	010-101-000-1	Primary or Trunk	0.7	Bituminous	10289	Thin Overlay > 4.5 IRI (V	13.655	0.058	0.451
	010-85-000-1	Primary or Trunk	0.5	Bituminous	10289	Thin Overlay > 4.5 IRI (V	12.836	0.043	0.494
	010-80-000-1	Primary or Trunk	0.5	Bituminous	10289	Thin Overlay > 4.5 IRI (V	12.775	0.042	0.536
	010-97-000-1	Primary or Trunk	3.7	Bituminous	10289	Thin Overlay > 4.5 IRI (V	12.578	0.323	0.859
	010-115-529-1	Primary or Trunk	0.0	Bituminous	15586	Structural Overlay @ 4 IF	8.939	0.005	0.864
	010-110-000-1	Primary or Trunk	1.0	Bituminous	15586	Structural Overlay @ 4 IF	7.165	0.182	1.046
2012	010-86-000-1	Primary or Trunk	3.5	Bituminous	10752	Thin Overlay > 4.5 IRI (V	15.061	0.285	1.331
	010-81-000-1	Primary or Trunk	3.0	Bituminous	10752	Thin Overlay > 4.5 IRI (V	13.208	0.260	1.590
	010-127-000-1	Primary or Trunk	1.2	Bituminous	16288	Thin Overlay @ 3 IRI (>H	9.061	0.153	1.744
	010-113-000-1	Primary or Trunk	2.5	Bituminous	16288	Structural Overlay @ 4 IF	8.593	0.515	2.258
2014	010-109-000-1	Primary or Trunk	1.0	Bituminous	17787	Thin Overlay @ 3 IRI (>H	14.399	0.086	2.344
2015	010-92-086-1	Primary or Trunk	0.2	Bituminous	12270	Recon @ 6 (VL,L & M)	2.759	0.078	2.422
2016	010-84-000-1	Primary or Trunk	0.5	Bituminous	12822	Thin Overlay > 4.5 IRI (V	12.425	0.039	2.461
	010-90-000-1	Primary or Trunk	0.5	Bituminous	12822	Thin Overlay > 4.5 IRI (V	10.466	0.048	2.509
2017	010-127-000-1	Primary or Trunk	1.2	Bituminous	20298	Thin Overlay @ 3 IRI (>H	9.061	0.153	2.662
2018	010-76-000-1	Primary or Trunk	0.7	Bituminous	14002	Thin Overlay > 4.5 IRI (V	13.068	0.057	2.719
2019	010-86-000-1	Primary or Trunk	3.5	Bituminous	14632	Thin Overlay > 4.5 IRI (V	15.061	0.285	3.004

PART G STRATEGY ANALYSIS CASE STUDIES

1 CASE STUDY 1 – LONG TERM NETWORK NEEDS

1.1 Introduction

The subject of this strategy analysis is a network of state roads. Due to lack of funding in recent years, the network is in generally poor condition exhibiting high levels of roughness with many links being single or intermediate lane. There is a large backlog of works needed to provide the service levels expected of this road network. The needed works encompass periodic maintenance of those roads in good or fair condition, rehabilitation or reconstruction of roads in poor condition and widening to two lane where traffic levels justify it.

This case study covers approximately 1,000 km of the road network, with the essential data being inventory (in particular pavement width), traffic and pavement condition (roughness).

The objectives of the study are:

- Determine the network needs – the unconstrained optimum solution with no budget constraints
- Examine the effects of constrained budgets over a 5-year period on network service levels and the distribution of expenditure between maintenance, rehabilitation and improvement works

1.2 Road Network

The network under study has a significant length of single (3 – 4 m) and intermediate (5 – 6 m) lane sections. Although most are of sealed standard, on many sections the surfacing has deteriorated severely with roughness in excess of 10 IRI. Traffic levels range from a few hundred to several thousand vehicles/day. The traffic mix contains a high proportion of two wheelers, three wheelers and agricultural tractors. There is also a significant volume of non-motorised traffic, mainly cycles and bullock carts.

A network matrix comprises a series of representative sections defined by ranges of the parameters that are of the most significance to the study being performed. For this case study the parameters selected to form the matrix are traffic volume (6 categories), carriageway width (3 categories) and roughness (5 categories). Thus the network matrix potentially comprises 90 (6 x 3 x 5) representative sections (network cells). However, some combinations do not exist in the road network (e.g. high traffic levels on narrow roads). The number of representative sections used in the analysis was 54, although all possible representative sections were created in the Road Network.

Traffic

The distribution in terms of AADT for the six traffic categories used in this case study are shown in Table G1 for both Motorised and NMT vehicle classes.

Table G1.1
Traffic Categories

Vehicle Type	Representative AADT by Traffic Category					
	1	**2**	**3**	**4**	**5**	**6**
	<500	**500 - 1000**	**1000 - 2000**	**2000 - 5000**	**5000 - 10000**	**> 10000**
Two wheeler	184	427	997	2560	3372	6744
Three wheeler	3	11	45	95	713	1425
Car	25	66	145	287	715	1429
Jeep	37	97	149	332	664	1329
Minibus	3	19	36	47	197	394
Bus	19	53	126	226	387	775
Light truck	7	17	40	153	611	1221
Medium truck	18	107	118	431	1186	2373
Heavy truck	2	24	110	260	253	506
Truck/trailer	7	8	13	37	48	96
Tractor	54	106	215	274	1058	2116
Total Motorised	**359**	**935**	**1994**	**4702**	**9204**	**18408**
Animal cart	53	86	164	207	264	527
Bicycle	70	336	536	2035	2665	5331
Total NMT	**123**	**422**	**700**	**2242**	**2929**	**5858**

Roughness

The range and representative values for each of the five roughness categories are shown in Table G1.2.

Table G1.2
Roughness Categories

Category	Roughness (IRI)	
	Range	**Representative Value**
1	< 4	3
2	4 – 6	5
3	6 – 8	7
4	8 – 10	9
5	> 10	12

Carriageway Width

Three carriageway width categories were used, representing single, intermediate and two lane roads. The range and representative values for each category are shown in Table G1.3. There were no four lane roads in the network being studied.

Table G1.3
Carriageway Width Categories

Category	Carriageway Width (m)		Lanes
	Range	Representative value	
1	< 4	3.5	Single
2	4 – 6	5.5	Intermediate
3	> 6	7.0	Two

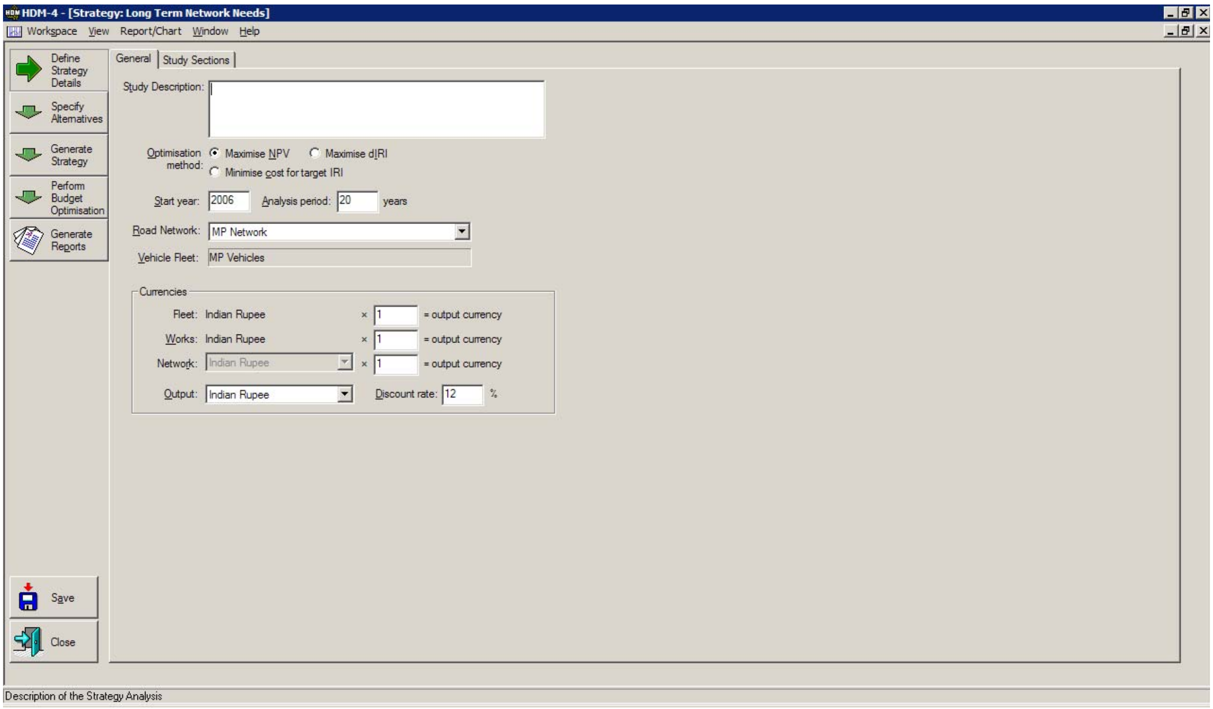
1.3 Define Project Details

In the **Define Strategy Details** screen, the following tab pages may be displayed:

