

APPLICATION OF HDM TECHNOLOGY AND INTERNATIONAL GOOD PRACTICE IN IMPROVING LONG TERM MAINTENANCE PLANNING IN TANZANIA

by

F Marmo*, J Lwiza**, T Toole*** and L L Parsley****

* Director of Maintenance, Tanzanian National Roads Agency

** Principal Maintenance Engineer, Tanzanian National Roads Agency

*** Manager, Asset Management, ARRB Transport Research Ltd, Australia

**** Senior Researcher, TRL Ltd, United Kingdom

ABSTRACT

TANROADS is in the final stages of implementing a new Road Maintenance Management System (RMMS). At the core of the system is a network information system which holds data on road ordinance, road inventory, road condition, works history and traffic. Following its completion the RMMS will provide a repository for the types of information required to enable TANROADS to be aware of the road assets under its command, and to use this information in developing medium and long term investment programmes using modern decision support tools.

In order to address future investment needs and priorities, the HDM-4 planning tool and established appraisal techniques for very low volume roads have been introduced as the decision support elements of the system, and employed in the development of a National Road Maintenance Programme (NRMP). This new capability complements current maintenance planning practices and policies in Tanzania. The configuration and practical application of the RMMS needs therefore to be viewed in terms of supporting TANROADS Business rules.

This paper describes the approach taken to configuring and adapting HDM-4, and describes examples of its application in determining appropriate standards, or intervention levels, for maintaining both paved and unpaved roads, and thereafter in applying these in estimating future budget needs and priorities. The approach takes due account of economic considerations in selecting optimum treatment standards, the issue of engineering risk, and road safety and other user considerations. The paper stresses the need for a balanced approach in standards development, and the consistent application of this in planning and subsequent delivery. The special needs of low volume roads have also been addressed through encouraging 'basic' accessibility as a fundamental objective. This has required the development and introduction of a number of 'novel' planning techniques drawing on practices in Tanzania and internationally.

1. INTRODUCTION

1.1 Background

The Tanzania National Roads Agency (TANROADS), which has responsibility for the management of all trunk and regional roads in Tanzania, is in the process of developing a new Road Maintenance Management System with the assistance of the UK's Department for International Development (DFID).

The system has been developed with the following considerations in mind:

- i) TANROADS required a system whose primary focus would be in providing data and in performing decision support analyses for network level planning and programming.

- ii) The system should build on earlier collected data, and be implemented within a software environment which can be readily updated and maintained.
- iii) Priority should be given to a) establishing a full asset inventory, b) supporting the effective use of resources at a regional level and c) introducing a rational means of allocating funds across regions.

The approach to the development of the system was described previously to this conference [1]. Since then, substantial progress has been made in developing and applying the system. The role of the asset inventory is provided by a software package named Road Mentor, and its development and population is described by Mosso et al [2] in a paper to this conference. To provide the analytical basis for the effective use of resources, and for distributing funds, TANROADS have adopted the PIARC owned HDM-4 [3], which is the successor to the World Bank's HDM III [4].

1.2 Scope and Objectives of this paper

This paper describes:

- i) the scope and functionality of HDM-4, and the basic justification for its adoption;
- ii) its role in the context of the overall RMMS, and the possible applications and organisational functions which it can support;
- iii) the activities undertaken to establish an HDM-4 operational system, and the background to a number of the key technical elements of the system, including its configuration;
- iv) the approach taken and results of investigations into setting maintenance standards and priorities for different road types, and traffic levels; and
- v) how the standards can be applied in forecasting budget requirements and generating works programmes.

2. THE HIGHWAY DEVELOPMENT AND MANAGEMENT TOOL

2.1 The scope and functionality of HDM-4

The new HDM-4 was first launched at the PIARC World Road Congress held in Kuala Lumpur in October 1999. It meets many of the needs of road authorities. Development of HDM-4 is an ongoing process, and a major upgrade is planned for 2003.

