Final Project Report

Component A: The Detailed Survey of Current Users of HDM-4

March 2023

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Abstract

This report is the Final Project Report for the study for the study "Component A: The Detailed Survey of Current Users of the Highway Management and Development Model Version 4 (HDM-4)".

The document is the final deliverable in the study and builds upon the D3 Draft Final Report and Implementation Plan, with updates reflecting further findings validation of the User and Business Requirements, and any feedback from the HDM-4 Steering Committee members on the previous study deliverables.

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CONTENTS

Executive Summary ii

1. Background 4
- 1.1 Overview of Hodos Media Limited 4
- 1.2 Overview of TRL 4
- 1.3 Overview of HDMGlobal 4

2. Introduction 5
- 2.1 Objectives of this Project 5
- 2.2 Introduction to the HDM-4 Analytical Framework 5
- 2.3 Requirements Gathering Methodology 6

3. State of the Art Analysis 9
- 3.1 HDM-4 and Road Asset Management Systems 9
- 3.2 Methodology 9
- 3.3 Results 9
- 3.5 Key Findings 14
- 3.6 Requirements Gathered from State of the Art Task Work 15

4. Key Opinion Leaders 16

5. Asset Management Best Practice and HDM-4 Implementation 21
- 5.1 ISO 55000 Series 21
- 5.2 PIARC Asset Management Manual 21
- 5.3 Requirements in relation to HDM-4 24

6. HDM-4 Literature Review 26
- 6.1 Publications Identified 26
- 6.2 Abstracts 27
- 6.3 Requirements Gathered from Literature Review 34

7. Multilateral Development Bank Methodology 36
- 7.1 The Asian Development Bank 36
- 7.2 The World Bank 37
- 7.3 Requirements Gathered from MDB Methodology Task Work 38

8. User Survey 40
- 8.1 Requirements Captured from the User Survey 40

9. Case Studies 45
- 9.1 Case Study 1 - Burkina Faso Road Maintenance Matching Fund 45
- 9.2 Case Study 2 - Chile 46
- 9.3 Case Study 3 - COMESA North-South Corridor 47
- 9.4 Case Study 4 - Malaysia: Performance Based Contracts (PBC) for Federal Roads in Peninsular 49
- 9.5 Case Study 5 - Namibia 50
- 9.6 Case Study 6 - Nigeria 52
- 9.7 Case Study 7 - Paraguay 53
- 9.8 Case Study 8 - Philippines 54
- 9.9 Requirements Gathered from Case Studies 55

10. Draft User & Business Requirements 56
11. Consolidated and Ranked User and Business Requirements 70
12. Validation of the End User Requirements 83
12.1 Mapping Exercise 83
12.2 Validation Exercise 86
13. Conclusions & Recommendations 90
14. ANNNEX A – DETAILED END USER CASE STUDIES 91
14.1 Burkina Faso 91
14.2 Chile 95
14.3 COMESA North-South Corridor 98
14.4 Malaysia 104
14.5 Namibia 111
14.6 Nigeria 119
14.7 Paraguay 123
14.8 Philippines 128

TABLES

Table 3-1: RAM systems that claim to interface with HDM-4 ... 11
Table 3-2: Systems that have functions like HDM-4 ... 11
Table 3-3: Systems that Explicitly Mention Operation in Low and Middle Income Countries (LMICs) ... 13
Table 3-4: Systems Used by End Users ... 14
Table 3-5: Requirements Collected from State of the Art ... 15
Table 5-1: PIARC Asset Management Manual Key Questions ... 22
Table 5-2: PIARC Asset Management Manual Maturity Level Descriptions ... 23
Table 5-3: Requirements Collected from RA Methodology ... 25
Table 6-1: Requirements Gathered from Literature Review ... 34
Table 7-1: Requirements Collected from MDB Methodology ... 38
Table 8-1: User Survey Requirements ... 40
Table 9-1: HDM-4 User Survey Case Studies ... 45
Table 9-2: Requirements Collected from Case Studies ... 55
Table 10-1: Draft Requirements Collected from the Study ... 56
Table 11-1: Final User and Business Requirements ... 70
Table 13-1: Chilean Road Network Composition ... 96
Table 13-2: Summary of Road Sections in the COMESA North-South Corridor ... 98
Table 13-3: Average Daily Vehicle-Kilometres in the North-South Corridor ... 99
Table 13-4: Border Posts in the North-South Corridor ... 100
Table 13-5: Border Post Delays at Chirundu ... 102

Table 13-6: Adopted HDM-4 Calibration Factors 105
Table 13-7: Road User Cost Savings and Net Benefits under Optimum Budget 106
Table 13-8: Road Deterioration Calibration Factors for Nigeria 120
Table 13-9: Accident Rates for Nigeria 121
Table 13-10: Paraguay Road Network Composition 126

Figures

Figure 2-1: Approach to User Requirements Capturing 8
Figure 12-1: Clustering of User Requirements 87
Figure 13-1: Two-stage Network Analysis Process 91
Figure 13-2: Burkina Faso Road Network Composition 92
Figure 13-3: Configuration and Parametrisation of the HDM-4 Model 95
Figure 13-4: Map of the COMESA North-South Corridor 99
Figure 13-5: Border Post Crossing Model 101
Figure 13-6: Sensitivity of Key Parameters on Total NPV 102
Figure 13-7: Two-stage Network Analysis Process 104
Figure 13-8: Impact of the Retained Budget Scenario on the Road Network Performance 106
Figure 13-9: Budget Distribution under Various Section Alternatives 107
Figure 13-10: Cash Flow for each Budget Scenario 108
Figure 13-11: Budget Allocation by Budget Scenario 108
Figure 13-12: Budget Allocation by Road Class 109
Figure 13-13: Funding Impact of Road Network Performance 110
Figure 13-14: Annual Cost Distribution by Different Work Type 110
Figure 13-15: Two-stage Network Analysis Process 111
Figure 13-16: Total Transportation Costs Graphic generated by the Namibian RAMS 114
Figure 13-17: Budget Repartition by Road Class by Budget Scenario 114
Figure 13-18: Budget Allocation by Work Type by Budget Scenario 115
Figure 13-19: Budget Spending profile over the analysis period by Work Type 115
Figure 13-20: Cash Flow Summary 116
Figure 13-21: Budget Repartition by Work Type 117
Figure 13-22: Annual Optimum Budget Distribution by Budget Scenario 117
Figure 13-23: Opportunity Cost of RA not spending Optimum Funding 118
Figure 13-24: Configuration and Parameterisation of the HDM-4 to the Local Conditions 123
Figure 13-25: Methodology of Configuration of the HDM-4 to the Local Conditions 124
Figure 13-26: Paraguay Road Network 125

ABBREVIATIONS/ACRONYMS

ADB	Asian Development Bank
AfDB	African Development Bank
API	Application Programming Interfaces
ARRB	Australian Roads Research Board
COMESA	Common Market for Eastern and Southern Africa
FCDO	Foreign, Commonwealth and Development Office
GDP	Gross Domestic Product
GFDT	Global Facility to Decarbonise Transport
GHG	Green House Gas
GNSS	Global Navigation Satellite Systems
HDM	Highway Development and Management Model
HVT	High Volume Transport
ICH	Institute of Cement and Concrete (Instituto del Cemento y del Hormigón)
IDB	Inter-American Development Bank
IP	Intellectual Property
IT	Information Technology
KOL	Key Opinion Leader
LMIC	Low and Middle Income Countries
MDB	Multilateral Development Bank
NMT	Non-Motorised Transport
NPV	Net Present Value
PBC	Performance Based Contracts
PIARC	World Road Association
PFC	Ponts Formation Conseil
PMT	Project Management Team
RA	Road Administration
R&D	Research & Development
RAM	Road Asset Management
REC	Regional Economic Communities
RED	Roads Economic Decision
RTFP	Regional Trade Facilitation Programme
SaaS	Software as a Service
SANRAL	South African National Road Agency Limited
SC	Steering Committee
SPADE	Systematic Paving Decision
TRL	Transport Research Laboratory
VOC	Vehicle Operating Cost

EXECUTIVE SUMMARY

This document is the Final Project Report, the fourth and final deliverable for the study to review how HDM-4 has been used since its launch in 2005. The document describes the current state of the art around HDM-4 and other Road Asset Management Software, and how they are deployed by Stakeholders, especially Multilateral Development Banks and Road Authorities. It documents the various activities of the study to generate a long list of draft User and Business Requirements, before consolidating these into a more accessible short list of Final User Requirements for further validation by End Users. The objective is to help better understand the use of HDM-4 by various Road Administrations (RAs), Multilateral Development Banks (MDBs), International Development Agencies, Consultants, Academics, and other stakeholders.

The consortium is led by Hodos Media and includes TRL and HDMGlobal as consortium partners. The consortium is supported by a variety of HDM-4 and Road Asset Management System (RAMS) subject matter experts, who have a number of years' experience between themselves in deploying these types of systems on behalf of Road Authorities in low and middle income countries.

Arguably, the work packages and subtasks in the study covered by this document (and indeed the entire study itself) have the overriding goal of identifying and capturing the user and business requirements for the next version of HDM-4. This is especially important for software design where the challenge is to ensure that the final product meets the needs of the end users and the businesses and organisations that will be using it. By gathering and documenting these requirements up front, software designers can better understand the goals and objectives of the development project and can design a system that meets these needs effectively.

Capturing user and business requirements also helps to ensure that the software design process is focused and efficient. By identifying and prioritising the most important requirements, designers can focus on building the features and functionality that are most critical to the success of the project.

The State of the Art Analysis of other software systems that operate in the same space as HDM-4 built upon the historic "competitor analysis" work conducted by Hodos Media and was supplemented by desk based research. Overall, searches online were limited as some systems did not include large volumes of information about whether they interface with HDM-4, and if so, how additional to their system's functions in a technical manner opposed to a marketing or sales narrative. It was generally unclear how the systems interfaced with HDM-4 when they claimed that they did. Lastly, it was uncertain as to whether many of these systems currently exist or are not in operation anymore.

Several companies offer a suite of asset management capabilities which could be quickly enhanced with HDM-4 type modules. This would give them an immediate competitive advantage and allow them to leap-frog the new HDM-4 delivery partner in terms of target markets and revenue generation. It is imperative therefore that the new entity responsible for HDM-4 is given full control of the intellectual property and maintains an IP log and roadmap for future development that encompasses new functionality, constant product evolution, and legally sound collaboration with third parties.

There are many published papers which present examples of HDM-4 use for different types of analysis, or examples of calibration of the HDM-4 models. It is found that the majority of the papers are supportive of HDM-4, and few provide direct evaluations of any weaknesses. The diversity of the papers published is an indication of the flexibility of the HDM-4 system when a user is familiar with its functionality and models. We have both reviewed and extracted user requirements from these papers.

The HDM-4 documentation gives a list of ways in which roads authorities use HDM-4, however there is no list of typical case studies or commentary on best practice. There is some best practice guidance available, for example ISO55001 standard for asset management or the PIARC Asset Manual, both of which were reviewed, and the relevant areas extracted. It is sensible for any future iteration of HDM-4 to use the similar approaches to these examples of best practice for Road Authorities, both in terms of terminology and logic.

We have identified Key Opinion Leaders within the Road Transport sector that could provide future collaboration opportunities for the managers of the new iteration of HDM-4. We have also identified experts from within the HDM-4 ecosystem that would be suitably qualified to be part of our proposed Technical

Advisory Group to help support the Steering Committee before, during and after the HDM-4 redevelopment process.

The core element of the study was a survey[1] of HDM-4 users in November and December 2022 which had 81 responses from a variety of end user types. Respondents were given the chance to add free-format text to identify ‘other potential improvement areas’ for HDM-4, and to give ‘other comments’ on HDM-4 and as hoped, these proved to be an excellent source of requirements, and were captured and classified, before being added to the global draft requirements table.

In terms of HDM-4 current usage, we created a standardised reporting template, and then tasked the three study team experts and TRL to produce a range of Case Studies where they had “hands-on experience” of deploying HDM-4. The shear variety in different deployments of HDM-4 yet again demonstrate both its utility and flexibility, with a range of new User Requirements identified and added to the global table.

In total we gathered ninety six different Draft User and Business Requirements into the global table (on page 56). This draft set of Requirements was then a consolidated and scored, before being placed into a Requirement Area ranked by its highest scoring Improvement Area, and the improvements in turn were ordered by their own scores.

The scoring given for each Requirement is suffixed by two codes in square brackets. The first of these codes identifies the source of the suggested improvement with the traceability codes as used consistently in this document. The second of these codes represents a score assigned to the requirement by the project team based on their interpretation of the likely magnitude of change to the existing software, cost/time to develop, and the number of times the suggestion was surfaced during the study. The second code is not intended to be scientific, rather it gives our assessment of the priority of the suggested improvement across the different views polled and approaches undertaken across the study. This led to a consolidated set of twenty two Final User and Business Requirements (page 70) which were analysed in more detail. In turn, they have been converted into a navigable PowerPoint slide deck repository for ease of validation amongst End Users.

We then conducted a Requirements mapping exercise between the HDM-4 Requirements work conducted in 2016 and the recent study Requirements. It appears that several recent requirements align with the older ones, such as Reporting, Vehicle Operating Cost Models, Traffic Data, Analysis Framework, VOC Calibration, Deterioration Models, Low Carbon Policies and Investments, Integration with other tools, Resilience to climate and other disasters, and Road Safety. As expected, there was some variation between priority areas, but no huge surprises.

Finally, we conducted a validation exercise with a cross section of representative end users which led to a further analysis of the end user requirements highlighting both the critical and non-critical requirements and providing a way to cluster the requirements into different categories. This now provides a useful starting point for defining the Minimal Viable Product and the scope for the HDM-4 redevelopment programme, which we can feed into the final Business Plan report in the Component B study that runs in parallel to the Component A Requirements study.

Although we have attempted to define the minimum viable product (MVP), any recommendation will clearly need to undergo much more detailed specification and analysis before contemplating inclusion in any software design and implementation plan. There are also dependencies between some of the requirements that will need to be investigated fully and which will need careful planning and prioritisation as part of a future systems requirements evaluation.

In conclusion, the study has provided valuable insights and recommendations for the next version of HDM-4. By carefully considering and prioritising the user and business requirements, we can ensure that the redeveloped HDM-4 system will effectively address the needs of its users and remain a valuable tool. The feedback obtained from the final validation exercise will be instrumental in guiding the redevelopment of HDM-4 and ensuring that it aligns with the expectations of the end users and any other relevant stakeholders.

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[1] Hodos Media - HVT051 - Component A - Survey Results Report V2 - 06 January 2023

1. Background

This document is the Draft Final Report and Implementation Plan, the third deliverable for the study to review how HDM-4 has been used since its launch in 2005. The document describes the current state of the art around HDM-4 and other Road Asset Management Systems, and how they are deployed by Stakeholders, especially Multilateral Development Banks and Road Authorities, as described with variety of Case Studies. It then goes on to establish draft User and Business Requirements ready for validation by End Users. The objective is to help better understand the use of HDM-4 by various Road Administrations (RAs), Multilateral Development Banks (MDBs), International Development Agencies, Consultants, Academics, and other stakeholders.

1.1 Overview of Hodos Media Limited

Hodos Media develops and publishes intelligent transport systems applications, using game-like approaches to engage the user. Hodos also has a consultancy division that provides a full advisory service in the transport domain. We are a Research & Development led company, having led, managed, and assisted dozens of R&D projects and customer engagements, in the UK and abroad.

Hodos Media conducted the HVT015 "Preparation of a Business Case for HDM-4" study between August 2019 and November 2020. The primary objective of that study was to produce a "bankable business plan" for the future of the Highway Development and Management (HDM) software product and exploring all the possible options for putting the ownership, management, and maintenance on a more sustainable and commercial basis.

1.2 Overview of TRL

TRL is acknowledged internationally providing research, consultancy, and software in all aspects of surface transportation. Focusing on Transport Safety, Transport for Sustainable Development (focussing specifically on identifying solutions to the road safety and environmental challenges of Low and Middle-Income Countries), Environment and Decarbonisation, Automation and Digitisation of Transport and New Mobility. Clients include Government agencies and International Funding agencies, such as the Asian Development Bank and the World Bank.

TRL delivers projects in every continent of the world focussing on road and asset management systems, processes and procedures supported by development of manuals, policy and standards and analysis and institutional and capability building programmes.

TRL is the official distributor of HDM-4 software. It regularly delivers HDM-4 training to clients around the world and provides consultancy on use of HDM-4.

1.3 Overview of HDMGlobal

HDMGlobal is an international consortium of academic and consultancy companies that have formed a partnership for the management of HDM-4. This was initially a five-year concession awarded by PIARC commencing June 2005 with exclusive rights for its distribution. Following the worldwide success of HDM-4 Version 2 during this period, in June 2010, and again in 2015, PIARC extended this for a further five years. The concession has been further extended to the end of July 2023.

The managing partner of the consortium is The University of Birmingham Enterprise (UoBE) with the following partners ATKINS, AECOM and TRL Ltd from the UK, ARRB Transport Research Ltd from Australia, PFC and EGIS from France, and ICH of Chile. The main partners are complemented by close links with the associate members of the Mexican Institute of Transport.

HDMGlobal regularly delivers training courses both online and around the world in collaboration with its partners, as well as providing HDM-4 consultancy services. Users of HDM-4 are supported by HDMGlobal technical support and through an online knowledge base and user groups.

2. Introduction

2.1 Objectives of this Project

This project research is funded by the UK Foreign, Commonwealth & Development Office (FCDO) through the High Volume Transport (HVT) applied research programme, which is managed by DT Global UK.

The primary objectives of the project are to undertake a review of RAs, MDBs, Consultants, Academics, and other Stakeholders to ascertain:

- How HDM-4 has been used historically.
- How relevant HDM-4 has been for their business processes.
- Views on future needs and potential improvements to HDM-4 to meet current and emerging needs.

2.2 Introduction to the HDM-4 Analytical Framework

This section gives a brief overview of the analytical framework of HDM-4, in order to help understand the background and context to the suggestions and recommendations made by the various stakeholders as presented later in this report.

HDM-4 is designed to support three main functions of the highway management process, namely planning programming, and preparation. The HDM-4 analytical framework is based around the concepts of pavement life cycle analysis. This is applied to predict the following over the life cycle of a road pavement:

- Road deterioration.
- Road work effects.
- Road user effects.
- Socio-economic and environmental effects.

The rate of pavement deterioration is directly affected by the standards of maintenance applied to repair defects on the pavement surface or to preserve the structural integrity of the pavement, thereby permitting the road to carry traffic in accordance with its design function. The long-term condition of road pavements directly depends on the maintenance or improvement standards applied to the road.

In addition to the capital costs of road construction, the total costs that are incurred by road agencies will depend on the standards of maintenance and improvement applied to road networks. The accuracy of the predicted pavement performance depends on the extent of calibration applied to adapt the default HDM-4 models to local conditions. There are three levels of calibration in HDM-4:

- Level 1 - Basic: This calibration level should be performed for all HDM-4 analyses and addresses the most critical parameters, while assuming that most of the HDM-4 default values are appropriate. It is based on secondary sources and is being done through “desk” studies with best estimates and therefore requires minimal field surveys and the time required is low (weeks).
- Level 2 - Verification: It requires moderate data collection or availability with moderate precision and seeks to verify and adjust HDM-4 predictions to the local observed conditions. This may require field surveys and data collection to obtain the necessary data and typically would be refined in subsequent years as the data history builds. This level of calibration requires more resources and time (months).
- Level 3 - Adaptation: This level comprises structured research (medium-term) and advanced data collection over a long time period (years) and may lead to the development of new relationships and models and the need to refine the HDM-4 software.

The impacts of the road condition, as well the road design standards, on road users are measured in terms of road user costs, and other social and environmental effects. Road user costs comprise vehicle operations costs, costs of travel time (for passengers and cargo) and costs to the economy of road accidents.

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

Road User Costs in HDM-4 are calculated by predicting physical quantities of resource consumption and then multiplying these quantities by the corresponding user specified unit costs.

Economic benefits from road investments are determined by comparing the total cost streams for various road works and construction alternatives against a base case (without project or do minimum) alternative, usually representing the minimum standard of routine maintenance. HDM-4 is designed to make comparative cost estimates and economic analyses of different investment options. 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.

HDM-4 has three analytical methods; strategy, programme, and project analysis:

- Strategic Analysis: This is used for long-term planning and policy development. Strategic analysis is typically focused on identifying the key issues and challenges faced by the road network and developing broad strategies and policies to address them. The outputs of a strategic analysis include recommendations for investments in the road network, its road condition performance and cost profiles based on different budget levels defined by the user.
- Programme Analysis: This is used for medium-term road maintenance planning. Programme analysis involves the identification of a list of candidate road maintenance activities that are aligned with the strategic objectives and priorities. The outputs of the programme analysis include a detailed list of proposed road maintenance activities, their estimated costs, and their expected benefits for different budget levels defined by the user.
- Project Analysis: This is used for the detailed planning and design of individual road improvement projects. Project analysis involves the evaluation of different maintenance and improvement options, the estimation of total transport costs, and the assessment of the expected benefits. The outputs of the project analysis include the road condition performance, cost estimates, and benefit-cost analyses for the individual road project analysed.

2.3 Requirements Gathering Methodology

The purpose of capturing user and business requirements for software design is to ensure that the final product meets the needs of the end users and the business or organisation that will be using it. By gathering and documenting these requirements up front, software designers can better understand the goals and objectives of the project and can design a system that meets these needs effectively.

Capturing user and business requirements also helps to ensure that the software design process is focused and efficient. By identifying and prioritising the most important requirements, designers can focus on building the features and functionality that are most critical to the success of the project.

Overall, the goal of capturing user and business requirements is to create a software system that is tailored to the specific needs of the end users and the business, and that can deliver value in a way that meets or exceeds their expectations.

In order to capture the User and Business Requirements we have used a variety of techniques during the study, including:

- Analysis of the Current State of the Art.
- Analysis of the Methodology of Road Authorities.
- Analysis of the Methodology of Multilateral Development Banks.
- A brief Literature survey.
- A User survey.
- Analysis of User Case studies.

At each stage, we added any relevant requirements captured to our "long list" of User Requirements. We then had to organise them in some way so they could be sorted, categorised, and prioritised. We decided to categorise them by type, before tagging each requirement in relation to a following user groups:

- Road Administrations (RAs)
- Multilateral Development Banks (MDBs)
- Consultants
- Academics
- Other stakeholders.

Each requirement also has a unique ID so it could be tracked through a system requirements and software design and build process and an "origination" tag, so we know where it came from.

The scoring given for each improvement is suffixed by two codes in square brackets. The first of these codes identifies the source of the suggested improvement (e.g. [MDB11] identifies the suggestion as coming from a multilateral development bank, [US1] identifies the suggestion as coming from a user survey, with the traceability codes as used consistently in this document. The second of these codes represents a score assigned to the suggestion by the project team based on their interpretation of the likely magnitude of change to the existing software, cost/time to implement, and the number of times the suggestion was surfaced from End Users. The second code is not intended to be scientific, rather it gives our assessment of the priority of the suggested improvement across the different views obtained.

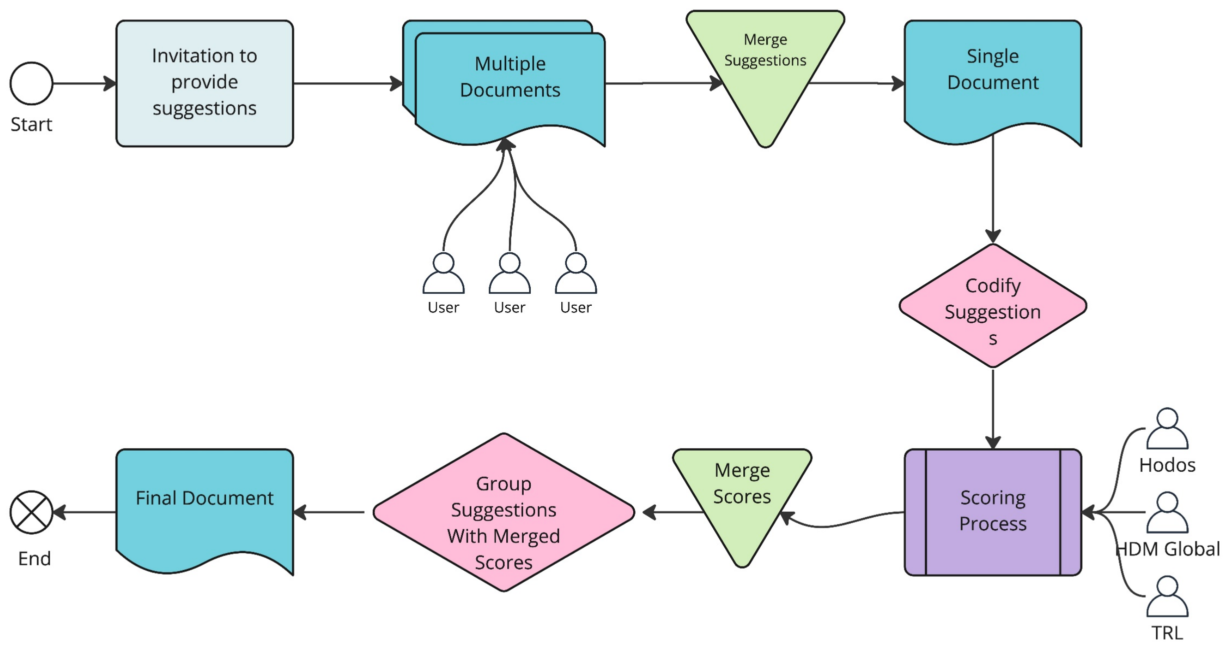
The 'Score' represents the maximum score for the improvement area across all the specific improvements identified. This was used to prioritise the improvement area. Using an average score was considered however this approach unfairly penalised those important requirements with a broad variety of improvement areas.

The final 'Analysis' is the project team's interpretation on the improvement area, particularly where we feel that the results of the various surveys and interviews are perhaps counter-intuitive or highlight different user preferences versus preferences that may be in the minds of other stakeholders.

Overall, the goal of sorting, categorising, and prioritising User Requirements is to make it easier to understand and manage the full set of requirements, and to ensure that the most important and necessary requirements are highlighted and addressed first in the software design process.

Figure 2-1 below outlines the approach taken:

Figure 2-1: Approach to User Requirements Capturing



Some of the recommendations may appear contradictory, reflecting the different types of users involved in the study activities. For example, some recommendations are for more detailed models such as on VOCs, while other recommendations are to simplify models and/or the interface.

Any recommendation will clearly need to undergo much more detailed analysis before contemplating inclusion in any software design and implementation plan. There are also dependencies between some of the requirements that will need to be investigated fully and which will need careful planning and prioritisation as part of a future systems requirements evaluation.

3. State of the Art Analysis

3.1 HDM-4 and Road Asset Management Systems

HDM-4 is an analytical and decision-making tool. HDM-4 is **not** a road asset management system. Road asset management systems typically manage road network referencing, provide mapping capabilities, allow scheduling and management of many different types of road surveys including inventory, condition, and traffic surveys. Some road asset management systems additionally incorporate analytical functions and models that they claim are similar to those used by HDM-4, or even interface to HDM-4. But HDM-4 is not a tool intended to store voluminous amounts of data over time, or to be used in operations of road networks. A useful analogy may be to consider HDM-4 as a calculator, and a road management system as a computer that enables storage and summary of the data needed to perform calculations.

3.2 Methodology

This project attempted to identify and analyse systems on the market that provided functions similar to HDM-4, or that interface to HDM-4. The purpose was to help try to identify systems that may be competitors to HDM-4, or that could potentially be impacted by upgrade of HDM-4.

This project built upon previous work conducted by Hodos Media that examine various software across the domain and was supplemented by internet searches. The following search terms were used: "road asset management systems", "infrastructure asset management systems", and "pavement asset management systems".

Information about the systems were transferred into an Excel Spreadsheet with the following columns:

- System name.
- Contact details.
- System overview.
- System features.
- What functions does it have like that of HDM-4?
- Does it interface with HDM-4?
- How does it interface with HDM-4?
- Pricing information.
- Location of operation.
- Case studies.
- Further links.
- Date last in operation.

Overall, the website search was limited as some systems did not include large volumes of information about whether they interface with HDM-4, and if so, how additional to their system's functions in a technical manner opposed to a marketing or sales narrative. It was generally unclear how the systems interface with HDM-4 if they claim that they do. Lastly, it was uncertain as to whether the system currently exists or is not in operation anymore. The dates of operation were acquired from case study reports or via website updates found online.

Finally, The State of the Art work proactively researched software referenced by the End Users in the User Survey, as well as other software relevant to the domain.

3.3 Results

From our research, we identified thirty-three types of relevant systems around the world. Of those, six already claim to interface with HDM-4 (Table 3-1 below). Fourteen have functions similar to HDM-4 (Table 3-2 below) and five explicitly mention that they implement their systems in developing countries in Africa, Asia, or South America (

Table 3-3 below).

Other than TRL, the four UK software providers (AgileAssets, Compass, Regenerate and XA) include their pricing document on the UK Government website, indicating that their focus is directed at UK Local Authorities. Other systems (e.g., Brightly Software, Global Road Technology, HIMS and Pavement Management Services) pricing strategy is done by individual quotations so the system can be tailored to the customers' needs and requirements. Most of the other systems do not have any pricing information on their websites.

Table 3-1: RAM systems that claim to interface with HDM-4

System Name	Interface with HDM-4	Year
Bentley Asset Management System: AssetWise	Yes – a Malaysian case study report published in 2020 said that the system used its Digital Twin technology to apply a pavement management system in conjunction with HDM-4. Highly unlikely – need to verify.	2022
Deighton Total Infrastructure Management System	Not sure whether Deighton tries to interface with HDM-4 – Deighton often claims that they replicate or implement the HDM-4 road deterioration models into dTIMS.	2022
HIMS	Yes – the website stated in 4 case studies that the pavement management system was based on the HDM-4 analysis engine.	Unknown (HIMS does not appear to have been marketed since 2015 at the latest)
IRAMS (by EOH/NEXTEC)	Yes (according to this project's case study with the Namibian Roads Authority)	2022
iROADS	Its flexibility allows it to be deployed anywhere in the world, for use with varied survey types, survey machines and integration with HDM-4.	2022
Maximo by IBM	A review conducted by ARRB in 2017 indicated that the system is flexible such that it is able to work together with other specialised pavement management systems such as HDM-4	2022
SATRA Infrastructure Management Services	SATRA is a reseller for HIMS plus other bespoke software developed by SATRA	2021

Table 3-2: Systems that have functions like HDM-4

System Name	Functions similar to HDM-4	Year
iROADS	Simplified lifecycle analysis module which can be used instead of HDM-4	2022
Maximo by IBM	Enhances customer return on assets with financial and performance analytics	2022

System Name	Functions similar to HDM-4	Year
Road Network Evaluation Tools (RONET)	Determines the allocation of expenditures among recurrent maintenance, periodic maintenance, and rehabilitation road works. Determines the "funding gap" defined as the difference between current maintenance spending and required maintenance spending.	2020
AgileAssets	Analysis scenarios by creating what-if scenarios for analysis comparisons to simplify forecasting and resource allocation	2022
Brightly Software: Assetic Pty	Full asset lifecycle prediction modelling and capital planning	2022
Causeway Horizons	Asset lifecycle and scenario modelling	2022
Confirm (Pitney Bowes) / Dude Solutions	Lifecycle costing measurements	2021
LogiRoad	Evaluate the cost of a business to better adjust its profitability	2021
Pavement Maintenance Management System (PAVER)	The system calculated modelled pavement condition following the implementation and predicts M&R cost avoidance	2022
Ramboll	Strategy design and GAP assessments, investment analysis and lifecycle costs, planning and risk analysis	2022
RAMM Software	Maintenance programme periods to review the estimated and claimed costs for the periods to maximise users' budget and efficiency	2022
Regenerate (Metis Consultants Ltd)	Investment modelling	2020
SMEC Pavement Management System	Undertakes full lifecycle analysis of treatment options and incorporates financial modelling	2018
XA by XIAS Highway Asset Management	Economic prioritisation and whole life costing	2022
Decision Optimisation Technology (DOT)	Predictive modelling and risk-based analysis	2021
Copperleaf	Model asset condition, performance measures and risks to create optimal lifecycle intervention strategies	2023
Direxyon	Predictive analysis and simulation of asset lifecycle to test future capital investment strategies	2021
SAP Linear Asset Management	Asset lifecycle management	2023
ICARO	Expert road management system	2022

Table 3-3: Systems that Explicitly Mention Operation in Low and Middle Income Countries (LMICs)

System Name	Explicit mention of operation in LMICs	Year
Bentley Asset Management System	Specific mentions of India and Asia	2022
Deighton Total Infrastructure Management System	USA, Canada, India, Asia, Africa	2022
HIMS	Brazil, Cambodia, India, Japan, New Zealand, Papua New Guinea, Samoa, Serbia, Sri Lanka, UAE, and Zambia	Unknown
IRAMS (by EOH/NEXTEC)	Various African countries including South African municipalities and provinces.	2022
Road Network Evaluation Tools (RONET)	Africa and other developing countries	2020
SATRA Infrastructure Management Services	India, Mozambique	2021

3.4 Comparable Operations

Several businesses listed in the following section provide asset management and estimated cost capabilities, though not with the modelling capabilities of HDM-4. Like HDM-4, many such business appear to require substantial updates and as part of such a refresh, could, in theory take on some of the same capabilities as HDM-4.

In our more detailed analysis of other RAM systems, they appeared to be quite dated, with many appearing to have been one-off deployments, but we have also found sovme newer looking approaches. We have attempted to identify from their web pages what features they have that are like HDM-4, whether they interface (or can) with HDM-4 and if so how, and their 'location' which typically means where they were implemented.

We believe that many of these systems were implemented for one or maybe two clients, and the consultant hoped they would be able to sell it as a product but then it never got sold to anyone else and therefore it has fallen by the wayside. This is an important Business requirement for the HDM-4 Upgrade to ensure continuity in the use of a legacy RAMS by an End User after making significant investments in their implementation. Then incorporation of an Application Programming Interface[2] (API) would provide ease of integration of HDM-4 with other systems to help mitigate this.

Furthermore, around five of them claim that they interface with HDM-4 in some capacity, but with very few details available on most of them:

- Bentley.
- Deighton.
- HIMS.
- iROADS.
- SMEC.

Interestingly, Confirm (Pitney Bowes) worked to deploy Confirm into the Philippines in 2002-2004 but there is no information on the Confirm website about HDM-4 interfaces.

[2] An API or Application Programming Interface is a set of rules and protocols that allows different software applications to communicate and share data with each other in a structured and efficient manner, for more information see the HDM-4 Final Business Plan Report from the parallel Component B study.

Of the systems identified in the user survey, very few claim that they interface with HDM-4 – this implies that they are manually exporting / importing data from their asset management system to HDM-4 and conducting all the calculations and transformations manually or by some sort of bespoke interface. The survey responses indicated that none of the respondents to the survey work for any of the road asset management systems identified in our search, despite inviting them to participate.

3.5 Key Findings

Several companies offer a suite of asset management capabilities which could be quickly enhanced with HDM-4 type modules. This would give them an immediate competitive advantage and allow them to leap-frog the new HDM-4 business in terms of target markets and revenue generation. It is imperative therefore that the new entity responsible for HDM-4 is given full control of the intellectual property and maintains a log and roadmap for future development that encompasses new functionality and constant reinvestment and product evolution. The User Survey of HDM-4 users by Hodos Media in November and December 2022 attracted 81 responses (Please see separate report[3]). Respondents identified which other asset management systems they were using (

Table 3-4 below). The most used system is Road Economic Decision Model (24), followed by RONET (14) and ROMDAS (10).

Table 3-4: Systems Used by End Users

System Name	Quantity of respondents that have used it
AgileAssets †	2
AMX	1
Bentley *	1
dTIMS *	2
Icaro Tech	2
iROADS * †	4
Logiroad	1
PAVER	6
Road Economic Decision Model (RED)	24
Road Scanners	1
Romaps	1
ROMDAS	10
RONET †	14
Sirway**	1
Vaisala	1
WDM	1
Yotta Horizons	1

* indicates that the system claims to interface with HDM-4

† indicates that the system has similar functions to HDM-4

** Identified in the User Survey

[3] Hodos Media - HVT051 - Component A - Survey Results Report V2 - 06 January 2023

3.6 Requirements Gathered from State of the Art Task Work

The State of the Art analysis has identified the importance of being able to interface with other Road Asset Management Systems.

Table 3-5: Requirements Collected from State of the Art

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
SoA1	State of the Art	Collaborator	Functional	Integration with other tools	Given the availability of so many asset management systems on the market (although few claim to interface with HDM-4) then incorporation of APIs would provide ease of integration of HDM-4 with other systems and provide a much better user experience and protect legacy investments

4. Key Opinion Leaders

The objective of this task was to identify Key Opinion Leaders and Super Users within the HDM-4 ecosystem for future collaborative activities. There are many types of organisations that could be potential collaborators with the HDM programme. Here are a few example categories:

- Consulting firms: Consulting firms that specialise in road asset management, transportation engineering, or related fields. These firms could provide expertise in developing and implementing asset management strategies, as well as training and technical support for the software.
- Research institutions: Research institutions that focus on road asset management, transportation engineering, or related fields. These institutions could provide expertise in developing new approaches and best practices for asset management, as well as contribute to ongoing research and development of the software.
- Government agencies: Government agencies responsible for road infrastructure management and maintenance. These agencies could provide insight into the needs and priorities of road asset management, as well as help to promote the adoption and use of the software.
- Non-governmental organisations (NGOs): NGOs focused on road infrastructure development and transportation issues. These organisations could provide insight into the needs and priorities of road asset management in lower income countries, as well as help to promote the adoption and use of the software.
- Other software vendors: Other software vendors that develop complementary or related products could be potential collaborators for HDM-4. These vendors could provide expertise in areas such as data analysis, GIS mapping, or visualisation, as well as contribute to the development of integrated software solutions.