- General
- Study Sections

1.3.1 General

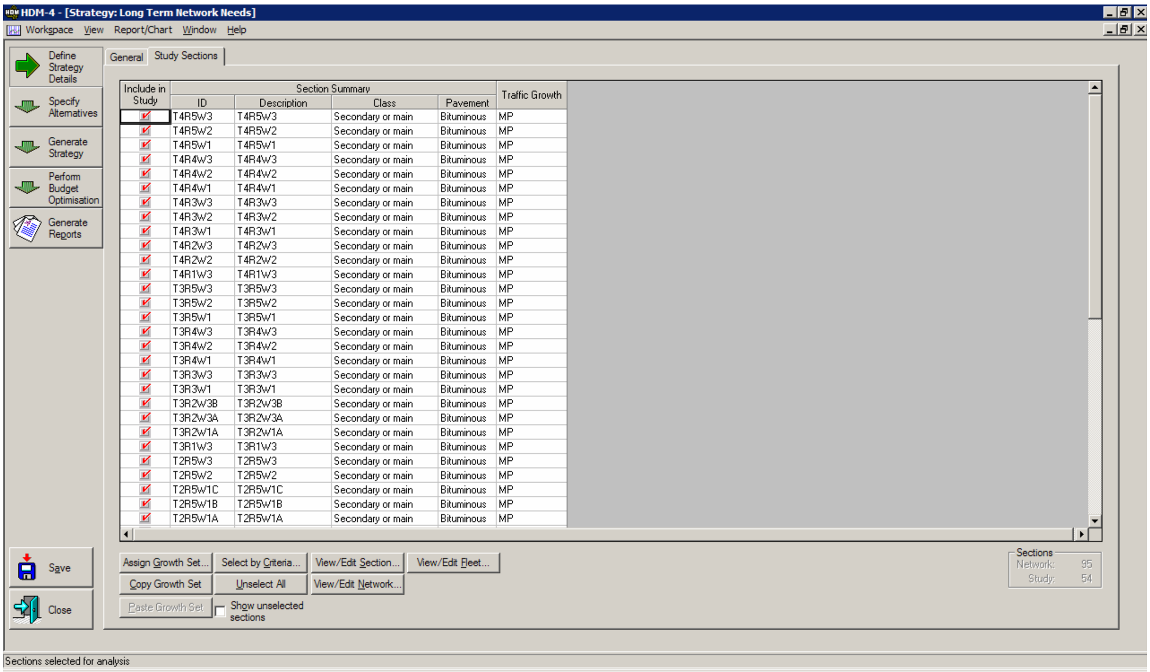
The information displayed in the General screen includes the study description, analysis type, analysis period, the pre-defined Road Network and Vehicle Fleet, and the currency to be used for the analysis.



The optimisation method selected for this case study is Maximise NPV. The analysis period is defined by the start year 2006 and a duration of 20 years (i.e. 2006 – 2025). The sections to be analysed are in the Road Network entitled MP Network, to which the MP Vehicles have been previously assigned as the Vehicle Fleet. The currency being used for this analysis is Indian Rupees and the discount rate has been set to 12%.

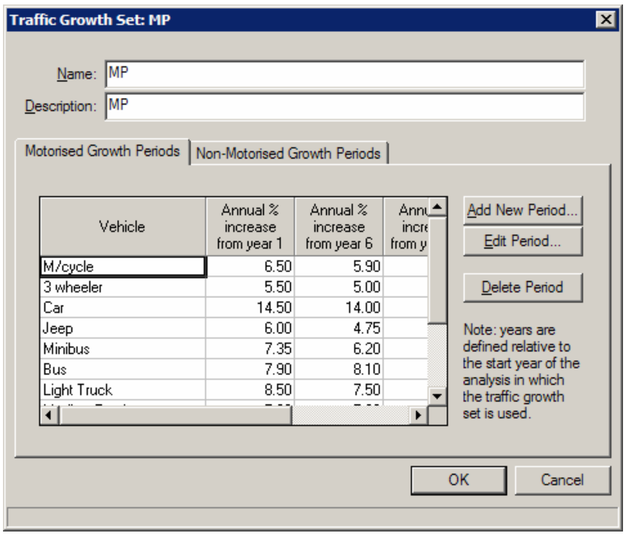
1.3.2 Study Sections

In this case study, 54 representative sections have been selected for analysis. Each representative section was given an identifier signifying the traffic category, the roughness category and the carriageway width category. Thus section T1R2W3 had the representative values from traffic category 1, roughness category 2 and carriageway width category 3.



By double-clicking on the section gives access to the section details. However, the **Traffic Growth** details can only be seen and edited through the **Vehicle Fleets** folder. To access the Traffic Growth Sets that have been previously created, the user needs to open the appropriate vehicle fleet (in this case MP Vehicles) in the Vehicle Fleet folder and click on the Edit Traffic Growth Sets button which then displays the previously created sets.

Double-clicking on the appropriate set (in this case MP) displays the details of the traffic changes over the analysis period. The MP traffic growth rate has been created with three traffic growth periods; from year 1, from year 6 and from year 11.

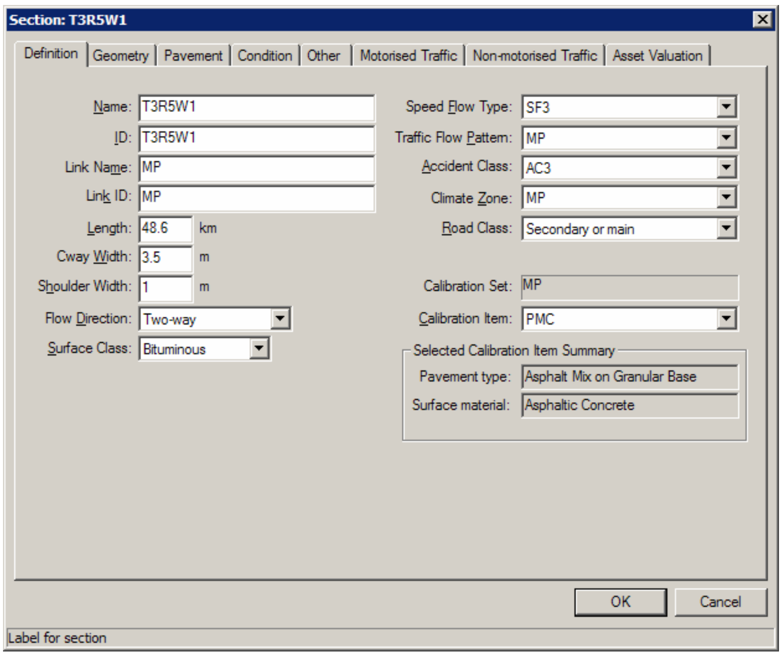


The section details are are described below.

- **Definition**

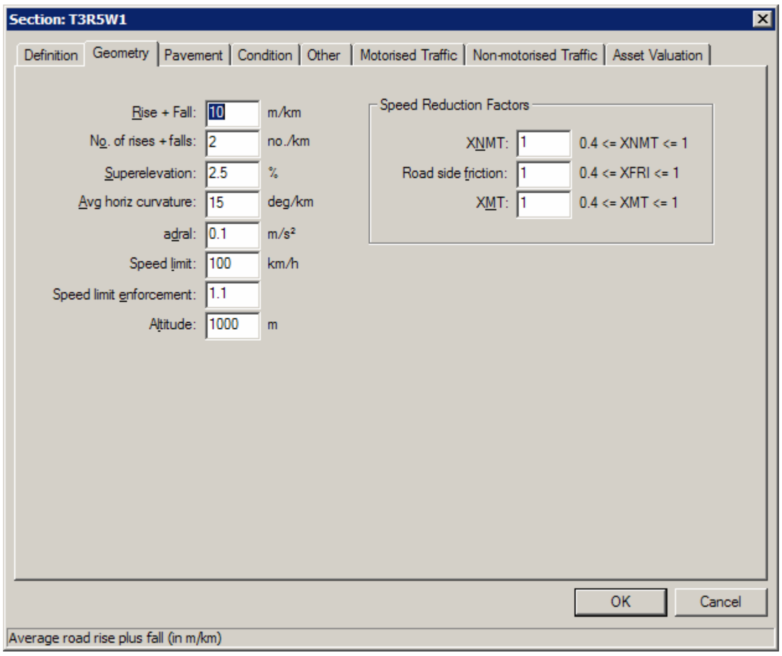
The representative section T3R5W1 is illustrated which indicates that the traffic on this section is as detailed for category 3 (see Table G1.1), the roughness is 12.5 (category 5) and the carriageway width category is 1. The carriageway width for this representative section is 3.5 m and the selected Speed Flow Type reflects this width.

The length indicates that there were a total of 48.6 km of this type of road in the network. Note that the length of road is the total length of road in the network of this type, which is not necessarily a continuous length.