Whilst HDM-4 employs a similar analytical framework and decision criteria to HDM-III, it can be applied to a considerably wider range of planning and management functions, namely:

- i) **Strategic Planning** in determining long term performance trends and expenditure requirements for an entire road network or sub-network.
- ii) Preparation of prioritised **Multi-year Works Programmes** under user-specified budget limits according to a variety of economic and service level criteria.
- iii) **Project Feasibility** to determine the economic benefits from individual road investment projects including upgrading, widening, lane additions, new road links, etc
- iv) A variety of **Policy Studies** such as the calculation of road user costs,(RUC) optimum maintenance standards, sustainable road network size, etc.

The above applications are deployed within a user friendly software environment which offers:

- a) Greater flexibility in model calibration and the availability of **new models** for non motorised and motorised traffic (NMT's and MT) and social and environmental factors.
- b) **Data** requirements can be tailored to the application.
- c) Operation within the **MS Windows** environment with universal data exchange utilities that make it possible to link with any database management system.
- d) A variety of standard and customised **outputs** for the different applications.
- e) **Technical support** and ongoing development is provided by an international team of experts led by PIARC in whom ownership is now vested.

2.2 Justification

In the context of Tanzania, justification for the adoption of HDM-4, was based on the following:

- i) **Support for Policy Objectives** – through extended functionality at a strategic and programme level to justify standards and long term spending levels, and its support by major donor and lending institutions.
- ii) **Overall Efficiency** – through the use of a modern software environment, increased data base connectivity and the incorporation of information quality level (IQL) concepts [5] which tailor data strategies to the intended application.
- iii) **Prospective Users** – the higher level applications lend support to decision making at a policy and network management level, as well as providing the project focus of HDM III.
- iv) **Types of Output** – including multi-year prioritised works programmes, optimum alternatives and graphs of long term performance trends for various investment scenarios.
- v) **Data Requirements** – the adoption of the IQL concept described above, and the techniques used to define and populate representative sections, considerably reduces data costs and maintains consistency in input data through the various levels of analysis.
- vi) **Sustainability** – in terms of the low investment required in developing the system, and the considerable network of users, many of whom belong to the World Road Association (PIARC), a body which represents the interests of highway authorities worldwide.
- vii) **Building on past investments** – by incorporating the results of earlier studies, such as the 1997 Paved Road Maintenance Programme (PRMP) which employed HDM-III, and results of local, regional and international research in a widely accepted framework.

2.3 Role of HDM-4 in the RMMS

Two major components of the system are recognised, namely Road Mentor 4 and HDM-4, each of which has different input requirements to meet its output requirements. The general flow of information and role of each component is illustrated in Figure 1.

Those aspects of Road Mentor which are more specific to HDM-4 include:

- i) the segmentation and aggregation processes used to define 'homogenous sections'. The output from this process forms the basic network section data records which are analysed in HDM-4.
- ii) User control over the selection of defined lengths of road and networks, including classes of road, zones, individual roads, or the entire network.

- iii) the various look up tables and default values held within the Road Mentor programme, or in configuration folders within HDM-4. These include values for the following types of data, many of which are representative in nature and are not measured on a regular basis:
 - a) Calibration factors for the road deterioration models, and maintenance response;
 - b) Configuration data, including Speed Flow Types, Climate Zones and Aggregate Tables for Traffic Volume, Road Class, Geometry Class, Construction Quality, Structural Adequacy, Ride Quality, Surface Condition and Surface Texture.
- iv) Creation of HDM-4 road network export files containing all the required variables.
- v) Road traffic composition data for vehicles using the network.