Some examples of HDM-4 subject matter experts that have been recommended to us by Key Opinion Leaders during the study include:

- Paul Starkey from the University of Reading is one of the most important experts in the field of non-motorised transport which will pose a challenge for this assignment, as it is not easy to incorporate this into the (or a new) model.
- John Hine has been working in the field of truck operating costs, particularly in Asia and Africa, so he knows this field particularly well. He has also used HDM-3, HDM-4, and also older road appraisal tools such as R-TIM.
- Mustapha Benmamaar. He works at the World Bank and also has made some recent work on truck operating costs.
- Chris Bennett is one of the most knowledgeable practitioners regarding HDM-4. He went to great lengths to collect most private reports and publications from most practitioners in this field and uploaded this info to an HDM-4 website[4]. Nobody else has such an archive collection of historical reports regarding HDM-4, and he has been working constantly with HDM for decades.

We also tried to identify organisations and individuals who have complementary skills and expertise, outside of the HDM-4 ecosystem, and who share a common goal of promoting excellence in road asset management. The following include some more specific examples of organisations that could be potential collaborators for HDM-4:

- Fugro: Fugro is a global provider of geotechnical, surveying, and asset management services for the infrastructure, construction, and mining industries. Fugro has extensive experience in road asset management and has developed proprietary software solutions that could complement HDM-4. Fugro's asset management software, ROAMES (Remote Observation Automated Modelling Economic Simulation), uses advanced technologies such as LiDAR and machine learning to collect and analyse data on road infrastructure conditions, allowing for more efficient and effective asset management. Fugro has worked

[4] URL: http://lpcb.org/index.php/document-library

on road infrastructure projects around the world, including in the United Kingdom, Australia, and the United States.

- The International Road Federation (IRF): The IRF is a global organisation that promotes safe and sustainable roads and mobility. The IRF has extensive experience in road asset management and has developed a range of training and certification programs that could be valuable for HDM-4 users. The IRF's flagship program, the Certified Road Safety Professional Program, is a globally recognised certification for road safety professionals, and could be complementary to HDM-4. The IRF also has a network of members and partners around the world, providing opportunities for collaboration and knowledge sharing.
- The American Association of State Highway and Transportation Officials (AASHTO): AASHTO is a non-profit association that represents state and territorial transportation agencies in the United States. AASHTO has extensive experience in road infrastructure management and has developed a range of guidelines and standards that could be valuable for HDM-4 users. AASHTO's Transportation Asset Management Guide provides a comprehensive framework for asset management in the transportation sector. AASHTO also has a range of technical committees and working groups that focus on different areas of transportation infrastructure management, providing opportunities for collaboration and knowledge sharing.
- The Centre for Pavement Engineering Education (CPEE): The CPEE is an Australian organisation that provides education and training in road infrastructure management and engineering. The CPEE has a range of courses and resources focused on road asset management and could be a valuable partner for HDM-4 in promoting the adoption and use of the software in lower income countries.
- International Association of Road Safety and Accident Investigation (IARSAI): IARSAI is an international organisation that promotes road safety and accident investigation. IARSAI has members and partners from around the world, including many lower to middle income countries.
- Transportation Research Board (TRB): TRB is a US-based organisation that provides research, education, and technical assistance in transportation. TRB has a global network of members and partners, including many academic institutions from lower to middle income countries.
- Institute for Transportation and Development Policy (ITDP): ITDP is a US-based organisation that promotes sustainable and equitable transportation. ITDP has a global network of partners and projects, including many in lower to middle income countries.
- Global Road Safety Partnership (GRSP): GRSP is a global organisation that promotes road safety and sustainable transportation. GRSP has members and partners from around the world, including many academic institutions from lower to middle income countries These organisations have extensive experience in road asset management and could be valuable collaborators for HDM-4 in promoting the adoption and use of the software, as well as developing new approaches and best practices for asset management.

In term of collaboration with organisations from lower and middle income countries, here are some potential partners from lower income countries that could be valuable collaborators for HDM-4:

- The African Development Bank (AfDB): The AfDB is a regional development bank that provides financing and technical support for infrastructure development projects in Africa. The AfDB has extensive experience in road infrastructure development and has developed a range of guidelines and standards that could be valuable for HDM-4 users in Africa. The AfDB also has a network of partners and stakeholders in the region, providing opportunities for collaboration and knowledge sharing.
- The Asian Infrastructure Investment Bank (AIIB): The AIIB is a multilateral development bank that provides financing and technical support for infrastructure development projects in Asia and the Pacific. The AIIB has extensive experience in road infrastructure development and could be a valuable partner for HDM-4 in promoting the adoption and use of the software in the region. The AIIB also has a network of partners and stakeholders in the region, providing opportunities for collaboration and knowledge sharing.
- The Development Bank of Latin America (CAF): CAF is a regional development bank that provides financing and technical support for infrastructure development projects in Latin America and the Caribbean. CAF also

has a network of partners and stakeholders in the region, providing opportunities for collaboration and knowledge sharing.

- The Association of Southeast Asian Nations (ASEAN): ASEAN is a regional intergovernmental organisation that promotes economic, political, and social integration among its member states in Southeast Asia. ASEAN has a range of programs and initiatives focused on infrastructure development, including road infrastructure, ASEAN also has a network of partners and stakeholders in the region, providing opportunities for collaboration and knowledge sharing.
- The International Road Federation (IRF) Africa: The IRF Africa is a regional organisation that focuses on promoting the development and management of road infrastructure in Africa. The IRF Africa provides training, technical assistance, and research on road asset management, and has developed a range of tools and resources that could be valuable for HDM-4 users in Africa.
- The Transport Research Laboratory (TRL): TRL is the official distributor of HDM-4 software, and regularly delivers HDM-4 training to clients around the world.
- The Road Federation of Latin America and the Caribbean (IRF-LAC): The IRF-LAC is a regional organisation that focuses on promoting the development and management of road infrastructure in Latin America and the Caribbean. The IRF-LAC provides training, technical assistance, and research on road asset management, and has developed a range of potentially relevant tools and resources.
- The University of Birmingham (UOB): The UOB has a strong link with the development and management of HDM-4 and has trained students from many LMIC countries. The University has been involved with many HDM-4 related implementations, supervised PhDs, and carried our research projects that could have benefits to future HDM developments, including the CRISPS project on climate resilience.

In terms of more academic collaborators who could be interested in working with HDM-4, especially in lower to middle income countries:

- University of Cape Town (South Africa): The University of Cape Town is one of the leading universities in Africa and has a range of expertise in road infrastructure management, including asset management, safety, and sustainability.
- University of Pretoria (South Africa): The University of Pretoria is another leading university in Africa with expertise in road infrastructure management. The university has a range of programs and research initiatives focused on road safety and asset management.
- University of the Witwatersrand (South Africa): The University of the Witwatersrand is a research-intensive university in South Africa with expertise in a range of fields, including road infrastructure management. The university has a range of research projects and partnerships focused on road safety and infrastructure management.
- University of Lagos (Nigeria): The University of Lagos is a leading university in Nigeria with expertise in road infrastructure management. The university has a range of research projects and partnerships focused on road safety and asset management and could be a valuable collaborator for HDM-4 in West Africa.
- Eduardo Mondlane University (Mozambique): Eduardo Mondlane University is the largest and oldest university in Mozambique with expertise in road infrastructure management. The university has a range of research projects and partnerships focused on road safety and asset management.
- Universidad Nacional de Colombia (Colombia): The Universidad Nacional de Colombia is the largest public university in Colombia with expertise in road infrastructure management. The university has a range of research projects and partnerships focused on road safety and asset management.
- Pontificia Universidad Católica del Perú (Peru): The Pontificia Universidad Católica del Perú is one of the leading universities in Peru with expertise in road infrastructure management.
- Federal University of Minas Gerais (Brazil): The Federal University of Minas Gerais is one of the leading universities in Brazil with expertise in road infrastructure management. The university has a range of

research projects and partnerships focused on road safety and asset management and could be a valuable collaborator.

These academic collaborators could provide valuable insights and research expertise to support the ongoing development and improvement of HDM-4, especially in lower to middle income countries, where the need for sustainable and efficient road infrastructure management is particularly critical.

In terms of individual key opinion leaders in the road asset management sector who are recognised for their expertise and thought leadership, here are a few examples:

- Dr. John Haddock is an internationally recognised expert in road asset management and has authored numerous books, articles, and technical papers on the subject. He has worked with government agencies and private sector companies around the world to develop and implement road asset management systems.
- Dr. Tim Colling is a leading expert in transportation engineering and asset management. He has published extensively on the subject and has worked with government agencies and private sector companies to develop and implement asset management strategies.
- Dr. Alireza Talebpour is an expert in traffic operations and simulation, with a particular focus on the use of technology to improve traffic flow and reduce congestion. He has worked with government agencies and private sector companies to develop and implement traffic management solutions.
- Dr. W. Ronald Hudson is a leading expert in pavement engineering and has authored numerous books, articles, and technical papers on the subject. He has worked with government agencies and private sector companies to develop and implement pavement management systems.
- Dr. Imad L. Al-Qadi is an expert in transportation engineering and infrastructure materials. He has published extensively on the subject and has worked with government agencies and private sector companies to develop and implement innovative solutions for transportation infrastructure management.

These experts and others like them can provide valuable insights and thought leadership on road asset management, as well as guidance on best practices, emerging technologies, and new developments in the field.

Although many of the key opinion leaders mentioned above are based in higher income countries, who frequently operate in Lower income geographies, there are also more localised experts:

- Dr Marcelo Bustos, Professor (Assistant) at National University of San Juan, Argentina: Dr Bustos has been active in HDM-4 training for 15+ years mainly in the South American region. His interests lie in road management systems, maintenance planning, and concrete pavements.
- Prof. Alex Visser, University of Pretoria (South Africa): Prog Visser has been involved with HDM-4 for a long time and has delivered many training courses at a professional level to participants from the African continent. His background is in road management systems, low-volume roads, and roads for heavy applications.
- Dr Stephan Krygsman, University of Stellenbosch (South Africa): Dr Krysgman has been using and promoting HDM-4 in South Africa and beyond for 15+ years. His interests are within Transport Economics, Geostatistics and Geoinformatics (GIS). His current project is 'Funding for roads' where focus is on the impact of transport infrastructure and services on economic development
- Dr. Gabriel Amoako-Adu is an expert in road asset management and has worked extensively in Africa, where he has helped to develop and implement road asset management systems in several countries. He has published numerous articles and technical papers on the subject and has been recognised for his contributions to the field.
- Dr. A.K.M. Abul Kalam Azad is an expert in road asset management and has worked in several low income countries, including Bangladesh and Nepal, to develop and implement asset management systems. He has published extensively on the subject and has been recognised for his contributions to the field.
- Dr. Nii Attoh-Okine is an expert in transportation engineering and has worked in several low income countries, including Ghana and Tanzania, to develop and implement transportation infrastructure

management systems. He has published numerous articles and technical papers on the subject and has been recognised for his contributions to the field.

- Dr. Daniel M. Frangopol is an expert in infrastructure management and has worked in several lower income countries, including Indonesia and Vietnam, to develop and implement infrastructure management systems. He has published extensively on the subject and has been recognised for his contributions to the field.

These experts and others like them can provide valuable insights and experience on the challenges and opportunities of deploying road and asset management systems in low income countries, as well as guidance on best practices and strategies for success.

5. Asset Management Best Practice and HDM-4 Implementation

This section discusses how HDM-4 fits into an overall asset management framework, in the context of two key resources, the ISO 55000 series and the PIARC Asset Management Manual. It helps to distinguish the differences between an asset management system and HDM-4 and helps to identify some business requirements for upgrade of HDM-4 as part of an asset management framework.

An asset management framework describes how organisations communicate their asset management approach to their workforce, to external stakeholders including politicians and the media, to external partners such as their supply chains, and to the public.

5.1 ISO 55000 Series

The ISO 55000 series[5] is an international standard that provides guidelines for the establishment, implementation, maintenance, and improvement of an asset management system. The standard is designed to help organisations optimise the use of their assets and improve the performance, reliability, and sustainability of those assets over their lifecycle.

The standard is based on the Plan-Do-Check-Act (PDCA) cycle, which is a continuous improvement model that consists of four stages:

- Plan: In this stage, the organisation defines its asset management policy and objectives, and develops a plan for achieving those objectives.
- Do: In this stage, the organisation implements its asset management plan and carries out the activities necessary to manage its assets effectively.
- Check: In this stage, the organisation monitors and measures the performance of its asset management system to ensure that it is meeting the objectives set in the planning stage.
- Act: In this stage, the organisation reviews the results of the monitoring and measurement activities and takes corrective action as needed to improve the performance of its asset management system.

ISO 55001:2014 is designed to be compatible with other management system standards, such as ISO 9001 (quality management) and ISO 14001 (environmental management), and it can be used in conjunction with sector-specific standards, such as ISO 55000 (asset management – overview, principles, and terminology) and ISO 55002 (asset management – guidelines for the application of ISO 55001).

The standard is divided into two main sections. The first section provides an overview of the standard and explains the purpose and scope of an asset management system. It also defines the key terms and concepts used in the standard. The second section outlines the requirements for an asset management system. These requirements cover areas such as leadership, planning, support, operation, performance evaluation, and improvement.

ISO 55000 is necessarily very generic in nature, intended to be applied to all types of assets and all types and sizes of organisation. These building blocks are difficult to interpret in relation to roads. For example, ISO 55000 essentially says that leadership and policies must be in place, that risks must be assessed, and information requirements must be stated, without giving examples of what these might look like in the context of roads organisations.

5.2 PIARC Asset Management Manual

The PIARC Asset Management Manual[6] follows the general principles of ISO 55000 but is very much geared towards roads organisations. This section describes some key elements of the manual and discusses their relevance to HDM-4.

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[5] https://www.iso.org/standard/55089.html

[6] https://road-asset.piarc.org/en

Table 5-1 below outlines key questions from the PIARC Asset Management Manual in relation to road asset management and HDM-4.

Table 5-1: PIARC Asset Management Manual Key Questions

Key questions in the PIARC Asset Management Manual	Relation to Asset Management Systems and HDM-4
What is the current state of the assets?	Road asset management systems often store data on multiple asset types, such as roads, bridges, other structures, drainage networks. HDM-4 has only ever been intended to analyse pavements. Asset Management Systems typically store inventory and condition surveys or inspections. Condition surveys are usually updated regularly (often annually, for road condition) and so build up a picture over time and use historical reporting and analyses to demonstrate improvement or otherwise of the network over time. HDM-4, on the other hand, only deals with a snapshot of (usually) the most recent data from the asset management system.
What is the required level of service?	Level of service is typically defined at the policy level by an agency. HDM-4 can be used at strategy level to quantify the costs of achieving given levels of service under different scenarios, and for the agency to choose an appropriate level of service that will satisfy road users and other stakeholders, and which is achievable under projected budgets. A typical asset management system, however, usually does not enable analysis of different scenarios, but can demonstrate what % of the network is achieving a given level of service, and/or can identify which categories or classifications of road should be maintained to a given level of service as determined by road agency policy.
Which assets are critical to sustained performance?	The road asset management system can be used to analyse and identify the critical assets on the network. These may be identified through a combination of criteria including traffic flows, network classification, or other social and economic criteria. Mapping is often crucial in identifying the critical portions of the network. HDM-4 is not geared towards identification of critical assets, but it is possible that, once identified, different maintenance standards can be applied in HDM-4 to maintain different parts of the network at different levels of service.
What are the best operations investment strategies?	HDM-4 can be used to perform unconstrained analyses to estimate the costs of maintaining a network at a certain level of service; or can be used to calculate optimal maintenance strategies under different budget constraints. A typical road asset management system would not be able to perform such analysis.
What is the best long-term funding strategy (including the optimum mix of preservation,	Similar to the previous question, HDM-4 can be used to analyse various scenarios under different budget

Key questions in the PIARC Asset Management Manual	Relation to Asset Management Systems and HDM-4
preventive maintenance, reactive maintenance, rehabilitation, and replacement)?	constraints, while typically road asset management systems would not include such functionality.

The above key questions demonstrate some fundamental differences between road asset management systems and HDM-4. HDM-4 can run and compare different budget scenarios to enable policy decisions to be made. Road asset management systems effectively implement the policies chosen and can be used to monitor the impact of those policies over time. Thus, road asset management systems and HDM-4 are complementary.

The PIARC Asset Management Manual also identifies different levels of maturity, as seen in Table 5-2 below. The final column in the table discusses these in relation to Road Asset Management Systems and HDM-4.

Table 5-2: PIARC Asset Management Manual Maturity Level Descriptions

Data Level	Description	Relation to Asset Management Systems and HDM-4
Basic	The organisation has limited experience and is at development stage. It largely views assets as a cost problem. No effective support from strategy, process, or tools. These can be a lack of motivation to improve.	If an organisation has no asset management system in place, then HDM-4 can still be used, but it is very much a manual process to collate data and to enter it into HDM-4. Such effort would almost always be undertaken by consultants since it is likely that there is limited capability in the roads organisation to conduct such analysis. It is also likely that the data on the network is not comprehensive or up-to-date, and that some major assumptions and simplifications have to be made in order to conduct an analysis.
Proficient	The organisation can say what it does and how it goes about it. An asset management strategy is clearly defined, process and tools are developed. The focus on the value and contribution of assets in terms of reliability and performance increase.	An organisation will have an asset management system in place. That asset management system may use analytical tools and conduct strategy analyses using HDM-4 or similar tools, likely once every 5 years or so. Given the relative infrequency of analyses, such analyses may be conducted by consultants.
Advanced	The organisation can control what it does in the way of processes. It specifies requirements and ensures that these are met through feedback. It is capable of learning and adapting itself. It not only uses experience to correct any problems but also uses experience to change the way it	An organisation will have an asset management system in place. That asset management system may use analytical tools and conduct strategy analyses using HDM-4 or similar tools. It will also use these tools to prepare annual works programmes, and continually evaluate the results of their

Data Level	Description	Relation to Asset Management Systems and HDM-4
	operates. Asset management strategies, processes, and tools are routinely evaluated and improved.	analyses to improve their use of the tools through better data quality assurance, higher level calibration, and field verification of treatment plans.

The above table demonstrates how road asset management systems and HDM-4, or similar tools can be used by roads organisations at different levels of maturity. HDM-4 can still be used in organisations at a basic level of maturity, but likely as a one-off exercise by consultants with poor data coverage and quality. As organisations become more proficient, they will implement asset management systems which systematise data collection and quality assurance and provide more automated functions and analyses to develop and update policies and procedures as part of a continual quality improvement program.

The PIARC Manual also describes several case studies covering different aspects of asset management, in terms of implementation, organisations, strategies and performance management:

- The Consejería de Transportes e Infraestructuras de la Comunidad in Madrid, Spain, clearly sets out the processes and procedure and the data they collect, the state of the network, and the levels of service they apply to that network. There was a significant reduction in budget for new infrastructure in recent years, with investment more allocated towards conservation of existing assets. Their systems are used to generate work plans for preventive maintenance, for both roads and bridges, and for scheduling routine maintenance. The processes seem to be based around current condition, not projected condition, and operate on a network of around 2,500 km.
- The Public Works Roads Department in Assam, India uses an asset management system to help plan and manage more than 44,000 km of state roads. Their asset management system manages pavement composition, roughness, structural strength, traffic volume, axle load data, and bridge and culvert condition, and history of works. It interfaces to HDM-4 for strategy and programme analysis applications.
- The Northeast Ohio Areawide Coordinating Agency (NOACA), Cleveland, Ohio in USA has a number of road concession arrangements and uses its asset management systems to plan and manage its concessions. Typical concession agreements focus on the components that most impact the safety and wide comfort level of the pavement, including International Roughness Index (IRI), pavement surface distress, rut depth and friction. It uses historical IRI data to calculate an average rate of change of IRI over a 5-year period and apply that to the network to determine the impact of investments over 5-year maintenance and rehabilitation plans.
- The Italian road agency, ANAS S.p.A, developed a methodology to define two main pavement performance indicators: a Functional Index combining transverse friction and roughness data to measure pavement condition, and a Structural Index to measure surface distress. At the time of the case study, the next step was to develop evolution models based on climate and traffic conditions and aging effects to calculate an Index of Future Deterioration.

What these four case studies demonstrate is the different data, methods and methodologies applied by different roads agencies. The clear conclusion is that flexibility should be allowed in HDM to cater for such different methodologies, based on review of international case studies.

5.3 Requirements in relation to HDM-4

The following table identifies some high-level requirements for HDM-4 derived from the above discussion.

Table 5-3: Requirements Collected from RA Methodology

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
RA1	AM & HDM-4 Implementation	RA	Non Functional	Ongoing development and support	Ensure software and user manuals share the same vocabulary and approaches of existing Best Practice manuals for Road Authorities
RA2	AM & HDM-4 Implementation	RA	Non Functional	Ongoing development and support	Inclusion of case studies in the documentation helps understand how different organisations use HDM-4 and other asset management systems and identify how HDM could incorporate flexibility to accommodate different methodologies
RA3	AM & HDM-4 Implementation	RA	Functional	Deterioration Models	Allow HDM to incorporate different deterioration models and methodologies
RA4	AM & HDM-4 Implementation	RA	Functional	Integration with Other Tools	The clear distinctions between HDM and asset management systems, and how they are used by roads agencies, highlights the need for good mechanisms for integration between HDM and other systems

6. HDM-4 Literature Review

There are many published papers which present examples of HDM-4 use for different types of analysis, or examples of calibration of the HDM-4 models. It was found that the majority of the papers are supportive of HDM-4, and few provide direct evaluations of its weakness. The diversity of the papers published is an indication of the flexibility of the HDM-4 system when a user is familiar with its functionality and models. We have reviewed and extracted some user requirements from these papers.

6.1 Publications Identified

There are many studies published on the use of HDM-4 for various purposes, and we have tried to focus on the most recently published. The following table gives a list of papers identified, with abstracts in the following pages.

ID	Publication
P01	Arango Álvarez, L. F. ., & Balbo, J. T. . (2022). Economic analysis of bicycle tracks using the HDM-4 model - case study for São Paulo city. TRANSPORTES, 30(2), 2695.
P02	Archondo-Callao, Rodrigo. 2008. Applying the HDM-4 Model to Strategic Planning of Road Works. Transport paper series; no. TP-20. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/17419 License: CC BY 3.0 IGO.
P03	Badasyan, Norayr and Hans Wilhelm Alfen. "Economic Results of Private Investments in the Road Infrastructure Projects: Does the HDM-4 Show the Big Picture?" *Public Works Management & Policy* 23 (2018): 324 - 345.
P04	Abdelilah Bannour, Mohamed El Omari, El Khadir Lakhal, Mohamed Afechkar & Pierre Joubert (2022) Highway pavement maintenance optimisation using HDM-4: a case study of Morocco's arterial network, International Journal of Pavement Engineering, 23:10, 3304-3317
P05	Gowda, S., Kavitha, G. & Gupta, A. Economic Analysis and Prioritisation of Non-core Roads in India: A Case Study. Int. J. Pavement Res. Technol. (2022). https://doi.org/10.1007/s42947-022-00250-2
P06	Bhavesh Jain, Devesh Tiwari, Manoranjan Parida, Ramesh Anbanandam, Assessment of vehicular fuel consumption and interaction with pavement characteristics using HDM-4 on Indian urban road network: A case of Pune city, Case Studies in Construction Materials, Volume 17, 2022, e01362, ISSN 2214-5095, https://doi.org/10.1016/j.cscm.2022.e01362.
P07	Kebebew, Biniyam and Quezon, Emer Tucay. (2022). Comparative Analysis on Road Users' Cost Using HDM-4 Software and Manual Technique A Case of Addis Ababa-Adama Expressway.
P08	Ochola, E.O., Odoki, J.B. (2022). Is a Further Increase in Fuel Levy in Kenya Justified? In: , et al. Advances in Road Infrastructure and Mobility. IRF 2021. Sustainable Civil Infrastructures. Springer, Cham. https://doi.org/10.1007/978-3-030-79801-7_11
P09	Federico Perrotta, Tony Parry, Luis C. Neves, Thomas Buckland, Emma Benbow, Mohammad Mesgarpour, Verification of the HDM-4 fuel consumption model using a Big data approach: A UK case study, Transportation Research Part D: Transport and Environment, Volume 67, 2019, Pages 109-118, ISSN 1361-9209
P10	Posada-Henao, J.J.; Sarmiento-Ordosgoitia, I.; Correa-Espinal, A.A. Effects of Road Slope and Vehicle Weight on Truck Fuel Consumption. Sustainability 2023, 15, 724.
P11	Rejani, V.U., Janani, L., Venkateswaralu, K. *et al.* Strategic Pavement Maintenance and Rehabilitation Analysis of Urban Road Network Using HDM-4. *Int. J. Pavement Res. Technol.* (2022).
P12	Sheldon A. Blaauw, James W. Maina, Georges A.J. Mturi, Alex T. Visser, Flexible pavement performance and life cycle assessment incorporating climate change impacts, Transportation Research Part D: Transport and Environment, Volume 104, 2022, 103203, ISSN 1361-9209.

6.2 Abstracts

ID: P01

Arango Álvarez, L. F. ., & Balbo, J. T. . (2022). **Economic analysis of bicycle tracks using the HDM-4 model - case study for São Paulo city**. TRANSPORTES, 30(2), 2695.

Abstract: In addition to technical studies, bicycle paths should be a product of planning and investment policies considering the ability of projects to generate socioeconomic benefits, implementing policies' objective analysis relevant to the feasibility of projects for the implementation of exclusive bike tracks. In this paper the Non-Motorized Traffic (NMT) model of the HDM-4 (Highway Development and Management) software is applied for the analysis of different alternatives for bicycle lanes, evaluating aspects such as current and potential cyclists demand, operation speed, capital costs and economic profile of bicycle users. The combination of such variables leads to technical and economic alternatives whose analysis results relevant differences in their profitability indicators. The analyses were carried out considering two scenarios; the first comprises the analysis of the profitability of alternatives structured with normative guidelines that, in terms of speed, represent ideal operating conditions; the second scenario consists of a more realistic evaluation for the city of São Paulo, considering speed restrictions and diversifying the user profile according to the per capita income of the main regions of the city. The results reflect interregional diversity about the desirability of bikeway projects based solely on the monetary benefits of reduced travel times. The kern results point out financial risk of the projects as governed by speed and traffic, also requiring a demand of over 1000 bicycles/day and an operation that exceeds 8 km/h to support bicycle projects investments.

Comments / User Requirements: The paper presents an interesting network-level analysis of the benefits from improved provision of cycle paths and makes use of the HDM-4 NMT models. They were able to demonstrate the economic benefits of bicycle infrastructure projects. They state that at the heart of the analysis is the benefits gained from improved operating speed. There is no evidence that they included other benefits derived from increasing NMT usage and did not consider impacts on the existing motorised traffic. They acknowledge that this was a network level analysis, and a finer level of analysis would be necessary at the project level for a more accurate feasibility of any local scheme. Although they considered the project a success, we can determine that the impact of NMT and MT was not adequate to make it possible to include the wider impacts of a modal shift to bicycles within their analysis, or other benefits derived from cycling which would have enhanced the feasibility study.

ID: P02

"Archondo-Callao, Rodrigo. 2008. **Applying the HDM-4 Model to Strategic Planning of Road Works**. Transport paper series; no. TP-20. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/17419 License: CC BY 3.0 IGO."

Associated HDM-4 Modules: Strategy Analysis

Abstract / Brief Overview: Although this report is from 2008 it provides an overview from the World Bank author on the use of HDM-4 for strategic analysis. The document provides a comprehensive introduction to the use of HDM-4 for the strategic analysis of a county's road network. The author concluded that HDM-4 could successfully be used to carry out an analysis if the data was gathered with due diligence and set up correctly to provide meaningful results.

It notes several elements of HDM-4 that could be improved to enhance the useability of the software and robustness of the results.

Optimisation algorithm: HDM-4 includes the EBM-32 optimisation method which was translated directly from the Fortran code originally provided. As translated the optimisation method has limitations on the size of the analysis that can be performed. If the analysis falls outside of these limits a different optimisation algorithm is automatically selected by HDM-4. The author recommends the size of the analysis is restricted so the EBM-32 optimisation method is used. The requirement is to improve HDM-4 would therefore be to recode the EBM-32 optimisation method so that the size limitations are removed.

The author notes that to produce a full set of reports for a strategic analysis, and to adequately interrogate the results, it is required to manipulate the results in a tool such as Excel. The requirement is therefore to provide improved reporting capabilities in HDM-4 more suitable to interrogating the results and display results appropriate for a network level analysis.

ID: P03

Badasyan, Norayr and Hans Wilhelm Alfen. "**Economic Results of Private Investments in the Road Infrastructure Projects: Does the HDM-4 Show the Big Picture?**" *Public Works Management & Policy* 23 (2018): 324 - 345.

Abstract: The Highway Development and Management model (HDM-4) is a software system developed for the evaluation and optimization of the economic benefits of the road projects and is widely used both by practitioners, decision makers, international consulting companies, and academia. This article analyses the application of the HDM-4 in the management of the private investment projects in the road sector thus trying to identify the main missing points for the evaluation of the big picture in the sector. The aim of the current study is to justify the need for the further development of a relevant plug-in tool for the HDM-4 to completely estimate the economic results of the projects in the road sector with private investments.

User Requirements: The paper states the need to include a wider range of costs and benefits into the economic analysis performed by HDM-4 to obtain a better assessment of the true economic benefits of a road investment project.

ID: P04

Abdelilah Bannour, Mohamed El Omari, El Khadir Lakhal, Mohamed Afechkar & Pierre Joubert (2022) **Highway pavement maintenance optimisation using HDM-4: a case study of Morocco's arterial network, International Journal of Pavement Engineering**, 23:10, 3304-3317

Abstract:

One of the key objectives of a pavement management system (PMS) is to find the optimal maintenance strategy, which minimises the sum of a road agency and user costs by maximising the net benefit to society. The PMS helps road agencies to better apply a selection of the right pavement treatments. The objective of the present paper is to show how the HDM-4 (Highway Development and Management 4) approach allows to develop a policy road leading to the optimal and robust selection of maintenance strategies under budgetary constraints, which minimises the sum of agency costs and road user costs in present value or maximises the net benefit to society over an analysis period. The findings could help road agencies to better apply the right pavement treatments. The present study is based on the exploitation of road network data, obtained from pavement structural condition survey, and performed by the National Studies and Road Research Center. The study applies a long-term simulation (20 years) of maintenance budget needs under different budget scenarios.

User Requirements: The paper describes a robust approach to performing a strategic analysis to determine the optimum maintenance standard to improve the network subject to budget constraints. One issue the author encountered was the selection of the correct discount rate as the country did not have a rate defined. The author therefore conducted a sensitivity on the discount rate and perform an analysis in Excel to select the optimum maintenance standards based on this sensitivity analysis. This highlights the need to perform sensitivity analysis within a strategy analysis and to be able to compare the results – currently sensitivity analysis is only supported in project analysis. The paper also presents some customised reports indicating that further reports are required within HDM-4 to adequately serve the strategy analysis results.

ID: P05

Gowda, S., Kavitha, G. & Gupta, A. **Economic Analysis and Prioritisation of Non-core Roads in India: A Case Study**. Int. J. Pavement Res. Technol. (2022). https://doi.org/10.1007/s42947-022-00250-2

Abstract: The road network is a major asset for every developing nation. Data collection, analysis, and arriving at economical maintenance work plans are said to be major goals for every road agency. Successful implementation of Pavement Management Systems can result in ease of decision-making about investments incurred for the maintenance of road networks. Advanced pavement maintenance strategies ensure the rational utilisation of limited funds scientifically. Based on existing pavement conditions, a systematic procedure is required to analyse the impacts of different maintenance strategies based on the predicted future pavement conditions. The present study attempts to develop a prioritised work programme for an identified non-core road network in India using the Highway Development and Management tool. Pavement distress data for non-core roads with a total length of 1743.9 km were collected using a Network Survey Vehicle and stored in a customised central database. Six maintenance strategies were formulated and predicted the International Roughness Index values, and they were compared with those obtained from the conventional maintenance strategy adopted by the state agency. Furthermore, an economic analysis was carried out, and the best strategy was proposed based on optimised costs. The predicted International Roughness Index (IRI) from the proposed strategy was found to be 37% lower than the predicted IRI using a conventionally adopted maintenance strategy. Such road asset management studies should be popularised by the state public works department for non-core roads to optimise the resources.

Comments / User Requirements: The authors highlight the importance of a Road Asset Management System to store collected data so that it is easily available to be used for robust decision-making. They describe how they have used the EXOR system to store their road inventory and condition, pavement composition, asset tagging, traffic, axle load, and accident data. This is linked to Transportation Intelligence Gateway which can extract homogeneous sections to be imported into HDM-4 for further analysis. They describe how they are currently using HDM-4 to perform strategic analysis and programme analysis and hope to utilise project analysis in the future. They bring back the results from an HDM-4 analysis into the system for customised reporting which can be done on a GIS system. Although they do not explicitly state any future HDM requirements they highlight the importance of being able to use HDM-4 with a RAMS and how critical that function is. Therefore, a requirement coming from this paper is the ability to link any future system easily to a user's RAMS so that existing data can be readily utilised.

ID: P06

Bhavesh Jain, Devesh Tiwari, Manoranjan Parida, Ramesh Anbanandam, **Assessment of vehicular fuel consumption and interaction with pavement characteristics using HDM-4 on Indian urban road network: A case of Pune city**, Case Studies in Construction Materials, Volume 17, 2022, e01362, ISSN 2214-5095, https://doi.org/10.1016/j.cscm.2022.e01362.

Abstract: Rapid urbanization and exponential increase in the number of vehicles on city roads have triggered issues like air pollution and accidents, endangering the health of millions of people in Indian cities. Vehicular emission is a major contributor to air pollution in Indian cities. This study primarily analyses the relative effects of riding quality and pavement surface type on vehicular fuel consumption (FC) in an urban environment. This study utilizes the Road Asset Management System (RAMS) applications to predict FC in different scenarios of pavement maintenance. Highway Development and Management (HDM-4) software was integrated into RAMS for network & economic analysis and FC prediction of the road network. The study was conducted on the Pune city road network in India, and the results revealed a 2.32 % reduction in fuel use if timely maintenance is provided. Over 0.128 million litres of fuel per 1000 vehicle-km can be saved over the study network of only 36.5 km over the next 15 years, equivalent to US$ 155,206.18 in 2021. The analysis of covariance test results showed the significant effect of pavement surface type on fuel consumption, with 4.86 % less fuel consumed on cement concrete surfaces than bituminous surfaces. About 99.431 litres per

1000 vehicle-km of fuel were utilized by the vehicle fleet on concrete pavements, while 104.513 litres per 1000 vehicle-km of fuel were consumed on bituminous pavements after adjusting for roughness characteristics of both the surface types.

User Requirements: The authors cite the importance of vehicle emission calibration to the local conditions as being a key factor in the reliability of the results. They state that while there are some published calibrations from other countries, there were none suitable for the Indian network they were analysing.

ID: P08

Ochola, E.O., Odoki, J.B. (2022). **Is a Further Increase in Fuel Levy in Kenya Justified?** In: , et al. Advances in Road Infrastructure and Mobility. IRF 2021. Sustainable Civil Infrastructures. Springer, Cham. https://doi.org/10.1007/978-3-030-79801-7_11

Abstract

Road transport is the predominant transportation mode in Kenya, contributing to about 9% of the GDP. Increased expenditure in roads has seen road assets become a significant portion of public investments that must be preserved. In Kenya, funds for road maintenance are primarily derived from fuel levy, which is charged per litre of petroleum imported. Despite the recent doubling of fuel levy charge, it is still inadequate for the entire network maintenance needs. This has prompted calls for a further increase in fuel levy in line with the government's "user pay" policy, much to motorists' chagrin. This study seeks to assess whether these calls are justified by comparing the benefits of increasing maintenance expenditure versus the road user cost (RUC) savings.

The study methodology involved undertaking network strategy analysis using the HDM-4 model. The model was used to quantify the optimal network maintenance needs, network performance under different budget scenarios, and the impact of increased maintenance funding on RUCs.

The study revealed that Kenya needs to double its fuel levy from the current US$ 0.18 per litre in order to meet its entire network maintenance requirements. It also revealed that every dollar invested in road maintenance translates to RUC savings of about US$ 5.53.

However, fuel levy charging is under threat as road user charging is becoming "politically unpopular". Also, vehicle fleets are switching to alternative fuels, and engine efficiencies are improving, leading to declining fuel consumption hence the need to explore alternative sources of maintenance financing. Keywords Road user charging Road user costs Maintenance needs.

Comments / User Requirements: This project uses HDM-4 network-level analysis to determine future maintenance costs and the impact of underfunding on the overall network condition. Using this analysis, they were able to consider the revenue from users required to fund the required maintenance needs and pre-empt the need to increase the fuel levy rather than allow the network to decline due to under-funding. They were not able to incorporate the changing fuel charges resulting from vehicles transitioning to different fuel types and increasing efficiency which leads to the requirement that in the future the vehicle models include options for alternative fuel sources such as electric, hydrogen, biofuels, and other emerging sources.