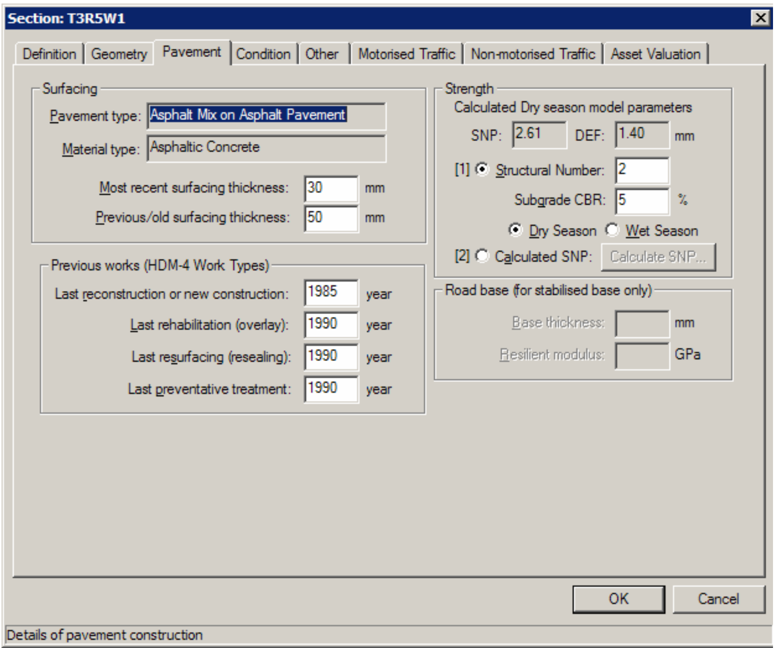
- **Geometry**

The geometry characteristics were held constant for all representative sections.



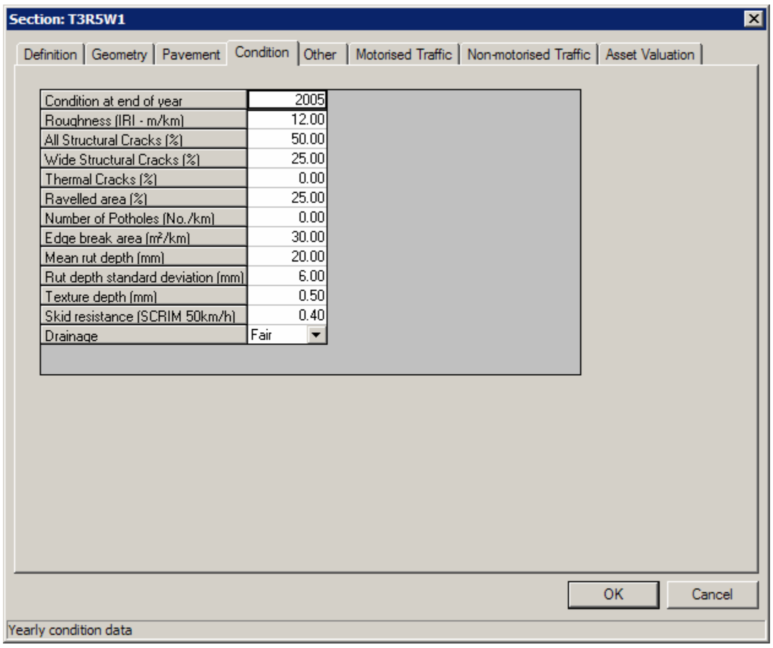
- **Pavement**

The pavement characteristics were varied with roughness category. It was assumed that sections with higher roughness would be older and have weaker pavement structures. The roughness category for this section (T3R5W1) was the highest (IRI > 10), and thus the pavement details indicate that the road was 20 years old in 2005, with no periodic maintenance over the past 15 years.



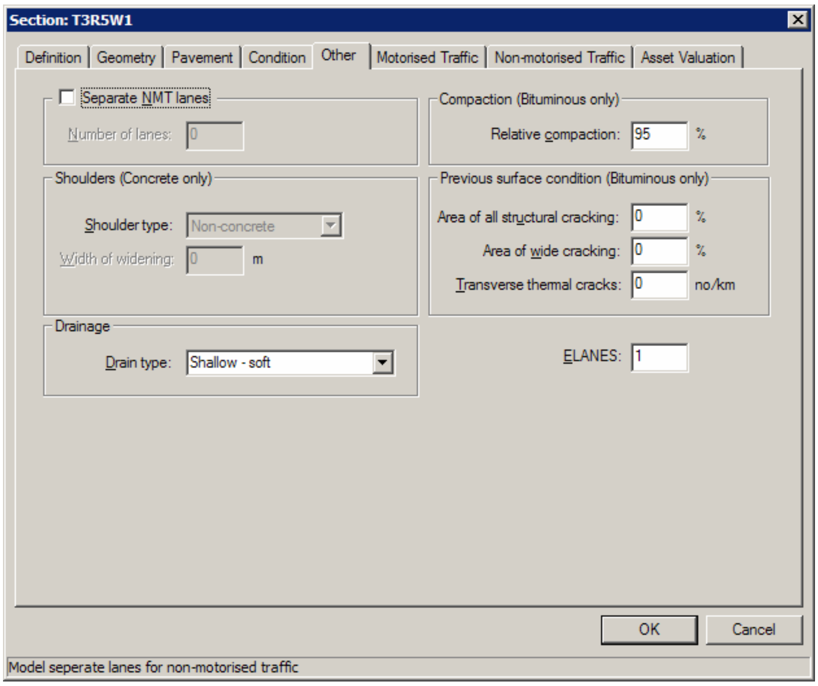
- **Condition**

A roughness of 12.0 has been used as the representative roughness for category 5. High representative values for the other distresses were used in conjunction with this roughness category.



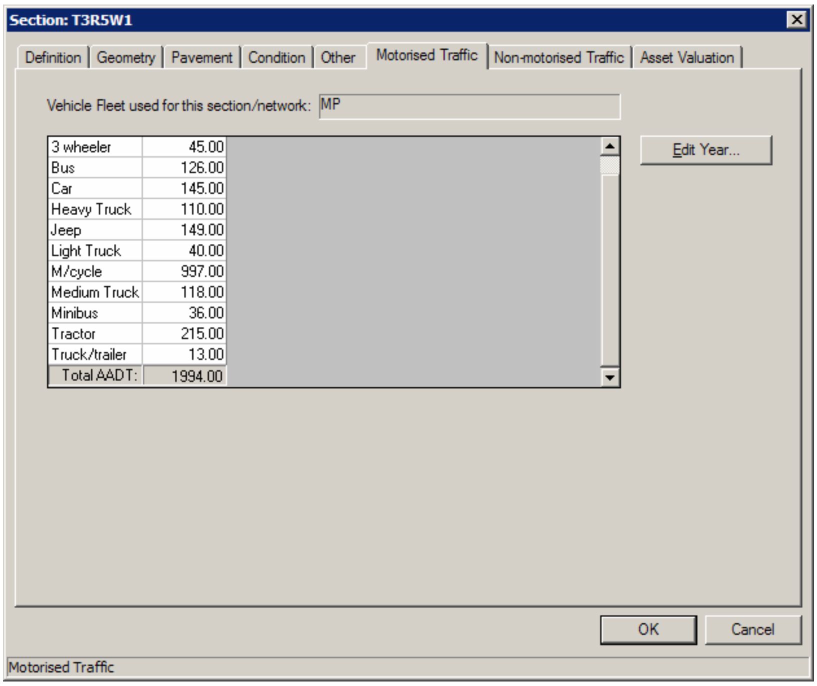
- **Other**

All values were held constant for all the representative sections with the exception of ELANES which was related to pavement width. A value for ELANES of 1 was used for single lane sections, 1.5 for intermediate lane and 2 for two-lane roads.



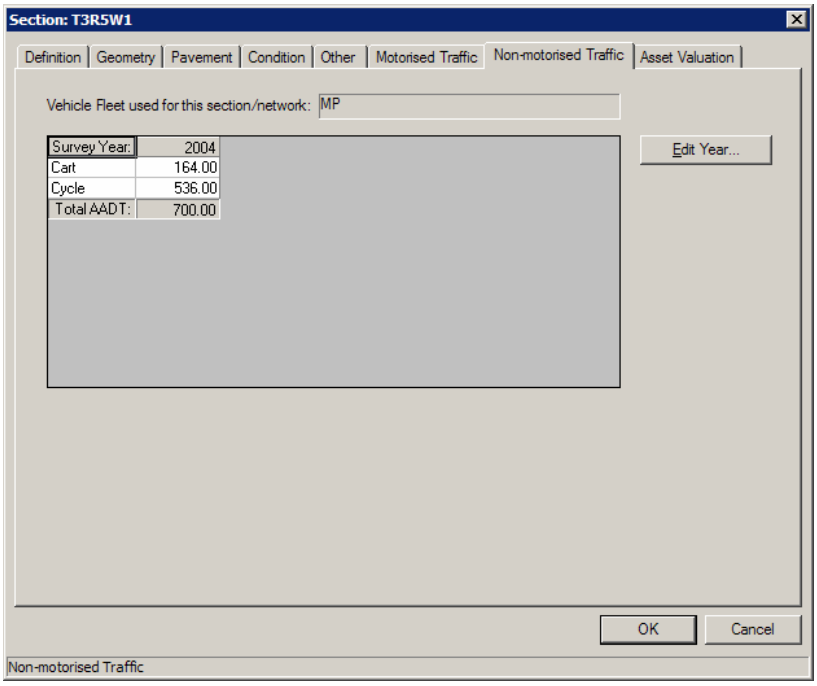
- **Motorised Traffic**

The total motorised AADT on this representative section is 1994 and the AADT for the individual vehicle classes are as listed for traffic category 3 in Table G1.1.