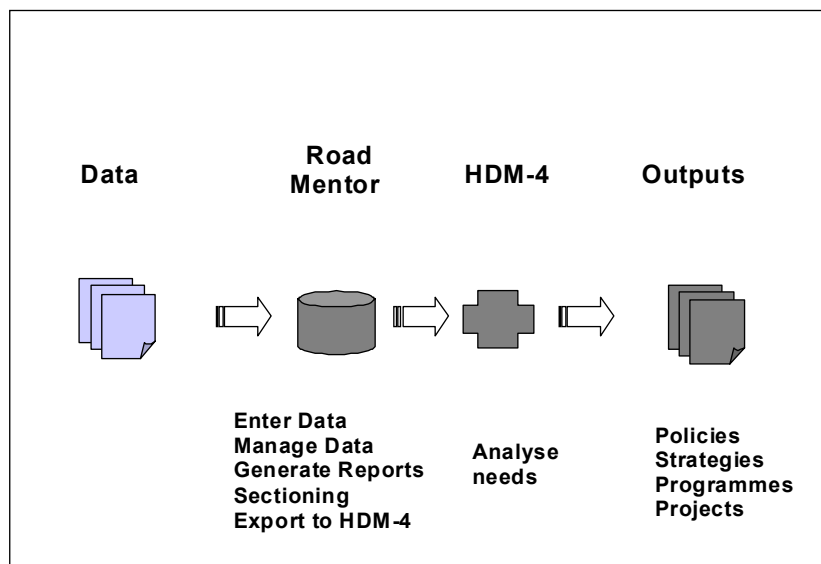


Figure 1 Flow of information and functions of RMMS components

The quality of data supplied through the system, including the ‘Configuration’ data, is key to the quality of the subsequent outputs produced from the system. Every effort must therefore be made to provide appropriate data.

HDM-4 also requires various other information to be stored directly within the system. This includes vehicle fleet data which is used to define the characteristics and costs attributed to vehicles which use the network, including appropriate calibration factors, and maintenance and improvement standards which define the types and costs of works performed on the network.

2.4 HDM-4 Operation and Management Functions

HDM-4 can be applied to both paved and unpaved roads. The management functions which can be supported are described in Table 1. Many of these fall under the responsibility of TANROADS. It can also be used to support policy analysis and to evaluate proposed strategies, programmes and projects, eg. on behalf of the Ministry of Works, and the Roads Fund Board.

Table 1
Possible uses of HDM-4: Management functions and , System Applications

Management Function	RMMS Application	Typical Aims	Spatial Coverage and Time horizon
Network Information	Road Mentor	<ul style="list-style-type: none"> - Management and reporting of information on road assets - Importation of survey data - Preparation of HDM-4 networks 	Network, with basic data provided at a sub-link level updated at periodic intervals
Planning	HDM-4 Strategy Analysis	<ul style="list-style-type: none"> - Formulation of objectives - Defining standards - Determining resources to support defined standards and objectives 	Network Long term (strategic)
Programming	HDM-4 Programme Analysis	Determining the work programme that can be obtained within the budget period and resource constraints	Network to Zone Medium term (tactical)
Preparation	HDM-4 Project Analysis	<ul style="list-style-type: none"> - Economic feasibility of alternatives for major development projects - Comparison of project alternatives 	Defined projects Short - Medium term
	Not applicable	<ul style="list-style-type: none"> - Design of works - Preparation and issue of contracts and works instructions 	Sub-network, Road-link, Section or project Budget year, annually
Operations	Not applicable	Planning and undertaking major or minor works to be done on specific sections and projects	Sections and sub-sections on specific projects or sub-networks
Monitoring and evaluation	All applications	Review of Performance Indicators	Network to project or sub-link level, as required
		Measuring achievements against performance, end product and financial targets	

3. ADAPTATION AND CONFIGURATION ACTIVITIES

3.1 General

Prior to employing HDM-4 in any analysis, various adaptation and configuration activities need to be undertaken. The detail to which each aspect was investigated varied based on its relative importance, and the availability of existing information. Many of the activities are of relevance to the Road Mentor system, since data is at the core of HDM-4.

The key activities undertaken were as follows:

1. Development of HDM-4 compatible survey procedures for paved and unpaved roads.
2. Creation of a full HDM-4 Workspace (or files), comprising road networks, fleets, maintenance standards and configuration data, and generation of paved road works programme to compare the results of HDM-III runs from the PRMP study and those produced by HDM-4.
3. Review of vehicle characteristics and operating cost information drawing on the PRMP, the Road Sector Development Project and research by TRL[7].
4. Development of appropriate “optimum” standards for paved and unpaved roads.
5. Use of the HDM-4 Strategic analysis application to evaluate the TANROADS National Road Maintenance Plan for the paved and unpaved road network using condition data collected for the entire paved road network in 2001, and unpaved data for the Dodoma and Kagera regions.
6. Use of the HDM-4 Programme analysis application in generating prioritised works programmes for the entire paved network and for the maintainable unpaved roads in Central Zone.