ID: P09

Federico Perrotta, Tony Parry, Luis C. Neves, Thomas Buckland, Emma Benbow, Mohammad Mesgarpour, **Verification of the HDM-4 fuel consumption model using a Big data approach: A UK case study**, Transportation Research Part D: Transport and Environment, Volume 67, 2019, Pages 109-118, ISSN 1361-9209

Associated HDM-4 Modules: Vehicle Operating Costs, Fuel Consumption, Emissions, Calibration

Abstract / Brief Overview:

This paper presents an assessment of the accuracy of the HDM-4 fuel consumption model calibrated for the United Kingdom and evaluates the need for further calibration of the model. The study focuses on HGVs and compares estimates made by HDM-4 to measurements from a large fleet of vehicles driving on motorways in England. The data was obtained from the telematic database of truck fleet managers (SAE J1939) and includes three types of HGVs: light, medium, and heavy trucks. Some 19,991 records from 1645 trucks are available in total. These represent records of trucks driving at constant speed along part of the M1 and the M18, two motorways in England. These conditions have been simulated in HDM-4 by computing fuel consumption for each truck type driving at a constant speed of 85 km/h on a flat and straight road segment in good condition. Estimates are compared to real measurements under two separate sets of assumptions. First, the HDM-4 model calibrated for the UK has been used. Then, the model was updated to consider vehicle weight and frontal area specific to the considered vehicles. The paper shows that the current calibration of HDM-4 for the United Kingdom already requires recalibration. The quality of the model estimates can be improved significantly by updating vehicle weight and frontal area in HDM-4. The use of HGV fleet and network condition data as described in this paper provides an opportunity to verify HDM-4 continuously.

User Requirements: This paper highlights the importance of VOC calibration and reliable data to perform this can be obtained. The requirement coming from this is the need to highlight the importance of VOC calibration, determine if the current defaults in HDM-4 are still applicable to a modern vehicle fleet, and to consider having standard VOC calibrations for different countries to prevent this work from being repeated by different practitioners.

ID: P07

Kebebew, Biniyam and Quezon, Emer Tucay, **Comparative Analysis on Road Users' Cost Using HDM-4 Software and Manual Technique A Case of Addis Ababa-Adama Expressway** (April 29, 2022). Available at SSRN: https://ssrn.com/abstract=4101641

Abstract: Continuous changes in vehicle technology, road condition, and traffic compositions initiate the change or updating of road users' cost models. So that it needs to practice a continuous revision or update periodically for realistic estimation of costs and benefits. This paper presented the relationship and comparison between road users' costs along Addis Ababa-Adamma's newly constructed expressway using the Highway Development and Management (HDM-4) Software and manually using formulations developed in the Portuguese model. The method started with data collection. All input data were collected from primary and secondary sources. The primary data utilised an interview, and secondary data were sourced from pertinent documents, both published and unpublished. More data were gathered that related to vehicles. The vehicles using the road are classified based on the manual from the Ethiopian Road Authority as cars, utilities, small buses, large buses, small trucks, medium trucks, heavy trucks, and truck trailers. The collected data have been input into the HDM-4 interface; the output of the analysis was vehicle operating costs, travel time, and road users' costs as a summation. Using a manual technique and HDM-4 Software, Birr 128.62/km/vehicle and Birr 139.23/km/vehicle, respectively, were found from road users' costs analysis. The result shows the difference of Birr 10.61. Also, the correlation coefficient of 0.75 is determined, which shows that the two results of road users' costs are highly related. As a result, the study reveals that the application of HDM-4 Software and the manual technique formulations from the Portuguese model can be adopted interchangeably to calculate Road Users' Cost of road sections in Ethiopia. Hence, the study results are expected to be an eye-opener for a future similar project by the concerned agencies.

Comments / User Requirements: In this study the authors were comparing the RUC HDM-4 models to a manual method for RUC calculations to compare the results. The authors do not justify the accuracy of the manual method of calculation; however, they conclude that there is a high correlation with the HDM-4 results, thus giving them confidence that HDM-4 is a viable tool to use for similar purposes in their country. There is no evidence in the paper that the authors attempted to calibrate the RUC components for their analysis. They state that although it is now common to include other costs such as "accident, environmental, congestion, crash, and various other social cost[s]". They state that the manual method requires a lot less data to perform the analysis and therefore is preferable where data collection is limited. This leads to the conclusion and requirement that HDM-4 is a data intensive model and simpler models would open up the software for increased use in data-poor countries or allow a high-level analysis to be performed quickly while more data is collected for an in-depth study.

ID: P10

Posada-Henao, J.J.; Sarmiento-Ordosgoitia, I.; Correa-Espinal, A.A. **Effects of Road Slope and Vehicle Weight on Truck Fuel Consumption**. Sustainability 2023, 15, 724.

Abstract: In this paper, we developed truck fuel consumption models for the particular assistance of professionals in charge of road project valuation in terms of predicting fuel used by trucks, which is an important topic on vehicle operating costs to be considered in the benefit–cost analysis of road projects. On the other hand, fuel consumption has a direct impact on emissions to the atmosphere, and thus future research can be conducted regarding estimations about emissions by trucks. In this research, we identified the effect of overall vehicle weight on truck fuel consumption in a free-flow regime. The methodology includes the design of experiments and factorial design as statistical techniques to obtain data, as well as linear and non-linear regressions to obtain models for two types of trucks: rigid (three axles) and articulated (six axles). Notably, there is no evidence of research previously conducted on the latter. We used statistical methods for the selection of trucks, equipment, road segments, and other aspects, obtaining good control in tests verifying the appropriate values for factors according to the planned ones. The results satisfy the expectations of the research, and it was demonstrated that the vehicle weight and roadway slope were significantly more important than speed alone, which was typically considered the main variable in other studies. On the other hand, longitudinal slopes higher than 5% were found to not be suitable for freight road corridors. It is recommended that 6-axle trucks instead of 3-axle trucks be used for a 16 t amount of cargo transported on a plain road (longitudinal slope under 3%). The HDM-4 model did not represent fuel consumption adequately for the current vehicle fleet operating on roads. Fuel consumption models must be updated, for instance, every 10 years, such that they can adapt to vehicle technological advances and the energetic improvement of fuels, including the proportion of biofuels and gas.

Comments / User Requirements: In their analysis they look at the fuel consumption of several different types of trucks, noting that predicting fuel consumption can be difficult as there are many factors such as speed, fuel quality, road geometry and loading characteristics to consider. They highlight that their analysis has highlighted that up to 30% of the time a truck is carrying no load, 20% are empty on urban roads, many carry goods under their maximum limit and in 12% of cases they are over overweight. These statistics are not modelled in HDM-4 for a typical vehicle where the loading is assumed to be constant, and that together with the use of uncalibrated models can account for up to 200% difference between prediction and actual consumption figures. The authors highlight the requirement that VOC models and parameters should be updated to better represent modern vehicle fleets and that a wider range of fuel types be included.

ID: P11

Rejani, V.U., Janani, L., Venkateswaralu, K. *et al.* **Strategic Pavement Maintenance and Rehabilitation Analysis of Urban Road Network Using HDM-4**. *Int. J. Pavement Res. Technol.* (2022).

Abstract: An efficient pavement management system assists the pavement engineers and authorities responsible for allocating funds for making cost-effective and consistent decisions about pavement maintenance management. Highway Development and Management System (HDM-4) is deployed to predict future technical and economic outcomes of potential investment decisions regarding maintenance management of road networks. The objective of the current work is to forecast budget requirements and predict the performance trends of an urban road network using the strategy analysis method of HDM-4. The analysis is carried out for two objective functions: maximising Net Present Value and minimising the total costs for a target road roughness. An unconstrained works program is formulated for 20-year analysis period. The total budget requirements for road network maintenance at a pre-defined serviceability level were estimated. A prioritized and optimised works programme is developed to maintain the road network within the available budget. The effect of the reduction in budget levels on the road network condition was also studied. The study revealed that the strategy application of HDM-4 has a potential scope in pavement management works by forecasting budget requirements and assessing the impact of various investment alternatives.

Comments / User Requirements: The authors note that HDM-4 is more frequently used for highways and higher-trafficked roads with few applications applied to urban networks. They therefore seek to apply HDM-4 to a small urban network to enable them to determine the optimum maintenance standards when seeking to maximise the NPV and to minimise costs to achieve a target IRI. They highlight the importance of performing a sensitivity analysis on the results, but this is not available in HDM-4 for a sensitivity analysis.

ID: P12

Sheldon A. Blaauw, James W. Maina, Georges A.J. Mturi, Alex T. Visser, **Flexible pavement performance and life cycle assessment incorporating climate change impacts**, Transportation Research Part D: Transport and Environment, Volume 104, 2022, 103203, ISSN 1361-9209,

Abstract: Construction, maintenance and demolition of pavements are often considered the only activities impacting the environment. This paper shows that user emissions, influenced by factors such as road roughness and climate change, are also important measurements of pavement sustainability. The objective of this paper is to complete a life cycle assessment of a typical flexible pavement based on the climate change forecast by using road deterioration and user emissions analysed with the Highway Development and Management 4 (HDM-4) package. Data from South Africa were used to prove the concept. Results showed that user emissions dominate life cycle environmental impacts, and that gradual warming and drying of the atmosphere attributed to climate change is beneficial to pavement deterioration and emissions alike. Although invariably debate about the impact of climate change has negative connotations, and the reality of many negative impacts, road authorities in South Africa are fortunate that less rainfall will be beneficial.

Comments / User Requirements: This paper focused on vehicle emissions under different climate change scenarios for flexible pavements only and uses the CO2 calculated by HDM-4 as the leading output indicator for the analysis. They have compared the CO2 cost for different maintenance standards over the lifecycle and concluded that the vehicle emissions often account for 96% to 99% of the total emissions. For the analysis they define a number of climate zones within HDM-4 to represent the average climatic conditions for Arid, Semi-Arid, Subhumid-Dry, Subhumid-moist, and Humid conditions found in South Africa. To account for the climatic changes predicted over time they ran HDM-4 with gradual changes to the climatic data and observed negligible differences. They state that extreme events cannot be accounted for within HDM-4. They did not include the impacts from congestion or geometry which they acknowledge could be important in some contexts.

The authors recognise a need to increase the range of vehicle types within HDM-4 to include hybrid- and electric-vehicles stating, "As electric vehicles are expected to increasingly replace internal combustion engines in the future, methods to quantify the effects of pavement roughness on electric vehicle energy use are required.".

6.3 Requirements Gathered from Literature Review

Th Literature Review captured the following User Requirements in Table 6-1 below:

Table 6-1: Requirements Gathered from Literature Review

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
LR1	P02	General	Functional	Data	Recode EBM-32 optimisation method to remove the current analysis size limitations
LR2	P02	General	Functional	Reporting	Provide improved reporting to enable interrogation of the results
LR3	P04, P05	General	Functional	Reporting	Provide improved reports required for network level analysis / provide the ability for a use to easily create custom reports based on their organisation's needs
LR4	P08, P09, P10	General	Functional	Calibration	VOC Calibration – improved documentation for calibration purposes, review of current defaults to represent a modern vehicle fleet, country database of VOC calibrations to provide greater consistency for HDM-4 projects
LR5	P06, P10	General	Functional	Low Carbon Policies and Investments	Importance of vehicle emission calibration to local conditions are a key factor in the reliability of results
LR6	P04, P11	General	Functional	Strategic Analysis	Sensitivity analysis is only currently available in project analysis, it should also be made available in strategy analysis
LR7	P01	General	Functional	Low Carbon Policies and Investments	Improve analysis including Non-motorised transport to include further impacts and wider economic benefits of shifts to this mode of transport
LR8	P03	General	Functional	Low Carbon Policies and Investments	Provide a framework to include Wider Economic Benefits into an analysis
LR9	P05	General	Functional	Integration with other tools	Enable easier linking of a RAMS to HDM-4
LR10	P08	General	Functional	Low Carbon Policies and Investments	Enable the user to define changing attribute values through an analysis to represent technology improvements

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
					and changing costs (fuel consumption / fuel costs)
LR11	P08, P10, P12	General	Functional	Low Carbon Policies and Investments	Include alternative fuel types such as electric vehicles, hybrid, hydrogen, etc
LR12	P07	General	Functional	Integration	Provide an HDM-4 interface/models that have a lower data requirement for countries that do not have sophisticated data collection process in place
LR13	P11	General	Functional	Urban Roads	Review use of HDM-4 on urban networks

7. Multilateral Development Bank Methodology

Multilateral Development Banks rarely "use" HDM-4 directly, although they may require recipient countries or agencies to use it (or rather, something like it) to justify feasibility studies for Bank-funded projects. Some development banks have produced general guidance for roads agencies or consultants on how to conduct economic analysis, but this guidance is not specific, and does not provide detailed procedures for use of HDM-4 for economic analysis of individual roads projects.

Multilateral Development banks have often also provided funding for roads agencies to implement economic analysis tools in order to conduct network-level economic analysis. Such funding is typically linked to implementation of road asset management systems. There are several examples of where this has been achieved (see Philippines case study in Chapter 9). Typically, such terms of reference from clients leave it open to implement 'HDM-4 or equivalent'. As seen earlier in this document, there is no real 'equivalent' of HDM-4 and so most implementations of pavement management systems for national roads agencies attempt some form of integration with HDM-4, to varying degrees of success.

7.1 The Asian Development Bank

The Asian Development Bank (ADB) published Guidelines for the Economic Analysis of Projects (ADB, 2017) to help ensure consistency of approach to economic analysis across all its projects. The guidelines give an overview of the types of savings that should be considered for economic analysis of projects across different sectors, including transport, power, water, urban development, and others.

Roads projects typically include construction, improvement or rehabilitation of intercity highways, inner cist urban roads, or rural feeder roads. Benefits of those projects are based on cost savings, typically including Vehicle Operating Cost (VOC) savings, and time cost savings, plus accident cost savings and reduction in environmental impacts.

For roads, the only explicit mention of use of HDM-4 in the guidelines are that "for road improvements, VOC savings are typically calculated using the Highway Development and Management Module" (para. 113). This calculates VOC by vehicle type (such as cars, trucks, buses) depending on the road characteristics (such as surface roughness, width, curvature), vehicle characteristics (such as speed, weight, age), and costs (such as prices of vehicles, fuel, maintenance). For traffic diverted from other routes or modes, VOC savings can be estimated by comparing the VOC of the road project under consideration with that of other routes or modes and can also be calculated for existing users on other routes or modes where traffic is diverted away from those routes, however these estimates are necessarily conducted outside of HDM-4 since HDM-4 does not provide functionality for assignment of traffic as a result of improvements.

The guidelines do state that HDM-4 "may not be appropriate [for rural feeder roads] as there will typically be virtually no motorized traffic without the project" (para. 118) and suggests an alternative approach to estimating net gains for rural households and firms as a result of improved access.

With regards to accident cost savings and reduction in environmental impacts, the guidelines do give advice on the types of costs that should be included. HDM-4 does not currently provide functionality for calculation of these other types of costs.

There have been some previous discussions between ADB and HDMGlobal in relation to potential incorporation of iRAP (International Road Assessment Programme) data to provide a high-level assessment of road safety impacts. Speed would be an important factor in any safety impact assessment.

There has also been some collaboration with ADB and HDMGlobal on a toolkit to calculate the lifecycle carbon cost of a project / network analysis from HDM-4 using additional data that the user enters into a spreadsheet. It is therefore possible to compare the carbon-impact of different alternatives. Costs for carbon can be included in the economic results. The impact of different carbon-offsetting schemes can also be used to show the impact of these on the overall carbon costs of the analysis – ADB has a separate tool to evaluate the carbon savings from different tree planting schemes, for example. The toolkit also includes the ability to look at different scenarios to transition to electric vehicles. There is scope for incorporating research and functionality into future extensions of HDM.

7.2 The World Bank

7.2.1 Transport Notes on the Economic Evaluation of Transport Projects (2005)

The World Bank in 2005 produced a series of Transport Notes (TRN) on the Economic Evaluation of Transport Projects (World Bank, 2005). This represents general guidance on how to conduct economic evaluation of transport projects. It is not guidance on how to use HDM, although does contain a number of references to HDM-4 which had been released in year 2000. Some of these notes do recommend use of HDM-4 to assess road maintenance on World Bank projects (TRN-13), in terms of evaluating alternative maintenance strategies, and use of the HDM-4 Vehicle Operating Cost model for calculation of VOCs (TRN-14).

- TRN-11 claims that HDM-4 models re-assigned traffic on roads. If only Base Traffic and Re-assigned Traffic is considered within the appraisal the implicit assumption is that all origins, destinations, time of travel choices and mode of travel choices remain fixed. However, modelling of induced traffic is extremely complex, and need to take account of mode choices, destination choices, time of travel choices, changes in trip frequency and land use changes, and is not covered in HDM-4.
- TRN-13 recommends HDM-4 to assess road maintenance in terms of evaluating alternative maintenance strategies on World Bank projects.
- TRN-14 recommends the HDM-4 Vehicle Operating Cost model for calculation of VOCs. It notes that the HDM VOC model is incremental in nature, so should the scale of the project represent a step change in the scale of say bus public transport or road haulage (e.g., a doubling or trebling of the fleet size) the model will not fully reflect the costs of the structural change that will occur within the sector. Additionally, this model will not be able to reflect the nature of regulatory or structural reform in either the bus sector or the road haulage sector.
- TRN-16 incorporates accident modelling, through the costing of road accidents and comparison of accident costs in the with and without cases.
- TRN-21 identifies that the application of HDM-4 to low-volume roads encounter problems related to the small magnitude of user benefits and the stronger influence of the environment rather than traffic on infrastructure deterioration.

7.2.2 Economic Analysis Guidance Note (2014)

The World Bank in 2014 produced an Economic Analysis Guidance Note (World Bank, 2014) for internal use by Bank staff to help implement the Bank's approach to economic analysis of projects. It is a general guideline, with guidance provided under specific topics and sectors. The general document sets out three questions: What is the project's development impact? Is public sector provision or financing the appropriate vehicle? What is the World Bank's value added?

In terms of development impact, the guidelines set out that the expected benefits must justify the cost, that expected benefits and costs are measured by comparing the situation **with** the project to the situation **without** the project, and that where there are multiple alternatives, then the selected project should maximised the net present value of expected nett benefits, or the least-cost alternative that produces a set of expected results unless explicit reasons are given for choosing another alternative. The Bank's environmental and social safeguards normally address sustainability issues, but in projects in which environmental sustainability is an intended impact, then the development impact of alternative projects should be considered. While HDM is not explicitly mentioned in this general guidance, all of these types of analyses are clearly possible using HDM.

One central element in the guidance note is that it encourages capacity development, stating the desirability for country governments to produce economic analysis of the projects for funding using the country's own systems, validated by the Bank's task team. It encourages the Bank team to steer country officials towards training on economic analysis and suggests in some cases building economic analysis capacity development into the project.

If full economic analysis is to be conducted, the guidance note also recommends a sensitivity analysis, ideally with Monte Carlo simulations around key parameters.

We are unaware whether the World Bank has specific internal guidance relating to use of HDM-4 for financing roads projects.

7.3 Requirements Gathered from MDB Methodology Task Work

The Requirements regarding Multilateral Banks (MDBs) are captured in Table 7-1 below:

Table 7-1: Requirements Collected from MDB Methodology

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
MDB1	ADB	MDB	Functional	Rural Roads	Include an approach (acceptable to MDBs and Governments) that works for rural roads with low traffic volume i.e., considers wider social and economic benefits in addition to savings in VOCs
MDB2	ADB	MDB	Functional	Low Carbon Policies and Investments	Include functionality to calculate the carbon costs of a project / network improvements
					Include carbon offsets
MDB3	ADB / TRL	MDB	Functional	Resilience to climate and other disasters	Incorporate Climate Risk and Vulnerability Assessment
					Improve HDM climate model to include additional climate parameters including for example rainfall intensity, impact of heatwaves
					Allow climate model or parameters to change through the analysis period
					Incorporate research into new materials and technologies
MDB4	ADB	MDB	Functional	Diverted and generated traffic	Include functionality to improve and systematise approach to diverted and generated traffic
MDB5	ADB / HDM Global	MDB	Functional	Road Safety	Simplified iRAP method to provide high-level assessment of safety impacts, potentially including speed and other safety factors
MDB6	ADB	MDB	Functional	Transparency and consistency in the application of HDM	Improve transparency and consistency, possibly through development of guidance documents for development banks and partners

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
MDB7	ADB	MDB	Functional	Asset valuation	Incorporate asset valuation methodologies, tools, and reports to allow comparison of asset valuation over time and to enable comparison among project alternatives
MDB8	WB TRN-11	MDB	Functional	Diverted and generated traffic	Review the traffic modelling within HDM-4 to ensure the different modes of traffic are able to be defined easily and the economic evaluation of alternatives remains correct. The traffic modes to be reviewed include normal traffic, induced traffic, generated traffic, diverted traffic as well as traffic mode shifts
MDB9	WB TRN-13	MDB	Functional	Maintenance Standards	Review ability of HDM to define maintenance standards that meet typical road maintenance policies
MDB10	WB TRN-14	MDB	Functional	Policy changes	Include the cost of sector policy changes within an analysis and allow shifts in policy to be reflected in the vehicle fleet to enable the costs and benefits or policy shifts to be evaluated
MDB11	WB TRN-16	MDB	Functional	Road Accidents	Improve the evaluation of crash rates within an analysis and ensure that the full costs of accidents are incorporated
MDB12	WB TRN-21	MDB	Functional	Low Volume Roads	Allow wider economic benefits of the investment to be reflected in the analysis Provide a standard methodology to evaluate and assign economic costs and benefits

8. User Survey

8.1 Requirements Captured from the User Survey

We conducted a survey of HDM-4 users in November and December of 2022 that attracted 81 responses. The results of this survey are described in detail in a fully separate report[7]. Respondents were given the chance to add free-format text to identify 'other potential improvement areas' for HDM-4, and to give 'other comments' on HDM-4. Table 8-1 gives a summary of the comments made, and we have taken the initial step of the categorisation process.

Please note that it is not possible to quantify from the table below how many users may have identified these 'additional' improvement areas, and in any event, not all respondents used this opportunity to expand upon their answers, so it is not possible to weigh the strength of support for each of these. However, the table does give an indication of the complexity of the tool and the likely difficulties in prioritising improvements, yet it begun the process of capturing and classifying User Requirements for the rest of the study.

Table 8-1: User Survey Requirements

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
US1	User Survey	General	Functional	Additional Models	Include models for forecasting accidents and road safety
US2	User Survey	General	Functional		Calculate incremental C02 emissions in WITH and WITHOUT project case
US3	User Survey	General	Functional		Identify mitigating measures to offset emissions (e.g., no of trees or hectares of trees to be planted to mitigate effects of generated traffic)
US4	User Survey	General	Data	Data	Reduce number of input variables, many of them are of low sensitivity
US5	User Survey	General	Functional	Deterioration Models	Relate the IRI deterioration models to user costs and agency costs through graphs and include default costs of maintenance and improvement activities, so that they serve as a reference for comparisons in developing countries where not yet
US6	User Survey	General	Functional		Modify the deterioration models and update them based on more mechanistic concepts, especially in asphalt pavements
US7	User Survey	General	Functional		In the modeling of a road X, include the possibility of placing, apart from

[7] Hodos Media - HVT051 - Component A - Survey Results Report V2 - 06 January 2023

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
					the total width of the track and the number of lanes, the % of traffic using each of the lanes (for consideration of the evolution of pavement parameters only). and for heavy vehicles, that there is the possibility of choosing which are the heavy vehicles that affect the pavement or that the system chooses them by number of axles), for operational costs, leave as is (distributed proportionally). For example: A 10.5-meter track, with 3 lanes: lane 1= 5%, lane 2=20% and lane 3=75% of heavy vehicles
US8	User Survey	General	Functional		Exchange of statistical data for calibration of deterioration models
US9	User Survey	General	Functional		Include models for cobbled surface paving
US10	User Survey	General	Functional		Include models for rigid paving with short slabs
US11	User Survey	General	Functional		Deterioration models should be more flexible and should not be so strongly based on AASHTO 1993 concepts
US12	User Survey	General	Functional	Generated Traffic	Generated traffic for new sections
US13	User Survey	General	Functional		It should be possible to include generated traffic and exogenous benefits in maintenance standards, not just improvements
US14	User Survey	General	Functional		In new sections, the fact that by including generated traffic, incorporates it as a dis-benefit should improved
US15	User Survey	General	Functional		Include generated / diverted traffic for feasibility studies
US16	User Survey	General	Functional		Do not require traffic to be specified for each road section involving traffic diversion

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
US17	User Survey	General	User	GIS	Improve data I/O and consider GIS functionality: it is essential nowadays for non-professional end users, in some applications (e.g., maintenance)
US18	User Survey	General	Non-functional	Help system and documentation	Help system needs to be improved
US19	User Survey	General	Non-functional		The default exercises should be updated and expanded, including exercises and the level of programmes or strategies
US20	User Survey	General	Non-functional	Integration with other tools	Flexible reporting and charting
US21	User Survey	General	Non-functional		Integrate intelligent business tools
US22	User Survey	General	Data		Incorporate additional formats for data exchange
US23	User Survey	General	Non-functional		Develop models as libraries so that they can be used by other tools
US24	User Survey	General	Non-functional	IT environment	Cloud-based
US25	User Survey	Consultant	Business	Licensing	License it for use on a per project basis
US26	User Survey		Business		Licensing by user will limit adoption
US27	User Survey	Consultant	Business		Flexible licensing methods and periods will be required for some clients.
US28	User Survey	Consultant	Business		Cost should not be so high for independent professionals
US29	User Survey	General	Functional	Low Volume Roads	Make it more easily applicable to tertiary / low volume roads
US30	User Survey	General	Functional		Incorporate functionality of RED into HDM-4
US31	User Survey	General	User	Models (general)	Have an ongoing programme to update models

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
US32	User Survey	General	User	Network Referencing	Network referencing in HDM-4 to use same network referencing system as in RAMS
US33	User Survey	Academic	Business	Ongoing development and support	Invite or fund students to do their theses using HDM-4
US34	User Survey	General	Business		Provide regular updates about software update progress
US35	User Survey	General	Functional	Other Assets	Economic and financial evaluation of expressway projects with complex tolling and structural infrastructure.
US36	User Survey	General	Functional		Lighting analysis
US37	User Survey	General	Functional		The integration of road structures such as tunnels, bridges, walls, speed bumps, culverts, ditches, among others, should be considered in the management of the HDM-4
US38	User Survey	General	Functional	Other Calculations / Functions	Asset valuation
US39	User Survey	General	Functional		Volume capacity ratio
US40	User Survey	General	Functional		The 'core' functions of HDM-4 must be retained i.e., RUE and RUC. These impart on HDM-4 its reputation for objectivity and robust results. If too many 'subjective' tools are added it will diminish the importance of the core functions and HDM-4 will lose its pre-eminence
US41	User Survey	General	Functional	Programme Analysis	Non-quantified benefits
US42	User Survey	General	Functional		Generate prospective scenarios
US43	User Survey	General	Functional		Allow for variable costs over the analysis period
US44	User Survey	General	Functional		Budget constraint analysis is very slow for large networks
US45	User Survey	General	Functional		Treat the incorporation of derived traffic in the projects, considering route options in WITHOUT a project with a status condition, and the alternative WITH a project. Systematize the treatment of

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
					derived traffic, with simple options for incorporating routes WITHOUT and WITH project
US46	User Survey	General	Functional		Evaluating between programmes. Generate consolidated reports of the optimal alternative as programmes between different sections evaluated.
US47	User Survey	General	Data	Traffic Data	Traffic data analysis
US48	User Survey	General	Data		Make it possible to differentiate traffic individually for different lanes
US49	User Survey	General	Functional	Urban Networks	Make it applicable to urban roads
US50	User Survey	General	User	User-friendliness	More user-friendly interface
US51	User Survey	General	User		Include procedures for calibration and tutorial in the model
US52	User Survey	General	User		Generate a calculation engine with a simple interface for loading data and downloading results
US53	User Survey	General	User		Use context-sensitive menus
US54	User Survey	General	Functional	Vehicle Fleets / Vehicle Operating Cost Models	Vehicle Operating Cost models to be updated for electric and hybrid vehicles
US55	User Survey	General	Functional		Add the state-traffic matrix of a province or country to the model
US56	User Survey	General	Functional		Vehicle fleet parameters are largely outdated
US57	User Survey	General	Functional		Non-motorised transport (NMT) is poorly modelled
US58	User Survey	General	Functional	Works Standards	Include in the works standards, the incorporation of structural criteria, such as SNP or deflections, to use it as intervention criteria. For example: When SNP<3 = Work "X"

9. Case Studies

In order to complete the work specified in Work Package 3: Current Usage Analysis, we created a standardised reporting template, and then tasked the three study team experts and TRL to produce a range of Case Studies where they had hands-on experience of deploying HDM-4. A summary of the various Case Studies is provided in Table 9-1 below:

Table 9-1: HDM-4 User Survey Case Studies

Engagement ID	Engagement Name	Road Authority / MDB	Team Member Responsible
CS1	Burkina Faso Road Maintenance Matching Fund	Ministry of Transport / MCC (USA)	Akli Ourad
CS2	Chile	MDSy F	Mauricio Salgado
CS3	Common Market for Eastern and Southern Africa	RTFP PMU	Jennaro Odoki
CS4	Malaysia: Performance Based Contracts (PBC) for Federal Roads in Peninsular	OPUS Malaysia / PLUS	Akli Ourad
CS5	Namibia	Namibia Roads Authority	Akli Ourad
CS6	Nigeria	Federal Roads Maintenance Agency	Jennaro Odoki
CS7	Paraguay	Inter-American Development Bank for the Ministry of Public Works and Communications	Mauricio Salgado
CS8	Philippines	OPUS Malaysia / PLUS	TRL

For each Case Study we extracted any novel User or Business Requirements and collated them into Table 9-2 on page 55.

The full set of detailed Case Studies have been moved to an Annex of this document, with the overviews outlined below.

9.1 Case Study 1 - Burkina Faso Road Maintenance Matching Fund

9.1.1 Timeframe

The implementation of a Road Maintenance Matching Fund took place between 2011 and 2014 as part of the Burkina Faso Compact programme.

9.1.2 Client

The analysis was conducted for the Ministry of Transport of Burkina Faso, with a team of local staff trained in HDM-4 to prepare a road master plan and a rolling road maintenance program.

9.1.3 Analysis Type

The HDM-4 analyses performed were at the network level, covering both strategic and programming analyses.

9.1.4 Network Size

The Burkina Faso road network comprises 16,392 km, as defined in the Road Referencing System of the Road Asset Management System (RAMS).

9.1.5 Purpose of Analysis

The analysis was part of a grant provided by the Millennium Challenge Corporation (USA) under the COMPACT program. The Road Maintenance Activity component required the preparation of a Road Master Plan and a 5-Year Periodic Road Maintenance Plan, both to be prepared by the Government of Burkina Faso staff. The technical assistance included the development of a Road Asset Management System with an HDM-4 interface, HDM-4 calibration, capacity building, strategic analysis, and program analysis.

9.1.6 Calibration Level

HDM-4 was calibrated to Level 2 for Burkina Faso's conditions and environment, adapting road deterioration, works effect, and road user effect models accordingly.

9.1.7 Key Considerations

- Connection to RAMS - An integrated interface between RAMS and HDM-4 facilitated the creation of strategic and tactical network matrices for analysis and the generation of network-based reports.
- Budget Optimization and Economic Analysis - Strategic and program analyses included budget optimization under various constraints, determining total road user costs, total transport costs, and road user cost savings.
- Project Performance - The project aimed to integrate road asset management principles into Burkina Faso's road management processes and procedures, with successful outcomes such as the creation of a Road Asset Management division, establishment of procedures and manuals, and capacity building.
- Project Value - The project's value at the network level included a 20-year strategic plan value and a 5-year road maintenance and improvement program value. The technical assistance project provided by MCC was valued at around $25 million.
- Challenges with HDM-4 - Challenges faced in the analysis included the need for an advanced HDM-4 interface for data export from RAMS and improved reporting capabilities at the network level.

9.1.8 Recommendations

Future versions of HDM-4 should focus on improving data import and reporting at the network level, ensuring adoption by road organizations and integration with road asset management processes and systems.

9.1.9 User Journey for MCC (Funding Agency)

MCC's user journey was satisfactory, with most of the Compact program implemented within the 5-year period and budget constraints.

9.1.10 User Journey for the Government of Burkina Faso (Beneficiary)

The beneficiary's user journey was excellent, with the government receiving funding and technical assistance for the implementation of the Road Maintenance Activity, as well as support for all projects and activities under the COMPACT program.

9.2 Case Study 2 - Chile

9.2.1 Date

The study began in 2017 as part of a continuous effort to update and improve the analysis and evaluation tools of the National Road Network.

9.2.2 Who was the Analysis Completed for

The analysis was completed for the Ministry of Social Development (Chile) with the aim of standardizing the HDM-4 tool for its use and application in the evaluation of interurban road projects.

9.2.3 Analysis Type

The analysis focused on the Configuration and Parameterization of the HDM-4 software to Chilean conditions, using existing information from the country to feed into standardized parameters for the different modules and submodules of the software.

9.2.4 Network Size

The Chilean road network consists of 20,582 km of surfaced roads.

9.2.5 Brief Network Description

The Chilean Road Network is divided into two classes: National roads and Regional Roads. The surfacing types are Asphalt Pavements and Concrete Pavements.

9.2.6 Brief Description of Reason for Analysis

The objective of this analysis was to modernize a tool for analysing and evaluating road projects, adapting to the standardization and improvement of the evaluation protocols of the Ministry of Social Development and the Ministry of Public Works. The goal was to create a standard tool representing the country's characteristics for road management, project evaluation, and strategic planning of road networks.

9.2.7 Level of Calibration Performed

Level 1 – Basic Application calibration was performed during the study.

9.2.8 Aspects Considered

The study considered several aspects/inputs of information, including historical data of functional and structural evaluation, vehicular traffic measurements, current regulations, historical meteorological records, road inventory, representative vehicle fleet, and representative works standards for maintenance and improvement.

9.2.9 Project Performance

The project was successful in developing a road project management and evaluation tool using HDM-4, resulting in calibration studies, adaptation of the HDM-4 tool for interurban project evaluation, and the generation of specific capacity studies and weighing studies that improved the representativeness of the parameters included in the programme.

9.2.10 Issues with HDM-4 in Completing the Analysis

No issues were identified with the use of HDM-4. Difficulties in this type of study mainly came from information sources unfamiliar with the parameters and/or units used by the different modules and submodules of the program. Additionally, modernising analysis and evaluation tools in government entities can be challenging, as leaving the paradigm of the old tool requires more effort in disseminating and training officials.

9.2.11 Describe the User Journey (for the Bank)

There is no Bank involved in this case study, as it concerns the use of HDM-4 by a national road agency and not a road investment project funded by a development bank or an international donor.

9.2.12 Describe the User Journey for the Chilean Road Authority

The user journey for the Chilean Road Authority has been excellent. The authority itself promoted the study to improve the basis of analysis tools for evaluating and planning road projects, giving continuity to research conducted in this area for years. Both professionals from the Ministry of Social Development and the Ministry of Public Works use the standardised HDM-4 parameters for evaluating road projects, planning, and investing in the conservation and maintenance budgets of the National Road Network.

9.3 Case Study 3 - COMESA North-South Corridor

9.3.1 Date

The assignment was carried out between July 2011 and September 2013.

9.3.2 Project Client

The analysis was completed for Project Management Unit (PMU) of Regional Trade Facilitation Programme (RTFP), which provides the Secretariat to the COMESA-EAC-SADC task Team.

9.3.3 Project Objective

The main objective of the project was to prepare a global overarching economic document that would satisfy donors (and private funds) that ultimately an efficient North-South Corridor is economically viable in the medium to long term period.

9.3.4 Project Scope

The project scope involved conducting a strategic level study of the North-South Corridor using the Highway Development and Management (HDM-4) tool to illustrate the primary economic benefits of an efficient North-South Corridor.

9.3.5 Network Size and Description

The road network comprised mainly trunk roads of asphalt concrete and surface treatment. It was generally in fairly good condition, although there were sections of road that were in urgent need of rehabilitation and improvement.

9.3.6 Methodology

The methodology included establishing a baseline case, defining link characteristics, collecting and processing data, calibrating HDM-4 models, developing investment scenarios, specifying improvement alternatives, and conducting HDM-4 runs and analyses of the results.

9.3.7 Unique Features

Three unique features of this project were corridor analysis passing through several different countries, vehicle and axle overloading, and analysis of delays at border posts.

9.3.8 Calibration Level

The target level of configuration and calibration was Level 1 Calibration.

9.3.9 Sensitivity Analysis

Sensitivity analysis was undertaken to determine the effects of variations in the values of key input data on Net Present Value (NPV) and the timing of positive cumulative net economic benefits.

9.3.10 Project Outcome

The project was successful as it demonstrated clearly that there was an attractive rate of return to be realized from investment in the North-South Corridor.

9.3.11 Project Value

The total financial investment required for road network improvement was calculated to be about US$ 9.8 billion, with an economic return on investment (NPV) of US$ 29.5 billion and a benefit/capital cost ratio of 4.6.

9.3.12 Issues with HDM-4

There was one particular issue with HDM-4 in completing the analysis, that is, modelling delays at border posts between countries. Also, HDM-4 was not adequately flexible enough to model the impacts of vehicle and axle overloading.

9.3.13 User Journey (for the Road Authority)

The user journey was very good, as the study objectively prepared a global overarching economic document that would satisfy donors and private funds regarding the economic viability of an efficient North-South Corridor in the medium to long term period. The study also helped promote the use of HDM-4 for road investment appraisal and policy studies within the countries through which the North-South corridor passes.