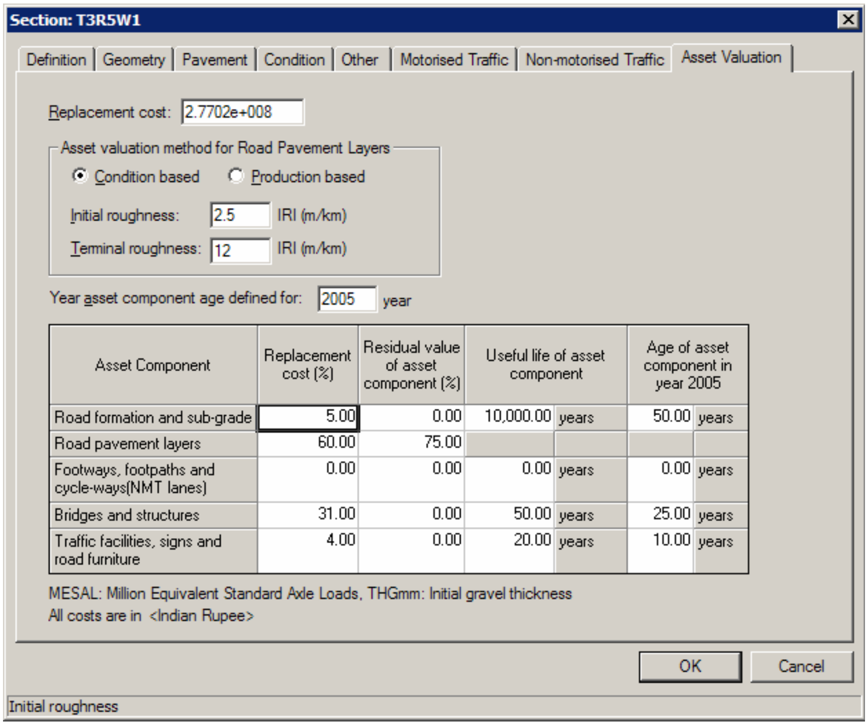
- **Non-motorised Traffic**

The non-motorised traffic is listed on this screen. The distribution of the NMT between carts and cycles for this representative section is as listed in Table G1.1 for traffic category 3.



1.3.3 Asset Valuation

This case study contains asset valuation, allowing the asset value of the total network to be estimated over time under different investment levels. To apply asset valuation in HDM-4, inputs are required in both the section details and in the works items details. The asset valuation screen from the section details is shown below.



For all the sections used in this case study, the condition based asset valuation method has been chosen. Also in each case the initial roughness has been set to 2.5 IRI and the terminal roughness to 12 IRI.

The replacement costs for the three categories of road used in this case study are summarised in Table G1.4. The replacement costs in Table G1.4 are given on a per km basis, whereas the costs in the asset valuation screen are the total costs for the section (i.e. takes into account the length of the section).

Table G1.4
Replacement Costs

	Single Lane	**Intermediate**	**Two Lane**
Total Cost (Rs/km)	5,700,000	8,200,000	9,900,000
Earthworks	5%	5%	5%
Pavement	60%	60%	58%
Footways etc.	0%	0%	0%
Bridges and culverts	31%	31%	33%
Road furniture	4%	3%	3%

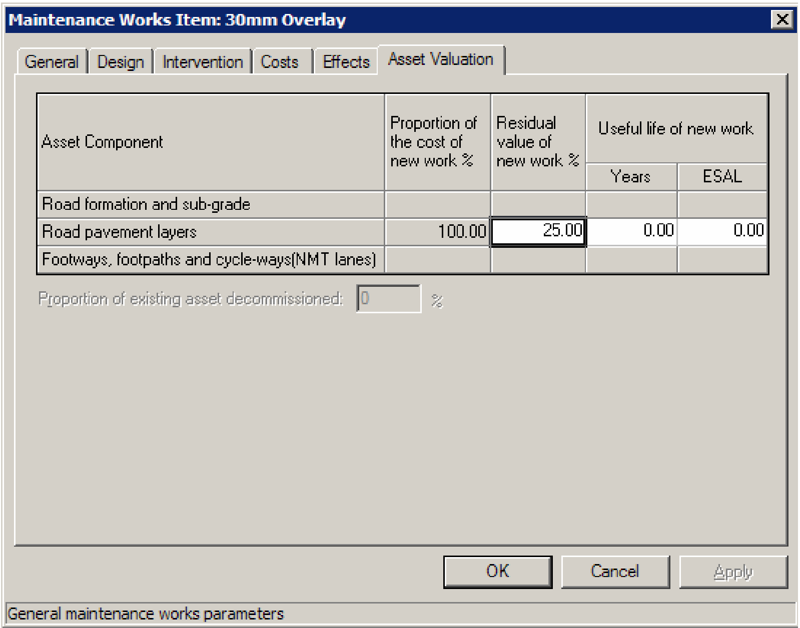
As condition based depreciation is selected for the pavement component, values are not needed for useful life and age as these are defined in terms of roughness. The value of 75% for residual value of the pavement is to reflect the fact that the pavement structure will still contribute to performance after maintenance (overlays) is applied. These remaining input values used in this case study are summarised in Table G1.5.

Table G1.5
Asset Valuation Data

	Residual Value	Useful Life	Age in 2005
Earthworks	0%	10,000	50
Pavement	75%	n/a	n/a
Footways etc.	0%	0	0
Bridges and culverts	0%	50	25
Road furniture	0%	20	10

The asset valuation details required in relation to works standards are stored in the works items/asset valuation tab page for each works item within a maintenance standard as shown below. The exceptions are routine maintenance activities such as edge repair, which do not require asset valuation details.

For maintenance standards, the only input relates to the pavement. If condition based depreciation is used, the useful life of the item is not needed and the only input is residual value.

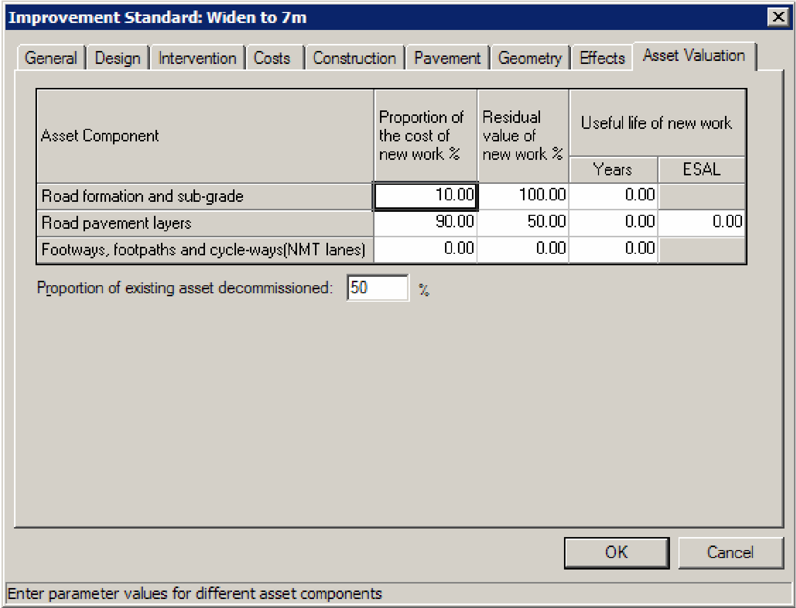


For the maintenance standards used in this case study, the residual values for each works item are listed in Table G1.6.

Table G1.6
Works Items Residual Values

Works Item	Residual Value
Overlays (20, 30, 40, 110 & 140 mm)	25%
Reconstruction (40 & 100 mm)	50%

For improvement standards more comprehensive inputs are needed, as shown below.



For the improvement standards used in this case study, the asset valuation details are summarised in Table G1.7. The per cent of asset decommissioned has been set at 50% to represent the removal and replacement of existing pavement layers.

Table G1.7
Asset Valuation Details for Improvement Standards

		Proportion of Cost	Residual Value	Useful Life
Reconstruction	Earthworks	0%	0%	0
	Pavement	100%	50%	n/a
	Footways etc.	0%	0%	0
Widening	Earthworks	10%	100%	0
	Pavement	90%	50%	n/a
	Footways etc.	0%	0%	0

1.4 Specify Alternatives

The types of roadworks applied in this case study were as follows:

- Renewal – thin overlay using various types of asphaltic material and thickness depending on the level of traffic
- Rehabilitation – thick overlay
- Reconstruction – rebuilding of the base and surfacing layers, while retaining the existing width
- Widening – rebuilding the sub-base, base and surfacing layers to a standard two lane width of 7m
- Routine – patching potholes and edge repair

The works items and the intervention criteria within each maintenance and improvement standard are listed in Table G1.8.