The following description concentrates on the activities related to:

- i) the re-assembly and analysis of the PRMP study in HDM-4 format, including development of a full trial configuration and HDM-4 Workspace for paved roads; and
- ii) the creation of an operational Workspace for works programme analysis.

3.2 Re-assembly and analysis of the PRMP study in HDM-4 format

The PRMP study was carried out in 1997 using road inventory and condition data available from an earlier version of Road Mentor. It used HDM III for economic analyses. The data was reassembled to create an HDM-4 paved network import file, having set out the appropriate conversion and data population rules for the road network variables. Road network calibration parameters, including those for cracking, rutting and roughness, were derived from studies conducted in nearby Kenya by TRL [6]. Additional variables required by HDM-4 and data on vehicle types and costs were assembled from a variety of other sources. The PRMP maintenance standards were also developed as equivalent HDM-4 standards.

The objectives of this exercise were fourfold, and produced the following results:

- i) To test the ability of HDM-4 to replicate the unconstrained works programme developed using HDM-III. A high degree of coincidence was obtained between the distributions of timings of different treatments on a section-by-section basis, with 85% of periodic reseal treatments predicted to be required within +/- 2 years of the stated PRMP timing.
- ii) To test the ability of HDM-4 to replicate the total budget estimates, in which case the cumulative figures for a 10 year budget period were within 3%.
- iii) To compare the unit vehicle operating costs (VOC/km travelled) for different roughness levels obtained from different studies. In this case, the HDM-4 default relationships were used to estimate VOC's/km with the input unit costs and vehicle characteristics defined based on the earlier review. This provided the following results:
 - a) for typical operating conditions, the unit VOC's varied between 15% above the RSDP figures, for light vehicles, and 12% below the RSDP figures, for heavy vehicles.
 - b) the unit VOC's for medium vehicles were within approximately 10% of those determined from field studies of vehicle operators by Hine et al [7].
- iv) The total transport costs should be comparable. This was assumed to be true, given the similarity in treatment timings, budget forecasts and unit VOC's.

From these results, it was evident that the initial adaptation and configuration of HDM-4 could produce comparable results to those derived from earlier studies, and provided considerable encouragement to TANROADS in the early stages of implementation of HDM-4.

3.3 Creation of an Operational HDM-4 Workspace

Development of an operational Workspace, and associated configuration, required the team to assess TANROADS ability to provide and update information on a regular basis, bearing in the mind the relative importance and sensitivity of outcomes to the various HDM-4 parameters. Whilst this can only be truly judged over a longer period of time, significant commitment to adopting a regular, structured approach to data assembly has been established.

The following sources of data are available for populating the HDM-4 road network folders, vehicle fleets and the configuration data:

- i) Ordinance data – comprising the list of roads, start and end kilometres etc recognised as forming part of the official road network.
- ii) Survey data – data which is collected at regular intervals through road condition, inventory and traffic surveys.
- iii) Historical data – including works history and construction information.
- iv) Research data – including calibration factors from field performance studies, vehicle fleet characteristics and desk study information for climate and topographical conditions.

Data for the HDM-4 road network data were derived from a number of sources, including:

- a) Data read directly from initial data or segmentation outputs.
- b) Data retrieved from look-up tables.
- c) Default data.

4. DEVELOPMENT OF MAINTENANCE STRATEGIES

4.1 Background

Most road investment tools and maintenance management systems operate by either applying user defined intervention or design standards in response to projected road and traffic conditions, or by analysing a prescribed set of options. Thus any “optimisation” or treatment selection that takes place assumes that the standards are set at appropriate levels. However, this is almost certainly not always the case. If appropriate maintenance standards are specified, considerable time can be saved in analysis, and a more reliable interpretation of outputs is likely to result.

“Optimum works” standards can be investigated using the strategic analysis application within HDM-4 by specifying a series of maintenance or improvement alternatives and applying them to a matrix of ‘representative’ road sections which cover the range of typical designs and conditions on the ‘real’ road network. A matrix might include ranges of traffic level, pavement condition, strength, climate, etc. In reality a true optimum is very difficult to achieve without an intensive investigation, due to the level of interaction of the numerous deterioration parameters and works standards effects. However, the process is a major advance in the process of identifying suitable standards based on economic criteria.