9.4 Case Study 4 - Malaysia: Performance Based Contracts (PBC) for Federal Roads in Peninsular

9.4.1 Date

The project concerning Performance Based Contracts (PBC) for federal roads in Peninsular Malaysia was conducted in 2016.

9.4.2 Project Client

The work was completed for the Malaysia Road Authority, JKR.

9.4.3 Project Objective

The objective was to conduct network level Strategic and Programming Analyses using HDM-4 to determine the most cost-effective 10-year maintenance and improvement program as the base reference budget for PBC bid evaluations.

9.4.4 Project Scope

The project scope included conducting HDM-4 analyses using the two-stage network analysis method and optimising budget and performance scenarios.

9.4.5 Network Size and Description

The total Federal Roads study network in Southern Peninsular Malaysia is approximately 2,710 km in length. The network consists of several road categories: Primary, Secondary, Industrial, Federal Institutional (FI), and Felda/Regional development roads.

9.4.6 Methodology

A Level-3 calibration of HDM-4 for Malaysian conditions and environment, previously conducted by OPUS for the expressway network under concession by PLUS, was used. The calibration led to the full adaptation of the road deterioration and works effect (RDWE) models for the conditions and environment prevailing in Malaysia. Budget optimization and wider economic costs/benefits were also considered.

9.4.7 Unique Features

The project focused on determining total road user costs, total transport costs, road user costs savings, maintenance savings for the road agency, and performance impacts on the road network as part of the PBC bid.

9.4.8 Calibration Level

The target level of configuration and calibration was Level 3 Calibration.

9.4.9 Project Outcome

This project was successful as it was the first phase in the introduction of performance-based road maintenance contracting in Malaysia to cover the national road network.

9.4.10 Project Value

The Net Present Value of the total 10-year program is estimated at RM 2,491.599 million.

9.4.11 Issues with HDM-4

Integrating HDM-4 with the local database proved difficult, requiring a special interface designed by the consultant. Additionally, generating network analysis reports within HDM-4 was impossible, necessitating the use of external software to read rundata files and produce meaningful network reports.

9.4.12 Recommendations

Future versions of HDM-4 should focus on improving data import and reporting at the network level, as well as allowing users to define reports without exporting to an external tool.

9.4.13 User Journey (for the Road Authority)

The user journey was successful as this project marked the first phase in the introduction of performance-based road maintenance contracting in Malaysia, covering the national road network. This followed the expressway road network experience managed under private-public relationship arrangements for the past 20 years. Under the project, all procurements are made by JKR and paid by the Government of Malaysia.

9.5 Case Study 5 - Namibia

9.5.1 Date

This collaboration began in 2006 as part of the HDM-4 dissemination program, and the ongoing activity has continued since then.

9.5.2 Country

The case study takes place in Namibia.

9.5.3 Who was the Analysis Completed for

The continuous HDM-4 collaboration is with the Namibian Road Authority, particularly with the Road Management System (RAMS) division, which is responsible for administration of the local RAMS and road network assessment, as well as preparation of long-term strategic plans and medium-term road maintenance and improvement programs.

9.5.4 Analysis Type

The analysis types conducted with HDM-4 were at the network level, focusing on strategic and programming analyses. HDM-4 was run at these levels of analysis following every data collection campaign, which occurred approximately every 2-3 years.

9.5.5 Network Size

The existing Namibian road network totals a length of 48,889 km, consisting of:

- 8,259 km surfaced roads.
- 39,438 km unsealed roads.
- The Namibian road network is composed of 17,000 fixed road sections.

9.5.6 Brief Network Description

The Namibian road network is divided into three classes:

- Trunk roads.
- Main roads.
- District roads.

The surfacing type is divided into four classes:

- Bitumen (mostly surface dressing).
- Gravel.
- Earth.
- Salt.

9.5.7 Brief Description of Reason for Analysis

This long-term assignment aims to provide continuous technical assistance to the Namibian Road Authority in integrating HDM-4 into their local RAMS and using it as the primary tool for strategic and program analyses and the preparation of long-term and medium-term road maintenance and improvement plans. Activities within this technical assistance include:

- Integration of HDM-4 with RAMS.

- Level-2 calibration of HDM-4.
- Strategic analysis with the preparation of a Road Master Plan.
- Programme analysis with the preparation and update of a 5-Year Road Maintenance & Improvement programme.
- Capacity building in the use of HDM-4 at all levels of analysis.

9.5.8 Level of Calibration Performed

HDM-4 underwent an initial configuration and level-2 calibration for Namibian conditions and environment in 2003. This calibration led to the adaptation of the road deterioration and works effect (RDWE) and road user effect (RUE) models for Namibian conditions at that time. Since 2003, several data collection campaigns have been conducted, allowing the National Road Authority of Namibia (RA) to compile additional sets of road information used to further improve the adaptation of road deterioration and road user effect models for Namibian conditions in 2012.

9.5.9 Aspects Considered

The following aspects were most considered in the use of HDM-4 in Namibia:

- Connection to RAMS:

An integrated interface between RAMS and HDM-4 was established. This interface is used to create strategic and tactical network matrices for strategic and program analysis levels. It can also be used at the project level to prepare road maintenance rehabilitation projects in the form of homogeneous road sections using the dynamic segmentation method. The HDM-4 interface is also used to extract HDM-4 analysis results from the rundata files to generate network-based reports, including the Total Transportation Cost graphic, which are not available in HDM-4.

- Budget Optimisation and Wider Economic Costs / Benefits:

Strategic and program analyses were conducted, including budget optimization under various budget constraints, such as the optimum budget and actual government budget scenarios, to show the impact of both on the road network performance and road user costs. The analysis extended to determining total road user costs, total transport costs, road user cost savings, and opportunity costs. Unfortunately, these costs and benefits are not generated by HDM-4 reporting for network-level analyses. The HDM-4 interface has been used to extract data from the HDM-4 rundata files to generate these outputs.

9.5.10 Project Performance

This continuous assignment, initiated in 2006 by the University of Birmingham, is one of the early HDM-4 dissemination projects following the release of HDM-4 versions 1 and 2. It is also one of the successful projects in integrating HDM-4 with the local RAMS. HDM-4 has been continuously used by the Namibia Road Authority at the network level since then, and Namibia can be considered one of the most successful examples of HDM-4 usage at the network level by a national road agency.

9.5.11 Value of Project

The value of a project at the network level differs from that of a single road project, as the network-level project value encompasses the program value. In the case of Namibia, the project value can be categorized in the form of a 20-year strategic plan value and a 5-year road maintenance and improvement program value. The latest values from 2020 are as follows:

- Strategic Plan: Total Cost of NAM$ 51 billion (Optimal Budget).
- 5-Year Program: Total Cost of NAM$ 16 billion (Optimal Budget).

9.5.12 Issues with HDM-4 in Completing the Analysis

All network analyses have been completed since the Namibian RA integrated HDM-4 into their road management process. However, this would have been extremely difficult, if not impossible, without the design and development of an advanced HDM-4 interface and its integration within the local RAMS. This interface greatly facilitated two key aspects in the use of HDM-4 at the network level when dealing with thousands of kilometres of roads:

- Export of data from the RAMS central database to HDM-4 in the form of strategic and tactical matrices, which reduced preparation time from months to minutes.
- Reporting at the network level, which is lacking in HDM-4, making it practically impossible to generate network analysis reports without using sophisticated external software to read rundata files and produce meaningful network reports.

9.5.13 Recommendations

Future versions of HDM-4 should focus on improving data import and reporting at the network level to ensure the model's adoption by road organisations and its integration within their road asset management processes and systems. The Namibian Road Authority's user journey serves as an example of where future developments of HDM-4 should be aimed.

9.5.14 Describe the User Journey (for the Bank)

There is no bank involved in this case study, as it concerns the use of HDM-4 by a national road agency rather than a road investment project funded by a development bank or an international donor.

9.5.15 Describe the User Journey for the Namibian Road Authority

The user journey for the Namibian Road Authority has been excellent. Their decision to be one of the first African nations to develop a Road Asset Management System (2002) and, more importantly, to integrate HDM-4 with the RAMS has proven successful. This has allowed them to benefit from the capabilities offered by HDM-4 as a key road network planning tool and has assisted them in introducing strategic and programming levels within their road asset management cycle. Namibia has been a pioneer in applying road asset management principles even before the establishment of the ISO 55001 standard for asset management.

The User Journey of the Namibian Road Authority serves as a prime example of where future developments of HDM-4 should be directed. The future of the HDM-4 experience lies in its adoption as an integral part of national road asset management processes, rather than its continuation as just a standard model for the evaluation of road investment at the project level. The latter has led to the HDM-4 model being primarily a consultant's tool, whereas its global objective is to serve as a national standard for managing complex and extensive country-wide road networks.

In conclusion, the Namibian Road Authority's journey in adopting HDM-4 and integrating it into their Road Asset Management System has been an outstanding success. The continuous collaboration since 2006 has allowed them to utilise HDM-4 as a vital tool for strategic and program analyses in road maintenance and improvement planning. The user journey highlights the importance of focusing on improving data import and reporting at the network level in future HDM-4 developments, encouraging broader adoption by road organisations as part of their asset management processes.

9.6 Case Study 6 - Nigeria

9.6.1 Date

The Infrastructure Management and Engineering Services Limited (IMES) carried out the assignment between November 2012 and May 2014.

9.6.2 Who was the Analysis Completed for

The analysis was completed for the Federal Ministry of Works (FMW) of Nigeria, Road Sector Development Team (RSDT), Federal Road Maintenance Agency (FERMA), and other related agencies.

9.6.3 Analysis Type

The analysis focused on the adaptation of the HDM-4 model based on data collected from field studies and statutory agencies. It included aspects such as climate, pavement types and performance, vehicle fleet, traffic characteristics, and vehicle operating costs.

9.6.4 Network size

The total national road network is approximately 200,000 km, with only about 65,000 km paved.

9.6.5 Network description

The Federal Government owns about 35,000 km of the total road network, which represents about 54% of the entire bituminous road network in Nigeria.

9.6.6 Brief Description of reason for analysis

The study aimed at improving decision-making on expenditures in the road sector by enabling effective and sustainable utilization of the latest highway development and management knowledge.

9.6.7 Level of Calibration performed

The target level of the configuration and calibration is Level 2 Calibration, focusing on the most sensitive parameters embedded in the HDM-4 system.

9.6.8 GHG Emissions and Climate Change

HDM-4 can be applied to predict vehicle emissions, but data suited for calibrating the emission models to conditions in Nigeria were not available. Default HMD-4 emission model parameters were recommended.

9.6.9 Accidents

Accident rates for roads in Nigeria were determined, and conservative estimates for accident reduction benefits were recommended.

9.6.10 Was the project successful?

Yes. The Customised HDM-4 Workspace developed for Nigeria has been used for feasibility studies, programming of works, and strategic planning of the road network.

9.6.11 Issues with HDM-4 in Completing the Analysis

One issue with HDM-4 was its inability to allow for entry of historical data or time series data collected for calibrating road deterioration models.

9.6.12 Describe the User Journey (for the Bank)

The project was funded by the World Bank through the Road Sector Development Team of the Federal Government of Nigeria. The World Bank was not involved.

9.6.13 Describe the User Journey (for the Road Authority)

The user journey started with HDM-4 training courses, followed by HDM-4 model calibration and configuration to conditions in Nigeria. The use of HDM-4 for road investment appraisal and policy studies has been rising in Nigeria, indicating a successful user journey.

9.7 Case Study 7 - Paraguay

9.7.1 Date

Between May 2018 and March 2019, marking a first milestone in the improvement of the tool for the analysis and planning of the Road Network of Paraguay.

9.7.2 Who was the Analysis Completed for

The Project was based on financing from the Inter-American Development Bank for the Ministry of Public Works and Communications (MOPC) of the Paraguayan government.

9.7.3 Analysis Type

The analysis conducted was associated with the Configuration and Parameterisation of the HDM-4 software to the local conditions of Paraguay, using existing information from the country for different parameters in the software modules and submodules.

9.7.4 Network Size

The existing Paraguayan road network totals a length of 77,348 km, consisting of 9,222 km surfaced roads and 68,126 km unsealed roads.

9.7.5 Brief Network Description

The Paraguay Road Network is divided into three road classes, including National roads, Departmental Roads, and Local Roads, with surfacing types divided into four classes: Paved, Asphalt Pavements, Concrete Pavements, and Unpaved.

9.7.6 Brief Description of Reason for Analysis

The study aimed to configure the HDM-4 software to local conditions of Paraguay to obtain a country-specific evaluation and analysis tool, using available information from the MOPC and Paraguayan government entities.

9.7.7 Level of Calibration Performed

The calibration level developed during the study corresponds to Level 1 – Basic Application.

9.7.8 Aspects Considered

Aspects considered for the Configuration and Parameterisation of HDM-4 included historical data of functional and structural evaluation, traffic measurements, current regulations, historical meteorological records, road inventory, and vehicle classification.

9.7.9 Project Performance

The project was successful in defining a baseline for the HDM-4 program under Paraguayan conditions and guidelines for future tool development.

9.7.10 Issues with HDM-4 in Completing the Analysis

No problems were identified with HDM-4. Difficulties mainly came from information sources, which were not familiar with parameters or units used by the software.

9.7.11 Describe the User Journey (for the Bank)

The Inter-American Development Bank financed the project, aiming to consolidate the adoption and use of the tool for formalising and standardising evaluations of investment initiatives from the MOPC.

9.7.12 Describe the User Journey for the Paraguayan Road Authority

The user journey for the Paraguayan Road Authority has been excellent, establishing a base for software use and guidelines for its application in different analyses. The adapted tool helped justify the need for resources in network maintenance and conservation. The study also provided training for professionals in public entities on the use of the tool and HDM-4 capabilities.

Between May 2018 and March 2019, marking a first milestone in the improvement of the tool for the analysis and planning of the Road Network of Paraguay.

9.8 Case Study 8 - Philippines

9.8.1 Implementation

The Department of Public Works and Highways (DPWH) in the Philippines has been using HDM-4 since the early 1980s, with full institutionalization occurring in the late 1990s. DPWH is responsible for the National Road Network, which comprises approximately 32,000 km of national roads.

9.8.2 Analysis Type

HDM-4 was integrated with the Confirm Asset Management System and used for both strategic, program analysis and project-level analysis at the feasibility stage by local design consultants.

9.8.3 Level of Calibration Performed

A level 2 calibration was conducted across selected sections of the national road network, using detailed survey, non-destructive testing, and trial pits at around 20 sites in the early 2000s.

9.8.4 Aspects Considered

As HDM-4 became institutionalized into the planning process, it became apparent that an interface with the planning and programming system would be more beneficial than bringing the results back into the Confirm asset management system.

9.8.5 Recommendations

It is recommended that, as part of any HDM-4 implementation in a roads agency, baselining and a process of continual quality improvement is established to monitor the effectiveness of the use of HDM-4 in the planning process.

9.8.6 User Journey (Development Banks)

The implementation in the Philippines was supported by ADB, World Bank, and DfID (now FCDO) in the UK over a period of more than 20 years.

9.8.7 User Journey (DPWH)

A cadre of 6-8 personnel in DPWH Planning Service are fully trained in HDM-4 and use it to run strategy and program analyses annually, demonstrating strong support and drive from DPWH for all projects.

9.9 Requirements Gathered from Case Studies

A range of Business and user Requirements were extracted across the difference Case Studies, and they are captured in Table 9-2 below:

Table 9-2: Requirements Collected from Case Studies

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
CS1	Burkina Faso	RA	Functional	Reporting	Improved importing and reporting at network level
CS2	Chile	RA	Functional	Data Requirements	Implementation of a new tool (HDM-4) instead of older HDM-III was complex and required considerable changes to data collection processes and procedures and training of officials. Massification of results
CS3	COMESA	RA	Functional	Modelling delays Modelling impacts of overloading	Modelling delays at border posts Modelling the impacts of vehicle and axle overloading
CS4	Malaysia	RA	Functional	Reporting	Improved importing and reporting at network level
CS5	Namibia	RA	Functional	Reporting	Improved importing and reporting at network level

Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
CS6	Nigeria	RA	Functional	Calibration of deterioration models	HDM-4 should allow for entry of historical data or time series data collected for calibrating road deterioration models
CS7	Paraguay	RA	Functional	Data Requirements Quality Assurance	Implementation of the HDM-4 required changing data collection processes and procedures, which is complex and expensive for a large road network. Also, quality control on inputs must be implemented to improve reliability of analyses and results
CS8	Philippines	RA	Functional	Implementation Support	Implementation support is key, across all areas of roads data collection, road data quality assurance, traffic data collection, calibration, development of processes and procedures, and institutionalisation across central, regional and district offices

10. Draft User & Business Requirements

In Table 10-1 we have compiled all the various Requirements identified from each relevant chapter of this final report:

Table 10-1: Draft Requirements Collected from the Study

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
1	SoA1	State of the Art	Collaborator	Functional	Integration with other tools	Given the availability of so many asset management systems on the market (although few claim to interface with HDM-4) then incorporation of APIs would provide ease of integration of HDM-4 with other systems and provide a much better user experience and protect legacy investments
2	LR1	P02	General	Functional	Data	Recode EBM-32 optimisation method to remove the current analysis size limitations

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
3	LR2	P02	General	Functional	Reporting	Provide improved reporting to enable interrogation of the results
4	LR3	P04, P05	General	Functional	Reporting	Provide improved reports required for network level analysis / provide the ability for a use to easily create custom reports based on their organisation's needs
5	LR4	P08, P09, P10	General	Functional	Calibration	VOC Calibration – improved documentation for calibration purposes, review of current defaults to represent a modern vehicle fleet, country database of VOC calibrations to provide greater consistency for HDM-4 projects
6	LR5	P06, P10	General	Functional	Low Carbon Policies and Investments	Importance of vehicle emission calibration to local conditions are a key factor in the reliability of results
7	LR6	P04, P11	General	Functional	Strategic Analysis	Sensitivity analysis is only currently available in project analysis, it should also be made available in strategy analysis
8	LR7	P01	General	Functional	Low Carbon Policies and Investments	Improve analysis including Non-motorised transport to include further impacts and wider economic benefits of shifts to this mode of transport

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
9	LR8	P03	General	Functional	Low Carbon Policies and Investments	Provide a framework to include Wider Economic Benefits into an analysis
10	LR9	P05	General	Functional	Integration with other tools	Enable easier linking of a RAMS to HDM-4
11	LR10	P08	General	Functional	Low Carbon Policies and Investments	Enable the user to define changing attribute values through an analysis to represent technology improvements and changing costs (fuel consumption / fuel costs)
12	LR11	P08, P10, P12	General	Functional	Low Carbon Policies and Investments	Include alternative fuel types such as electric vehicles, hybrid, hydrogen, etc
13	LR12	P07	General	Functional	Integration with other tools	Provide an HDM-4 interface/models that have a lower data requirement for countries that do not have sophisticated data collection process in place
14	LR13	P11	General	Non Functional	Urban Roads	Review use of HDM-4 on urban networks
15	RA1	AM & HDM-4 Implementation	RA	Non Functional	Ongoing development and support	Ensure software and user manuals share the same vocabulary and approaches of existing Best Practice manuals for Road Authorities
16	RA2	AM & HDM-4 Implementation	RA	Non Functional	Ongoing development and support	Inclusion of case studies in the documentation helps understand how different organisations use HDM-4 and other asset management systems, and identify

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
						how HDM could incorporate flexibility to accommodate different methodologies
17	RA3	AM & HDM-4 Implementation	RA	Non Functional	Ongoing development and support	Allow HDM to incorporate different deterioration models and methodologies
18	RA4	AM & HDM-4 Implementation	RA	Non Functional	Ongoing development and support	The clear distinctions between HDM and asset management systems, and how they are used by roads agencies, highlights the need for good mechanisms for integration between HDM and other systems
19	MDB1	ADB	MDB	Functional	Rural Roads	Include an approach (acceptable to MDBs and Governments) that works for rural roads with low traffic volume i.e., considers wider social and economic benefits in addition to savings in VOCs
20	MDB2	ADB	MDB	Functional	Low Carbon Policies and Investments	Include functionality to calculate the carbon costs of a project / network improvements Include carbon offsets
21	MDB3	ADB / TRL	MDB	Functional	Resilience to climate and other disasters	Incorporate Climate Risk and Vulnerability Assessment Improve HDM climate model to include additional climate parameters including for example rainfall

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
						intensity, impact of heatwaves
						Allow climate model or parameters to change through the analysis period
						Incorporate research into new materials and technologies
22	MDB4	ADB	MDB	Functional	Diverted and generated traffic	Include functionality to improve and systematise approach to diverted and generated traffic
23	MDB5	ADB / HDM Global	MDB	Functional	Road Safety	Simplified iRAP method to provide high-level assessment of safety impacts, potentially including speed and other safety factors
24	MDB6	ADB	MDB	Functional	Transparency and consistency in the application of HDM	Improve transparency and consistency, possibly through development of guidance documents for development banks and partners
25	MDB7	ADB	MDB	Functional	Asset valuation	Incorporate asset valuation methodologies, tools, and reports to allow comparison of asset valuation over time and to enable comparison among project alternatives
26	MDB8	WB TRN-11	MDB	Functional	Diverted and generated traffic	Review the traffic modelling within HDM-4 to ensure the different modes of traffic are able to be defined easily and the economic evaluation of

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
						alternatives remains correct. The traffic modes to be reviewed include normal traffic, induced traffic, generated traffic, diverted traffic as well as traffic mode shifts
27	MDB9	WB TRN-13	MDB	Functional	Maintenance Standards	Review ability of HDM to define maintenance standards that meet typical road maintenance policies
28	MDB10	WB TRN-14	MDB	Functional	Policy changes	Include the cost of sector policy changes within an analysis and allow shifts in policy to be reflected in the vehicle fleet to enable the costs and benefits or policy shifts to be evaluated
29	MDB11	WB TRN-16	MDB	Functional	Road Accidents	Improve the evaluation of crash rates within an analysis and ensure that the full costs of accidents are incorporated
30	MDB12	WB TRN-21	MDB	Functional	Low Volume Roads	Allow wider economic benefits of the investment to be reflected in the analysis Provide a standard methodology to evaluate and assign economic costs and benefits
31	CS1	Burkina Faso	RA	Functional	Reporting	Improved importing and reporting at network level
32	CS2	Chile	RA	Functional	Data Requirements	Implementation of a new tool (HDM-4) instead of older HDM-III was complex and

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
						required considerable changes to data collection processes and procedures and training of officials.
						Massification of results
33	CS3	COMESA	RA	Functional	Modelling delays	Modelling delays at border posts
					Modelling impacts of overloading	Modelling the impacts of vehicle and axle overloading
34	CS4	Malaysia	RA	Functional	Reporting	Improved importing and reporting at network level
35	CS5	Namibia	RA	Functional	Reporting	Improved importing and reporting at network level
36	CS6	Nigeria	RA	Functional	Calibration of deterioration models	HDM-4 should allow for entry of historical data or time series data collected for calibrating road deterioration models
37	CS7	Paraguay	RA	Functional	Data Requirements	Implementation of the HDM-4 required changing data collection processes and procedures, which is complex and expensive for a large road network
					Quality Assurance	Also, quality control on inputs must be implemented to improve reliability of analyses and results

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
38	CS8	Philippines	RA	Non-Functional	Implementation Support	Implementation support is key, across all areas of roads data collection, road data quality assurance, traffic data collection, calibration, development of processes and procedures, and institutionalisation across central, regional and district offices.
39	US1	User Survey	General	Functional	Additional Models	Include models for forecasting accidents and road safety
40	US2	User Survey	General	Functional		Calculate incremental C02 emissions in WITH and WITHOUT project case
41	US3	User Survey	General	Functional		Identify mitigating measures to offset emissions (e.g., no of trees or hectares of trees to be planted to mitigate effects of generated traffic)
42	US4	User Survey	General	Data	Data	Reduce number of input variables, many of them are of low sensitivity
43	US5	User Survey	General	Functional	Deterioration Models	Relate the IRI deterioration models to user costs and agency costs through graphs and include default costs of maintenance and improvement activities, so that they serve as a reference for comparisons in developing countries where not yet

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
44	US6	User Survey	General	Functional		Modify the deterioration models and update them based on more mechanistic concepts, especially in asphalt pavements
45	US7	User Survey	General	Functional		In the modelling of a road X, include the possibility of placing, apart from the total width of the track and the number of lanes, the % of traffic operating in each of the lanes (for consideration of the evolution of pavement parameters only). and for heavy vehicles, that there is the possibility of choosing which are the heavy vehicles that affect the pavement or that the system chooses them by number of axles), for operational costs, leave as is (which is distributed proportionally). For example: A 10.5-meter track, with 3 lanes: lane 1= 5%, lane 2=20% and lane 3=75% of heavy vehicles
46	US8	User Survey	General	Functional		Exchange of statistical data for calibration of deterioration models
47	US9	User Survey	General	Functional		Include models for cobbled surface paving
48	US10	User Survey	General	Functional		Include models for rigid paving with short slabs
49	US11	User Survey	General	Functional		Deterioration models should be more flexible and should not be so

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
						strongly based on AASHTO 1993 concepts
50	US12	User Survey	General	Functional	Generated Traffic	Generated traffic for new sections
51	US13	User Survey	General	Functional		It should be possible to include generated traffic and exogenous benefits in maintenance standards, not just improvements
52	US14	User Survey	General	Functional		In new sections, the fact that by including generated traffic, incorporates it as a dis-benefit should be corrected
53	US15	User Survey	General	Functional		Include generated / diverted traffic for feasibility studies
54	US16	User Survey	General	Functional		Do not require traffic to be specified for each road section involving traffic diversion
55	US17	User Survey	General	User	GIS	Improve data I/O and consider GIS functionality: it is essential nowadays for non-professional end users, in some applications (e.g., maintenance)
56	US18	User Survey	General	Non-functional	Help system and documentation	Help system needs to be improved
57	US19	User Survey	General	Non-functional		The default exercises should be updated and expanded, including exercises and the level of programmes or strategies

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
58	US20	User Survey	General	Non-functional	Integration with other tools	Flexible reporting and charting
59	US21	User Survey	General	Non-functional	Integration with other tools	Integrate intelligent business tools
60	US22	User Survey	General	Data	Integration with other tools	Incorporate additional formats for data exchange
61	US23	User Survey	General	Non-functional	Integration with other tools	Develop models as libraries so that they can be used by other tools
62	US24	User Survey	General	Non-functional	IT environment	Cloud-based
63	US25	User Survey	Consultant	Business	Licensing	License it for use on a per project basis
64	US26	User Survey		Business	Licensing	Licensing by user will limit adoption
65	US27	User Survey	Consultant	Business	Licensing	Flexible licensing methods and periods will be required for some clients.
66	US28	User Survey	Consultant	Business	Licensing	Cost should not be so high for independent professionals
67	US29	User Survey	General	Functional	Low Volume Roads	Make it more easily applicable to tertiary / low volume roads
68	US30	User Survey	General	Functional	Low Volume Roads	Incorporate functionality of RED into HDM-4
69	US31	User Survey	General	User	Models (general)	Have an ongoing programme to update models
70	US32	User Survey	General	User	Network Referencing	Network referencing in HDM-4 to use same network referencing system as in RAMS

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
71	US33	User Survey	Academic	Business	Ongoing development and support	Invite or fund students to do their theses using HDM-4
72	US34	User Survey	General	Business		Provide regular updates about software update progress
73	US35	User Survey	General	Functional	Other Assets	Economic and financial evaluation of expressway projects with complex tolling and structural infrastructure.
74	US36	User Survey	General	Functional		Lighting analysis
75	US37	User Survey	General	Functional		The integration of road structures such as tunnels, bridges, walls, speed bumps, culverts, ditches, among others, to be considered in the management of the HDM-4
76	US38	User Survey	General	Functional	Other Calculations / Functions	Asset valuation
77	US39	User Survey	General	Functional		Volume capacity ratio
78	US40	User Survey	General	Functional		The 'core' functions of HDM-4 must be retained i.e., RUE and RUC. These impart on HDM-4 its reputation for objectivity and robust results. If too many 'subjective' tools are added it will diminish the importance of the core functions and HDM-4 will lose its pre-eminence
79	US41	User Survey		Functional	Programme Analysis	Non-quantified benefits
80	US42	User Survey	General	Functional		Generate prospective scenarios

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
81	US43	User Survey	General	Functional		Allow for variable costs over the analysis period
82	US44	User Survey	General	Functional		Budget constraint analysis is very slow for large networks
83	US45	User Survey	General	Functional		Treat the incorporation of derived traffic in the projects, considering route options in WITHOUT a project with a status condition, and the alternative WITH a project. Systematize the treatment of derived traffic, with simple options for incorporating routes WITHOUT and WITH project
84	US46	User Survey	General	Functional		Evaluating between programmes. Generate consolidated reports of the optimal alternative as programmes between different sections evaluated.
85	US47	User Survey	General	Data	Traffic Data	Traffic data analysis
86	US48	User Survey	General	Data		Make it possible to differentiate traffic individually for different lanes
87	US49	User Survey	General	Functional	Urban Networks	Make it applicable to urban roads
88	US50	User Survey	General	User	User-friendliness	More user-friendly interface
89	US51	User Survey	General	User		Include procedures for calibration and tutorial in the model

No.	Unique ID	Origination	User Type	Classification	Area	Potential Improvement Areas / Comments
90	US52	User Survey	General	User		Generate a calculation engine with a simple interface for loading data and downloading results
91	US53	User Survey	General	User		Use context-sensitive menus
92	US54	User Survey	General	Functional	Vehicle Fleets / Vehicle Operating Cost Models	Vehicle Operating Cost models to be updated for electric and hybrid vehicles
93	US55	User Survey	General	Functional	Works Standards	Add the state-traffic matrix of a province or country to the model
94	US56	User Survey	General	Functional		Vehicle fleet parameters are largely outdated
95	US57	User Survey	General	Functional		Non-motorised transport (NMT) is poorly modelled
96	US58	User Survey	General	Functional		Include in the works standards, the incorporation of some structural criteria, such as SNP or deflections, to use it as intervention criteria. For example: When SNP<3 = Work "X"

11. Consolidated and Ranked User and Business Requirements

Table 11-1 below is a consolidated and ranked list of Requirement Areas and related individual improvements identified from a combination of user survey, interviews with stakeholders and experts from development banks and research institutions, case studies provided by team members, desk research and literature review.

Each Requirement Area was ranked by its highest scoring Improvement Area, and the improvements in turn are ordered by their own scores.

The scoring given for each improvement is suffixed by two codes in square brackets. The first of these codes identifies the source of the suggested improvement (e.g. [MDB11] identifies the suggestion as coming from a multilateral development bank, [US1] identifies the suggestion as coming from a user survey, with the traceability codes as used consistently in this document. The second of these codes represents a score assigned to the suggestion by the project team based on their interpretation of the likely magnitude of change to the existing software and the number of times the suggestion was surfaced from End Users. The second code is not intended to be scientific, rather it gives our assessment of the priority of the suggested improvement across the different views obtained.

The 'Score' column represents the maximum score for the improvement area across all the specific improvements identified. This was used to prioritise the improvement area.

The final 'Analysis' column is the project team's comment on the improvement area, particularly where we feel that the results of the various surveys and interviews are perhaps counter-intuitive or highlight different user preferences versus preferences that may be in the minds of other stakeholders.

Some of the recommendations may appear contradictory, reflecting the different types of users involved in the study activities. For example, some recommendations are for more detailed models such as on VOCs, while other recommendations are to simplify models and/or the interface.

Any recommendation will clearly need to undergo much more detailed specification and analysis before contemplating inclusion in any software design and implementation plan. There are also dependencies between some of the requirements that will need to be investigated fully and which will need careful planning and prioritisation as part of a future systems requirements evaluation.

Table 11-1: Final User and Business Requirements

ID	Requirement Area	Improvement Areas	Score	Analysis
UR1	Reporting	• Improved reporting and monitoring at network level [LR2][126] • Custom reports [LR3][119] • Flexible reporting and charting [US20][91] • Evaluating between programmes - generate consolidated reports of the optimal alternative across different programmes. [US46][44]	126	The ability to display data from an HDM-4 analysis is essential to communicate and interrogate the results from an analysis. The current reporting mechanism in HDM-4 is outdated and user expectations have increased in the light of many new data visualisation tools. Improved reporting was a common theme identified by many users

ID	Requirement Area	Improvement Areas	Score	Analysis
UR2	Vehicle Fleets / Vehicle Operating Cost Models	• Update VOC models for electric and hybrid vehicles [US54][105] • Update vehicle fleet parameters for modern vehicle types [US56][79] • Improve modelling of Non-Motorised Transport [US57][60] • Core functions (RUE and RUC) must be retained, these give HDM its reputation for objectivity and results. [US40][41]	105	Vehicle technology and reliability have developed since the initial study for the default vehicle types in HDM-4 and they often need modifying to take account of this Updated VOC models for electric and hybrid vehicles would also be used for Low Carbon Policies and Investments (see also UR7) Incorporate mechanisms to model changes in vehicle fleet composition over time, for example by allowing negative growth rates for certain vehicle types so that they can be phased out over time
UR3	Traffic Data	• Improve traffic data analysis [US47][94] • Differentiate traffic individually for different lanes for traffic reporting and analysis [US48][36] • Enable calculation and reporting of volume capacity ratio [US39][14] • Add the state-traffic matrix of a province or country to the model [US55][14]	94	The results of an HDM-4 analysis are very sensitive to traffic volumes, it is therefore important to ensure traffic and vehicles can be modelled correctly Other delays are not modelled in HDM-4 – for instance, delays due to road works – so this general requirement may be expanded to support such functionality. Axle loading is supported in HDM-4 through sensitivity analysis, or by setting up HDM-4 data inputs in a certain way This requirement perhaps highlights the need for a wider range of case studies and applications as in UR12
UR4	Analysis Framework	• Systematize the treatment of derived traffic, with simple options for incorporating routes WITHOUT and WITH project [US45][78] • Provide a standard methodology to evaluate and assign economic costs and benefits [MDB12][68]	78	Improvements are required to the way diverted traffic is defined to provide ease and consistency through HDM-4, as currently the traffic is defined using both vehicle traffic counts and vehicle composition as a percentage of the total traffic. Note that Sensitivity Analysis is already included in HDM-4 for project analysis and the same approach could be adopted for

ID	Requirement Area	Improvement Areas	Score	Analysis
		• Provide functionality to enable sensitivity analysis in strategy analysis [LR6][30] • Remove size limitations on Expenditure and Budgeting Model (EBM-32) [LR1][28] • Allow for variable costs over the analysis period [US43][25] • Budget constraint analysis is very slow for large networks [US44][25] • Generate prospective scenarios [US42][12]		Programme and Strategy Analysis. Programme and Strategy Analysis tend to be much larger networks so the time and resources to run many sensitivities for these would be significant Note that the Expenditure and Budgeting Model (EBM-32) methodology is used to optimise a work programme with budget constraints but has limitations on the analysis size that HDM-4 can easily exceed. HDM-4 assumes fixed unt costs throughout an analysis and users identified the need to include the ability to vary these costs. HDM-4 requires a user to manually enter all scenarios they wish to explore but some users want the software to do this automatically
UR5	VOC Calibration	• Improved documentation for calibration purposes, review of current defaults to represent a modern vehicle fleet, country database of VOC calibrations to provide greater consistency for HDM-4 projects [LR4][75] • Include the cost of sector policy changes within an analysis and allow shifts in policy to be reflected in the vehicle fleet to enable the costs and benefits or policy shifts to be evaluated [MDB10][31]	75	The importance of adapting and calibrating HDM-4 to local conditions is always highlighted to improve the reliability of an analysis. The documentation and tools available have been highlighted by users as an area for improvement to achieve this Strong support was received for promoting the sharing of such calibration efforts to make the data available for wider use and reduce the need for many individuals performing the same calibration efforts There may be a significant cost of implementing a policy change – for instance, an institutional or infrastructure cost – which may not be included in the economic evaluation – exogenous costs such as this should be enabled in HDM-4 for more flexibility and not just associated with an improvement standard

ID	Requirement Area	Improvement Areas	Score	Analysis
UR6	Deterioration Models	• Have an ongoing programme to update the deterioration models [US31][72] • Relate the IRI deterioration models to user costs and agency costs through graphs and include default costs of maintenance and improvement activities, to serve as a reference for comparisons in developing countries [US5][62] • Deterioration models should be more flexible and should not be so strongly based on AASHTO 1993 concepts [US11][48] • Include models for cobbled surface paving [US10][46] • Reduce number of input variables, many of them are of low sensitivity [US4][40] • Allow allocation of % of traffic types to different lanes for purposes of deterioration modelling [US7][28] • Allow for entry of historical data or time series data collected for calibrating road deterioration models [CS6][22] • Exchange of statistical data for calibration of deterioration models [US8][21]	72	The need for regular reviews and improvements to the deterioration models was identified by users to ensure the software represents new materials, construction methods and impacts in a timely manner rather than a major update every 10-20 years. This equally applies to other models in HDM-5 This is both a technical and business requirement that needs sustainable funding There is some contrast with some users requesting more complex modelling, while some are suggesting the data requirements should be simplified. This highlights the breadth of data available to users of HDM-4 from countries with little data to those who are data-rich. It also highlights the need for deterioration models to be flexible. As with VOC models, users also identified the importance of calibration of the existing models

ID	Requirement Area	Improvement Areas	Score	Analysis
UR7	Low Carbon Policies and Investments	• Include vehicles with alternative fuel types including electric, hybrid, hydrogen [LR11][67] • Vehicle emissions calibration [LR5][61] • Calculate incremental C02 emissions in WITH and WITHOUT project case [US2][59] • Include framework for wider economic benefits in analysis [LR8][56] • Include carbon costs of project/ network improvements [MDB2][41] • Include wider benefits of shift to non-motorised transport [LR7][39] • Include carbon offsets [MDB2][34] • Include mitigating measures for carbon offsets (e.g., tree planting) to mitigate effects of generated traffic [US3][30] • Enable the vehicle fleet to change during the analysis period [LR10][27]	67	Many organisations are now requiring an analysis to include the carbon impact of the investment The users have identified the key improvements in HDM-4 required to deliver this within the software rather than resorting to external tools