Table G1.8
Works Items and Intervention Criteria

Works Type	Standard	Works Items	Criteria
Maintenance	Routine	Edge Repair	Edge break > 1 m^2/km
		Patch Potholes	Potholes > 10 no./km
	Renewal	20 mm Overlay	AADT < 2000 & IRI < 6
		30 mm Overlay	2000 < AADT < 10000 & IRI < 6
		40 mm Overlay	AADT > 10000 & IRI < 6
	Rehabilitation	110 mm Overlay	AADT < 10000 & 5 < IRI < 12
		170 mm Overlay	AADT > 10000 & 5 < IRI < 12
	Long Term Maintenance Policy	20 mm Overlay	AADT < 2000 & 5 < IRI < 6 or AADT < 2000 & IRI < 6 & 10 < ACA < 20
		30 mm Overlay	2000 < AADT < 10000 & 5 < IRI < 6 or 2000 < AADT < 10000 & IRI < 6 & 10 < ACA < 20
		40 mm Overlay	AADT > 10000 & 5 < IRI < 6 or AADT > 10000 & IRI < 6 & 10 < ACA < 20
		110 mm Overlay	6 < IRI < 12
		Reconstruct – 40 mm surface	AADT < 500 & IRI > 12
		Reconstruct - 100 mm surface	AADT > 500 & IRI > 12
Improvement	Reconstruct 40	Pavement reconstruction with 40 mm surface	IRI > 10
	Reconstruct 100	Pavement reconstruction with 100 mm surface	IRI > 10
	Widen to 7m	Widen to 7 m	AADT > 1000

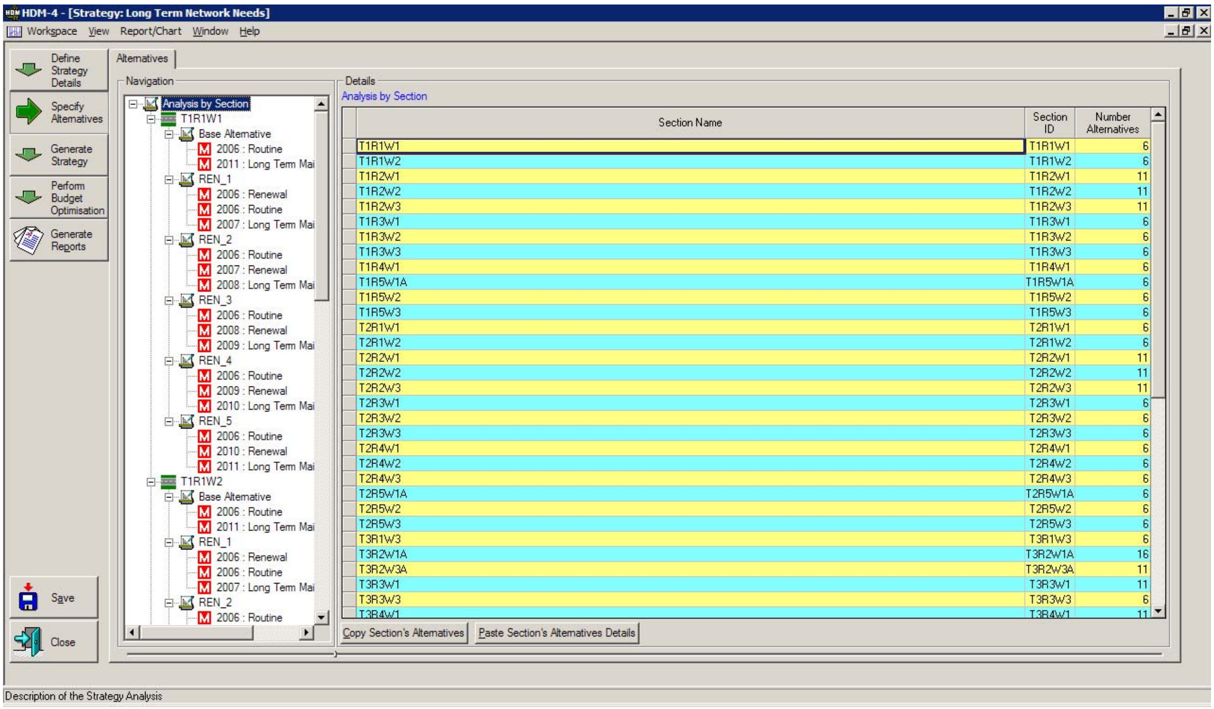
Alternatives that apply a maintenance or improvement standard are assigned to each section with an effective year within the 5-year planning period. The Long Term Maintenance Policy (LTMP) is assigned as the Base Alternative to each section after the 5-year planning period, i.e. from year 2011.

Not all standards need to be tested for all sections; for example, widening does not need to be assigned to the lower traffic sections, the renewal alternative does not need to be assigned to sections with high roughness, etc. The alternatives that have been assigned to each section are listed in Table G1.9. Routine maintenance is applied to all the sections.

Table G1.9
Assignment of Maintenance and Improvement Standards

Section	Renewal	Rehab	Recon 40	Recon 100	Widening
T1R1W1 - W3	Y				
T1R2W1 - W3	Y	Y			
T1R3W1 - W3		Y			
T1R4W1 – W3		Y			
T1R5W1 – W3			Y		
T2R1W1 – W3	Y				
T2R2W1 – W3	Y	Y			
T2R3W1 – W3		Y			
T2R4W1 – W3		Y			
T2R5W1 – W3				Y	
T3R1W1 – W2	Y				Y
T3R1W3	Y				
T3R2W1 – W2	Y	Y			Y
T3R2W3	Y	Y			
T3R3W1 – W2		Y			Y
T3R3W3		Y			
T3R4W1 – W2		Y			Y
T3R4W3		Y			
T3R5W1 – W2				Y	Y
T3R5W3				Y	
T4R1W1 – W2	Y				Y
T4R1W3	Y				
T4R2W1 – W2	Y	Y			Y
T4R2W3	Y	Y			
T4R3W1 – W2		Y			Y
T4R3W3		Y			
T4R4W1 – W2		Y			Y
T4R4W3		Y			
T4R5W1 – W2				Y	Y
T4R5W3				Y	

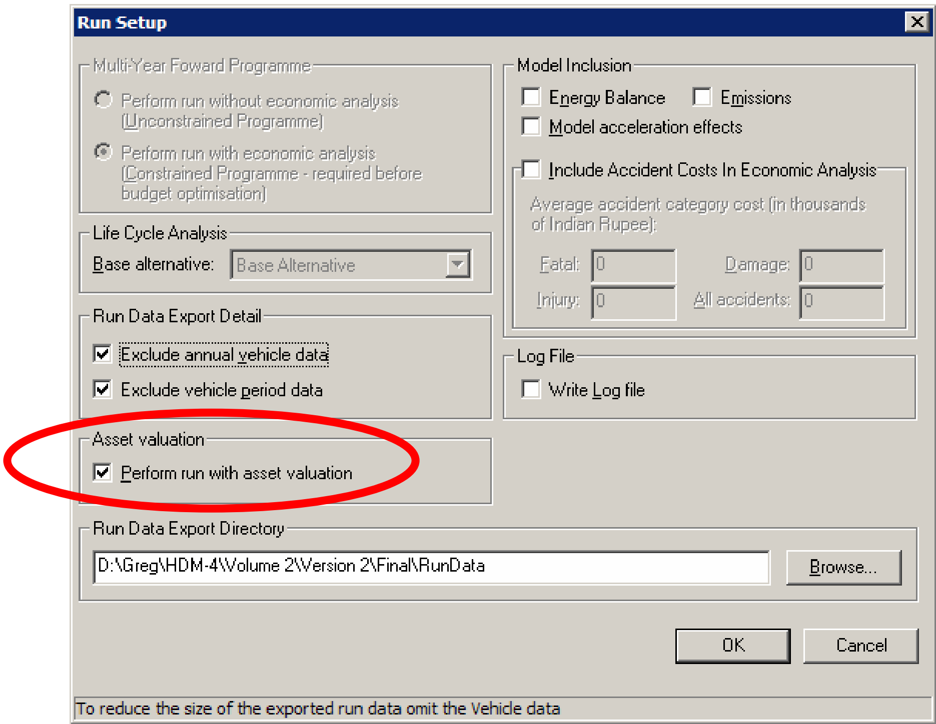
The number of alternatives assigned to each section are listed in the screen below. The year that the maintenance and/or improvement standards are applied can be viewed by expanding the assignments in each section in the navigation menu. For example, for section T1R1W1, the maintenance standard Renewal is applied in each year of the 5-year planning period (i.e. 2006 to 2010 inclusive) together with the LTMP alternative the following year.



1.5 Generate Strategy

1.5.1 Perform Run

The destination of the outputs from the analysis are specified in the Run Set-up dialogue. Options are available for the inclusion of the other models. When using asset valuation, the box must be checked in Run Setup.