4.2 Incorporating Policy Issues

Bearing in mind that the HDM-4 tool will select treatments based on economic criteria it is also necessary for practical application to consider the following issues in defining and choosing between alternatives:

- i) minimum user acceptable levels of riding quality by road class and traffic category;
- ii) minimum accessibility criteria for low volume unpaved roads. In such circumstances it is often difficult to justify significant investment using conventional economic selection criteria, yet access is vital to socio economic development;
- iii) acceptance of engineering risk, primarily in terms of surface distress, on low volume roads where interventions are difficult to justify;
- iv) clear definition of maintainable and unmaintainable conditions, so as to encourage better use of scarce maintenance budgets and to identify the need for capital investment.

The incorporation of these issues helps define acceptable ‘base alternatives’, which under severe budget constraint or low traffic volumes, provide a minimum acceptable solution. These should be met first, and conventional economic criteria used to distribute surplus funds.

Clearer guidance is now available from a variety of reputable sources on how to address such issues, and is perhaps more pragmatic than hitherto approaches which were often driven by maximising the ‘apparent’, or most readily measured, economic benefits. Amongst the most recent guidelines in this area are: the ‘Draft SADC Guidelines on low volume sealed roads’ [8], draft DFID ‘Guidelines on the management of unsealed roads’ [9] and the World Bank’s Guidelines on ‘The design and appraisal of ultra low volume road infrastructure’ [10]. These were considered in the development and application of the standards described herein.

4.3 Paved roads

For paved roads, the following were investigated:

- i) The development of set of “optimum” economic based standards, as a matrix of treatment intervention strategies for different road conditions and traffic levels.
- ii) The refinement of the standards following further trials on a section-by-section basis using the Arusha region as a test case.

4.3.1 Initial Trials

The initial trials employed a matrix of 7 roughness/condition ranges, 5 traffic levels and 26 treatment options. The alternatives were examined using the HDM-4 Strategic Analysis module to produce a set of ‘Optimum Section Alternatives’, with the alternative giving the highest NPV being chosen as the best alternative for each matrix cell. The input data for each representative sections was determined by grouping data representing 277 homogeneous sections on the road network into 35 traffic/roughness cells, and determining typical values for all HDM-4 road network variables, thus the underlying analysis sections were truly representative of the network.

The treatment options tested included the following:

- a) Various routine maintenance options including allowing cracking and ravelling to develop to potholing then intervening, cutting and patching wide cracks before they develop to potholes, sealing cracks soon after they initiate and various levels of patching.
- b) Surface treatment policies in response to cracking, including at various percentages of wide cracking, and employing single and double bituminous surface treatments.
- c) Overlay and reconstruction policies, such as 50 mm, 75 mm and 100 mm overlays and full pavement reconstruction at different roughness levels and various combination treatments, including shape correction before sealing and varying the level of preparatory treatments.

Evidence of the economic efficiency of such an approach was illustrated by the Economic Internal Rates of Return (EIRR) obtained. The range of the EIRR for major treatments was 19 to 46 for medium traffic roads (200 – 800 vpd) and 34 to 64 for high traffic roads (>800vpd). However, for low traffic roads, routine maintenance was the most economic option.

The results confirmed the following:

1. Timely interventions, including routine crack sealing, will considerably increase the economic effectiveness of maintenance.
2. Delaying treatments until rehabilitation or reconstruction is required will prove extremely costly, and give relatively low, but acceptable EIRR's.
3. Lower cost solutions are required at low volume roads for any interventions to be viable. Thus every effort should be made to identify workable alternative technology solutions.

4.3.2 Refinement of the initial standards

Whilst the initial solutions were chosen to maximise NPV, in many situations the resultant road conditions were considered to be below acceptable standards by the TANROADS Directors and Engineers, and the project team.

To ensure acceptable solutions were generated, the following approach was adopted:

- i) A 'base alternative' was chosen as a minimum acceptable matrix of engineering standards.
- ii) The 'with project alternative' had a similar matrix structure, but included a variety of maintenance, rehabilitation and reconstruction alternatives.