ID	Requirement Area	Improvement Areas	Score	Analysis
UR8	Generated and Diverted Traffic	• Include generated / diverted traffic for feasibility studies [US15][66] • Generated traffic is currently incorporated as a disbenefit, this should be corrected [US14][64] • Include generated traffic and exogenous benefits in maintenance standards, not just improvements [US13][60] • Include functionality to improve and systematise approach to diverted and generated traffic [MDB4][38] • Review the traffic modelling within HDM-4 to ensure the different modes of traffic are able to be defined easily and the economic evaluation of alternatives remains correct. The traffic modes to be reviewed include normal traffic, induced traffic, generated traffic, diverted traffic as well as traffic mode shifts [MDB8][38] • Do not require traffic to be specified for each road section involving traffic diversion [US16][28]	66	This category of Traffic Data (see UR3) has been identified as a separate area for development by users Users have identified two types of requirements (i) review of the economic evaluation of diverted and traffic and (ii) review of the mechanism to define these modes of traffic The feedback indicates some misunderstanding on the economic evaluation of diverted and generated traffic which points to the requirement for training, case studies and implementation support (see UR9)

ID	Requirement Area	Improvement Areas	Score	Analysis
UR9	Implementation Support	• Provide regular updates about software update progress [US34][66] • Improve implementation support [CS8][56] • Improve transparency and consistency, through development of guidance documents for development banks and partners [MDB6][43] • Enable the tool to be backwardly compatible with HDM-4 data sets [CS2][32] • Improve dissemination and sharing of results [CS2][27] • Ensure software and user manuals share the same vocabulary and approaches of existing Best Practice manuals for Road Authorities [RA1][18] • Invite or fund students to do their theses using HDM [US33][14]	66	While some of these requirements around implementation support may not relate to the HDM software itself, some may (depending upon the way in which the software is implemented), but all are important to the overall user perception and interaction with the software
UR10	Licensing	• Allow flexible licensing systems, e.g., on a per project basis, or per user, or for limited time period [US25][63] • Allow cost reductions for independent professionals [US28][57]	63	HDM-4 is often used for the evaluation of a one-off project for funding, and users highlight the need for a more flexible licencing for these circumstances The IT environment will also enable the development and management of more flexible licencing system (see also UR 18)

ID	Requirement Area	Improvement Areas	Score	Analysis
UR11	Integration with other tools	• Additional formats for data exchange [US22][61] • Improve data I/O and consider GIS functionality: [US17][52] • Enable better integration and linkage of HDM to RAMS [LR9]&[RA4][50] • Allow HDM to use same network referencing as RAMS [US32][37] • Provide models as libraries for use by other tools [US23][27] • APIs [SoA1][24] • Dashboarding [US21][8]	61	Although there are many examples of HDM-4 integration with external systems, users have identified that this is not a simple task and improvements are required to enable this HDM was not envisioned to be a complete Road Asset Management System (RAMS), so it is important that links to RAMS are made easier. This will open up its integration with existing systems and help to embed HDM's use in the road management lifecycle The fact that this is not higher up the priority list is probably due to HDM-4 use typically being at the one-off project level Some more sophisticated users want to use components of the HDM system rather than the whole system, and they have stated that access to the models or the tools through APIs will enable them to do this This could be another avenue for revenue generation but would probably require good support service to support RAMS vendors

ID	Requirement Area	Improvement Areas	Score	Analysis
UR12	User-friendliness / help system / documentation	• Update the default exercises, including exercises on the level of programmes or strategies [US19][57] • Include procedures for calibration and tutorial in the model [US51][56] • Include case studies in relation to usage with asset management systems [RA2][50] • Use context-sensitive menus [US53][51] • Improve the help system [US18][45] • More user-friendly interface [US50][33] • Generate a calculation engine with a simple interface for loading data and downloading results [US52][10]	57	It is perhaps surprising that user-friendliness is not higher on the list of user-requirements as HDM is often said to have an outdated unfriendly interface but perhaps this highlights functionality is more important that looks, and once the initial learning curve has been overcome it is not difficult to navigate through the interface HDM-4 has extensive documentation, but users have highlighted there needs to be improvements to this and within the software inside to guide new users especially
UR13	Resilience to climate and other disasters	• Allow climate model or parameters to change through the analysis period [MDB2][57] • Improve existing climate model to include additional climate parameters including for example rainfall intensity, impact of heatwaves [MDB2][45] • Incorporate Climate Risk and Vulnerability Assessment [MDB3][34] • Incorporate research into new materials and technologies [MDB3][20]	57	While resilience to climate and other disasters are important topics for governments, development banks and research organisations, perhaps surprisingly the results of the user survey did not appear to indicate that they were of high importance in the user community

ID	Requirement Area	Improvement Areas	Score	Analysis
UR14	Low Volume Roads	• Include framework for wider economic benefits in analysis [LR8][56] • Make it more easily applicable to tertiary / low volume roads [US29][44] • Provide models that have a lower data requirement for countries that do not have sophisticated data collection process in place [LR12][44] • Allow wider economic benefits of the investment to be reflected in the analysis [MDB12][40] • Incorporate functionality of RED into HDM-4 [US30][30]	56	It is surprising that this requirement is not higher up the list as it is often stated that HDM-4 cannot be used for low-volume roads. This may be a consequence of those having this requirement often use a tool such as the Roads Economic Decision Model (RED) instead. Some users likely use both HDM-4 and RED separately, and did not necessarily suggest combing RED functionality into HDM-4 Typically, low-volume roads cannot be economically justified on the vehicle benefits alone and therefore a framework for including monetised wider economic benefits into the evaluation, so they are reflected in the economic indicators Need for multi-criteria analysis of benefits (beyond NPV) and not only low volume roads
UR15	Quality Assurance	• Provide quality control on inputs to improve reliability of analyses and results [CS7][53]	53	Data reliability and quality are currently assumed to be the responsibility of the user, although the interface prevents data that is out of acceptable range from being entered This should be considered in line with other requirements identified by users requesting improved highlighting of important and sensitive inputs
UR16	Modelling delays / Modelling impacts of overloading	• Modelling delays at border posts [CS3][39] • Modelling the impacts of vehicle and axle overloading [CS3][39]	39	Simplify modelling delays at traffic flow descriptions, such as checkpoints and border posts

ID	Requirement Area	Improvement Areas	Score	Analysis
UR17	Maintenance Standards	• Include in the works standards, the incorporation of some structural criteria, such as SNP or deflections, to use it as intervention criteria. For example: When SNP<3 = Work "X" [US58][36] • Review ability of HDM to define maintenance standards that meet typical road maintenance policies [MDB9][30]	36	Although not a highly supported user requirement, adding a new trigger for work standards should be simple to achieve as long as the data is already computed in HDM-4 The range of maintenance and improvement items is embedded in the HDM Work Effects models and should be reviewed with the context of UR6 (Deterioration Models) to ensure there is consistency between the two, as well as supporting work activities that are not currently supported It was perhaps surprising that including improvements for concrete pavements was not highlighted as this is not included in HDM-4 This indicates that the main focus of HDM-4 use is on unsealed and bituminous pavements, but concrete pavements should not be ignored
UR18	IT environment	• Cloud-based [US24][36]	36	The decision to develop a cloud-based version of the software is a fundamental software architectural issue that provides many advantages that makes delivery and management of many of the user requirements and the product easier and more sustainable Although this area was not ranked highly it is thought unlikely the users considered these advantages and therefore considered the platform secondary to the functionality provided

ID	Requirement Area	Improvement Areas	Score	Analysis
UR19	Road Safety	• Improve the evaluation of crash rates within an analysis and ensure that the full costs of accidents are incorporated [MDB11][35] • Include simplified iRAP method to provide high-level assessment of safety impacts, potentially including speed and other safety factors [MDB5][18] • Include models for forecasting accidents and road safety [US1][17]	35	Accident Analysis is included in an HDM-4 analysis but is simplistic, requiring the user to enter accident rates and costs per accident type Accident rates can only be changed when an improvement is applied, they are not responsive to changes in road conditions, traffic volumes, traffic speed, etc Evidence from case studies indicate that not every analysis includes road safety therefore this may have been a factor in the low score Road safety is becoming high on the agenda and improvements in this area perhaps should have been higher on the requirements list to push the agenda forward
UR20	Asset valuation	• Incorporate asset valuation methodologies, tools, and reports to allow comparison of asset valuation over time and to enable comparison among project alternatives [MDB7][29]	29	HDM-4 includes the ability to perform a limited asset valuation of the pavement only To perform an asset valuation within HDM-4 requires additional data to be supplied which is often omitted There are many different approaches to asset valuation. Any approach taken by HDM-4 needs to be assessed to ensure wide acceptance
UR21	Urban Roads	• Review use of HDM for urban networks [LR13][26]	26	Decision-making models for urban roads are very different from those of rural roads Evaluation and prioritisation of treatments on urban roads is often based on very different parameters and criteria from rural roads. When evaluating urban roads there are often many other factors involved in the decision making such as street capacity, junctions, safety, accessibility, traffic management, safe facilities for

ID	Requirement Area	Improvement Areas	Score	Analysis
				pedestrians/cyclists as well as public transportation, sustainability, and maintenance to preserve the road condition. Incorporating all these factors within HDM would require a significant review to ensure it meets the objectives for this type of analysis Urban road decision-making for pavement maintenance is typically not only based around roughness or condition, but also includes traffic congestion. For decisions on new urban roads, traffic modelling needs to be done outside HDM-4 to assign traffic volumes to alternative routes beforehand Therefore, any decision to include modelling of urban roads and generation of treatments and plans would have significant repercussions for the entire model
UR22	Other Assets	• Structures, tunnels, culverts, ditches [US37][21] • Lighting analysis [US36][8] • Expressway projects [US35][0]	21	HDM was a tool aimed at pavements – including the analysis of other assets would certainly broaden the scope beyond what was originally intended The analysis of highways/freeways is supported in HDM-4, but some applications of HDM-4 are applied to expressways that include "smart" dynamics to control access and speed on the road and these are not directly supported in the current HDM-4

For more ease of use the Final User and Business Requirements were converted into a navigable slide deck so they could be presented more easily to end users for the final validation exercise.

12. Validation of the End User Requirements

In this chapter, we present the results of the validation of the Final User and Business Requirements developed throughout the study duration. The validation involved a variety of key opinion leaders and domain experts external to our study team, in the field of HDM-4 and Road Asset Management Systems, who generously provided their time and feedback on the consolidated requirements list and offered recommendations for the next version of HDM-4. We also conducted a mapping exercise with some User Requirements workshops carried out in 2016.

12.1 Mapping Exercise

Here is a short profile of each of the Key Opinion Leaders contacted for this exercise:

- Dr. Tyrone Toole is a highly respected expert in the field of transportation engineering, with a focus on road infrastructure management and planning. He holds a Ph.D. in Civil Engineering and has over 25 years of experience working in both academia and industry. Dr. Toole is known for his contributions to the development and implementation of road asset management systems and strategies in various countries. He has published numerous papers and is frequently invited to speak at international conferences and workshops.
- Dr. Michel Norbert is a leading authority on pavement engineering and transportation planning. With a Ph.D. in Civil Engineering, he has an extensive background in research and consulting on pavement design, maintenance, and management. Dr. Norbert has worked with multiple government agencies and private organisations to develop and implement innovative solutions for improving road networks. His work has been recognised through numerous awards, and he is a sought-after speaker at industry conferences and events.

The rationale for carrying out the requirements mapping exercise between the requirements workshop held in 2016[8] and the fresh requirements captured in this more recent study is to identify the changes in user needs, priorities, and expectations that have emerged over the intervening years. This exercise will help to ensure that the updated system remains relevant, effective, and aligned with the evolving needs of its users and stakeholders. Some specific reasons for conducting the requirements mapping exercise include:

- Identifying changes in user needs: Over time, user needs and expectations can change due to various factors, such as advancements in technology, shifts in user priorities, or changes in the external environment (e.g., new regulations or standards). By mapping the requirements from 2016 to those captured in 2023, you can identify any new or emerging needs that should be addressed in the updated system.
- Reassessing priorities: Some requirements identified in 2016 may have been deprioritised or become less relevant due to changes in the field or user preferences. The mapping exercise will help us reassess the importance of these requirements and determine whether they should still be addressed in the updated system or whether resources should be allocated to other, more pressing needs.
- Ensuring consistency and compatibility: Comparing the requirements from 2016 and 2023 can help identify any inconsistencies or potential conflicts between the old and new requirements. Resolving these issues during the mapping exercise can help ensure that the updated system remains coherent and compatible with its intended purpose and user expectations.
- Evaluating progress: The requirements mapping exercise can serve as an opportunity to evaluate the progress made in addressing the needs identified in 2016. By comparing the old and new requirements, you can assess whether the previously identified needs have been adequately addressed or if further work is required.

[8] A Preliminary Evaluation of Options for the Development of Road Asset Management Tools and the HDM Suite: Request 1 – Development areas and readiness, Tyrone Toole, John Hine and Alexandra Spernol, January 2016

- Informing future development: The mapping exercise can help inform the future development of the system by providing insights into emerging trends, user preferences, and potential areas for improvement. These insights can be used to guide the development of the system and ensure that it remains relevant and valuable to its users and stakeholders.

We have attempted to map the recent requirements (2023) with the older set from 2016. Please note that the mapping might not be perfect due to differences in terminology, priorities, and focus areas. Nonetheless, the comparison can still provide valuable insights into how user requirements have evolved over time.

Recent Requirements (2023)	2016 Requirements	2016 Priorities
UR1 Reporting	SDU3 – HDM reports (High Priority Improved solutions)	Software usability
UR2 Vehicle Fleets / Vehicle Operating Cost Models	RUE1 – VOC (High Priority Immediate solutions, High Priority Improved solutions)	VOC, particularly need for calibration within countries
UR3 Traffic Data	RUE2 – Traffic model (Medium Priority Immediate solutions, Medium Priority Improved solutions)	Medium
UR4 Analysis Framework	EADC3 – Optimisation (High Priority Immediate solutions)	Economics including optimisation and risk
UR5 VOC Calibration	EADC1 – Calibration (High Priority Immediate solutions)	VOC, particularly need for calibration within countries
UR6 Deterioration Models	RDWE4 – New models (High Priority Immediate solutions, High Priority Improved solutions)	High
UR7 Low Carbon Policies and Investments	SEE2 – GHG (High Priority Immediate solutions, High Priority Improved solutions)	Wider economic benefits
UR8 Generated and Diverted Traffic	Not directly mapped	Not directly mentioned
UR9 Implementation Support	Not directly mapped	Not directly mentioned
UR10 Licensing	Not directly mapped	Not directly mentioned
UR11 Integration with other tools	SDU1 – HDM platform (High Priority Improved solutions)	High
UR12 User-friendliness / help system / documentation	Software usability	Software usability

Recent Requirements (2023)	2016 Requirements	2016 Priorities
UR13 Resilience to climate and other disasters	RDWE1 – Climate (High Priority Improved solutions), AM2 – Climate (Medium Priority Immediate solutions, Medium Priority Improved solutions)	Economics including optimisation and risk
UR14 Low Volume Roads	Not directly mapped	Not directly mentioned
UR15 Quality Assurance	Not directly mapped	Not directly mentioned
UR16 Modelling delays / Modelling impacts of overloading	Not directly mapped	Not directly mentioned
UR17 Maintenance Standards	Not directly mapped	Not directly mentioned
UR18 IT environment	Not directly mapped	Not directly mentioned
UR19 Road Safety	SEE1 – Road safety (High Priority Immediate solutions, High Priority Improved solutions)	Road safety and crashes
UR20 Asset valuation	EADC2 – Valuation (High Priority Immediate solutions)	Economics including optimisation and risk
UR21 Urban Roads	Not directly mapped	Not directly mentioned
UR22 Other Assets	Not directly mapped	Not directly mentioned

It appears that several recent requirements align with the older ones, such as Reporting, Vehicle Operating Cost Models, Traffic Data, Analysis Framework, VOC Calibration, Deterioration Models, Low Carbon Policies and Investments, Integration with other tools, Resilience to climate and other disasters, and Road Safety. However, there are also new requirements that do not have a direct mapping to the older set. These might reflect new user needs, changes in technology, or shifting priorities over time.

The mapping exercise generated an interesting discussion around the potentially unfair lower scoring of the recent requirements perceived as needing too much work or put in the "too hard basket," it is essential to consider how these requirements have evolved and whether they can be adapted to fit the current context. For example, low hanging fruit around Road Safety (crashes) can be more easily adopted, without needing full on integration with, for example, iRAP.

In terms of publications, Dr Toole suggested to focus more on knowledge and best practices instead of solely on software, which should be considered the enabler. This can be considered while working on the HDM-4 system, ensuring that the models and methodologies are transferable to other decision support tools and fostering a better understanding of the best practices in the field.

In summary, the requirements mapping exercise between the 2016 workshops and the 2023 study was a useful step in ensuring that the updated system effectively addresses the evolving needs of its users and stakeholders. This exercise has helped identify any changes in user needs, reassess priorities, and inform future development to ensure that the system remains relevant and effective.

12.2 Validation Exercise

Here is a short profile of each of the Key Opinion Leaders contacted for this exercise:

- Professor Martin Snaith is a renowned expert in transportation economics and highway management, with a distinguished career spanning over three decades. He holds a Ph.D. in Pavement Engineering and has held various academic and advisory positions throughout his career. Prof. Snaith is widely regarded for his research and publications on road asset valuation, capital investment strategies, and the development of economic models for transportation decision-making. He is frequently invited to serve on expert panels and to contribute to industry conferences and events.
- Dr. Ian Greenwood is a prominent expert in transportation systems and infrastructure management, with a strong focus on data-driven decision-making and policy development. He holds a Ph.D. in Civil Engineering and has extensive experience in both academia and consulting. Dr. Greenwood is known for his work on the application of advanced data analysis techniques to inform transportation planning and investment decisions. He has published numerous research articles and is a regular speaker at industry conferences.
- Dr. Christian Dunkerley is a leading expert in transport economics and infrastructure financing, with a particular focus on the role of multilateral development banks in supporting transportation projects. He holds a Ph.D. in Economics and has a wealth of experience working with international financial institutions and government agencies to promote sustainable development in the transportation sector. Dr. Dunkerley is recognised for his insights into the challenges and opportunities associated with financing transportation infrastructure and has been invited to speak at numerous industry events and conferences.

The first key opinion leader to provide feedback on the Final User and Business Requirements was Prof. Martin Snaith, who emphasised the importance of preventing the proliferation of simple and appealing clones that could compromise HDM-4's established probity. He stressed the need for transparency and auditability in HDM-4 usage and suggested that capital valuation based on road condition should be its appropriate use.

Prof. Snaith proposed a "suitcase process" where simple inputs can be transparently used and tweaked into standard HDM requirements. This approach could help avoid the need for clones and maintain the probity of the redeveloped HDM-4 system. He also highlighted the importance of addressing the needs of different road types and traffic conditions in HDM-4. He identified two main concerns:

- Balancing Requirements and Software Complexity: Prof. Martin Snaith raised concerns about the potential risk of incorporating too many requirements, which might result in an overly complex system. In response, we have carefully prioritised the most critical requirements, ensuring the system remains focused and manageable. We should also maintain the distinction between HDM-4 and a RAMS to avoid confusion and ensure that the redeveloped HDM-4 system serves its intended purpose effectively.
- Low Volume Roads, Capital Valuation, and Corruption: To address these concerns, we will focus on incorporating capital valuation based on road conditions into the system. Transparency and auditability will be crucial in maintaining the integrity of the redeveloped system, and we will ensure that the relationships and calibrations are transparent and traceable.

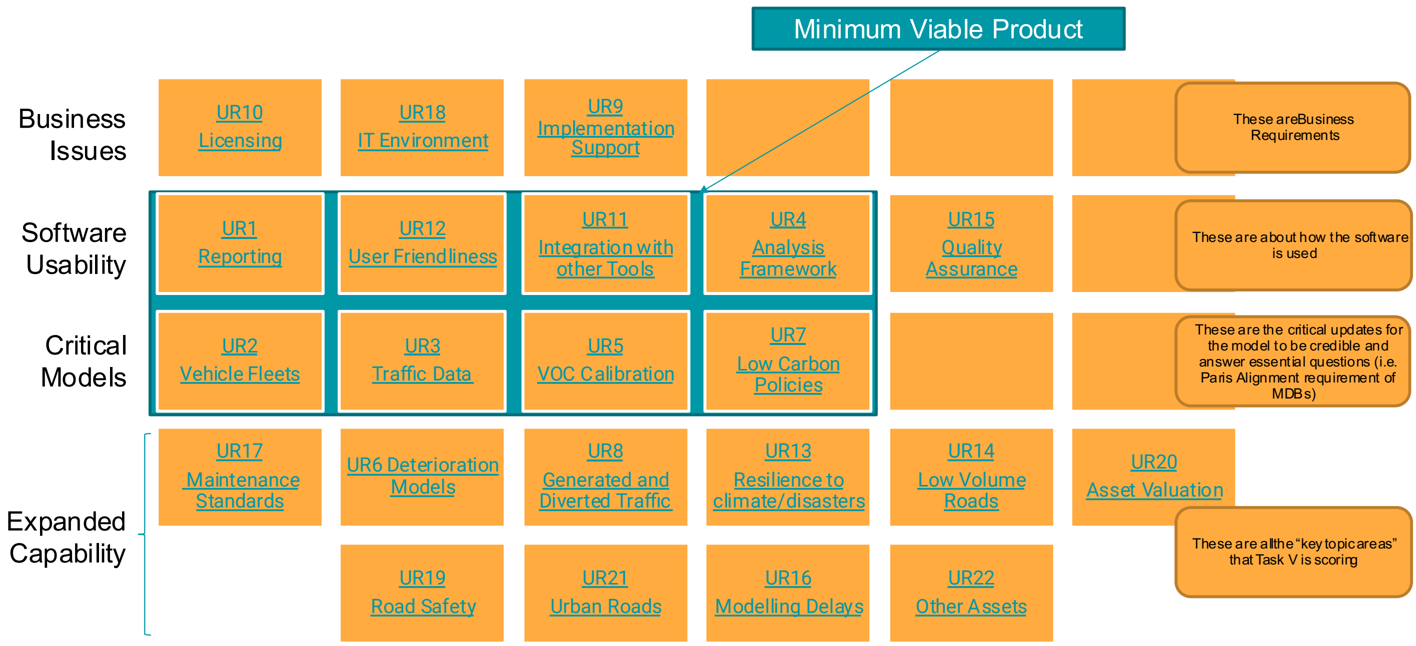
Dr. Ian Greenwood provided a comprehensive analysis of the study end user requirements and further consolidated the requirements into four main groups:

- Business Issues.
- Software Usability.
- Critical Models.
- Expanded Capability.

Together with Dr. Greenwood, we have also provided a way to cluster the requirements into these different categories and this is expressed in

Figure 12-1 below:

Figure 12-1: Clustering of User Requirements



In our shared opinion, Business Issues have less to do with the user experience and should be decided upon by the funders. Software Usability, on the other hand, includes both critical and non-critical requirements. Critical Models are the items that need to be addressed to make the outputs of a redeveloped HDM-4 credible and meet what are now hygiene needs of the Multilateral Development Banks (MDBs) such as the World Bank and the Asian Development Bank. For example, Dr. Greenwood emphasised the importance of incorporating Low Carbon Policies (GHG) as a priority into the next version, as the MDBs have an agreement not to fund projects that are non-aligned with the Paris Agreement.

To be clear, the high scoring requirements that fall outside of the shaded box of the MVP remain important, and they not completely removed or absent (such as UR6 Deterioration Models) they are just not updated at the MVP stage, and the MVP remains reliant upon working with the legacy models initially, to be updated as soon as possible The Minimal Viable Product by definition, has to make some trade off against what can be taken to market. Our analysis represents a starting point, and we leave it to the Technical Advisory Board to make the final definition regrading those requirements that are essential for the MVP.

The only somewhat contentious issue surrounds UR10 (Licensing) as this requires not only a business decision but also some software development in order to implement it, so it rather straddles both areas.

Expanded Capability requirements are all nice to have but not as crucial as the critical models. According to Dr. Greenwood, he ranked the expanded capability requirements in the following order of priority:

1. Maintenance Standards: Addressing limitations on triggering works and allowing the selection from any input data fields will help improve the system's flexibility.
2. Deterioration Models: Revaluating existing models and considering the incorporation of risk-based pavement deterioration models will enhance the system's reliability.
3. Generated and Diverted Traffic: Focusing on guidance for using the system effectively, rather than introducing new models.

4. Resilience and Disasters: While this area is largely outside HDM-4's scope, providing guidance on using HDM-4 for modelling scenarios, such as post-flooding events, will be beneficial.
5. Low Volume Roads: Integrating basic maintenance/renewal regimes and offering guidance on using the system effectively.
6. Asset Valuation: Documenting various approaches used globally before implementation.
7. Road Safety: Focusing on the integration of iRAP and a redeveloped HDM-4 analyses, rather than incorporating iRAP into a redeveloped HDM-4.
8. Urban Roads: Emphasising network modelling and field validation to address urban road issues.
9. Modelling Delays: Recognising the limitations of redeveloped HDM-4 in addressing traffic control and alternative routes.
10. Other Assets: Prioritising pavement management before expanding into other assets.

This analysis provides a useful foundation for the World Bank's Task V “Key Topic Areas” scoring work.

Dr. Greenwood highlighted the limitations of the Maintenance Standards, particularly on triggering works and the inability to select from all input data fields. He also suggested relooking at the Deterioration Models to ensure that they are still relevant, as there are now many risk-based pavement deterioration models available.

He emphasised the importance of guidance on how to use the system for Generated and Diverted Traffic and Resilience and Disasters, as these are largely outside of HDM-4's scope. Dr. Greenwood also noted that Low Volume Roads can be dealt with by including basic maintenance and renewal regimes, and that this is more about guidance on how to use the system than a brand new model.

Dr. Greenwood pointed out that there are many approaches to Asset Valuation being used around the world, and that it is important to document these options before implementing them. He also noted that Road Safety is important, but that iRAP works at a completely different level of data than HDM-4 and has credibility in the field of road safety. He suggested that the focus should be on how to easily integrate the two analyses, rather than fundamentally bringing iRAP into a redeveloped HDM-4.

Regarding Urban Roads, Dr. Greenwood stated that this is a network modelling issue and that no road authority should use HDM-4 output as their work programme. He emphasised that all urban issues should be considered and validated in the field. He also noted that Modelling Delays requires an understanding of traffic control arrangements and alternative routes, and that if the delay is just at a border crossing, the solution is not within HDM-4.

Finally, Dr Christian Dunkerley of CAF (Development Bank of Latin America) provided valuable insights and feedback from a multilateral development bank stakeholder and end user perspective. He agreed with the core work for improving HDM-4 focusing on UR1 (Reporting), UR2 (Vehicle Fleets), UR3 (Traffic Data), UR4 (Analysis Framework), UR5 (VOC Calibration), UR7 (Low Carbon Policies), UR11 (Integration with other Tools), and UR12 (User Friendliness). He also highlighted the importance of addressing the lack of calibration data for HDM-4 users, by suggesting the mobilisation of the international HDM community to collect this data and creating a website or cloud ecosystem for storing recommended calibration data for the model, allowing users to easily access the required data. Christian also mentioned the need for a formal discussion on setting up an online storage facility that includes key inputs related to vehicle operating costs and other non-project specific standard HDM-4 parameters for certain countries.

Dr Dunkerley explained that HDM-4 was traditionally employed to measure benefits for rural/inter-urban links and its main strength is linking the quality of the road surface with vehicle operating costs. HDM-4 is typically used in developing countries where the road quality is poor, leading to high operating costs for vehicles, and vehicle operating cost savings make the largest share of benefits from road projects in these countries. In contrast, in developed countries, the appraisal of inter-urban projects tends to be carried out at the network level and focuses on intersections and road capacity.

However, Dr Dunkerley notes that there are some User Requirements that he does not agree with and that would be difficult to integrate into HDM-4 without reducing its simplicity and usefulness:

- UR13: Resilience to Climate/Disasters - Better addressed through a separate network-based risk model.

- UR14: Low Volume Roads - Wider socio-economic analysis needed, beyond HDM-4's scope.
- UR19: Road Safety - Simplistic assessment within HDM-4; better addressed through a separate tool.
- UR21: Urban Roads – Agreed with Dr Greenwood that it should not be incorporated.
- UR20: Asset Valuation - HDM-4's focus is on pavements; other assets can be assessed outside of HDM-4 using specialised tools.

Dr Dunkerley believes that these additional assessments should be done outside of HDM-4 using separate tools, to summarise his overall position:

- The focus on improving HDM-4 should be on UR1, UR2, UR3, UR4, UR5, UR7, UR11, and UR12.
- Calibration data availability is a crucial issue to address.
- Better data should be a priority (UR15). An international community could be mobilised to collect this data, and a cloud ecosystem could be created to store and share recommended calibration data.
- HDM-4's strength lies in measuring the impact of poor road surfaces on Vehicle Operating Costs (VOCs). Focus should be on maintaining and improving this aspect.
- Trying to add tools to estimate travel time savings, such as at border crossings, could negatively impact HDM-4's core functions. HDM-4 cannot compete with specialised tools like Four-Stage Models and microsimulation tools that have been in development for over 40 years.

13. Conclusions & Recommendations

In this Final Report, our consortium partners, subject matter experts and independent Key Opinion Leaders have conducted a comprehensive analysis of end user requirements for a redeveloped HDM-4. By identifying critical and non-critical requirements and organising them into a developmental pathway, we have established a foundation for defining the Minimal Viable Product (MVP) and the scope for the HDM-4 redevelopment programme. This information will be integrated into the Component B: Final Business Plan report, which runs parallel to the Component A Requirements study.

Our extensive analysis has examined the current state of the art in HDM-4 and other Road Asset Management Software, their deployment by stakeholders, and the user and business requirements that will shape the next version of HDM-4. By carefully prioritising these requirements and incorporating valuable feedback from validation exercises, we can ensure that the redeveloped HDM-4 system will effectively address user needs and continue to be a valuable tool in the road transport sector.

The study has also identified potential collaboration opportunities and experts who could be part of a Technical Advisory Group, supporting the Steering Committee throughout the HDM-4 redevelopment process. Furthermore, our in-depth research into HDM-4 usage, case studies, and best practices will hopefully contribute to the ongoing improvement and evolution of the system.

This report provides valuable insights and recommendations for the next version of HDM-4. By carefully considering and prioritising user and business requirements, we can ensure that the redeveloped HDM-4 system will effectively address the needs of its users and remain a valuable tool. The feedback obtained from the final validation exercise will be instrumental in guiding the redevelopment of HDM-4 and ensuring that it aligns with the expectations of the end users and any other relevant stakeholders.

As the Steering Committee progresses with the HDM-4 redevelopment process, the next critical step is to conduct an in-depth specification and analysis of the recommended MVP. This stage is vital as it will help identify any dependencies and relationships between requirements, which may not have been apparent in the earlier phases. By taking these factors into account, The Steering Committee can create a robust and comprehensive systems requirements evaluation.

A thorough systems requirements evaluation is crucial in ensuring that the redeveloped HDM-4 system is designed and implemented effectively. This evaluation will not only help prioritise requirements but also allow for better resource allocation and project management throughout the redevelopment process. It will enable the winning development team to address potential challenges and mitigate risks before they become significant issues.

Moreover, a comprehensive evaluation of system requirements will facilitate improved communication and collaboration among stakeholders, including end users, developers, and decision-makers. This will help to align expectations, foster a shared understanding of project goals, and ensure that everyone is working towards a common vision.

Furthermore, conducting a detailed specification and analysis of the MVP will provide invaluable insights into the feasibility and viability of the proposed solution. This information will help the development team make informed decisions regarding the technical aspects of the redevelopment, such as software architecture, integration with existing systems, and scalability to accommodate future growth and advancements in technology.

In conclusion, a comprehensive approach to systems requirements evaluation is essential to the success of the redeveloped HDM-4 system. It will ensure that the system effectively addresses the needs of its users and stakeholders while maintaining its relevance and value to the road transport sector. By diligently executing this next crucial step, the Steering Committee can pave the way for a successful HDM-4 redevelopment, ultimately benefiting the entire road transport community.

14. ANNNEX A – DETAILED END USER CASE STUDIES

14.1 Burkina Faso

14.1.1 Date

Between 2011 and 2014 for the implementation of a Road Maintenance Matching fund as part of the Burkina Faso Compact programme.

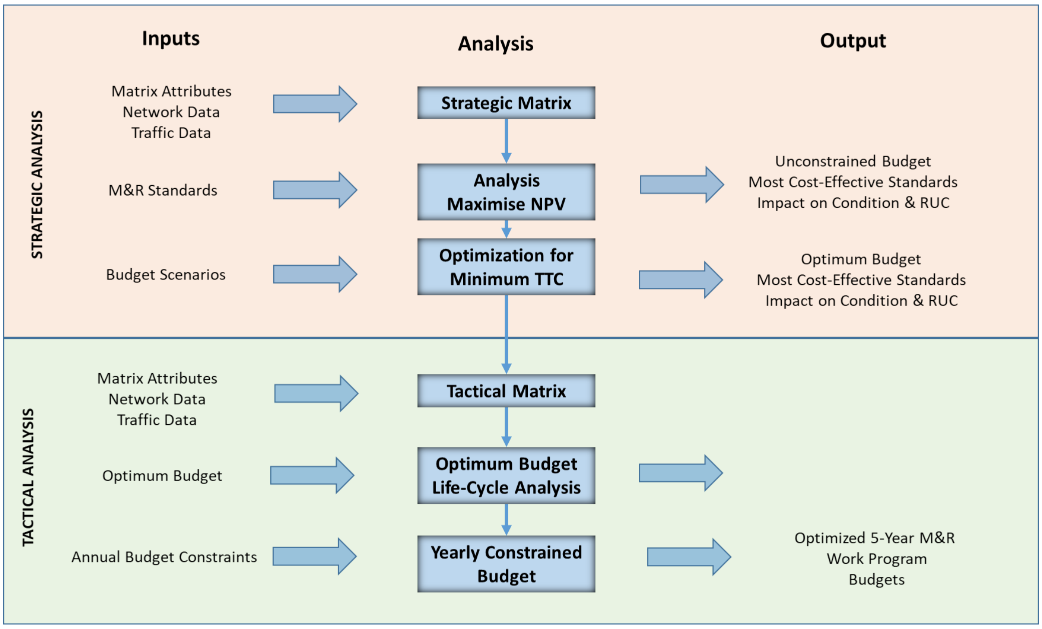
14.1.2 Who Was the Analysis for

This is a unique experience in a way that probably for the first time it was a cadre of staff from a National Organisation in the developing world that took charge in the preparation of road master plan and a rolling road maintenance program using HDM-4. The cadre of staff belong to the Ministry of Transport of Burkina Faso. The assignment was completed by the local staff after undergoing an extensive network level HDM-4 training under consultant oversight.

14.1.3 Analysis Type

The analysis types conducted with HDM-4 were at network level and concerned the Strategic and Programming Analyses. A run of HDM-4 at these levels of analysis was conducted. The two analyses were always conducted successively following the two-stage network analysis method as shown in Figure:

Figure 14-1: Two-stage Network Analysis Process



14.1.4 Network Size

The existing Burkina Faso road network is defined in the Road Referencing System of the RAMS and totals a length: 16,392 km.

14.1.5 Brief Network Description

The Burkina Faso Road Network is divided into three road classes including:

- National roads.
- Regional Roads.
- Departmental Roads.

The surfacing type is divided into four classes including

- Bitumen (mostly surface dressing).

- Modern earth.
- Standard earth.
- Improved tracks type A.
- Improved tracks type B.
- Ordinary tracks.

The distribution of the road network between the three road classes and the surface types is indicated below:

Figure 14-2: Burkina Faso Road Network Composition

Road Classification	Surface Type						
	Bitumen RB	Modern earth RM	Standard earth RO	Improved Tracks Type A PA	Improved Tracks Type B PB	Ordinary Tracks PO	Total (km)
National Roads (km)	3.059	102	2.233	475	264	595	6.728
Regional Roads (km)	28	0	161	1.720	490	1.145	3.544
Departmental Roads (km)	13	0	103	1.677	2.537	695	5.025
Total length main network (km)	3.100	102	2.497	3.872	3.291	2.435	15.297
Rural tracks (km)	0	0	0	0	0	46.095	46.095
Total Network (km)	3.100	102	2.497	3.872	3.291	46.095	61.392

14.1.6 Brief Description of Reason for Analysis

This assignment was done as part of a grant provided by the Millennium Challenge Corporation (USA) as part of the COMPACT program. The latter had a Road Maintenance Activity with two conditions precedent which included the preparation of a Road Master Plan and a 5-Year Periodic Road Maintenance Plan. It was made mandatory the road master plan and the 5-year periodic maintenance plan are prepared by the Government of Burkina staff.

The different activities being provided as part of this technical assistance included:

- Development of a 'Système de Gestion du Patrimoine Route' (Road Asset Management System) with an HDM-4 Interface.
- Level-2 calibration of HDM-4.
- Capacity building in the use of HDM-4 at all levels of analyses.
- Strategic Analysis with the preparation of a Road Master Plan.