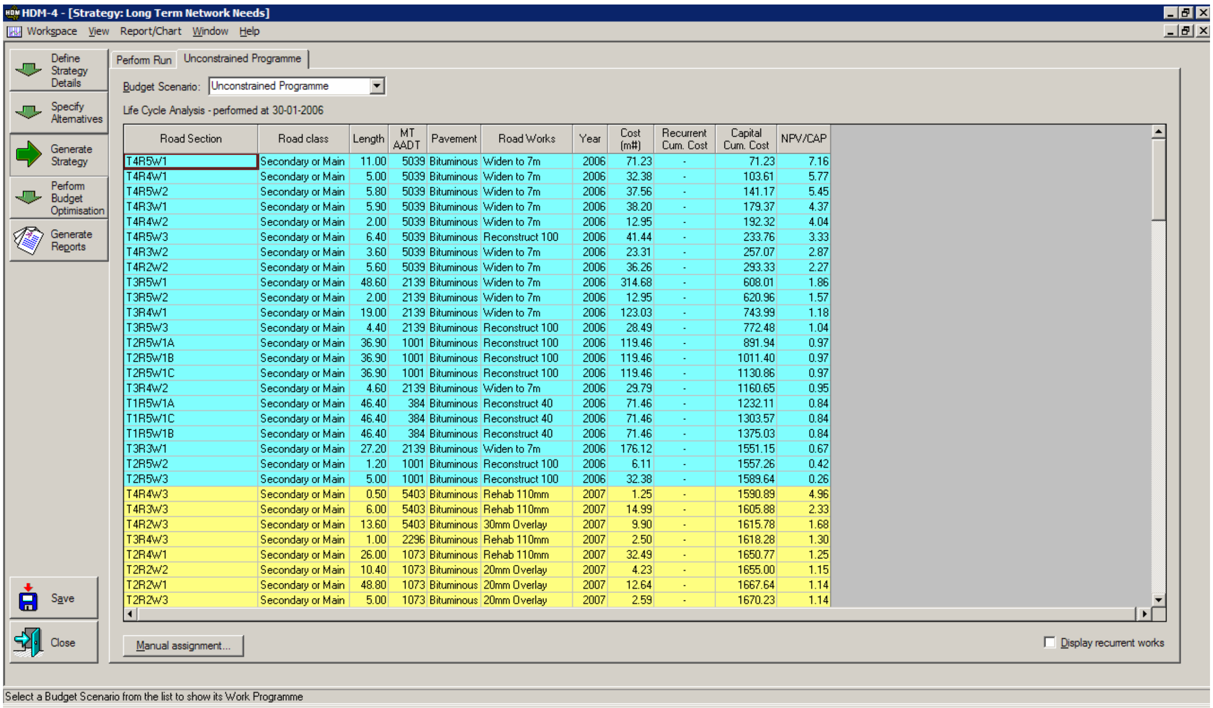


It is normal to exclude annual and period vehicle data as, if these are saved in the output file, run time is much longer and the output file can be very large. This information would normally only be saved if one wanted to check some of the details because the analysis results are suspect. The export directory must be specified in order for the analysis to be carried out.

Clicking ‘Start’ executes the run and enables the results of the unconstrained programme analysis to be viewed.

1.5.2 Unconstrained Programme

Having completed the run, the Unconstrained Programme can be viewed by pressing the associated tab.



The unconstrained programme shows the alternative for each section that has the highest NPV and is the optimum solution when there is no budget constraint. Key parameters shown include the treatment year, capital cost, cumulative capital costs and NPV/CAP, the latter being the preferred prioritisation indicator for capital budgeting.

In this screen the following two options can also be selected:

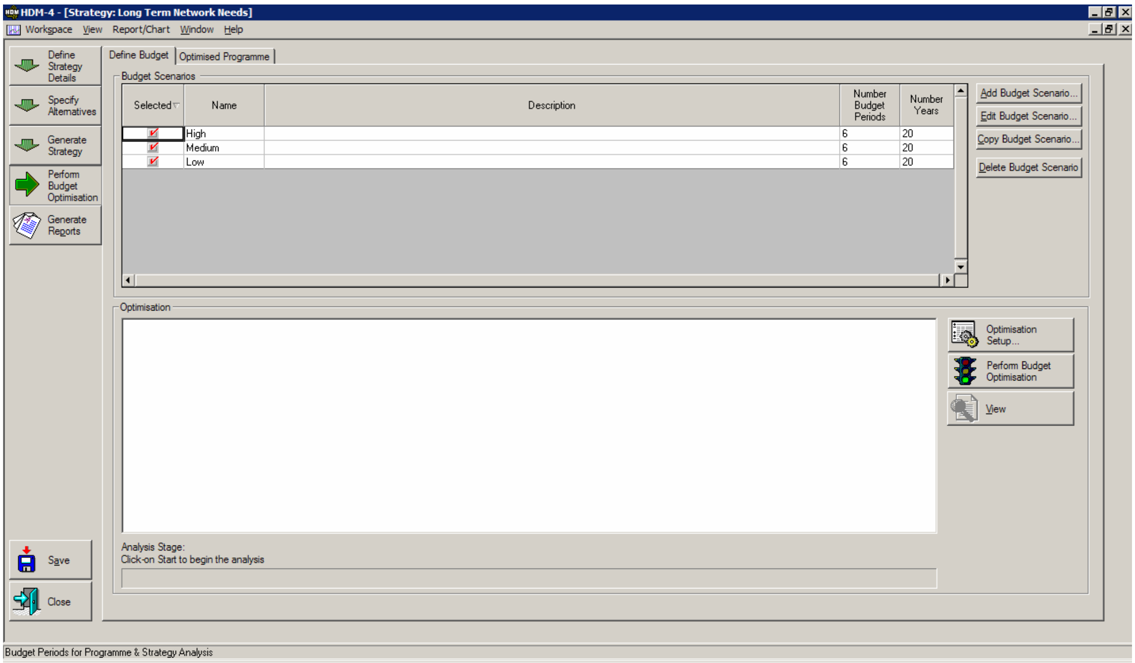
- Select sections for **Manual assignment** (shown in the bottom left of the screen). This allows works which have an NPV of zero or greater to be selected as committed works and the budget reserved for their treatment. Where budget optimisation is performed the total value of the works for these sections is removed from the available budget prior to performing budget optimisation.
- Selecting **Display recurrent works** (shown in the bottom right of the screen) shows the treatments and associated costs for all recurrent works in addition to the capital works.

It is useful at this point to scroll through the active screen and note the capital budget distribution by year, as this will be important for assessing investment needs and for budget optimisation purposes. The total budget needed to the five year plan (i.e. the cumulative capital cost at the end of year 5 (2010)) is 2242 million. This figure can then be used to examine various budget constraint scenarios in the budget optimisation procedure.

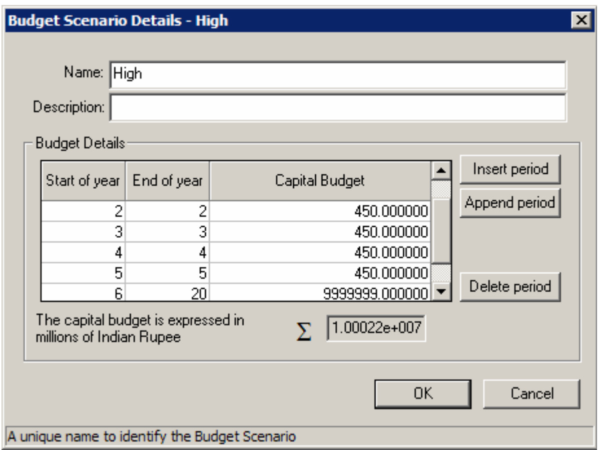
1.6 Perform Budget Optimisation

1.6.1 Define Budget

The budget scenarios that are to be investigated need to be defined. For this case study, the analysis considers budget constraints only for the 5 years of the planning period. For years 6 to 20 an unconstrained budget is assigned.

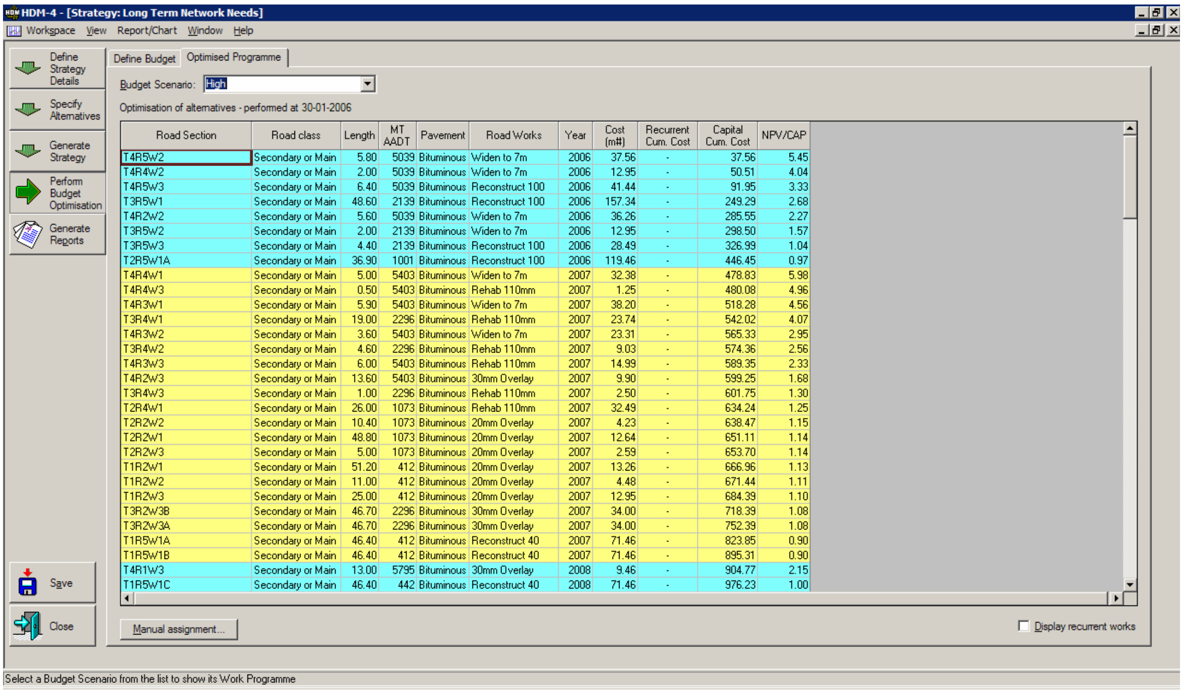


Three budget constraint scenarios have been created in this case study; high, medium and low. The high scenario budget level was obtained by taking the unconstrained five year total (approx 2250 million) and splitting this total evenly between the five years – a more balanced 'unconstrained' solution. The medium budget was set at 75% of high and the low budget at 50% of high. An unconstrained budget was assigned for the remaining part of the analysis period.