These final alternatives are presented in Tables 2 and 3.

On the basis of a network level programme analysis, the adopted solutions were shown to be only marginally less efficient in economic terms than the optimum economic standards described earlier. They were therefore adopted as the standards for generating a long term works programme.

Table 2
'With Project' Standards for Paved Trunk and Regional Roads

Roughness IRI m/km	Traffic (AADT)			
	LOW < 200	MEDIUM A 201 – 500	MEDIUM B 501 – 800	HIGH > 800
< 5	RM	RM	RM	RM
5-6	RM	RM	RM	SBST & Shape Correction @ 10% ACA
6-7	RM	RM	SBST & Shape Correction @ 15 % ACA	
7 – 8	RM	SBST & Shape Correction @ 20% ACA	Overlay 50 mm	Overlay 50mm
8 – 10	SBST and Shape Correction @ 25% ACA	Overlay 50 mm	Overlay 75 mm	
> 10	REHAB ST	REHAB ST	REHAB AC	Overlay 100 mm
Routine surface maintenance (RM)				
Patch potholes	ALL	ALL	ALL	ALL

Table 3
‘Base case’ for Paved Trunk and Regional Roads

Roughness IRI m/km	LOW < 200 AADT	MEDIUM 201 – 500 AADT	MEDIUM 501 – 800 AADT	HIGH > 800 AADT
< 5	RM	RM	RM	RM
5-6	RM	RM	RM	SBST & Shape Correction @ 10% ACA
6-7	RM	RM	SBST & Shape Correction @ 15 % ACA	
7 – 8	RM	SBST & Shape Correction @ 20% ACA		
8 – 10	SBST & Shape Correction @ 25% ACA			
> 10				
Routine surface maintenance (RM)				
Patch potholes	ALL	ALL	ALL	ALL

Notes to Tables 2 and 3: ACA – Area of All cracking (%), cracks with width 1mm and above; SBST – single bituminous surface treatment; AC – asphaltic concrete; REHAB – rehabilitation; RECON – Full reconstruction.

4.4 Unpaved roads

For unpaved roads, the following approach was pursued. Firstly, optimum economic-based surface grading frequencies were investigated using established methods [11]. The weakness of this approach is it often fails to offer an acceptable solution at very low traffic volumes. However, it provides a basis for optimising surface conditions on medium and high volume roads. Secondly, the economic benefits of maintaining different access standards was investigated. This aims to provide ‘Full’ access quality by minimising total transport costs where traffic levels are in excess of 50 AADT, and ‘Basic’ access for lower traffic levels. ‘Basic’ access comprises year round passability to most classes of vehicles without being overly concerned with roughness levels. In the case of ‘Full’ access, the aim is to apply optimum surface maintenance strategies in conjunction with periodic and routine activities, whereas in the case of ‘Basic’ access the aim is to minimise the cost of maintenance to meet the stated objective. A third category of access, namely ‘Partial’ access, can also be defined which involves substantial periods of the year when motorable access is severed. This option is unlikely to be acceptable for trunk or regional roads. However, given that many unpaved roads in Tanzania are in this category, it was selected as an appropriate ‘base alternative’ when investigating access standards.

4.4.1 Optimum surface maintenance frequencies

The first step was to investigate optimum frequencies for the following surface maintenance techniques, all of which are different forms of grading, but differ in cost by a factor of 8, namely:

Light grading	Light trimming (< 40 mm) and spreading or removal of loose material. This operation is normally done without the application of water and without compaction.
Heavy grading	Deep cutting (>40 mm) with reshaping, mixing with water, spreading and compaction.
Reprocessing	Ripping and loosening existing layer to full depth of surfacing (or to 150 mm), mixing with water, shaping and compaction.

The effects of each treatment are significantly different, with reprocessing having the greatest impact on re-setting the surface quality to close to that of a newly constructed surface with similar deterioration characteristics. At the other extreme, light grading may only slightly reduce the roughness of an already rough road, and the subsequent rate of deterioration will be rapid. Heavy grading, involving mechanical compaction, lies between the two extremes.