- Programme Analysis with the preparation and update of a 5-Year Road Maintenance & Improvement programme.

14.1.7 Level of Calibration Performed

HDM-4 has been calibrated to Level 2 for Burkina Faso conditions and environment prior to its use. The level 2 calibration of HDM-4 has led to the adaptation of the road deterioration and works effect (RDWE) and road user effect (RUE) models for the conditions and environment prevailing in Burkina Faso.

14.1.8 Aspects Considered

The following aspects were most considered in the use of HDM-4 in Burkina Faso

14.1.8.1 Connection to SGPR (RAMS)

An integrated interface between the SGPR (RAMS) and HDM-4 was established (Figure 4). The interface is used to create strategic and tactical network matrices[9] for strategic and programming analysis levels. It can also be used at the project level to prepare road maintenance rehabilitation projects in the form of homogeneous road sections using the dynamic segmentation method. The HDM-4 interface is also used to extract HDM-4 analysis results from the rundata files to generate network-based reports that do not exist in HDM-4, notably the Total Transportation cost graphic.

14.1.8.2 Budget Optimisation and Wider Economic Costs / Benefits

The Strategic and Programme analyses were done in full including budget optimisation under various budget constraints including the optimum budget and actual government budget scenarios to show the impact of both on the road network performance and road user costs. The analysis extended to determining total road user costs, total transport costs, and road user costs savings. Unfortunately, these costs and benefits are not generated by HDM-4 reporting for network level analyses. The HDM-4 interface has been used to extract data from the HDM-4 rundata files to generate these outputs.

14.1.8.3 Project Performance

This a typical example on the use of HDM-4 by a Road Administration in their Asset Management process. The objective of this project aimed at placing road asset management principles at the heart of the road management process and procedures in Burkina Faso. This was achieved by the supporting reform in the road sector by introducing sound road asset management principles such as the creation of a Road Asset Management division within the Ministry of Transport, the establishment of road asset management procedures and manuals, the introduction of the strategic and programming management levels and the preparation of a road master plan and a 5-year periodic road maintenance plan, the development and implementation of a SGPR (RAMS) and the adoption and integration of HDM-4 as the key road maintenance planning tool. The project also included a series of road asset management capacity building trainings include an extensive course on the use of HDM-4 at network level.

14.1.8.4 Value of Project

The value of a project at network level is different from that of a single road project. The value of a project at network level is that of the program value. In the case of Burkina Faso, the value of the project can be categorised in the form of a 20-year strategic plan value and a 5-year road maintenance and improvement program value. The latest values from the 2014 are as follows:

5-Year Program: Total Cost of 147 billion FCFA (Actual Budget). The value of the technical assistance project provided by MCC was around $25 million including periodic maintenance works on around 250 kms. The value of the entire Compact program was around half a billion dollar.

[9] A strategic and network matrix is a group of sections that are grouped according to user-defined criteria to represent the road networking being analysed.

14.1.8.5 Issues with HDM-4 in Completing the Analysis

Network analyses has been completed in Burkina Faso RA after the integration of HDM-4 in their road management process. However, this would have been extremely difficult if not impossible without the design and development of an advanced HDM-4 interface and its integration within the local SGPR (RAMS). This interface facilitated greatly two key aspects in the use of HDM-4 at network levels when dealing with thousands of kilometres of roads. The two aspects included:

The export of data from the SGPR (RAMS) central database to HDM-4 in the form of strategic and tactical matrices. Without this facility, the preparation of data for these two network analysis levels would have taken months instead of minutes as this is now the case with the integrated HDM-4 interface with the Burkina Faso RAMS. This issue has been the most important obstacle in the use of HDM-4 at network level by most road administrations around the world.

Reporting at network level is very poor in HDM-4. Most reports have been designed by people who are totally project oriented. It is practically impossible to generate network analysis reports without using external software to read rundata files and produce meaningful network reports. The following are suggestion for high-level network reporting that may be included in the next version of HDM-4 drawn from the Burkina Faso case study.

14.1.9 Recommendations

Any newer versions of HDM-4 must focus mostly on improving data import and reporting at network level to ensure adoption of the model by road organisations and its integration withing their road asst management processes and systems.

HDM-4 needs few improvements for its use at project level. It already satisfies most of the project-level analysis requirements whether engineering or economic. Any proposals that would focus on improving further project level features and neglect network level analyses will be counter-productive and will not contribute to the adoption of HDM-4 as a key road planning tool in the management of road networks.

14.1.10 Describe the User Journey for MCC (The funding agency)

MCC is not a development Bank but a government aid agency. Their Compact programmes are substantial (in excess of half a billion USD). The Compact include several individual complementary projects hence the name of Compact. The Compact is always executed over a period of 5-years. In the case of the Burkina Faso Compact I, the MCC user journey was totally satisfactory as most of the Compact program was implemented within the 5-year period and within budget.

14.1.11 Describe the User Journey for the Government of Burkina Faso (Beneficiary)

The user journey for the recipient of the MCC grant and all the technical assistance provided to them has been excellent. The decision of this technical assistance was the result of negotiations between the Governments of Burkina Faso and the USA who agreed to the 5-Year Compact programme to provide funding for the implementation of several projects including the Road Maintenance Activity.

Under the Compact program of MCC, all procurements are made by an independent Procurement agent reporting to another independent structure called Millennium Challenge Account (MCA) – Burkina Faso. MCA is setup by MCC for the implementation of the Compact program. Therefore, the procurement of the RAMS and HDM-4 related-activities are procured by MCA’s procurement agent.

MCC supported the funding of all projects and activities under the COMPACT Program including the Road Maintenance Activity.

14.2 Chile

14.2.1 Date

The study begun during 2017, being part of a continuous development in updating and improving the analysis and evaluation tools of the National Road Network.

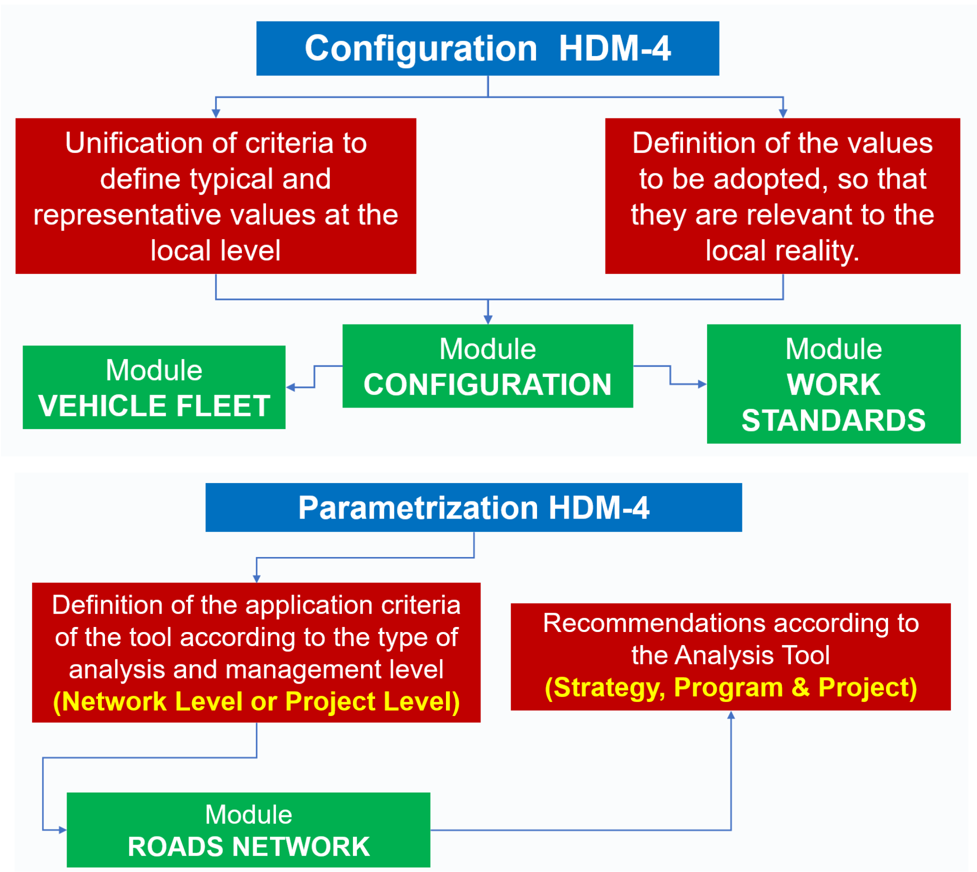
14.2.2 Who was the Analysis Completed for

The Ministry of Social Development (Chile), with the aim of standardising the HDM-4 tool for its use and application in the evaluation of interurban road projects.

14.2.3 Analysis Type

The analysis conducted is associated with the Configuration and Parameterisation of the HDM-4 software to the conditions of Chile. For this, the existing information in the country has been used to feed into the different standardised parameters that make up the different modules and submodules of the software.

Figure 14-3: Configuration and Parametrisation of the HDM-4 Model



14.2.4 Network Size

The existing Chilean road network totals a length 20,582 km surfaced roads.

14.2.5 Brief Network Description

The Chilean Road Network is divided into two road classes including:

- National roads.
- Regional Roads.

The surfacing type is divided into two classes including:

- Asphalt Pavements.
- Concrete Pavements.

The distribution of the road network between the three road classes and the four surface types is indicated below:

Table 14-1: Chilean Road Network Composition

Type	PAVED (km)			
	Asphalt	PPC	Asphalt/PPC	Basic Roads
Nacional (A) (km)	7.683,77	1.156,02	514,1	0,0
Regional (B) (km)	5.302,86	361,18	19,37	95,70
Provincial (C) (km)	1.878,97	112,54	0,36	66,74
(D) (km)	2.702,92	228,88	0,0	164,15
(E) (km)	208,34	20,51	0,0	65,85
Totals (km)	17.776,86	1.879,13	533,83	392,44

14.2.6 Brief Description of Reason for Analysis

The objective of Parameterizing the HDM-4 model to the conditions of Chile is to modernise a tool for the analysis and evaluation of road projects, adapting to a standardization and improvement of the evaluation protocols of the Ministry of Social Development and the Ministry of Public Works.

The adaptation and modernization of the model aims to generate a standard tool that represents the characteristics of the country and can be used for road management, project evaluation and strategic planning of road networks.

The configuration is carried out based on the information available in the country, considering its availability in the different government entities, which in turn would benefit from updating the tool.

This study entails the comparison of the results delivered by the current evaluation tool (HDM-III) and the results of HDM-4, with the objective of sensitivity to the impact of the modernization.

14.2.7 Level of Calibration Performed

The calibration level developed during the study corresponds to Level 1 – Basic Application.

14.2.8 Aspects Considered

For the Development of the Configuration and Parameterisation of the HDM-4 model to the conditions of Chile, the following aspects/inputs of information were considered.

- Historical data of Functional and Structural evaluation of the National Road Network.
- Information available from vehicular traffic measurements.
- Current Regulations in terms of design, construction, and maintenance of pavements – Road Manuals.
- Historical Meteorological records of different sectors of the country.
- Road Inventory of the National Road Network.

- Representative Vehicle Fleet; features and associated costs.
- Representative Works Standards; Maintenance and Improvement.

The analysis of the current evaluation tool has been considered important, in order to identify the differences that exist between both; inputs required, parameters considered and the results.

14.2.9 Project Performance

It was successful since the study for the development of a road project management and evaluation tool such as HDM-4. From this study, calibration studies have been generated, the adaptation of the HDM-4 tool for the evaluation of interurban projects and the generation of specific capacity studies and weighing studies that improve the representativeness of the parameters included in the program.

14.2.10 Issues with HDM-4 in Completing the Analysis

No problems are identified with the use of HDM-4.

The difficulties in this type of study come mainly from the sources of information, which are not familiar with the parameters and/or units used by the different modules and submodules of the program. In addition to the above, the modernization of analysis and evaluation tools in government entities is always a challenge, since leaving the paradigm of the old tool entails a greater effort in dissemination and training of officials.

14.2.11 Describe the User Journey (for the Bank)

There is no Bank involved as this is case study concerns us of HDM-4 by a national road agency and not a road investment project funded by a development bank or an international donor.

14.2.12 Describe the User Journey for the Chilean Road Authority

The user journey for the Chilean Road Authority has been excellent. It is important to emphasize that the same authority has promoted the study, looking to improve the basis of analysis tools for the evaluation and planning of road projects, giving continuity to the research that has been conducted for years in this area.

The objective of the study was to generate a common base of the parameters that make up HDM-4 for the modelling, analysis, and evaluation of the road networks in Chile, which was complemented with the Calibration study of the Deterioration and Vehicle Operation Costs models. Both professionals from the Ministry of Social Development, as well as those from the Ministry of Public Works, use this Object Base for the evaluation of road projects. The HDM-4 files (Object) are used for the planning and investment of the conservation and maintenance budgets of the National Road Network.

14.3 COMESA North-South Corridor

The COMESA (Common Market for Eastern and Southern Africa) North-South Corridor runs between the port of Dar es Salaam in Tanzania to the Copperbelt of Zambia and DR Congo and down through Zimbabwe and Botswana to the ports in southern Africa, taking in 'spur' connections through Malawi and Mozambique in the east.

14.3.1 Date

The assignment was carried out between July 2011 and September 2013.

14.3.2 Who was the Analysis Completed for

The analysis was completed for Project Management Unit (PMU) of Regional Trade Facilitation Programme (RTFP), which provides the Secretariat to the COMESA-EAC-SADC task Team.

The Regional Economic Communities (REC) of the Common Market for Eastern and Southern Africa (COMESA), the Southern Africa Development Community (SADC) and the East African Community (EAC) have long recognised the importance of improving trade facilitation in the context of deepening regional integration and in reducing the costs of cross-border transactions and so improving livelihoods. As such, the RECs have supported a number of trade facilitation instruments as well as developing plans for regional infrastructural development programmes.

14.3.3 Analysis type: (Project, programming, strategic level analysis)

Strategic Level Analysis of Investments in the North-South Corridor Using HDM-4.

RTFP PMU wished to demonstrate whether an efficient North-South Corridor is economically viable to the region or otherwise. The North-South Corridor was a pilot Aid for Trade programme which was administered through the COMESA-EAC-SADC Tripartite process that focuses on transport and transit issues.

RTFP PMU therefore proposed to undertake a study with the main objective of preparing a global overarching economic document that would satisfy donors (and private funds) that ultimately an efficient North-South Corridor is economically viable in the medium to long term period. RTFP PMU commissioned the University of Birmingham (as the Consultant) to use the Highway Development and Management (HDM-4) tool to conduct a strategic level study of the North-South Corridor to illustrate the primary economic benefits of an efficient North-South Corridor.

14.3.4 Network Size

The road network comprised mainly paved roads of asphalt concrete and surface treatment. It was generally in fairly good condition although there were sections of road that were in urgent need of rehabilitation and improvement. The table below gives a summarised distribution of the road sections included in this study and the map below of the North-South corridor.

Table 14-2: Summary of Road Sections in the COMESA North-South Corridor

Country	No of Sections	Length (km)	Network Coverage (%)
Botswana	20	1,252	12
DR Congo	4	400	4
Malawi	17	1,076	10
Mozambique	4	412	4
Republic of South Africa	8	1,901	18
Tanzania	14	982	9
Zambia	34	2,616	24
Zimbabwe	16	2,058	19
Total	**109**	**10,697**	100

Figure 14-4: Map of the COMESA North-South Corridor

14.3.5 Brief Network description:

The road network comprised mainly trunk roads. There were also heavily trafficked sections that created bottlenecks in terms of structural capacity, and cause closure of the whole network if blocked e.g., bridge crossings.

Traffic on the North-South Corridor is characterised by exports of mining and agricultural products and imports of manufactured goods. The main operating feature of the regional road transport routes identified by RTFP (2008), which affected transport efficiency, costs, and tariffs, was the severe imbalance of freight flows, leading to empty return hauls. This imbalance could be seasonal and an empty return haul by road effectively means that the transport cost almost doubles. The traffic data collected as part of the study gives a summary of the average daily vehicle-kilometres by country in the table below. This shows that the roads in the Republic of South Africa carry about 70% of the total number of vehicle-kilometres in North-South Corridor. The number of medium and heavy goods vehicles, expressed as a percentage of the total vehicle-kilometres for each country, varies from about 2% in DR Congo to 29% in Zambia.

Table 14-3: Average Daily Vehicle-Kilometres in the North-South Corridor

Country	Average Daily Veh-km	Percent of Average Daily Veh-km	Percent of country Veh-km by Medium and Heavy Goods
Botswana	2,383,106	4.9	12.0
DR Congo	167,821	0.3	2.0
Malawi	2,004,301	4.1	15.0
Mozambique	271,124	0.6	2.0
Republic of South Africa	34,370,000	70.0	25.8
Tanzania	1,496,000	3.0	12.0
Zambia	4,287,838	8.7	29.0

Zimbabwe	4,135,458	8.4	28.0

In the study it was estimated that the cost of delays at border post crossings in the region amounted to many millions of US dollars. Table 3 presents the Border Posts in the North-South Corridor.

Table 14-4: Border Posts in the North-South Corridor

No	Name of Post	Countries Joined
1	Kasumbalesa	DR Congo - Zambia
2	Tunduma BP	Tanzania - Zambia
3	Songwe	Tanzania - Malawi
4	Victoria Falls	Zambia - Zimbabwe
5	Chirundu	Zambia - Zimbabwe
6	Kazangula	Zambia - Botswana
7	Mchinji	Zambia - Malawi
8	Zobue	Malawi - Mozambique
9	Dedza	Malawi - Mozambique
10	Beit Bridge	Republic of South Africa - Zimbabwe
11	Lobatse	Republic of South Africa - Botswana
12	Gabarone	Republic of South Africa - Botswana
13	Martin's Drift	Republic of South Africa - Botswana
14	Nyamapanda	Zimbabwe - Mozambique

14.3.6 Brief Description of Reason for Analysis

The main aim of the first stage of the study was to prove the feasibility of using HDM-4 to show, at the strategic level, the economic benefits of an efficient North-South Corridor in relationship to trade in the region.

The specific objectives were to prepare and apply HDM-4 at a strategic level to study the impact of different road investment alternatives on the North-South corridor road network, and to determine the need for a further study of the North-South Corridor.

In order to achieve the objectives of this project, the Consultant carried out a number of tasks which are summarised as follows:

- Established a baseline case of the present economic situations within the Corridor.
- Defined the link characteristics within the corridor and the network structure for HDM-4 application.
- Identified, collected, and processed data needed for the specific study including the present vehicle characteristics as well as expected new vehicle types that will use the corridor once it is improved.
- Adapted HDM-4 to local conditions, initially achieved a Level 1 Calibration of HDM-4 models.
- Developed several investment scenarios for the North-South Corridor which considered growth in trade, traffic, and the economy.
- Specified different road improvement alternatives for the corridor and for each future scenario that was analysed.
- Carried out a number of HDM-4 runs as necessary for all the combinations of factors and improvement alternatives and conducted analyses of the results.

The main project deliverables included the following: a customized HDM-4 workspace for North-South Corridor, Strategic level studies related to agreed future road network improvement scenarios and their financial, economic, and technical impacts, and project final report that documented the study methodology, procedures, and results.

There were at least three unique features of this project: (i) corridor analysis passing through several different countries, (ii) vehicle and axle overloading and (iii) analysis of delays at border posts.

14.3.6.1 Overloading

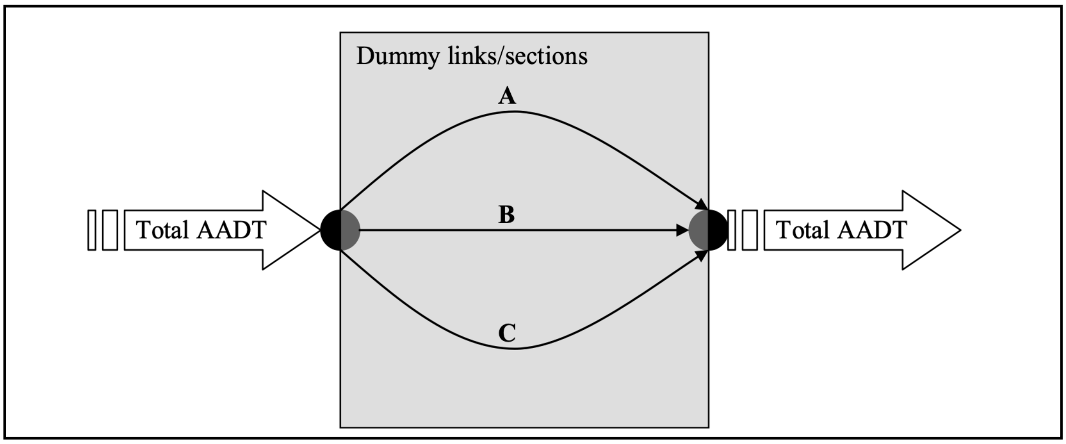
Overloading on the Corridor has been an issue based on specific studies in the region. Regional freight traffic is usually carried in large double trailer, seven-axle combination rigs, with a maximum gross vehicle mass (GVM) of 56 tonnes. In order to preserve the road infrastructure and ensure reasonable usable lifetimes, countries in the region have generally agreed the following axle load limits (RTFP, 2008): single-steering-axle two tyres 8 tonnes, single-axle dual-tyres 10 tonnes, tandem axle four tyres 16 tonnes, tandem axle dual tyres 18 tonnes, triple-axle six tyres 24 tonnes, and triple-axle twelve tyres 24 tonnes. However, not all countries apply these axle loading limits. According to one report ANE (2007) of a study on axle load survey in Mozambique, it was found that 35% of trucks were overloaded by 34%.

In this study, the impacts of overloading on the Corridor were reflected in the HDM-4 models in terms of increased road deterioration and agency costs resulting from higher equivalent standard axle loads, and increased vehicle operation costs as a consequence of higher gross vehicle mass (GVM).

14.3.6.2 Border Posts and Delays

The modelling of delays at border posts necessitated advanced (or special) use of HDM-4 in order to study the related impacts. The border post crossings were modelled within the road network using dummy road sections with adjusted characteristics to simulate the delays experienced in real border crossing operations. **Error! Reference source not found.** illustrates the representation of the dummy links and the traffic characteristics associated with each dummy link labelled A, B and C.

Figure 14-5: Border Post Crossing Model



The vehicles using link A are Passenger Cars, Buses, Mini-Buses, Light vehicles; the vehicles using link B are Refrigerated Trucks, Oil Tankers; and the vehicles using link C are Heavy Trucks, Containerised. The AADT for each dummy link was determined on the basis of the traffic composition on the border approach road sections.

As an example of the modelling approach described above, the details of border post delays at Chirundu are presented in below:

Table 14-5: Border Post Delays at Chirundu

Dummy Link	Vehicle types	Travel Direction	Delays (in Hours)
A	Passenger Cars, Buses, Mini-Buses, Light vehicles	North-bound	1
		South-bound	1
B	Refrigerated Trucks, Oil Tankers	North-bound	31
		South-bound	7
C	Heavy Trucks, Containerised	North-bound	32
		South-bound	32

Source: Transport Logistic Consultants

In modelling using HDM-4, the total cost of delays at border posts was calculated from the sum of the following cost components: value of goods delayed, additional vehicle crew cost, additional overhead cost, and passenger time value.

14.3.7 Level of Calibration performed

The target level of the configuration and calibration was Level 1 Calibration. This determined the value of required basic input parameters, adopted many default values, and calibrated the most sensitive parameters with best estimates, included desk studies and minimal field surveys.

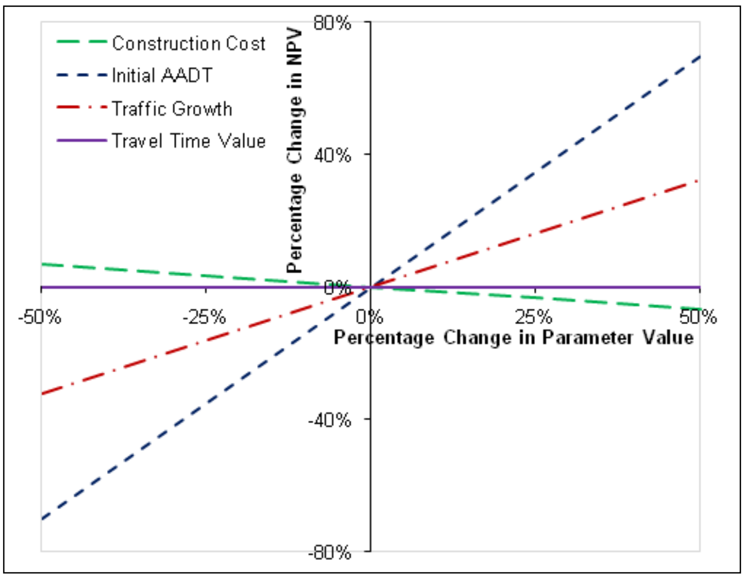
14.3.8 Aspects considered

Sensitivity Analysis

It was important to recognise the medium and low levels of confidence in some of the data used in this study. A sensitivity analysis was therefore undertaken to determine the effects of variations in the values of key input data on Net Present Value (NPV) and the timing of positive cumulative net economic benefits. The input parameters tested were initial AADT, traffic growth rate, construction costs and travel time value. The base values used in the study were varied from -50% to +50%.

Below is a “spider diagram” that illustrates the degree of sensitivity of each parameter tested on NPV. With respect to NPV, initial AADT is clearly the most sensitive parameter followed by traffic growth rate. Travel time value and construction costs were the less sensitive parameters.

Figure 14-6: Sensitivity of Key Parameters on Total NPV



14.3.9 Was the project successful?

The project was successful as it demonstrated clearly that there was an attractive rate of return to be realised from investment in the North–South Corridor. A full road works programme for 20 years has also been produced showing when each section is to receive an intervention with costs. This programme was adopted by the road agencies that manage the roads along the North South corridor to guide preparation of their own national road investment plan.

14.3.10 Value of Project

The total financial investment required for road network improvement was calculated to be about US$ 9.8 billion of which US$ 6.4 billion was capital investment and US$ 3.4 billion was recurrent costs. Technically the long-term average road condition, over the 20-year analysis period, would be 3.1 IRI. The total financial requirement for border post improvement was about US$ 0.7 billion of which US$ 0.3 billion was capital investment and US$ 0.4 billion was recurrent costs. The annualised financial requirement to improve the road network was approximately US$ 46,700 per km. The economic return on this investment (i.e., the NPV) would be US$ 29.5 billion. The benefit/capital cost ratio associated with this investment would be 4.6.

14.3.11 Issues with HDM-4 in Completing the Analysis

There was one particular issue with HDM-4 in completing the analysis, that is, modelling delays at border posts between countries. Also, HDM-4 was not adequately flexible enough to model the impacts of vehicle and axle overloading.

14.3.12 Describe the User Journey (for the Bank)

The Bank was not involved.

14.3.13 Describe the User Journey (for the Road Authority)

The user journey was very good. The study objectively of prepared a global overarching economic document that would satisfy donors (and private funds) that ultimately an efficient North-South Corridor is economically viable in the medium to long term period.

In the backdrop, the Roads Development Agency (RDA) of Zambia obtained funds from the European Union Contribution Agreement to meet the costs of the techno studies and detailed engineering studies for the rehabilitation of the T002 road between Serenje and Nakonde. The 611.5km Serenje–Nakonde section was further subdivided into three subsections for ease of project implementation. These were:

- Serenje-Mpika (238.3km).
- Mpika-Chinsali (164.6km).
- Chinsali-Nakonde (208.6km).

Three International Consultants were awarded contracts to carry out the feasibility and detailed design of the Serenje-Nakonde road.

There were similar experiences in the other countries as well. Thus, the study helped promote the use of HDM-4 for road investment appraisal and policy studies within the countries through which the North-South corridor passes.

14.4 Malaysia

14.4.1 Date

A project concerning the Performance Based Contracts (PBC) for federal roads in peninsular in 2016.

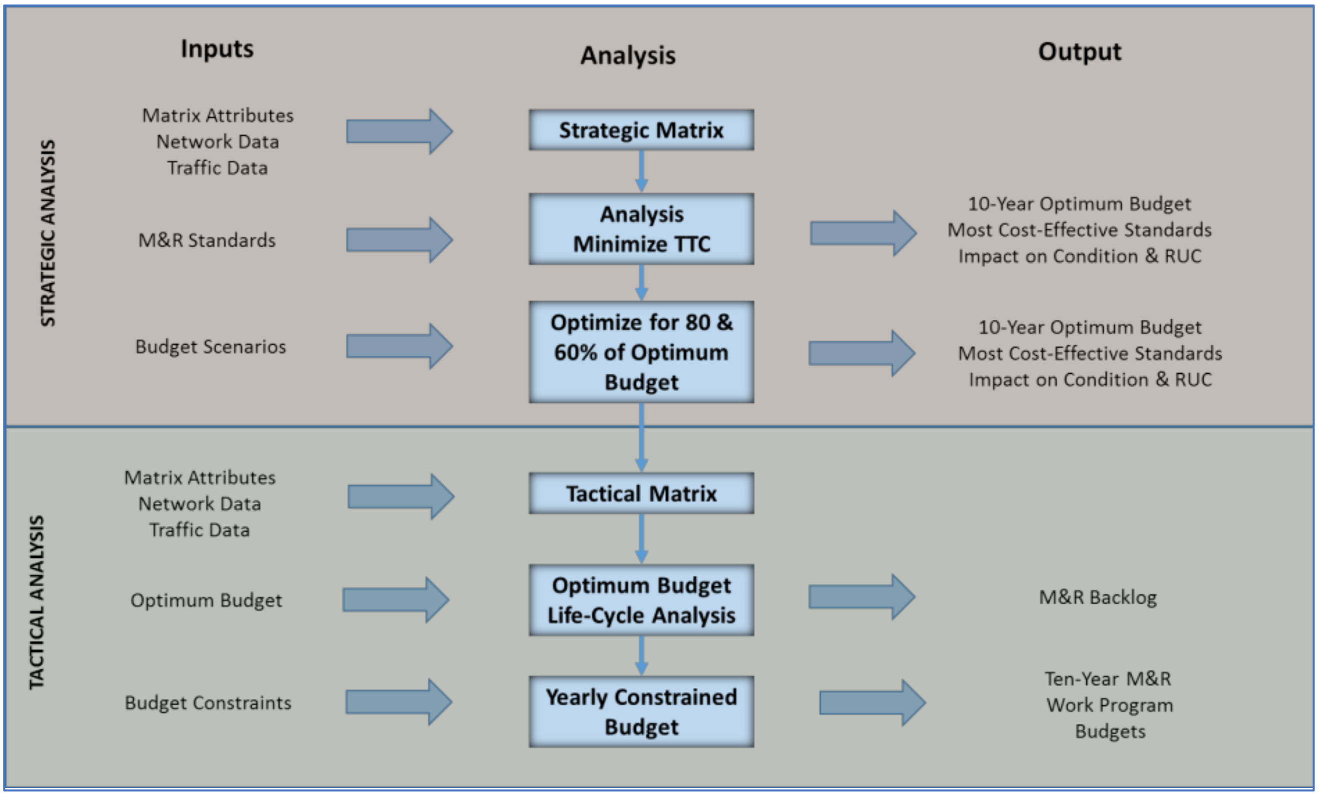
14.4.2 Who was the Analysis for

The work was completed for the Malaysia Road Authority, JKR.

14.4.3 Analysis Type

The analysis types conducted with HDM-4 were at network level and concerned the Strategic and Programming Analyses. A run of HDM-4 at these levels of analysis was conducted following the two-stage network analysis method as shown in **Error! Reference source not found.** below.

Figure 14-7: Two-stage Network Analysis Process



14.4.4 Network Size

The total Federal Roads study network in Southern Peninsular Malaysia is approximately 2,710 km in length. The network consists of several road categories: Primary, Secondary, Industrial, Federal Institutional (FI) and Felda/Regional development roads.

14.4.5 Level of Calibration Performed

A level-3 calibration of HDM-4 for Malaysia conditions and environment conducted previously by OPUS for the expressway network under concession by PLUS, under the supervision of Consultant Akli OURAD, has been used. The level 3 calibration of HDM-4 has led to the full adaptation of the road deterioration and works effect (RDWE) models for the conditions and environment prevailing in Malaysia.

The Level 3 calibration adjustment factors adopted for the federal roads are indicated in the table below:

Table 14-6: Adopted HDM-4 Calibration Factors

Pavement Group	Adjustment Factors										
	Krid	Krst	Kcia	Kciw	Kcpa	Kcpw	Kgm	Kgs	Kgc	Kgr	Kgp
P1T1AMAB	2.26	0.65	0.75	0.80	0.72	2.00	0.03	0.80	0.75	0.60	0.00
P1T1AMAP	0.00	5.50	0.78	1.85	0.09	0.30	0.03	0.01	0.01	0.01	0.00
P2T2AMGB	0.10	0.01	1.00	1.00	0.15	0.55	0.03	0.05	0.05	0.05	0.00

Key:

Krid: Initial densification of rutting (where applicable)
Krst: Rutting progression due to structural fatigue
Kcia: Initiation of all cracking
Kciw: Initiation of wide cracking
Kcpa: Progression of all cracking
Kcpw: Progression of wide cracking
Kgm: Roughness progression due to age-environment
Kgs: Roughness progression due to structure
Kgc: Roughness progression due to cracking
Kgr: Roughness progression due to rutting
Kgp: Roughness due to plastic deformation

14.4.6 Aspects Considered

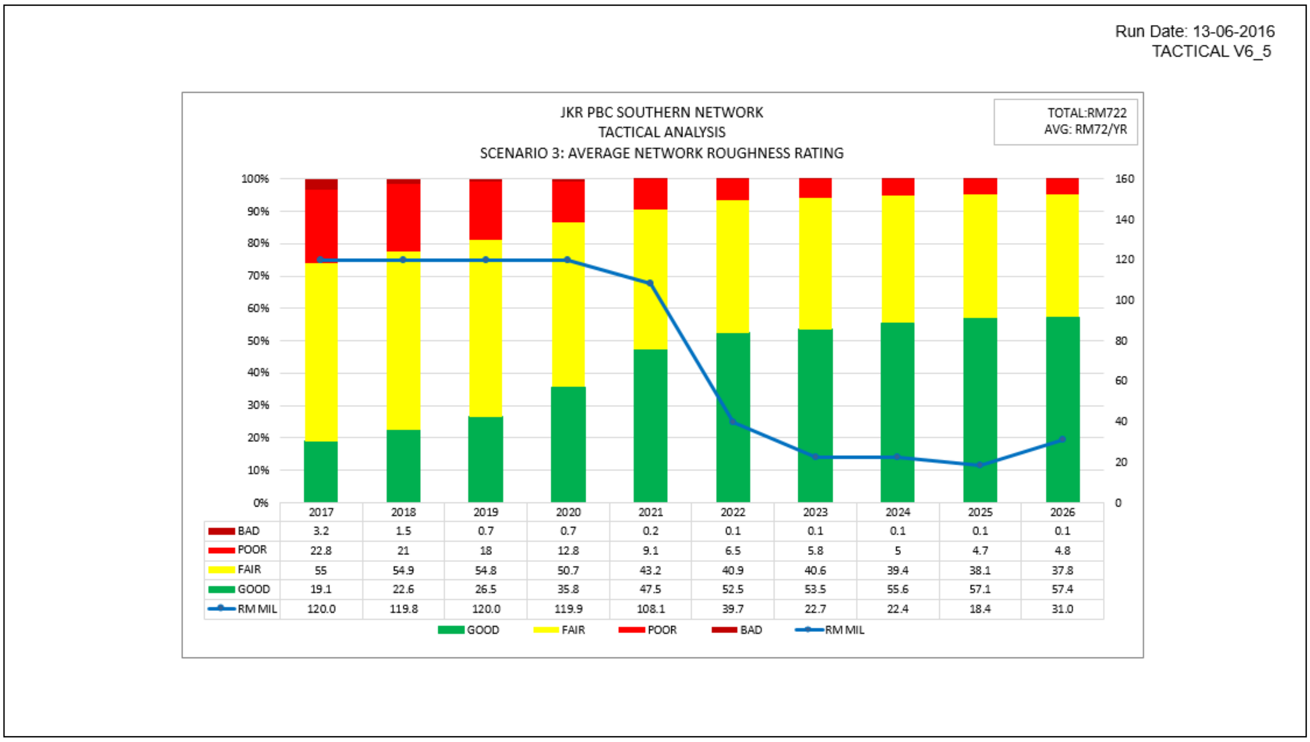
The following aspects were most considered in the use of HDM-4 in this project in Malaysia.

- Budget Optimisation and Wider Economic Costs / Benefits. The Strategic and Programme analyses were done in full including budget optimisation under various performance and budget scenarios to determine the most cost-effective 10-year program of maintenance and improvement to serve as the base reference budget for the PBC bid evaluations.
- Economic Costs / benefits. The analysis extended to determining total road user costs, total transport costs, road user costs savings, maintenance savings for the road agency and performance impacts on the road network object of the PBC bid.

14.4.7 Project Performance

This a typical example on the use of HDM-4 by a Road Administration in preparation for the procurement of Performance Base Contract (PBC) for the road maintenance of a part of their road network. The following Figure 3 shows an output derived outside HDM-4 that shows the performance impact of the retained Budget Scenario.

Figure 14-8: Impact of the Retained Budget Scenario on the Road Network Performance



Combined condition and spending shows the impact of the spending profile on the condition of the road network. This scenario was adopted by the Road Agency as the 10-year budget shows an improvement on the overall performance.