1.6.2 Optimised Programme

Having set up the budget scenarios, then the user needs to click on Perform Budget Optimisation to produce the Optimised Programmes for each defined scenario.



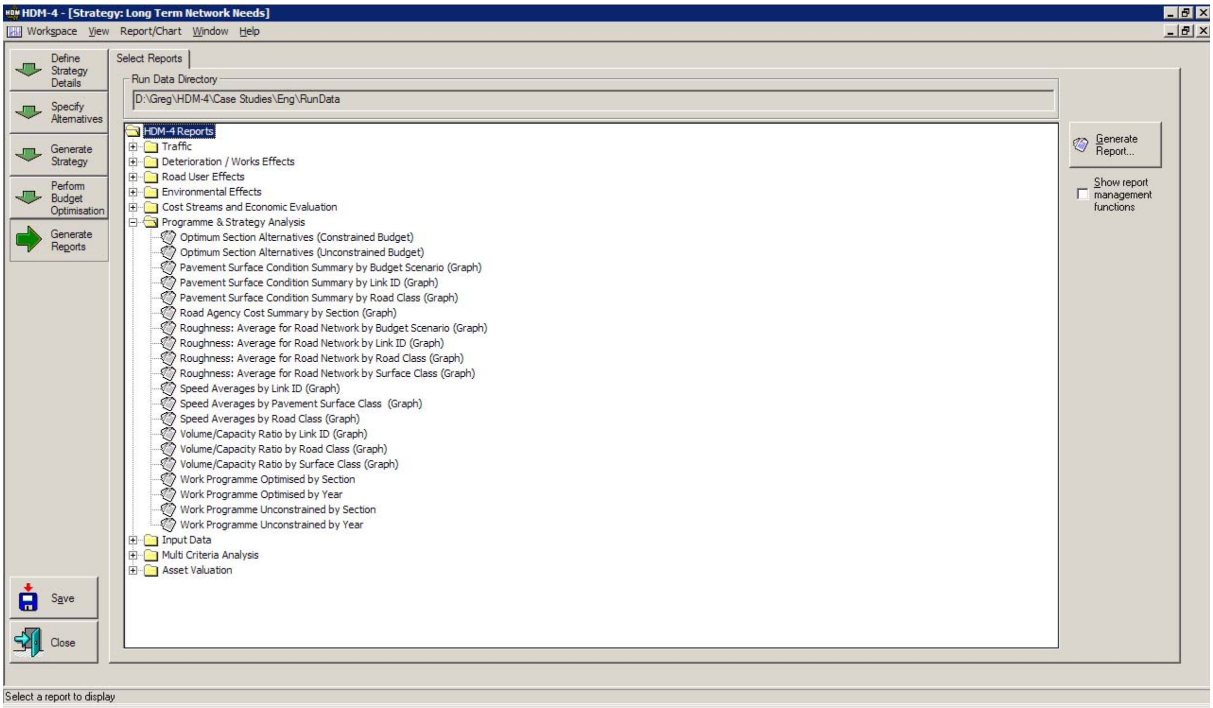
Road Section	Road class	Length	MT AADT	Pavement	Road Works	Year	Cost (m#)	Recurrent Cum. Cost	Capital Cum. Cost	NPV/CAP
T4R5W2	Secondary or Main	5.80	5039	Bituminous	Widen to 7m	2006	37.56	-	37.56	5.45
T4R4W2	Secondary or Main	2.00	5039	Bituminous	Widen to 7m	2006	12.95	-	50.51	4.04
T4R5W3	Secondary or Main	6.40	5039	Bituminous	Reconstruct 100	2006	41.44	-	91.95	3.33
T3R5W1	Secondary or Main	48.60	2139	Bituminous	Reconstruct 100	2006	157.34	-	249.29	2.68
T4R2W2	Secondary or Main	5.60	5039	Bituminous	Widen to 7m	2006	36.26	-	285.55	2.27
T3R5W2	Secondary or Main	2.00	2139	Bituminous	Widen to 7m	2006	12.95	-	298.50	1.57
T3R5W3	Secondary or Main	4.40	2139	Bituminous	Reconstruct 100	2006	28.49	-	326.99	1.04
T2R5W1A	Secondary or Main	36.90	1001	Bituminous	Reconstruct 100	2006	119.46	-	446.45	0.97
T4R4W1	Secondary or Main	5.00	5403	Bituminous	Widen to 7m	2007	32.38	-	478.83	5.98
T4R4W3	Secondary or Main	0.50	5403	Bituminous	Rehab 110mm	2007	1.25	-	480.08	4.96
T4R3W1	Secondary or Main	5.90	5403	Bituminous	Widen to 7m	2007	38.20	-	518.28	4.56
T3R4W1	Secondary or Main	19.00	2296	Bituminous	Rehab 110mm	2007	23.74	-	542.02	4.07
T4R3W2	Secondary or Main	3.60	5403	Bituminous	Widen to 7m	2007	23.31	-	565.33	2.95
T3R4W2	Secondary or Main	4.60	2296	Bituminous	Rehab 110mm	2007	9.03	-	574.36	2.56
T4R3W3	Secondary or Main	6.00	5403	Bituminous	Rehab 110mm	2007	14.99	-	589.35	2.33
T4R2W3	Secondary or Main	13.60	5403	Bituminous	30mm Overlay	2007	9.90	-	599.25	1.68
T3R4W3	Secondary or Main	1.00	2296	Bituminous	Rehab 110mm	2007	2.50	-	601.75	1.30
T2R4W1	Secondary or Main	26.00	1073	Bituminous	Rehab 110mm	2007	32.49	-	634.24	1.25
T2R2W2	Secondary or Main	10.40	1073	Bituminous	20mm Overlay	2007	4.23	-	638.47	1.15
T2R2W1	Secondary or Main	48.80	1073	Bituminous	20mm Overlay	2007	12.64	-	651.11	1.14
T2R2W3	Secondary or Main	5.00	1073	Bituminous	20mm Overlay	2007	2.59	-	653.70	1.14
T1R2W1	Secondary or Main	51.20	412	Bituminous	20mm Overlay	2007	13.26	-	666.96	1.13
T1R2W2	Secondary or Main	11.00	412	Bituminous	20mm Overlay	2007	4.48	-	671.44	1.11
T1R2W3	Secondary or Main	25.00	412	Bituminous	20mm Overlay	2007	12.95	-	684.39	1.10
T3R2W3B	Secondary or Main	46.70	2296	Bituminous	30mm Overlay	2007	34.00	-	718.39	1.08
T3R2W3A	Secondary or Main	46.70	2296	Bituminous	30mm Overlay	2007	34.00	-	752.39	1.08
T1R5W1A	Secondary or Main	46.40	412	Bituminous	Reconstruct 40	2007	71.46	-	823.85	0.90
T1R5W1B	Secondary or Main	46.40	412	Bituminous	Reconstruct 40	2007	71.46	-	895.31	0.90
T4R1W3	Secondary or Main	13.00	5795	Bituminous	30mm Overlay	2008	9.46	-	904.77	2.15
T1R5W1C	Secondary or Main	46.40	442	Bituminous	Reconstruct 40	2008	71.46	-	976.23	1.00

As can be seen in the above screen, the cumulative capital costs for each year in the high budget scenario (450 million/year) is not exceeded.