The analysis involved using HDM-4 Strategic Analysis and creating a large number of section alternatives for light and heavy grading at intervals of between 1 and 12 times per year and full depth reprocessing at intervals between 1 and 7 years. Five traffic levels (25, 50, 100, 200 and 400 AADT), a single starting road condition (fair) and a single climate (moderate), were selected, with and without regraveling during the analysis period. A similar base alternative was used in all cases.

The outcome of the analysis is shown in Table 4 as a set of optimum grading frequencies for each operation, with the optimum chosen on the basis of maximising NPV.

Light grading is the norm in Tanzania and is performed up to two times per year on important routes, and less on other routes. Given the wide range, and sometimes very high traffic levels using unpaved roads, the conditions on these roads are likely to be substantially below optimum.

Table 4
Optimum surface maintenance frequencies for unpaved roads

AADT	Light grading	Heavy grading	Reprocessing
25	1 per year	1 in 2 years	1 in 8 years
50	2 per year	1 per year	1 in 4 years
100	5 per year	2 per year	1 in 2 years
200	9 per year	6 per year	1 per year
400	14 per year	12 per year	2 per year

4.4.2 Investigation of access quality standards for unpaved roads

The access standards which were investigated included the following:

- i) 'Full' standard, in which the optimum surface maintenance standards for each traffic level were applied along with routine off carriageway maintenance, spot repairs on an annual basis and full regraveling when the thickness of material was reduced to 50 mm.
- ii) Basic standard, in which no surface maintenance was applied other than a limited amount of spot regraveling and routine off carriageway works and spot repairs.

- iii) Partial standard, comprising two levels, namely moderate loss of access and substantial loss (termed poor). This also received spot repairs and routine treatments to prevent the access standard worsening further.

Analyses were done for two sets of conditions, namely:

1. 'steady state' operating conditions of full, basic and partial (moderate) where the economic efficiency of leaving roads in each condition was examined; and
2. 'improved' conditions, where capital investment is required to restore damaged sections to either a full or basic access standard, and thereafter to maintain the road at each standard. The analysis assumed all roads would be gradually returned to a fully passable standard over a six year period.

For partial standards, road user costs can be affected by the reduced quality of access and this was taken into account. However, whilst the agency and user cost streams of each alternative could be evaluated within HDM-4, completion of the analysis required the data to be transferred to an Excel spreadsheet. This is because changes in road user costs related to access quality is achieved by altering the vehicle fleet characteristic within HDM-4, as opposed to being a road section characteristic which impacts vehicle operating costs. Since maintenance and improvement strategies aim to change road section conditions, to determine the true economic consequences of such changes, as road conditions change then the corresponding fleet characteristics should also change for the 'with project' case, whilst holding the base alternative constant. This could only be achieved by exporting and analysing the economic data externally in order to compute the cost effectiveness of the multi-year works. The adopted base case was 'partial' access.

The Net Present Values and EIRR's of different strategies were determined and the results, as EIRR's, are summarised in Tables 5 and 6.

Table 5
EIRR's related to access quality – Steady State Conditions

Traffic	AADT	Full	Basic	Partial (Mod)
High	200	>> 250	155	120
Medium	50	> 200	29	12
Low	25	95	7	No solution

- Notes
1. Medium – lower limit of traffic level quoted as AADT.
 2. An EIRR of < 12 per cent is non-viable in economic terms (negative NPV).
 2. No solution equates to a negative NPV for which EIRR is indeterminate.

Table 6
EIRR's related to access quality – Improved Conditions with Capital Investment

Road User Costs	Traffic	AADT	Partial to Full	Partial to Basic
Increased to account for partial loss of access	High	200	150	100
	Medium	50	125	22
	Low	25	51	No solution
No allowance for loss of access	High	200	132.7	No solution
	Medium	50	19.1	No solution
	Low	25	No solution	No solution

From the above, the results of the analysis confirmed the following:

1. 'Full' access standards are well justified for roads carrying greater than 50 vehicles per day;
2. Use of conventional economic justification for maintenance at 'ultra low' traffic levels requires allowance to be made for increased road user costs as a result of interrupted access;
3. Achieving and maintaining 'Basic' access would still provide a positive economic return under medium and high traffic conditions should this strategy need to be adopted because of severe budgetary constraints;
4. Strategies for 'ultra low' volume unpaved roads will require minimum cost solutions to be vigorously pursued given the lack of an economic justification for maintaining them.