14.4.8 Value of Project

The Net Present Value of the total 10-yaer programme is estimated at RM 2,491.599 million as shown in the table below:

Table 14-7: Road User Cost Savings and Net Benefits under Optimum Budget

State	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs	Net Exogenous Benefits (E)	Net Present Value (NPV = B+E-C)
Johor State	770.377	548.943	540.723	2,178.827	0.000	1,638.104
Melaka State	132.522	85.552	85.262	356.955	0.000	271.693
Negeri Sembilan	285.745	198.671	195.137	776.939	0.000	581.802
Total Southern Region	1,188.645	833.166	821.122	3,312.721	0.000	2,491.599

14.4.9 Issues with HDM-4 in Completing the Analysis

As with all network analyses, it proved difficult to integrate HDM-4 with the local database. In Malaysia a special interface was designed and used by the Consultant to perform the export of data to HDM-4 for strategic and programme analyses.

It is practically impossible in HDM-4 to generate network analysis reports without using external software to read rundata files and produce meaningful network reports. The following reports generated outside HDM-4 as part of this study could be included in the next version of HDM-4.

Figure 14-9: Budget Distribution under Various Section Alternatives

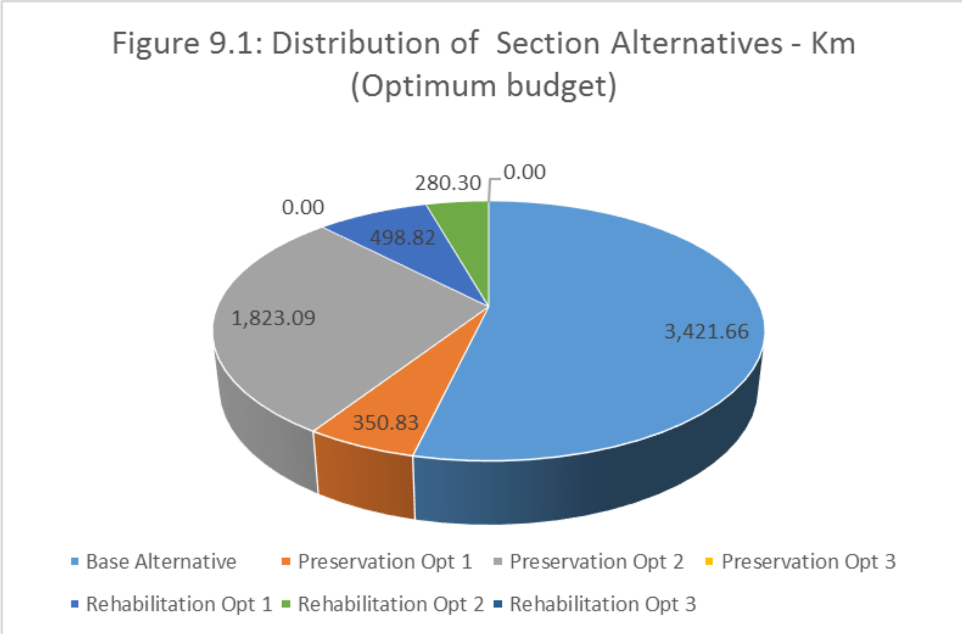


Figure 14-10: Cash Flow for each Budget Scenario

Year	Budget in RM million		
	Optimum Budget	75% Optimum Budget	50% Optimum Budget
2017	256.340	208.119	167.678
2018	351.487	260.156	151.635
2019	9.555	9.555	181.120
2020	2.066	2.066	13.441
2021	6.296	0.000	0.000
2022	15.803	1.926	0.000
2023	1.926	0.000	0.000
2024	15.779	4.842	0.000
2025	20.752	12.974	3.208
2026	19.936	25.522	13.987
2027	5.098	12.163	31.847
2028	142.546	102.083	49.925
2029	17.075	7.483	27.546
2030	23.364	11.109	158.723
2031	16.411	14.545	9.703
2032	19.766	26.994	26.994
2033	12.357	12.357	12.357
2034	3.827	3.827	3.827
2035	23.354	18.708	12.005
2036	24.539	24.539	20.611
Total 10 Years	**699.940**	**525.160**	**531.068**
Total 20 Years	**988.278**	**758.968**	**884.606**
Average 5 Years	**125.149**	**95.979**	**102.775**
Average 10 Years	**69.994**	**52.516**	**53.107**
Average 20 Years	**49.414**	**37.948**	**44.230**

Figure 14-11: Budget Allocation by Budget Scenario

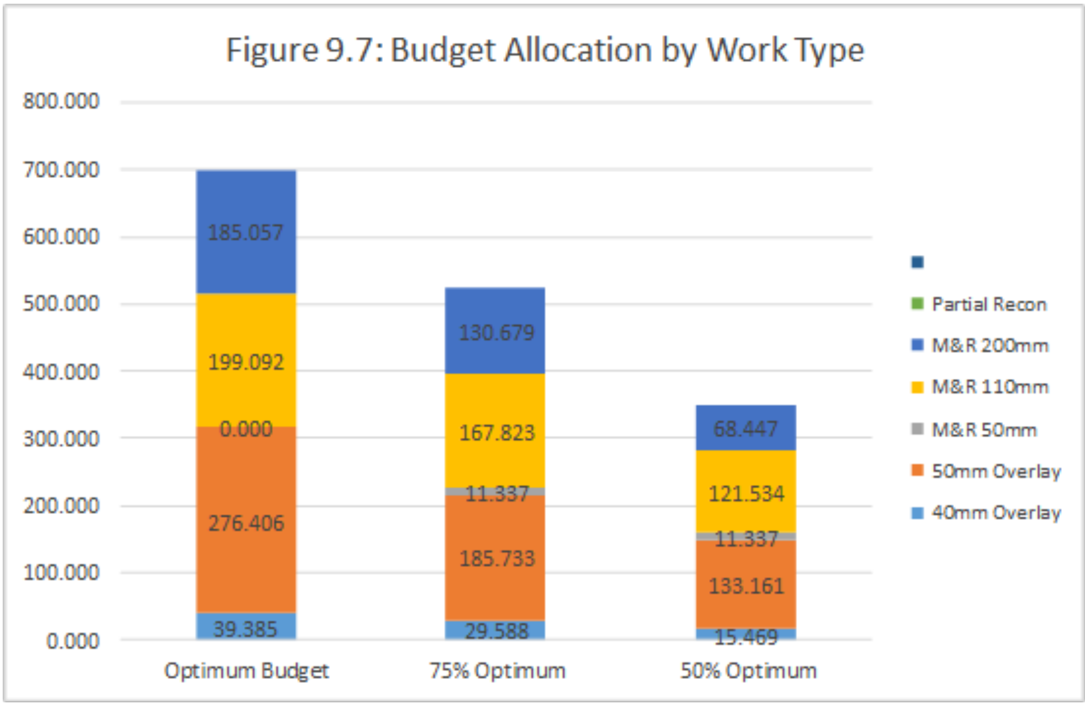


Figure 14-12: Budget Allocation by Road Class

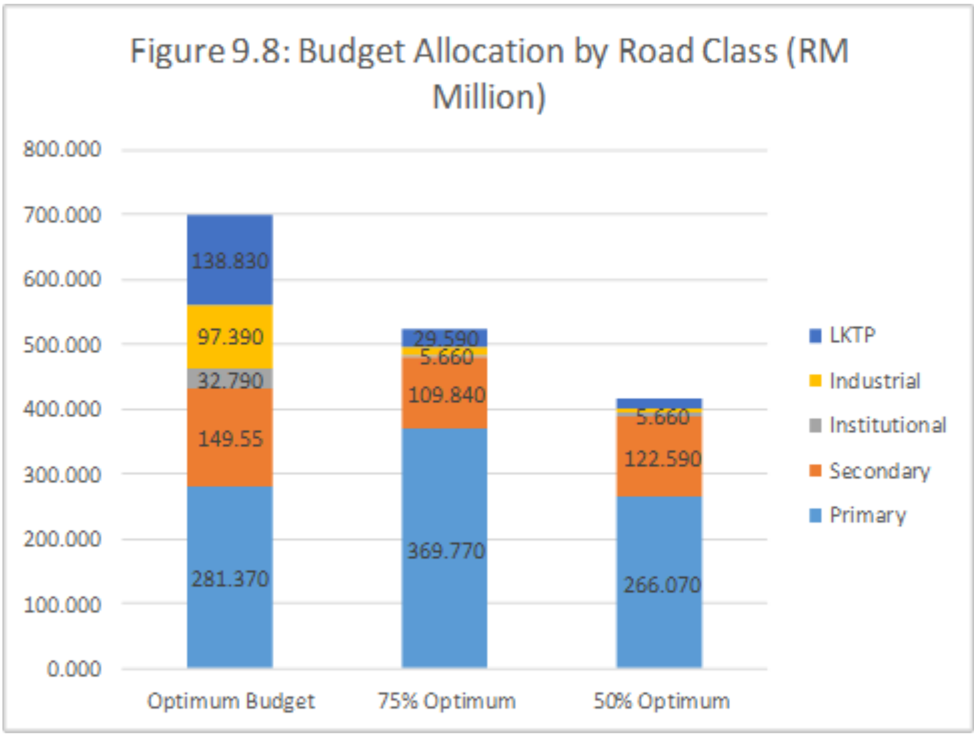


Figure 14-13: Funding Impact of Road Network Performance

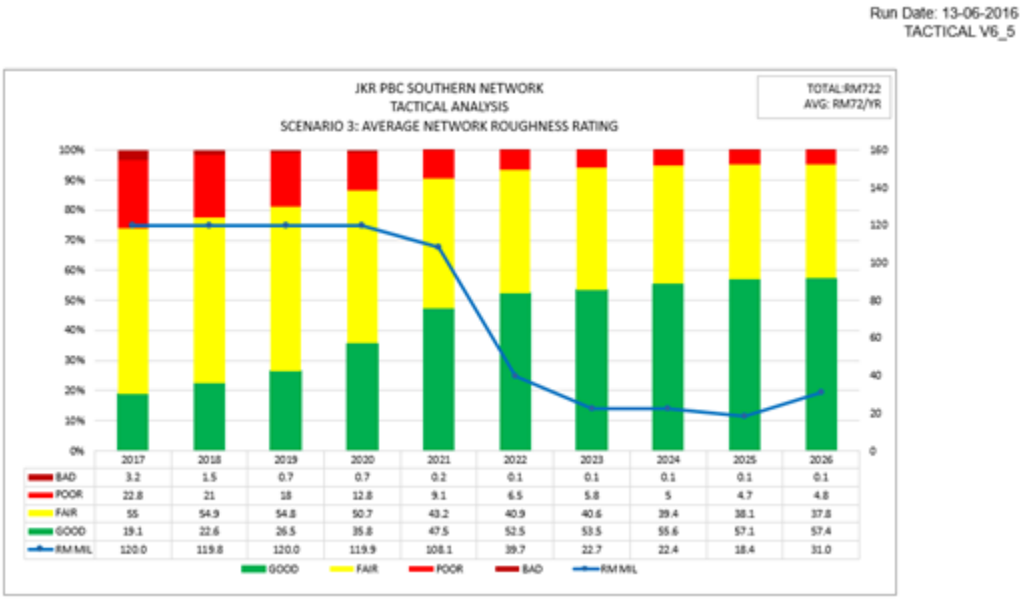
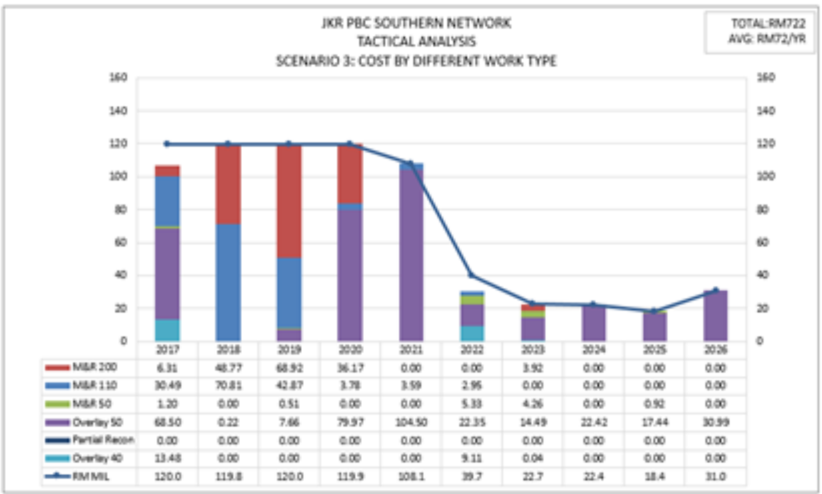


Figure 14-14: Annual Cost Distribution by Different Work Type



14.4.10 Recommendations

Any newer version of HDM-4 should focus mostly on improving data import and reporting at network level to ensure adoption of the model by road organisations and its integration withing their road asst management processes and systems. The software should have the ability to define user reports without having to export to an external tool.

14.4.11 Describe the User Journey (Bank)

The project was fully funded by the government of Malaysia, no development Bank was involved.

14.4.12 Describe the User Journey for JKR

This project was successful as it was the first phase in the introduction of performance-based road maintenance contracting in Malaysia to cover the national road network. This follows up from the expressway road network experience which is managed under private-public relationship arrangement for the last 20 years.

Under the project, all procurements are made by JKR and paid by the Government of Malaysia.

14.5 Namibia

This collaboration began in 2006 with the University of Birmingham as a part of the HDM-4 dissemination programme. Namibia was one if the first countries to adopt HDM-4 as the main road maintenance and improvement planning tool.

14.5.1 Date

There has been ongoing activity since 2006.

14.5.2 Country

The Case Study is in Namibia.

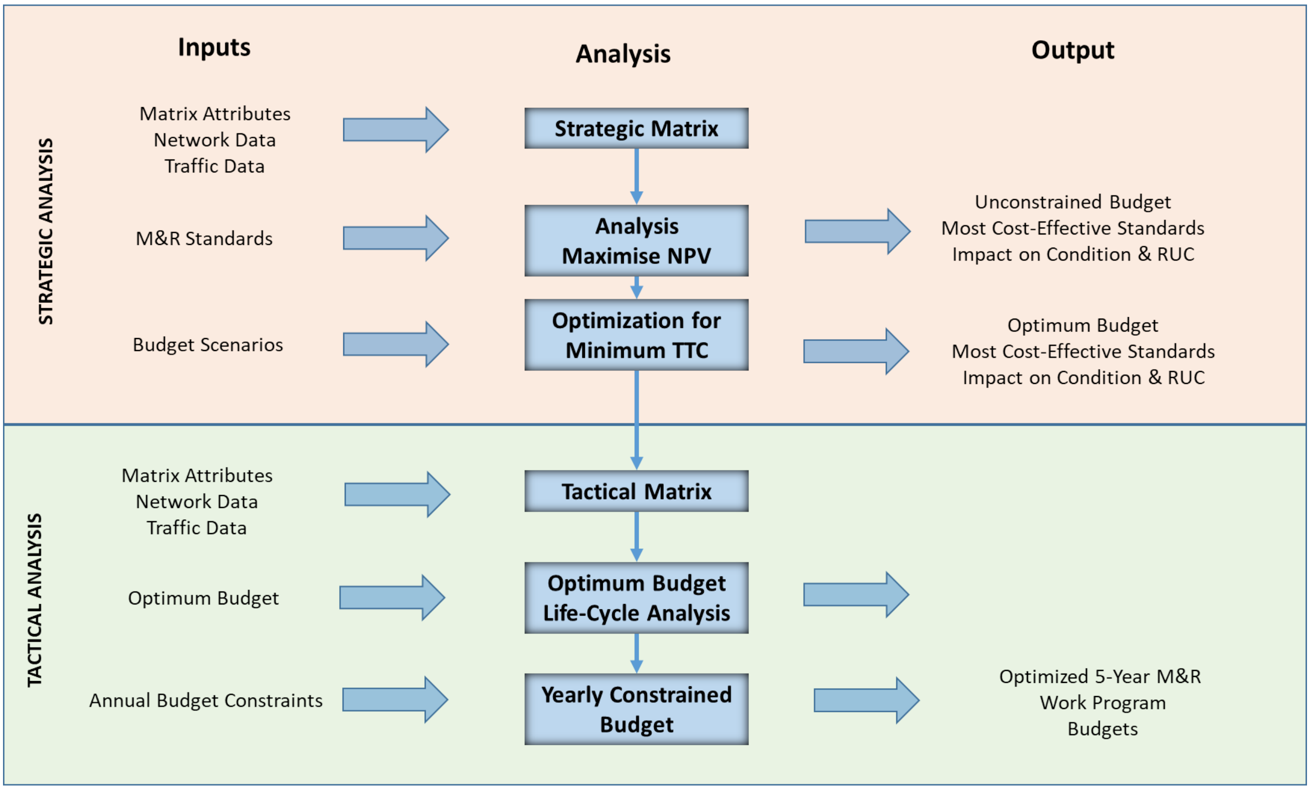
14.5.3 Who was the Analysis Completed for

The continuous HDM-4 collaboration is with the Namibian Road Authority and with the Road Management System division. This division is responsible for the administration of the local RAMS and road network assessment but also for the preparation of the long-term strategic plans and the medium-term road maintenance and improvement programmes.

14.5.4 Analysis Type

The analysis types conducted with HDM-4 were at network level and concerned the Strategic and Programming Analyses. A run of HDM-4 at these levels of analysis was conducted following every data collection campaign roughly around every 2-3 years. The two analyses were always conducted successively following the two-stage network analysis method as shown in **Error! Reference source not found.** below:

Figure 14-15: Two-stage Network Analysis Process



14.5.5 Network Size

The existing Namibian road network is defined in the Road Referencing System of the RAMS and totals a length: 48,889 km consisting of:

- 8,259 km surfaced roads.
- 39,438 km unsealed roads.

The Namibian Road network is made of 17,000 of fixed road sections.

14.5.6 Brief Network Description

The Namibian Road Network is divided into three road classes including:

- Trunk roads.
- Main Roads.
- District Roads.

The surfacing type is divided into four classes including

- Bitumen (mostly surface dressing).
- Gravel.
- Earth.
- Salt.

14.5.7 Brief Description of Reason for Analysis

This long-term assignment is a permanent technical assistance of the Namibian Road Authority in integrating HDM-4 in the local RAMS and using it as the main tool for the strategic and programme analyses and the preparation of the long-term and medium-term road maintenance and improvement plans. The different activities being provided as part of this technical assistance include:

- Integration of HDM-4 with the RAMS.
- Level-2 calibration of HDM-4.
- Strategic Analysis with the preparation of a Road Master Plan.
- Programme Analysis with the preparation and update of a 5-Year Road Maintenance & Improvement programme.
- Capacity building in the use of HDM-4 at all levels of analyses.

14.5.8 Level of Calibration Performed

HDM-4 has been the object of an initial Configuration and Level 2 Calibration of HDM-4 for Namibian conditions and environment in 2003. The level 2 calibration of HDM-4 has led to the adaptation of the road deterioration and works effect (RDWE) and road user effect (RUE) models for the conditions and environment prevailing in Namibia at that time. However, since 2003 several data collection campaigns were conducted which allowed the National Road Authority of Namibia (RA) to compile additional sets of road information that has been used to further improve the adaptation of the road deterioration and road user effect models for Namibian conditions in 2012.

14.5.9 Aspects Considered

The following aspects were most considered in the use of HDM-4 in Namibia

14.5.9.1 Connection to RAMS

An integrated interface between the RAMS and HDM-4 was established . The interface is used to create strategic and tactical network matrices for strategic and prog analysis levels. It can also be used at the project level to prepare road maintenance rehabilitation projects in the form of homogeneous road sections using the dynamic segmentation method. The HDM-4 interface is also used to extract HDM-4 analysis results from the rundata files to generate network-based reports inexistant in HDM-4 notably the Total Transportation cost graphic.

14.5.9.2 Budget Optimisation and Wider Economic Costs / Benefits

The Strategic and Programme analyses were done in full including budget optimisation under various budget constraints including the optimum budget and actual government budget scenarios to show the impact of both on the road network performance and road user costs. The analysis extended to determining total road user costs, total transport costs, road user costs savings and opportunity costs. Unfortunately, these costs and benefits are not generated by HDM-4 reporting for network level analyses. The HDM-4 interface has been used to extract data from the HDM-4 rundata files to generate these outputs.

14.5.10 Project Performance

This continuous assignment since 2006, is one of the early HDM-4 dissemination projects initiated by the University of Birmingham after the release of HDM-4 version 1 and thereafter version 2. It is also one of the successful projects in integrating HDM-4 with the local RAMS. HDM-4 has been continuously being used by the Namibia Road Authority at network level since then. Namibia can be considered as one the most successful usage of HDM-4 at network level by a national road agency.

14.5.11 Value of Project

The value of a project at network level is different from that of a single road project. The value of a project at network level is that of the programme value. In the case of Namibia, the value of the project can be categorised in the form of a 20-year strategic plan value and a 5-year road maintenance and improvement program value. The latest values from the 2020 are as follows:

- Strategic Plan: Total Cost of NAM$ 51 billion (Optimal Budget).
- 5-Year Program: Total Cost of NAM$ 16 (Optimal Budget).

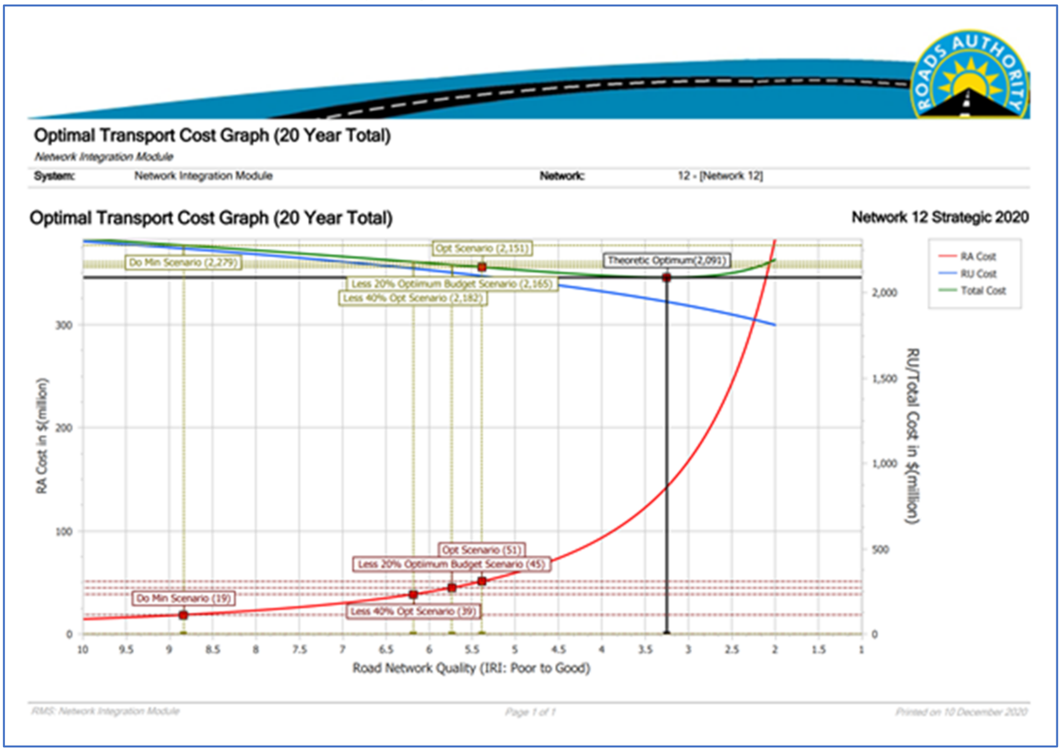
14.5.12 Issues with HDM-4 in Completing the Analysis

All network analyses having been completed since the Namibian RA integrated HDM-4 in their road management process. However, this would have been extremely difficult if not impossible without the design and development of an advanced HDM-4 interface and its integration within the local RAMS. This interface facilitated greatly two key aspects in the use of HDM-4 at network levels when dealing with thousands of kilometres of roads. The two aspects included:

Firstly, the export of data from the RAMS central database to HDM-4 in the form of strategic and tactical matrices. Without this facility, the preparation of data for these two network analysis levels would have taken months instead of minutes as this is now the case with the integrated HDM-4 interface with the Namibian RAMS. This issue has been the most important obstacle in the use of HDM-4 at network level by most road administrations around the world.

Secondly, reporting at network level is lacking in HDM-4. It is practically impossible to generate network analysis reports without using super sophisticated external software to read rundata files and produce meaningful network reports. For instance, although an HDM-4 network analysis under optimal budget selects road maintenance and improvement plans that minimise total transportation costs, HDM-4 is incapable of producing a graphic (see below) that can prove this:

Figure 14-16: Total Transportation Costs Graphic generated by the Namibian RAMS



The following are typical examples of network management reports that have been generated by the HDM-4 interface with the Namibia RAMS that could or rather should be provided by the reporting module of HDM-4.

Figure 14-17: Budget Repartition by Road Class by Budget Scenario

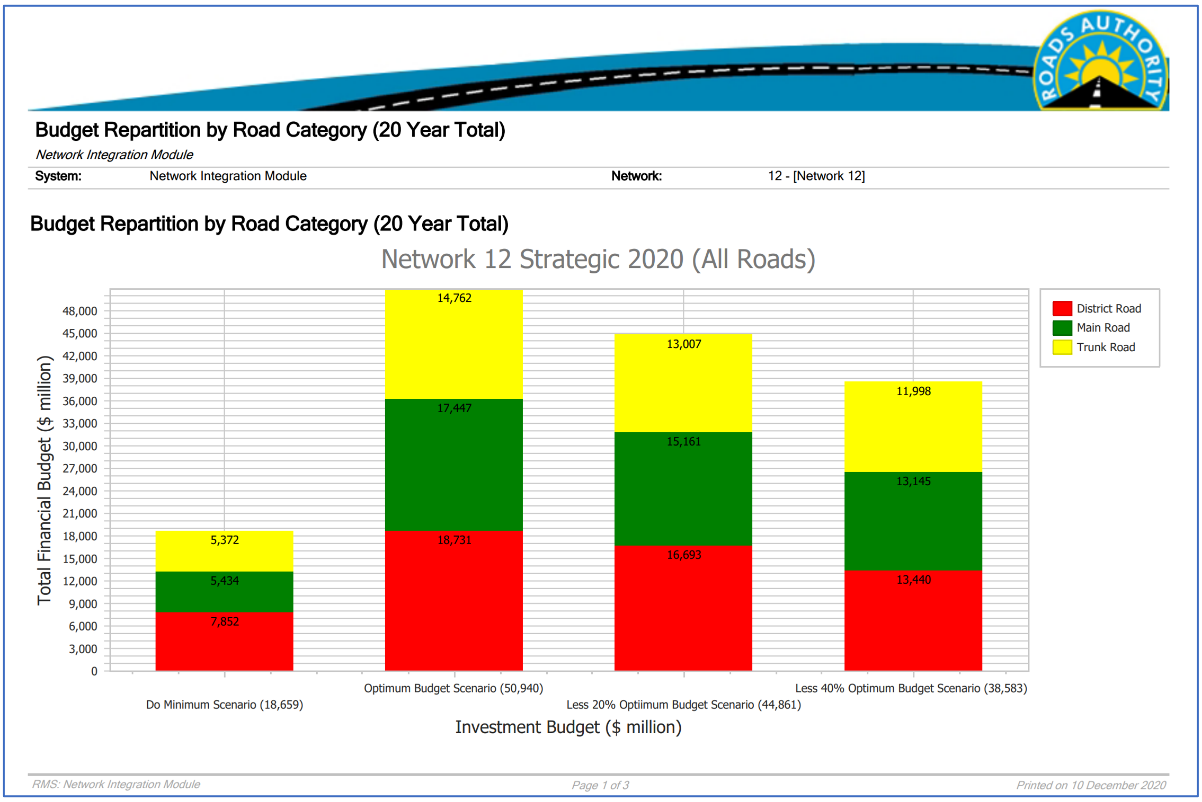


Figure 14-18: Budget Allocation by Work Type by Budget Scenario

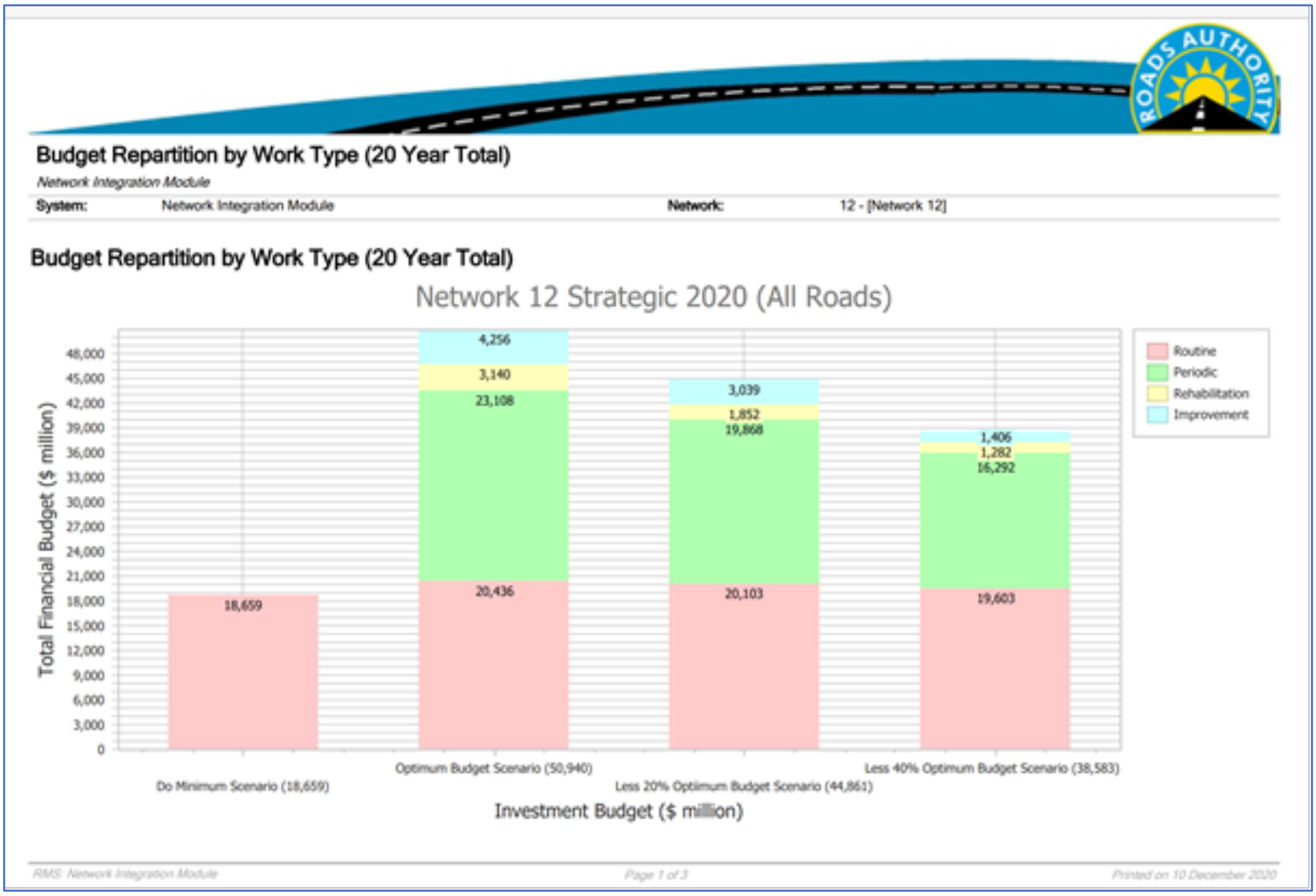


Figure 14-19: Budget Spending profile over the analysis period by Work Type

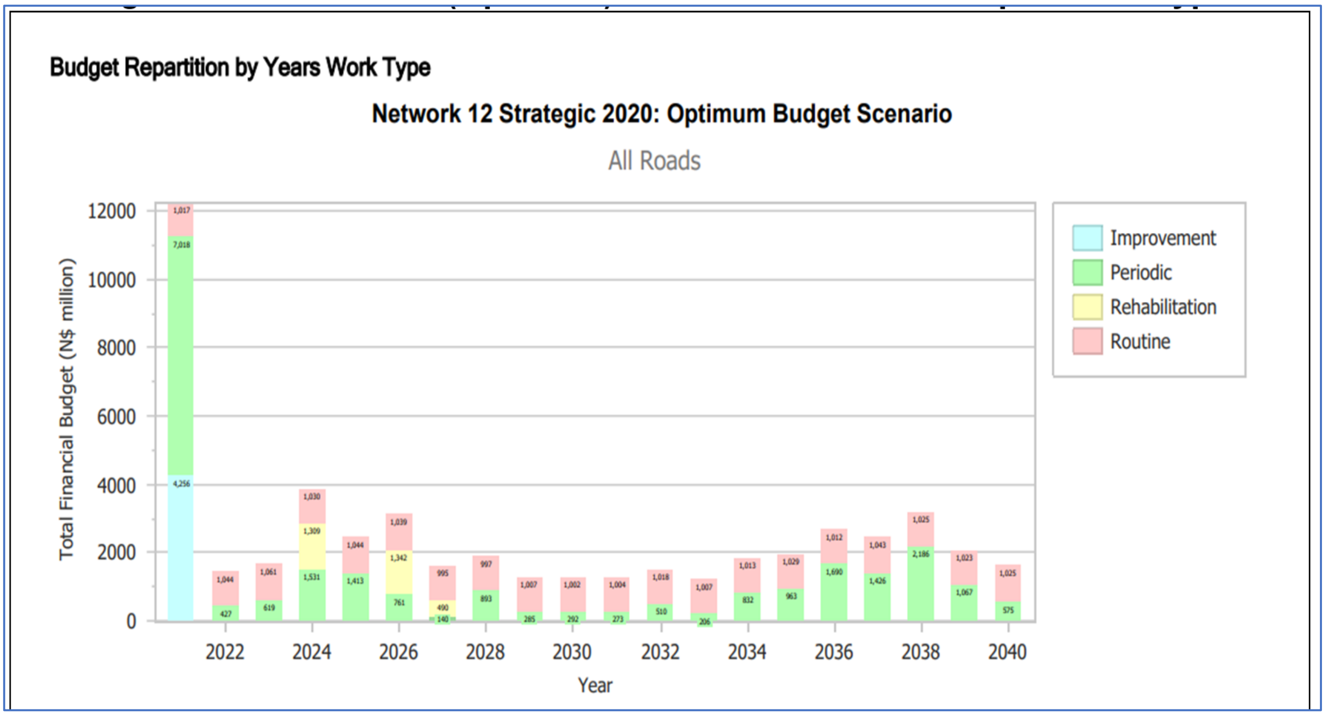


Figure 14-20: Cash Flow Summary

Budget Repartition by Years Work Type

	Cash Flow Summary		
	Road Agency Costs (RAC) in N$ million		
Year	Capital	Recurrent	Total RAC
2021	11,274.24	1,017.01	12,291.26
2022	427.04	1,044.47	1,471.52
2023	619.19	1,060.95	1,680.15
2024	2,840.04	1,029.90	3,869.94
2025	1,413.38	1,044.11	2,457.48
2026	2,102.43	1,039.16	3,141.59
2027	629.36	995.31	1,624.67
2028	893.15	997.46	1,890.60
2029	284.90	1,007.27	1,292.17
2030	291.96	1,002.28	1,294.24
2031	272.84	1,003.79	1,276.63
2032	509.84	1,018.17	1,528.01
2033	206.14	1,006.50	1,212.64
2034	831.80	1,013.19	1,844.98
2035	963.47	1,028.75	1,992.21
2036	1,689.84	1,011.53	2,701.37
2037	1,426.16	1,043.45	2,469.61
2038	2,186.28	1,024.84	3,211.12
2039	1,066.82	1,022.83	2,089.65
2040	575.04	1,024.89	1,599.94
Total	30,503.92	20,435.88	50,939.80
Average	1,525.20	1,021.79	2,546.99