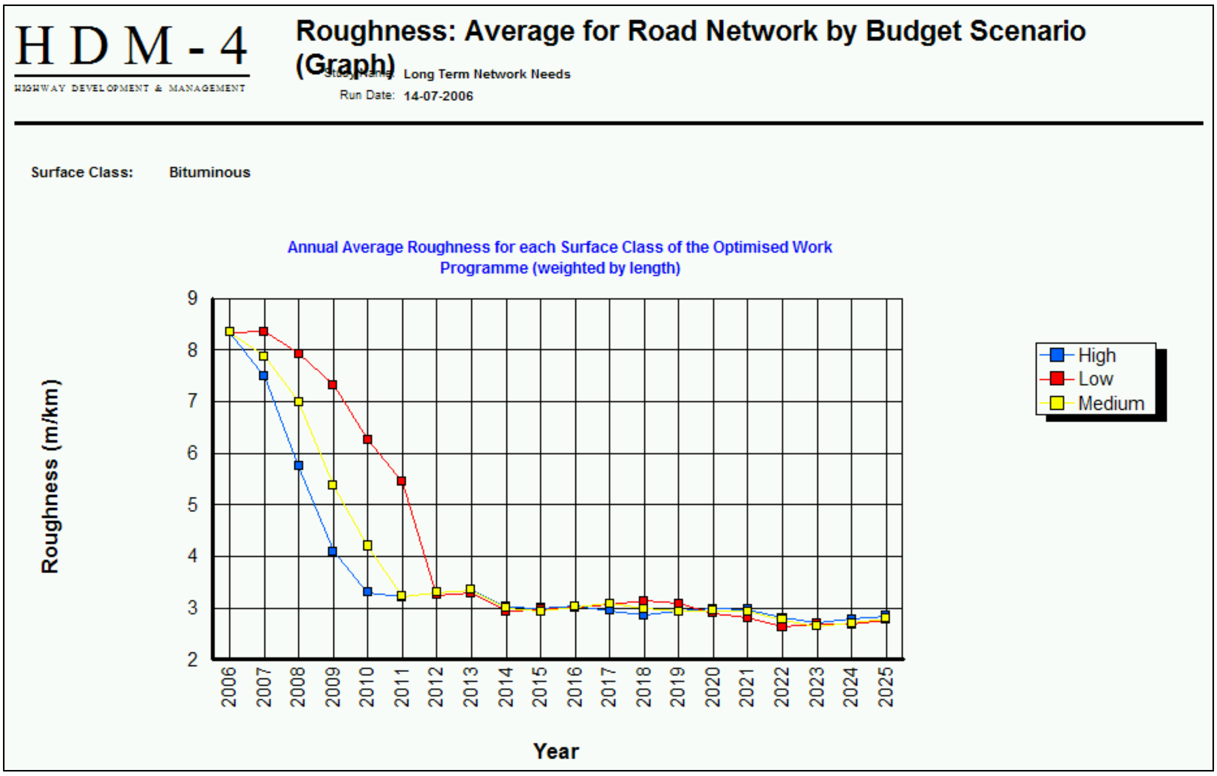
1.7 Generate Reports

Having run the analysis it is now possible to **Generate Reports** and perform a similar check of key reports to ensure the data inputs and modeling are as expected. These should be examined and verified as any subsequent results are dependent on the performance of individual sections, with results aggregated to represent the network.

For Programme and Startegy analysis case studies a wider selection of reports are available, and examples of a selection of useful reports for the particular case study are given below. The following screen shows the list of reports available in the Programme and Strategy Analysis folder.

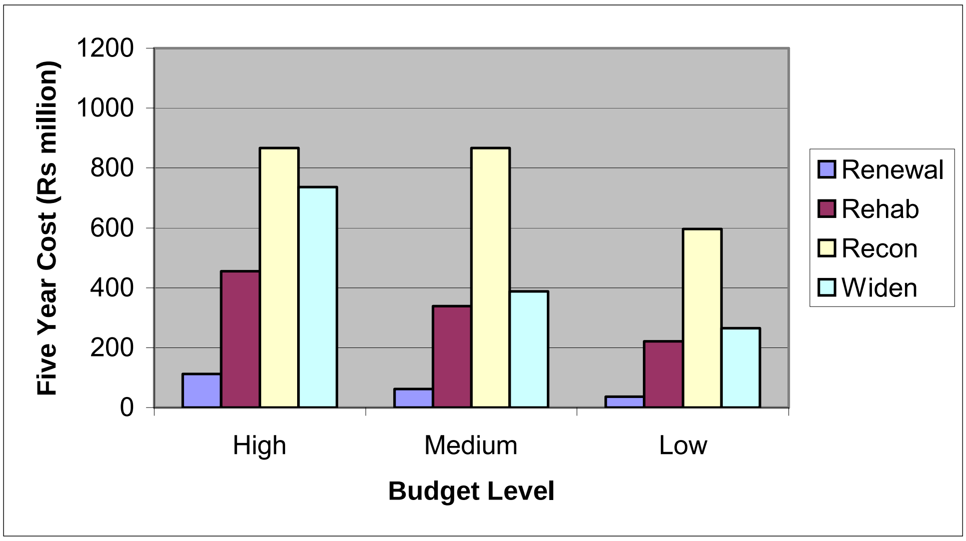


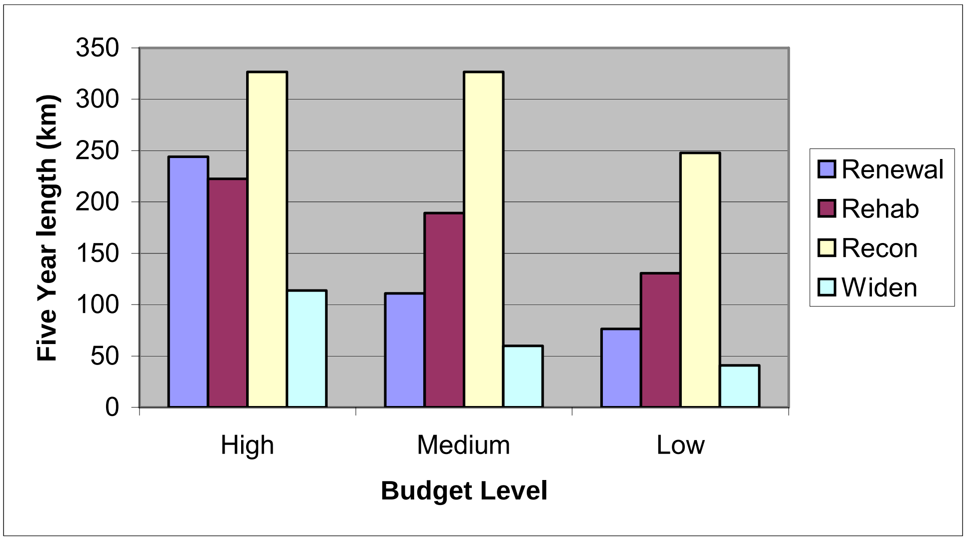
The Roughness: Average for Road Network by Budget Scenario graph presents the average roughness weighted by length for each scenario.



Others are tabular and these can be exported and used for further analysis or summary outside HDM-4 (e.g. in Excel).

The report Work Programme Optimised by Section was exported and the analysis results summarised to show the total cost and length of different categories of works over the five years.





These graphs show that, as the budget level is reduced, the proportions spent on maintenance and improvement works remain broadly the same.

1.8 Asset Valuation Analysis

The asset valuation reports currently available in HDM-4 show annual asset value by section for each section alternative generated. There is no summary reporting showing the total asset value for the network. To obtain this information the relevant data from the output file (rundata.mdb) must be extracted.

Figure G1.1 shows the change in the asset value of the total analysis network over the 5-year planning period.

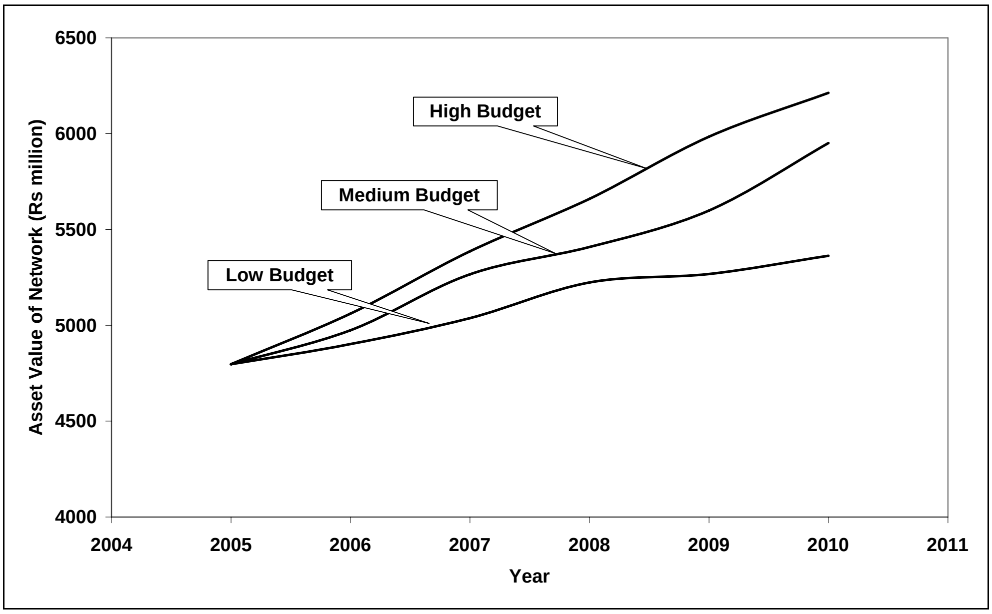


Figure G1.1
Asset Valuation for the Budget Scenarios

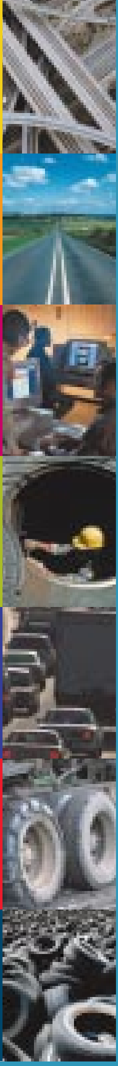
Table G1.10 compares the increase in asset value with the total expenditure over the five year period.

Table G1.10
Comparison Of Increase in Asset Value and Expenditure

Budget Level	Increase in Asset Value (Rs million)	Total Expenditure (Rs million)	Increase in Asset Value as % of Expenditure
High	1,416	2,064	69%
Medium	1,154	1,671	69%
Low	566	1,112	51%

The increase in asset value is less than expenditure. The asset as initially defined in the road network includes components for bridges, road furniture etc. which depreciate over time while no work is applied to these items by HDM-4 to enhance their asset value. At the same time as maintenance and improvement is applied to different sections, the other sections are also depreciating.

The results of the optimisation, presented earlier, showed around 70% of expenditure was for improvement works (reconstruction and widening). It is this component that increases the asset value. Maintenance works are simply keeping pace with depreciation of the pavement, given an adequate budget. With a low budget, depreciation is more than maintenance expenditure.



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