In applying the results in determining budget requirements and priorities, the following approach should be used:

- If 'Full' access standards prove unaffordable for medium and high traffic roads, an 'Intermediate' strategy involving reduced maintenance frequencies should be adopted. This would provide some insurance against complete loss of road assets, at least until adequate funds become available.
- Adoption of a 'holding strategy' which aims to provide at least 'Basic' access should be used as a minimum acceptable 'base alternative'.

5. SUMMARY AND CONCLUSIONS

1. The background to the adoption and subsequent adaptation and configuration of HDM-4 as a network level maintenance planning tool has been described, with significant progress made in bringing the system to an operational status.
2. The potential for the system to remain sustainable is highly likely as demonstrated by TANROADS commitment to implementing regular data collection and research studies, and the focus on data of prime importance, together with the support afforded by the PIARC led development of the HDM-4 system.
3. A pragmatic approach to standards development, and their subsequent application, has been described. The techniques used combine a pragmatic mix of conventional economic appraisal, local policy and international good practice.
4. Application of the methods described has now been extended to long term budget forecasts for both paved and unpaved roads, and in determining prioritised works programmes at a road section level. For unpaved roads, because of current limitations in the software the full use of HDM-4 for standards and work programme analysis has been restricted to the maintainable network.

6. ACKNOWLEDGEMENTS

The paper is published with the permission of the Chief Executives of TANROADS, TRL Ltd and ARRB Transport Research Ltd.. TRL and ARRB contributions are funded through support to the Government of Tanzania provided by the Department for International Development of the United Kingdom. The Authors wish to thank senior staff in the respective organisations and the project team for their support. Any views expressed are not necessarily those of DFID.

7. REFERENCES

- [1] Katala, J and T Toole (2000). Road management systems: Development of the Road Mentor system in Tanzania. Paper to Tanzanian Annual Road Convention, 2000. Dar es Salaam.
- [2] Mosso, T, D Weston, J Katala, J Mallya and N Mwangosi (2002). Road maintenance management systems: Implementation of the Road Mentor 4 system in the Central Zone of Tanzania
- [3] Kerali, H R G (2000). Overview of HDM-4. Highway Development and Management Series. Volume 1. The World Road Association (PIARC), Paris, France.
- [4] Watanatada T., Harral C.G., Paterson W.D.O., Dhareshwar A..M., Bhandari A., and Tsunokawa K., (1987). The highway design and maintenance standards model volume 1: description of the HDM-III model. *The Highway Design and Maintenance Standards Series*. Baltimore: Johns Hopkins for the World Bank.
- [5] Paterson, W.D.O., and Scullion T., (1990). Information systems for road management: draft guidelines on system design and data issues. *Infrastructure and Urban Development Department Report INU77*. Washington DC: The World Bank.
- [6] Morosiuk, G, T Toole, M J O'Connell and C R Jones (1995). Long term performance of the Kenya paved road network. TRL Project Report. Crowthorne, United Kingdom.
- [7] Hine, J H et al (1997). A comparison of freight transport operations in Tanzania and Indonesia. TRL Research Report 267. Crowthorne: Transport Research Laboratory.
- [8] SATCC (2002). Guidelines for the planning, design, construction and maintenance of low volume sealed roads (Draft). SATCC Technical Unit, Maputo.
- [9] Toole, T, G Morosiuk, R Petts and S Done (2001). Management guidelines for unsealed roads (Draft). TRL Project Report. Crowthorne, United Kingdom.
- [10] Lebo, J and D Schelling (2000). The design and evaluation of rural transport infrastructure. World Bank Technical Paper. The World Bank, Washington DC.
- [11] Jones, T E and R Robinson (1986). A study of the cost effectiveness of grading unpaved roads in developing countries. TRL Research Report 91. Crowthorne: Transport Research Laboratory.