Figure 14-21: Budget Repartition by Work Type

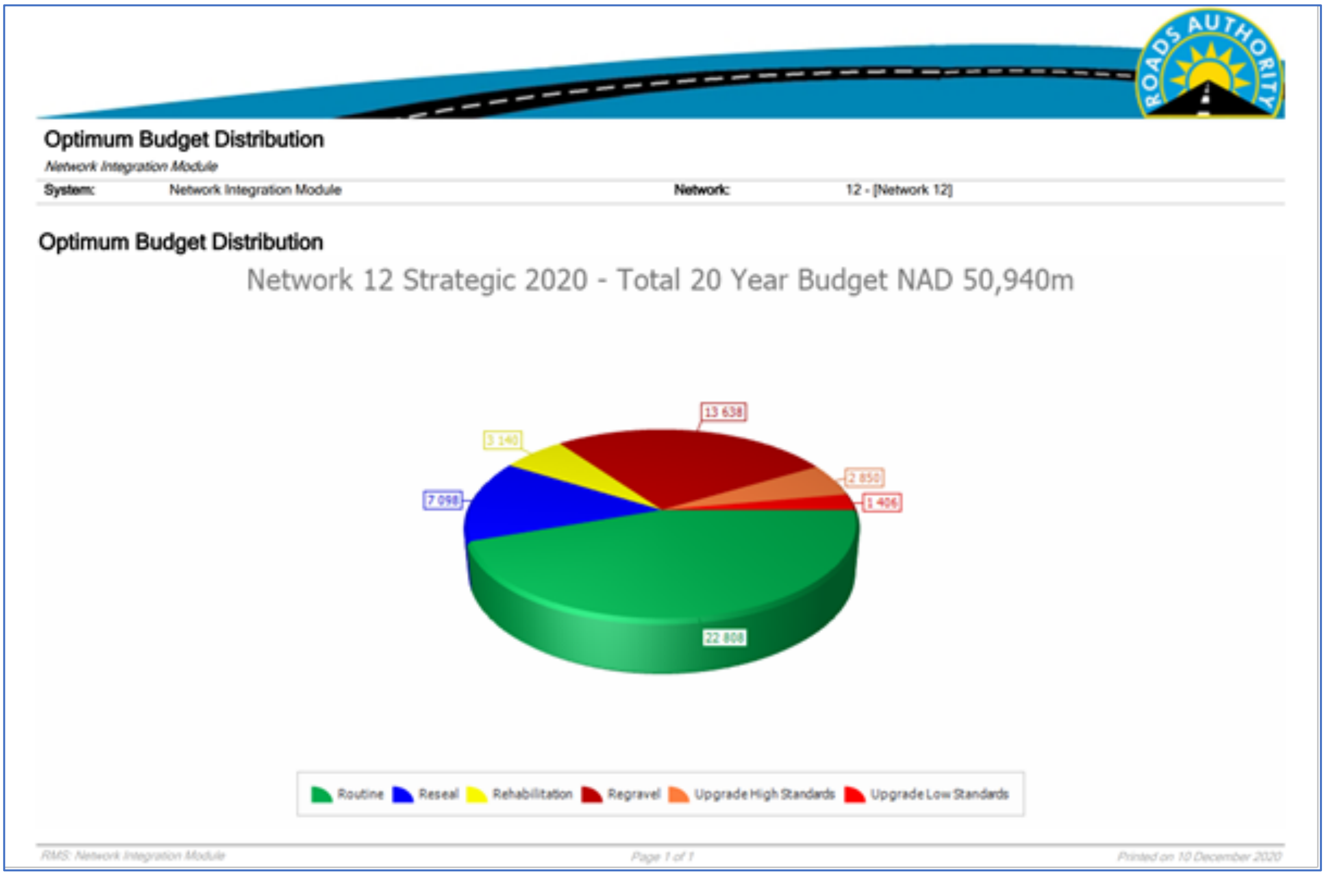


Figure 14-22: Annual Optimum Budget Distribution by Budget Scenario

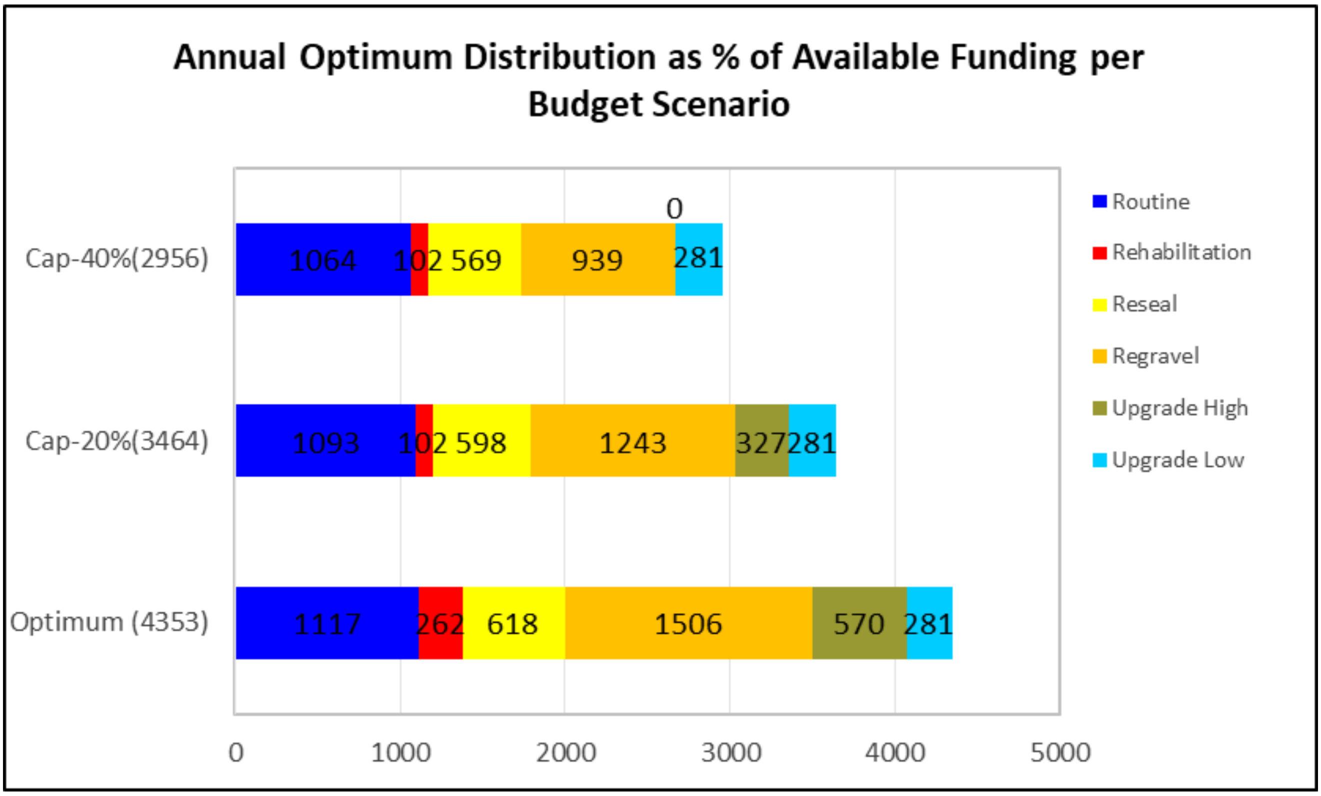
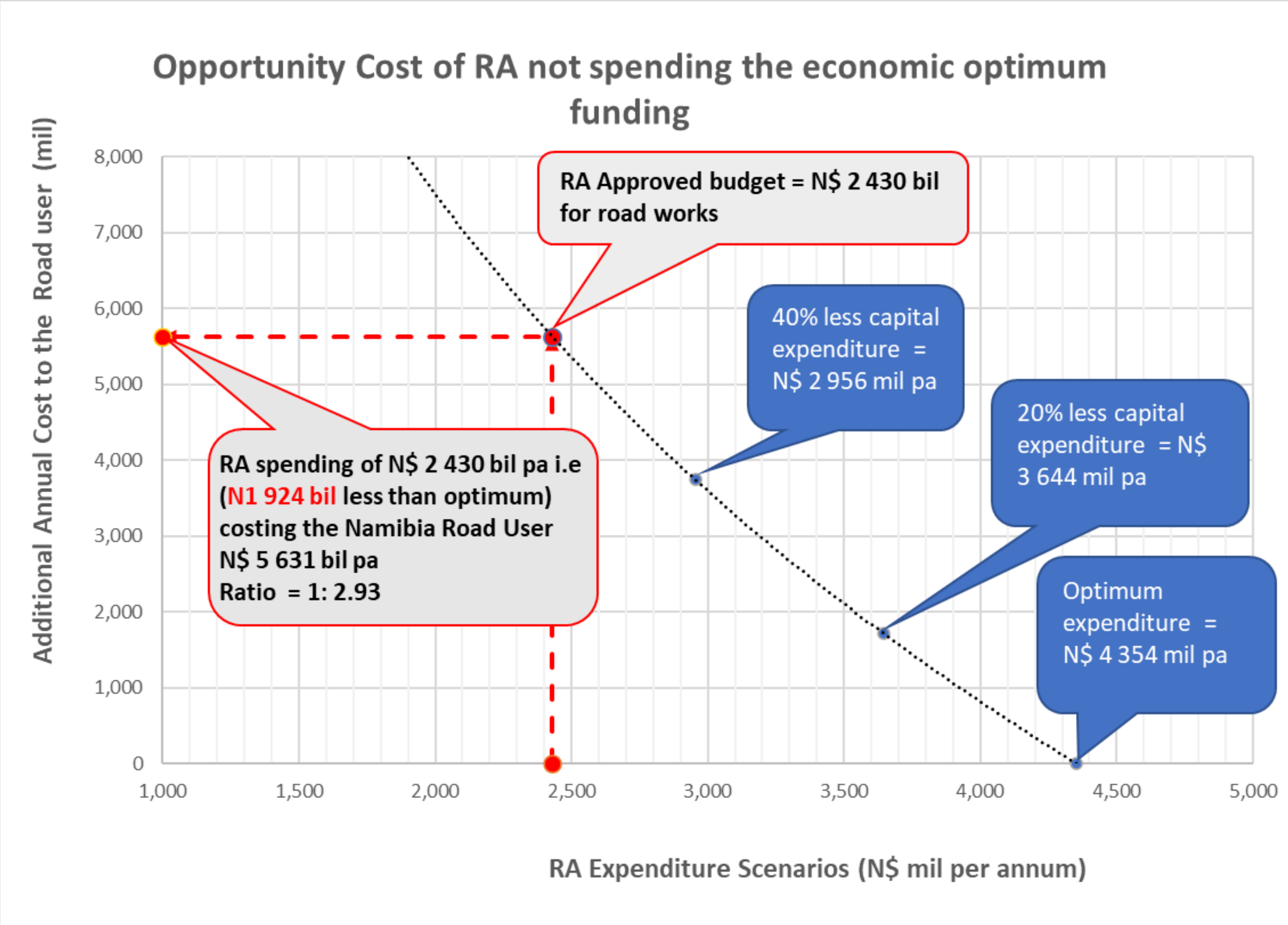


Figure 14-23: Opportunity Cost of RA not spending Optimum Funding



14.5.13 Recommendations

Any newer versions of HDM-4 must focus mostly on improving data import and reporting at network level to ensure adoption of the model by road organisations and its integration withing their road asst management processes and systems. The following high-level management generated by the Namibian

14.5.14 Describe the User Journey (for the Bank)

There is no Bank involved as this is case study concerns the use of HDM-4 by a national road agency and not a road investment project funded by a development bank or an international donor.

14.5.15 Describe the User Journey for the Namibian Road Authority

The user journey for the Namibian Road Authority has been excellent. Their decision to be one of the first African nation to develop a Road Asset Management System (2002) and more importantly integrate HDM-4 with the RAMS has been excellent. This has allowed them to benefit from the capabilities offered by HDM-4 in its use as key road network planning tool and has assisted them in the introduction of the strategic and programming levels within their road asset management cycle. Namibia has been a pioneer in applying road asset management principle before even the establishment of ISO 55001 standard for asset management.

The User Journey of the Namibian Road Authority es a typical example on where next developments of HDM-4 should be aimed at. The future of the HDM-4 experience is in its adoption as integral part of national road asset management processes and not its continuation as just a standard model for the evaluation of road investment at project level. The latter led the HDM-4 model to be just a Consultant’s tool whereas its global objective is to be a national standard for managing complex and extensive country-wide road networks.

14.6 Nigeria

14.6.1 Date

The assignment was carried out by Infrastructure Management and Engineering Services Limited (IMES) between November 2012 and May 2014.

14.6.2 Who was the Analysis Completed for

The work was completed for the Federal Ministry of Works (FMW) of Nigeria, Road Sector Development Team (RSDT), Federal Road Maintenance Agency (FERMA) and other related agencies.

14.6.3 Analysis type: (Project, programming, strategic level analysis)

The adaptation of the model for Nigeria was based on analysis of data collected from field studies as well as data obtained from statutory agencies. The data collected was analysed for the following aspects: climate, pavement types and performance, vehicle fleet, traffic characteristics and vehicle operating costs. Due to the nature of data available, cross-sectional analysis method was used for the calibration of the HDM-4 road deterioration model to simulate pavement performance under local conditions of Nigeria. The HDM-4 default values were updated, where appropriate, to be consistent with the results of model calibration. The relevant pavement deterioration factors have all been updated based on the analysis results. The information obtained from the road agencies on construction practices and local specification was used in the selection of the road pavement layer materials for paved bituminous roads and unsealed roads in order to reflect local quality control regime with respect to completed road works.

Road user effects model was calibrated with respect to speed and traffic flows at various periods of the day and for different road types. The fuel consumption patterns of the representative vehicles under various road conditions on road types in Nigeria were ascertained. The rate of tyre wear, fuel consumption and vehicle maintenance with respect to spare parts usage under the respective road condition were confirmed through field survey carried out by interviewing drivers and vehicle operators in different parts of Nigeria.

14.6.4 Network size

The total national road network is approximately 200,000 km made up of 33,000 km Federal roads, 50,000 km State roads, and 117,000 km Local Government roads. Only about 65,000 km of the 200,000 km are paved mostly in bituminous layers others are unsealed roads.

14.6.5 Network description

The Federal Government owns about 35,000 km of the total road network, which represents about 54% of the entire bituminous road network in Nigeria. The balance is shared between the 36 States and the 774 Local Government Areas. As of 2018, the total length of federal government roads in Nigeria reached 36 thousand kilometres. Secondary routes made up around 18 thousand kilometres of the total network. Some 17 thousand kilometres were trunk routes while 343 kilometres were branch roads.

14.6.6 Brief Description of reason for analysis

The study aimed at improving decision-making on expenditures in the road sector by enabling effective and sustainable utilization of the latest highway development and management knowledge. The study developed the basis for an effective implementation of decision-support methods and computerised tools for use by the FMW, Road Sector Development Team (RSDT) and other related agencies with the aim of achieving sustainable operation.

The relationships in HDM-4 that predict the deterioration of roads was calibrated to reflect road deterioration rates in local conditions. This entailed surveying a cross-section of roads to establish observed condition of roads, and then adjusting the HDM-4 road deterioration calibration factors to match the HDM-4 predicted rates of deterioration to those observed in the field. The values of the relevant calibration factors for the deterioration of bituminous roads in humid and sub-humid climate zones are listed in the table below:

Table 14-8: Road Deterioration Calibration Factors for Nigeria

Distress	Calibration Factor	Calibration Value	
		Sub-humid	Humid
Cracking Initiation	Kcia	1.14	1.21
Cracking Progression	Kcpa	0.91	0.83
Edge Break	Keb	1.11	0.64
Potholing Progression	Kpp	1.0	1.0
Rutting	Krst	5.27	4.11
Roughness	Kgm	0.95	1.09

Road works data was collected from FMW and the Federal Road Maintenance Agency (FERMA) for bituminous and unsealed roads. The information collected included different road works activities under routine and periodic maintenance, improvement and development works, and special works. Data was also collected on maintenance history for various treatment types, and the condition of the road pavement before and after treatment. This information was used to calibrate HDM-4 works effects models for different types of treatments such as new construction or reconstruction, overlay, and reseal. The financial unit costs of road works items were also collected and expressed in economic terms.

In order to calibrate the Vehicle Operating Cost (VOC) relationships, surveys of vehicle fleet operators (bus companies, truck operators, taxi companies, etc) were undertaken to estimate the rates of vehicle consumption of parameters such as fuel, tyres, spare parts, etc. VOC related calibration factors were then adjusted in HDM-4 to match the HDM-4 predicted rates to those derived from vehicle operators.

Calibration factors for Speed, Fuel, Spare Parts, and Tyre Wear were derived by IMES, and the values of these factors were calculated for each of the 17 vehicle types.

14.6.7 Level of Calibration performed

The target level of the configuration and calibration is Level 2 Calibration, and the calibration carried out concentrated on the most sensitive parameters embedded in the HDM-4 system. This required measurement of additional inputs and moderate field surveys to calibrate key predictive relationships to local conditions.

14.6.8 GHG Emissions and Climate Change

HDM-4 can be applied to predict vehicle emissions which are considered to be the most damaging to the natural environment and human health. These include the following types of vehicle exhaust emissions: Hydrocarbon (HC), Carbon monoxide (CO), Nitrous Oxide (NO), Sulphur Dioxide (SO2), Carbon Dioxide (CO2), Particulates (Par) and Lead (Pb).

The emission models included in HDM-4 predict vehicle exhaust emissions as a function of vehicle speed, fuel consumption and vehicle service life. Data suited for calibrating the emission models to conditions in Nigeria were not available. However, since the fuel consumption, speed and service life models were calibrated, the effects will be reflected in the emissions model outputs. Thereafter, default HMD-4 emission model parameters is recommended.

14.6.9 Accidents

Accident rates for roads in Nigeria were determined in the IMES study for a range of road classes. These rates are for ‘unimproved’ roads. There is little information that could be sourced on reductions in accidents due to road improvements. A conservative approach to accident reduction benefits was recommended with reductions due to road improvements of about 20-25% were considered obtainable.

The 'unimproved' rates for a 2-lane road and a 4-lane road from the IMES study are reproduced in the table below together with reduced rates of approximately 20-25% for the 'improved' scenario.

Table 14-9: Accident Rates for Nigeria

Road Class	Accident Type	Accidents per 100 million vehicle-km	
		Unimproved Roads	Improved Roads
2-lane road	Fatal	17	13
	Injury	50	40
	Damage only	120	90
4-lane road	Fatal	9	7
	Injury	37	30
	Damage only	75	55

The average accident costs in Nigeria for 2012 derived in the IMES study were:

- Fatal – US$ 186,600.
- Injury – US$ 37,320.
- Damage only – US$ 1,000.

Following extensive studies and recommendations by Miller 2010, the economic value to society of preventing a road fatality can be simply estimated, as follows:

- Value of Statistical Life VSL (US$) = 120*GDP

  where:

  - VSL = economic value (US$) of preventing one road death
  - GDP = average per capita income in year N.

The valuation of prevention of serious injury is based on a research report for TANROADS (SweRoad, 2004), where serious injury cost was estimated as 20% of the VSL.

In HDM-4, changes in accident rates can only be triggered as a result of road improvements such as road widening, upgrading from an unsealed road to a bituminous road, etc. In this strategic analysis the road works are. The logic in HDM-4 does not allow accident rates to be changed as a result of maintenance or reconstruction of existing roads. However, using the accident data above, the benefits of reducing accident rates can be derived externally and then included as exogenous benefits in HDM-4.

14.6.10 Was the project successful?

Yes. The Customised HDM-4 Workspace developed for Nigeria contains all the calibration factors and configuration parameters derived in this study, and has since been used to perform feasibility studies, programming of works and strategic planning of the road network. This formed the basis of decision-support methods and computerised tools for the Federal Ministry of Works (FMW), Federal Road Maintenance Agency (FERMA) and other related agencies.

14.6.11 Issues with HDM-4 in Completing the Analysis

There was one particular issue with HDM-4 in completing the analysis, that is, HDM-4 does not allow for entry of historical data or time series data collected for calibrating road deterioration models.

14.6.12 Describe the User Journey (for the Bank)

The project was funded by the World Bank through the Road Sector Development Team of the Federal Government of Nigeria. The World Bank was not involved.

14.6.13 Describe the User Journey (for the Road Authority)

The user journey started with a series of HDM-4 training courses held both at the University of Birmingham UK and then in Nigeria in 2010 that were attended by members of staff of the Federal Ministry of Works (FMW) of Nigeria, Road Sector Development Team (RSDT), Federal Road Maintenance Agency (FERMA) and other related agencies. The training activities was followed by HDM-4 model calibration and configuration to conditions in Nigeria. The user journey has been very good. The use of HDM-4 for road investment appraisal and policy studies has been rising in Nigeria.

14.7 Paraguay

14.7.1 Date

Between May 2018 and March 2019, marking a first milestone in the improvement of the tool for the analysis and planning of the Road Network of Paraguay.

14.7.2 Who was the Analysis Completed

The Project was based on financing from the Inter-American Development Bank for the Ministry of Public Works and Communications (MOPC) of the Paraguayan government. A project of about 10 months that allowed generating a base for the use of the tool and its application in the analysis and evaluation of road projects.

14.7.3 Analysis Type

The analysis conducted was associated with the Configuration and Parameterisation of the HDM-4 software to the local conditions of Paraguay. For this, the existing information in the country was fed into the different parameters that make up the different modules and submodules of the software.

Figure 14-24: Configuration and Parameterisation of the HDM-4 to the Local Conditions

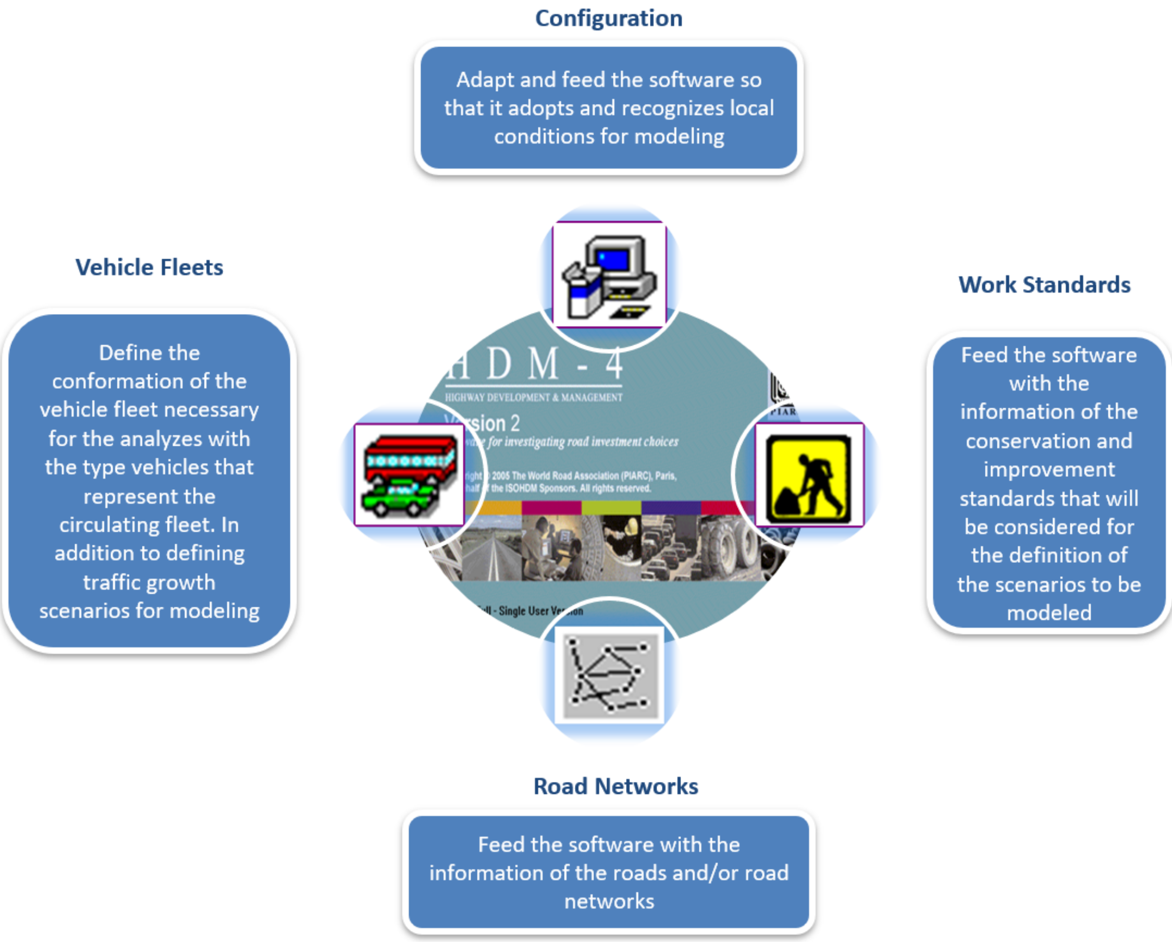
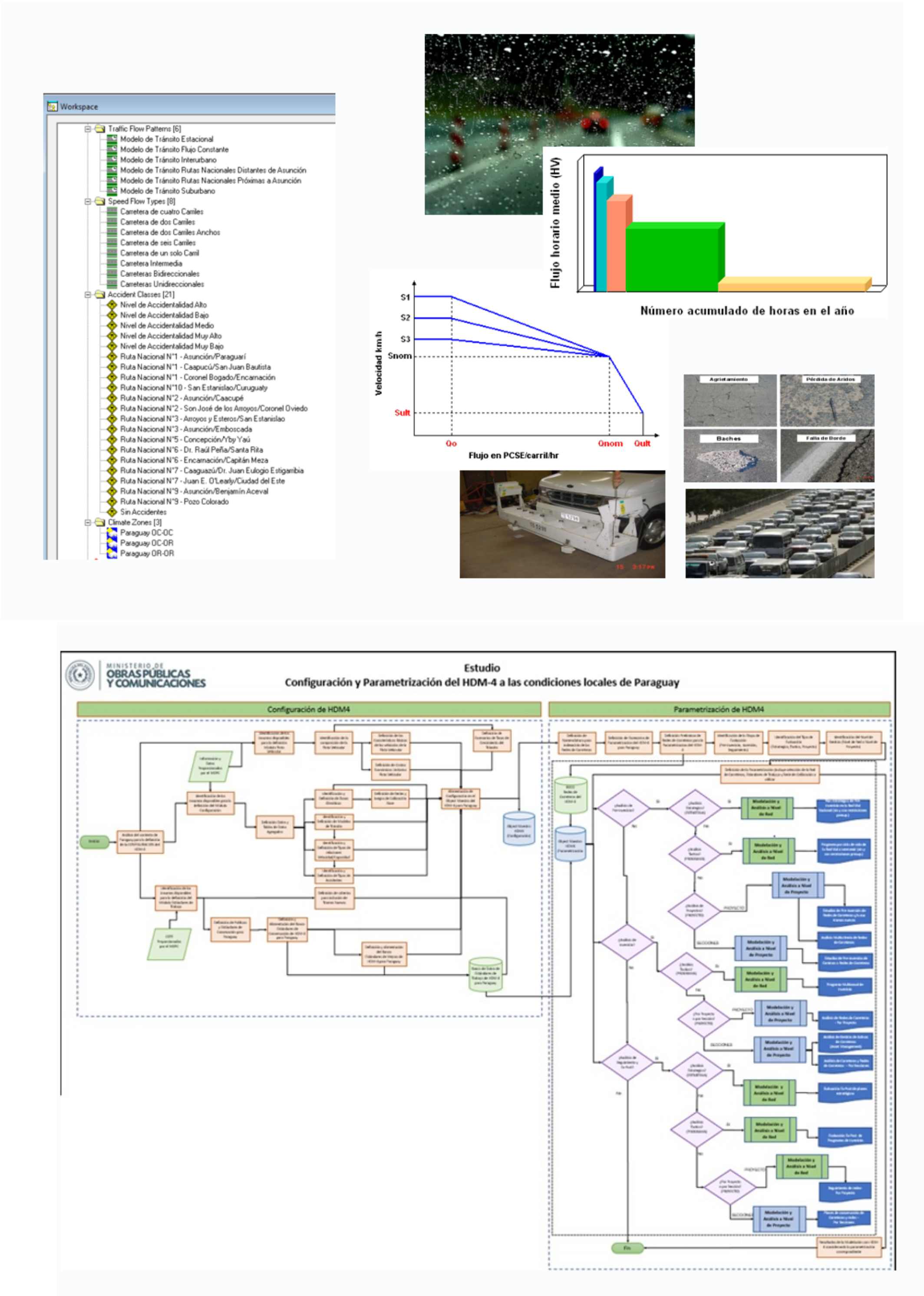


Figure 14-25: Methodology of Configuration of the HDM-4 to the Local Conditions



14.7.4 Network Size

The existing Paraguayan road network is defined by the Ministry of Public Works and Communications (MOPC) (see map below) and totals a length: 77,348 km consisting of:

- 9,222 km surfaced roads.
- 68,126 km unsealed roads.

Figure 14-26: Paraguay Road Network

14.7.5 Brief Network Description

The Paraguay Road Network is divided into three road classes including:

- National roads.
- Departmental Roads.
- Local Roads.

The surfacing type is divided into four classes including:

- Paved.
- Asphalt Pavements.
- Concrete Pavements.
- Unpaved.

The distribution of the road network between the three road classes and the four surface types is indicated in shown below:

Table 14-10: Paraguay Road Network Composition

Type	Type of surface							TOTAL (km)
	PAVED (km)						UNPAVED (km)	
	Asphalt	S.T.	PPC	Blocks	Stone	Stone/Grav el	Gravel	
Nacional (km)	3.084,01	91,94	15,00	0,00	0,00	0,00	303,20	**3.494,15**
Departamental (km)	3.265,92	358,00	0,00	10,67	773,79	592,33	11.091,07	**16.091,79**
Vecinal (km)	0,00	0,00	0,00	0,00	600,50	429,59	56.731,42	**57.761,52**
Totales por tipo de Superficie (km)	**6.349,93**	**449,95**	**15,00**	**10,67**	**1.374,29**	**1.021,92**	**68.125,69**	**77.347,46**

Source: Ministries of Public Works and Communications (MOPC), November 2018

14.7.6 Brief Description of Reason for Analysis

The objective of the study is to configure the HDM-4 software to the local conditions of Paraguay in order to obtain an evaluation and analysis tool adapted to the characteristics of the country that consider the particularities of the country.

This adaptation is made based on the information available from the MOPC and the Paraguayan government entities that could feed the definition of the parameters of the different modules that make up the software.

In turn, the guidelines to be followed for an improvement of this first adaptation have been defined, in terms of the calibration of the HDM-4 modules and submodules, as well as the guidelines to be followed in relation to the analyses and evaluations that are should be performed with the adapted tool.

14.7.7 Level of Calibration Performed

The calibration level developed during the study corresponds to Level 1 – Basic Application.

14.7.8 Aspects Considered

For the Development of the Configuration and Parameterisation of HDM-4 to the local conditions of Paraguay, the following aspects/inputs of information were considered.

- Historical data of Functional and Structural evaluation of the National Road Network of Paraguay.
- Information available from traffic measurements.
- Current Regulations in terms of design, construction, and maintenance of pavements.
- Historical Meteorological records of different sectors of the country.
- Road Inventory of the National Road Network.
- Vehicle Classification; features and associated costs.

14.7.9 Project Performance

The project was successful in achieving the definition of a baseline for the HDM-4 program under the conditions of Paraguay.

In turn, the guidelines for the development of the tool in the future were defined; Important information to collect, the way in which it should be collected, specific studies to develop and the most relevant parameters to consider for a future calibration.

14.7.10 Issues with HDM-4 in Completing the Analysis

No problems are identified with the use of HDM-4.

The difficulties in this type of study come mainly from the sources of information, which are not familiar with the parameters and/or units used by the different modules and submodules of the program. In some cases, this type of study defines the bases for the way in which information is captured and collected, with the aim of making it useful for feeding HDM-4. In other cases, the available information must be processed and adapted so that it can be used to adapt the software to local conditions.

14.7.11 Describe the User Journey (for the Bank)

The key role of the Inter-American Development Bank was focused on financing the project; however, its interest was in turn motivated by the consolidation in the adoption and use of the tool to give greater formality and standardization to the evaluations of investment initiatives generated from the Ministry of Public Works and Communications (MOPC).

14.7.12 Describe the User Journey for the Paraguayan Road Authority

The user journey for the Paraguayan Road Authority has been excellent. Establishing a base for the use of the software, as well as the definition of guidelines for its application in the different analyses, has been beneficial for the definition and planning of resources to be allocated for the construction and maintenance of the National Road Network of Paraguay. At the same time, the analysis and evaluations with the adapted tool have made it possible to justify to other ministries the need to inject resources for the maintenance and conservation of the network.

On the other hand, as part of the study, training is carried out for different professionals from public entities in Paraguay to publicize the results of the Configuration and Parameterization of the software, and in turn provide training in the use of the tool, both in modeling as in the potentialities of HDM-4.The objective of the study was to generate a common base of the parameters that make up HDM-4 for the modeling, analysis and evaluation of Paraguayan road networks, generating a tool for professionals from the Ministry of Public Works and Communications that allows them to evaluate road projects. and plan investments in construction and maintenance within the National Road Network.

The study improved the reports and results of the Ministry of Public Works and Communications and delivered to the Ministry of Finance for the purposes of approving annual budgets for investment in maintenance and improvement of the road network.

14.8 Philippines

14.8.1 Date

HDM-4 has been used in the Department of Public Works and Highways (DPWH) in Philippines since the early 1980s, with initial implementation under the Bureau of Maintenance. However, it was not fully institutionalised at that time, and responsibility for operation of HDM-4 was moved to the DPWH Planning Service in in the late 1990s.

14.8.2 Implementation

DPWH is responsible for the National Road Network in Philippines, comprising some 32,000 km of national roads.

DPWH started implementation of the Confirm Asset Management System (supplied by Pitney Bowes) in the early 2000s for the national road network. Policies, processes, and procedures covering network referencing and road data collection, including responsibilities of central, regional and district offices, were written, and a large training programme was conducted across all of those offices.

HDM-4 was integrated with the Confirm Asset Management System under a separate consultancy effort. That included establishment of policies and procedures for review and update of vehicle operating costs, maintenance standards, and treatment standards; establishment of calibration test sections on the network. A new planning process was also introduced, explicitly requiring annual HDM-4 analysis of the national road network by a central team, with a process for review and validation of the HDM-4 results by regional and district office personnel as part of their annual planning and programming process.

Separate consultancy projects implemented a National Traffic Counting Programme, including a combination of permanent embedded counters and mobile counters for different classes of road. Robust data quality review and assurance measures were also implemented to identify potential traffic data anomalies. A formal process for generating traffic projections was also implemented involving the traffic data collection team and the HDM-4 team in planning service.

All asset management and planning systems were integrated with GIS, enabling visualisation of data and analyses. Lightweight GIS apps were implemented and made available on DPWH's intranet to all users across the organisation and particularly for field offices to validate data and analyses.

In addition to its own use at network level, DPWH also requires consultants to use HDM-4 for conduct of major feasibility studies. DPWH provided an HDM-4 workspace with calibrated road deterioration models for use by consultants and provided guidance to consultants on the approaches to be used.

HDM-4 was also used by TRL in the DPWH Bureau of Research and Standards (BRS) to investigate use of stabilised sub-bases for heavily trafficked roads, and to develop methods of using indigenous materials in the Philippines. The cost of road construction and associated environmental degradation can be greatly reduced if locally available materials, found near the road alignment, can be used in construction, thereby reducing the extraction and haulage of expensive high quality aggregates. Such materials may often be of marginal engineering quality in terms of standard specifications but, by modification and/or suitable design and construction methods, their use can be very cost effective.

14.8.3 Analysis Type

The interface between HDM-4 and Confirm was built to summarise and homogenise latest data from the field, including road inventory and condition data, and to translate those data into HDM-4 data types and formats for strategic and programme analysis. The homogenisation process was configurable in Confirm to enable generation of alternative logical matrices for analysis in HDM-4.

HDM-4 was also used for project-level analysis at feasibility stage by local design consultants, therefore there is a considerable amount of experience among local consultants in country.

14.8.4 Level of Calibration performed

A level 2 calibration was conducted across selected sections of the national road network, using detailed survey, non-destructive testing, and trial pits at around 20 sites in the early 2000s. These sites gave a representative sample of roads of different age, construction type, and traffic loading. The precise locations of those calibration sections were documented to allow revisit and resurvey for future validation purposes.

14.8.5 Aspects Considered

The results of HDM-4 analyses were initially intended to be brought back into the Confirm asset management system. However, as HDM-4 became institutionalised into the planning process, it became apparent that an interface with the planning and programming system would be more beneficial.

Project alternatives in HDM-4 are based on a simplified model of the road network. Identification of a project alternative within HDM-4 based on that model does not necessarily reflect the full reality on the ground, in terms of the linear extent of the proposed project, the activities that need to be conducted, and other local issues. Where HDM-4 might suggest a reseal on a stretch of road between km 5 and km 8 in year 1, there are a hundred reasons why that work might not go ahead as planned. Firstly, the homogenisation process by its nature summarises the condition data and may mask some recorded defects on the physical network, therefore the suggested extents and condition of the project need to be verified in the field. Next, the HDM-4 recommendation does not consider any additional work that might need to be included (e.g., slope protection, drainage, localised heavy patching) that might increase the cost to such an extent that the project is not viable in that year, or which indeed may change the nature and costs of the entire project. An adjoining road may also have been identified as needing maintenance, and both roads could be combined into a single project for procurement purposes. Alternatively, a safety-related project such as a junction re-design may been programmed in that vicinity and therefore the projects should be combined together. In other words, HDM-4 produces a high-level project and programme that needs to be investigated in the field and needs to be subject to engineering design and detailed programming. Very few roads agencies have the ability to track the development of projects from initial identification through to procurement and execution, yet DPWH in Philippines has these systems in place.

14.8.6 Recommendations

As part of project implementation in Philippines, the results of HDM-4 network-level optimisation for the first year were compared with the actual projects implemented on the ground in the following years, i.e., having gone through review, evaluation, procurement, and execution. A scoring mechanism was established on the actual projects in the plan which gave points for correct identification of extent (chainage) of the project by HDM-4 (entirely within, or partially within), the severity and type of treatment, and the year in which the project actually took place. It was identified in the early 2000s that approximately 50% of the Department's approved periodic maintenance budget was correctly identified by HDM-4. The intention was to continually improve the use of the model year-by-year (through improving road network data quality, improving quality and accuracy of traffic data and traffic forecasting, review of road deterioration curves, estimation of exogenous costs and inclusion in HDM-4 at an early stage) to improve the accuracy of the models. It is recommended that, as part of any HDM-4 implementation in a roads agency, baselining and a process of continual quality improvement is established to monitor the effectiveness of use of HDM-4 in the planning process.

14.8.7 User Journey (Development Banks)

Much of the implementation in Philippines was with the support of ADB, World Bank and DfID (now FCDO) in UK over a period of more than 20 years. The World Bank provided funding for implementation of the asset management systems and planning processes as well as other major support in computerising DPWH; while ADB provided funding for implementation of the pavement management system of which HDM-4 formed a part. Use of HDM-4 for the work in Bureau of Research and Standards was funded by DfID.

14.8.8 User Journey (DPWH)

For all projects, there was strong support and drive from DPWH. A cadre of 6-8 personnel in DPWH Planning Service are fully trained in HDM-4 and use it to run strategy and programme analyses annually.

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